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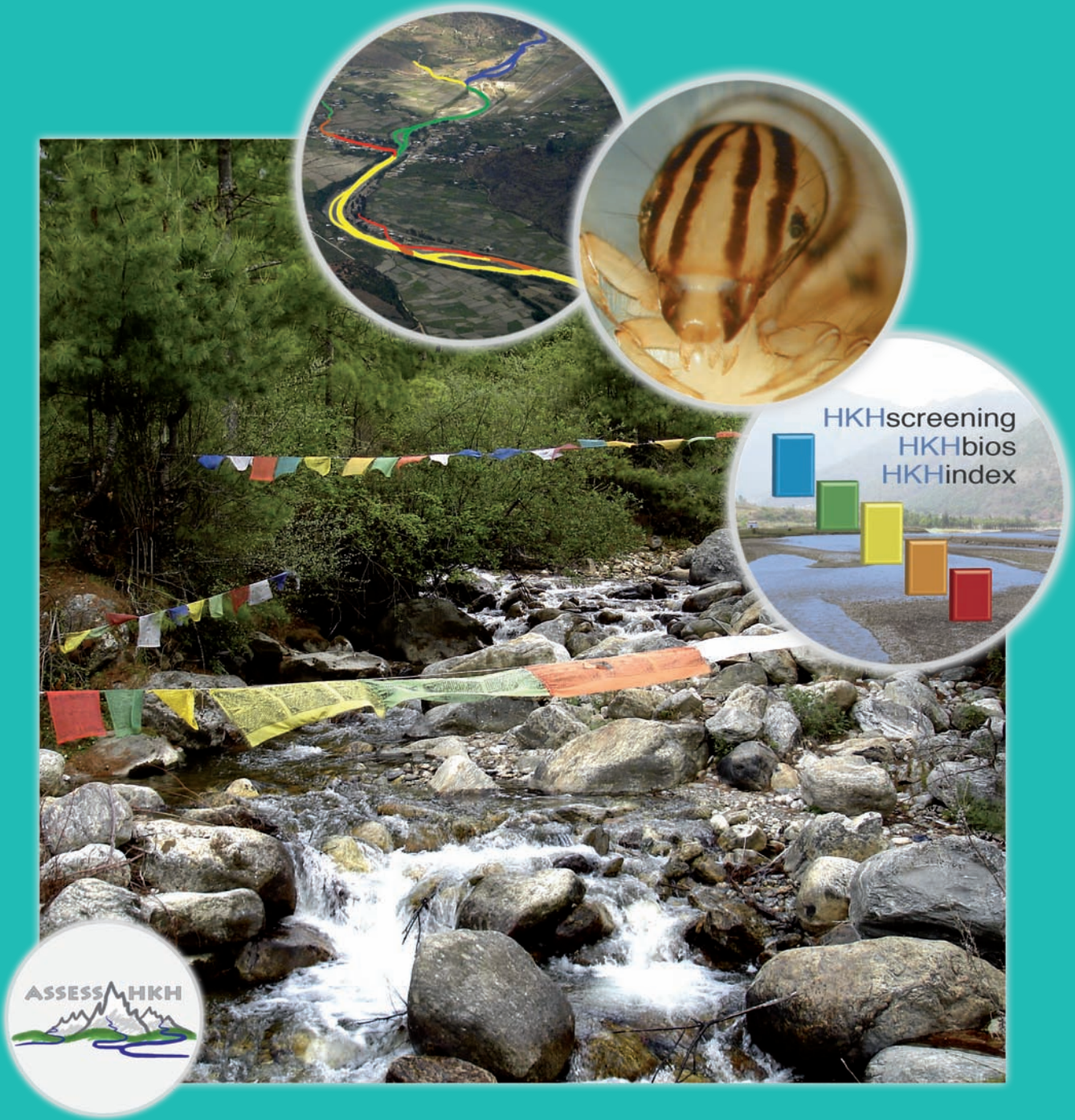

Edited by Otto Moog, Daniel Hering, Subodh Sharma, Ilse Stubauer & Thomas Korte

A product of

ASSESS-HKH

Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region

Edited by

Otto Moog[1], Daniel Hering[2], Subodh Sharma[3], Ilse Stubauer[1] & Thomas Korte[2]

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The ASSESS-HKH project is supported by the European Commission under the sixth Framework Programme contributing to priority "Specific measures in support of international co-operation (INCO), A.2.1. Managing humid and semi-humid ecosystems".

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This volume provides the extended abstracts of presentations given on the conference "Rivers in the Hindu Kush-Himalayan Region: Ecology and Assessment" held in Kathmandu and Dhulikhel, Nepal, 3-7 March 2008.

It furthermore includes some contributions, which were not presented on the conference but result from the project ASSESS-HKH (Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region).

Introduction

Venue of the conference

The final conference of ASSESS-HKH was held in Kathmandu, Dhulikhel, Nepal. It was hosted and organized by the University of Kathmandu, Nepal, the International Centre for Integrated Mountain Development (ICIMOD), the University of Natural Resources and Applied Life Sciences Vienna (BOKU), Austria and the University of Duisburg-Essen, Germany.

The ASSESS-HKH project

www.assess-hkh.at

The Hindu Kush-Himalaya (HKH) region is rich in various natural resources. Its environment is world-famous for its beauty and benefits. The Himalaya has served for centuries as a source of abundant waters.

But today widespread damage and destruction are occurring. Noticeable signs are increased floods during the monsoon periods and droughts in the summer months. Focusing on water quality, diseases caused by contaminated water are among those most prevalent. This causes untold suffering to local populations in the mountain settlements and to millions more in the plains below.

The aim of the ASSESS-HKH research work was to develop tools for ecological river assessment. The tools were jointly designed by European partners, who provided the experience from recent research activities, and Asian partners, who provided the knowledge about Asian river catchments and their management necessities. The evolved environmental monitoring tools will serve citizens and scientists of the Hindu Kush-Himalayan region and will provide scientific basis for policy recommendations, transnational water resource planning, and ecosystem management.

The ASSESS-HKH project is supported by the European Commission under the sixth Framework Programme contributing to priority "Specific measures in support of international co-operation (INCO), A.2.1. Managing humid and semi-humid ecosystems". STREP - specific targeted research or innovation project, Contract number: INCO-CT-2005-003659

Objective of the conference

The conference aimed at presenting the project's results to scientists, water managers and students. A further vital interest covered the exchange of knowledge about biological assessment and biomonitoring methods used in the Asian countries. Thus, this conference was seen as a forum to discuss aspects of the Himalayan river ecology, the taxonomic status of the HKH river fauna, the water quality monitoring and the protection of aquatic biodiversity in the Hindu Kush-Himalayan region with local and international representatives of theoretic and applied river ecology. The conference was broken down into five sessions:

Session 1
The ASSESS-HKH project: A biological river assessment methodology developed for the Hindu Kush-Himalaya region

Session 2
Regional results and consequences of the ASSESS-HKH project

Session 3
Results of limnological research in the Hindu Kush-Himalaya region and beyond

Session 4
Aspects of river quality assessment in the Hindu Kush-Himalaya region and beyond

Session 5
Socio-economic demands for sustainable river quality management

Sustainable water management needs to be based on a sound scientific fundament

Foreword to the book of extended abstracts of the scientific conference "Rivers in the Hindu Kush-Himalayan Region: Ecology and Assessment" held in Kathmandu and Dhulikhel, Nepal, 3-7 March 2008.

O. Moog[1], D. Hering[2], T. Korte[2], S. Sharma[3] & I. Stubauer[1]

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The water that we use, the air that we breathe, the energy that we consume, are ending resources. Among these, "water issues are one of the major problems that humanity must solve for its survival". This maxim was laid down in the 1st Asia-Pacific Water Summit that was held in Beppu, Japan on 3-4 December 2007, with the participation of top-level decision makers from the Asia-Pacific region. For the first time in the history of humanity, 49 States have decided to meet at the highest level to discuss the Asian aspects of water issues.

On a worldwide scale there is a clear understanding and a political will that the sustainable use of renewable resources is a primary necessity for the survival of mankind and needs primary solutions for the planet's economic, social and environmental development. The preservation and enhancement of water quality is also a key issue relating to environmental protection in the HKH area. However, the fundamental scientific aspects of sustainable water management in the HKH area are still quite poorly understood. Biological monitoring of river quality, which is crucial for an understanding and managing aquatic ecosystems, is largely un-addressed in this region. This is presumably due to a paucity of knowledge on the indigenous fauna in the HKH streams as well as a lack of appropriate monitoring methodologies.

With respect to the target area the need for a sustainable water management is underlined by the fact that the Hindu Kush-Himalaya Region provides the water resources for hundreds of million people downstream. But these rich resources are not distributed evenly in time and space. There is a clear peak of water discharge during monsoon time in summer followed by a period of steadily decreasing runoff from autumn to spring. The increasing demand for water, the large variety of water uses and also the direct use of the river catchments have partially impaired many rivers in such a way that they completely lost their natural functionality and thus can no longer provide their ecological services to mankind. Ecosystem services are the processes by which the environment produces resources that we often take for granted, such as clean water, timber, medicinal herbs, habitat for fisheries, and pollination of native and agricultural plants (Barbour 2008). In terms of aquatic ecosystems, these services include mitigation of drought and floods, self-purification capacity and the cycling and transport of nutrients, the maintenance of biodiversity, detoxification and decomposition of waste – just to name some of the key services. In this context it takes no wonder that the majority of child deaths and general hospital visits in many countries of the HKH region are due to water-borne diseases.

This book of extended abstracts may contribute to spread the seed of sustainable water management in the HKH countries by summarizing the outcome of the scientific conference "Rivers in the Hindu Kush-Himalayan Region: Ecology and Assessment" held in Kathmandu and Dhulikhel, Nepal, 3-7 March 2008. This international symposium aims at:

- Exchange of knowledge about biological methods of river quality assessment used in the Asian countries
- Serving as a forum to discuss aspects of Himalayan river ecology, the taxonomic status of the HKH river fauna, water quality monitoring and the protection of aquatic biodiversity in the Hindu Kush-Himalayan region with local and international representatives of theoretic and applied river ecology
- Disseminating the results of the EU funded project ASSESS-HKH to students, water managers and scientists.

The contribution of the EU funded project ASSESS-HKH (INCO-CT-2005-003659) to sustainable water management is to provide water managers, politicians and decision makers a tool: A tool for evaluating the ecological status of river quality. The idea behind is that a sustainable water use needs to be based on sound knowledge on the quality of the resource that one wants to use. Different status classes of river (water) quality allow different uses or need different decisions to guarantee a future utilization for a broad community of users.

On one hand, the assessment of river or water quality is not new. The early beginnings in Europe date back till 1850 when huge cholera epidemics decimated the human population in large towns and capitols. On the other hand – especially in Asia - the methodologies for water quality evaluation

are mainly based on physical and chemical data. But rivers are not simply water bodies that can be described in terms of chemical quality. Rivers are living systems; their services for the human society are provided by biota. Therefore the water management and water protection need to include the knowledge of bio-monitoring for sustainable management decisions. "If we fail to protect the biology of our waters we will not protect human uses of that water" (Karr & Chu 1999). A further advantage of bio-monitoring is the long-term aspect of indication. In comparison to the indicative value of chemical water analyses that just describe the situation of the very moment of sampling the biological survey gives evidence for a fairly longer period of weeks and months.

Even when the impacts are clear, biological monitoring via a defensible sampling approach, measures and documents whether effects are significant, and to what extent. The frequency and duration of impacts are better measured with bio-monitoring. Biological surveys and assessment also provide evidence of species loss, magnitude of impact, and a baseline for goals for recovery.

21 scientific papers, noted down by a collective of scientists from Asia, Europe and America recapitulate the state of art of theoretical and applied hydro-biological knowledge in the Hindu Kush-Himalaya region with a special focus on the assessment of the ecological quality of rivers. This publication is the first of a series of various printed outcomes that will help to provide a sound scientific basis for a sustainable water use in this wonderful, remarkable and important area of our planet.

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ASSESS-HKH: Proceedings of the Scientific Conference "Rivers in the Hindu Kush-Himalaya – Ecology & Environmental Assessment"

The societal benefit of biological assessment and monitoring in rivers

M.T. Barbour

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Abstract

Awareness of the value-added of biological monitoring and assessment to water resource management is increasing world-wide, but is limited in countries that are in their infancy of environmental protection. Because biological communities integrate the response to pollutants and human disturbance through their continuous exposure to the magnitude, duration, and frequency of these pollutants, these indicators provide the most information on ecological condition. I discuss 4 themes: (1) our knowledge of the ecology of rivers and the human-induced stressors that apply to rivers; (2) societal benefits of ecosystems and biomonitoring to ensure those benefits are maintained; (3) communicating our science to influence policy and decision-making; and (4) recommendations for implementation of biomonitoring and assessment. Our role as river scientists is to translate ecological theory into application tools, become communicators of credible science that protect and restore aquatic ecosystems, and provide sound science to form the basis of making informed decisions regarding aquatic resources.

Key words: biomonitoring, ecosystem services, aquatic ecology, environmental assessment, river ecology.

Introduction

Biological assessment and monitoring of aquatic resources have been well-developed in many parts of the world, namely, Europe, Australia, the United States, and Great Britain. These countries have used bioassessment to determine ecological status and condition, and to regulate land practices that impose pressures on aquatic systems. In other parts of the world, bioassessment is in its infancy, but is increasing rapidly as a scientific foundation to support decisions regarding the protection of aquatic resources. The comprehensive and collaborative project "Development of an ASSESSment system to evaluate the ecological status of the rivers in the Hindu Kush-Himalaya (HKH) region" (acronym: ASSESS-HKH, INCO-CT-2005-003659) is a prime example of how bioassessment is developing as a viable tool for ecological evaluation.

To understand the importance of a bioassessment/biomonitoring network, one must recognize the value of the services that high-quality aquatic resources provide society. Ecosystem services are the processes by which the environment produces resources that we often take for granted, such as clean water, timber, medicinal herbs, habitat for fisheries, and pollination of native and agricultural plants. In terms of aquatic ecosystems, these services include mitigation of drought and floods, the cycling and transport of nutrients, the maintenance of biodiversity, detoxification and decomposition of waste – just to name some of the key services. To be clear, an ecosystem is a community of animals and plants interacting with one another and with their physical environment. People are part of ecosystems. The health and well-being of human populations depends upon the services provided by ecosystems and their components – organisms, soil, water, and nutrients (ESA 2007, www esa.org).

In this paper, I discuss four themes that describe the societal benefits of bioassessment and biomonitoring in rivers: (1) Our knowledge of the ecology or rivers and the human-induced stressors that apply; (2) The societal benefits of ecosystems and biomonitoring to ensure that those benefits are maintained; (3) How we should communicate our science to influence policy and decision-making; and (4) Recommendations for implementation of biomonitoring and assessment.

Discussion

Theme 1: Our knowledge of the ecology of rivers and the human-induced stressors that apply.

There is much information on the ecology of rivers in the scientific literature. Perhaps the seminal paper that describes the transition of the ecology from the headwaters to the mainstem rivers is the Stream Continuum Concept by Vannote et al. (1980). The river system begins primarily as a allochthonous system, deriving its energy and food base from outside the stream, and then transitions to a fully autochthonous system whereby the energy source is produced from within. As the river flows to its confluence with the sea or other source, it becomes a combination of energy sources. The ecology of rivers is dependent upon these transitional phases. While many researchers have commented on exceptions and specific details of river ecology, this concept is generally the rule throughout the world.

We know much about the components of river systems, including not only the biology, but the hydrology and hydrogeomorphology, the energy pathways just discussed, and the water quality in different types of river systems. We also know the primary stressors to flowing waters, whether it be from

land development and floodplain encroachment or from discharges from human activities in the watershed. These stressors ascribe to either a physical alteration or chemical contamination, or, in some cases, a biotic interaction such as invasive or exotic species. In all cases, the biology is the ultimate arbiter of conditions in the water, because organisms and their life cycles are long-term residents being exposed to varying pollutants and other stressors.

A biological condition gradient (Davies & Jackson 2006) can be established to illustrate the relationship between biological condition and stressor gradients (Figure 1).

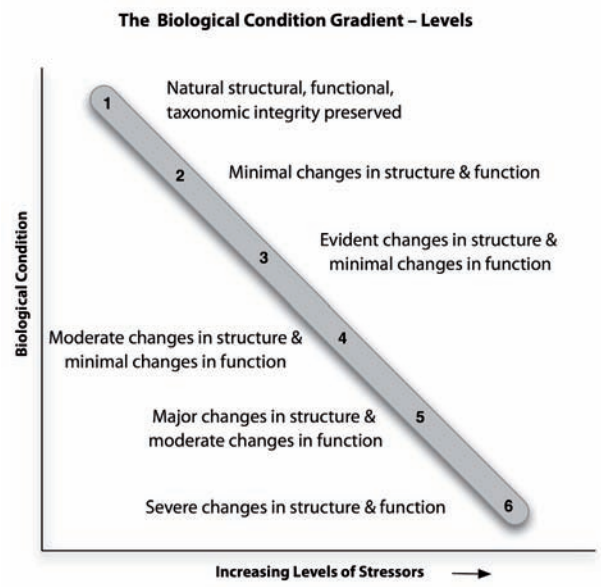

Figure 1: The biological condition gradient-levels.

The condition of the biology, and, thus, ecological condition, is highest when no stressors exist and natural environmental conditions are the norm. The gradient declines as stressors (single or multiple) increase in magnitude, duration, and frequency until the biological condition is at its worse. Using this concept, many government agencies have been able to evaluate the overall ecological condition of its waters, identify key stressors with combined biological, chemical, and physical data, and prescribe protective or restoration measures. However, knowing the biological condition is critical for these decisions to be made.

Theme 2: The societal benefits of ecosystems and the biomonitoring to ensure that those benefits are maintained.

We understand that biomonitoring is not repairing or preserving our ecosystems, but simply measuring the status. So, why and how would a poor or otherwise human-strained society, having few resources dedicated to proper sewage treatment or waste disposal facilities, get value from spending money on monitoring conditions that are already impaired? Understanding imparts meaning, i.e., having the scientific evidence of the condition of the resource provides the template from which informed decisions are made.

Even when the impacts are clear, biological monitoring via a defensible sampling approach measures and documents whether effects are significant, and to what extent. The frequency and duration of impacts are better measured with biomonitoring. Biological surveys and assessment also provide evidence of species lost, magnitude of impact, and a baseline for goals for recovery. The HKH series of projects is providing a foundation for this baseline.

If impacts are not clear, biomonitoring is used to document the condition of the aquatic resource and detecting subtle problems. One can project the ecological risk from these data when plans for land development are underway. Environmental regulations are increasingly being codified into law, and biomonitoring is a key companion for water quality standards and criteria. Biomonitoring as a measure of ecological integrity provides a baseline for protection of national or provincial parks and their waters, and identifies excellent water quality waters as reference condition. Even if we are sufficiently enlightened to value the environment and recognize the importance to humans for protecting or restoring ecosystem integrity, society still demands a process of documenting effects and assigning cause (i.e., biomonitoring) as justification for spending money for cleanup.

Theme 3: How we communicate our science to influence policy and decision-making.

We, as scientists, have a challenge to communicate our science. We typically communicate to our managers, who, in turn, will pass on the information to policy makers and then to the public. It is probable that twists in our message occur that change the meaning or provide an incomplete message. Scientists are generally not skilled in communicating complex scientific principles to non-scientists (Barbour et al. In Press). However, As Dr. J. Karr stated (2006), "When scientists fail to make a strong case for decisions based on science, the long-term costs often outweigh the short-term economic arguments for not using scientific insights. With the conservation imperative taking on a global scale, many scientists are reaching out in new directions of scientific writing. The growing response of freshwater scientists to global change is setting a precedence in communicating the issues of water quality, water availability, flow alteration, climate change, and freshwater sustainability, to name a few. How can we, as a society, continue to prosper and maintain a quality of life we desire if we continue to erode the environment?

Scientists require a translation pyramid for taking ecological data from the field, through the laboratory processing, analyzed for meaning, described in detail, summarized into key sound "bites" for assimilation by non-scientists (Barbour et al. 2004). Sometimes, this translation pyramid needs a facilitation process to be meaningful to the public and to ensure the message is not lost or misused. In most countries, the science of biological monitoring and assessment is way ahead of

the regulatory and policy framework used to manage water resources. Our challenge as scientists is to get involved in decision-making processes and support the translation of biological condition knowledge into regulatory standards. This requires that we become better communicators. We have a self-imposed mandate to provide the best possible science in a way that can form the foundation of making informed decisions. By doing this, we enlighten society to maintain healthy systems capable of self-repair, adaptation, and long-term provision of ecosystem goods and services.

Theme 4: Recommendations for implementation of biomonitoring and bioassessment.

Implementing biomonitoring and bioassessment in a water resource program involves two key components. The first is to choose ideal ecological indicators that bridge the gap between sound science and decision-making. These indicators will have these attributes: be easy to measure and interpret; be sensitive prior to severe damage; be sensitive to a range of stressors and levels; be widely applicable across water types; distinguish between natural variation and human disturbance; contribute to the diagnosis of impairment; and be meaningful to the public. The ASSESS-HKH project has followed this model.

The second is we scientists must be able to take these indicators and move up the communication translation pyramid – from raw data to the "sound bite" that is most meaningful for our message. For a bioassessment, the translation pyramid consists of considering these indicators as the ecological "currency" by which we describe the status or condition of the water resource and affect decisions (Figure 2).

My challenge to scientists, in particular the aquatic ecologists of these proceedings, is fourfold: (1) Continue to strengthen our technical approaches. The outcomes of the ASSESS-HKH project, e.g. the river quality maps,is are an excellent foundation for infusing bioassessment into decision-making. Refinement and enhancements will come from "lessons learned" of having implemented a complex, comprehensive survey and assessment over a wide typology. (2) Talk with (and listen to) the public and policy makers. Perhaps the most important part is the listening. (3) Dare to speak up in the realm of day-to-day decision-making. Get involved! Be open-minded and be communicative. (4) Write outside technical publications. Only scientists read scientific articles. Engage in preparing articles for the non-scientist, the manager, the politician.

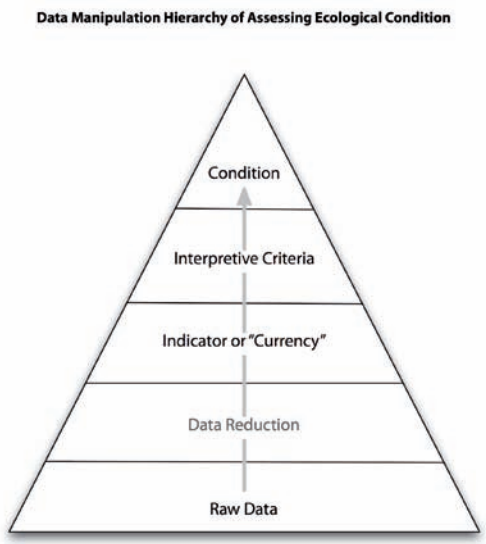

Figure 2: Data manipulation hierarchy of assessing the ecological condition.

Conclusions

Biomonitoring and bioassessment are critical to the success of managing our aquatic resources. The ASSESS-HKH project is an example of how that premise is executed in multiple countries where the collection of scientists in those countries has a common goal. Bioassessment as the fulcrum of the ASSESS-HKH project resulted in the training of biologists through the five countries of the HKH region, the determination of the ecological condition of the waters, provision of organism tolerance information to support causal analysis, and a reporting mechanism for disseminating the ecological information of the HKH region. The role of these scientists is to: (1) translate ecological theory and first principles into application tools; (2) become communicators and facilitators of credible science for actions that protect and restore water quality that result in ecosystem recovery; and (3) provide sound science to form the basis of making informed decisions regarding our aquatic resources.

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The ASSESS-HKH project: Context, approaches, objectives and results

I. Stubauer[1], O. Moog[1], D. Hering[2], T. Korte[2], A. Hoffmann[3], K. Brabec[4], S. Sharma[5], M. Shrestha[6], M.A. Kahlown[7], M.A. Tahir[7], A. Kumar[8], M.P. Sharma[8], M.F. Bari[9], A.B.M. Badruzzaman[9] & G.K. Chhopel[10]

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Abstract

ASSESS-HKH is a three years research project funded by the European Union (Contract number: INCO-CT-2005-003659). The main objective is to develop and apply a biological assessment system to evaluate the ecological river quality to provide a scientific basis for identification of sustainable water policy options and management strategies. The assessment tools were jointly developed by European partners, who provide the experience from recent research activities, and Asian partners, who provide the knowledge about Asian river catchments and management necessities. The project is organised in 8 workpackage defining the time line for necessary actions such as establishment of a stream typology, definition of reference conditions and impairment classes for the rivers in the Asian countries including a review of existing policies for water management. Research work comprises the knowledge on benthic invertebrates and their value to classify the river's ecological quality. All activities were accompanied by information events for local residents, universities and water managers. In total 390 benthic invertebrate samples from about 115 rivers in 5 different ecoregions were taken in two different seasons accompanied by collecting information on 95 parameters that describe river characteristics. Invertebrates of the samples were taxonomically identified, counted and entered into a specifically developed software tool. This dataset was the basis for developing ecological river assessment methods, called HKHscreening (Rapid Field Assessment), HKHbios (HKH Biotic Score) and HKHindex (Multimetric Index). Furthermore, a software tool (ECODAT) for calculation of these methods was developed. The monitoring tools will serve citizens and scientists of the Hindu Kush-Himalayan region and will provide scientific basis for policy recommendation, mitigation strategies, transnational water resource planning, and sustainable ecosystem management.

Key words: assessment system, ecological status, river quality, benthic invertebrates, sustainable water management.

Introduction

The Hindu Kush-Himalayan (HKH) region is not only the world's highest mountain region, but also the most populous area covering some 3,500 km² over eight countries from Pakistan in the west to Mynamar in the east. It sustains approximately 140 million people and affects the lives of more than three times as many in the plains and river basins below and is a vast storehouse of hydropower, timber, firewood, medicinal plants, rich minerals and last, but not least, water. The rivers provide water and hydro-power for hundreds of millions of people downstream. Thus, water is the central resource the EU funded research project ASSESS-HKH (Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region) is focusing on.

ASSESS-HKH mainly aims at developing tools for river assessment and river basin management for the HKH region. This research project is supported by the European Commission under the sixth Framework Programme contributing to priority "Specific measures in support of international co-operation, A.2.1. Managing humid and semi-humid ecosystems", STREP - specific targeted research or innovation project (Contract number INCO-CT-2005-003659). The project started on April 15th 2005 and ends in April 2008. The project includes an intensive exchange of knowledge between Asian and European partners, between scientists and water managers and between natural and social scientists. Four European and six Asian institutions are involved in the project:

(1) BOKU - University of Natural Resources and Applied Life Sciences Vienna, Department of Water, Atmosphere and Environment, Institute of Hydrobiology and Aquatic Ecosystem Management, Austria as project coordinator
(2) UDE - University of Duisburg-Essen, Centre for Microscale Ecosystem, Department of Hydrobiology, Essen, Germany

(3) UMag - Otto-von-Guericke University Magdeburg, Faculty of Economics and Management, Chair of Economic Policy, Magedeburg, Germany
(4) MasUniv - Masaryk University, Faculty of Science, Department of Zoology & Ecology, Brno
(5) KU - Kathmandu University, Dhulikhel, Nepal
(6) ICIMOD - International Centre for Integrated Mountain Development, Kathmandu, Nepal
(7) PCRWR - Pakistan Council of Research in Water Resources, Islamabad, Pakistan
(8) AHEC - Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, India
(9) BUET - Bangladesh University of Engineering & Technology, Dhaka, Bangladesh
(10) NECS - National Environment Commission Secretariat, Thimphu, Bhutan

The specific project objectives can be summarised as follows:

– Establishing scientific partnerships between Europe and Asia to promote transfer and adaptation of European research as a significant and verifiable contribution to international sustainable development.
– Achieving a better understanding of ecosystem dynamics in the rivers and streams of the Hindu Kush-Himalayan region.
– Developing and applying an ecological assessment system with benthic invertebrates to provide a scientific basis for identification of sustainable water policy options and management strategies.
– Developing tools for ecological water management and river basin planning, in particular invertebrate taxa inventories, sampling methods adapted to regional conditions, river assessment systems and related tools for application.
– Creating public awareness of the invaluable resource water in the HKH region to promote the sustainable handling and usage of water.

Methods

Using benthic macroinvertebrates as bioindicators for assessing the ecological status of rivers and streams is widely accepted and represents state of the art in Europe and North America, Australia and South Africa (e.g. Davis & Simon 1995, Karr & Chu 1999, Metclafe-Smith 1994, Norris 1994, Hering et al. 2004, Furse et al. 2006), as well as gaining increasing importance in some areas of the HKH region (e.g. Sharma 1996, Pradhan 1998). These organisms inhabit the bottom substrates of freshwater streams and rivers and are large enough to be seen without magnification. Generally, due to their large number of species and their wide range of systematic origin (e.g. worms, molluscs, crayfish and insects) benthic macroinvertebrates are capable of reflecting different human-induced deteriorations: organic pollution, acidification, habitat modification and overall stream degradation and disturbances. Therefore, they enable a comprehensive assessment of streams and rivers. To reach the main objective of designing and evaluating an assessment system for rivers in the Hindu Kush-Himalaya region, the work was organised in three main phases:

– preparatory work: set up of a rough stream typology, definition of reference conditions and main river stressors, development of a common sampling method, site selection
– data: sampling of benthic invertebrates and measurement of parameters, that characterise the river sites and catchments, storage of data in a common database
– results: development of assessment methods including software

Definition of stream typology, description of reference criteria and stressors

Following the principles of the EU Water Framework Directive, the ASSESS-HKH methodology is based on the reference approach. The ecological quality of a river section is evaluated by comparing an observed ecological situation (expressed in terms of benthic invertebrate population criteria) with a target situation that represents the reference status (high ecological quality). As the application of a reference based assessment system relies on well-defined river types, the workflow started with the development of a river typology for the region under investigation. A stream typology is a regional classification of streams characterising their natural differences (e.g. size, altitude, and substrate). The stream typology serves as basis for all subsequent steps of the assessment system development and the definition of mitigation measures.After a comprehensive literature survey it turned out, that no suitable stream typology existed in the HKH countries. Following this, the WWF terrestrial ecoregions (Olson et al. 2001, http://www.worldwildlife.org/science/ecoregions.cfm) have been selected as appropriate geographic units. Within this framework of ecoregions, a more detailed river typology for the HKH region has been generated, which in addition is based on catchment size, altitude, and geology (Sharma & Moog 2005a). The following five ecoregions and eleven zones in the HKH countries (sub-ecoregions, bioregions) were selected as basic study area:

Eastern Himalayan Broadleaf Forests (IM 0401)
  Inner Valleys and Passes in Western and Central Bhutan
  Mid-hills and Mahabharata Range in Nepal
Himalayan Subtropical Pine Forests (IM 0301)
  Southern Mountains and Gorges in Bhutan
  Middle Mountains and Valleys in Nepal
  Almora Hills in the Kumaon Himalaya in India
  Muree Hills in the Islamabad Region in Pakistan
Western Himalayan Broadleaf Forests (IM 0403)
  Simla Valleys in India
  Indus River Basin (catchment of Tarbella Reservoir) in Pakistan
Lower Gangetic Plains Moist Deciduous Forests (IM 0120)
  Padma and Meghna River Basin in Bangladesh
  Terai in Nepal
Upper Gangetic Plains Moist Deciduous Forests (IM 0166)
  Siwalik/Terai in India

For these ecoregions, criteria to describe the reference conditions of a river stretch were selected. Existing reference criteria in literature served as a first basis that was consequently refined and adapted to the specific conditions and requirements in the HKH region. As final product, a harmonised list of criteria to describe reference conditions in the HKH rivers was set up (Sharma & Moog 2005b).

To get a clear understanding of the driving forces, pressures and possible impacts affecting river quality in the HKH region a list of numerous human disturbances of rivers was produced based on questionnaires and literature reviews (Sharma & Moog 2005a, Pradhan et al. 2005). A review of existing policies with regard to sustainable water management and socio-economic aspects related to the pressures and impacts were produced (Pradhan et al. 2005). Among the manifold pressures two commonly spread and relevant pressures for the HKH-region were chosen for investigations: organic pollution and river damming (for water abstraction, irrigation and/or hydropower use). Organic pollution was considered as the main stressor affecting the riverine benthic invertebrate community within the HKH region.

For the final selection of sampling sites the "Himalayan Subtropical Pine Forests (IM 0301)" was chosen as Core Stream Type in Bhutan, Nepal, India and Pakistan. At least one additional stream type was selected out of the above mentioned list in these countries for sampling. In Bangladesh, the Lower Gangetic Plains (IM 0120) with and without tidal influence were chosen. A scheme was elaborated to assign candidate sites to five different pressure gradients ranging from reference status to bad status. A set of 17 sites per stream type was selected, with the following designation of candidate sites: 4 sites of a high (reference) status, 4 sites of a good status, 3 sites of a moderate status, 3 sites of a poor status and 3 sites of a bad status.

From sampling to data storage

There was a clear understanding among partners that harmonised field and laboratory work is an inevitable must for the success of the project. To achieve this goal, manuals on a standardised sampling (Moog 2007) and sorting procedure (Hartmann et al. 2007), on additional microhabitat sampling (Korte et al. 2006), on a HKH site protocol (Korte & Moog 2006), and on a rapid field assessment protocol (Moog & Sharma 2005) to be filled on-site were produced.

Field work was conducted twice: in a post-monsoon period (November /December 2005) and in a pre-monsoon period (March / April 2006). A total of 390 macroinvertebrate samples were taken. Multi-habitat sampling (MHS) approach in line with common international standards was carried out, in order to receive comparable data from all stream types. A comprehensive site protocol was filled, recording basic geographic and geological information, hydrological and morphological attributes at the catchment, reach and site scale. Record of these data was necessary to later validate the impairment status and other forms of degradation of individual sites that were assigned during the pre-classification before sampling. Additional to the standard sampling, microhabitat-specific samples were collected, which were analysed with respect to e.g. substrate and current preferences of different taxa. This information aims to fill some of the gaps in ecological knowledge and serves as a base for parts of the HKH assessment system (Korte et al. 2008a).

Samples were preserved and transported to the lab, where all specimens were sorted out of the sediment, pre-identified and conserved for the further treatment. Pre-identification was done to the lowest possible taxonomic level (mainly order or family level). Due to the overall comparatively poor scientific knowledge on the Asian river fauna it was agreed to perform a joint identification workshop for three weeks in summer 2006. Under the guidance of resource persons and taxonomic experts, who especially prepared taxonomic keys on all major taxa groups for this purpose (Graf et al. 2006a, 2006 b; Hartmann 2006, Huber et al. 2006a, 2006b, Janecek 2006, Nesemann & Sharma 2006a to 2006j, Rozkosny & Brabec 2006, Soldan & Bauernfeind 2006), the Asian and European scientists identified the collected specimens jointly during the workshop.

For storing the field and biological data, a software called HKHdip (data input programme) was programmed based on software from previous Austrian national and EU funded projects (www.ecoprof.at, www.aqem.de). The software was designed to enable standardised data entry for both site protocol parameters and species-per-site information. A HKH taxa catalogue serving as a base for the taxa entry was compiled previously to the software programming to have state of the art taxonomic information in the background of the software. The taxa catalogue currently comprises 8097 taxa (about 5400 species or working names, for those species which are not described up to now) (Sharma et al. this volume).

Results

Assessment tools

The environmental descriptions of the site protocol and the taxa information in the above mentioned database were used as a basic input, as the development of tools for the evaluation of the ecological status of rivers within ASSESS-HKH is focusing on bio-indication, i.e. the use of benthic invertebrates.

A three-tier methodology was developed and evaluated. The three methods provide three levels of increasing discriminatory power to detect the effects of environmental impacts on the benthic macroinvertebrates, i.e. from a rapid field bioassessment method over a score-based assessment method that needs only simple data processing facilities (MS Excel) to an assessment method operable with special application software.

The rapid field bioassessment method: HKHscreening

The basis module that has been developed is a Field Screening method, which acts as a manually calculated overview method on the river quality status of an investigation site. The assessment procedure is based on both, the sensory criteria and the biota that can be identified in the field with a special focus on benthic invertebrates. Taxonomy covers different levels, depending on the possibility to determine a specimen in the field, but must be done consistently among river types. For the ASSESS – HKH Region two Screening Field Protocols have been developed: a Screening Field Protocol for Mountains (all ecoregions exceptive Gangetic Plains) and a Screening Field Protocol for Lowlands (only Gangetic Plains). The Field Screening method provides a cost-effective, but scientifically valid procedure for assessing the ecological quality of rivers and streams. It allows multiple investigations of a large number of sites within a short time span. The method also serves as an "early warning" method to quickly identify areas for urgent attention or to set priorities for the selection of sites for detailed investigation. For details of the method refer to Hartmann et al. (this volume).

The score based method: HKHbios

A macroinvertebrate based scoring system (HKHbios) was developed based on existing score-based methods (NEP-BIOS, Sharma & Moog 1996; GRS-Bios, Nesemann et al. 2007) and on new data from 390 multi-habitat-samples. The HKHbios is a method similar to the British BMWP (Armitage et al. 1983), where taxa found at a site, mainly on family and genus level are used as indicators for the river quality. A so called score is assigned to each taxon and the overall HKH Biotic Score is calculated as weighted average score of all taxa present at the specific site. The resulting numerical value is compared to an ecoregion-specific transformation table for the determination of the Ecological Water Quality Class. The application of the HKH Biotic Score provides a sound bio-monitoring tool to evaluate the ecological quality of the rivers in the Hindu Kush-Himalaya Region. For details of the method refer to Ofenböck et al. (this volume).

The multi-metric index: HKHindex

An ecoregion specific multimetric assessment method for ecological river quality assessment in the Hindu Kush-Himalaya region, the HKHindex based on ecoregion, altitude and catchment size was developed. Metrics are able to reflect, e.g. the degree of organic pollution or morphological degradation. The result of a multimetric assessment on a given river stretch is a single value, the Multimetric index which is compared with the index under reference conditions. The deviation of the observed index from the reference index can be expressed as a river quality class. Abiotic and biotic data were evaluated and about 50 metrics were calculated. Environmental parameters were analysed with Principal Component Analysis (PCA) for definition of stressor gradients. Candidate and core metrics were defined using correlation analysis of stressor gradients and metrics. For all observed stream types a set of core metrics was detected, that is able to evaluate deterioration of river quality. The mean value which is derived from the core metric values gives the HKHindex that can directly be assigned to a water quality class. For details of the method refer to Korte et al. (this volume).

The ASSESS-HKH software

A software package named HKH Eco-data Management Tool which is comparable to its European counterparts, has been developed. The software consists of the module HKHdip for input of site protocol data, taxa data and data storage, the module HKHscreening for input and evaluation of the Rapid field assessment and the module HKHbios for input of taxa for the biotic score method and calculation of the same. These modules can be run under one software package as well as independently from each other. The HKHindex part must be operated under the full HKHdip version, as this module need sound taxonomy and thus the taxa database with ecological information in the background. This catalogue of macroinvertebrate taxa of the HKH region and ecological information is part also of the software. All raw data and calculated values can be exported to Access or Excel. The software will be available for the public under www.assess-hkh.at after the end of the project.

Water quality maps

Water quality maps serve as an easily readable tool to identify hot spots and to show where immediate action is required and are a valuable visual aid in dissemination activities. The following areas in the partner countries were selected for the production of water quality maps (see also ICIMOD 2007):

Bangladesh	Dhaka city area
Bhutan	area around Thimphu and Paro
India	the Kosi river system
Nepal	Pokhara Municipality and Bagmati River Basin
Pakistan	area around Islamabad and Rawalpindi

For water quality mapping the HKHscreening method was applied (Hartmann & Moog, this volume). In each area, between 20 and 50 sites were sampled, depending on the size of the area and the sources of effluents. The river quality per site was evaluated and a coloured map of the investigated rivers was drawn with blue for high quality (Class I), green for good quality (Class II), yellow for moderate quality (Class 3), orange for poor quality (Class IV) and red for bad quality (Class V). For details on water quality maps refer e.g. to Alam et al. (this volume), Sharma et al. (this volume), Shrestha et al. (this volume). The water quality maps were analysed and a follow up report on policy measures for sustainable river management strategy in the Hindu Kush-Himalayan Region was elaborated. For details refer to Shrestha et al. (this volume)

Involvement of the public

To disseminate the work programme and outputs as well as involve the concerned public, several information strategies were implemented besides the general information via the project web page www.assess-hkh.at. During the field work, the local population was informed by a huge number of information events. Local information events provided the most important means to create public awareness and acceptance. The events aimed at informing the local population, living adjacent to the sampled river sites, about the objectives of the project and particularly about the role of aquatic bio-indicators. Public flyers and posters were prepared to support the events, which are available in English as well as in local languages, such as Urdu, Hindi, Nepali and Bengali. Specific information events were also held at university level and for water managers in each Asian country. In total over 50 events were organised which were attended by over 1800 people across the concerned region.

Summary and outlook

The EU funded project ASSESS-HKH is a story of success: during the past three years all milestones and objectives set up for the project, have been achieved. The project's design has been based on approved approaches and its stepwise assembly allowed a quick response and an effective quality control.

In the preparation phase quite a lot of gaps needed to be filled.

The proven ecoregion approach could be adopted via a geographical specification of the WWF Global 200 terrestrial ecoregions. These "bioregions" served as eco-geographical units for the establishment of a simple river typology. As a threshold for unimpaired natural conditions a list of criteria that describe/indicate pristine river landscapes has been developed. And, as a consequence, also the conditions that describe human impacts have been portrayed. But this process could only start after the most relevant anthropogenic pressures that deteriorate the HKH streams have been quantified. It was clear from the beginning that benthic macroinvertebrates will serve as the targeted bio-indicators. Anyhow, for this region a common methodology for data sampling and storage needed to be developed and applied for all stream types under investigation. To ensure a harmonised field work, a couple of guidelines for selecting the sampling sites, for pre-classifying candidate sampling sites, for multi-habitat sampling and for treatment of samples in the lab have been jointly produced. The identification of the riverine bio-indicators was one of the most challenging parts of the laboratory work. But with the help of local knowledge and international top taxonomists who produced quite effective determination keys this possible obstacle could be coped.

Data evaluation for the method development was done centrally to ensure a harmonised procedure and minimise error sources. As main scientific achievements, three methods for monitoring the ecological status of rivers with different levels of precision were developed: the HKHscreening, the HKHbios and the HKHindex method. A software for data input and calculation of results (ECODAT) was computed. All products of ASSESS-HKH will be freely available for the public via the ASSESS-HKH web page (www.assess-hkh.at), which will be maintained for at least two more years beyond the project. All activities of ASSESS-HKH were accompanied by numerous information events for the concerned public with the objective to create awareness on importance of clean rivers and to increase the understanding of river water quality and associated uses. The target audience consisted of a broad spectrum of the local interested public, pupils, students, teachers, water managers, stakeholders and politicians.The co-operation of Asian and European scientists contributed remarkably to knowledge transfer and capacity building for local scientists in the Asian partner countries. Resource persons from European partners joined the Asian teams during the first sampling campaign to ensure a harmonised work flow throughout the data collection. Further, a workshop on the determination of benthic macroinvertebrates was organised for three weeks in 2006, where local scientists determined benthic invertebrates under the guidance of taxonomic experts from Europe.

The knowledge and capacity gained during the project provides a valuable background for further monitoring activities and promotes studies on bio-indication in streams and rivers of the HKH region. The ASSESS-HKH project can be regarded as a pilot study for the HKH region in the field of river water quality monitoring with bio-indicators, as biological water quality assessment in the Asian partner countries was carried out for first time.

In the field of implementing the project results, several activities beyond the project have already been undertaken or are in progress, some of them are mentioned below:

- Pakistan and Bhutan explore the possibilities to establish regular water quality monitoring in their country.
- In Nepal, several rivers have been investigated with the method of ASSESS-HKH (e.g. Mahadev Khola at Bhaktapur, Khimti River and Punyamati River).
- In Nepal (at KU), a "Benthological Society of the Hindu Kush-Himalayan Region" has been established. This society will promote research in aquatic ecology based on benthic invertebrates.

Further, all participating Asian countries are in close contact with the Water Authorities in their countries to promote biological water quality monitoring and future ecological studies in rivers. Although the ASSESS-HKH project was a story of success during its runtime, only the future will show if this joint effort was effective in terms of sustainability. In this spirit we hope that all partners and friends together with the concerned target groups will keep the aims of ASSESS-HKH alive.

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Development of a field screening methodology to evaluate the ecological status of the streams in the HKH region

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Abstract

The principle objective of ASSESS-HKH is to develop and validate a three-tier methodology by using benthic macroinvertebrate assemblages for assessing the ecological quality of rivers in the Hindu Kush-Himalayan Region (Bangladesh, Bhutan, India, Nepal & Pakistan), representing different degrees of precision. The basis module which has been developed within this frame is a Field Screening method, which acts as a manually calculated overview method on the river quality status of an investigation site. The assessment procedure is based on both, the sensory criteria and the biota that can be identified in the field with a special focus on benthic invertebrates. Taxonomy covers different levels, depending on the possibility to determine a specimen in the field, but must be done consistently among river types. For the ASSESS-HKH Region two Screening Field Protocols have been developed: a Screening Field Protocol for Mountains (all ecoregions exceptive Gangetic Plains) and a Screening Field Protocol for Lowlands (only Gangetic Plains). The Field Screening method provides a cost-effective, but scientifically valid procedure for assessing the ecological quality of rivers and streams. It allows multiple investigations of a large number of sites within a short time span. The method also serves as an "early warning" method to quickly identify areas for urgent attention or to set priorities for the selection of sites for detailed investigation.

Key words: benthic invertebrates, river quality assessment, Hindu Kush-Himalaya.

Introduction

The project "Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region (ASSESS-HKH)" aims at developing tools for river assessment and river basin management in the HKH region jointly by Asian and European partners. It represents one of the first research activities in this region that targets river quality assessment using benthic macroinvertebrates as bioindicators. The principle objective of ASSESS-HKH is to develop and validate a three-tier methodology to identify environmental hot spots in rivers of the HKH region. The three-tier methodology comprises a basic field screening method, a score-based assessment method on mostly higher taxonomic bioindication units (genus, family, order) and a multi-metric assessment method for the detailed analysis of biological data based on the best available taxonomic resolution. The field screening methodology (HKHscreening) acts as a manually calculated overview method on the river quality status of an investigation site. As proven in Europe, Australia and North America, biological data are a worthwhile addition or substitution for the detection of pollution and for the determination of the ecological status of rivers. Biological data are particularly well suited for the determination of steep pollution- and disturbance gradients. Thus, they seem to be particularly suited for world regions, in which organic pollution is a major problem.The quality assessment of surface water based on biological methods started about 150 years ago. The first biological indicator systems (saprobic systems) had been developed in the first years of the 20th century in Central Europe, when pollution was most apparent. Kolenati (1848), Hassal (1850) and Cohn (1853) observed that organisms that occur in polluted water are different from organisms that occur in clean water. The present situation in the HKH region is somewhat comparable to the European situation at this time (rapid population and urban growth, industrial development, extensive use of water and natural resources).In Europe, North America, Australia and South Africa several rapid assessment procedures have been devised and some have been regularised. Rapid bioassessment protocols are practical technical references for conducting cost-effective yet scientifically valid biological monitoring programmes. They provide reports that can easily be translated to management and public employing environmentally benign procedures (Barbour et al. 1999, Sivaramakrishnan 2000). Because rapid field assessment constitutes a scientifically-based, but applicable solution for a cost-effective approach to water quality monitoring, the application of such an approach in developing countries is very much appealing (Resh, 1995).

Methods

Data

In the HKH countries Bangladesh, Bhutan, India, Nepal & Pakistan (see Figure 1) sampling was performed in two different seasons (pre- and post monsoon). The multi-habitat sampling (MHS) technique described by Moog (2007) in line with common international standards

Figure 1: Field of study – HKH countries.

was carried out, in order to receive comparable data from all stream types and from sites representing different stages of degradation. As prerequisite for site selection, criteria were defined for selecting reference sites (Sharma & Moog 2005a) and for sites affected by environmental stressors (Moog & Sharma 2005). The set of impaired sites represents a degradation gradient in response to a pre-selected, dominant environmental stressor/pressure such as organic load and river damming. A set of at least 17 sites were sampled per stream type in each country: 4 high quality (reference), 4 good, 3 moderate, 3 poor and 3 bad.

The final site selection had to be revised for most stream types, as sites of all targeted ecological status were not always available and accessible. Based on Ecoregions (WWF 200) (Olson et al. 2001) several "stream types" were selected across the HKH region for sampling. Sites within ecoregions were characterized by their altitude, upstream catchment size and pre-dominant geological type. Overall, data from 380 MHS-samples were available from five Asian countries. All macroinvertebrates found have been identified to the best level possible.

Table 1: Sensory features: river water shows unnatural turbidity (example).

Field decision support table	river quality classes					
Multiple choices possible	I	II	III	IV	V	VI
Non minerogenic turbidity			1	1	2	

Scope

For the development of the ASSESS-HKH assessment methodology two major stressors have been defined:

1) Water pollution mainly caused by organic load, such as sewage from both private households and industries. The entry of organic material into freshwater ecosystems is linked to an increase of the aerobic metabolism to break down organic compounds. This, in turn, causes severe oxygen depletion and indirectly and directly affects the in-stream fauna.

2) Flow alteration caused by transversal dams or weirs. Dams and weirs not only reduce the flow velocity directly upstream of the structures, but also lead to a strong decrease of habitat variation, such as monotonous substrate compositions with accumulations of fine sediments and a poor current diversity. The reduction of flow causes oxygen depletion and accumulation of organic matter.

The screening methodology was primarily developed for estimating the ecological status of a site due to impacts of organic pollution (organic degradable wastes). As the effects of weirs and dams cause a similar pressure as direct organic pollution, the screening method is applicable for assessing the impact of both pressures.

Setup of the screening field protocol

The field screening methodology is based on the Austrian method for screening the ecological quality of rivers and streams - assessment of saprobiological quality of rivers ('Bestimmung der saprobiologischen Gewässergüte von Fließgewässern') - developed by Moog et al. (1999). It was adapted for ASSESS-HKH by Moog & Sharma (2005). The field screening methodology provides the user a field screening decision support table to estimate the organic pollution status of a river. Based on an assessment of sensory criteria and the biota that can be identified in the field with a special focus on the bioindicative value of benthic invertebrates, the decision support table visualises the personal impression of the surveyor. The chart is designed by expert consensus characterising observable features at different sabrobity levels. Only those criteria which can be surveyed in the field without doubt are estimated.

The assessment should be oriented on river type specific parameters and on criteria that may potentially occur at the sampling site (e.g. the absence of "red" chironomids is not evaluated, if their habitat (mud, sand) is missing). Each appropriate observation of the listed criteria has to be marked in the adequate column "river quality classes" in the field screening decision support table according to the following rules.

'+' or '-' account for 1 point; '+' means criterion was observed and '-' means criterion was not observed
'++' account for 2 points
'+++' account for 3 points
words (e.g. high, few, many) or percentages (e.g. 25%) account for 2 scores each (also in the case of verbal double indications like "few/medium").

If '+' or '-' occur in a row all '+' or '-' within the row have to be scored adequately. If "words" or "percentages" occur in a row only those words or figures that meet the observation (e.g. "none to few") have to be scored in that row. For

the classification of river quality classes the entries of each column are summed up. The majority of points per column "river quality class" are decisive for the estimation of the river quality class under study.

Sensory features

Sensory features are characterised as non-natural turbidity, non-natural colour, foam, odour and waste dumping.

Table 2: Sensory features: river water shows unnatural turbidity (example).

Field decision support table	river quality classes					
Multiple choices possible	I	II	III	IV	V	VI
Non minerogenic turbidity			1	1	2	

Ferro-sulphide reduction

Ferro-sulphide reduction phenomena are caused by oxygen depletion and are valuable descriptors of river quality classes. The dimension of reduction phenomena indicates the degree of oxygen depletion.

Bacteria, fungi, periphyton

The degrees of coverage as well as the dimension of periphyton are good indicators of nutrient content. The following indicators that must be visible to the naked eyes are used: sewage fungi & bacteria, sulphur bacteria, algae (=periphyton) in thin layers, % periphyton in significant layers and filamentous green algae.

Macroinvertebrates

A special is focus lies on the bioindicative value of benthic invertebrates. Taxonomy can cover any level, depending on the possibility to determine a specimen in the field, but must be done consistently among river types. A site has to be classified with respect to river type specific reference conditions. The following indicator features are used: species richness, abundance, number of sensitive species and number of tolerant species.

Focus is on richness and tolerance/intolerance measure. The score value of benthic macroinvertebrates is corresponding to the HKHbios scores (Ofenböck et al. 2008). Within the HKHbios assessment system macroinvertebrates are ranked using a ten point scoring system. The scores reflect the sensitivity of taxa to organic pollution (oxygen depletion), chemical pollution as well as on hydromorphological deficits. Taxa with high scores indicate high sensitivity to stressors and taxa with low scores indicate high tolerance to stressors (Ofenböck et al. 2008). Besides filling in the decision support table the provision of a taxa list with relative abundance for each taxon is required. The estimation of abundance is according to the following scheme

Table 3: Estimation of abundance.

Abundance	Verbal description
1	single finding, rare
2	few
3	medium
4	many
5	masses

Data analysis

The selection of macroinvertebrates used as bioindicatores results from the following rationales: Assurance that the indicators occur in all ecoregions; guarantee of an equal distribution of indicators for all quality classes; consideration of only those taxa which can be identified in the field without doubt.

NMS-analysis

Verification of the existing ecoregion definitions are done by multivariate analysis "non-metric multidimensional scaling" (NMS; Kruskal 1964). The Soerensen-coefficient (SK; Soerensen 1948) was used for determine the distance. The data are ln transformed. For the analysis 283 taxa identified on the best available level from a total of 183 reference sites (river quality class I) and good sites (water quality class II) have been used. For better understanding all graphs are displayed in a two-dimensional way.

Pre-classification

For scoring taxa according to their distribution along river quality classes an estimation of the river quality of sites was necessary. The pre-classification was based on the 'Guidance manual for pre-classifying the ecological status of HKH rivers' (Moog & Sharma 2005). The pre-classification considered three different stressor types: Organic pollution, river damming for water abstraction and regulation and effects of river engineering.

Distribution of indicators among quality classes

The selection of taxa used as bioindicators is designed by expert consensus. The expert judgement is based on:

– autecological knowledge of benthic invertebrate species
– reference scores assigned by different authors (e.g. GRS-BIOS (Nesemann et al. 2007), NEPBIOS (Sharma & Moog 2005b)
– range and distribution pattern of each taxon among quality classes (considering pre-classification and stressor gradients)
– abundance of taxa within quality classes
– field work experience

Results

The examination of the NMS-scatterplot overlayed by ecoregions shows the grouping of mountainous ecoregions (Himalayan Subtropical Pine Forest, Eastern Himalayan Broadleaf Forest, Western Himalayan Broadleaf Forest and Upper Gangetic Plains) and Lower Gangetic Plains (Figure 2).

The stress value of the NMS-analysis is 0.15. According to Kruskal (1964, in Hartung & Elpelt 1999) values < 0.05 are described as good results, values between 0.1 und 0.15 as satisfying and values between 0.15 und 0.2 as sufficient.
As a result two Screening Field Protocols have been developed for the ASSESS-HKH region: a screening field protocol

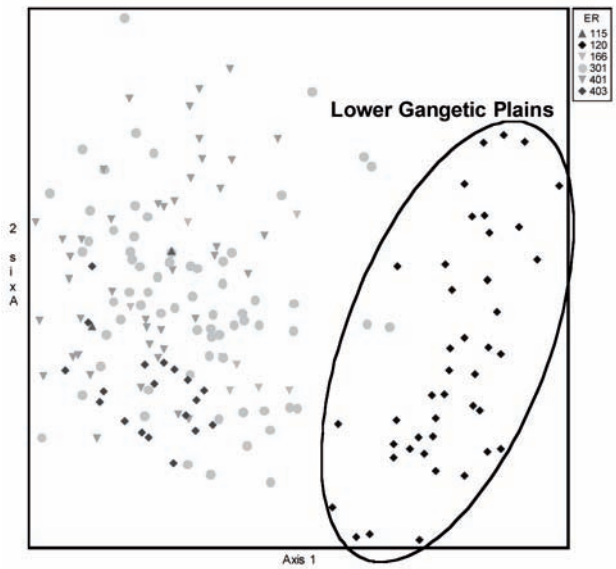

Figure 2: NMS-Scatterplot overlayed by ecoregions; axis 1 and 2.

for mountains (all ecoregions exceptive Gangetic Plains) (see Table 7) and a screening field protocol for lowlands (only Gangetic Plains) (see Table 8). Based on expert consensus a selection of macroinvertebrate taxa which act as bioindicators have been made for mountains and Lower Gangetic Plains.

For the distribution of indicators among quality classes the abundance of taxa within quality classes has been visualised (see Figure 3). As an example the distribution of the family Rhyacophildae Gen. sp. is demonstrated. The distribution of scores in the decision support table results from the range and distribution pattern of each taxon among quality classes (see Table 6).

Discussion

The screening assessment system is based on sensory criteria and the biota that can be identified in the field with a special focus on benthic invertebrates. The collection of water chemistry data is not obligatory for the application of the screening methododolgy.

Table 4: Selected bioindicators for mountains (all ecoregions exceptive Gangetic Plains).

Taxon	Species
Rhithrogena	spp.
Perlidae	Gen. sp.
Plecoptera	Gen. sp.
Euphaeidae	Gen. sp.
Stenopsyche	spp.
Rhyacophilidae	Gen. sp.
Caenis	spp.
Heptageniidae	Gen. sp.
Psephenidae	Gen. sp.
Glossosomatidae	Gen. sp.
Sphaeriidae	Gen. sp.
Simuliidae	Gen. sp.
Psychomyiidae	Gen. sp.
Tabanidae	Gen. sp.
Potamidae	Gen. sp.
Libellulidae / Corduliidae	Gen. sp.
Hydropsychidae (medium to many)	Gen. sp.
Planorbidae	Gen. sp.
Lymnaeidae	Gen. sp.
Physa	spp.
Leeches (more than naturally occurring)	Gen. sp.
Chironomids with red colour	Gen. sp.
Bezzia-Group	Gen. sp.
Psychodidae white	Gen. sp.
Air-breathing animals, e. g. rat-tail maggots	Gen. sp.
Oligochaeta/Tubificidae (mud-worms)	Gen. sp.

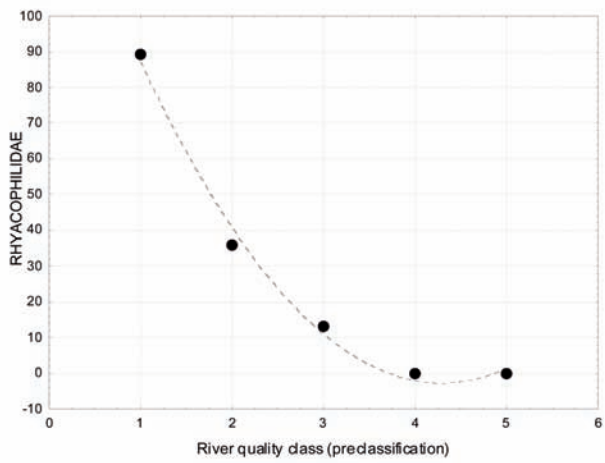

Figure 3: Distribution of the family Rhyacophilidae Gen. sp. among different river quality classes (preclassification).

Table 5: Selected bioindicators for lowlands (only Gangetic Plains).

Taxon	Species
Heptageniidae	Gen. sp.
Brachycercus	spp.
Anagenesia (Palingeniidae)	spp.
Ephemera	spp.
Elmidae	Gen. sp.
Hydraenidae	Gen. sp.
Prawn (Palaemonidae, Atyidae)	Gen. sp.
Planorbidae	Gen. sp.
Pleuroceridae (Brotia)	Gen. sp.
Thiaridae	Gen. sp.
Vivparidae	Gen. sp.
Amblemidae	Gen. sp.
Unionidae	Gen. sp.
Psychodidae (white)	Gen. sp.
Baetidae different types	Gen. sp.
Chironomids with red colour	Gen. sp.
Psychodidae white	Gen. sp.
Air-breathing animals,e. g. rat-tail maggots	Gen. sp.
Oligochaeta / Tubificidae	Gen. sp.

Nevertheless we recommended measuring the following chemical parameters:

– Water temperature
– Conductivity
– Oxygen content & oxygen saturation
– BOD5

As pysico-chemical measurements provide only a partial assessment of the health and condition of aquatic ecosystems, an assessment based only on the measurement of physical/chemical parameters may not detect adverse water quality conditions if measurements have not been taken at the right time or under the right conditions. Furthermore, the effects of contamination on an aquatic ecosystem may last long after physical and/or chemical conditions have returned to normal.

Physico-chemical parameters are precise, discriminatory and quantitative for the variables to be determined at the moment of sample collection. But there are thousands of chemicals that may be discharged to a stream and only few chemicals are selected for routine chemical analysis and the concentration of pollutant vary with time leaving their effect for many weeks or months. Therefore, in recent years there is a shift in emphasis towards the development of more holistic measures for assessing aquatic ecosystem condition (biological assessment).

Table 6: Scoring of Rhyacophilidae Gen. sp. in the decision support table (Screening field protocol for mountains).

Field decision support table	river quality classes					
Multiple choices possible	I	II	III	IV	V	VI
Rhyacophilidae Gen. sp.	3	2	1			

Within the frame of ASSESS-HKH physico-chemical date have been used for an orientating pre-classification and a rough calibration of biological results. The significance of the Screening results is evaluated by the use of Spearman rank correlation of chemical results and screening protocol results. The screening field protocol for mountains has been tested in Bhutan, Nepal, Pakistan and India. The screening field protocol for lowlands was tested in Bangladesh and Nepal. We cite data from Bangladesh as an example for the validation of the screening field protocol.

As freshwater macroinvertebrates require various given amounts of dissolved oxygen in stream water, oxygen content was selcted for analyses. The variables respond strongly to the results of the screening field protocol expressed as river quality classes (river quality class/oxygen content r= 0.89).
As part of the project river quality maps of selected representative stretches of rivers of the HKH region have been prepared ny the use of the HKH screening protocols (ICIMOD 2007). The river quality map indicated by different colours is found to be a very effective tool for visual interpretation and impression to all concerns from village layman to executive personnel.

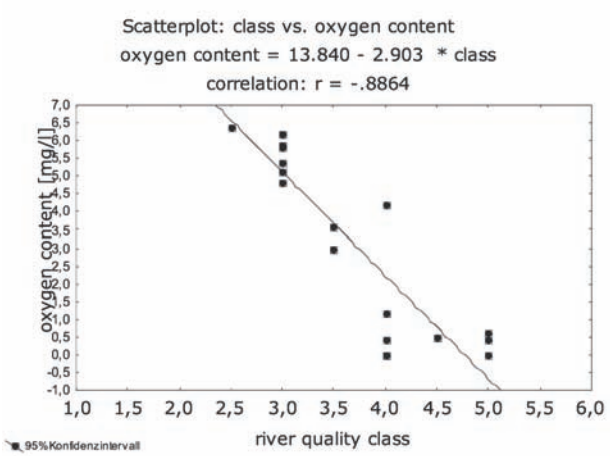

Figure 4: Correlation of screening field protocol results (river quality class) versus oxygen content.

Conclusions

To conclude, the river quality classification method through screening field protocol tool is found to be a useful tool for sustainable development of river resource including river assessment and river basin management for the HKH countries. The tool is also found effectively useful for recording features (both natural and anthropogenic activities) seen

along the rivers. The screening field protocol tool is also useful for monitoring of the quality of rivers in terms of temporal (seasonal) and spatial variations caused by natural phenomena and manmade interventions. For making wider use for similar type of study in other countries, the screening field protocol needs to be updated on the regular basis in terms of bio-indicators. In such way new families of macroinvertebrates can be incorporated in the protocol, based on the state of the art of scientific know how. Dissemination of all methodology used in this study needs to be imparted among the interested persons on regular basis through workshops, conferences and publications.

The field screening method provides a cost-effective, but scientifically valid procedure for assessing the ecological quality of rivers and streams. It allows multiple investigations of a large number of sites within a short time span. The method also serves as an "early warning" method to quickly identify areas for urgent attention or to set priorities for the selection of sites for detailed investigation.

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Table 7: Screening protocol (Mountains) for assessing the river quality of streams in the ASSESS-HKH region.

Screening Protocol (Mountains) for assessing the river quality of streams in the ASSESS-HKH region						
support table	river quality classes					
Multiple choices possible	I	II	III	IV	V	VI
Sensory features	To be ticked/counted if not in accordance with natural river type					
Non natural turbidity, Suspended solids			+	+	++	
Non natural colour		+	+	+	++	
Foam		+	+	+	+	
Odour (water)		+	++	++	++	
Waste dumping		+	+	+	+	
Ferro-sulphide reduction – (water velocity< 0,25 m/s)	-					
Mud reduced but with aerobic surface		+	+++	++		
Mud reduced but with anaerobic surface				++	+++	+++
Lower surface of stones (% cover black dots)		< 25 %	25-75 %	75-100 %	100%	100%
Upper & lower surfaces of stones				+	++	++
Ferro-sulphide reduction – (water vel.) 0,25-0,75 m/s)	-	-				
Mud reduced but with aerobic surface			+	+++	+	+
Mud reduced but with anaerobic surface				+	++	++
Lower surface of stones (% cover black dots)			< 50 %	50-100 %	100%	100%
Upper & lower surfaces of stones					+++	+++
Ferro-sulphide reduction – (water velocity > 0,75 m/s)						
Lower surface of stones (% cover black dots)			< 25 %	25-50 %	50-100 %	50-100 %
Upper & lower surfaces of stones					+++	+++
Bacteria, fungi, periphyton						
Sewage fungi & bacteria (visible to the naked eyes)	(-)	(-)	few	medium	many +++	many +++
Sulphur bacteria (visible to the naked eyes)	(-)	(-)	(-)	+	+++	+++
Stones with algal vegetation (periphyton) in thin layers	++	++				
% of thick, significant layers of algae	< 25 %	25-75 %	75-100 %	75-100 %	few	
Filamentous green algae	none to few	filaments, tufts	large tufts	(large) tufts	+	
Benthic macroinvertebrates						
Species richness	medium/high	(very) high	medium	few	very few	+++none**
Dominance of very sensitive organisms (8 to 10)*)	+++					
Dominance of sensitive organisms (6 to 8)*)	+	+++	+			
Dominance of medium tolerant organisms (4 to 6)*)			+++	+		
Dominance of tolerant organisms (3 to 4)*)			+	+++	+	
Dominance of extremely tolerant organisms (1 to 2)*)					+++	
Rhithrogena spp.	+++	++				
Perlidae	++	+				
Plecoptera	++	+				
Euphaeidae	++	+				
Stenopsyche spp.	++	+	+			
Rhyacophilidae	+++	++	+			
Caenis spp.	+	++	++			
Heptageniidae	++	++	+			
Psephenidae	++	+++	+			
Glossosomatidae	++	+++	+			
Sphaeriidae	+	+	++			
Simuliidae	+	++	++			
Psychomyiidae	+	+++	++			
Tabanidae	+	++	+++			
Potamidae	+	++	++	+		
Libellulidae / Corduliidae		+	+++	++		
Hydropsychidae (medium to many)		+	+++	+		
Planorbidae		++	+++	+		
Lymnaeidae		+	+++	++		
Physa spp.			+	++		
Leeches (more than naturally occurring)	-	-	+	+++	+	
Chironomids with red colour		very few	few	medium	+++many	
Bezzia-Group				+	++	
Psychodidae white				+	+++	
Air-breathing animals, e. g. rat-tail maggots					+++	+++
Oligochaeta / Tubificidae (mud-worms)	0 to very few	few	few/medium	medium/many	many	
Sum of columns						

*) check scores in the HKHbios scoring list **) if only airbreathing organisms

Table 8: Screening protocol (Lowlands) for assessing the river quality of streams in the ASSESS-HKH region.

Screening Protocol (Lowlands) for assessing the river quality of streams in the ASSESS-HKH region						
Decision support table	river quality classes					
Multiple choices possible	I	II	III	IV	V	VI
Sensory features	To be ticked/counted if not in accordance with natural river type					
Non natural turbidity, Suspended solids			+	+	++	
Non natural colour		+	+	+	++	
Foam		+	+	+	+	
Odour (water)		+	++	++	++	
Waste dumping		+	+	+	+	
Ferro-sulphide reduction – (water velocity< 0,25 m/s)	-					
Mud reduced but with aerobic surface		+	+++	++		
Mud reduced but with anaerobic surface				++	+++	+++
Lower surface of stones (% cover black dots)		< 25 %	25-75 %	75-100 %	100%	100%
Upper & lower surfaces of stones				+	++	++
Ferro-sulphide reduction – (water vel.) 0,25-0,75 m/s)	-	-				
Mud reduced but with aerobic surface			+	+++	+	+
Mud reduced but with anaerobic surface				+	++	++
Lower surface of stones (% cover black dots)			< 50 %	50-100 %	100%	100%
Upper & lower surfaces of stones					+++	+++
Ferro-sulphide reduction – (water velocity > 0,75 m/s)						
Lower surface of stones (% cover black dots)			< 25 %	25-50 %	50-100 %	50-100 %
Upper & lower surfaces of stones					+++	+++
Bacteria, fungi, periphyton						
Sewage fungi & bacteria (visible to the naked eyes)	(-)	(-)	few	medium	many +++	many +++
Sulphur bacteria (visible to the naked eyes)	(-)	(-)	(-)	+	+++	+++
Stones with algal vegetation (periphyton) in thin layers	++	++				
% of thick, significant layers of algae	< 25 %	25-75 %	75-100 %	75-100 %	few	
Filamentous green algae	none to few	filaments, tufts	large tufts	(large) tufts	+	
Benthic macroinvertebrates						
Species richness	medium/high	(very) high	medium	few	very few	+++none**
Dominance of very sensitive organisms (8 to 10)*)	+++					
Dominance of sensitive organisms (6 to 8)*)	+	+++	+			
Dominance of medium tolerant organisms (4 to 6)*)			+++	+		
Dominance of tolerant organisms (3 to 4)*)			+	+++	+	
Dominance of extremely tolerant organisms (1 to 2)*)					+++	
Heptageniidae	++					
Brachycercus spp.	++					
Anagenesia (Palingeniidae) spp.	++					
Ephemera spp.	++					
Elmidae	+++	++				
Hydraenidae	+++	++				
Prawn (Palaemonidae, Atyidae)	+	++	++			
Planorbidae	+	++	+			
Pleuroceridae (Brotia)	+	++	+			
Thiaridae	+	++	++	+		
Vivparidae	+	++	++	+		
Amblemidae	+	++	++			
Unionidae		++	++	+		
Psychodidae (white)				+	+	
Baetidae different types	3 or more	2 or 3	1 or 2	1		
Chironomids with red colour		single	few	medium	+++ many	
Air-breathing animals, e. g. rat-tail maggots					+++	+++
Tubificidae (mud-worms)	single	few	few/medium	medium/many	many**	
Sum of columns						

*) check scores in the HKHbios on the back page **) if only airbreathing organisms

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Development and application of the HKH Biotic Score to assess the river quality in the Hindu Kush-Himalaya

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Abstract

The main objective of ASSESS-HKH (a research project funded by the European Union; contract number: INCO-CT-2005_003659) was to develop and apply biological assessment systems to evaluate the ecological river quality for the Hindu Kush-Himalaya region. A macroinvertebrate based scoring system (HKHbios) was developed based on data from 390 multi-habitat-samples from five Asian countries (Bangladesh, Bhutan, India, Nepal and Pakistan) and comprising five ecoregions. Sampling was performed in two different seasons (pre- and post monsoon) and all macroinvertebrates were identified to the best taxonomic resolution possible. All sites were pre-classified based on physico-chemical and hydro-morphological conditions. This pre-classification was used for applying numerical procedures to verify the suitability of macroinvertebrates as indicators for the Ecological Quality of running waters. Scores were assigned by considering range and distribution patterns of each taxon among quality classes following the mathematical procedure of Sharma (1996), autecological information and expert judgement. In total 199 taxa were ranked, including taxa on class, family, subfamily, genus and species level. An indicator weight was introduced to emphasize the relevance of stenoecious taxa. The proposed HKHbios index is finally calculated as a weighted average score per taxon. The resulting numerical value is compared to an ecoregion - specific transformation table for the determination of the Ecological Water Quality Class. Based on the experiences of the ASSESS-HKH project the application of the HKH Biotic Score provides a sound bio-monitoring tool to evaluate the ecological quality of the rivers in the Hindu Kush-Himalaya Region.

Key words: benthic invertebrates, river quality assessment

Introduction

Freshwater macroinvertebrates require various physico-chemical conditions in stream water as well as specific microhabitats to survive and to build sustainable populations. Therefore the assemblage of species (e.g. number and type of benthic invertebrate taxa) reflects the overall condition of a given site. Score-based systems for bio-indication using indicator taxa scored according to their sensitivity to stressors, facilitate the interpretation of large quantities of data resulting from the biological monitoring of rivers (Armitage et al. 1983). The processing of data reduces the ecological information to make the results more accessible to managers and decision makers for water body management. Such score-based assessment methods are mostly based on higher taxonomic bio-indication units (genus, family, order), need only simple data processing facility and promise a quick, less expensive and easy way of making judgments on river quality.

Score based methods were already developed and applied in the Hindu Kush-Himalaya region in the past. In the 1990ies a first region-specific score based method for Nepalese rivers (NEPBIOS) was developed which represents an adaptation of the BMWP/ASPT system (Sharma 1996, Sharma & Moog 1996). Some modifications and several applications of the NEPBIOS followed (e.g. Pradhan 1998, Sharma & Moog 2005, Khanal & Moog 2003) and more recently a new scoring system was developed for the Ganga River system (GRS-Bios, Nesemann 2007). The EU-funded research project ASSESS-HKH (contract number: INCO-CT-2005_003659) provided the opportunity to develop a new score based biological assessment method (HKHbios) applicable to a wider geographical range and a variety of different stream types in the region. On the one hand the development of the HKHbios was based on already existing biological assessment methods for the HKH-region (NEPBIOS Sharma & Moog 1996; GRS-Bios, Nesemann 2007) on the other hand on data from some 380 new samples collected during ASSESS-HKH. The new dataset comprises data from a large geographical and altitudinal gradient range and 5 different ecoregions (WWF Global 200 ecoregions) and therefore data on a larger number of benthic invertebrate taxa.

Data basis

Overall, data from about 380 MHS-samples from five HKH countries were available. All macroinvertebrates sampled have been identified to the best level possible. In Bangladesh 68 samples were taken at 34 sites divided into tidal and non-tidal influence from a single ecoregion (Lower Gangetic Plains; IM0120). In Bhutan 34 samples were taken from 17 sites in ecoregion IM0301 (Himalayan Subtropical Pine Forests), and other 41 samples from 21 sites in Eastern Himalayan Broadleaf Forest (IM0401). In India, sites from two different

ecoregions were selected for sampling: Upper Gangetic Plains (IM0166), where 32 samples have been taken from 16 sites. In ecoregion IM0301, 17 sites were selected and 34 samples taken. 4 samples were taken in an additional, neighbouring stream type. In Nepal, 17 sites each were selected from three different ecoregions (IM0301, IM0401, IM0120). Thus 102 samples were taken in total. In Pakistan, 41 sites were taken from two different ecoregions, twenty-four of which were from ecoregion IM0301 and seventeen from Western Himalayan Broadleaf Forest (IM0403). In total 82 samples were taken. Sampling was performed in two different seasons (pre- and post monsoon). MHS samples were taken at each site and an elaborated site protocol was completed for each site in both seasons.

The investigated sites were equally distributed among all five ecological status classes (high=reference, good, moderate, poor and bad) to strengthen the statistical analyses. To achieve this goal a pre-classification process was used for the selection of the sampling sites to estimate the ecological status before sampling. This pre-classification was based on the 'Guidance Manual for Pre-classifying the Ecological Status of HKH rivers' (Moog & Sharma 2005). The pre-classification considered three different stressor types: Organic pollution, river damming for water abstraction and regulation and the effects of river engineering.

Data storage and data management

All data were entered and stored by partners in the HKH-software ECODAT which was developed within the ASSESS HKH Project (Vogl et al. 2007) using the tool for data storage (HKHdip). All country specific data were merged and served as the database for the development of assessment methods and software. In addition to biotic data (taxa lists and related abundances) all site protocol data including ecoregions, river names, site names, dates of sampling, sample codes and pre-classification status are stored in the database.

Methods

Scoring of indicator taxa

Within the HKHbios assessment system macroinvertebrates are ranked using a ten point scoring system. The scores reflect the sensitivity of taxa to organic pollution (oxygen depletion), chemical pollution as well as on hydromorphological deficits. Taxa with high scores indicate high sensitivity to stressors and taxa with low scores indicate high tolerance to stressors.

The procedure for assigning scores follows Sharma (1996), where in a first step a numerical procedure is applied and in a second step the final value is assigned by expert judgement. The numerical procedure comprises the calculation of a 'Guide Score' based on the distribution and frequency of taxa among the pre-classified river quality classes. The calculation follows Sharma (1996), adapted to a 5 class system:

Guide Score = SI/Stot x 10 + SII/Stot x 7.75 + SIII/Stot x 5.5 + SIV/Stot x 3.25 + SV/Stot

SI, SII, SIII, SIV, SV are the total numbers of sites representing the quality classes according to the pre-classification where a certain taxon was found, Stot = total number of sites where a certain taxon was found and 2.25 is the score interval with 10 as maximum (5 pre-classified quality classes) as the scale ranges from 1 point to ten points.

Taxa occurring only at pristine sites are assigned to be ranked as 10, taxa occurring only at heavily polluted sites with a score of 1. Taxa that showed no clear preferences are not scored. Sites were assigned either to mountains (ecoregions IM0301, IM0401, M0166, IM0403) or lowlands (Ecoregion IM0120). In some cases the assignment of scores on genus or family level is split for lowlands and mountains regarding dissimilar ecological requirements.

Calculation of the HKHbios

The method of HKHbios involves the determination of average score per taxon (ASPT) of the indicator species present in a sample of macroinvertebrates:

$$\text{ASPT} = \frac{\sum_{1}^{i} Score_i}{number\ of\ taxa}$$

were $Score_i$ = score of taxon i.

During the development process also the weighting of selected taxa as well as the inclusion of abundance values of indicators was tested. For weighting, only taxa that showed a very clear preference to very good conditions (score 8-10) or very bad conditions (score = 1) were considered, whereas a weight of 3 was assigned to strong indicators, a weight of 5 for very strong indicators.

The weighted average score per taxon (ASPTw) was calculated as

$$\text{ASPT}_{\text{W}} = \frac{\sum_{1}^{i} Score_i * Weight_i}{\sum_{1}^{i} Weight_i},$$

weighted average score per taxon including abundance classes (ASPTw) was calculated as

$$\text{ASPT}_{\text{WA}} = \frac{\sum_{1}^{i} Score_i * Weight_i * abundance_i}{\sum_{1}^{i} Weight_i * abundance_i}$$

were $Score_i$ = score of taxon I and $Weight_i$ = weight of taxon i

Results

Taxa Scoring

Different taxa scores as a result of the guide score calculations and expert judgement were tested for the development of the HKHbios. Applying an iterative process the best combination of scores was evaluated aiming to achieve the highest accuracy in discriminating different river quality classes (with respect to pre-classification) for each ecoregion.

The resulting scoring list includes 199 taxa in total. It comprises of 2 taxa on class level, 139 taxa on family level, 4 taxa on genus subfamily level, 51 genera and 3 taxa on species level. The scoring list is subdivided into mountains and lowlands. For mountainous ecoregions (IM0301, IM0401, M0166, IM0403) scores are available for 186 taxa, for lowlands (IM0120) 155 taxa are scored.

In a further step the effect of including abundance values and weightings for selected taxa was tested and correlated with the pre-classification. The results show that the integration of abundance (classes) is not appropriate. Especially sites of very good quality are often ranked too low because medium and lower scored taxa - which are also present - show in many cases much higher abundance than high ranked taxa. Thus the average score per taxon of pristine sites tends to result in values that are not significantly distinguishable from good and moderate ones.

The highest discrimination efficiency was found for HKHbios calculation using only weightings for selected taxa. For mountainous areas (ecoregion IM0301 - Himalayan Subtropical Pine Forests, IM0401- Eastern Himalayan Broadleaf Forests, IM0403 - Western Himalayan Broadleaf Forests, IM0166 - Upper Gangetic Plains Moist Deciduous Forests) 24 taxa were weighted. For the lowland regions (IM0120 - Lower Gangetic Plains Moist Deciduous Forests) only taxa with high rankings (indicators for high quality) were weighted. Taxa scores and weightings for indicator taxa are given in Table 2.

Definition of threshold values for ecological quality classes

Different methods have been developed for defining boundaries between quality classes (see Barbour et al. 1999). The derivation of threshold values to discriminate between different stages of stress is based on the index ranges in dependency on the estimated quality class (pre-classification) for each ecoregion separately. A five class scheme was used for the delineation of quality classes based on the distribution of values under reference conditions. The proposed class boundaries were defined using unequal class ranges considering that there is not always a linear relationship to stressor intensity. Threshold values are summarized in Table1.

Table 1: Class boundaries for individual ecoregions

class boundaries	IM0120	IM0166	IM0301	IM0401	IM0403
reference/good	≥ 5.5	≥ 7.5	≥ 6.8	≥ 7.7	≥ 7.5
good/moderate	≥ 4.9	≥ 6.5	≥ 5.7	≥ 6.3	≥ 6
moderate/poor	≥ 4.3	≥ 5.3	≥ 4.7	≥ 4.6	≥ 4.3
poor/bad	≥ 3.3	≥ 4	≥ 3.4	≥ 2.3	≥ 2.6

Application of the HKHbios: evaluating new streams

First, new streams are assigned to the membership of an ecoregion. The taxalist from a new stream is compared with Table 2 (chose either column 'mountains' or 'lowlands', depending on the ecoregion). Those taxa that are ranked are used for calculating the HKHbios of a new site, whereby the following formula is applied:

$$\text{HKHbios} = \frac{\sum_{1}^{i} HKHbios - Score_i \cdot Weight_i}{\sum_{1}^{i} Weight_i}$$

were $Score_i$ = score of taxon I and $Weight_i$ = weight of taxon i

For lowland streams (IM0120, IM0166) the scores in column 'lowland', for mountain streams (IM0301, IM0401, IM0403) the scores in column 'mountain' are to be applied. The resulting HKHbios can be allocated to a river quality class according to Table 1.

Discussion

The high number of samples and the wide geographical range of data origin allowed the scoring of a comparably large number of taxa according to their distribution among different quality classes and their autecological demands. For assigning scores a calculation procedure was applied in dependency of the distribution of taxa among pre-classified quality classes. As the pre-classification was mainly based on abiotic criteria and the distribution of infrequent taxa may sometimes give stochastic results the inclusion of expert judgement based on autecological knowledge was inevitable. Taxa with a wide ecological range or taxa with unclear preferences (e.g. air breathing taxa) were assumed not to be valuable bioindicators and were not scored at all.

Altogether 186 indicator taxa are provided for mountainous ecoregions and 155 taxa are available for the lowlands. As taxa that are distributed in both mountains and lowlands, sometimes indicate different quality classes, different scores were assigned for the HKHbios list for lowlands and mountains. E.g. Heptageniidae Gen. sp. are scored 7 in mountain rivers, where the family also occurs frequently in river quality class II but scored 10 for lowlands, where it is an indicator for river quality class I. In total, scores to 199 taxa out of about 600 taxa recorded were assigned. The use of such a large number of indicators has many advantages such as to guarantee a sufficient number of indicator taxa per site

and thus, a more stable bioindication. On the other hand, the majority of indicators are indicators of good to moderate water quality. It is unavoidable that the resulting index tends to underestimate sites of very good quality and overestimates sites of bad quality. Hence, a higher indication weight for indicators at the very end of both scales has proved to be useful. Only taxa that showed a distinct preference to reference (score of 8-10) or very bad conditions (score=1) were weighted. As the results show, the weighting of 25 selected taxa clearly increased the overall performance of the index. The resulting HKHbios is finally calculated as a weighted average score per taxon.

To regard differences in communities under reference conditions and to achieve the best discrimination power for distinguishing different quality classes the threshold values for class boundaries were set individually for each ecoregions.

Conclusion

The HKHbios was developed to provide a scientifically sound tool for monitoring running waters in the Hindu Kush-Himalaya region by evaluating the river quality based on benthic invertebrates. The development of the HKHbios was based on a dataset of about 380 sites comprising data from five countries and covering five ecoregions. 199 indicator taxa were scored according to their sensitivity to different stressors. As the HKHbios is mainly based on higher taxonomical units (family, genus) that can easily be identified by trained biologists, it is a cost -effective, but scientifically valid method for biological surveys. The score based assessment simplifies the interpretation of biological data and makes the results more accessible to water managers. The HKHbios is recommended for the use of water quality assessment within the whole HKH region that can be applied to all stream types that were covered by the ASSESS-HKH project (see Table 2).

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Table 2: HKHbios scoring list. Mountain: Scores for mountainous areas (ecoregion IM0301 - Himalayan Subtropical Pine Forests, IM0401- Eastern Himalayan Broadleaf Forests, IM0403 - Western Himalayan Broadleaf Forests, IM0166 - Upper Gangetic Plains Moist Deciduous Forests); Lowland: scores for lowland regions (IM0120 - Lower Gangetic Plains Moist Deciduous Forest)

Taxon	**Species**	**Mountain**	**Lowland**	**Weight**
SPONGILLIDAE	Gen.sp.	7	7	1
DUGESIIDAE	Gen.sp.	4	4	1
NEMATODA	Gen.sp.	2	2	1
Pila	globosa	6	6	1
ASSIMINEIDAE	Gen.sp.		6	1
BITHYNIIDAE	Gen.sp.	5	5	1
LYMNAEIDAE	Gen.sp.	4	4	1
NERITIDAE	Gen.sp.		8	1
Onchidium	sp.		8	1
PHYSIDAE	Gen.sp.	2	2	1
PLANORBIDAE	Gen.sp.	4	6	1
Gyraulus	labiatus	4	6	1
Gyraulus	convexicusculus	4	6	1
PLEUROCERIDAE	Gen.sp.	6	6	1
POMATIOPSIDAE	Gen.sp.	8	8	1
STENOTHYRIDAE	Gen.sp.	8	8	1
SUCCINEIDAE	Gen.sp.	5	5	1
THIARIDAE	Gen.sp.	4	4	1
VIVIPARIDAE	Gen.sp.	6	6	1
AMBLEMIDAE	Gen.sp.	7		1
ARCIDAE	Gen.sp.		8	1
CORBICULIDAE	Gen.sp.	4	4	1
PSAMMOBIIDAE	Gen.sp.		8	1
SPHAERIIDAE	Gen.sp.	6	6	1
Pisidium	sp.	7	7	1
UNIONIDAE	Gen.sp.	6	6	1
Lamellidens	sp.	5	5	1
NEPHTHYDAE	Gen.sp.	5	5	1
NEREIDIDAE	Gen.sp.	6	6	1
LUMBRICIDAE	Gen.sp.	5	5	1
MEGASCOLECIDAE	Gen.sp.	6	6	1
MICROCHAETIDAE	Gen.sp.	7	7	1
NAIDIDAE	Gen.sp.	3	3	1
OLIGOCHAETA	Gen.sp.	2	2	1
TUBIFICIDAE	Gen.sp.	1	1	1
GLOSSIPHONIIDAE	Gen.sp.	4	4	1
SALIFIDAE	Gen.sp.	3	3	1
ATYIDAE	Gen.sp.	6	6	1
CIROLANIDAE	Gen.sp.	8	8	1
CYMOTHOIDAE	Gen.sp.	5	5	1
GAMMARIDAE	Gen.sp.	8		1
HYMENOSOMATIDAE	Gen.sp.		8	1
MYSIDAE	Gen.sp.	6	6	1
NEONIPHARGIDAE	Gen.sp.		10	1
PALAEMONIDAE	Gen.sp.	6	6	1
PARATHELPHUSIDAE	Gen.sp.	6	6	1
POTAMIDAE	Gen.sp.	7	7	1
Himalayapotamon	sp.	7		1

Taxon	Species	Mountain	Lowland	Weight
TALITRIDAE	Gen.sp.		8	1
AMELETIDAE	Gen.sp.	10	10	1
Acentrella	sp.	8		1
Baetiella	sp.	8	8	1
Baetis	sp.		9	1
Cloeoninae	Gen.sp.	5	5	1
Platybaetis	sp.	8	8	1
CAENIDAE	Gen.sp.	7	7	1
Brachycercus	sp.		10	1
Caenis	sp.	7	7	1
EPHEMERELLIDAE	Gen.sp.	7	7	1
Cincticostella	sp.	8	10	1
Drunella	sp.	9		1
Ephacerella	sp.	8	8	1
Torleya	sp.	7	7	1
Ephemera	sp.	8	10	1
Epiophlebia	sp.	10	10	5
HEPTAGENIIDAE	Gen.sp.	8	10	1
cf. Notacanthurus	sp.	8		1
Cinygmula	sp.	9		1
Ecdyonurus	s.l.	8	10	1
Epeorus	sp.	8	10	1
Iron	sp.	9	9	5
Rhithrogena	sp.	9	10	3
ISONYCHIIDAE	Gen.sp.	10	10	1
LEPTOPHLEBIIDAE	Gen.sp.	7	7	1
Euthraulus	sp.	8	10	1
NEOEPHEMERIDAE	Gen.sp.	10		5
Potamanthellus	sp.	10	10	5
PALINGENIIDAE	Gen.sp.	10	10	1
POTAMANTHIDAE	Gen.sp.	10	10	1
Prosopistoma	sp.	10	10	5
AESHNIDAE	Gen.sp.	7	7	1
AMPHIPTERYGIDAE	Gen.sp.	7	7	1
CALOPTERYGIDAE	Gen.sp.	8	8	1
CHLOROCYPHIDAE	Gen.sp.	6	6	1
COENAGRIONIDAE	Gen.sp.	5	5	1
CORDULEGASTERIDAE	Gen.sp.	10	10	1
CORDULIIDAE	Gen.sp.	5	5	1
Macromia	sp.	7	7	1
EUPHAEIDAE	Gen.sp.	9	9	1
LESTIDAE	Gen.sp.	7	7	1
LIBELLULIDAE	Gen.sp.	6	6	1
MEGAPODAGRIONIDAE	Gen.sp.	10	10	1
PLATYCNEMIDAE	Gen.sp.		7	1
PROTONEURIDAE	Gen.sp.	5	5	1
SYNLESTIDAE	Gen.sp.	9	9	1
CAPNIIDAE	Gen.sp.	10		5
CHLOROPERLIDAE	Gen.sp.	9	9	3
LEUCTRIDAE	Gen.sp.	10	10	1
NEMOURIDAE	Gen.sp.	9	9	1
Amphinemura	sp.	9		5

Taxon	Species	Mountain	Lowland	Weight
Indonemoura	sp.	10	10	5
Mesonemoura	sp.	9	9	1
Nemoura	sp.	9		1
PELTOPERLIDAE	Gen.sp.	10		5
PERLIDAE	Gen.sp.	8	8	1
PERLODIDAE	Gen.sp.	9		1
TAENIOPTERYGIDAE	Gen.sp.	10		5
Aphelocheirus	sp.	7	9	1
BELOSTOMATIDAE	Gen.sp.	6		1
CORIXIDAE	Gen.sp.	6		1
Micronecta	sp.	5		1
Sigara	sp.	6	6	1
HEBRIDAE	Gen.sp.	7	7	1
MESOVELIIDAE	Gen.sp.	6	6	1
NAUCORIDAE	Gen.sp.	7	7	1
NEPIDAE	Gen.sp.	6	6	1
NOTONECTIDAE	Gen.sp.	3	3	1
PLEIDAE	Gen.sp.	4		1
VELIIDAE	Gen.sp.	7		1
CORYDALIDAE	Gen.sp.	7	7	1
SISYRIDAE	Gen.sp.	7	7	1
CHRYSOMELIDAE	Gen.sp.	8	8	1
CURCULIONIDAE	Gen.sp.	5		1
DRYOPIDAE	Gen.sp.	5	5	1
DYTISCIDAE	Gen.sp.	5		1
ELMIDAE	Gen.sp.	8	8	1
EULICHADIDAE	Gen.sp.	8	8	1
GYRINIDAE	Gen.sp.	6	7	1
HALIPLIDAE	Gen.sp.	6	6	1
HYDRAENIDAE	Gen.sp.	7	8	1
HYDROPHILIDAE	Gen.sp.	6		1
NOTERIDAE	Gen.sp.	4	4	1
PSEPHENIDAE	Gen.sp.	8	8	1
Eubrianacinae	Gen.sp.	9	9	1
Eubriinae	Gen.sp.	8	8	1
Psephenoidinae	Gen.sp.	8	8	1
SCIRTIDAE	Gen.sp.	8	8	1
APATANIIDAE	Gen.sp.	9	9	1
BRACHYCENTRIDAE	Gen.sp.	8	8	1
Brachycentrus	sp.	6	6	1
Micrasema	sp.	10	10	5
CALAMOCERATIDAE	Gen.sp.	10		1
DIPSEUDOPSIDAE	Gen.sp.	5	5	1
Ecnomus	sp.	6	6	1
GLOSSOSOMATIDAE	Gen.sp.	8	8	1
Agapetinae	Gen.sp.	9	9	5
Glossosomatinae	Gen.sp.	8	8	3
GOERIDAE	Gen.sp.	9	9	5
HELICOPSYCHIDAE	Gen.sp.	10	10	1
HYDROBIOSIDAE	Gen.sp.	10		1
HYDROPSYCHIDAE	Gen.sp.	7	9	1
Cheumatopsyche	sp.	7		1

Taxon	Species	Mountain	Lowland	Weight
Diplectrona	sp.	8		1
HYDROPTILIDAE	Gen.sp.	7	9	1
LEPIDOSTOMATIDAE	Gen.sp.	8	8	5
LIMNEPHILIDAE	Gen.sp.	7		1
Limnocentropus	sp.	9		5
ODONTOCERIDAE	Gen.sp.	7	7	1
Marilia	sp.	7	7	1
PHILOPOTAMIDAE	Gen.sp.	7	7	1
PHRYGANEIDAE	Gen.sp.	8		1
Pseudoneureclipsis	sp.	8	8	1
POLYCENTROPODIDAE excl. Pseudoneureclipsis	Gen.sp.	7		1
PSYCHOMYIIDAE	Gen.sp.	7	7	1
RHYACOPHILIDAE	Gen.sp.	8	8	1
Rhyacophila	sp.	8		1
Himalopsyche	sp.	9		5
Stenopsyche	sp.	8	8	1
UENOIDAE	Gen.sp.	10	10	5
PYRALIDAE	Gen.sp.	7	7	1
ATHERICIDAE	Gen.sp.	9	9	1
BLEPHARICERIDAE	Gen.sp.	10		1
Ceratopogonidae type Bezzia	Gen.sp.	2	2	1
CHIRONOMIDAE red	Gen.sp.	1	1	3
Diamesini	Gen.sp.	7	8	1
Orthocladiinae	Gen.sp.		8	1
Tanytarsini	Gen.sp.		4	1
CULICIDAE	Gen.sp.	2		1
DEUTEROPHLEBIIDAE	Gen.sp.	8	8	1
DIXIDAE	Gen.sp.	9		1
DOLICHOPODIDAE	Gen.sp.	2	2	1
EMPIDIDAE	Gen.sp.	8	8	1
EPHYDRIDAE	Gen.sp.	1	1	5
LIMONIIDAE	Gen.sp.	8	8	1
cf. Antocha	sp.	8	8	1
MUSCIDAE	Gen.sp.	1	1	1
PEDICIIDAE	Gen.sp.	9	8	1
cf. Dicranota	sp.	8	8	1
PSYCHODIDAE black	Gen.sp.	6	6	1
PSYCHODIDAE white = Psychoda	Gen.sp.	1	1	5
RHAGIONIDAE	Gen.sp.	9	9	1
SCIARIDAE	Gen.sp.	6	6	1
SCIOMYZIDAE	Gen.sp.	8	8	1
SIMULIIDAE	Gen.sp.	7	7	1
SYRPHIDAE	Gen.sp.	1	1	5
TABANIDAE	Gen.sp.	6	7	1
TIPULIDAE	Gen.sp.	7	8	1
LOPHOPODIDAE	Gen.sp.	7	7	1
PLUMATELLIDAE	Gen.sp.	7	7	1

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Development of the HKH-Index for ecological river quality assessment in the Hindu Kush-Himalaya region

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Abstract

The ASSESS-HKH project developed tools for ecological river quality assessment of the rivers in the Hindu Kush-Himalaya (HKH) region (Bangladesh, Bhutan, India, Nepal and Pakistan). One of these assessment tools is the multimetric index, the HKH-Index; the development comprised the following work steps. A stream typology was developed, which served as a base for further investigations. Sampling sites were selected a priori with the help of a pre-selection procedure (Moog & Sharma 2005), which guaranteed that sampling sites were evenly spread over the different stream types and along a deterioration gradient from near natural to heavily impacted conditions. Altogether 380 standardized samples of macroinvertebrates were taken in Bangladesh, Bhutan, India, Nepal, and Pakistan in two sampling seasons. At each sampling site 93 environmental parameters were recorded. Principal Component Analysis (PCA) was carried out to detect most important environmental parameters. Benthic macroinvertebrates were identified to the best attainable taxonomic level. Metrics were calculated for each sampling site. Correlation analysis between metrics and environmental parameters revealed metrics, which are most responsive to river deterioration. For each ecoregion a set of core metrics were selected for the HKH-Index. Metric values were standardized. The mean of a set of standardized core metric values gives the HKH-Index. The range of the index under reference conditions was defined and a five-class river quality system was generated.

Key words: ASSESS-HKH, metric, benthic macroinvertebrates, river quality class, ecoregion.

Introduction

Multimetric ecological river quality assessment methods based on benthic macroinvertebrates represent the state of the art in Europe (e.g. Verdonschot & Moog 2006, Hering et al. 2006a, Vlek et al. 2004, Pinto et al. 2004, Böhmer et al. 2004, Ofenböck et al. 2004) and North America (e. g. Weigel et al. 2002, Barbour et al. 1999) and is also applied in South America (Baptista et al. 2007, Moya et al. 2007) and in parts of South-Africa (Ollis et al. 2006). In Asia no efforts have been carried out in this direction until now. First steps in ecological river quality assessment based on macroinvertebrates are applied partly only in Nepal (Sharma 1996) and India (CPCB 1999, 2004). This is contradictory since there is a pressing need for the implementation of ecological river quality assessment and biomonitoring in this region (e.g. UNEP 2006, SAWAN 2005). In the last three years scientist from Europe and Asia tried to fill this gap and jointly developed a multimetric assessment method, the HKH-Index.

Karr (1981) developed the multimetric assessment approach, initially on fish. A multimetric assessment methodology integrates the effects of a lot of environmental stressors on the ecosystem. The basic idea is, that the negative effects of human activities on a given river stretch is evaluated through the community of animals, which are living in this river stretch, e. g. the benhic macroinvertebrate community. Benthic macroinvertebrates are able to reflect the ecological health of the river ecosystem since they are sensitive to eutrophication, organic pollution, hydromorphological deterioration, and human activities in the floodplain and catchment area, respectively. A multimetric index calculates metrics, which derive from the latter community of animals. Metrics are e.g. number of stonefly species, Shannon Wiener Diversity index or number of stone dwelling animals in the river. The main characteristic of a metric is that it is responsive to stress; ideally it is specific to a certain stressor. The application of a multimetric assessment results in a single value, the multimetric index. The multimetric index is compared to expected values under reference conditions. The deviation of the observed index from the reference index can be expressed as a river quality class.

The ASSESS-HKH project developed a multimetric index for Bangladesh, Buthan, India, Nepal and Pakistan. The development was based on a rough stream typology, a-priori classification of sampling sites (Moog & Sharma 2005) and a standardized sampling method based on the Multi-Habitat sampling (Moog 2005). The stream typology is based on the ecoregions of the WWF global 200 (Olson et al. 2001), altitude, and catchment size. For five stream types a separate HKH-Index was developed.

Methods

Approach

In a first work step a stream typology was defined in the participating countries of the ASSESS-HKH project to assign rivers with comparable natural environmental conditions to a certain stream type. The WWF Global 200 ecoregions (Olson et al. 2001) were selected as appropriate eco-geographic units. Within this framework of ecoregions, a more detailed river typology for the HKH region was generated, which in addition was based on catchment size and altitude (see table 1). The HKH-Index was developed for each stream type separately. Prior to sampling, a pre-classification of candidate sampling sites were carried out using the criteria specified in Moog & Sharma, 2005. The latter pre-classification mainly detects impacts on rivers due to organic pollution.

For the development of the multimetric index in each stream type a set of sampling sites were selected which exhibit a gradient from near natural conditions to heavily impacted conditions.

Sampling and metric calculation

A standardized Multi-Habitat sampling procedure (Moog 2005) was carried out at each sampling sites. Hence, the number of different substrate types was sampled depended on their overall share. 93 environmental parameters were recorded at each sampling site. Sampling sites were sampled twice, post-monsoon (Oct. 2005 – Jan. 2006 and pre-monsoon (March 2006 – June 2006) resulting in 380 sampling sites (see Table 1). All specimens were removed from the samples and identified to the lowest attainable taxonomic level. 93 metrics were calculated for each sampling site.

Gradient analysis

Box & Whisker Plots and Principal Component Analysis (PCA) were applied to the environmental parameters a) to detect parameters with a long gradient, and b) to reduce redundant information. For the PCA the environmental parameters were assigned to the stressor groups eutrophication, organic pollution, hydromorphology and landuse of the floodplain. The PCA was carried out for lowland rivers and mountainous rivers and for the different stressor groups separately. Finally, two to three environmental parameters were chosen from each stressor group. In addition PCA axis value1 and axis value 2 of each sampling site were selected for further investigations. The PCA axis value of a sampling site reflects the impact of all parameters of a certain stressor group.

Selection of candidate metrics

The metrics were correlated with the selected environmental parameters of each stressor group to detect metrics, which are responsive to the increase or decrease of the environmental parameters. Graphical analyses were applied to reveal the latter ability (Fore et al. 1996, Karr & Chu, 1999). Metrics which respond monotonic increasing or decreasing were most suitable. Therefore, frequency scatter plots in combination with the Spearman rank correlation test were the most suited option. A metric was selected as a candidate metric for the multimetric index if it showed monotonic response over the whole gradient range of a given stressor and exhibits a Spearman rank correlation coefficient (r) > 0.5.

In addition sampling sites were divided into stressed and unstressed sites with respect to a given stressor. Therefore, the 33rd and 67th percentiles of all stressor gradients were calculated. The latter percentile values were used as threshold values to divide the sampling sites into stressed and unstressed sites. Then, box plots were applied showing a given metric and its response to stressed and unstressed sampling sites. In this case a metric was selected as a candidate metric if the two interquartile boxes (25th / 75th percentile) of stressed and unstressed sampling sites were not overlapping (see Figure 1). The latter metrics were assigned as candidate metrics exhibiting good discriminating efficiency (Vlek et al. 2004; Ofenböck et al. 2004). The aim was to find at least 3 core metrics per metric type within a given stressor group (according to Hering et al. 2006a). If this criterion was not fulfilled «non-overlapping» of interquartile ranges were decreased to 30th /70th percentile.

Selection of core metrics

From the set of candidate metrics the core metrics of the HKH Index were selected according to the following rules. 1. Metrics should belong to different metric groups. This guaranteed the HKH-Index reflects comprehensive ecological information. According to Hering et al. (2006a) metrics can be compiled to four different metric groups, i.e. a) composition

Table 1: Stream typology based on ecoregion, catchment size and altitude.

Ecoregion	[m a.s.l.]	Catchment [km²]	Number sampling sites
Lower Gangetic Plains	45-250	500 – 1000	51
Upper Gangetic Plains	45-250	500 – 1000	18
Himalayan Subtropical Pine Forest	500 – 2000	50 – 500	78
Western Himalayan Broadleaf Forest	1000 – 2500	50 – 500	17
Eastern Himalayan Broadleaf Forest	1000 – 2500	50 – 500	34

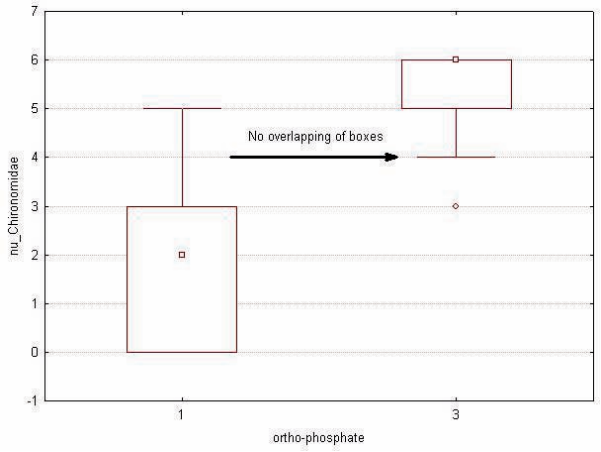

Figure 1: Example of "non-overlapping" interquartile range (25th/75th) for metric "sum all families". Metric is suitable as candidate metric. 1= sampling sites unstressed, 3 = sampling sites stressed by landuse (deforestation).

and abundance metrics, b) richness and diversity metrics, c) sensitivity and tolerance metrics and d) functional metrics. Composition and abundance metrics give the relative proportion of a taxon or taxonomic group with respect to its total number or abundance, respectively. Richness and diversity metrics are giving the number of species, genera, or higher taxa within a certain taxonomical entity, including the total number of taxa and all diversity indices. Sensitivity and tolerance metrics are related to taxa known to respond sensitively or tolerantly to a stressor or a single aspect of the stressor, respectively. Functional metrics reflect certain overlaying ecological features of animals, e.g. substrate or current preferences. Consequently, taxonomic units could be summarized to functional groups (see below and Table 4).

Inter-correlation tests between candidate metrics were carried out to detect redundant metrics. A threshold value for Spearman's r > 0.75 was considered as a high correlation between two metrics. This observation was conducted for each stream type and within each metric group separately. Deletion criteria were as follows: 1. Deletion of the metric which shows a higher over all correlation (according to Hering et al. 2006a). 2. Comparison of Box & Whisker-Plots of metrics which were highly correlating: That metric was kept which showed the best separation between stressed and unstressed sampling sites. 3. Comparison of abundance information. Metrics which were based on individual numbers were evaluated weaker than metrics based on abundance classes or relative share values. Hence, in a case of inter-correlation the latter metrics were considered for the selection as core metric.

Calculation of upper and lower anchor values

The range of a metric was fixed through upper and lower anchor values (Hering et al. 2006a). 95th and 5th percentile were defined as upper and lower anchor values for the metrics of stressors organic pollution and eutrophication. Regarding the stressor hydromorphology and landuse maximum and minimum values of the metrics were defined as upper and lower anchor values. The upper anchor value reflects reference conditions and the lower anchor values reflects the heavily impacted situation. Hence, the upper anchor value of a metric which values increase with the increase of impairment is smaller than the according lower anchor value (upper anchor value < lower anchor value) and vice versa.

Standardization of metrics values

In a next step all core metric values were transformed to a value between 0 and 1 (see formula 1). Hence, all metric values were comparable with each other.

$$\text{Standardized metric value} = \frac{\text{Metric value} - \text{Lower Anchor}}{\text{Upper Anchor} - \text{Lower Anchor}}$$

Formula 1: Standardization of metric values (Hering et al. 2006a).

Standardized metric values > 1 were set back as one and metrics values < 0 were set back as zero.

Final selection of core metrics

Finally, a metric was chosen as core metric if the according 25th percentile value in reference conditions was greater than 0.5. These metrics were considered as robust metrics, since they obtained in 75% per cases values > 0.5 in reference conditions. In addition the coefficients of variance (C.V.) for the latter metrics were calculated to measure their variability relative to the mean. Metrics were selected as core metrics which had a variability C.V. < 1. These metrics were considered as most effective for river quality assessment, and hence build the metrics for the HKH-Index calculation.

Calculation of the HKH-Index

The mean of the core metrics gives the HKH-Index. The set of core metrics that have to be calculated for the HKH-Index is depended on the stream type (ecoregion) in which the sampling site is located.

Setting class boundaries

To assign the river quality class to a sampling site the multimetric index needs to be compared to the multimetric index under reference conditions. The degree of deviation from the reference conditions gives the river quality class. Consequently, the class boundary for class "high" must be clearly defined. The mean, which derived from the 25th percentile values of the core metrics under reference conditions, was chosen as lower class boundary for class "high". This value takes the natural variability of core metric values in reference conditions into account. Thus, only metrics were considered as core metrics, which obtain a value > 0.5 (see above "Final selection of core metrics") the minimum value for class boundary "high" could be 0.5. The following class boundaries, river quality class "good" (2) to "bad" (5), were evenly spread over the range that was left after setting the boundary for class "high".

Results and Discussion

Gradient analysis

Table 2 gives the environmental parameters, which were selected from the gradient analysis. These parameters exhibited the largest range. Hence, they are most suitable for the following gradient-metric correlation analysis. Parameters detecting eutrophication and organic pollution had low values at near natural sampling sites and high values at heavily impacted sampling sites. The environmental parameter density of wooded riparian vegetation showed high values in near natural conditions, i.e. 100% density of wooded riparian vegetation. The environmental parameter "number of bank fixation" increased with the increase of impairment. Landuse Indeces weight the effect of different utilisation intensities. E.g. the impact of villages and urban sites is evaluated bigger than the impact of cropland on the river ecosystem.

Selection of core metrics

Table 4 shows the different sets of core metrics for each stream type. They build the basis for the HKH-Index calculation. Each stream type can be evaluated with four to six core metrics. These metrics are considered as robust metrics, since they obtained in reference sampling sites in 75% per cases metric values > 0.5 (metric value standardized). In addition they were identified as highly responsive to deterioration of river quality. richness & diversity metrics and sensitivity & tolerance metrics could be detected for each stream type to distinguish impairment. Previous investigations in other countries also showed, that richness & diversity metrics are most suitable (Gray & Delaney 2008 in press, summary e.g. in Barbour et al. 1999). Nevertheless, other investigations also revealed that richness & diversity metrics showed no response to river deterioration and may also be influenced by catchment size and sampling method (Heino et al. 2007, McCormick et al. 2004). The selection of EPT taxa in all stream types as core metric emphasizes the importance of this group for the ecological evaluation of rivers in the HKH region (compare also e.g. Hrodey et al. 2008, Moya et al. 2007, Baptista et al. 2007, Ortiz et al. 2005). The metric "Average Score per Taxon" (ASPT, Armitage et al. 1983) was selected in four of the five stream types as core metric. Investigations in different European stream types revealed that this sensitivity & tolerance metric is one of the "best" macroinvertebrate metric to detect and evaluate impact on river ecosystems (Johnson et al. 2006).

Oligochaeta are known from many investigations to be pollutant tolerant (for review see Aston 1973). Their number increase especially with the increase of eutrophication (e.g. King & Richardsen 2007, McCormick et al. 2004). The sensitivity & tolerance metric Batidae-Simuliidae-Hydropsychidae-Chironomidae (BaSiHyCh.) is introduced for the first time. Individuals of all these families may increase considerable in numbers parallel to the increase of river pollution (Flinders & Ragsdale 2007, Buss & Salles 2007, Marques et al. 2003, Buss et al. 2002, Armitage et al. 1983). The reason is that due to eutrophication and organic pollution suspension feeders (many Hydropsychidae and Simuliidae), algae grazer (many Baetidae) and oxygen depletion resistant collectors (many Chironomidae) may profit up to a certain degree. Consequently, certain species within these families are able to increase their individual numbers tremendously. In this work we showed that the individual numbers of the latter families may be summed up to detect pollution in rivers (see e.g. Figure 2).

Table 2: Environmental parameters selected for gradient-metric correlation analysis.

	Environmental parameters lowland	Environmental parameters mountain
Stressor group	PCA Axis 1 values	PCA Axis 1 values
	PCA Axis 2 values	PCA Axis 2 values
	Nitrate	Conductivity
	Ortho-phosphate	Ortho-phosphate
Organic pollution	PCA Axis 1 values	PCA Axis 1 values
	PCA Axis 2 values	PCA Axis 2 values
	BOD5	BOD5
	E-coli	E-coli
Hydromorphology	PCA Axis 1 values	PCA Axis 1 values
	PCA Axis 2 values	PCA Axis 2 values
	Density wooded riparian vegetation	*Density wooded riparian vegetation*
	Number bank fixation	*Number bank fixation*
Landuse	PCA Axis 1 values	PCA Axis 1 values
	PCA Axis 2 values	PCA Axis 2 values
	Landuse Index (Hering et al. 2006b)	Landuse Index (Hering et al. 2006b)
	Landuse Index of floodplain	Share of forest in the floodplain
	Share of villages in the floodplain	

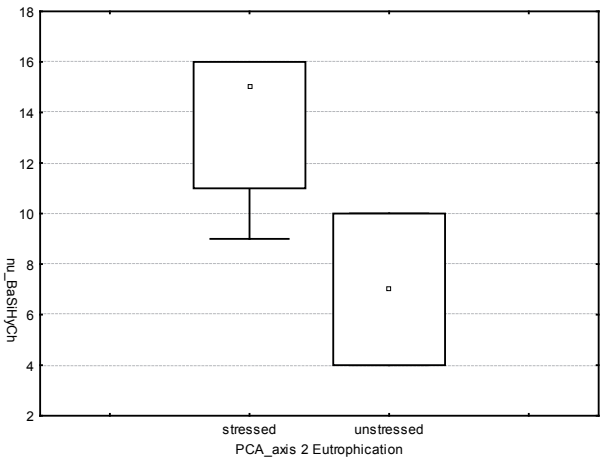

Figure 2: Number of Baetidae, Simuliidae, Hydropsychidae and Chironomidae specimens (BaSiHyCh) in unstressed and stressed sampling sites (Western Himalayan Broadleaf Forest). Specimen numbers of each family were transformed into abundance class (Meier et al. 2006) and summed up.

Only three functional metrics, describing habitat preferences, were identified as suitable. The reason is that habitat – and current preferences are the only functional metrics available for the development of the HKH-Index. These metrics were developed within the ASSESS-HKH project. Other functional metrics, which are suitable to detect river quality deterioration, like feedings types (Rawer-Jost et al. 2000, Kerans & Karr 1994) were not available. The knowledge about the ecology of the benthic macroinvertebrates of the HKH region still is scarce.

The streams observed in the Lower Gangetic Plains did not exhibit core metrics in reference conditions which 25th percentiles obtain values > 0.5 (exception: metric abundance of Oligochaeta). Hence, core metrics in reference conditions do not obtain regularly high values. We conclude that this stream type does not have any reference conditions any more. Therefore metrics which detect river degradation, e.g. ETP taxa or ASPT, are not able to obtain large values. Only ubiquitous taxa were left which are able to tolerate a certain degree of impairment.

Class boundaries

Table 3 gives the range of the indices for each of the five river quality classes. The different ranges of the river quality class "high" between the ecoregions, stream types respectively is due to the fact, that metrics in reference conditions exhibit a natural variability. This is caused by temporal patterns, e. g. alteration in discharge, temperature, weather conditions, biotic interactions, regional variability and heterogeneity in stability of habitat (e.g. Collier 2008, Southerland et al 2007, Miller et al. 2004, Barbour et al. 1992, Hildrew & Townsend 1986). Since most of the sampling sites for the development of the HKH-Index derived from different region (countries) of the ecoregion Himalayan Subtropical Pine Forest (n = 78) the variability within metrics of reference sites is quite large. This results in a lower boundary for river quality class "high" than in other ecoregions.

Conclusion

A multimetric assessment method for ecological river quality assessment in the Hindu Kush-Himalaya region, the HKH-Index was developed for Bangladesh, Bhutan, India, Nepal, and Pakistan. A stream typology, which was based on ecoregion, altitude and catchment size served as basis. For all observed stream types a set of core metrics was detected, that is able to evaluate deterioration of river quality. The mean value which derives from the core metric values gives the HKH-Index. A five-class river quality system was developed on the basis of the HKH-Index variability of reference sites. The degree of alteration from the natural index range can be transformed into a river quality class.

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Table 3: Class boundaries

Ecoregion/river quality class	1 "high"	2 "good"	3 "moderate"	4 "poor"	5 "bad"
Lower Gangetic Plains	≥ 0.47	≥ 0.35	≥ 0.24	≥ 0.12	< 0.12
Upper Gangetic Plains	≥ 0.65	≥ 0.49	≥ 0.33	≥ 0.16	< 0.16
Himalayan Subtropical Pine Forest	≥ 0.58	≥ 0.44	≥ 0.29	≥ 0.15	< 0.15
Eastern Himalayan Broadleaf Forest	≥ 0.77	≥ 0.58	≥ 0.39	≥ 0.19	< 0.19
Western Himalayan Broadleaf Forest	≥ 0.78	≥ 0.50	≥ 0.39	≥ 0.20	< 0.20

Table 4: Final set of core metrics per ecoregion and stream type. Metric types: c/a = composition and abundance metrics, r/d = richness and diversity metrics, s/t = sensitivity and tolerance metrics, f = functional metrics. Abundance units: # = number, nu_ = number individuals transformed into abundance class (Meier et al. 2006), [%] = relative share. UA = upper anchor value (reference), LA = lower anchor value (heavily impacted). UA > LA = metric decrease with increase of river deterioration. UA < LA = metric increase with increase of river deterioration. fam = families. gen = genus. ind = individuals. E = Ephemeroptera (Mayflies), P = Plecoptera (Stoneflies), T = Trichoptera (Caddiesflies). D (M) = Margalef Diversity Index. D (E) = Evenness Diversity Index. D (S-W) = Shannon Wiener Diversity Index. Plec = Plecoptera. Dip = Diptera, Olig = Oligochaeta, BaSiHyCh = Batidae-Simuliidae-Hydropsychidae-Chironomidae. ASPT (_w) = Average Score Per Taxon (_weighted). Lphil = Lithophil (only on stones). Lith = Lithal (stone dwelling animals). Pel = Pelal (mud dwelling animals).

Himalayan Subtropical Pine Forest	c/a	UA	LA	r/d	UA	LA	s/t	UA	LA	f	UA	LA
	[%] EPT fam	68.8	0	D (E)	0.86	0.23	ASPT	7. 5	4. 8			
				D (M)	7.4	1.07						
Eastern Himalayan Broadleaf Forest	c/a	UA	LA	r/d	UA	LA	s/t	UA	LA	f	UA	LA
				D (S-W)	3.09	0.03	ASPT	7	1	nu_Lphil	12	0
				nu_Dip	2	6	nu_Olig	0	7			
				# EPT gen	16	0						
Western Himalayan Broadleaf Forest	c/a	UA	LA	r/d	UA	LA	s/t	UA	LA	f	UA	LA
	[%] EPT ind	90.6	4.9	D (M)	3.92	0.8	nu_BaSiHyCh	4	16			
	[%] Plec fam	14. 2	0				ASPT	7.3	6.35			
Lower Gangetic Plains	c/a	UA	LA	r/d	UA	LA	s/t	UA	LA	f	UA	LA
	[%] EPT fam	33.3	0	# EPT gen	6	0	nu_Olig	0	6	nu_Pel	0	22
							BMWP	101	5			
Upper Gangetic Plains	c/a	UA	LA	r/d	UA	LA	s/t	UA	LA	f	UA	LA
	[%] EPT fam	58.8	0	D (S-W)	2.73	0.9	BMWP	146	0	nu_Lith	26	0
							ASPT	7.07	1			
							nu_BaSiHyCh	*2*	*13*			

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Contribution to the knowledge of aquatic macroinvertebrates from Hindu Kush-Himalaya

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Abstract

The Hindu Kush-Himalayan (HKH) region is one of the world's highest mountain range covering some 3500 km over eight countries from Afghanistan in the west to Myanmar in the east. This region is known as world's youngest mountain range offering highest altitudinal variation on Earth with extreme climatic contrasts. Despite such unique features, very less is known in terms of taxonomic knowledge of aquatic macroinvertebrates from this region. This paper introduces 8097 taxa of aquatic macroinvertebrates with author's name and the year of original publication fully cited, with the complete list available in excel spread sheet but not included in this paper. The main source for this compendium was already published available literature updated with the inclusion of findings from EU funded ASSESS-HKH project (INCO-CT-00-0069). Some of the earliest taxonomic findings from Pakistan, India, and Bangladesh are from The Fauna of British India including Ceylon and Burma series published by Taylor and Francis publication. Bhutan is one of the least explored countries. Almost all the taxa included in the species inventory belonging to Bhutan are from ASSESS-HKH project findings.

Key words: taxonomy, biogeography, aquatic insects, aquatic invertebrates.

Introduction

The biota of an aquatic ecosystem directly reflects the conditions existing in the environment and the information available have been utilized very extensively in the biological monitoring of water pollution levels worldwide. The most commonly used bioindicators of river water pollution includes phytoplankton, macrophytes, zooplankton and macrozoobenthos. Hellawell (1978) reviewing the literature found that macroinvertebrates (macrozoobenthos) were the most popular group of organisms used for instream monitoring of river water quality followed by protozoa and algae. Experience in Europe and elsewhere clearly indicated that for routine monitoring of rivers the most appropriate biological assessment methods appear to be those based on benthic macroinvertebrates.

It is a big challenge to prepare an inventory of biological resources and assess their conservation status. On one hand the biological diversity of the Himalaya due to varied climatic and altitudinal conditions is very rich, and on the other hand information when available is so scattered that collecting those information and compilation of data in itself is a very tedious job. The water quality assessment methods in this region are therefore, largely based on chemical and microbiological analysis besides several limitations.

To promote biological methods i.e., monitoring water pollution using macroinvertebrate fauna as bioindicators, therefore demands at the very begining an inventory. No attempt has yet been carried out in this regard in the member states of Hindu Kush-Himalaya (HKH). This research therefore can be regarded as a valuable contribution and the species inventory as a living document for all times.

Historical background

Most of the taxonomical works on fauna from the HKH have been carried out by the researchers abroad. Probably, insects from Nepal as described by Hope in "Synopsis of Nepal Insects" published in 1831 (Atkinson, 1980) is one of the earliest contributions. Unfortunately, the literature available describing biota from the region are highly scattered. A preliminary review as follows, accessible with considerable difficulties, on the expeditions to Nepal and elsewhere in the region, based on which several taxonomic works have been made possible by several organizations clearly indicates that the researchers in sixties and seventies were more enthusiastic than in the later years. In the later years, however, individual approach has increased as reviewed in the following pages. It is beyond the reach of this report to cite every author's contribution nevertheless; the citation given herein in its summarized form is enough to keep us informed of the present taxonomic situation of macroinvertebrates from the region. It is due to the lack of proper information sources that the local researchers could not bring their ideas growing up.

Plecopterans described by Harper in different occasions were collected in 1967 by the Canadian Expedition to Nepal. Similarly, materials on which the further study on Plecoptera

is based were mostly collected by the II Yugoslav Entomological Expeditions to Nepal in 1980. The present knowledge on Ephemeroptera has been made possible due to Japanese Himalayan Expeditions 1952-53 and 1960, Yugoslavian Nepal Expedition April/May 1978, and the results of Himalaya Expeditions of J. Martens 1983-84. Similarly, the materials collected by Prof. H. Janetschek in a Research Scheme Nepal Himalaya Expedition-1961 has been the basis for more than 45 publications all over the world. The work on Diptera of Nepal was stimulated by the collections of two expeditions organised by British Museum to Nepal first in 1954 and the second in 1961-62. The publication of Kimmins is also based on the study of the collections made by the same British Expeditions (Table 1).

Ephemeroptera

Ephemeroptera have been very poorly known as compared to other group of insects. Some Ephemeroptera of the families Baetidae, Ephemerellidae, Ephemeridae and Heptageniidae have been described earlier. Findings from ASSESS-HKH project added species from the family Isonychiidae, Leptophlebiidae, Ameletidae, Arthropleidae, Neoephemeridae, Palinginiidae, Polymitarcyidae, Potamanthidae, Prosopistomatidae, and Trichorythidae. Hubbard and Peters (1978) reported ephemeropterans from India and other regions in 'A Catalogue of the Ephemeroptera of the Indian Subregion'. Contributions on the Ephemerellidae from Nepal has been done by Ueno (1955), Allen and Edmunds (1963), and Allen (1971, 1973).

Odonata

Dragonflies of the families Amphiterygidae, Calopterygidae, Chlorocyphidae, Euphaeidae, Chlorolestidae, Lestidae, Coenagrionidae, Platycnemididae, Platystictidae, Protoneuridae, Epiophlebiidae, Gomphidae, Aeshnidae, Cordulegastridae, Corduliidae, and Libellulidae have been reported from the region. Dragonflies described by Selys (1854) is the earliest record from Nepal. Fraser (1933, 1934, 1936) in the monograph of the dragonflies of British India cited some as probably occurring in Nepal. St. Quentin (1970) has summarised the results of German and Austrian Expeditions (1961-1970). In Kumar and Prasad (1981) key and regional bibliography of 64 spp. are listed for Nepal. Based on a preliminary checklist of the Nepalese dragonflies (Kiauta, 1984), Vick (1989) has produced a list of Dragonflies with summary of their altitudinal distribution recorded from Nepal. This list includes together with a list of 172 spp. of Odonata from Nepal an annovated bibliography with 113 titles of the authors (both local and international) with notes and comments on taxonomic reliabilities. The contributions of M. Mahato (Ref. Vick 1989) as a first Nepalese resident specializing in this order is noteworthy.

Plecoptera

Plecoptera of the families Taeniopterygidae, Capniidae, Leuctridae, Nemouridae, Peltoperlidae, Perlodidae and Perlidae have been reported earlier. Contributions to the knowledge of Nemouridae and Perlidae is relatively worthy enough to be mentioned. Contributions on Plecoptera in general

Table 1: List of expeditions led in the collection of macroinvertebrates.

Year	Expeditions
1952-53	Japanese Expeditions to Nepal Himalaya. Ref. Kihara, H. (1955).
1961	IInd Expedition of the Research Scheme Nepal Himalaya in the Khumbu Himal Ref. Janetschek, H. (1990) edited.
1961	German and Austrian Expeditions to Nepal (st. Quentin 1970).
1961-1962	The British Museum (Natural History) Expedition to East Nepal Ref. Sheals, J. G. and Inglis, W. G. (1965).
1962	Nepal Expedition-1962. Ref. Ebert (1966).
1963	Himalayan Expedition of Chiba University, Japan. Ref. Numata, M. (1965, 1975).
1964	Nepal Expedition-1964. Ref. Dierl (1966)
1967	Canadian Expedition to Nepal Ref. Harper (1974)
1969	Himalaya Expeditions by J. Martens. Ref. Martens, J. (1984).
1970	German and Austrian Expeditions to Nepal (St. Quentin 1970).
1972	The Netherlands Centre for Alpine Biological Research sponsored Expedition to Nepal (Ref. Vick 1989).
1973	The Netherlands Centre for Alpine Biological Research sponsored Expedition to Nepal (Ref. Vick 1989).
1975-1977	India-Nepal Expedition of the Natural History Museum in Basel (Ref. Satô 1979).
1976	The Netherlands Centre for Alpine Biological Research sponsored Expedition to Nepal (Ref. Vick 1989).
1978	I-Yugoslav Himalayan Expedition. Organised by the Slovenian Natural History Museum in Ljublijana (Ref. Braasch 1981)
1980	II-Yugoslav Entomological Expedition to Nepal Organised by the Slovenian Natural History Museum in Ljublijana (Sivec 1981).
-	Nepal Alpine Zone Research Project. Ref. Roback, S. S. and Coffman, W. P. (1987).
1983	Himalaya Expeditions by J. Martens. Ref. Martens, J. (1984).

have been carried out by Zwick and Sivec (1980) and Sivec (1981). Perlidae from Nepal have been described by Klapálek (1912), Wu (1935), Wu (1940), Kimmins (1946) and Harper (1976, 1977). Family Capniidae has been studied by Aubert (1959), Kimmins (1947), Zhiltzova (1969), Jewett (1975), and Harper (1977). Family Leuctridae has been described by Jewett (1958), Harper (1977) and Zwick and Sivec (1980). *Cryptoperla spec.2* (Zwick, 1977) has been identified as *Cryptoperla pentagonalis* (Zwick and Sivec, 1980) of the family Peltoperlidae probably as the only specimen of this family reported from Nepal. Zwick and Sivec (1980) has jointly described three species of the family Perlodidae.

Coleoptera

Aquatic Coleoptera of the families Dryopidae, Dytiscidae, Elmidae, Gyrinidae, Helophoridae, Heteroceridae, Hydraenidae, Hydrophilidae, Hydroscaphidae, Noteridae and Psephenidae have been reported. Remarkable contributions to the families Dryopidae from Nepal are due to Satô (1981) and Olmi (1986). Similarly, Dytiscidae are due to Vazirani (1965), Guéorguiev (1975), Wewalka (1975, 1979) and Brancucci (1982, 1983, 1986), Elmidae are due to Delève (1970), Jäch (1982, 1984) and Biström (1983), Gyrinidae are due to Ochs (1924, 1929, 1930, 1966) and Vazirani (1984). The only contribution to the family Helophoridae is due to Angus (1992). Mascagni (1990, 1993, 1995) and Miller (1995) have contributed on the family Heteroceridae. Contribution to the Knowledge of the family Hydraenidae from Nepal is due to Jäch (1989). Similarly, Hydrophilidae is due to Bamuel (1992), Wooldridge (1977), Gentili (1982, 1988, 1989, 1991, 1995), Schödl (1991, 1992, 1993), Hebauer (1994), Orchymont (1925, 1928), Schödl and Ji (1995) and Schönmann (1995). Hydroscaphidae from Nepal are described by Löbl (1994) and the presence of the family Psephenidae with *Psephenoides gahani* and *Psephenoides voltalis* as the representative types has been indicated in the publication of Jäch (1984). Distribution of the species Canthydrus ritsemae of the family Noteridae has been mentioned by Jäch and Ji (1995).

Trichoptera

Kimmins (1964) has reported twenty-eight species of Trichoptera from Nepal in his "Trichoptera from Nepal" publication. Caddisflies of the families Rhyacophilidae, Glossosomatidae, Philopotamidae, Polycentropodidae, Stenopsychidae, Hydropsychidae, Hydroptilidae, Phryganeidae, Limnephilidae, Odontoceridae, Leptoceridae, Uenoidae, and Lepidostomatidae have been described by him in this paper. In a Wiggins and Peterson (1969) edited publication authors reported the caddisflies of the family Limnocentropodidae. Three lepidostomatid caddisflies are described from Nepal by Ito (1986) with descriptions of two new species. Five species of Lepidostomatidae were previously recorded (Martynov, 1936; Fisher, 1970).

Diptera

The dipteran of the family Simuliidae (Lewis, 1964; 1972), Syrphidae (Coe, 1964), Tipulidae (Alexander 1956, 1957, 1958, 1959, 1968), Psychodidae (Vaillant, 1965) etc. from Nepal are described. Similarly Chironomidae from Nepal are well described by Roback and Coffman (1987) and Reiss (1968). Readers are recommended to refer series 'Diptera from Nepal' as published on several occasions in the Bulletin of the British Natural History Museum for details. Other groups of macrozoobenthos are very poorly known from Nepal. Crustaceans of the family Potamidae (Pretzmann, 1966) have been described. Study on Aquatic leeches is limited to family level only (Yadav and Mishra, 1982). Detailed studies on leeches however is done by Nesemann and Sharma (1997). Studies on mollusca is also available (Sharma, 1996).

Table 2: A summary of the total aquatic insects species reported from Nepal known to author (*na* stands for information not available).

	Total number of species	
Macroinvertebrate group	Kathmandu Valley	Nepal
Coleoptera	15	181
Diptera	55	202
Ephemeroptera	33	29
Megaloptera	1	na
Odonata	5	202
Oligochaeta	5	na
Trichoptera	14	59
Gastropoda	7	na
Heteroptera	7	na
Plecoptera	9	67
Hirudinea	2	na

Conclusions and recommendations

The hemimetabolous insects are those undergoing simple or incomplete metamorphosis. This includes all the species of Odonata, Ephemeroptera, and Plecoptera. The aquatic immature forms of these orders have respiratory gills, whereas the adults are terrestrial. The holometabolous insects contain the largest number of aquatic or semiaquatic species. The early instars are totally unlike the adult. There is no evidence of external wings, the legs and antennae may be reduced or entirely missing, and the eyes are simple ocelli as opposed to the compound eyes of adults. Megaloptera, Neuroptera, Trichoptera, Lepidoptera, Hymenoptera, Coleoptera, and Diptera are the seven orders of endopterygoites, the life cycle of which is of the type holometabolous metamorphosis (meaning complete change).

A summary of total species of the aquatic insects reported from Nepal as known to author and included in this report are tabulated (Table 2).

From the above background information it is evident that the lack of taxonomic knowledge is not the cause for which we are lacking behind in using insects to monitor water quality. The problem is lack of proper source from where information could be derived. The latest inventory of Nepal's Insects has been compiled by Thapa (1997). Biologists believe that life originated in the sea, and from there all species of plants and animals evolved. The origin of insects has been a subject of controversy. Did insects originally evolved in sea or freshwaters. However Rick (1971) postulated that the original insects were aquatic and spent their whole life in water. The understanding of aquatic insects evolution and phylogeny has been hampered for there are relatively less fossil record of freshwater animals as compared to marine animals. The fossil record of damselflies and dragonflies is more complete as compared to other aquatic insect orders.

Edmunds (1972, 1975) has reviewed evolutionary trends within the Ephemeroptera. Similarly, Illies (1965) has reviewed the evolutionary history of the Plecoptera. The order Trichoptera appears to have arisen from a megalopteran-like ancestor with a larval stage much like that of the present-day caddisfly family Philopotamidae (Ross, 1956). There are extremely helpful reviews of the biology of aquatic insects in the orders as mentioned above such as: Odonata (Corbet, 1980), Ephemeroptera (Brittain, 1982), Plecoptera (Hynes, 1976), and Trichoptera (Mackay and Wiggins, 1979). Latest status of species inventory from the HKH region is tabulated (Table 3).

All the partner countries in the HKH region are recommended to publish comprehensive list of macro invertebrates based on all available sources. Series of Fauna of British India, Journals published from the museums, collection in the natural history museum, and contact with relevant entomologists inside and outside the country are the main sources of information collection. This species inventory is incomplete and needs updating with feedback from partner countries.

Table 3: Latest status of species inventory from the HKH region. Database is managed as HKHdip software.
HKHdip = Hindu Kush-Himalaya data input programme.

Macroinvertebrates group (INSECTA)	Species composition HKH in total	Macroinvertebrates group (NON-INSECTA)	Species composition HKH in total
Coleoptera	2420	Bivalvia	63
Diptera	2144	Gastropoda	115
Ephemeroptera	295	Hirudinea	63
Heteroptera	109	Nematoda	2
Megaloptera	1		
Odonata	282		
Plecoptera	182		
Trichoptera	1159		
Others	1265		

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ASSESS-HKH: Proceedings of the Scientific Conference "Rivers in the Hindu Kush-Himalaya – Ecology & Environmental Assessment"

The contribution of ASSESS-HKH to a sustainable water use in the Hindu Kush-Himalayan region – an economic analysis

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Abstract

The ecological assessment system for running waters developed by the ASSESS-HKH project is based on benthic macroinvertebrates and is a powerful tool to assist in the formulation of sustainable water policy options and management strategies.From an economic perspective, water quality benefits are typically measured using the concept of consumer surplus, which can be estimated using a number of economic valuation methodologies. However, in the HKH region most of the available methods that provide proxy estimates of value for non-marketed goods such as water quality are not applicable. The ASSESS-HKH river quality maps, as a major project outcome, can be used to utilize water in an environmentally, socially, and economically more efficient way. Thus, these river quality maps have important implications in terms of balance of interest between the different user groups. Moreover, they are able to attract attention of the decision makers and enable timely measures to be taken for improving the deteriorating water quality. The most obvious benefit resulting from informed water management decisions is the possibility to minimize direct and indirect costs associated with water-related diseases.

Key words: management strategies, policy, water quality maps, benefit.

Introduction

In the Hindu Kush-Himalayan (HKH) region, freshwater is an abundant resource supplying the needs of about 500 million people living in South Asia. The region's principal demands for fresh water are for irrigation, household and municipal water use, and industrial uses. Rivers in this region not only provide water for the people's needs, but also are major foci for both religious and cultural activities. Surface water in the region is imperilled by untreated industrial and municipal discharges, and runoff pollution from agriculture. As a result, deteriorating water quality poses a great threat to both the environment and the health of the people. A broad spectrum of direct and indirect socio-economic driving forces responsible for the degradation of water resources has been identified. Therefore, the management of water and its sustainable use is an economic, social, and political issue encompassing all sectors of an economy (Turner et al. 2004). This interrelation between economy and water management was highlighted during the Dublin Conference on Water and the Environment in 1992. There it was stated that "water has an economic value in all its competing uses and should be recognized as an economic good" (WMO 1992). Past failure to recognize the economic value of water has led to the degradation and depletion of water resources. Therefore, managing water as an economic good is crucial to achieve an efficient and equitable use, and to encourage conservation and protection of water resources. Economic evaluation of policies that are aimed to improve water quality in river ecosystems requires two types of information: (1) costs of implementing required mitigation and management strategies for both consumer and producer and (2) the benefits to society from water quality improvements (Ribaudo & Hellerstein 1992). In this article we will focus on the societal benefits derived form improving water quality and review a variety of economic methodologies that are used to compute these benefits and discuss their applicability in the HKH-region. Finally, we will highlight the contribution of ASSESS-HKH project ("Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region", funded by the European Union, INCO-CT-2005-003659) and its influence on sustainable water use in the HKH-region.

Methods

Water as an economic good

From the perspective of economic theory, a natural resource has an economic value it is considered valuable and when it is in limited supply. Further, a consumption good is said to be limited or scarce if it carries opportunity costs. This means that in order to obtain one additional unit of the good an individual needs to give up something else – some amount of another good, or an opportunity to do or not do something, or pay a monetary price. Related to water, the concept of opportunity costs reflects the fact that by consuming water, the user is depriving another user of the water. If that other user values the water higher, then society experiences opportunity costs as a result of this misallocation of water resources. Therefore, opportunity costs of water are zero only

when there are no alternative uses and when its quantity and quality are not limited. If opportunity costs are neglected, water is undervalued, which can cause investment failures and misallocations of the resource between users (Rogers et al. 1998).

A prerequisite for incorporating water resources in economic considerations is their valuation. This valuation is based on the link between structure and functional processes of aquatic ecosystems and the goods and services they provide to society. Thus, the economic value of water quality is determined by its impact on social welfare, which is defined by the aggregate impact on the utility of individuals in society and their willingness to pay for it or accept an amount of money as compensation for its loss (Turner et al. 2004).

Different classification schemes for the valuation of water resources exists, which are based on the different types of values associated with the goods and services provided by water resources. De Groot (1992) categorizes the value of water resources according to the impact on human welfare, differentiating between ecological (conservation and existence value), social (health values) and economic values (consumptive and productive use, employment value). Whereas Young (1996) distinguishes between commodity benefits (derived from drinking, cooking, sanitation, and economic activity), public and private recreational values (fishing), waste assimilation benefits, damages connected to water quality deterioration and existence values. Referring to water quality, Feenberg and Mills (1980) discriminate between withdrawal benefits (e.g. municipal water supply and domestic use benefits, agricultural irrigation and livestock watering benefits) and in-stream benefits (e.g. fish production benefits, recreational benefits).

A classification advocated by several authors (e.g. Pearce & Moran 1994, Turner et al. 2004) and also favoured by us is the concept of the total economic value, which is based on different human uses and motives for appreciation of a good's value. Individuals not only benefit from the consumption of goods (use values), but may benefit from the existence of a resource such as a recreation site, even if they do not intend to visit the site. Thus, from an economic perspective, values can be associated equally with the consumption of goods and services purchased in markets and with the utility or satisfaction from a good or service for which no payments are made (Binning et al. 1995).

The concept of total economic value has a composite nature, with use and non-use values as the two broad value categories (Pearce & Moran 1994, Turner et al. 2004).

Use values comprise all those aspects of total economic value, which stem from actual or potential use of water. Non-use values, in contrast, are completely independent of any actual or potential use. They stem, for example, from the ethical, spiritual, or religious desire to conserve water resources for the future or for its own sake. On a lower level, use values may be classified into direct use value, indirect use value, and option value. Non-use values may be classified into bequest value and existence value.

Direct use value – Water quality has a direct use value if certain quality levels directly satisfy human needs. This includes consumptive use (e.g. drinking water) for cleaning or livestock watering, as well as productive use (e.g. industrial resources) for irrigation, or sustaining fish production. However, direct use value also includes non-consumptive use (e.g. fishing, swimming, tourism, scientific and educational purposes) and benefits related to increased housing and land values.

Indirect use value – Water quality has an indirect use value for humans because the quality of water supports both economic and ecological attributes that benefit society. For example, rivers and streams with good water quality play an important role in maintaining ecosystem services that support biological productivity in aquatic ecosystems and self-purification processes.

Option Value – Option value is the idea that even if humans do not currently use and rely on good water quality, there is a value in the option of preserving this resource for the future. It can be regarded as insurance for possible future demand for good water quality.

Non-use values – Non-use values are rooted in ethical, spiritual, or religious beliefs and can be classified into existence value and bequest value. Existence value is based on the satisfaction of merely knowing that water of good quality exists, even without intending to use it. The bequest value of good water quality is a type of intergenerational altruism in which people are willing to pay for or forgo current? benefits to ensure that future generations enjoy access to clean water. Stewardship value stems from ethical or religious beliefs that humans are responsible for maintaining certain water quality levels, even without benefiting from it (e.g. spiritual value of water in Buddhist and Hindu religion).

Classification of economic valuation procedures

Economists use different approaches to value non-market goods. Indirect approaches, or revealed preference methods, are procedures to elicit preferences from actual, observed, market-based information. Preferences for environmental goods and services are revealed indirectly when persons purchase a marketed good to which the environmental good is related (Pearce & Moran 1994). Direct approaches, or stated preference methods, are procedures to elicit personal preferences directly by the use of consumer surveys and experimental techniques. Individuals are asked directly to state or reveal their preferences for the environmental good, service, or proposed change in environmental quality (Pearce & Moran 1994). The Hedonic Pricing method examines environmental resource goods traded in the real market and compares environmental quality with market prices. This

is commonly done by comparing property prices to environmental variables. For example, the price of a house also reflects the surrounding environment, thus property prices are low in heavily polluted, industrialized areas. However, the Hedonic Pricing method has limits in its application in developing countries. It requires a huge amount of high quality data to analyse the housing market and this market must be competitive (Markandya et al. 2002), requirements which are not fulfilled in most HKH countries. The travel cost method measures the value of a nature reserve or a recreation site by the opportunity cost of time and travel spent on the way to this locality as well as on physical expenses at the locality. The economic benefits associated with changes in water quality levels are derived by using a demand curve (Dumas et al. 2005).

Another valuation approach is to study an individual's behaviour in averting the consequences of poor environmental quality. Individuals confronted with water quality problems can make a variety of so-called averting or defensive expenditures to reduce the damage caused by water pollution (e.g. purchasing bottled water), which would not normally be made (Ribaudo & Hellerstein 1992). These expenditure increases represent a lower bound to the economic benefits of policy that improves water quality.

The Hedonic Pricing, travel cost and averting behaviour methods are indirect valuation methods that estimate the benefits of water quality improvement (or other non-market goods) through an examination of demands for related market goods (Dumas et al 2005). However, these indirect methods are only suitable for the estimation of use value, as non-use value may not be reflected in market choices and behaviour. The most widely used method for estimating people's valuation of a natural resource is the contingent valuation. In this approach people are asked directly about their willingness to pay for a given (often fictitious) water quality improvement.

This method is applicable in different predefined circumstances and is thus very flexible in revealing individual preferences. However, some economists criticize the contingent valuation approach because of its hypothetical nature. They argue that the respondents only declare intentions, which may not reflect actual behaviour (Turner et al. 2004). This is particularly true in situations where the respondents are not familiar with the environmental circumstances and consequences described in the questionnaire.

The application of the contingent valuation method in developing countries is also criticized because the majority of respondents have low income levels and their economic activities are not monetized. In addition, developing countries are characterized by higher unemployment rates, existence of informal markets, differences in social values, less recreation time, and unsustainable resource extraction. Therefore, a different perception of non-market resources compared to developed countries could result (Alam 2006).

Results and discussion

Valuing environmental benefits of water quality improvement in HKH countries

In recent years several studies were conducted to estimate the monetary value of surface water quality improvements in the HKH region. Tiwari (2002) used the contingent valuation technique to analyse the users willingness to pay (WTP) for improved water quality in Kathmandu, Nepal. He found the users mean maximum WTP for improved water quality varied between Nepalese Rupees Rs 2 to Rs 6 (=US$ 0.03-0.08), which is 0.5 to 1 percent of the monthly household income. Markandya & Murty (2004) estimated the socio-economic benefits of the Ganges Action Plan, a river cleaning programme of the Ganges River in India. The authors quantified use and non-use benefits, health benefits to the poor households living along the river, and agricultural benefits to farmers. The estimated benefit/cost-ratio was 1.68 and the total benefit added up to the equivalent of US$ 290.4 million, of which 67% could be attributed to non-use values. Thus, the program of cleaning the Ganges had net positive social benefits.

For the Buriganga River in Dhaka, Bangladesh, a river also monitored by the ASSESS-HKH project, Alam (2006) performed a cost-benefit analysis of a proposed cleanup programme. An extended contingent valuation technique was used to circumvent the problems related to the mostly non-monetized economic activities in developing countries. In addition to asking respondents about their direct contribution of cash, they were also asked about their contribution in terms of time for improving the environment (e.g. 'How much time are you willing to contribute to make the Buriganga River safe for swimming?') (Alam 2006). The survey results showed that more than one-quarter of all interviewed households were prepared to contribute money for the cleanup of the Buriganga River and nearly one-third were willing to invest time to improve the ecological health of the river.

When these contributions were expanded to the total population of Dhaka, the annual value of the community contribution was Bangladeshi Taka Tk 446 million (US$ 8 million). Overall, the total cost of the cleanup programme was only about one-quarter of the benefit, thus the benefits of the proposed river restoration far outweighed the costs (Alam 2006).

Water quality and health costs

Lack of an adequate supply of clean water is one of the most severe environmental problems in the HKH-region with impacts on human health and economic development. Total health costs due to lack of safe drinking water were estimated in Nepal (Tiwari 2002), Pakistan (World Bank 2006), Bangladesh, and India (Brandon & Homman 1995) at 2.0, 1.8, 1.5, and 2.7 percent of the GDP, respectively. The link between deteriorating water quality, health risk, and imposed

high health costs is well established throughout the HKH region. In the 'cost-of-illness' approach, market prices are used to value the costs or benefits associated with changes in water quality and its health impact. This type of health economic analysis includes direct costs for medical care borne by the health system, the community, the patient, and her family or caregivers. It also includes indirect costs due to losses in productivity caused by morbidity, mortality, or leisure losses (Hutton 2001). The poor quality of drinking water and its health impact has major socio-economic consequences for all HKH-countries. A study concluded that 20-40% of the hospital beds in Pakistan are taken by patients suffering from water-related diseases, such as diarrhoea, typhoid, cholera, dysentery, and hepatitis (World Bank 2006). In most countries, diarrhoeal and typhoid mortality in children accounts for the majority of these socio-economic losses, followed by the mortality impacts of typhoid in the older population. In HKH countries approximately 20% of all deaths among children under five years of age is caused by diarrhoeal diseases, except in Pakistan, where the proportion is 14% (data for the year 2000, WHO 2007).

Hutton & Haller (2004) conducted a study funded by the World Health Organization (WHO) to estimate the economic costs and benefits of different interventions to improve water and sanitation services on a sub-regional level. The interventions ranged from improvements required to meet the UN Millennium Development Goals (MDG) for water supply ('To halve, by 2015, the number of people without sustainable access to safe water supply and improved sanitation') and the provision of regulated piped water supply in houses and sewage connection with partial sewerage for everyone.

The predicted reduction in cases of diarrhoea for each intervention was calculated. Intervention costs included the full investment and annual running costs. Intervention benefits were composed of time savings related to better access to water and sanitation facilities, the increase of productive time resulting from less time off work, health sector and patients cost savings from less treatment of diarrhoeal cases, and the value of prevented deaths (Hutton & Haller 2004). In South and Southwest Asia (the sub-region covering the HKH countries) all proposed water and sanitation improvements were cost-beneficial. Hutton & Haller (2004) concluded that every US$1 invested in water supplies and sanitation to meet the Millennium Development Goal generates US$6 in economic returns. By improving water quality, people benefit not only from better health and more productive time, but also from more time in school and improved educational attainment. Thus, investing in water quality improvement, water supply, and sanitation creates economic benefits that outweigh the costs.

The comparison of different economic valuation methods for environmental and health benefits revealed marked differences. Contingent valuation is the most widely used method for valuing environmental gains in the HKH-region. The extended contingent valuation technique propagated by Alam (2006), which evaluates willingness to invest time, is an interesting approach to circumvent problems associated with low income levels of the interviewed population and their inability to contribute money. Other commonly used valuation methods, like Hedonic Pricing and the travel cost approach, have limited applicability in the HKH-region, because it is often difficult or impossible to establish a relationship between water quality and related market goods. In contrast, the valuation of health benefits relies mostly on market prices

ASSESS-HKH biomonitoring approach and its socio-economic impacts

The ultimate goal of inland water quality monitoring is to manage water resources in a proactive and sustainable way. Water quality is a key issue in maintaining and improving public health, enhancing economical productivity, and developing socio-economic infrastructure in the HKH-region. The ASSESS-HKH project developed and implemented a biological monitoring system based on benthic macroinvertebrates (aquatic substrate-dwelling insects, crustaceans, molluscs and annelids) to provide a scientific basis for identification of sustainable water policy options and management strategies. One of the main project outcomes was the development of river quality maps for ecological water management and integrated river basin planning.

Information derived from water quality monitoring programs and river quality maps are essential for national planning and water policy development, investment targeting, and regulatory purposes (Ongley 1997) (Table 1). River quality maps can help to regulate allocation of water resources between agriculture, domestic, municipal, and industrial uses. Thus, intersectoral competition and conflicts between the different users can be more easily mediated (balance of interest between the different user groups). River quality maps can also be used to analyse relationships between ecosystem change and socio-economic activities in rivers and streams.

Moreover, river quality maps are excellent communication tools to translate and communicate scientific environmental data into relevant and understandable information for politicians, policy makers, and the public. Thus, they are able to attract attention of decision-makers and enable timely measures to be taken for improving deteriorating water quality.

Compared to traditional physico-chemical monitoring approaches, biological monitoring programmes have various advantages (Hering et al. 2004, Resh 2007). Especially the use of benthic macroinvertebrates as environmental indicators is a very cost-effective way to gain sound and relevant information about the water quality status and the impacts of anthropogenic stressors in streams and rivers in the HKH region. Benthic macroinvertebrates are characterized by high diversity and strong links between biological community parameters (e.g. diversity, taxa composition,

Table 1: Usefulness of water quality monitoring in HKH-countries.

Sectors and tasks	Uses and benefits
National planning and water policy development	Help set priorities for governments in water resource management and national water policy strategies
	Develop integrated water resource management (IWRM)
	Track effectiveness of policies and interventions by linking the effect of mitigation policies on water quality changes
	Perform sustainable landscape planning and industrial development (especially with regard to Environmental Impact Assessments or EIA)
	Balance interests of different water users
Water resource conservation and restoration	Prevent further degradation of water resources and their biota near natural and sensitive river sections
	Help to reverse the degradation of water resources through the detection of pollution hot spots
	Inform the public about water quality conditions in rivers and streams (education and awareness)
Public health	Help to designate water uses based on water quality classes to minimize human health risks
Regulatory purposes	Effectiveness of wastewater treatment and proper sanitation facilities
	Implement user charges for maintenance of good water quality
Investment targeting	Locate risk areas where investments to improve water quality are necessary
	Plan and locate treatment facilities

abundance) and quality and quantity of stressors. In addition, benthic macroinvertebrates are a comparatively good taxonomic group, thus, making them the most widely used biological indicator group. Furthermore, the costs to implement a nation-wide biological monitoring programme (e.g. equipment, maintenance, capacity building, training, and data analyses costs) are low compared to physio-chemical monitoring programmes (Resh 2007).

The implementation of a water quality monitoring programme and defining clear institutional responsibilities is the first step to stop the deterioration of water resources in the HKH-countries. Furthermore, a better coordination between government institutions and agencies involved in water management, and a more effective implementation of existing acts and regulations related to the protection of water resources are necessary.

Our short review on economic evaluation of water quality improvements in the HKH-region clearly demonstrates the benefits to society outweighed the costs for implementing the required mitigation and management strategies. Thus, investing in water quality monitoring is encouraged, because it generates economical, ecological, and social benefits. The most obvious benefit resulting from informed water management decisions is the possibility to minimize direct and indirect costs associated with water-related diseases.

Conclusions

The case studies performed in the HKH-region to estimate the economical value of river restoration programmes and water quality improvements show that the benefits outweigh the costs. Thus, valuation of non-market benefits of water quality and their integration into economic analyses has significant policy implications, because it takes into account the unpriced or underpriced outcomes of a proposed policy decision (Alam 2006). From an economic point of view, these examples demonstrate that necessary funding can be generated within local communities in the HKH-region and that investing to improve water quality is important.

Experiences gained during local ASSESS-HKH dissemination events show that water quality maps are a powerful tool to raise awareness of the water quality status in rivers and streams in the HKH-countries. Awareness of environmental deterioration is a prerequisite for valuing environmental goods and thus generating funds from communities and private sectors to invest in water quality improvement programmes. Moreover, this approach has the potential to include local communities in decisions about water management, allocation, and use of water resources.

The ASSESS-HKH project improved the scientific understanding of the interaction between anthropogenic impacts and biological processes within the investigated river ecosystems in the HKH-region. River quality maps can help design and implement sustainable water management strategies and enable decision-makers to realize gains from investments.

Although the socio-cultural, institutional, and economic setting of water policy and management differs in the HKH-countries, we advocate that basic principles of a more integrated water management approach should be incorporated into water policy and management strategies to mitigate effects of water quality degradation and to safeguard river systems and their provision of goods and services for the benefit of the people in the HKH countries.

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Results and consequences of the ASSESS-HKH Research Project in Nepal

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Abstract

The research project 'Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region' acronym as ASSESS-HKH was officially initiated following Kick Off meeting held in Brno, Czech Republic from 19 - 25th June 2005. Supported by the European Commission under the sixth Framework Programme (Contract number: INCO-CT-2005-003659), this study covered three of the ten ecoregions in Nepal within the WWF Global 200 ecoregions. Altogether fifty-one sites were selected representing three different ecoregions. The major outputs have been, besides others, development of a Rapid Field Bio-screening Protocol (RFBP) which includes Nepalese Biotic Score (NEPBIOS) extended from the original list of benthic macroinvertebrates with 92 indicators (82 family level indicators, 8 generic level, and 2 species level) to 169 indicators (124 family level, 1 sub family level, 43 generic level, and 1 species level). A regional capacity building workshop was organised on taxonomy and biosystematics of macroinvertebrates from the Hindu Kush-Himalayan region for the project partners, which became the basis of macroinvertebrates taxa database maintained in the HKHdip (Hindu Kush-Himalaya data input programme). Three major information events were held during the study period for the interested public and local decision makers, two for school and university level students, and one at international level on completion of the project for dissemination of the results.

Key words: aquatic, macroinvertebrates, Hindu Kush-Himalaya, bio-monitoring, biotic score.

Introduction

Hindu Kush-Himalaya (HKH) extends from Myanmar in the east to Afghanistan in the west covering a distance of about 3500 km. The HKH is considered one of the richest regions in water resources. Large rivers in this region provide water and power for the worlds' largest population living downstream. Hence, sustainable use of natural resources and preservation of existing environment has become major challenge for researchers in the region. Nepal is a landlocked country surrounded by China in north and India in south. Southern Nepal is a continuation of Gangetic plains, while the northern region represents the central part of the Hindu Kush-Himalayan mountain range. There are four major river basins within the country namely Sapta Koshi, Narayani, Karnali, Mahakali, and six others i.e., Mechi, Kankai, Kamala, Bagmati, West Rapti, Babai (Figure 1).

Figure 1: Major river basins of Nepal (not to the scale).

Major rivers are snow-fed type which flow through the high mountains in the country and thus have turbulent and rapid flow and considerable self-cleansing abilities through mechanical and oxidation processes. All large rivers are fed by snowmelt from the Himalaya, and hence they are perennial. Others are spring-fed types flowing through the middle hills and are subject to human interventions such as water abstraction for irrigation and micro-hydropower development, and effluent discharges. Mean annual rainfall in Nepal is about 1,700 mm, 75% of which occurs during the monsoon season from June through September. Hence, the rivers are subject to high flood conditions during this period and rest of the months, water flowing through the river has been seen to be noticeably decreasing.

The concern about water quality for drinking purpose is widespread among the public in Nepal. However, not much attention is given to quality of water in the river. Mostly the poor and migrated laborer communities are directly dependent on rivers as a source of drinking water. These people are ignorant of the health consequences of contaminated water.

As a result in Nepal alone, some 44,000 children under the age of five die every year from water-borne diseases, and women are deprived of education for they spend most of their time in taking care of their sick children. This study is, therefore, focused on the development of new assessment tools and upgrading the existing ones which are applicable in assessing the water quality status of the rivers in the Nepalese Hindu Kush-Himalaya.

Table 1: List of Global 200 ecoregions represented in Nepal with the river basins considered during this study shown in grey.

Code	Ecoregion	River basins
IM0115	Himalayan subtropical broadleaf forests	
IM0120	Lower Gangetic Plains moist deciduous forests	Bagmati
IM0301	Himalayan subtropical pine forests	Narayani
IM0401	Eastern Himalayan broadleaf forests	Bagmati, Saptakoshi and Narayani
IM0403	Western Himalayan broadleaf forests	
IM0501	Eastern Himalayan subalpine conifer forests	
IM0502	Western Himalayan subalpine conifer forests	
IM0701	Terai-Duar savannah and grasslands	
PA1003	Eastern Himalayan alpine shrub and meadows	
PA1021	Western Himalayan alpine shrub and meadows	

Methods

The overall research was based on an ecoregional approach. The study area was selected on the basis of WWF (World Wildlife Fund) based Global 200 Ecoregions. Nepal iscomprised of 10 global ecoregions, of which three ecoregions were covered during this study, namely IM0120, IM0401, IM0301 (Table 1). Studied area includes Rautahat district in the Lower Gangetic Plains, Makwanpur, Kavrepalanchowk and Bhaktapur districts in the Eastern Himalayan Broadleaf forests, and Kaski, Parbat, and Baglung districts in the Himalayan Subtropical Pine Forests.

Four sites were selected from reference conditions, four from slightly polluted conditions, and three each from polluted to extremely polluted conditions. Rivers were categorized into five different category classes based on level of pollution ranging from I as reference to V as extremely polluted using the Rapid Field Bio-screening Protocol (Moog 2007).
Macroinvertebrates were completely identified with the aid of microscope and available keys for identification in the laboratory. Results obtained from Rapid Field Bio-screening were validated with the application of NEPBIOS based ASPT (Sharma 1996) and GRSBIOS based ASPT (Nesemann et al. 2007).

Overall sampling approach focused on documentation of the status of sampled sites as precisely as possible, in terms of macroinvertebrates diversity and density, and the application of this knowledge through score and indices in biological assessment. For the purpose, both qualitative and quantitative samplings were carried out. Qualitative samplings were taken from all possible habitat types as supportive to quantitative sampling (Moog 1995) particularly to add up information on macroinvertebrates taxa diversity. Quantitative samples were taken following a multi-habitat sampling approach (Moog 2005). This approach includes 20 sampling units taken from all habitat types at the sampling site, each with a share of at least 5 % coverage. A habitat assessment protocol was filled for each site. Share of each habitat type with minimum 5 % coverage was estimated in the field and samples were taken from those habitats separately. A total of 20 samples were taken and a single composite sample was prepared. An AQEM/STAR net sampler with 500 micron mesh size was used in multihabitat sampling. This sampler was specially developed and preferred than Surber sampler because it reduces the amount of sediments in a sample and hence the time for sorting. The net is attached to a metal frame of size 25 by 25 cm. The opening of the net was placed opposite to the flow of the river vertically on the stream bed. The substrate was disturbed by hands up to varying depths depending upon the sampled substrate in order to dislodge the animals from the substrate.

Results and discussion

Findings from Himalayan Subtropical Pine Forests (IM0301) – Macroinvertebrates composition and abundance

In total 81 families of macroinvertebrates were identified from IM0301 belonging to 21 orders, 8 classes and 5 phyla (Table 2). Arthropoda was the most diverse phylum comprising of 67.77% of identified taxa. Planariidae was the singlemost family recorded belonging to the least diverse phylum Platyhelminthes. Similarly, 10 families from Mollusca, 7 families from Annelida and 2 families from Nemertea were representing. Seven genera of class Insecta, 1 of Malacostraca, 4 each of the class Oligochaeta and Hirudinea, 1 of Enopla, 1 of Turbellaria, 5 of Bivalvia and 14 of class Gastropoda could be identified. All taxa are entered into a database with the software HKHdip (Hindu Kush-Himalaya data input programme). The highest macroinvertebrates abundance (total

Table 2: Representative number in each identified taxonomical level of IM0301 ecoregion.

Taxonomical level	Representative number
Phylum	5
Class	8
Order	21
Family	81
Genus	38

Table 3: Total individuals and individual density at each site studied from IM0301 ecoregion.

Site no.	Site code	RQC	Total individuals	Average individuals	Individual density (individuals/m^2)	Average density
1	N02DH011	I	797.00	499	637.6	399.22
2	N02PA011	I	25.00		20	
3	N02YA011	I	845.00		676	
4	N02OR011	I	329.00		263.2	
5	N02YA021	II	1103.00	744.3	882.4	595.4
6	N02KH031	II	95.00		76	
7	N02OR021	II	1459.00		1167.2	
8	N02PU011	II	320.00		256	
9	N02MO011	III	157.00	551.7	125.6	441.3
10	N02KH011	III	671.00		536.8	
11	N02KH021	III	827.00		661.6	
12	N02BI011	IV	12.00	349	9.6	279.2
13	N02PH011	IV	948.00		758.4	
14	N02PA021	IV	87.00		69.6	
15	N02PH021	V	235.00	538	188	430.4
16	N02PH031	V	1204.00		963.2	
17	N02BE011	V	175.00		140	

Table 4: Dominant taxa with their percent (%) abundance in each site of IM0301 ecoregion.

Site code	RQC	Dominant taxa	% Abundance	Substrate composition*	Altitude (m)
N02DH011	I	Baetidae	25.34	MA-MG-ME	1291
N02PA011	I	Perlidae	56	MA-ME-MI-MG	902
N02YA011	I	Baetidae	29.6	MG-MA-ME	1225
N02OR011	I	Caenidae	30.01	ME-MI-AK	917
N02YA021	II	Baetidae	37.71	MA-ME-MG	1219
N02KH031	II	Sphaeriidae	29.47	ME-MA-MI	658
N02OR021	II	Thiaridae	76.28	AK-MI-PS	764
N02PU011	II	Thiaridae	25	ME-MA-AK	720
N02MO011	III	Corixidae	79.61	MG-MA-ME	957
N02KH011	III	Chironomidae	40.98	PP-PE-MI-AK	684
N02KH021	III	Bithyniidae	28.05	AK-MI-ME	682
N02BI011	IV	Dryopidae	33.33	MI-ME-MA	781
N02PH011	IV	Tubificidae	60.06	MA-ME-MI	823
N02PA021	IV	Elmidae	27.58	MA-ME-MI	890
N02PH021	V	Physidae	27.23	MA-ME-MI	820
N02PH031	V	Tubificidae	50.24	ME-MA-MI	810
N02BE011	V	Libellulidae	25.71	ME-MA-MI	672

*MG-Megalithal, MA-Macrolithal, ME-Mesolithal, MI-Microlithal, AK-Akal, PS-Psammal, PP-Psammopelal, PE-Pelal.

counted individual number=1459) and density (individuals per m^2=1167.2) was recorded from Orlan Khola downstream (N02OR021) in Pokhara city about 200 meters north from western part of Phewa Lake and the lowest in Bijayapur Khola (N02BI011) east of Pokhara valley (abundance=12 and density=9.6 respectively). Variation in abundance and density of macroinvertebrates could be observed between the sites with different River Quality Classes (RQC) and within the same RQC. Average individuals and average individual density was observed highest for RQC II followed by RQC III,

Table 5: Summarized result of river quality class (RQC) with the application of NEPBIOS/ASPT and GRSBIOS/ASPT in IM0301 ecoregion.

		Water quality class	
Site code	RQC	(NEPBIOS/ASPT)	(GRSBIOS/ASPT)
N02DH011	I	II	I-II
N02PA011	I	II	I
N02YA011	I	II	II
N02OR011	I	II	I-II
N02YA021	II	II	II
N02KH031	II	II-III	II
N02OR021	II	II-III	II
N02PU011	II	II-III	II
N02MO011	III	II	I
N02KH011	III	II-III	II-III
N02KH021	III	II-III	II-III
N02BI011	IV	II	I-II
N02PH011	IV	II-III	II-III
N02PA021	IV	II	I-II
N02PH021	V	III	III
N02PH031	V	II-III	II-III
N02BE011	V	II-III	II

RQC IV, and RQC I and RQC IV respectively (Table 3). Out of a total of 81 families of macroinvertebrates, the most dominant families in each site are tabulated in Table 4 along with the type of substrates and altitude at the given site.

River Quality Status in IM0301

The general trend of river quality status among the sites was found to be in the state of moderately polluted to critically polluted as determined by NEPBIOS/ASPT (Sharma 1996). Comparison is also done as to the results obtained with the application of GRSBIOS/ASPT (Nesemann et al., 2007). Only the Phirke khola downstream (N02PH031) was found to be heavily polluted (class III). None of the sites revealed class I or I-II. All of the sites with class I were categorized as II with the application of NEPBIOS/ASPT, which showed the moderately polluted conditions. Three out of four sites with class II were categorized to class II-III with the application of NEPBIOS/ASPT i.e. in the state of critically polluted (Table 5).

Table 6: Representative number of macroinvertebrates in each identified taxonomical level from IM0401 ecoregion.

Taxonomic level	Representative number
Order	18
Phylum	4
Classes	6
Family	69
Subfamilies	13
Genus	57

Findings from Eastern Himalayan Broadleaf Forests (IM0401) – macroinvertebrates composition and abundance

Altogether 17 sites were assessed from five streams in the Middle Hills. The streams sampled were Punyamata Khola, Chandeshwori Khola, Roshi Khola in Kavrepalanchwock district, Mahadev khola in Bhaktapur District and Ghatte Khola in Makwanpur District. A total number of 69 families of macroinvertebrates were found in the quantitative sampling (Table 6). Fifty-nine families belong to class Insecta comprising of 85.5%. Remaining 10 taxa of macroinvertebrates include Opisthopora (1), Plesiopora (1), Hirudinia (2), Tricladida (1), Veneroidea (1), Mesogastropoda (2), and Basommatophora (2), with number in brackets indicating the number of family level taxa identified. Complete and updated taxa list is available as a database in the software HKHdip (Hindu Kush-Himalaya data input programme).
Highest number of macroinvertebrates was found in Punyamata Khola at Ugreshwor Mahadev (N03PU031) and lowest in Punyamata at Rohini Bhanjang-Jaljale Khola (N03PU011). Macroinvertebrates of the orders Plecoptera, Trichoptera, Heteroptera, Coleoptera and Odonata were found only in N03PU011. Punyamata khola at Subba Gaon (N03PU051) was dominated by dipterans, whereas N03PU031 consisted of a large number of oligochaetes only

Table 7: Total individuals and individual density at each site studied from IM0401 ecoregion.

Site code	RQC	Total individuals	Average individuals	Individual density (individuals/m^2)	Average density
N03PU011	I	219	281.25	175	225
N03RO011	I	563		450	
N03CH011	I	152		122	
N03MA011	I	191		153	
N03GH011	II	481	255.5	385	204
N03RO021	II	217		174	
N03MA021	II	239		191	
N03MA031	II	85		68	
N03PU021	III	42	577.33	34	462
N03RO031	III	1524		1219	
N03CH021	III	166		133	
N03PU051	IV	53632	18684.67	42906	14948
N03RO041	IV	2294		1835	
N03GH021	IV	128		102	
N03PU031	V	498080	180744	398464	144595
N03PU041	V	43968		35174	
N03GH031	V	184		147	

(Table 7). Out of a total of 69 families of macroinvertebrates, the most dominant families in each site are tabulated in Table 8 along with the type of substrates and altitude at the given site.

River quality status in IM0401

Application of NEPBIOS/ASPT in river quality assessment revealed classes that varied from class II to IV while GRSBIOS/ASPT showed classes from I-II to IV (Table 9).

Table 8: Dominant taxa with their percent (%) abundance in each site of IM0401 ecoregion.

Site code	RQC	Dominat taxa	% Abundance	Substrate composition	Altitude (m)
N03PU011	I	Simuliidae	37.40	MG-MA-ME-MI-AK	2160
N03RO011	I	Ephemeridae	11.37	MG-MA-ME-MI-AK-PS	1550
N03CH011	I	Caenidae	14.47	MG-MA-ME-MI-AK-PS	1635
N03MA011	I	Baetidae	17.80	MG-MA-MI-PS-PE	1500
N03GH011	II	Psephinidae	37.63	MG-MA-ME-MI-PE	1750
N03RO021	II	Caenidae	24.88	MG-MA-ME-MI--PS	1482
N03MA021	II	Micronectidae	23.85	MG-MA-ME-MI	1405
N03MA031	II	Baetidae	17.65	MG-MA-ME-MI-AK-PS	1357
N03PU021	III	Simuliidae	40.48	MA-ME-MI-AK	1505
N03RO031	III	Tubificidae	53.15	MG-MA-ME-MI	1460
N03CH021	III	Baetidae	37.35	MG-MA-ME-MI-AK-PS	1490
N03PU051	IV	Tubificidae	72.77	ME-MI-PP-AR	1447
N03RO041	IV	Tubificidae	39.76	MG-MA-ME-MI	1340
N03GH021	IV	Planorbidae	67.19	MA-ME-MI	1740
N03PU031	V	Tubificidae	99.59	PP	1451
N03PU041	V	Tubificidae	97.82	PS-PP-PE	1449
N03GH031	V	Hydropsychidae	49.46	MA-ME-MI-AK-	1663

*MG-Megalithal, MA-Macrolithal, ME-Mesolithal, MI-Microlithal, AK-Akal, PS-Psammal, PP-Psammopelal, PE-Pelal.

Table 9: Summarized result of river quality class (RQC) with the application of NEPBIOS/ASPT and GRSBIOS/ASPT in IM0401 ecoregion.

		Water quality class	
Site code	RQC	(NEPBIOS/ASPT)	(GRSBIOS/ASPT)
N03PU011	I	II	I-II
N03MA011	I	II	II
N03CH011	I	II	I-II
N03RO011	I	II	II
N03GH011	II	II	II
N03MA021	II	II	I-II
N03MA031	II	II	II
N03RO021	II	II	II
N03PU021	III	II	II-III
N03RO031	III	II-III	II-III
N03CH021	III	II	II
N03PU051	IV	IV	IV
N03RO041	IV	II-III	III
N03GH0211	IV	II-III	II
N03PU031	V	IV	IV
N03PU041	V	III	III
N03GH031	V	II	II-III

Findings from Lower Gangetic Plains (IM0120) – macroinvertebrates composition and abundance

In the studied area 59 families of macroinvertebrates taxa were recorded from 17 sampling sites representing 22 orders, 10 classes and 5 phyla as shown in Table 10. The highest macroinvertebrates abundance (total counted individual number = 2960) and density (individuals per square meter = 2368) was recorded in Jhajh Nadi (N01JH021) and the lowest in Lal Bakaiya Nadi (N01LB011) (abundance = 171 and density = 136.8 respectively) except Tributary of Chandni (N01TR011) where no benthic macroinvertebrates were present (Table 11). Large variations in abundance and density of macroinvertebrates could be observed between the sites with different quality classes and within the same Class. Average individuals and average individual density was observed highest for Class IV followed by Class II, Class III, and Class V respectively (Table 12).

Table 10: Representative number in each identified taxonomical level from Lower Gangetic Plains.

Taxonomical level	Representative number
Phylum	5
Class	10
Order	22
Family	59

River quality status in IM0120

NEPBIOS/ASPT classified twelve sites into class II–III, three sites into class II one into class III– V and one into class IV. Similarly GRSBIOS/ASPT classified seven sites into class II, six sites into class II–III, two sites into class III, one site into class III– IV and one site into class IV (Table 13).

Dissemination and capacity building

Local dissemination and information events were carried out during the first working period (April 2005 – April 2006), at least once in every ecoregion to be studied. The first event was organised in the month of November 2005 in Pokhara, attended by 67 participants, of which 39 were permanent resident, 3 were represented from non governmental (NGO) and governmental organizations, 6 teachers and remaining others were faculties. The second event was held at Kathmandu University in Dhulikhel in the same period attended by 43 participants mostly school level students and teachers and community level leaders. The third event organized in the auditorium hall of Gaur Municipality, Rautahat district on 28 Dec. 2005 was attended by school level students, science teachers, and principal of the concerned schools, local people, community level leaders and NGO's personnel. Altogether 44 secondary level schools participated in the event with more than hundred individuals participating. Participants emphasized on the need of some timely precautionary role to protect the aquatic life and human health and suggested corrective measures to conserve the polluted rivers.

Table 11: Total individuals and individual density at each site studied from IM0120 ecoregion.

Site no.	Site Code	RQC	Total individuals	Average individuals	Individual density (individuals/m^2)	Average density
1	N01BA011	I	2228	849	1782.4	679
2	N01BA021	I	178		142.4	
3	N01DO011	I	629		503.2	
4	N01LA011	I	362		289.6	
5	N01KA011	II	262	589	209.6	471
6	N01LB011	II	171		136.8	
7	N01CH011	II	999		799.2	
8	N01BG011	II	926		740.8	
9	N01SO011	III	228	411	182.4	329
10	N01BA031	III	536		428.8	
11	N01JH031	III	470		376	
12	N01JH011	IV	1633	1767	1306.4	1413
13	N01JH021	IV	2960		2368	
14	N01BG021	IV	709		567.2	
15	N01CH021	V	490	481	392	385
16	N01LA021	V	954		763.2	
17	N01TR011	V	0		0	

Table 12: Dominant taxa with their percent (%) abundance in each site of IM0120 ecoregion.

Site code	RQC	Dominant taxa	% Abundance	Substrate composition	Altitude (m)
N01BA011	I	Bithyniidae	28	PE - MA	73
N01BA021	I	Bithyniidae	15	PE - PP	72
N01DO011	I	Amblemidae	19	PP - PS	82
N01LA011	I	Corbiculidae	28	PS - PP	83
N01KA011	II	Amblemidae	27	PP – PE - ME	80
N01LB011	II	Corixidae	37	PS – PP – PE	74
N01CH011	II	Thiaridae	62	PP - PS	85
N01BG011	II	Chironomidae	41	PE – MI	87
N01SO011	III	Thiaridae	23	PE	72
N01BA031	III	Tubificidae	91	PP – PE	71
N01JH031	III	Thiaridae	31	PS – PP	76
N01JH011	IV	Planorbidae	48	PE	77
N01JH021	IV	Tubificidae	42	PP - PE	77
N01BG021	IV	Tubificidae	37	PE – PP – MI - MA	86
N01CH021	V	Chironomidae	87	PP – PS – ME- PE – AK – MI - MA	83
N01LA021	V	Chironomidae	73	PP – PS	82
N01TR011	V	No animal	--	PE	84

Table 13: Summarized result for RQC with the application of NEPBIOS/ASPT and GRSBIOS/ASPT in IMO120 ecoregion.

Site code	RQC	NEPBIOS/ASPT	GRSBIOS/ASPT
N01BA011	I	II - III	II
N01BA021	I	II - III	II
N01DO011	I	II - III	II
N01LA011	I	III	II
N01KA011	II	II - III	II
N01CH011	II	II - III	II
N01SO011	II	III	II-III
N01JH031	II	II - III	II
N01LB011	III	II - III	II-III
N01BG011	III	II - III	II-III
N01BG021	III	II - III	II-III
N01JH011	IV	II - III	III
N01LA021	IV	II - III	II-III
N01JH021	IV	III	III
N01CH021	V	II - III	II-III
N01BA031	V	III - IV	III-IV
N01TR011	V	IV	IV

They believe that the river quality is essential for the availability of safe drinking water and to keep the surrounding environment clean.

A regional capacity building workshop was organized on the Macroinvertebrates' taxonomy & bio-systematics for evaluating the ecological status of rivers in the Hindu Kush-Himalayan (HKH) region from August 20-Sept. 7, 2006 by Aquatic Ecology Centre of Kathmandu University for emerging young taxonomists from the partner countries. This training workshop attended by at least two participants from each member Asian country was focused on capacity building and exchange of knowledge on the determination of benthic invertebrates from rivers in the HKH region. The benthic fauna of all samples from the second sampling campaign were identified, counted and electronically stored during the training period.

Similarly, a field based training workshop was organized on the application of rapid field bio-assessment by Kathmandu University in Kathmandu from 2-7 March 2007 for the Asian project partners. The major goal of this training workshop was to present the proposed field-based screening method to adapt it to HKH stream types and ecoregions.

Conclusions and recommendations

River quality assessment using Rapid Field Bio-Screening Protocol (RFBP) is clearly one of the quickest methods as it can provide fast classification of the quality of river while in field. It is more suitable for the application to rivers where the main stressor is organic pollution. The features and criteria mentioned in the protocol, based on the judgment of river quality classification is more suited to assess organic pollution as a stressor to river ecological condition. There is scope for further development of the protocol for application to rivers which are impaired by water abstraction.

As GRSBIOS is an extended version of NEPBIOS with most of the scores originating from the later, when applied to assess the quality of rivers reveals similar results. The present study showed differences in the case of rivers flowing through the ecoregion - Himalayan Subtropical Pine Forests, where GRSBIOS was found more effective in differentiating the reference status of rivers compared to impaired sites. This is due to the fact that GRSBIOS list includes more taxa compared to NEPBIOS from this region. Whereas in polluted conditions, the results obtained are comparable. It can be concluded that NEPBIOS and GRSBIOS work similarly in cases of impairments with organic pollution.

Macroinvertebrates diversity in the rivers of Eastern Himalayan Broadleaf forests ecoregion collected by multihabitat sampling when compared to qualitative method of sampling was less abundant. The rivers in this ecoregion have high current dominated by rocky substratum and the use of Multihabitat Sampler needs modification. It is, therefore, recommended that the area of the sampling device be increased to 50 by 50 cm to accommodate a larger area. The number of individual taxa was high in reference site, reduced extremely in urban river section, and again recovered in downstream of rural area observed along Punyamata Khola and Roshi Khola. For disturbed conditions, it is recommended to include only 10 jabs in multihabitat sampling approach.

Biomass measure was found most effective in Lower Gangetic Plains to monitor the quality of rivers affected by organic

load. In Lower Gangetic Plains, among non-insecta, Naididae was the most diverse family with thirteen species. Insecta was identified up to the family level only except for Order Ephemeroptera and Malacostraca while non-insecta upto the genus/species level. The most precise assessment of the ecological condition of aquatic ecosystem would require the identification of macroinvertebrates to the species level.

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Results and Consequences of the ASSESS-HKH Research Project in Bangladesh

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Abstract

River pollution assessment requires various types of data of aquatic life in order to evaluate the ecological health of rivers. The benthic macroinvertebrates as Bio-monitoring used for detecting aquatic life impairments, that is, detecting ecological change on the basis of the presence or absence of indicator species. This study introduces Multi Habitat Sampling (MHS) and Rapid Field Bio-monitoring protocol and HKHbios score for assessing the river water quality. The field screening based on rapid field bio-assessment method provides an overview of river water quality status at an investigation site. Samples were collected from 34 sites on 25 regional rivers in the north-eastern region of Bangladesh. The selected sites represent a gradient of river pollution from less polluted to moderate polluted to severely degraded stretches of rivers to be able to assess biodiversity and thereby the health of rivers. Rivers around Dhaka city are critical pollution to very heavy to extreme pollution due to industrial effluents, wastewater, municipal sewage disposal, faecal contamination, agro-chemicals and large amount of suspended sediments carried by upstream flow. The study has been conducting monitoring of river water, primarily to establish the status of water quality and detect the changes of benthic macroinvertebrates community of these rivers. The benthic macroinvertebrates as bio-indicators data were used to determine the water quality status and classify the rivers in Class I, II, III, IV or V based on ASSESS-HKHbios Score Index. River water quality around Dhaka city was prepared using river water status classification. Water quality map provides a good visual picture of pollution status of river.

Key words: river pollution, bio-monitoring, multi habitat sampling (MHS), macroinvertebrates, biodiversity, rapid field bio-assessment.

Introduction

Biological assessments of river water quality for monitoring, planning and restoration have been use for over two decades primarily in the U.S. Europe, Australia, South Africa resulting in a considerable body of experience in the developed countries, but only limited experience exists in the developing countries. Water quality programmes and standards in Bangladesh are based on physical and chemical parameters. In addition to such water quality information, integrated river management requires data regarding the health of aquatic communities. Thus determining if a stream is supporting desired aquatic life and maintaining biodiversity is also important. Biodiversity indicates the variety and variability among living organisms and the ecosystems in which they occur. It encompasses expressions of the relative abundances of different ecosystems, species, and genus. There are strong indications that river water pollution is affecting biodiversity in both rivers and floodplains, and that deterioration of water quality is affecting the supply for human use.

The main objective of this study, which was conducted within a EU funded research project (Commission of the European Union 2005), was to develop tools to assess the ecological status of selected rivers in the Hindu Kush-Himalyan region using benthic macroinvertebrates as aquatic bio-indicators. In this collaborative research the Asian Scientists form Bangladesh, Bhutan, India, Nepal and Pakistan and the European Scientists from Austria, Czech Republic and Germany jointly developed and tested methodology for biological assessment combining European scientist's experience from their recent research activities and Asian scientist's knowledge about their respective river catchments and their management necessities. This paper presents results and the consequences of application of bioassessment in selected rivers comprising small and medium rivers in the north-central Bangladesh. For application in case of large rivers, the methodology needs adaptation.

Ecological river assessment using bioassessment methods

These methods are regularly used in number of countries, such as USA, Europe, Australia and South Africa. USEPA (2008) points out that the strengths of bioassessment methods as follows.

– Bioassessment provides indications of cumulative impacts of multiple stressors, not just water quality.
– Biological community condition reflects both short- and long-term effects, and directly evaluates the condition of the water resource.

– Biological data can be interpreted based on regional reference condition where single reference sites are lacking or inadequate.
– Properly developed methods, metrics, and reference conditions provide a tool that enables a direct measure of the ecological condition of a waterbody.
– Once a framework is in place for bioassessment, biological monitoring can be relatively inexpensive, and easily performed with standard protocols and consistent training.

The benthic macroinvertebrates are miniature animals without a backbone, such as worms, snails, mussels, crayfish, insects etc. These creatures are widespread and common in streams and rivers worldwide. They are easily caught with a net and can be seen with the bare eye. Biological assessments of water quality are based on the composition of the benthic macroinvertebrates. They comprise immature aquatic stages of insects, together with crustacea (shrimps), mollusca (snails and bivalves), oligochaeta (worms), and hirudinea (leeches). The sensitivity and tolerance to pollution shown by different members of benthic macroinvertebrates vary from species to species. It is known that organisms that occur in polluted water are different from organisms that occur in clean water. For assessment, such communities have been divided into five groups – very sensitive organisms, sensitive organisms, medium tolerant organisms, tolerant organisms and extremely tolerant organisms.

ASSESS-HKH is one of the first research activities aimed at developing a methodology for evaluation of river ecology using aquatic bio-indicators in the HKH Region. The main outcome of the research was:

– Introduction of the approach and methods for bioassessment,
– Demonstration of the ways rapid bioassessment may be used in stream monitoring, planning, management and restoration, and
– Development of an eco-data management tool (ECODAT) to assist scientists to quickly evaluate the ecological status of rivers based on catalogue of taxa/matrics of macroinvertebrates. A metric is a measurable characteristic of the biota that changes in some predictable way with Increased human influence.

Methodology

The first essential task was the establishment of a stream typology for the HKH-region. A stream typology is a regional classification of streams based on their characteristics, such as ecoregion, size, altitude, substrate, geology, soils, etc. The stream typology served as the basis for all subsequent steps of the assessment system development and recommending mitigation measures. Bioassessment method was based on comparing biological measures of a given stream site with an expected state, i.e. reference condition that would exist in the same type of stream in the absence of human disturbance. Reference sites were established by assessing "minimally' impaired stream sites, as it was rarely possible to find sites with no impairment at all.

A three-tier methodology was used for to detect hot spots in selected rivers in the participating Asian countries. The three methods: rapid field bioassessment method, a score based method and an eco-data management software, provided three levels of increasing discriminatory power to detect impairments. ASSESS-HKH Methodology Manual describes the fundamentals and the application of a standardized sampling procedure and three biological assessment methods as follows:

– HKHscreening: Screening method based on Rapid Field Bioassessment method,
– HKHbios: Score Bioassessment method, and
– HKHindex: Multimetric Bioassessment method

The HKHscreening (rapid field Bio-assessment method) is a basic screening method that serves as an "early warning" method to quickly identify areas for urgent attention or to set priorities for the selection of sites for detailed investigation. The field screening method provides an overview on the river quality status of an investigation site. The procedure is based on sensory criteria and the biota that can be identified in the field with a special focus on the bio-indicator value of benthic macroinvertebrates. The important sensory features include: turbidity, foam, colour, odour, suspended solids and waste dumping, oxygen reduction (ferro-sulphide reactions), etc. and commonly found biota comprises periphyton, bacteria, fungi, algae, etc. Benthic macroinvertebrate criteria that are considered include species richness, abundance, sensitive taxa, tolerance, etc.

The HKHbios is a score-based assessment method on mostly higher taxonomic bioindication units (genus, family, order) that needs only simple data processing. HKHbios score based on the number and type of taxa, that is taxa composition provides an indication of the overall ecological status of a site. The HKHindex (multi-metric assessment method) is a scientifically sound method for the detailed analysis of biological data based on the best available taxonomic resolution.

Site selection

First, reconnaissance was carried out along the selected river stretches to acquaint the field investigators and researchers themselves with the surrounding conditions at different sites. Available maps, such as topographic maps of 1:25,000 scales was used to determine the location of sampling sites along the river stretches.

Secondly, while selecting the sampling sites along river stretches, major abiotic features, such as point of effluent discharge, land use, solid waste disposal, growth centre, bank condition, substrate composition, and meeting of tributaries were considered. Such features were observed and noted within one hundred metre stretch of each site.

Based on reconnaissance visits, discussion with relevant organizations and local people 34 sites on 25 regional rivers in the north-eastern Bangladesh were selected for sampling and analysis (Fig. 1). Of the selected sites, 25 lie on Mymensingh, Sherpur, Jamalpur, and Tangail area, 3 in Gazipur, 3 in Narayanganj and 3 near Dhaka.

The selected sites represent a gradient of river pollution from less polluted to moderate polluted to severely degraded stretches of rivers to be able to assess biodiversity and thereby the health of rivers.

Rapid field bioassessment protocol completion and sampling

Firstly for the rivers in the northeast regions samples were collected in two seasons: pre-monsoon (March - April) and post-monsoon (November - December) in 2006 for assessment of regional river ecological status and to examine if there is any seasonal difference in the biological metric. Next to identify the hot spots in the rivers surrounding Dhaka metropolis, sampling was done in pre-monsoon (March - April) in 2007 for water quality mapping which was useful in suggesting restoration measures.

In order to obtain samples representative of the overall biological integrity within a stream reach, sampling was done using the multi-habitat approach, thus sampling units being distributed over the selected reach of a river such that samples were included from each habitat type present. Sampling started from the most downstream point of the investigated section to avoid a self-made turbidity which would hamper the water quality. The preferred habitat for assessment is a "riffle" section of the river. Physical characteristics recorded at each site included: stream width; depth; water velocity; water temperature; weather conditions; substrate composition; canopy cover; stream bank condition and immediate upstream land use. All data were entered into a field protocol and rapid field protocol along with additional comments that were pertinent to the site evaluation. Also DO was measured and water samples were collected for determination of pH, alkalinity, conductivity, BOD, etc. for characterization of selected river reaches.

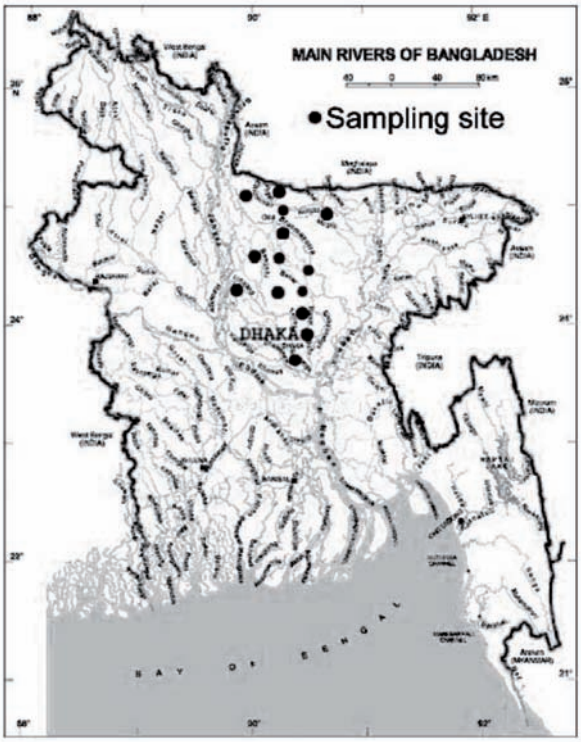

Figure 1: Map of sampling sites.

Samples were collected using an 18 inch wide x 12 inch high D-frame net with a 500 µm mesh size. The net was placed in the riffle at an appropriate location and an area immediately upstream of the net is thoroughly disturbed by hand, ensuring that all pieces of substrate are moved and rubbed clean of attached organisms.

Sorting and assignment of biotic score

Field sorting: Aquatic plants, sticks, branches, stones and other unwanted materials were removed after rinsing and the sessile organisms were separated and collected. Samples were transferred from the net to sample containers and preserved with formalin (formaldehyde of 4% concentration) or in sufficient 95% ethanol in containers to cover the sample after field sorting. Tightly closed sample containers were labeled by marker pen indicating the stream and the river name, site code and date of sampling etc.

Processing and sorting in the laboratory: Laboratory processing include picking organisms from the sample, sorting the organisms into taxonomic groups, identifying organisms to lowest possible taxonomic level, and entering data into the database.

From analysis of samples collected from the rivers in the northeasren zone in the pre-monsoon and post-monsson seasons in 2006, 65 family, 9 sub-family and 63 genus and species were detected from 34 sites in 25 rivers. The details of identification and findings of analysis have been presented in Table A.1 in Appendix A.

Based on species abundance and richness numerical scores were assigned to potential water quality classes, viz. Class I (none to very slight organic pollution), Class II (moderate pollution), Class III (critical pollution), Class IV (heavy pollution), and Class V (very heavy to extreme pollution). The water quality class of the rivers in the northeast region is given in Table 1.

Water quality mapping

For water quality mapping five rivers surrounding the Dhaka metropolis were seleted. Some of these rivers are severely polluted due to discharge of industrial effluents, municipal wastewater and untreated sewage. The rivers are: Buriganga

Table 1: Frequency of water quality classes at sampling sites.

			Water WQ classes determined based on									
	River	Site	First sampling					Second sampling				
			I	II	III	IV	V	I	II	III	IV	V
1	Balu	Ichhapura			1						1	
2	Turag	Ashulia			1					1		
3	Old Brahma-putra Br.	Olipura/Sonargaon D/S		1						1		
4	Sutia	Kaoraid		1						1		
5	Khiru	Kaoraid			1					1		
6	Khiru	Dhamsur			1					1		
7	Rangsha	Tarakanda			1				1			
8	Khuria	Amuakanda		1						1		
9	Khuria	Dewgram		1						1		
10	Boraghat	Haluaghat Dn.		1						1		
11	Tarai	Munshir Hat	1							1		
12	Gangina	Gangina Par		1						1		
13	Melang	Mazracora		1					1			
14	Boraghat	Butiapara Up.	1						1			
15	Jhenai	Charpolisha		1					1			
16	Jhenai	Chandra		1						1		
17	Chellyakhali	Shonnyashi Vita	1						1			
18	Bhogai	Noyabil Hatipagar	1					1				
19	Bhogai	Jamirakanda D/S		1								1
20	Bhogai	Jamirakanda U/S		1					1			
21	Bhaitkamari	Tallukpara			1				1			
22	Katakhali	Garaikuti			1					1		
23	Banar	Harinatala	1						1			
24	Bongshai	Modhupur D/S			1					1		1
25	Bongshai	Modhupur U/S			1					1		
26	Fotikjani	Hamidpur		1					1			
27	Lohojang	Gunotia		1					1			
28	Pungli	Pungli village		1						1		
29	Lohojang	Korothia		1							1	
30	Bongshi branch	Pushto Kamzi			1				1			
31	Bongshi	Shutrapur		1						1		
32	Old Brahmaputra	Olipura/Sonargaon U/S		1					1			
33	Tributary of Old Branch	Olipura/Sonargaon		1						1		
34	Buriganga	Postogola				1						
		Frequency	5	18	10	1	0	1	12	17	2	2
		Percentage	14.7	52.9	29.4	2.9	0	2.9	35.3	50	5.9	5.9

on the south, Tongi khal and part of Balu river on the north, Balu river and part of Shitalakkhya river on the east and Turag on the west. samples were collected from 20 representative sites on the five rivers.

A total of 34 taxon were detected. These are Tubificidae, Micronectidae, Nepidae, Notonectidae, Dytiscidae, Hydrophilidae, Chironomidae, Culicidae, Planorbidae, Psychodidae, Syrphidae, Pila, Belostomatidae, Corbiculidae, Noteridae, Lymnaeidae, Physidae, Naididae, Baetidae, Coenagrionidae, Protoneuridae, Pleuroceridae, Sphaeriidae, Unionidae, Palaemonidae, Bithyniidae, Corixidae, Thiaridae, Nercididae, Nephthydae, Atyidae, Mysidae, Gerridae and Ephydridae. Using above taxon HKHBIOS scores were determined for each site as presented in Table 2.

Then biotic scores were assigned and used to prepare water quality map as shown Figure 2. On the map water quality is represented using seven different colours: Blue for water quality Class I, Green for water quality Class II, Yellow for water quality Class III, Orange for water quality Class IV, Red for water quality Class V, Black for no higher aquatic life and white indicates no sampling.

Results and discussion

Table 1 shows that 53% of the total sampled sites lie in WQC II, followed it by WQC III. There are five sites falling in WQC I, a single site belonging to WQC IV and none was in Class V. Similarly, in second sampling 50% of the total sampled sites lie in WQC III and 35.3% followed in WQC IV. There are two sites falling in WQC IV and V respectively and a single site belonging to WQC I. This indicates that most of the river water is moderate to critically polluted. Among the sampled rivers, the Tarai, Boraghat, Chellyakhali, Bhogai and Banar had none to very slight organic pollution during first sampling. But the water quality of these rivers became moderately polluted during the second sampling period, largely due to monsoon agricultural runoff, reflecting seasonal difference in the macroinvertebrate community. Overall, most of the rivers (Table 1) contain all water quality classes, ranging from II to III. It has been observed that the rivers are generally polluted by faecal contamination, agrochemicals, washing and bathing.

From Table 2 containing water quality classes determined for mapping, it is seen that 40 percent of the total sampled sites lie in WQC III, followed it by WQC IV. There is only one site falling in WQC II and not a single site belonging to

Table 2: Frequency of water quality classes at sampling sites on rivers around Dhaka city.

			Water quality class				
Site no.	River	Site	I	II	III	IV	V
1	Balu1	Demra				1	
2	Shitalakkhya2	Demra			1		
3	Balu3	Lanchhata					1
4	Balu4	Ichhapura				1	
5	Turag5	Bindan					1
6	Turag6	Thermong				1	
7	Balu7	Dhopapara			1		
8	Balu8	Pipulia			1		
9	Turag9	Istema field				1	
10	Turag10	Tiebpur			1		
11	Turag11	Chapai		1			
12	Turag12	Ashulia				1	
13	Buriganga13	Postogola					1
14	Dhaleshwari14	Ferighat			1		
15	Dhaleshwari15	Charkundolia			1		
16	Dhaleshwari16	Dharmaganj				1	
17	Shitalakkhya17	Katchpur				1	
18	Turag18	Baimile					1
19	Turag19	Boroibari			1		
20	Bongshi	Sutrapur			1		
		Frequency	0	1	8	7	4
		Percentage (%)	0	5	40	35	20

WQC I. This indicates that the quality of the river water is severely degraded. The rivers are largely polluted by industrial effluents, municipal sewage disposal, faecal contamination, and agro-chemicals. Among the sampled rivers, the Turag contains water quality classes, ranging from II to V.

The water quality map shows that as expected the Buriganga is seen to be severe to very heavy to extremely polluted due to effluent discharge from Hazaribag tannery and other industries on the river bank and untreated sewage disposal from Dhaka city. On the western side, Turag river is also seen to be very heavy to extremely polluted and heavily polluted. On the northern side Tongi Khal is also very heavy to extremely polluted and heavily polluted due to effluents from Tongi industrial area as well as wastewater disposed from surrounding areas. Upper reaches of Balu is very heavy to extremely polluted due to agricultural runoff, however condition is improved changing to yellow colour and again slightly changed to orange colour after its confluence with Tongi Khal indicating heavy pollution. Again in the downstream reach of Balu pollution level increases and it becomes class V. Below its confluence with Sitalakkhya at Demra water quality slightly improves to class IV and Sitalakkhya at Kachpur water quality class III. Further upstream in Turag and Bongshi river water quality class is seen to be mixture of class IV and III. In Dhaleshwari river water quality falls mostly in class III as there is no direct discharge of effluents and sewage.

Analysis of causes of impairment

A total of eight stressing factors have been identified along the river stretches, which have been grouped into four broad categories, such as (i)effluents,(ii)human interferences and infrastructure, (iii) hydromorphological degradation and (iv) ecological disturbances, and personal hygiene and sanitation as presented in Table A.3 in Appendix A. However, the table information does not provide the relative importance of the stressing factors. In addition, other features like settlement density and land uses have also been used in each stressing factor. This analysis has been used later for identifying mitigation options and designing strategies for sustainable river management.

Two river basins, including the Balu and Shitalakkhya have shown all types of stressing factors. Among the other six river basins, the Turag does not have environmental and ecological disturbances by animal washing. In case of the Buriganga basin, there is absence of agricultural effluents (runoff) whereas the Dhaleshwari basin does not have sewage discharge, solid wastes dumping and sand and gravel extraction. In sutia does not have any industrial effluents whereas Bongshi has industrial effluents. The industrial effluents in Turag also include tannery wastes.

The effluents (agricultural runoff, industrial effluents, municipal wastes and solid waste) are found to be the largest stressing factor. Among these, the occurrence of industrial effluents and then sewage discharge has been the largest.

Mitigation strategy

Dissemination events were held and awareness created among different strata of the society, such as local community, water and environment sector planners, managers, decision makers as well as university students through seminars,

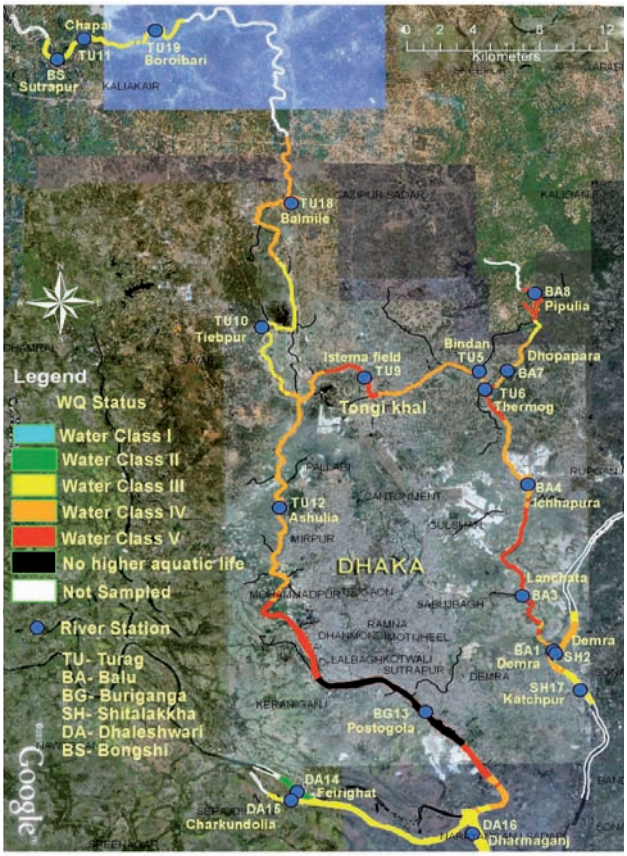

Figure 2: Water quality map around Dhaka city.

posters, flyers, newsletters, and newspaper articles. Motivation and interest for adopting bioassessment for water quality programmes for restoring riverine ecological integrity have been generated, but more works in terms of follow-up research and training for capacity building needs to be done. Regulatory and incentive measures as well as construction of adequate treatment plants and improved recycling were suggested to reduce pollution load, and compliance monitoring should be adopted for enforcement of regulating measures. From the review of the many issues and gaps that exist in water resources quality management, it is recommended that the following actions be taken on a priority basis.

– Water quality status of river at a given site determined;
– Identify pollution sources (presented in Table A.5 in Appendix A.)
– Awareness-motivation (regulatory agency and polluters);
– Regulatory and incentive measures (treatment plant and recycling) to reduce pollution load;
– Water quality inspection and enforcement
– Compliance enforcement and monitoring
– Periodic sampling and water quality checking.

Conclusions

The physical, chemical and biological characteristics of river water have changed due to organic and inorganic pollution. Particularly organic pollution has changed the benthic macroinvertebrate community. The changes mainly occur due to the varying sensitivities of the different components of the community to the stresses caused by pollution. The present study indicates benthic macroinvertebrates as bio-indicators provide a deeper understanding of ecosystem dynamics and serve as a basis for policy development and ecosystem management. Therefore, it is proved that biological data are a worthwhile addition or substitution for the detection of pollution and for the determination of the ecological status of rivers.

Water Quality Maps enable one to visualize water quality in rivers. It is a useful tool for water resources managers and decision makers involved in sustainable management and utilization of river resources. As expected, the study demonstrates that the river around Dhaka city are very polluted, the condition of Buriganga being the worst. It looks like a cesspool of wastewater with fowl smell. Water of such a river is not suitable for any useful purpose except navigation. It is reassuring to note that good awareness has been created about this endemic pollution problem with clarion call to save the Burigana. Recently a number of initiatives have been taken by a several authorities and organization, notably the Ministry of Forest and Environment, the Department of Environment and Bangladesh Inland Water Transport Authority to restore the occupied river front from land grabbers, prevent encroachment. Disposal of untreated sewage and industrial effluent must be prevented. Bio-monitoring, as used in western countries as part of their regular monitoring programme, can be a useful tool for assessing ecological status of these and other rivers. Such tools should be embedded in a regular national water quality motoring programme and assessment of ecological status of rivers in the country. This will need creation of awareness and capacity building and in this endeavour universities and agencies can work in partnership. Awareness creation has been started, although in limited in scale, through this EU-funded multidisciplinary collaborative study undertaken by the BUET.

Acknowledgements

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Appendix

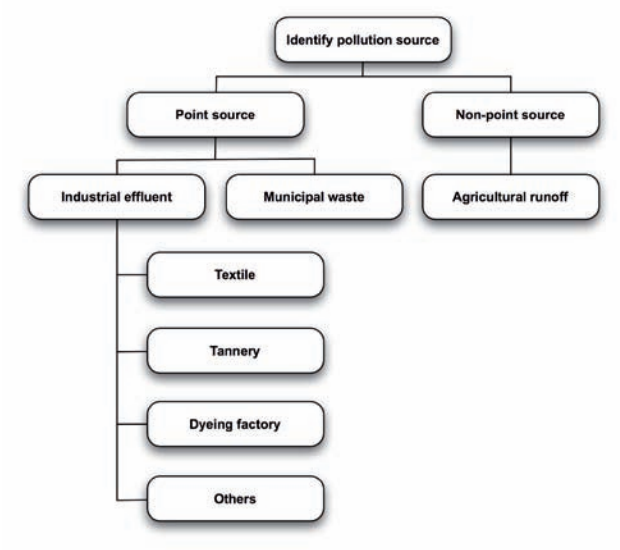

Figure A: Potential pollution sources in Bangladesh.

Table A1: List of taxa based on identifiction of collected samples.

Class / Order	Family	Scientific Name
Prosobranchia (C. Gastropoda)	Ampulariidae	*Pila globosa*
Prosobranchia	Bithyniidae	*Digoniostoma cerameopoma, Digoniostoma sp.*
Prosobranchia	Pleuroceridae	*Brotia costula, Brotia sp., Paludomus conica*
Prosobranchia	Thiaridae	*Melanoides pyramis, M. tuberculatus, Thiara granifera, T. lineata, T. scabra, Thiara sp.*
Prosobranchia	Viviparidae	*Bellamya (Filopaludina) bengalensis, Idiopoma dissimilis, Mekongia crassa*
Pulmonata (C. Gastropoda)	Lymnaeidae	*Lymnaea acuminate, Radix luteola, R. persica*
Pulmonata	Physidae	*Physa (Haitia) mexicana*
Pulmonata	Planorbidae	*Gyraulus convexiusculus, G. euphraticus, G. labiatus, Gyraulus sp. Indoplanorbis exustus, Segmentina calatha, S. trochoidea*
Bivalvia	Corbiculidae	*Corbicula assamensis, C. bensoni, C. cashmiriensis, C. striatella Corbicula sp.*
Bivalvia	Sphaeriidae	*Pisidicum (Afropisidium) clarkeanum, P. nevillianum*
Bivalvia	Unionidae	*Lamellidens marginalis*
Bivalvia	Amblemidae	*Parreysia favidens favidens, P. favidens ssp., P. viridula, Radiatula bonneaudi, R. caerulea*
Polychaeta	Nephthydae	*Nephthys oligobranchia, Nephthys sp.*
Oligochaeta	Microchaetidae	
Oligochaeta	Naididae	*Branchiodrilius sempri*
Oligochaeta	Tubificidae	*Aulodrilus pluriseta, Aulodrilus sp., Branchiura sowerbyi, Branchiura sp., Limnodrilus claparedeanus, L. hoffmeisteri, Limnodrilus sp.*
Hirudinea	Glossiphoniidae	*Placobdelloides fulvus*
Hirudinea	Hirudinidae	*Asiaticobdella birmanica*
Hirudinea	Salifidae	*Salifa lateroculata*
Crustacea	Atyidae	
Crustacea	Mysidae	
Crustacea	Palaemonidae	*Macrobrachium sp.*
Crustacea	Potamidae	
Crustacea	Parathelphusidae	*Sartoriana spinigera*
Crustacea	Talitridae	*Platorchestia platensis*
Ephemeroptera	Baetidae	*Cloeon sp.*
Ephemeroptera	Caenidae	*Brachycercus sp., Caenis sp.*
Ephemeroptera	Ephemeridae	*Ephemera sp.*
Ephemeroptera	Prosopistomatidae	*Prosopistoma sp.*
Odonata	Synlestidae	
Odonata	Coenagrionidae	
Odonata	Corduliidae	
Odonata	Gomphidae	
Odonata	Libellulidae	
Odonata	Protoneuridae	
Heteroptera	Belostomatidae	
Heteroptera	Corixidae	*Micronecta sp., Sigara sp., Synaponecta sp.*
Heteroptera	Gerridae	
Heteroptera	Vellidae	

Class / Order	Family	Scientific Name
Heteroptera	Mesoveliidae	
Heteroptera	Micronectidae	
Heteroptera	Nepidae, Nepinae, Ranatrinae	
Heteroptera	Notonectidae	
Heteroptera	Pleidae	
Coleoptera	Curculionidae	
Coleoptera	Dytiscidae	
Coleoptera	Gyrinidae	
Coleoptera	Haliplidae	
Coleoptera	Hydrophilidae	*Berosus sp.*
Coleoptera	Noteridae	
Trichoptera	Dipseudopsidae	
Trichoptera	Ecnomidae	
Trichoptera	Hydropsychidae	
Trichoptera	Hydroptilidae	*Hydroptila sp.*
Trichoptera	Leptoceridae	*Leptocerus sp.*
Lepidoptera	Pyralidae	
Diptera	Ceratopogonidae	
Diptera	Chironomidae , Chironominae,Chironomini Orthocladiinae,Tanypodinae Tanypodini, Tanytarsini	
Diptera	Culicidae, Culicinae	
Diptera	Dolichopodidae	
Diptera	Ephydridae	
Diptera	Psychodidae	
Diptera	Stratiomyiidae	
Diptera	Syrphidae	*Eristalis sp.*
Diptera	Tabanidae	

Sample ID	pH	EC	DO	O_2 Satut.	Alkal.	Total Hard.	Cl^-	BOD5	NH_4 mg/L	NO^{2-} mg/L	NO^{3-}	PO_4^{-3}	Total PO_4	E-coli
Balu	7.40 28.4°C	927	5.74	74.8	225	176	90.0	17.2	21.25	0.636	49.0	6.60	8.50	10000
Turag	7.48 28.8°C	1343	4.32	56.3	307	184	190	16.0	9.9	1.576	47.5	4.50	5.60	480
Old Brah-mapu Br.	6.62 26.8°C	235	3.5	46	80	50	18	5.6	0.13	0.045	9.3	0.29	0.40	3850
Sutia	7.55 27.5°C	377	5.34	68.4	130	118	8.0	9.2	.27	.011	8.9	1.24	1.27	10
Khiru(KA)	7.70 27°C	324	5.60	70.7	133	130	13	8.8	.15	.027	13.1	.82	.86	20
Khiru(KB)	7.90 28.6°C	2030	3.24	43.3	392	038	58	28	2.45	0.070	43.5	6	6.40	60
Rangsha	7.34 25.9°C	222	5.15	67.2	067	46	13	6.0	0.78	.057	11.9	1.31	1.78	190
Khuria(KX)	7.05 27.1°C		529	6.44	80	167	98	48	23	12.80	.382	11.3	4.0	5.80
Khuria(KY)	7.16 27.8°C	275	4.54	64.2	104	88	23	4.7	.91	.031	13	.97	1.17	26
Boraghat(BX)	7.47 25.9°C	216	8.19	100.9	68	56	16	4.4	.56	.038	8.8	0.22	0.40	420
Tarai	6.29 25.6°C	86.9	6.23	76.1	016	026	04.0	3.3	0.34	.082	8.7	.22	.45	80
Gangina	6.15 27.3°C	89.7	5.30	67.9	032	014	08.0	1.9	2.04	0.035	9.5	0.20	0.52	215
Melang	6.73 29.1°C	113.3	7.36	96.6	20	60	08.0	3.9	1.10	0.023	9.0	0.23	0.70	10
Boraghat(BZ)	6.44 27.3°C	276	6.40	82.9	48	44	07	3.4	1.14	0.029	10.8	0.32	0.52	08
Jhenai(JA)	7.69 28°C	506	6.70	79.1	224	164	11	2.4	.32	.056	8.3	0.89	1.29	80
Jhenai(JB)	7.34 29.1°C	356	7.25	95	135	124	14	2.5	.83	.024	10.5	1.05	1.47	480
Chellyakhali	6.77 25.6°C	117.6	6.75	84.3	30	38	08.0	8.0	1.61	0.022	7.8	0.45	0.83	160
Bhogai(BO)	6.77 25.8°C	142.5	6.38	78.4	43	52	07	3.8	0.62	0.042	18.3	0.36	0.84	20

Sample ID	pH	EC	DO	O_2 Satut.	Alkal.	Total Hard.	Cl^-	BOD5	NH_4 mg/L	NO^{2-} mg/L	NO^{3-}	PO_4^{-3}	Total PO_4	E-coli
Bhogai(BP)	6.89 27°C	128.6	6.69	84	31	38	08	5.0	1.03	0.050	14.7	0.30	0.83	Nil
Bhogai(BQ)	6.89 27°C	128.6	6.69	84	31	38	08	5.0	1.03	0.050	14.7	0.30	0.83	Nil
Bhaitkamari	6.30 27.8°C	145.8	5.81	75	40	46	05	4.8	0.27	0.049	13.5	0.38	0.59	Nil
Katakhali	7.41 29.3°C	274	6.76	88.9	95	94	10	5	0.32	.009	8.4	0.46	0.80	76
Banar	6.91 29.7°C	132	5.29	69.4	49	30	07.0	3.7	.39	.018	8.5	.28	.91	40
Bongshai(YB)	7.12 30.7°C	392	5.59	77.5	152	130	20	3.4	2.33	.027	14.1	1.04	1.29	96
Bongshai(XB)	7.03 32°C	382	3.79	52.4	141	122	16	2.6	1.10	.061	10.4	.60	1.28	16
Fotikjani	8.19 32.4°C	600	10.29	142.9	195	164	43.3	7.6	.72	.064	9.2	1.31	1.56	1400
Lohojang(LO)	7.22 31.3°C	565	4.08	55.4	217	200	23	4.8	0.30	0.024	12.8	0.87	1.64	110
Pungli	8.25 28.2°C	387	5.50	70.5	165	150	10	5	0.65	.039	11.1	0.83	1.09	26
Lohojang(LP)	9.33 32.5°C	2820	1.25	17.2	1036	38	106	74	7.63	.106	73	6.50	6.50	500
Bongshi bran.	7.63 34.3°C	678	6.24	79.7	174	210	57	7.4	0.49	.039	12.5	1.67	1.76	130
Bongshi	7.80 31.9°C	174.9	5.84	80.9	392	158	97.5	7.6	1.30	.120	8.5	2.41	2.62	240
Old Brahmaputra	6.55 28.1°C	283	2.98	38.1	70	70	18	7.6	.35	.059	12.6	.38	.77	3420
Tributary to Old Branch	6.90 28.7°C	436	4.37	56	95	124	43	12	1.79	0.136	14.6	.95	1.46	9380
Buriganga	7.25 29.2°C	1032	2.19	28.6	245	166	76	8.6	14.35	0.019	8.4	4.06	6.30	22480

Table A3: Classification of river stressing factors, Bangladesh.

Groups	Stressing factors	Balu	Buri ganga	Dhale shwari	Shita lakkhya	Turag	Old Brahmapu Br.	Sutia	Bongshi
Effluents	Sewage discharge	√	√	x	√	√	√	X	√
	Industrial effluents	√	√	√	√	√	X	X	√
	Agricultural runoff	√	X	√	√	√	√	√	√
	Solid wastes	√	√	X	√	√	X	X	√
Activities & facilities	Navigation	√	√	√	√	√	X	√	√
Environmental & ecological disturbances	Sand/gravel extraction	√	√	X	√	√	X	X	X
	Animal washing	√	√	√	√	X	√	√	√
Personal hygiene and sanitation	Bathing and washing	√	√	√	√	√	√	X	√

Table A4: Suggested strategies for mitigation of industrial effluent related pollution.

Stressing factors	Mitigation programs	Responsible agencies
Waste dumping	Prohibition of dumping Awareness to locals Provision of incentives Development of River banks for prevention of encroachment.	City corporation Municipality Water Supply and Sewage Authority (WASA) Department of Environment (DoE)
Sewerage discharge	Prohibition of direct discharging Treatment plants & recycling Awareness to locals Provision of incentives Adopt regular monitoring	City corporation Municipality Municipality Water Supply and Sewage Authority (WASA) Department of Environment (DoE)
Agricultural effluent	Encourage use of manure Awareness to locals Provision of incentives Adopt regular monitoring	Dept of Agriculture DOE/NGOs Dept of Agriculture DOE/NGOs Municipality/DOE Municipality/DOE
Industrial effluent	Prohibition of direct discharging Conduct compliance monitoring Awareness Provision of incentives	Municipality/DOE Dept of Env/Industry Municipality/DOE/NGOs/University

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Water quality assessment of River Satluj using benthic macroinvertebrates

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Abstract

Aquatic macroinvertebrates play a significant role in river quality assessment since they respond very sensitive to human induced impacts on rivers and streams. The Satluj river at Nathpa Jhakri hydro power plant was chosen to observe the impact of regulated flow on the water quality. The present study involved sampling, pre-identification and identification of macroinvertebrates and computing the % occurrence of families of various taxonomic groups and conducting physico-chemical analysis of samples from selected locations. Macroinvertebrates chosen were identified up to family level, and bioassessment at various locations has been done using NEPBIOS score system while the physico-chemical water quality assessment was done on the basis of of the National Sanitation Foundation water quality index (NSF). Regulation in the catchment's area of the River Satluj at Nathpa and Jhakri in Kinnaur district (Rampur village) increase during monsoon up to 700 to 2500 cumecs and decrease during lean period from 100 to 150 cumecs. It was found that the water quality at five stations using the NSF was found to be in class III, while water quality class on the basis of Benthic Macroinvertebrate using the NEPBIOS biotic score system was also found to be in class III.

Key words: benthic macroinvertebrates, indicators, NEPBIOS, NSF water quality index.

Introduction

The aquatic biomonitoring is used to measure the response of aquatic communities to anthropogenic stressors on account of energy source, water quality, habitat quality, flow region and biotic interactions. The environmental stressors include toxic substances, urban influences, sedimentation and flow regulation. The benthic macroinvertebrates have been found as the most common faunal assemblages used in the bioassessment, which provides a more reliable assessment of long term ecological changes in the condition of a aquatic system than do rapidly changing physico-chemical measurement on toxicity tests.

Well developed monitoring programs involve physical, chemical, and biological measurements (Reynoldson et al. 1989) and provide information on the effect of the water quality on aquatic system. Benthic macroinvertebrate species respond differentially to biotic and abiotic factors in their environment and consequently, macroinvertebrate community structure has been used as an indicator of the status a water body of a water body. Benthic invertebrates vary greatly, both spatially and temporally over virtually all scales in polluted and non polluted flowing water systems (Hynes 1960, Hynes 1970 & Cummins 1979). Biotic index systems have been developed which give numerical scores to specific "indicator" organisms at a particular taxonomic level. Changes in presence/absence, numbers, morphology, physiology or behavior of these organisms can indicate that the physical and/or chemical conditions are outside their preferred limits. Presence of numerous organism families of highly tolerant organisms usually indicates poor water quality (Hynes 1994). The advantage of using macroinvertebrates as bio-indicators are that they are visible to unaided eyes and can be retained by a sieve having a mesh size of 500 µm pore diameter. They have sedentary and long life span and are sensitive to organic pollution thermal impact, substrate alteration and toxic pollution inhabiting of lakes reservoirs, rivers, stream and other water bodies developed. The qualitative and quantitative changes in the benthic population have also been used as pollution indices (Dhillon et al. 1995). Therefore the primary objective of study was to evaluate the w ater quality of Kosi River using macroinvertebrates with the application of NEPBIOS score system. The other objectives were the bioassessment result validation by physico chemical analysis using National Sanitation Foundation(NSF) water quality index and to describe the importance of using macroinvertebrates as pollution indicator. The occurrence of benthic macroinvertebrates community along with the distribution of taxa-group of the river has also been discussed.

River Satluj and its tributaries

The Satluj river (Figure 1) rises as Langchhen Khabab river from Rakas lake in the Tibetan Plateau at an elevation of about 4572 m. It forms one of the five main tributaries of Indus river. Origin of Satluj river is very near to the Indus headwaters. Satluj river travels about 322 km in the Tibetan

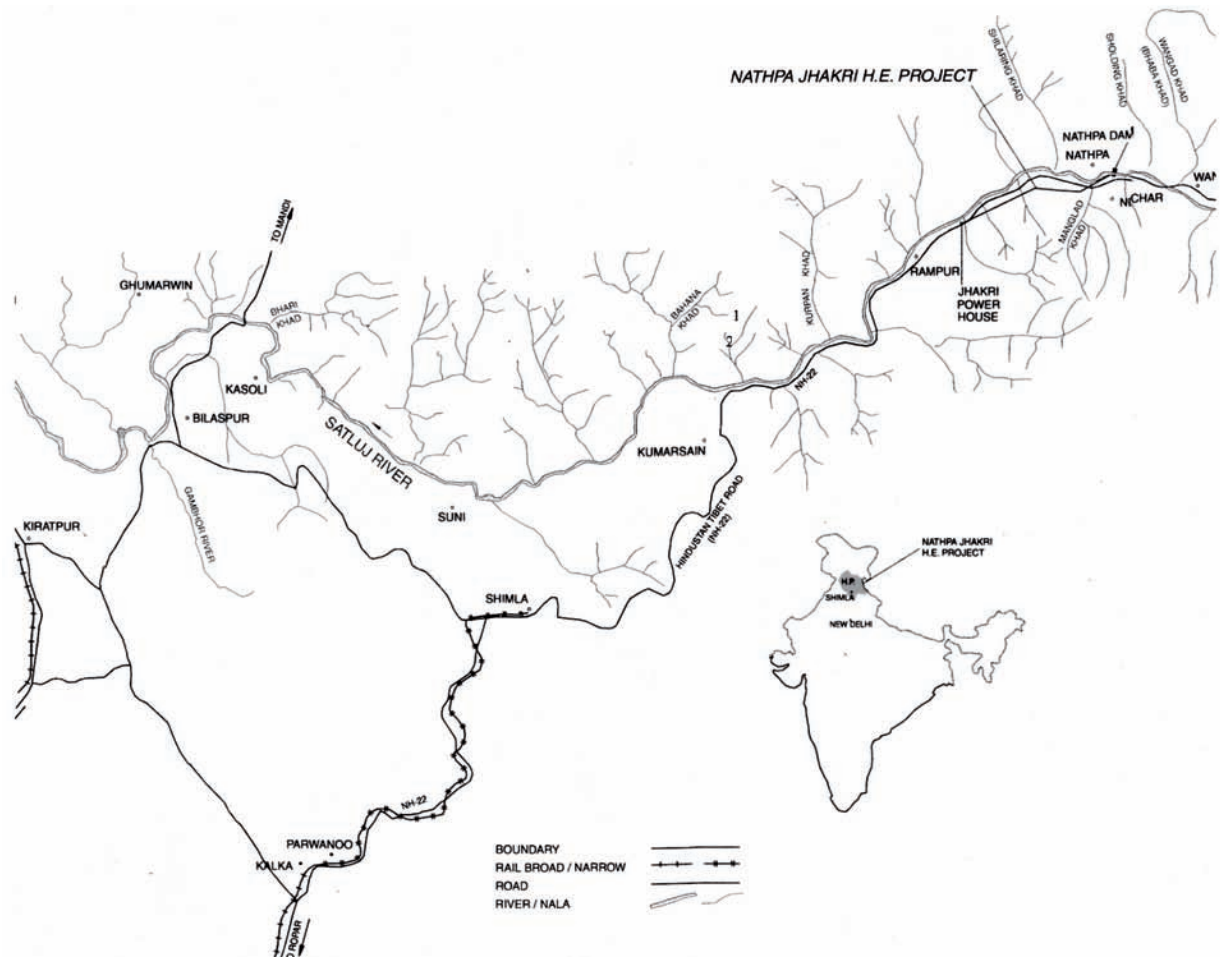

Figure 1: Location and vicinity map of Satluj river (source WRDM, IIT Roorkee).

province of Nari-Khorsam forming a plateau of successive deposits of boulders, gravel clay and mud. The flow of Satluj obtained mainly from snow and glaciers has cut a valley about 914 m deep through these deposits. Catchment area of Satluj river in Tibet is 36075 km^2. The entire catchment area in Tibet plateau and some area in the downstream are mostly without rainfall and have a cold desert climate. This results in low flow in the Satluj river until it is joined by its major tributary Spiti near Namgia in India.

The Satluj river enters India in the state of Himanchal Pradesh near Shipkila. It flows along a southwestern course in Kinnaur district of Himanchal Pradesh where it gets both snow and rain. The river has carved spectacular gorges where it has cut across the Zaskar, main Himalaya and Dhauladhar ranges. It flows at the base of the Shimla ridge and enters the lower hills in Bilaspur area where the gigantic Bhakra dam has been constructed across it. The total catchment area of Satluj river upto Bhakra dam is about 56874 km^2, of which 22305 km^2 is in India including Spiti basin. The river then enters the plains of Punjab to finally drain into the Indus river in Pakistan. Alpine, Subalpine, temperate and sub tropical forests are formed at different elevations. Important tributaries of the Satluj upstream of Nathpa are river Spiti and river Baspa. Many human settlements have come up along the Satluj river. The important amongst these are Namgia, Kalpa, Jhakri, Rampur and Bilaspur.

Physiographic characteristics

Indian part of the Satluj basin is elongated in shape and covers outer Himalayas (shivalik ranges), middle Himalayas (Dhauladhar range) and greater Himalayas (Greater Himalayan range and Zaskar range). The great or main Himalayan range runs in an arc shape along the northern part of the Himachal Pradesh State. It is comprised of snow clad peaks, glaciers and deep valleys. This range has been cut by the river Chenab and Satluj. Dhauladhar range in the east part of Himachal Pradesh gives way to a series of mountain ranges of the lower Himalaya. There are Naga Tibba range, the Shimla hills and the Churdhar range. Shivalik hills are extensive in Kangra, Hamirpur, Una, Mandi, Bilaspur, Solan and Sirmour districts. The elevation of catchment up to Bhakra dam varies widely from about 500 m to 7000 m although only a very small area exists about 6000 m. Mean elevation of the basin is about 3000 m. the gradient is very steep at its source and gradually reduces downstream. Owing to large differences in seasonal temperatures and great range

of elevation in the catchment, the snowline is highly variable, descending to an elevation of about 2000 m during winter. The permanent snow line in this part of Himalayan range is about 5400 m. Broadly snow covered area is confined to Spiti, Baspa and upper Satluj sub basins. About 11 % area of the total Satluj catchment lies under glaciers.

Climate

The great contrast in geographical relief results in variety of climate in the Himalayas. Numerous small climate differences occur over short horizontal distances. These differences are controlled by altitude, local relief and mountain barrier effect most important being altitude and aspect. Due to variations in altitude, climate varies from hot and moist tropical climate in lower valleys to cool temperate climate at about 2000 m and tends towards polar as the altitude increases beyond 2000 m.

Subtropical	450 – 900 m
Warm temperate	900 – 1800 m
Cool temperate	1800 – 2400 m
Cold high mountain	2400 – 4000 m
Snowy and frigid	above 4000 m

As seen, the altitude controls not only temperature but also the rainfall. Furthermore, the south facing slopes are more sunny and also get more rain, and the varied topographic and agroclimatic conditions permit cultivation of a wide variety of crops and fruits.

The study area

Several hydroelectric projects on river Satluj and its tributaries have been identified and are in different stages of implementation. The 1500 MW Nathpa Jhakri Hydroelectric Project (NHJEP) is a run-of the river project on the river Satluj with a dam near village Nathpa in district Kinnaur and an underground power house near village Jhakri in district Shimla (Figure 2). The sampling area is on Hindustan Tibet road NH-22 approximately 150 km from Shimla. The area lies in the lesser Himalayan range which are seismically active zone – IV (IS: 1983-84). The region has a history of occurrence of earthquakes greater than 5 at Richter Scale. About 405 cumecs of water is required to harness the installed capacity of the project. During monsoon the flow of the river varies from 700 to 2500 cumecs, and from 100 to 150 cumecs during the lean months. In the lean period, the entire water in the river at Nathpa is required for power generation. In between Nathpa and Jhakri there are several khads (small streams). Flow of Sholding khad is also diverted into HRT during lean period. The river reach between Nathpa and Jhakri is situated in steep mountain terrain making it almost inaccessible. Environmental impacts of the project are therefore not expected to spill over to large area. The study area falls in three tehsils (administrative division of a district) i.e. Rampur tehsil of Shimla district, Nichar tehsil of Kinnaur district and Nirmand tehsil of Kullu district. In elevation, the first 100 m from the river bed is predominantly rocky and do not support much of the vegetation. There is great variation of altitude with rugged terrains and hard climatic conditions in the study area.

Methods

Multihabitat sampling (AQEM consortium 2002) was applied to catch the animals. Hence, animals are caught from the most dominant substrate types. This procedure (Figure 3) results in sampling of approximately 1.25 m2 stream bottom area. Net of mesh size 500µm is used for collecting the macro invertebrates. The organisms are preserved immediately in 80% ethanol or 4% formaldehyde. These samples are returned to the laboratory for processing. The collected macroinvertebrates were sorted and identified to the best taxonomic level. Table 3 gives the list of macroinvertebrates

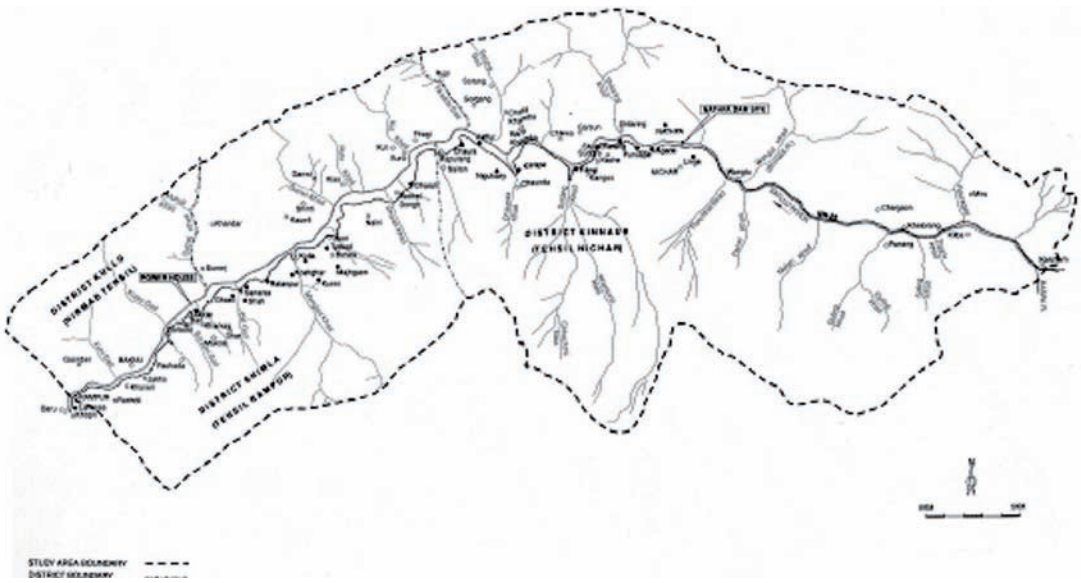

Figure 2: Study area.

species encountered. Water samples were collected in plastic container for and used for Physico-Chemical analysis using standard methods (APHA 1998) (The results of the analysis are reported in Table 1). Samples for Microbiological examination were collected in sterilized & dried non-reactive Borosilicate glass bottles.

The schematic flow chart of the steps involved in the Methodology is given in Figure 3.

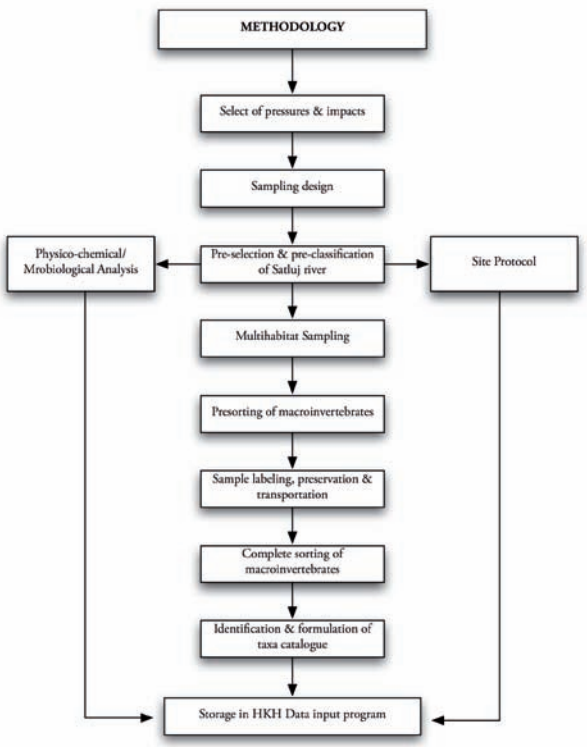

Figure 3: Flow chart of methodology.

Results and discussion

Physico-chemical and biological parameters

The analyzed parameters are shown in Table 1. On the basis of these chemical parameters the Water quality can be determined using NSF water quality index.

NSF water quality index

NSF International, founded in 1944 as the National Sanitation Foundation, is known for the development of standards, product testing and certification services in the areas of public health, safety and protection of the environment.

The index is basically a mathematical means of calculating a single value from multiple test results. The index result represents the level of water quality in a given water basin, such as a lake, river, or stream. The Water Quality Index uses a scale from 0 to 100 to rate the quality of the water, with 100 being the highest possible score. Once the overall WQI score is known, it can be compared against the following scale to determine how healthy the water is on a given day. Water supplies with ratings falling in the good or excellent range would able to support a high diversity of aquatic life. In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water. Water supplies achieving only an average rating generally have less diversity of aquatic organisms and frequently have increased algae growth. Water supplies falling into the fair range are only able to support a low diversity of aquatic life and are probably experiencing problems with pollution. Water supplies that fall into the poor category may only be able to support a limited number of aquatic life forms, and it is expected that these waters have abundant quality problems. A water supply with a poor quality rating would not normally be considered acceptable for activities involving direct contact with the water, such as swimming.

Table 2: Water quality scores.

WQI quality scale	
91-100:	Excellent water quality
71-90:	Good water quality
51-70:	Medium or average water quality
26-50:	Fair water quality
0-25:	Poor water quality

Station 1
The range using NSF water quality index for the site is 56, which is indicative of moderately polluted water quality (Class III).

Station 2
The range using NSF water quality index for the site is 69, which is indicative of moderately polluted water quality (Class III).

Station 3
The range using NSF water quality index for the site is 68, which is indicative of moderately polluted water quality (Class III).

Station 4
The range using NSF water quality index for the site is 69, which is indicative of moderately polluted water quality (Class III).

Station 5
The range using NSF water quality index for the site is 65, which is indicative of moderately polluted water quality (Class III).

Biological parameters

The common and dominant groups of macroinvertebrates are given in the figures 4-8. The calculation of water quality on the basis of macroinvertebrates families was done on the basis of NEPBIOS using pre-classification Sheet.

Table 1: Physicochemical and biological analysis of water samples.

Site Name	W-01	W-02	W-03	W-04	W-05
pH	8.1	8.2	8.1	8.1	8.1
Conductivity [µS/cm]	544	366	225	212	370
Turbidity NTU	21.4	1.42	1.28	1.16	11.7
Oxygen content [mg/l]	3.21	9.09	8.25	8.68	8.08
Oxygen saturation [%]	44.5	108.3	110.5	89.5	109.7
Alkalinity [CO_3^{2-}] [mmol/l]	165	141	89	91.4	167
Total hardness [mmol/l]	213	201	102	109	174
Chloride [mg/l]	15.6	13.4	7.2	28.7	16.4
Ammonium [mg/l]	0.69	0	0	0.1	1.53
Nitrite [mg/l]	0.032	0.004	0.007	0.056	0.026
Nitrate [mg/l]	0.2	0.3	1.1	1.5	0.5
Ortho-phosphate [µg/l]	250	110	190	570	660
Total phosphate [µg/l]	390	940	1150	660	1700
BOD5 [mg/l]	4	3	3.9	6.2	4.1
E-coli [n/100 ml]	1600	1600	1600	1600	1600
TDS [ppt]	0.34	0.22	0.12	0.11	0.18
Estimated class using NSF W.Q. index	III	III	III	III	III
NSF index value	56	69	68	69	65
Water quality index legend	50-70	50-70	50-70	50-70	50-70

NEPBIOS biotic index

A suitable biological method based on indices or score system is possible only when local reference communities are properly scored. Taking this fact into consideration the Nepalese taxa were scored, the average score per taxon (ASPT) calculated and a different biotic score method for Nepal developed with the name Nepalese Biotic Score (Sharma et al. 2006) abbreviated as NEPBIOS. The calculation of the water quality on the basis of the presence of the macroinvertebrates families is done on the basis of NEPBIOS using the Preclassification sheet. Two procedures were followed in scoring the taxa.

(1) Numerical procedure:
This procedure follows the following formula:
Guide Score = SI/STot × 10 + SI-II/STot × 8.57 + SII/STot × 7.14 + SII-III/STot × 5.71 + SIII/STot × 4.28 + SIII-IV/STot × 2.85 + SIV/STot × 1.43
Where SI, SI-II, SII, SII-III, SIII, SIII-IV, SIV are the total number of sites representing the pollutional classes I, I-II, II, II-III, III, III-IV, IV.
Stot= SI+SI-II+SII+SII-III+SIII+SIII-IV+SIV
1.43 is the score interval with 10 as maximum.

(2) Professional judgments:
Step-I: Based on the reference made to the scores that has previously been assigned by different authors in their respective country of origin, and the range of pollutional class represented by each taxon in the rivers of Nepal.

Step-II: Based on the distribution pattern of each taxon (family level) in response to pollutional level. The comparison of family (taxon) distribution with the distribution of observed water quality classes was carried out to observe if any families with the same ecological distribution are differently scored. If so whether or not the reasons are matching.

Once NEPBIOS/ASPT is calculated reference should be made to the transformation table below for interpretation on the water quality of the particular site investigated.

On the basis of the NEPBIOS score system, the species present in the samples of the all the site at Satluj River shows that water quality of the river belongs to class-III.

On the basis of the macroinvertebrates communities and their relationship with physico-chemical-microbiological parameters the water quality of the river Satluj was found to be moderately polluted in the post commissioning phase, which belongs to the water quality class III. The NEPBIOS score system can be applied to assess the ecological health of large numbers of stream & rivers. This also indicates that these Insect have the capability to adapt to varied aquatic habitats due to their structural organization and physiology (Arvind 1994).

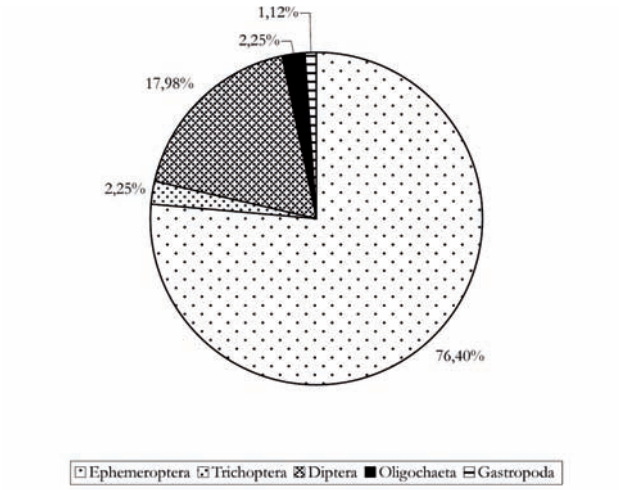

Figure 4: Abundance of benthic macroinvertebrates communities at station 1 of Satluj river.

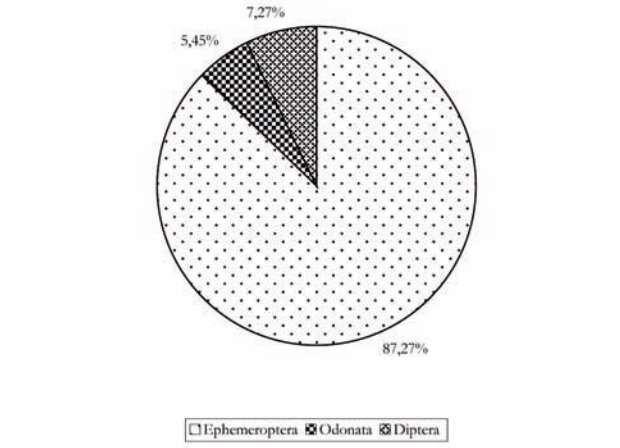

Figure 5: Abundance of benthic macroinvertebrates communities at station 2 of Satluj river.

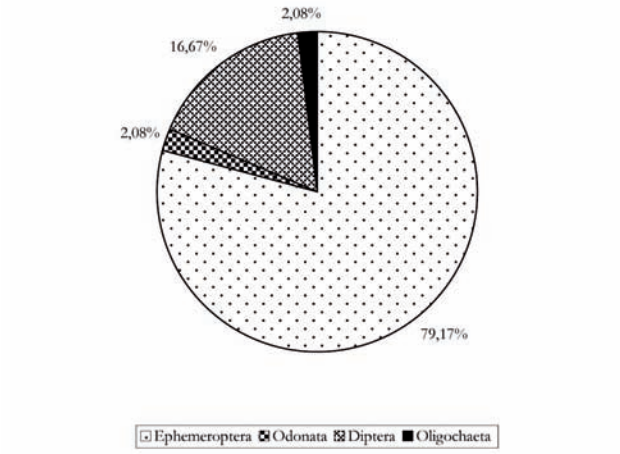

Figure 6: Abundance of benthic macroinvertebrates communities at station 3 of Satluj river.

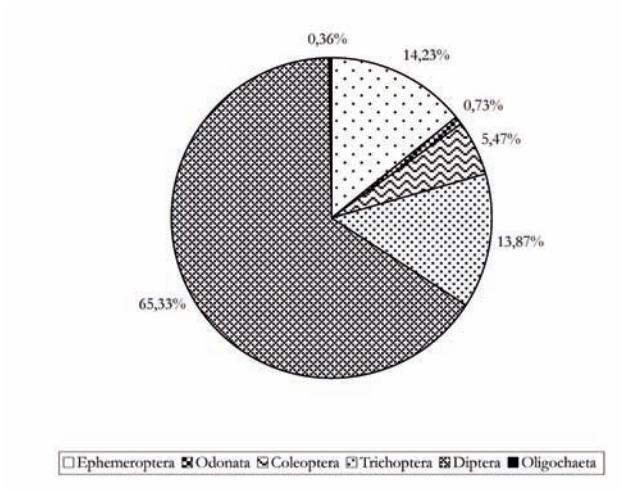

Figure 7: Abundance of benthic macroinvertebrates communities at station 4 of Satluj river.

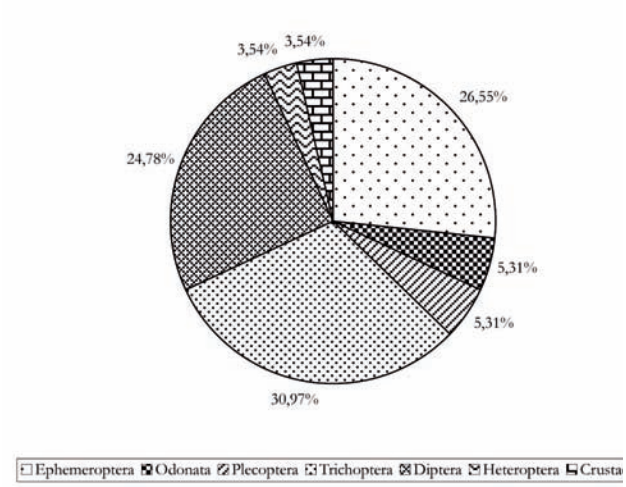

Figure 8: Abundance of benthic macroinvertebrates communities at station 5 of Satluj river.

Table 3: Water quality scores based on NEPBIOS.

NEPBIOS/ASPT	Water quality
8.00-10.00	I
7.00-7.99	I-II
5.50-6.99	II
4.00-5.49	II-III
2.50-3.99	III
1.01-2.49	III-IV
1	IV

Conclusions

The results using the NEPBIOS score system were compared with the results of NSF index, which showed a significant similarity with each other. It means that the NEPBIOS can be used as a method to evalute the river quality in Indian HKH region.

The results show that all the locations analyzed for quality using macroinvertebrates and physico-chemical analysis are in the range of water quality class III (Moderately Polluted) at all the stations.. The measures to reduce point and non-point sources of pollution have been suggested to get the quality suitable for drinking purposes.

Abbreviations

NSF: National Sanitation Foundation; NEPBIOS: Nepalese Biotic Score; WQI: water quality index; APHA: American Public Health Association; ASPT: average score per taxon; BOD: biochemical oxygen demand; DO: dissolved oxygen; NTU: Nephelometric turbidity unit ; U/S: upstream; D/S: downstream.

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The effect of environmental conditions on the taxonomic and functional structure of benthic macroinvertebrate communities in the Hindu Kush-Himalayan region

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Abstract

The effect of environmental conditions on the taxonomic and functional-feeding structure of benthic macroinvertebrate communities in streams and rivers of the Hindu Kush-Himalayan region was studied. In total 190 stream and river reaches distributed in different altitudes from 3 to 2885 m above see level were selected on a gradient of anthropogenic impact and were sampled twice – in the pre-monsoon and post-monsoon season. A large number of environmental parameters including morphological, physical, habitat degradation and land-use parameters as well as water chemistry were measured or assessed. The large data-set was analyzed for most important gradients in the taxonomic and functional-feeding structure using Non-metric Multidimensional Scaling and subsequent fitting of environmental parameters. The effect of 3 groups of variables – basic physical, habitat degradation, and floodplain land use – was separated using variance partitioning based on Canonical Correspondence Analysis. The results indicate a strong relationship between taxonomic structure and altitude and associated water temperature and flow conditions. Variance partitioning as well as fitting of environmental parameters revealed that in the dry pre-monsoon season the taxonomic structure was affected mainly by direct anthropogenic impacts (e.g. source pollution), while in the post-monsoon season by indirect anthropogenic impacts (e.g. eutrophication, proportion of crop land).

Key words: streams, macroinvertebrates, Asia, habitat degradation, land-use.

Introduction

Water quality of streams and rivers varies considerably through Asia. Some streams, situated especially in mountain areas, are pristine or nearly pristine, in contrast most lowland streams are highly affected by source and non-source pollution.

Hindu Kush-Himalayan region offer a large altitude gradient with streams facing different temperature regimes. At this altitude gradient also the land-use changes together with population density accompanied by waste disposal. Rivers with agricultural land-use receive large amount of fertilizers, pesticides as well as organic and inorganic particles. Fertilizers then cause eutrophication of waters, pesticides are poisonous to aquatic organisms and solid particles cause high water turbidity, which affects primary production. It is hard to separate the effect of just the natural physical and chemical parameters in unaffected streams, because these parameters usually change along with the distance from the source (Lindegaard & Brodersen 1995). The separation of natural environmental factors from the anthropogenic influences in the Hindu Kush-Himalayan region faces the same difficulties. Moreover, the influence of all these factors on the communities of aquatic organisms is further complicated by the seasonality of rainfall in the region. The contamination of rivers is more apparent during the dry season when the water flows are insufficient to dilute pollutants (Dudgeon 2000). On the other hand, catchements are washed out into the rivers during monsoon rainfalls (Neumann & Dudgeon 2002).In this study we tried I) to identify most important gradients in the taxonomic and functional-feeding structure of benthic macroinvertebrate communities in the Hindu Kush-Himalaya region and II) to assess and compare the degree of influence of land-use and habitat degradation on the structure of the same communities between pre-monsoon and post-monsoon season.

Methods

Study sites

Within this study 190 stream and river reaches in the Hindu Kush-Himalaya region distributed in different altitudes (from 3 to 2885 m above see level) were selected on a gradient of anthropogenic influence. These sites covered five ecoregions: Lower Gangetic Plains Moist Deciduous Forests, Himalayan Subtropical Pine Forests, Eastern Himalayan Broadleaf Forests, Western Himalayan Broadleaf Forests, and Upper Gangetic Plains Moist Deciduous Forests. The catchement area of the selected sites ranged from 0.5 to 2465 km^2 (median = 40 km^2) and the sites covered streams and rivers of the 1st to 6th Strahler's order (median = the 3th order). The selected streams also covered various hydraulic conditions – from pools to waterfalls.

Sampling and physico-chemical measurement

Each sample was taken from 20 points of an area 25 x 25 cm distributed proportionally to the share of habitats at the site and sampling was carried out in two seasons (pre- and post-monsoon) giving the total number of 380 (2 x 190) samples. The samples were hand-sorted, the animals identified to family and counted.

A large number of environmental parameters including morphological, physical, habitat degradation and land-use parameters as well as water chemistry were measured or assessed. Because of inconsistencies in the methodology of measurement or because of many gaps, some parameters were excluded from statistical analyses. Finally the environmental variables were divided into three groups: I) the basic physical II) habitat degradation and III) floodplain land-use variables. All variables included in the analyses are listed in Table 1.

The proportions of functional-feeding strategies were calculated for each sample using the Euro-limpacs database (Euro-limpacs Consortium 2007) which is based on a 10-point system (10 points are distributed among feeding strategies according to their share in the estimated feeding strategy of each taxon). Taxa richness was standardized to 100 individuals per sample according to Heck et al. (1975) to be comparable among sites of different number of collected individuals.

Statistical treatment

Only samples with at least 150 individuals of benthic macroinvertebrates were included in statistical analyses (146 pre-monsoon and 121 post-monsoon samples). Only taxa with at least 10 occurrences or with total abundance higher than 50 individuals were considered for statistical analyses.

We employed Kruskal's Non-metric Multidimensional Scaling (NMDS) (Cox & Cox 2001) separately on both the abundance and functional–feding data (abundance data were log (x+1) transformed, functional feeding data were standardized to unit variance; Bray–Curtis dissimilarity indices were used) to reduce the variability in each data–set to a two–dimensional space. Then, to identify the most important gradients in the taxonomic and functional-feeding

Table 1: List of three groups of environmental variables used in statistical analyses. Value 1-6 is assigned to the variable "flow conditions" according to the roughest flow type available at the site (1-pool, 2-slack, 3-run, 4-riffle, 5-rapid, 6-waterfall). "Use-Index" is calculated as follows: Use-Index = 2 x (% terraces+ % crop land + % villages) +4 x (% pasture urban sites + % urban sites).

Basic physical parameters	catchment area
	stream order
	altitude
	width of the floodplain
	mean depth at bankfull discharge
	shading at zenith
	stream width
	number of flow types
	flow conditions
	water temperature
	mean depth
	maximum depth
	mean current velocity
	maximum current velocity
Parameters of habitat degradation (presence/absence data)	stagnation
	torrent modification
	channelling for navigation
	straighteninng
	removal of coarse woody debris
	cut-off meanders
	culverting
	longitudinal impoundments at sampling sites
	removal/lack of natural floodplain vegetation
	source pollution
	non-source pollution
	sewage overflows
	eutrophication
	acidification
	liming
	toxic substances
	rubbish
	building materials
	faeces
	slaughter waste
	industrial waste
	washing/bath
Floodplain land-use parameters	% deciduous native forest
	% coniferous native forest
	% mixed native forest
	% wetland (mire, reeds)
	% open grass-/bushland
	%naturally unvegetated
	% non-native forest
	% terraces (hilly region)
	% crop land (tillage, lowland)
	% pasture
	% clear-cutting
	% urban sites (residual)
	% urban sites (industrial)
	% villages
	Use-Index
	width of wooded riparian vegetation (m)

Table 2: Environmental variables best fitted into the NMDS ordination based on the taxa abundances.

variable	pre-monsoon				post-monsoon			
	NMDS1	NMDS2	r^2	p	NMDS1	NMDS2	r^2	p
taxa richness	-0,386	0,922	0,447	<0,001	-0,334	0,943	0,457	<0,001
altitude	-0,723	-0,691	0,448	<0,001	-0,917	-0,399	0,444	<0,001
flow conditions	-0,966	-0,259	0,520	<0,001	-0,974	-0,228	0,432	<0,001
water temperature	0,939	0,344	0,471	<0,001	0,851	0,526	0,212	<0,001
source pollution	0,282	-0,959	0,186	<0,001	-0,195	-0,981	0,021	ns.
non-source pollution	0,904	-0,428	0,267	<0,001	0,948	-0,318	0,351	<0,001
eutrophication	0,866	-0,500	0,164	<0,001	0,913	-0,408	0,231	<0,001
rubbish	-0,201	-0,980	0,338	<0,001	-0,154	-0,988	0,165	<0,001
crop land (%)	0,979	0,206	0,120	0,001	0,997	0,076	0,287	<0,001
urban sites (residual)	0,358	-0,934	0,154	<0,001	0,341	-0,940	0,111	0,001
use index	0,529	-0,8489	0,175	<0,001	0,812	-0,5834	0,313	<0,001

structure, we fitted environmental parameters to the two-dimensional diagrams as vectors (the goodness of fit statistic was squared correlation coefficient (r^2) and the significance of fitted vectors was assessed using 1000 permutations of environmental variables). NMDS and subsequent fitting were performed in R environment for statistical computing and graphics (http://www.r-project.org/).

To determine the effect of habitat degradation and land-use on the taxonomic and functional-feeding structure of benthic macroinvertebrate communities, we employed variance partitioning using Canonical Correspondence Analysis (Borcard et al. 1992, Peres–Neto et al. 2006). This analysis partition the total variation in abundance data to fractions which are attributable to groups of environmental parameters, i.e. the output of this analysis is the portion of variabily in the abundance data–set explained by the groups of environmental parameters (in this case the proportion of variability explained by basic physical parameters, habitat degradation and floodplain land–use).

Results

In the pre-monsoon season 145 taxa were identified, out of which 82 occurred in at least 10 samples or their total abundance was higher than 50 individuals and were used for analyses (minimal, median and maximal frequencies and total abundances of taxa were 2, 21, 133 occurrences and 19, 310 and 34681 individuals respectively). In the post-monsoon season 153 taxa were identified, out of which 85 occurred in at least 10 samples or their total abundance was higher than 50 individuals and were used for analyses (minimal, median and maximal frequencies and total abundances of taxa were 2, 21, 140 occurrences and 23, 283 and 159816 individuals respectively).

Taxonomic structure of benthic macroinvertebrates

The fitting of environmental variables on the two–dimensional NMDS ordinations revealed that in both the pre–monsoon and post–monsoon seasons the taxonomic structure of benthic macroinvertebrates reflected best the altitude gradient associated with hydraulic conditions and water temperature

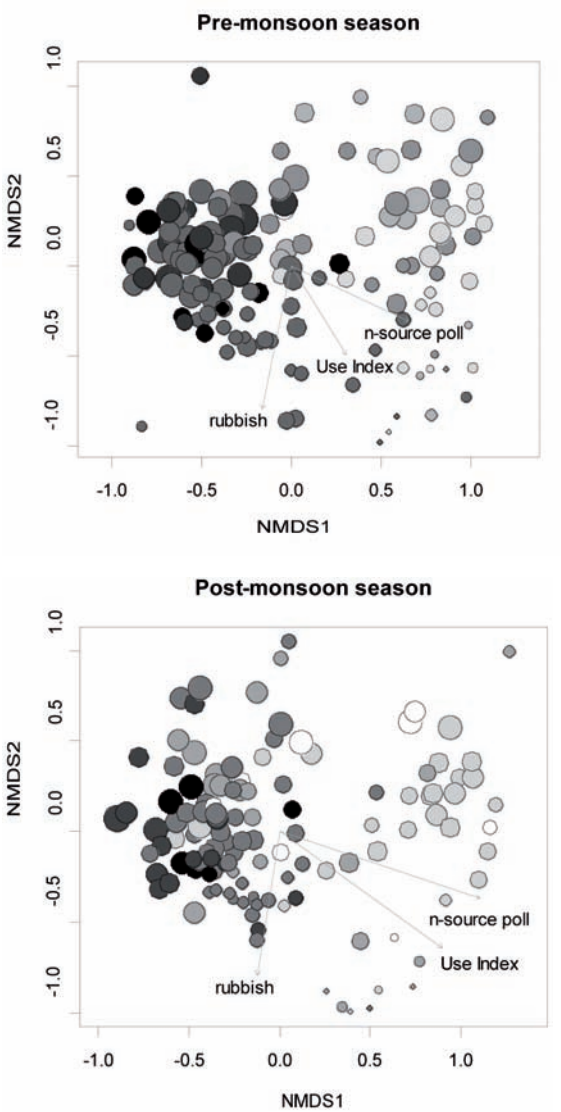

Figure 1: NMDS ordinations of sites based on taxa abundances in the pre- and post-monsoon season. The color of points indicate the maximum flow conditions observed at site (see Tab. 1; black color = waterfall, white = pool), while the area is proportional to the taxa richness standardized to 100 individuals in each sample. Vectors of some of the best fitted variables are displayed. "n-source poll" = non-source pollution.

Table 3: Environmental variables best fitted into the NMDS ordination based on the functional-feeding strategies.

variable	pre-monsoon				post-monsoon			
	NMDS1	NMDS2	r^2	p	NMDS1	NMDS2	r^2	p
flow conditions	-0,925	0,379	0,262	<0,001	-0,568	-0,823	0,199	<0,001
altitude	-0,890	0,456	0,138	<0,001	-0,848	-0,530	0,159	<0,001
water temperature	0,952	-0,308	0,210	<0,001	0,512	0,859	0,070	0,015
mean current velocity	-0,577	0,817	0,101	0,001	-0,8667	-0,499	0,247	<0,001
non-source pollution	0,897	-0,441	0,144	<0,001	0,7486	0,663	0,161	<0,001
eutrophication	0,955	-0,297	0,107	<0,001	0,898	0,44	0,232	<0,001
rubbish	-0,396	0,918	0,020	ns.	0,492	-0,871	0,207	<0,001
crop land (%)	0,881	-0,473	0,084	0,002	0,871	0,491	0,153	<0,001
use index	1,000	0,003	0,070	0,004	0,977	0,212	0,237	<0,001

(this gradient was projected on the NMDS1 axis) (Figure1, Table2). The distribution of samples alongthe second axis (NMDS2) could be best attributed to taxa richness.

Regarding the habitat degradation parameters, the presence of rubbish, which together with source pollution pointed against the taxa richness, was the best fitted variable in the pre-monsoon season. In the post-monsoon season non–source pollution and eutrophication were more significant parameters of habitat degradation. These parameters pointed against altitude and water temperature, taking also part in the main gradient.

Considering the effect of floodplain land-use proportion of crop land, corresponding to non-source pollution and eutrophication, was more important in the post-monsoon season, while proportion of residual urban sites, corresponding to source pollution and presence of rubbish, was slightly more important in the pre-monsoon season.

Functional–feeding structure of benthic macroinvertebrates

In the pre–monsoon season the ordination of functional-feeding strategies reflected best the proportion of collectors/gatherers, followed by the proportion of active and passive filter-feeders and grazers. Similarly, in the post-monsoon season the ordination reflected best the proportion of active and passive filter-feeding strategies, followed by the proportion of grazers and collector/gatherers (Figure 2).

The functional feeding structure reflected the environmental conditions to a lesser extend compared to the taxonomic structure. In the pre–monsoon season hydraulic conditions together with water temperature had the highest fit on the ordination of samples, while degradation and land-use parameters were fitted very poorly. By contrast, in the post-monsoon season habitat degradation and land use parameters belonged among the best fitted variables (Table 3, Figure 3).

Physical parameters

Basic physical parameters explained higher portion of variance in the taxonomic structure (17 and 19.4 % in the

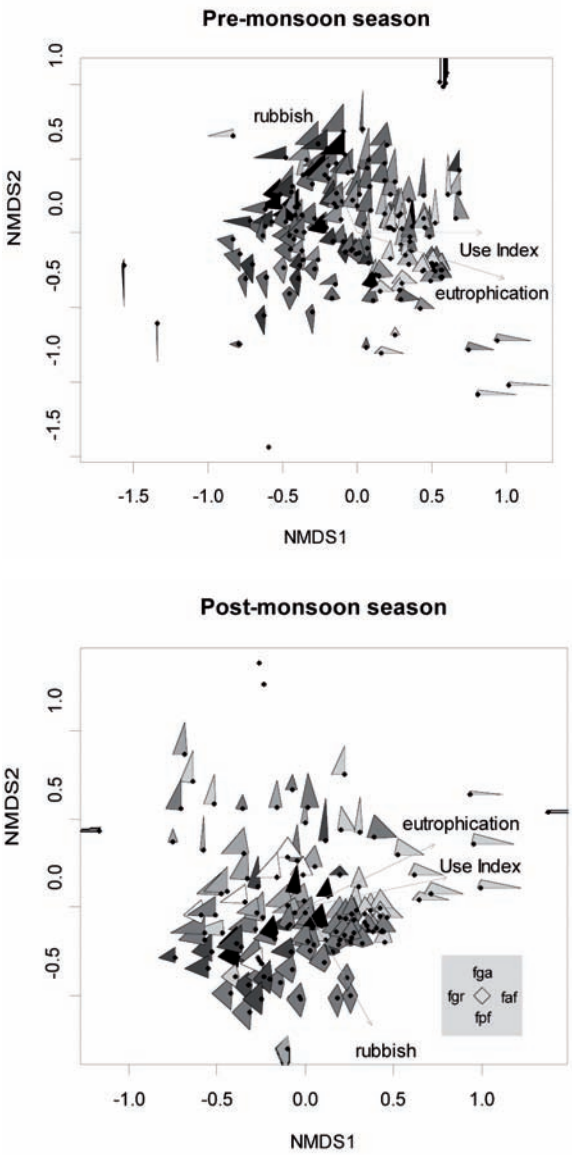

Figure 2: NMDS ordinations of sites based on functional-feeding strategies in the pre- and post-monsoon season. The color of symbols indicate the maximum flow conditions observed at site (see Tab. 1; black color = waterfall, white = pool), while the extension of symbols express the proportion of four dominant functional-feeding strategies, as indicated in the bottom right corner of the second figure. fga – collectors/gatherers, faf and fpf – active and passive filter feeders respectively and fgr – grazers.

pre- and post-monsoon season respectively) than in the functional-feeding structure of the benthic macroinvertebrate communities (10.3 and 16.8 in the pre- and post-monsoon season respectively). There was also a slight increase in the portion of variance explained by physical parameters in the post-monsoon season compared to the pre-monsoon season (Figure 2), though physical parameters explained a significant part of variance in all cases.

Habitat degradation

The parameters of habitat degradation explained 12.4 and 13.1 % of variance in the taxonomic and 9.0 and 13.1 % of variance in the functional-feeding structure of the benthic macroinvertebrate communities in the pre- and post-monsoon season respectively (Figure 2). There was a slight increase of variance explained in the post-monsoon season compared to the pre-monsoon season. However, the variance explained by habitat degradation, when added to the variance explained by basic physical parameters, represented only 3.3 and 3.2 % (considering the taxonomic structure) and only 1.1 and 0.0 % (considering the functional-feeding structure) in the pre- and post-monsoon season respectively. The remaining 9.1 and 9.8 % (taxonomic structure) and 7.9 and 13.1 % (functional-feeding structure) of the variance were shared with the variance explained by physical parameters (Figure 3). Thus, habitat degradation parameters did add a significant ($p < 0.01$) part of information when explaining the taxonomic structure, but not when explaining the functional-feeding structure of benthic macroinvertebrate communities.

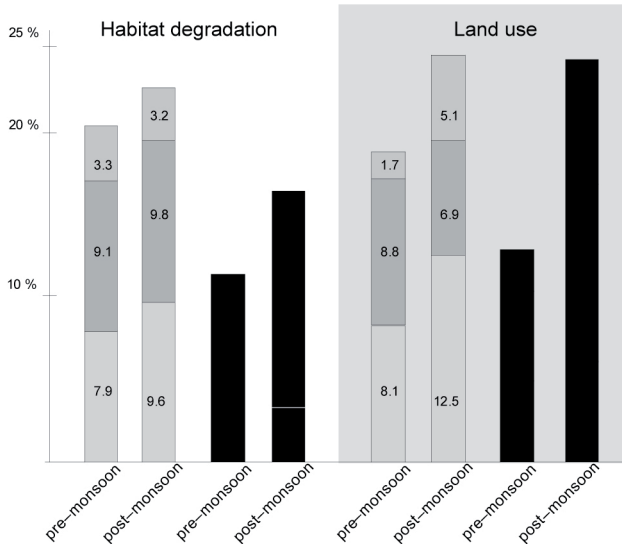

Figure 3: The amount of variance in the taxonomic (filled columns) and functional-feeding (shaded columns) structure explained by physical parameters (the bottom parts of columns), and by habitat degradation (upper parts of four columns in the left) and land-use (upper parts of four columns in the right), and the variance shared (middle parts of columns).

Land-use

Floodplain land-use explained 10.5 and 12.1 % of variance in the taxonomic and 8.0 and 18.2 % of variance in the functional-feeding structure of the benthic macroinvertebrate communities in the pre- and post-monsoon season respectively. Thus, concerning the taxonomic structure, the variance explained by land use slightly increased in the post-monsoon season compared to the pre-monsoon season, while the portion of variance in the functional-feeding structure explained by land-use was more than two times higher in the post-monsoon season than in the pre-monsoon season (Figure 2). Land use added a significant part of information to that explained by physical parameters when explaining the variance in both the taxonomic and functional-feeding structure, and the added information was about three times higher in the post-monsoon season (5.1 and 7.6 % in the taxonomic and functional-feeding structure respectively) than in the pre-monsoon season (1.7 and 2.5 %).

Discussion

Community structure

In both seasons the taxonomic structure of benthic macroinvertebrate communities strongly reflected the altitude gradient, along which also water temperature and flow conditions changed (Figure 1). This pattern followed the River Continuum Concept of Vannote et al. (1980) with high-altitude streams representing upper reaches and lowland streams and rivers lower reaches. In our study the altitude gradient was followed also by changes in land-use, e.g. the proportion of crop land increased with decreasing altitude, and similarly by non-source pollution and eutrophication, which were more frequent in lower reaches.

On the other hand, taxa richness remained constant along the altitudinal gradient, but was negatively related to the Use Index, occurrence of rubbish on banks and the proportion of residual urban sites, which indicate anthropogenic impacts. In this view it seemed that the community composition changed along with the altitude, reflecting changes in water temperature, flow and land use parameters associated with non source pollution and eutrophication, while taxa richness was affected mainly by direct anthropogenic impacts. Jacobsen et al. (1997) found the diversity of stream invertebrates to be higher in lower altitudes compared to higher altitudes in a set of four groups of streams in Ecuador and Denmark. This contradiction might be explained by higher pollution of streams and rivers in lower altitudes in Asia, while Jacobsen et al. (1997) studied rivers without any significant sources of pollution.

Regarding the functional feeding structure, no strong effect of environmental conditions could be observed. This might

be due to insufficiently high taxonomic level of identification (family) and/or due to the use of species traits which were not verified in conditions of Asian streams – the same families may be represented by different species with different functional-feeding strategies.

Seasonal patterns

Generally, the variance explained by each of the three groups of environmental variables tested was slightly higher in the post-monsoon season. This was apparent especially in case of land-use parameters, which in the post-monsoon season explained even more variance in the functional-feeding structure than basic physical parameters, and to the variance already explained by physical parameters added three tomes higher amount of explained variance compared to the pre-monsoon season. These results might indicate a higher rate of communication of streams and rivers with their floodplains during monsoons and support findings of Neumann & Dudgeon (2002), who reported toxic effect of agricultural runoff during monsoon rainfall.

Both habitat degradation and land-use parameters were for the most part included in the physical parameters when partialling out the variance in both the taxonomic and functional structure, though separately they could be effectively fitted into the ordinations of sites. Considering the taxonomic structure, source pollution and rubbish together with proportion of residual urban sites were slightly better fitted into the pre-monsoon ordination compared to the post-monsoon. Conversely, non-source pollution, eutrophication, Use Index and proportion of crop land were better fitted into the post-monsoon ordination. Fits of these parameters in the ordinations were not particularly strong, nevertheless they were consistent and their weakness might be justified by a highly heterogeneous data-set. These results probably bring further evidence that benthic macroinvertebrate communities in streams with seasonal rainfall are affected by direct anthropogenic impacts (like source pollution) during the dry season (Dudgeon, 2000) and by indirect anthropogenic impacts (eutrophication, non-source pollution) in the wet season (Neumann & Dudgeon, 2002).

Conclusions

Within this study a strong relationship between the taxonomic structure of benthic macroinvertebrate communities and altitude gradient associated with further environmental parameters was identified. Further, the results indicated different effect of land-use and habitat degradation parameters on the benthic macroinvertebrate community structure in pre-monsoon and post-monsoon season.

Although some parameters of land-use and habitat degradation could be effectively related to macroinvertebrate communities and different patterns were observed in pre- and post-monsoon season, finer measurements of environmental parameters in further studies would be appreciated.

Functional-feeding structure of benthic communities was more difficult to interpret in terms of environmental conditions and for further studies we suggest finer identifications of macroinvertebrates (preferably at least at genus level) and verification of species traits in the conditions of Asian streams and rivers.

Acknowledgements

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A survey of the caddisflies (Insecta, Trichoptera) of Bhutan, with suggestions for further research

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Key words: Trichoptera, Bhutan, distribution, taxonomy

Introduction

The caddisflies of the Kingdom of Bhutan are poorly investigated. Except for the results of an expedition by the Natural History Museum Basel (Switzerland) in 1972 which were published by Fernand Schmid (1975), very few specimens became known. As a result of a research trip by the author in 2006, our knowledge has improved. At present 166 species are known. The list is given in the result chapter. On the other hand, some adjacent regions are relatively well investigated. There are many papers containing information on Trichoptera from Assam, Kameng (=Arunachal Pradesh) and Sikkim, mainly by Fernand Schmid, after specimens collected in the 1960s, and Nepal, by several authors including myself. Trichoptera data from Tibet, Bangladesh and Myanmar, however, are scarce. A regional summary does not exist. In spring 2006, the senior author joined a research group which investigated the ecological conditions of running waters in Bhutan within the frame of the EU funded ASSESS-HKH project (INCO-CT-2005-003659). A part of the project that deals with the development of an assessment system to evaluate the ecological quality of the rivers in the Hindu Kush-Himalaya region, deals with the increase of knowledge on the biodiversity of benthic macroinvertebrates as this group serve as bio-indicators of the ecological quality. In a preliminary survey of Nepal, Malicky (2006) listed over 300 species. Although the area of Bhutan is smaller, we may expect more than this for the following reasons. It is known from many publications that the region of northern Thailand, northern Myanmar, Yunnan, Assam etc. is extraordinarily rich in Trichoptera species which has historical reasons. Bhutan is closer to this region than Nepal. Even this preliminary list which is mainly based on the results of a three-week trip in Bhutan, but long research in Nepal, we know 34 species of the genus Rhyacophila in Bhutan, but 32 in Nepal; among the family Glossosomatidae we know 16 species in Bhutan but 14 in Nepal, and in Lepidostomatidae 16 and 15 respectively. On the other hand, many more species of Hydroptilidae, Polycentropodidae, Ecnomidae, Hydropsychidae and Leptoceridae are expected whose main activity periods is not April; e.g. we know in Bhutan only 19 hydropsychids, in Nepal 53; or only 9 leptocerids, in Nepal 49.

Methods

There are two important methods to collect Trichoptera: day catch by sweepnet, and light trapping during night time. It is evident that sweepnet catches become more important in cooler regions and higher elevations but less efficient under tropical conditions. Bhutan is a country with big climatic contrasts; therefore both methods are appropriate and should be used at any site. Collection of larvae is important too, but at the present state of our knowledge it is in most cases not possible to identify larvae to species; but knowledge on species level is fundamental for any study of biodiversity. To increase the knowledge of caddisflies a research programme is suggested below.

Our 2006 trip was performed in the period of 14 April to 5 May which is, in principle, a good season for collecting adult caddisflies, but as many species are seasonal, only a minor proportion of species may be found in April. In Bhutan adult Trichoptera may be found in all months, therefore collecting activity is necessary at any time of the year. Under the given circumstances the results of our trip were good, but collecting trips especially destined to collect caddisflies would have better results. The present list is by far not complete, and many more species are expected to be found in future.

Results

In the results chapter we provide a list of species known from Bhutan, with indication of other countries where the species were found. Several species were found as females only without corresponding males and can therefore not be named at the present state of our knowledge.

Rhyacophilidae
Himalopsyche biansata Kimmins: Sikkim, Tibet
Himalopsyche digitata Martynov: Nepal, Garhwal, Sikkim, Kameng
Himalopsyche horai Martynov: Nepal, Penjab, Garhwal, Sikkim, Kameng, Kaschmir, Kullu
Himalopsyche lepcha Schmid: Sikkim
Himalopsyche malenanda Schmid: Nepal, Garhwal, Sikkim, Kameng

Himalopsyche tibetana Martynov: Nepal, Garhwal, Sikkim, Chumbi, Tibet
Rhyacophila aureostigma Schmid: West Bengal
Rhyacophila bhuchanadhara Schmid: Assam
Rhyacophila bidens Kimmins: Nepal, Sikkim, Kameng, Garhwal, Kumaon, Manipur, Myanmar, Yunnan, Tibet, Vietnam
Rhyacophila chayulpa Schmid: Nepal, Garhwal, Sikkim, Kameng
Rhyacophila chembo Schmid: Nepal, Sikkim, Kameng
Rhyacophila dongkyapa Schmid: Nepal, Sikkim, Kameng, Manipur
Rhyacophila drokpa Schmid: Assam, Manipur, Garhwal, Thailand
Rhyacophila kando Schmid: Nepal, Garhwal, Sikkim, Kameng
Rhyacophila khiympa Schmid: Sikkim, Yunnan
Rhyacophila kubra Schmid: Sikkim
Rhyacophila lepcha Schmid: Sikkim
Rhyacophila melanippe Malicky: Bhutan only
Rhyacophila mnemosyne Malicky: Bhutan only
Rhyacophila ngorpa Schmid: West Bengal, Sikkim, Tibet
Rhyacophila obscura Martynov: Turkestan, Afghanistan, Usbekistan, Pakistan, Nepal, Garhwal, Sikkim, Kaschmir, Kullu
Rhyacophila pyrrha Malicky: Bhutan only
Rhyacophila rhombica Martynov: West Bengal, Vietnam
Rhyacophila rongpa Schmid: Sikkim, Kameng, Manipur
Rhacophila scissa Morton: Garhwal, Sikkim, Kameng, Assam, Manipur, Myanmar, Thailand, Guangdong, Vietnam
Rhyacophila spinalis Martynov: Nepal, Tibet, Garhwal, Sikkim, Kameng
Rhyacophila stenostyla Martynov: Nepal, Garhwal, Sikkim, Tibet
Rhyacophila styligera Kimmins: Myanmar
Rhyacophila tecta Morton: Assam, Kameng, Myanmar
Rhyacophila tolungpa Schmid: Sikkim, Kameng
Rhyacophila trashipa Schmid: Manipur
Rhyacophila tsona Schmid: Manipur
Rhyacophila yullha Schmid: Sikkim
Rhyacophila zhungpa Schmid: Nepal, Sikkim, Kameng, Garhwal
Hydrobiosidae
Apsilochorema tigmatejanam Schmid: Nepal
Apsilochorema utchtchunam Schmid: Nepal, Vietnam
Glossosomatidae
Agapetus aineias Malicky: Nepal
Agapetus chitraliorum Schmid: Pakistan
Agapetus mahadhyandica Schmid: Pakistan
Agapetus oinopion Malicky: Bhutan only
Agapetus triangularis Martynov: Nepal, Pakistan, Uttar Pradesh
Agapetus wolframi Malicky: Bhutan only
Glossosoma atchintitam Schmid: Assam
Glossosoma atestas Malicky & Chantaramongkol: Nepal, Himachal Pradesh, Darjeeling, Sichuan, Yunnan, Vietnam
Glossosoma caudatum Martynov: Nepal, Myanmar, Sichuan, Yunnan, Vietnam
Glossosoma confluens Kimmins: Myanmar
Glossosoma dentatum Martynov: Nepal, Pakistan, Afghanistan
Glossosoma dirghakantakam Schmid: Assam, Sikkim
Glossosoma kissottoi Malicky: Nepal
Glossosoma lar Malicky: Bhutan only
Glossosoma varjakantakam Schmid: Bhutan only
Glossosoma sp.
Hydroptilidae
Orthotrichia sp.
Scelotrichia sp.
Plethus sp.
Stactobia sp. 1
Stactobia sp. 2
Philopotamidae
Chimarra aminadab Malicky: Nepal
Chimarra cumata Malicky & Chantaramongkol: Nepal, Thailand, Vietnam
Chimarra mars Malicky: Bhutan only
Chimarra megara Malicky: Bhutan only
Chimarra oinone Malicky: Bhutan only
Chimarra oreithyia Malicky: Bhutan only
Chimarra pasiphae Malicky: Bhutan only
Chimarra pontos Malicky: Bhutan only
Chimarra ram Malicky: Nepal
Chimarra semiramis Malicky: Bhutan only
Chimarra talos Malicky: Bhutan only
Chimarra vesta Malicky: Bhutan only
Dolophilodes didactylus Sun & Yang: Yunnan
Dolophilodes flaviventris Kimmins: Myanmar
Dolophilodes ornata Ulmer: Iran, Afghanistan, Kirgisistan, Pakistan, Nepal, Setschuan, Shaanxi
Dolophilodes tibetana Kimmins: Kashmir, Nepal, Himachal Pradesh, Shaanxi, Tibet
Dolophilodes torrentis Kimmins: Myanmar, Thailand, Vietnam
Kisaura filiformis Mey: Vietnam, Thailand
Kisaura maia Malicky: Bhutan only
Kisaura teisiphone Malicky: Bhutan only
Wormaldia kambaitiensis Malicky: Myanmar
Wormaldia relicta Martynov: Nepal, Myanmar, "Kurseong (E.Himalayas)", Sikkim, Thailand, Vietnam
Wormaldia sunkosiana Malicky: Nepal
Stenopsychidae
Stenopsyche dirghajihvi Schmid: Nepal, Sikkim, Kameng, Tibet, Shaanxi, Hainan, Setschuan, Yunnan
Stenopsyche haimavatika Schmid: Nepal, Garhwal, Sikkim, Kameng, Thailand
Stenopsyche himalayana Martynov: Afghanistan, Pakistan, Himachal Pradesh, Nepal, Garhwal, Sikkim, Assam, Thailand, Yunnan, Sichuan, Vietnam
Stenopsyche similis Ulmer: Kashmir, Penjab, Garhwal, Nepal, Uttar Pradesh, Sikkim, Kameng
Polycentropodidae
Plectrocnemia banksi Fischer: Nepal
Ecnomidae
Ecnomus hyas Malicky: Bhutan only
Psychomyiidae
Psychomyia benyagai Malicky & Chantaramongkol: Himachal Pradesh, Uttar Pradesh, Thailand, Vietnam
Psychomyia bhutana Oláh: Nepal, Kashmir, Uttar Pradesh
Psychomyia chompu Malicky & Chantaramongkol: Nepal, Thailand
Psychomyia dugpa Schmid: Nepal, Garhwal, Sikkim, Kameng
Psychomyia kumari Schmid: Garhwal
Psychomyia schefterae Schmid: Garhwal

Psychomyia scottae Schmid: Sikkim
Psychomyia suni Schmid: Sikkim, Kameng, Manipur
Paduniella magadha Schmid: Afghanistan, Pakistan, Nepal
Tinodes natichastra Schmid: West Bengal
Hydropsychidae
Diplectrona burha Schmid: Pakistan, Penjab, Kashmir, Garhwal, Himachal Pradesh, Nepal, Sikkim, Bengalen, Thailand, Vietnam, Taiwan
Cheumatopsyche ceres Malicky & Chantaramongkol: Nepal, Thailand, Vietnam
Cheumatopsyche matuta Malicky: Nepal
Cheumatopsyche ningmapa Schmid: Nepal
Hydropsyche aiakos Malicky: Nepal, Myanmar
Hydropsyche atlas Malicky & Chantaramongkol: Nepal
Hydropsyche binaria Mey: Nepal, Thailand
Hydropsyche charon Malicky & Chantaramongkol: Bhutan only
Hydropsyche claviformis Mey: Nepal, Kullu
Hydropsyche dhusaravarna Schmid: Nepal, Tibet
Hydropsyche kaznakovi Martynov: Afghanistan, Usbekistan, Pakistan, Kashmir, Nepal, Tibet
Hydropsyche gkarmai Malicky: Bhutan only
Hydropsyche rakshakaha Oláh: Pakistan, Kashmir, Nepal
Hydropsyche sp.
Hydromanicus eleasar Malicky: Nepal, Myanmar
Hydromanicus makareus Malicky: Bhutan only
Hydromanicus truncatus Betten: Tibet, Nepal, Thailand, Yunnan, Vietnam
Macrostemum fastosum Walker: Nepal, Sikkim, Myanmar, Thailand, Laos, Vietnam, China, Taiwan, Philippines, Malaysia, Sumatra, Bali, Sri Lanka
Macrostemum thomasi Mey: Nepal
Arctopsychidae
Arctopsyche composita Martynov: Nepal, Garhwal, Sikkim, Kameng
Arctopsyche integra Schmid: Sikkim, Assam, Kameng
Arctopsyche lobata Martynov: Nepal, Garhwal, Sikkim, Kameng, Manipur, Penjab, Yunnan, Tibet, Zhejiang, Sichuan, Myanmar
Phryganeidae
Eubasilissa maclachlani White: Pakistan, Kullu, Nepal, Shanxi, Guangxi, Sichuan, Yunnan, Sikkim, Assam, Myanmar, Thailand, Vietnam
Neurocyta brunnea Martynov: Tibet
Neurocyta drukpa Schmid: Bhutan only
Brachycentridae
Brachycentrus kozlovi Martynov: Afghanistan, Pakistan, Tibet, Kaschmir, Ladakh, Garhwal, Kameng
Micrasema punjaubi Mosely: Punjab
Micrasema sp.
Limnocentropodidae
Limnocentropus himalayanus Martynov: Nepal, India
Goeridae
Goera maithili Schmid: Kameng
Goera raghu Schmid: Sikkim, Kameng
Limnephilidae
Apatania ottomoogi Malicky: Bhutan only
Apatania sp.
Phylostenax himalus Mosely: Afghanistan, Pakistan, Nepal, Garhwal, Sikkim, Kameng, Tibet
Pseudopotamorites rufescens Martynov: Nepal, Sikkim, Tibet
Pseudostenophylax angulatus Schmid: Garhwal, Nepal, Sikkim
Pseudostenophylax griseolus Martynov: Garhwal, Nepal, Sikkim
Pseudostenophylax ovalis Schmid: Nepal, Garhwal
Pseudostenophylax squamolineatus Schmid: Garhwal, Nepal, Sikkim, Kameng
Lepidostomatidae
Dinarthrum assamensis Mosely: Nepal, Sikkim, Assam
Dinarthrum destructum Ulmer: Sikkim, Myanmar
Dinarthrum iamba Mosely: Myanmar
Dinarthrum liber Malicky: Assam, Kameng
Dinarthrum ma Malicky: West Bengal
Dinarthrum menoitios Malicky & Mey: Sikkim
Dinarthrum punjabicum Martynov: Punjab, Nepal
Dinarthrum simplex Kimmins: Nepal
Dinarthrum steelae Mosely: Myanmar
Dinarthrum tesarum Mosely: Kumaon
Indocrunoecia heterolepidia Martynov: Sikkim, Changra
Indocrunoecia libitina Malicky: Himachal Pradesh
Lepidostoma inaequalis Martynov: W.Himalayas
Lepidostoma leukothoe Malicky: Assam, Kameng
Paraphlegopteryx astridae Malicky: Bhutan only
Zephyropsyche schmidi Weaver: Assam, Sikkim
Uenoidae
Neophylax tenuicornis Ulmer: Sichuan
Uenoa hiberna Kimmins: Nepal, Uttar Pradesh, Thailand
Helicopsychidae
Cochliophylax chrysothoe Schmid: Kameng
Sericostomatidae
Gumaga orientale Martynov: Japan, Thailand, Fujian, Sichuan, Myanmar
Leptoceridae
Adicella sp.
Oecetis dvichakha Schmid: Bhutan only
Oecetis penicillata Kimmins: Myanmar, Nepal, Himachal Pradesh
Setodes er Malicky & Chantaramongkol: Bhutan only
Setodes fluvialis Kimmins: Pakistan, Nepal, Myanmar, Thailand, Sichuan, Yunnan
Setodes fragilis Oláh: Bhutan only
Setodes sychaeus Malicky: Bhutan only
Setodes sp. 2
Setodes sp. 3
Calamoceratidae
Anisocentropus salsus Betten: Nepal, Thailand, Assam, Malaysia, Sikkim
Ganonema fuscipenne Albarda: Thailand, Vietnam, Laos, Sichuan, Jiangxi, Guizhou, Malaysia, Sumatra, Java

Discussion

Trichoptera are important ecological indicators, indicating environmental conditions of water bodies, the kind of biotope which they inhabit, as well as its conditions in pollution and other disturbance, mainly caused by man. But at our present knowledge there are too few data available from Bhutan to start a state of the art bio-monitoring. By far more data are necessary. It may be expected that some hydropsychid species are, like in other regions, tolerant to a certain degree of pollution, but our data from Bhutan are not enough to clearly point out these bio-indicative aspects.

Other ecological impressions from our trip are scarce. Glossosoma kissottoi appears to be tolerant to a certain pollution of larger rivers such as Thimphu Chhu and Paro Chhu, but most other species need clean water.

Apatania ottomoogi is remarkable as it lives in relatively large rivers such as Thimphu Chhu and Paro Chhu where we have found many empty pupal cases in the bottom samples; the main flight period of this species is probably earlier in the year. Other Apatania species are normally living in small springbrooks, often in very cold water.

The high number of Rhyacophila species is characteristic of the region and not only the result of sites in higher elevations. High numbers of Rhyacophila species are also found in relatively low elevations such as Tsirang in 1700 and Dungkar in 1370m asl. The rich Rhyacophila fauna of northern Thailand includes many sites under 1000m asl.

Suggestions for future research

Research on Trichoptera is essential in any country for the assessment of the conditions of natural water bodies as these insects are excellent indicators for biodiversity and environmental conditions. In the initial phase research work should be guided by foreign scientist (top taxonomists) because at present there are no fundamentals in existence in Bhutan. The necessary steps are 1. collecting, 2. preserving, and 3. scientific work with the collected material.

1.) Collecting. To get a reasonable survey of the fauna, collecting trips should be organised during all months of the year in all parts of the country. In the begin, these collecting trips should be supervised by a foreign experienced scientist who knows the sampling and preservation techniques, and who can adapt the sampling design under changing conditions. A team of 2-3 persons will be optimal for the collecting trips. To ensure economic performance, the use of a small camping bus is suggested. People may stay in it overnight during the night collecting activity; otherwise hotel accommodation would be necessary which means higher cost, long driving distances and time loss. In Bhutan most relevant sites may be accessed by road and short walking distances.

Collecting methods include sweepnet catch by daytime and light-trapping by night. Both methods are well established, and good equipment is available. Cost for these instruments and gears are low, and some of them may easily be homemade. However, it is essential to collect at the appropriate time of the day (and year). For instance, setting of the light-traps must be done exactly in a time interval (which is known by experience by the collectors) between daylight and dusk. This is often the same as dinnertime, and if it is missed because people are used to eat exactly at this time, the catch will be extremely reduced.
As a first step to get a good survey of the country's fauna, collections by 2 persons are suggested for a period of two full years, so that many sites may be visited two or three times (the more, the better) and that at least 5 days (including night catches) per week are spent with the work. Sorting of the collected material may be done by other helpers, which will also result in obtaining many by-catches from other insect groups which must also be preserved and made available for study to other specialists.

2.) Preserving. To obtain a good basis for the continuation of the work, it is absolutely necessary to establish a scientific collection. This is best done by founding a Natural History Museum even if it would be small in the beginning. The collections must be kept in a good technical standard (selection of drawers of good quality, of good glass containers, good protection against heat, sunlight, fungus, pest insects etc.) and in accordance with the recommendations by the International Code of Zoological Nomenclature which are (Rec.72G): "Every institution in which name-bearing types are deposited should 1. ensure that all are clearly marked so that they will be unmistakably recognized as name-bearing types; 2. take all necessary steps for their safe preservation; 3. make them accessible for study; 4. publish lists of name-bearing types in its possession or custody; and 5. so far as possible, communicate information concerning name-bearing types when requested."

So it is obligatory to have educated museologists for the care on the collection.

3.) Scientific work: The collected material must be studied in a professional way. It is common in almost all countries of the world that not enough good taxonomists are available. For Trichoptera, the situation is slightly better, but the first evaluation can at present only be done by foreign specialists. To some extent they may do the work in Bhutan, but part of this work must be done abroad because the necessary literature and voucher collections cannot be transported to Bhutan. Therefore, permission need to be given for the transport of specimens abroad. This situation will remain until a good handbook for the identification of Bhutanese Trichoptera was made. For practical reasons, this book should also include the fauna of adjacent countries. The production of this book should be jointly made by foreign scientists in cooperation with Bhutanese colleagues. In realistic view, this may be a programme for about 20 years. Realisation in about ten years would be possible only at much higher cost, but it will not work in shorter time. For the education of specialists in Bhutan, introductory courses by foreign specialists are easily available.

Publications of the results should be no problem. Many scientific journals of international level are available in many countries, and also in Bhutan itself it is easy to produce this kind of publications. Electronic data banks are now essential for faunistic and zoogeographic work, all the more as nowadays the aspects of biodiversity are of an increasing interest on a world-wide scale. Experience is available with this special type of databanks, but decisions in this respect may

be made later when a reasonable quantity of data will be available. The present senior author (Malicky) is willing to support all of these activities, to give courses, to help with the collections and with the identifications.

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Variation in time and gear in the fish assemblage of the rivers flowing through Chitwan National Park and its latest update

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Abstract

Biota at any place is the product of evolutionary and biogeographic process, which means that the resident biota at any site varies according to the geographic region as well as in evolutionary time. Though, there are some records of fish diversity in the rivers Rapti and Narayani which flow through Chitwan National Park, this work updates the record incorporating the variations caused by time and the fishing gear. The first set of sampling was done using a backpack electrofishing gear between 2003 February to 2004 January and the second set was done in April –May 2007 using locally prepared nets and traps through the professional fishermen. 32 species of fish were captured from Narayani river in both the sampling, though with different assemblage and the fish diversity in Rapti river had much difference with 30 species in the first sampling using electric gear and 23 from the second using the local gear. Nevertheless, the compilation of the two gives more or less complete and latest fish diversity of those rivers and this information could be used for many purposes.

Key words: fish assemblage, Chitwan National Park, temporal variation, fishing gear, record update.

Introduction

Biota at any place is the product of evolutionary and biogeographic process (Karr, 1991; Westra, 1995). It means that the resident biota at any site varies according to the geographic region as well as in evolutionary time. In addition to these variations in the assemblage of the biota in time and space, sampling techniques and gears too play role in concealing the reality. In science it is often accepted that no single sampling techniques and gears are perfect to show a complete assemblage of biota at any given place. This paper tries to assess these differences in the fish assemblage of two important rivers, Narayani and Rapti flowing through Chitwan National Park and to compile the latest update. Either to initiate conservation programs or to start commercial production of any species of fish, a sound and through knowledge of its distribution, abundance, ecology and biology are the primary requirements. However, in Nepal this kind of studies are very limited due to various reasons. Nepal, with a huge amount of water resources and rich diversity of fish species, has a tremendous potential for fisheries development as well as enormous opportunity to develop fish base assessment techniques for different purposes.

The inland water resource of Nepal includes natural waters such as rivers, lakes and reservoirs, and also village ponds, marginal swamps and irrigated paddy fields and equals 818500ha (Khanal, 2001). Out of this, the network of rivers and streams, which are more than 6000 in number alone covers around 395000ha of surface. In total, the length of rivers and its tributaries in Nepal exceeds well past 45000 km mark. Similarly, a total of 182 species of fish belonging to 93 genera under 31 families and 11 orders has been reported from Nepal (Shrestha, 2001). The high diversity of the species including fish in Nepal is mainly attributed to its unique location and spectacular geography. Some information on ecological and population characteristics of the fish, such as region and altitude of occurrence, habitat preference, temperature range, maximum length, feeding habit, life history and a crude status of many of the fish species are available. The list of fish species from very large as well as some important rivers from Nepal has been developed by various authors (Rajbanshi 1982, Talwar and Jhingran 1991, Shrestha 1990 and Shrestha 1994). However, these works appear sporadically and clearly lacks a follow-up.

Thus, this work tries to compare the fish assemblage sampled by electrofishing gear in 2003 (Jha 2006) with that of traditional methods in 2007 (Shrestha 2007) to show temporal and sampling technique base variations and to update the assemblage information which could be used in utilization, conservation, management and monitoring of both the water and fisheries resources of Nepal. The present work is based on primary data collected from the fieldwork and the main objectives of this work are (1) to describe the species number and composition of fish in specified rivers, (2) to see if there are any temporal and gear based variations in the species composition in the specified rivers, (3) and to update the information on fish base assemblage of those rivers.

Methods

In 2007 an intensive fish sampling was done by using traditional gear such as local fish nets in rivers Narayani and Rapti and the assemblage was found to be substantially different from the sample taken by electrofishing gear in the same rivers in 2003.The main strategy of this paper is to compare the

original work of the author done in 2003 and 2007 to study the temporal and gear based variations of fish assemblage in rivers Narayani and Rapti and to update the information. Since this work is a comparison of two samplings on different dates and by different gears, the methodologies of two are described separately.

Samplings done in 2003 by using electrofishing gear

The first round of research work was done for an academic purpose and its sampling of fish assemblage was done in 2003. Fish sampling was done using electro fishing gear and this could be the beginning of the application of electro fishing gear for fish sampling in Nepal, as there very few records. The method followed here was a simple but standard wading type with a person carrying a backpack electro-fishing unit. He was assisted by two persons each carrying a long dip nets to collect the shocked fish and a third person carrying a bucket to empty the nets. For the safety, the persons involved in fishing were insulated by a long wading boots.

There were altogether five sampling sites, three in Narayani and two in Rapti rivers. In each site, the fish sampling was done in two runs, 1 and 2 respectively. The stretch of each sampling site was mostly between 50 to 100 meters. The time for each run were tried to be fixed around 20 minutes and was never less than 30 minutes for the total of run 1 and 2 in any of the sample in all seasons. Consistent sampling design for each site was applied to avoid biased results.

After the first sampling in the spring, replicate of it were taken corresponding to all major seasons. With 5 sites and four replicate of these, there are altogether 20 samplings that constitute this work. Many of the fish species were identified in the fieldwork itself with the help of number of keys (Rajbanshi 1982; Shrestha 1994, 1995; Talwar and Jhingran 1991) and the local people. Some unidentified species were preserved in 10% formalin and were latter identified with the generous help of the experts.

Samplings done in 2007 by using traditional gears such as nets

In this research work there were 6 sampling sites, 3 each in Narayani and Rapti rivers. Here, the local fishermen were selected and hired for whole day for sampling in each site. The common fishing gears used were cast net, gillnet, tiyari, dhadiya or khunga, which are available locally. In fact gillnets are so common that almost all fishermen own that. Boat was also used for fishing in Narayani but not in Rapti River as it is shallower.

As in 2003 sampling, this time too, many of the fish species were identified in the fieldwork itself with the help of number of keys and the local people. Some unidentified species were preserved in 10% formalin and were latter identified with the generous help of the experts.

Results

The results of this study showed an interesting and clear temporal and sampling gear based variations of the fish assemblage between the 2003 and 2007 samplings. The total of 32 species of fish belonging to 4 orders and 10 families were captured from river Narayani during 2003 samplings (Table 1 and 2). Similarly 6 orders, 13 families and 32 species were recorded from 2007 samplings. Though the numbers of species on both occasions were same, the composition of the assemblage was very different. Figures 1 shows the fish orders and number of fish species on two different samplings in Narayani.

In terms of order it is simply an addition of 2 new orders Beloniformes and Osteoglossiformes in the recent sampling to the previous list of Cypriniformes, Perciformes, Siluriformes and Synbranchiformes but this difference at the level of order is a huge difference. At family level there was clear visible variations both in terms of number and composition as there were only 10 fish family during 2003 sampling but 13 in 2007 and 6 of the new family were not recorded in 2003 while 3 of the previous family were not captured in 2007 (Table 2).

Though the species number was identical in both the samplings, it is interesting to note that the composition of the assemblage was significantly different. In both occasions the total numbers of species was 32 but between them only 16 were common. It means only 50% of species were common between these two samplings and this seems a big change (Table 3).

Table 1: Fish orders in 2003 and 2007 samplings.

Number of order		Number of order	
2003 - Rapti	2007 - Rapti	2003 - Narayani	2007 - Narayani
Cypriniformes	Beloniformes	Cypriniformes	Beloniformes
Perciformes	Cypriniformes	Perciformes	Cypriniformes
Siluriformes	Perciformes	Siluriformes	Osteoglossiformes
Synbranchiformes	Siluriformes	Synbranchiformes	Perciformes
	Synbranchiformes		Siluriformes
			Synbranchiformes
4	5	4	6

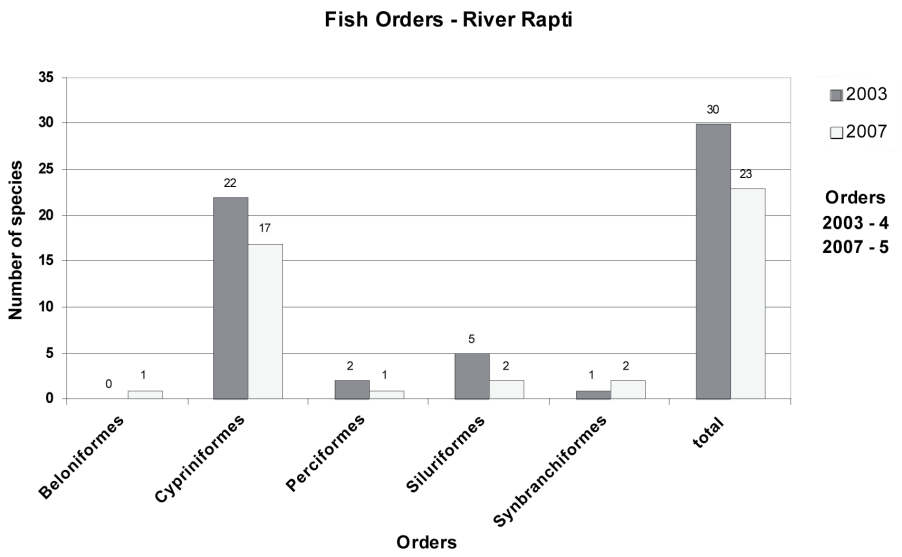

Figure 1: Fish orders in 2003 and 2007 samplings

River Rapti too highlights the temporal and sampling gear based variations in fish assemblage. In terms of fish orders 2007 sampling recorded 5 orders an addition of Beloniformes to the list of Cypriniformes, Perciformes, Siluriformes and Synbranchiformes recorded in 2003 (Table 1 and Figure 2). Remarkably there were more fish families in 2003 at 10 compared to 8 in 2007 samplings. Out of these 5 families from 2003 were not recorded in 2007 and 3 from 2007 were not recorded in 2003, showing a significant variations in composition of the assemblage (Table 4).

The numbers of species recorded from Rapti River in two samplings were also visibly different at 30 and 23 in 2003 and 2007 respectively (Table 5). Moreover only 9 species were common between the two samplings indicating that the effect of time and sampling gear is significant in the samplings.

In total, when the records of both these samples were combined Narayani River was found to be holding 6 fish orders, 16 families, 34 genera and 48 fish species (Table 3). Similarly Rapti River was found harboring 5 fish orders, 13 families, 30 genera and 44 fish species when the records of two samplings were combined (Table 5). This should be the latest fish assemblage update of these two important rivers that flow through one of the most important protected area of the country.

Table 2: Fish families in 2003 and 2007 samplings – Narayani.

2003 - Narayani family	2007 - Narayani family	Differences family	Total family
Amblycipitidae	Ambassidae	Ambassidae - 2007	Ambassidae
Balitoridae	Amblycipitidae	Bagridae -2007	Amblycipitidae
Channidae	Bagridae	Belonidae - 2007	Bagridae
Cobitidae	Balitoridae	Channidae - 2003	Balitoridae
Cyprinidae	Belonidae	Mastacembelidae - 2003	Belonidae
Gobiidae	Cobitidae	Nandidae - 2007	Channidae
Mastacembelidae	Cyprinidae	Notopteridae - 2007	Cobitidae
Psilorhynchidae	Gobiidae	Psilorhynchidae - 2003	Cyprinidae
Schilbeidae	Nandidae	Synbranchidae - 2007	Gobiidae
Sisoridae	Notopteridae		Mastacembelidae
	Schilbeidae		Nandidae
	Sisoridae		Notopteridae
	Synbranchidae		Psilorhynchidae
			Schilbeidae
			Sisoridae
			Synbranchidae
10	13	9	16

Table 3: Fish species in 2003 and 2007 ssamplings – Narayani.

2003 - Narayani	2007 - Narayani	Difference - Narayani	Difference - Narayani	Narayani
species	species	2003	2007	Common species
Acanthocobitis botia	*Amblyceps mangois*	*Acanthocobitis botia*	*Monopterus cuchia*	*Amblyceps mangois*
Amblyceps mangois	*Monopterus cuchia*	*Barilius barila*	*Aorichthys seenghala*	*Aspidoparia morar*
Aspidoparia morar	*Aorichthys seenghala*	*Barilius shacra*	*Badis badis*	*Barilius bendelisis*
Barilius barila	*Aspidoparia morar*	*Botia almorhae*	*Barilius barna*	*Barilius vagra*
Barilius bendelisis	*Badis badis*	*Channa orientalis*	*Chagunius chagunio*	*Botia lohachata*
Barilius shacra	*Barilius barna*	*Channa punctatus*	*Cirrhinus reba*	*Brachydanio rerio*
Barilius vagra	*Barilius bendelisis*	*Lepidocephalus guntea*	*Danio devario*	*Clupisoma garua*
Botia almorhae	*Barilius vagra*	*Mastacembelus armatus*	*Glyptothorax pectinopterus*	*Crossocheilus latius*
Botia lohachata	*Botia lohachata*	*Neolissochilus hexagonolepis*	*Labeo calbasu*	*Garra gotyla*
Brachydanio rerio	*Brachydanio rerio*	*Psilorhynchus pseudecheneis*	*Mystus bleekeri*	*Glossogobius giuris*
Channa orientalis	*Chagunius chagunio*	*Puntius conchonius*	*Mystus tengara*	*Glyptothorax telchitta*
Channa punctatus	*Cirrhinus reba*	*Puntius sophore*	*Chitala chitala*	*Glyptothorax trilineatus*
Clupisoma garua	*Clupisoma garua*	*Schistura rupecula*	*Chanda nama*	*Labeo dero*
Crossocheilus latius	*Crossocheilus latius*	*Schizothorax richardsonii*	*Pseudecheneis sulcatus*	*Nemacheilus corica*
Garra gotyla	*Danio devario*	*Semiplotus semiplotus*	*Puntius ticto*	*Schistura beavani*
Glossogobius giuris	*Garra gotyla*	*Tor putitora*	*Xenentodon cancila*	*Tor tor*
Glyptothorax telchitta	*Glossogobius giuris*			
Glyptothorax trilineatus	*Glyptothorax pectinopterus*			
Labeo dero	*Glyptothorax telchitta*			
Lepidocephalus guntea	*Glyptothorax trilineatus*			
Mastacembelus armatus	*Labeo calbasu*			
Nemacheilus corica	*Labeo dero*			
Neolissochilus hexagonolepis	*Mystus bleekeri*			
Psilorhynchus pseudecheneis	*Mystus tengara*			
Puntius conchonius	*Nemacheilus corica*			
Puntius sophore	*Chitala chitala*			
Schistura beavani	*Chanda nama*			
Schistura rupecula	*Pseudecheneis sulcatus*			
Schizothorax richardsonii	*Puntius ticto*			
Semiplotus semiplotus	*Schistura beavani*			
Tor putitora	*Tor tor*			
Tor tor	*Xenentodon cancila*			
32	32	16	16	16

Total species: 16 + 16 + 16 = 48

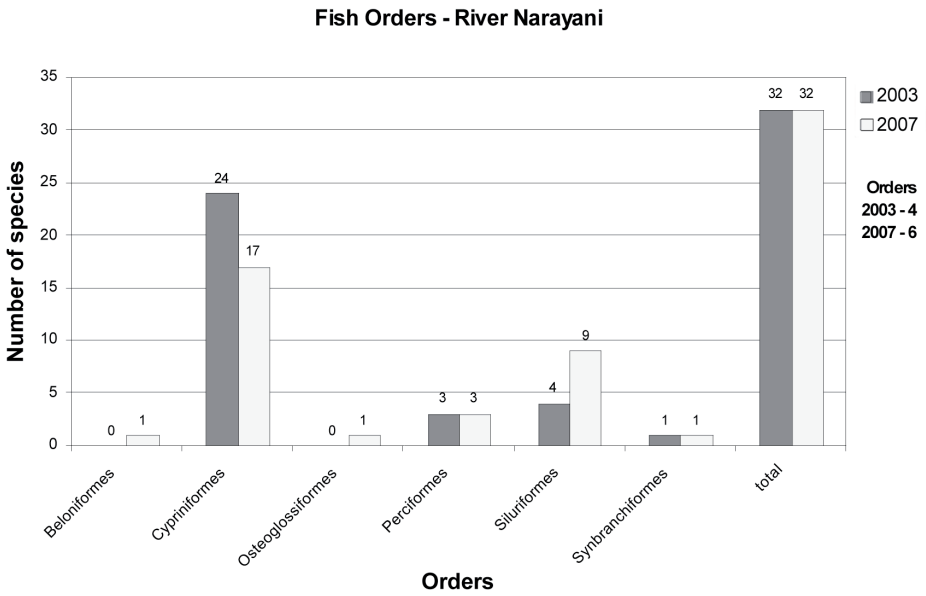

Figure 2: Fish orders in 2003 and 2007 samplings.

Table 4: Fish families in 2003 and 2007 samplings – Rapti.

2003 - Rapti	2007 - Rapti	Differences	Total
Family	Family	Family	Family
Amblycipitidae	Ambassidae	Amblycipitidae -2003	Ambassidae
Balitoridae	Bagridae	Channidae - 2003	Amblycipitidae
Channidae	Balitoridae	Gobiidae - 2003	Bagridae
Cobitidae	Belonidae	Heteropneustidae - 2003	Balitoridae
Cyprinidae	Cobitidae	Psilorhynchidae - 2003	Belonidae
Gobiidae	Cyprinidae	Ambassidae - 2007	Channidae
Heteropneustidae	Mastacembelidae	Bagridae - 2007	Cobitidae
Mastacembelidae	Sisoridae	Belonidae - 2007	Cyprinidae
Psilorhynchidae			Gobiidae
Sisoridae			Heteropneustidae
			Mastacembelidae
			Psilorhynchidae
			Sisoridae
10	8	8	13

Discussion

The fish assemblage comparison of two important rivers Narayani and Rapti that flows through Chitwan National Park produced an amazing and interesting results and their compilation is perhaps the most complete list ever produced in terms of primary information. The variation in temporal assemblage of fish species is well known. It is said that even a day and night assemblage differs with each other. Seasonal variation of the fish composition of a river is also well established and is attributed to their biological and ecological traits such as feeding and reproduction. In addition, the variations of assemblage over a couple of years could be attributed to evolutionary and accelerated global climatic changes. This work compares the primary work of Jha (2006) where the fish sampling had been made in 2003 with the help of back-pack electro-fishing gear and Shrestha (2007) in which the sampling was done by using traditional gear such as cast nets and that too by local fishermen. Thus, there are both temporal differences as well as in the sampling gears and techniques. Spatiotemporal and gear related variations of fish assemblage has been worked out by many with significant results (Winemiller 1990, Pusey et al. 1993, Taylor et al. 1996, Morgan 2002, Cook et al. 2004, Meador and McIntyre 2003, Magill and Sayer 2002 and Kennard et al. 2006). The results of all those works have invariably shown that the fish assemblage

Table 5: Fish species in 2003 and 2007 samplings – Rapti.

2003 - Rapti	2007 - Rapti	Difference - Rapti	Difference - Rapti	Rapti
species	species	2003	2007	Common species
Acanthocobitis botia	*Acanthocobitis botia*	*Amblyceps mangois*	*Amblypharyngodon mola*	*Acanthocobitis botia*
Amblyceps mangois	*Amblypharyngodon mola*	*Barilius shacra*	*Barilius barna*	*Aspidoparia morar*
Aspidoparia morar	*Aspidoparia morar*	*Botia almorhae*	*Barilius jalkapoorei*	*Barilius barila*
Barilius barila	*Barilius barila*	*Botia lohachata*	*Chagunius chagunio*	*Barilius bendelisis*
Barilius bendelisis	*Barilius barna*	*Channa orientalis*	*Danio devario*	*Barilius vagra*
Barilius shacra	*Barilius bendelisis*	*Crossocheilus latius*	*Gagata sp.*	*Labeo dero*
Barilius vagra	*Barilius jalkapoorei*	*Garra annandalei*	*Macrognathus pancalus*	*Lepidocephalus guntea*
Botia almorhae	*Barilius vagra*	*Garra gotyla*	*Mystus tengara*	*Mastacembelus armatus*
Botia lohachata	*Chagunius chagunio*	*Glossogobius giuris*	*Osteobrama cotio*	*Puntius conchonius*
Channa orientalis	*Danio devario*	*Glyptothorax pectinopterus*	*Parrambassis ranga*	
Crossocheilus latius	*Gagata sp.*	*Glyptothorax telchitta*	*Puntius chola*	
Garra annandalei	*Labeo dero*	*Glyptothorax trilineatus*	*Puntius ticto*	
Garra gotyla	*Lepidocephalus guntea*	*Heteropneustes fossilis*	*Tor tor*	
Glossogobius giuris	*Macrognathus pancalus*	*Nemacheilus corica*	*Xenentodon cancila*	
Glyptothorax pectinopterus	*Mastacembelus armatus*	*Neolissochilus hexagonolepis*		
Glyptothorax telchitta	*Mystus tengara*	*Psilorhynchus pseudecheneis*		
Glyptothorax trilineatus	*Osteobrama cotio*	*Puntius sophore*		
Heteropneustes fossilis	*Parrambassis ranga*	*Schistura beavani*		
Labeo dero	*Puntius chola*	*Schistura rupecula*		
Lepidocephalus guntea	*Puntius conchonius*	*Schizothorax richardsonii*		
Mastacembelus armatus	*Puntius ticto*	*Tor putitora*		
Nemacheilus corica	*Tor tor*			
Neolissochilus hexagonolepis	*Xenentodon cancila*			
Psilorhynchus pseudecheneis				
Puntius conchonius				
Puntius sophore				
Schistura beavani				
Schistura rupecula				
Schizothorax richardsonii				
Tor putitora				
30	*23*	*21*	*14*	*9*

Total species: 21 + 14 + 9 = 44

vary in space, time and sampling techniques. This indicates that to gauge a complete composition of fish species of any rivers the number of sites, seasons and multiple gears are the prerequisite. Therefore, this work is a pioneer work in this regard. The result of this work has shown that the fish assemblage has differed tremendously between 2003 and 2007 and this could be because of the different gears used in those two samplings and also may be due to the pronounced climatic and habitat changes associated with the temporal change. Some of the earlier studies in the river Narayani have shown different figures on the composition of fish species. Some early studies reported 62 species from Gandak River system of Chitwan Valley, whereas Shrestha (1990) described 57 species from river Narayani and Rapti. Edds (1986) first reported 113 native fish species from the water of Chitwan National Park and then latter (1993) came up with 107 species.

Shrestha (1999) reported 35 species from this river, but then they were mentioned as coldwater species. Rajbanshi (2001) has mentioned around 47 species in this river but there is no discrimination between coldwater and warm water species. Similarly, Swar (2001) has also mentioned 35 species from this river as coldwater species.

Some of those figures are very close to the study of Jha (2006) where 32 species were described, but many earlier studies have a highly inflated numbers including that of Bhusal (2003). This may be because many studies were base upon exaggerated secondary information. Another reason for high species number is perhaps due to the unwillingness to update the synonyms as mentioned in widely accepted fish base information pool (www.fishbase.org). The most recent primary work in this regard by Shrestha (2007) has also reported 32 species from this river but assemblage is drastically different. This proves multiple sampling gears are required to obtain the complete information of fish species and that too incorporating temporal dimension.

River Rapti has been relatively less worked out. Dhital and Jha (2002) collected 69 species from this river and Rajbanshi (2001) has listed 41 species. Once again these figures are much higher than Jha (2006) where 30 species were recorded and the higher figure obtained in other works is based on secondary information or at least scientific sampling techniques applied have not been described. However, the list of Jha (2006) from this river has been complemented by Shrestha (2007), where only 23 species have been described but remarkably different composition. This variation in composition too highlights the temporal and gear based variations in fish assemblage, which is on many occasion ignored but is significant.

The composition of fish species obtained in this work for these two rivers should be very much near the true assemblage of fish as it has applied two different gears and incorporated the temporal dimension. 48 species for river Narayani and 44 for Rapti is the strictly scientific outcome of this work and should merit over many other list lacking scientific sampling techniques and based upon secondary information. This kind of true list has a wide range of application in utilization, conservation, monitoring, and developing tools in the overall management of the fisheries as well as water resources.

Conclusions

It is a well established fact that fish species assemblage varies in space, time and sampling techniques. This work has also proved this fact by comparing the 2003 and 2007 samplings, which has a significant time interval and different methods of samplings and as such different assemblages. In one hand the variations in assemblage of these two samplings were significantly visible on the other hand the compilation of the two has also given a more complete list of the species as these are based on scientific and primary information. 48 species for river Narayani and 44 for Rapti is perhaps the nearest to the reality in those areas. Such information could be replicated to the other rivers as well and would serve a variety of purpose.

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Effects on population density and mercury concentration in the northern pike (Esox lucius) in Lake Årungen after manipulation of a top predator

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Abstract

This paper deals with manipulation of a top predator fish in Lake Årungen, the northern pike (Esox lucius L.), and its impacts on the density and mercury concentrations in the muscle tissue. The experimental manipulation of the pike population was initiated in 2004, with an extensive removal of large pike (> 65 cm). The relative abundance of small pike increased significantly in 2005 and 2006 compared to the pre-manipulation period. Such an increase in the number of small pike is attributed to the reduced predation by large-sized pike. In addition, increased abundance of pike in the open water area, after the manipulation of its population, also indicates that small pike got good feeding condition after the removal of large pike. The mercury concentrations in muscle tissues of pike were significantly lower in 2005 compared to 2003. We observed faster growth rate of pike after the manipulation. The faster growth rate of pike might have played a major role in the reduced mercury concentrations in the remaining pike population through growth biodilution. This gives an indication that the removal of large-sized top predators, such as pike, could be an indirect method to reduce the mercury concentrations in fish.

Key words: cannibalism, bioaccumulation, growth rates, biodilution, food web.

Introduction

A large proportion of young age classes of fish in a lake may be consumed by piscivorous fish (Popova 1978; Tonn et al. 1992; Paukert & Willis 2003; Svenning & Borgstrøm 2005). Some piscivores, such as pike, may also exhibit cannibal-driven dynamics to structure its population (Le Cren 1965; Kipling 1983; Giles et al. 1986; Bry et al. 1992; Grønkjær et al. 2004). Generally, fisheries are directed towards the exploitation of larger and older fish (Pierce et al. 1995; Craig 1996) that favors the small ones (Carlson et al. 2007). Although environmental factors play an important role in structuring pike population (Hassler 1970; Kipling 1984), removal of larger pike may result in increased year-class strength of young pike due to reduced cannibalism (Casselman & Harvey 1975; Mosindy et al. 1987).

The mercury (Hg) content in the environment has risen far above the natural level due to global anthropogenic activities (Johnels et al. 1967; Fjeld et al. 1994; Swain et al. 2007). The atmospheric deposition of Hg is highly correlated to its concentration in fish (Fjeld & Rognerud 1993). The main toxic (neurotoxic) and bioavailable form of Hg in fish is methyl mercury (MeHg), and virtually all (> 95 %) of the total mercury (THg) is found in the form of MeHg in fish (Bloom 1992; Clarkson 1993; Watras et al. 1998; Kidd 1998). The MeHg bioaccumulates and biomagnifies up the food chain (Cabana et al. 1994; Watras et al. 1998), and in freshwaters, maximum values are found in top predator fish species (Clarkson 1993; Kidd et al. 1995; Bowles et al. 2001; Lockhart et al. 2005), such as pike. On the other hand, fast growth rate of a fish tends to decline the concentration of THg in the muscle tissue (Kidd et al. 1999; Cizdziel et al. 2002; Campbell et al. 2003).

Many studies have described Hg variations in fish tissues on the basis of physico-chemical conditions in the lakes, for example, reduced pH enhances Hg uptake by fish (Wren & MacCrimmon 1983; Watras et al. 1998); Hg concentrations in fish is positively correlated with the dissolved organic carbon (McMurtry et al. 1989; Watras et al. 1998; Belger & Forsberg 2006). Biological factors, especially food web structure, are considered important in explaining the variation of Hg concentrations in and between organisms (Rask & Metsälä 1991; Vander Zanden & Rasmussen 1996; Gorski et al. 2003). Isotopes of nitrogen ($^{15}N/^{14}N = \partial^{15}N$) and carbon ($^{13}C/^{12}C = \partial^{13}C$) can be used to define the relative trophic positions of organisms and to determine the source and flow of carbon through a food web respectively (Cabana & Rasmussen 1994; Campbell et al. 2006).

Manipulation of fish population in a lake is generally targeted to increase the lake clarity by increasing the dominance of piscivore fish so as to reduce the planktivorous and benthivorous fishes (mainly cyprinid fishes) leading to an increased dominance of zooplankton that can efficiently graze upon phytoplankton (Langeland 1982; Shapiro & Wright 1984; Jeppesen et al. 1997; Søndergaard et al. 2000). However, few mitigation measures have been available in lakes with high levels of Hg in top predator fish species, especially in lakes

without any point source for Hg pollution. Some of the previous studies have demonstrated that the change in Hg concentrations is evident in the remaining fish community after extensive exploitation of fish biomass in lakes (Göthberg 1983; Verta 1990; Surette et al. 2006). The purpose of the present study was to examine the effects of extensive exploitation of large-sized pike on density, individual growth rates and Hg concentrations in the remaining pike population. To accomplish this, a whole-lake experiment was initiated in Lake Årungen during pike spawning in May 2004, with an extensive removal of large pike that continued in May 2005 and 2006 (Sharma & Borgstrøm 2008a; Sharma et al. 2008).

Methods

Study area

Lake Årungen, situated in the southeastern part of Norway, is a eutrophic lake with an average depth of 8.1 m (Skogheim & Abrahamsen 1980). The 52 km^2 catchment area is mainly dominated by the agricultural and forest area which is drained into the lake through five main tributaries (Fig. 1).

The major fish species in the lake are roach [*Rutilus rutilus* (*L.*)], perch (*Perca fluviatilis L.*), and pike. In addition, rudd (*Scardinius erythrophthalmus*), tench (*Tinca tinca*), European eel (*Anguilla anguilla*), and Crucian carp (*Carassius carassius*) are other fish species recorded in Lake Årungen. Based on

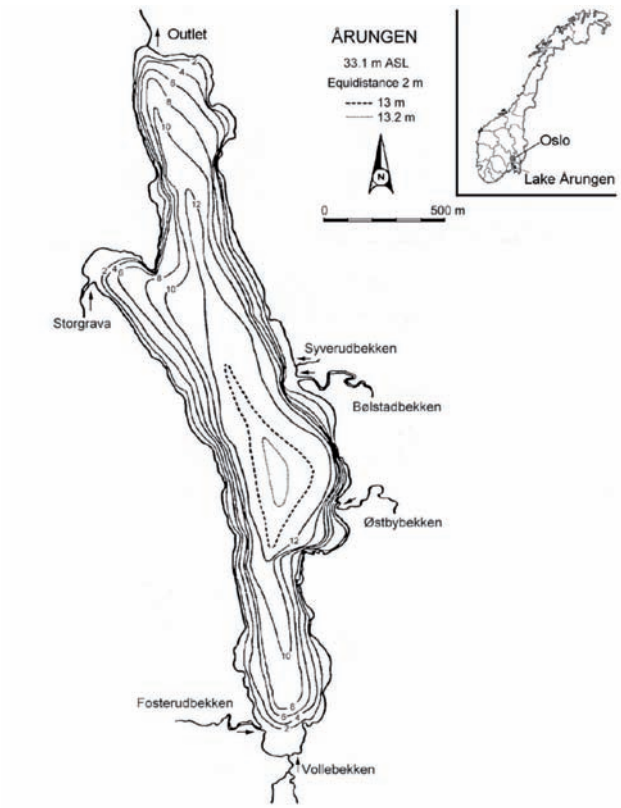

Figure 1: Map of Lake Årungen (redrawn after Skogheim & Abrahamsen 1980). The lake is situated in southeastern part of Norway.

the number of fishermen, the recreational angling may have increased recently in Lake Årungen, with up to 40 fishermen observed simultaneously in May-June 2004-06.

The pollution to the lake originates mainly from the agricultural runoff and municipal discharges. Total phosphorus (TP) in Lake Årungen has decreased considerably in the period from 1976 to 1985 and has been maintained below 55µg TP/liter due to change in the agriculture practice, e.g. less autumn ploughing (Yri 2003). At present, there are no point sources of mercury to the lake. The stomach content analysis as well as the $\partial^{15}N$ signatures indicated that pike was at the top level on the food web of Lake Årungen (Sharma et al. 2008).

Experimental removal of large pike

Although some extensive recreational fishing was carried out in Lake Årungen time to time by fishermen, the reliable statistics of these events are lacking. The experimental manipulation of pike population in the lake began in 2004 by using gillnets of large mesh sizes (mainly 52 mm from knot to knot) aiming to remove the large individuals (≥ 65 cm). The removal of large-sized pike continued until May 2006. A total of 547, 314, and 337 pike were removed in 2004, 2005 and 2006 respectively. In total, a biomass of 2237 kg of pike was removed from the lake, of which approximately 65 % was contributed by pike ≥ 65 cm.

Population estimations

Mark and recapture method was performed to estimate the pike population. Pike were marked with numbered Floy anchor tags during the spawning period at the end of April and beginning of May during 2004-06. Gillnets were set just outside the vegetation belt and pike were forced to move towards the nets by disturbing them with boat and oars. The nets were lifted immediately and pike were stored in small tanks for few minutes before they were tagged just below the dorsal fin. Pike were recaptured with the main effort during the last part of May, and the recapture was continued during rest of the year. The mark and recapture of pike was performed all around the littoral areas of the lake.

The number of pike was estimated by Chapman's modified Petersen method (Ricker 1975), with following equation:

$$\hat{N} = \left[\frac{(M+1)(C+1)}{R+1} \right] \quad (1)$$

Where, is the population estimate, M is the number of marked pike, C is the number of pike in controlled fishing, and R is the number of recaptured pike in controlled fishing. The annual mortality rate (A) was determined after calculating the annual survival rate (S) using the formula A = 1 – S (Ricker 1975). The annual survival rate of pike during the

Table 1: Number of tagged, controlled, and recaptured pike > 45 cm during 1980 - 83 and 2004 - 06, with corresponding estimated numbers of pike with confidence limits (0.95), mortality rates due to the experimental exploitation, total biomass, and average weight (After: Sharma & Borgstrøm 2008b).

Year	Length-class (cm)	Number tagged (M)	Number examined for tags (C)	Number recaptured (R)	Estimated number (N)	Confidence limits (0.95)	Mortality due to experimental exploitation	Total biomass (kg)	Average weight (kg)
2004	45.0-64.9	103	243	39	634	467-884	0.38	2257	2.02
	65.0-103.9	142	304	89	485	395-595	0.63		
2005	45.0-64.9	186	248	30	1502	1063-2196	0.17	1790	1.10
	65.0-86.9	35	66	19	121	79-193	0.55		
2006	45.0-64.9	185	170	19	1590	1039-2544	0.11	2503	1.35
	65.0-85.9	33	167	21	260	172-406	0.64		

year 1 (2004-05) and year 2 (2005-06) were calculated by using the following formula (Ricker 1975).

$$S_1 = \frac{R_{12} M_2}{M_1 R_{22}} \qquad (2)$$

Where, S_1 is the survival rate during year 1; M_1 is the number fish marked at the start of the first year; M_2 is the number of fish marked at the start of the second year; R_{12} is the recaptures of first-year marks in the second year; and R_{22} is the recaptures of second-year marks in the second year.

Pike diet analysis

Stomach contents were analyzed to find out the main food items of pike. Total length of pike as well as the biomass of prey fish species was measured to the nearest mm and g respectively. Out of 337 pike dissected, 37 pike had prey-fish in their stomachs that could be measured.

Annual length increment of pike

Backcalculated length of individual pike at 1+, 2+, 3+, and 4+ ages was used to determine the size-class of pike at these ages. The backcalculation was performed with the method described by Sharma & Borgstrøm (2007). The annual length (mm) increment for these age-classes was calculated based on the difference in length in year t+1 and year t during the period 2001 to 2005.

Sampling and analysis of THg

Sampling of pike (n = 66 in 2003; n = 34 in 2005) for the analysis of THg was done by gillnetting. Muscle tissues for the analysis were collected by the standard procedure following EMERGE protocol (Rosseland et al. 2003). Total length (LT) of pike was measured to the nearest mm. Pike sex was determined by the visual examination of gonads. Metapterygoid bones were used for the age determination and backcalculation of the total length at age (Sharma & Borgstrøm 2007). The analysis of THg (wet weight, ww) was carried out by using the Perking-Elmer model FIMS 4000 Flow Injection Mercury System at the Environmental Chemistry Section, Norwegian University of Life Sciences. Anton paar microwave oven was used for dissolution of fish muscles. The calibration curves of four different synthetic standards were used to calibrate the equipment. The DORM-2 (piked dog-fish, *Squalus acanthias L.*), certified reference material of National Research Council of Canada, Ottawa, was used to control the accuracy of the method. The blanks were used and were corrected against the sample values (see also Desta et al. 2006).

Statistical analyses were performed in MINITAB release 14 and SigmaStat 3.0.1 software. THg concentrations were log-transformed after detecting the skewed distribution in the original data. Comparison of THg concentrations during pre- and post-manipulation were performed by ANCOVA (statistic F) using the total length as the covariate. THg concentrations in pike between 2003 and 2005 from the same age-group were compared by Mann-Whitney Test. Difference in the annual length increment of 1+ to 3+ pike from 2001 to 2005 were tested by Kruskal-Wallis test and the pair-wise comparison was done by Dune's method. All the comparisons and relationships were considered statistically significant at $p < 0.05$.

Results

Population size and structure

Total estimated number of pike (> 45 cm) increased from 1119 in 2004 to 1623 in 2005 and reached 1850 in 2006. There was a significant increase in the number of pike in length-class 45-64.9 cm in 2005 compared to 2004 ($H = 17.112$, $df = 2$, $p < 0.001$) with further higher number in 2006 (Table 1; Fig. 2). The pike ≥ 65 cm, on the other hand, declined significantly in 2005 compared to 2004 ($H = 19.535$, $df = 2$, $p < 0.001$) due to the experimental exploitation of large pike. However, a small increase in the number of pike ≥ 65 cm was observed from 2005 to 2006.

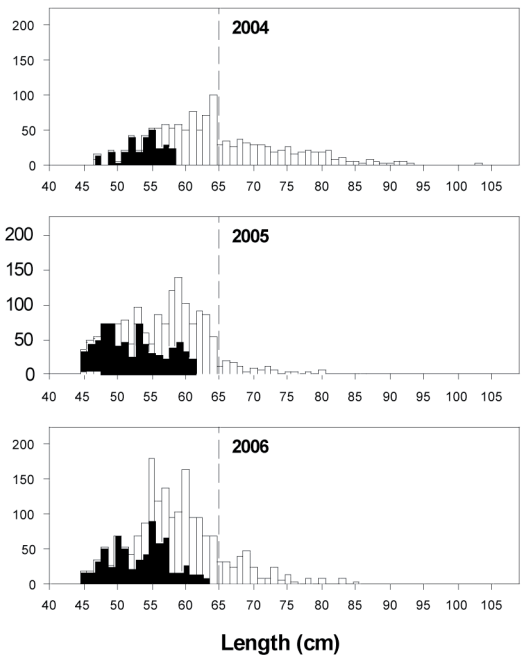

Figure 2: Length distribution of pike (> 45 cm) in Lake Årungen during April/May 2004-06. Black bars indicate 3+ years' pike. (After: Sharma et al. 2008).

Mortality rates

The annual mortality rates of pike (> 45 cm) from 2004 to 2005 and from 2005 to 2006 were 0.86 and 0.56, respectively (Table 2). The experimental exploitation rate of large pike was more than 55 % in 2004-06; however, the exploitation rate of small pike declined gradually from 2004 to 2006 (38 % to 11 %; Table 1).

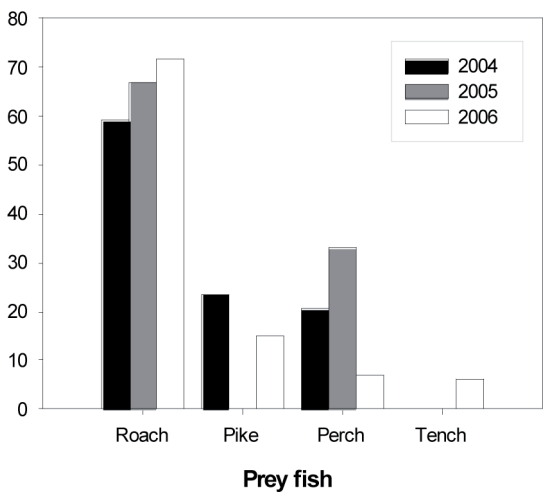

Figure 3: Weight (%) of prey-fish in the stomach contents of pike in Lake Årungen during 2004-06 (After: Sharma & Borgstrøm 2008b).

Table 2: Annual mortality rates of pike from 2004 to 2005 and from 2005 to 2006 based on the number of tagged and recaptured pike in different years. The symbols used in the table are described in the equation (2) (After: Sharma & Borgstrøm 2008b).

Period	M1	M2	R12	R22	Annual mortality rate (A)
2004-05	245	221	7	49	0.87
2005-06	221	218	18	40	0.56

Diet of pike

It was revealed that pike was an exclusively piscivore, feeding mainly on roach, perch, and some small (mainly 2+ age) pike in Lake Årungen. In 2006, tench was also recorded in the stomach contents of pike. Roach was the main prey fish species of pike that constituted ca. 79 % of the diet in number during 2005-06. If we consider biomass consumption, pike was the second dominant food item in terms of weight in the years 2004 and 2006 (Fig. 3).

Pike growth rates

Annual length increment of pike was significantly higher in 2005 compared to 2003 for 1+ (Kruskal-Wallis Test: $H = 19.917$; $df = 4$; $p < 0.001$), 2+ ($H = 44.411$; $df = 4$; $p < 0.001$), and 3+ pike ($H = 40.976$; $df = 4$; $p < 0.001$). It was also observed that 2+ and 3+ pike had significantly faster growth rates in 2005 compared to the previous years (2001-04) as indicated by Dunn's all pair-wise comparison method ($p < 0.05$; Fig 4).

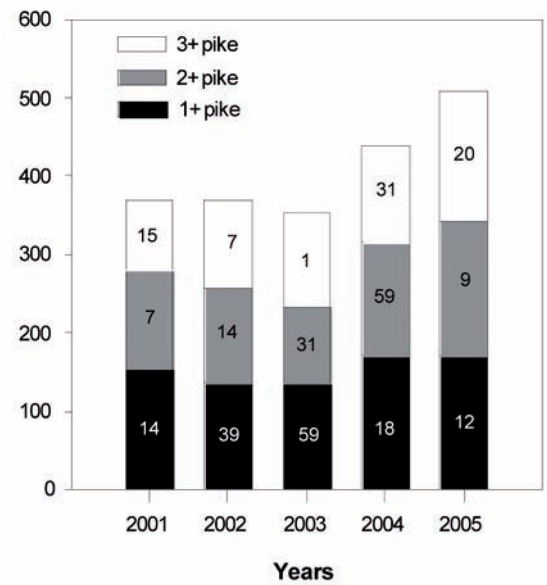

Figure 4: Annual increment of total length of pike at different age-classes (1+ to 3+) based on the difference in mean total length in year t+1 and year t during the period 2001 to 2005. Number inside bar indicates the sample size for corresponding age-classes. (After: Sharma et al. 2008).

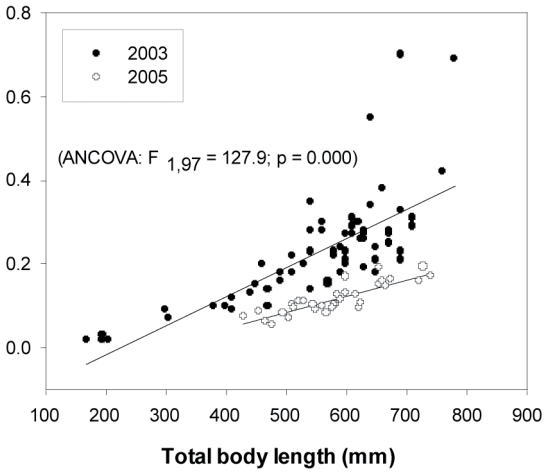

Figure 5: THg concentrations in muscle tissue of pike in 2003 and 2005. The comparison was performed by ANCOVA by using total body length as the covariate. (After: Sharma et al. 2008).

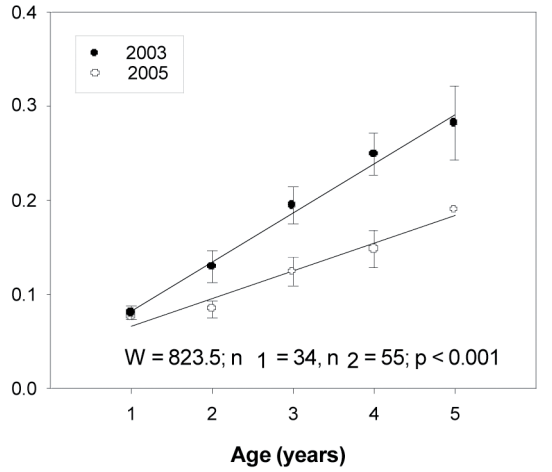

Figure 6: THg concentrations in pike muscles in 2003 and 2005 for the same age-classes. Range of the error bar represents 1-standard deviation on the mean value of THg for respective ages. (After: Sharma et al. 2008).

THg concentrations: 2003 vs. 2005

A significantly lower THg concentrations was observed in pike in 2005 compared to 2003 (ANCOVA: F1,97 = 127.9; p = 0.000; Fig. 5). In pike between 1-5 years, a significantly lower THg concentrations were observed in 2005 compared to 2003 (Mann-Whitney Test: W = 823.5; n1 = 34, n2 = 55; p > 0.001; Fig 6).

Discussion

Biotic factors, especially the density-dependent factors, play a major role in determining fish population density (Le Cren 1965). Cannibalism is one of these factors, proposed to play an important role in regulating fish population structure in lakes (Le Cren 1965; Kipling 1984; Svenning & Borgstrøm 1995). The number of one-year-old and two year old pike seems to be controlled by cannibalism (Le Cren 1965; Persson et al. 2006), and even a very low rate of cannibalism can have a significant effect upon mortality, depending on the age composition of the population (Le Cren 1965; Fox 1975). All the victims of cannibal pike in Lake Årungen during 2004 and 2006 were two-year-olds. Thus, the significant increase in the number of three-year-old pike from the spawning period in 2004 to the spawning period in 2005 could be due to a reduced consumption of two-year-old pike after the heavy removal of large pike from the middle of May 2004. Similarly, continuous efforts to remove large pike after the spawning periods in 2005 and 2006 might have led to the larger proportion of three-year-old pike in 2006.

Although pike behaviour may vary across locations (Diana 1979; Jepsen et al. 2001), and utilise the habitat in an ideal free manner (Haugen et al. 2006), they may distribute spatially in a size-determined fashion to avoid intraspecific risks (Nilsson 2006). A study in the outlet of River Kajaaninjoki to Lake Sokajärvi in Finland indicated that small pike showed a lower movement rate compared to the large pike (Vehanen et al. 2006). Such a difference in the movement may be due to the fact that small and moderate-sized pike are restricted to vegetated areas in shallow waters (Grimm & Backx 1990), probably to avoid predation from larger pike. A 3-5 times higher CPUE in the pelagic and littoral habitats in Lake Årungen in summer 2005-06 compared to 1978-80, despite simply a doubling of the population number (Sharma & Borgstrøm 2008b), indicates a higher swimming activity of small pike, and a more free ranging behaviour in nearly absence of large pike.

Recreational angling can act as an effective mortality factor (Johnson & Martinez 1995), and angling can contribute to a large proportion of the pike harvest from a lake (Pierce et al. 1995; Pierce & Cook 2000). Although the mortality rate of pike in Lake Årungen due to the experimental exploitation efforts decreased from 2004 to 2006, the mortality rate due to other reasons was still high (~37 %). Since angling activities in Lake Årungen seem to have increased in recent years compared to the 1980s and 1990s, the additional mortality is probably due mainly to the recreational fishery. By introducing a minimum size limit for pike capture, a further increase in survival and recruitment of pike are expected, resulting in a higher total population number of pike. Extensive harvest of fish may reduce the bioavailable MeHg in a lake as explained by Verta (1990) in Lake Hakojärvi in southern Finland and Surette et al. (2006) in three lakes of Northern Québec. However, although the harvest of pike in Lake Årungen was high in 2004, this is probably a small biomass compared to the total fish biomass in the lake. The most plausible reasons for the decline in THg concentrations in pike from 2003 to 2005 may therefore be either biodilution due to increased growth rates, or a shift to a diet composed of less MeHg, for example a shift from benthos to more cladocerans, as observed in roach and perch in the lake (Sharma and Borgstrøm 2008a), might have reduced the level of THg in main prey fish species of pike as has been documented by Sharma et al. (2008).

Conclusions

Selective exploitation of large pike in Lake Årungen may have led to increased survival of small pike (mainly 2+ pike), giving a significantly higher number of pike > 45 cm, despite a very high annual fishing mortality. The high mortality rate of pike due to recreational fishing may reduce the potential for high predation rate on roach, i.e., the full effect of a pike manipulation experiment may not be obtained as long as no restrictions are set on the ordinary fishing activity, for example by introduction of a minimum size (around 65 cm) for pike capture. On the other hand, exploitation (manipulation) of the large-sized cannibal pike, i.e. the top piscivore, may be an important tool for reducing Hg concentrations in remaining fish populations, and thereby reducing health risk to humans.

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Effect of thermal effluent discharge on the macroinvertebrate abundance in the Sitalakhya River in Bangladesh

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Abstract

The River Sitalakhya bordering the southern part of Dhaka City is a branch of the River Brahmaputra. Two Combined Cycle Power Plants (CCPP) are situated on the banks of this river within a one kilometer stretch. These plants discharge the hot effluent at a distance downstream from their respective intake points. One power plant has a side-bank discharge and the other has a submerged port discharge. The cumulative effect of these thermal discharges has increased the temperature of the Sitalakhya River water. The effect is further compounded by the tidal nature of the Sitalakhya. A small scale macroinvertebrate sampling campaign was conducted in December 2007 covering the one kilometer stretch in the longitudinal direction of the Sitalakhya River. A Mixing-zone model was used to predict the nature of the thermal plume and the temperature of the water using the available hydrodynamic and meteorological data. Macroinvertebrate sampling was performed along five different transects of the river primarily covering the width of the plumes on the up and downstream of the discharge points. Water quality parameters, such as dissolved oxygen, temperature, electrical conductivity, biochemical oxygen demand, chemical oxygen demand, nitrate, orthophosphate and suspended solids were measured at two different depths along each transect. The physico-chemical data along with the macroinvertebrate sampling results were used to determine the ecological status of the Sitalakhya River along the sampled stretch.

Key words: water quality, pollution, bio-indicators, thermal plume.

Introduction

Water is the single most important resource for the well-being of aquatic communities. Water is essential for the survival of human being, for the socio-economic development of the country and preservation of its natural environment. Maintaining sufficient supply of clean water for the growing population such as that of Dhaka City is a major challenge. The Dhaka Water Supply Authority (DWASA) provides water to the 15 million in habitants of the city by extracting groundwater using 424 deep tubewells in addition to the surface water withdrawn from the Sitalakhya and the Buriganga Rivers.

The River Sitalakhya bordering the southern part of Dhaka City is a branch of the River Brahmaputra. A number of industries have been constructed along the banks of this river primarily because of its proximity to the capital and ease of transporting the goods via the intricate river system. These industries include textile dyeing and finishing industries, cement manufacturing industries and power plants. Two Combined Cycle Power Plants (CCPP) are situated on either banks of this river within a one kilometer stretch. These plants withdraw large quantities of cooling water from the river and discharge the hot effluent at a distance downstream from their respective intake points. One power plant has a side-bank discharge and the other has a submerged port discharge. The cumulative effect of these thermal discharges has increased the temperature of the Sitalakhya River water. The effect is further compounded by the tidal nature of the Sitalakhya. As a result, the aquatic environment for living organisms is likely to be affected and bioaccumulation of harmful substances in the water-dependent food chain may occur. This poses enormous threat to the human being as well as likely to create serious environmental hazard endangering the aquatic lives.

Benthic macroinvertebrates indicates biological response to increasing levels of stressors throughout their life stages. Some of these stages are more sensitive than others to particular stressors responding quickly to stress during a sensitive stage of life. Benthic macroinvertebrates as bio-indicators have a wide range of pollutant tolerances among the various species, therefore, are well suited for the assessment of site-specific pollution impacts and to determine the river water quality.

The primary objective of this study is to assess the impact of thermal effluent discharged into the Sitalakhya River from the power plants situated on either bank. Also, the effect of this discharge, if any, on the benthic macroinvertebrates will be assessed using the sampling protocol developed by the ASSESS-HKH team. The methodology developed by this project will be used to classify the river section to get a better perspective of the ecological health of the river Sitalakhya. The study area of Shitalakhya River is located between

23° 40' 54" N to 23° 40' 37" N latitudes and 90° 31' 37" E to 90° 31' 57" E longitudes. Assessment of the water quality of Sitalakhya river and the impact of thermal discharge presented here builds on two major thermal plume studies carried out for two different power generators, namely, the Siddhirganj Power Plant and the CDC Globeleq. Based on the mixing zone modeling results transects were selected across the width of the river to collect benthic samples as well as to analyze the physical, chemical and biological parameters. The macroinvertebrate sample data along with the chemical data were used for assessing the water quality of the Sitalakhya River using the ASSESS-HKHbios Score Index (Figure 1).

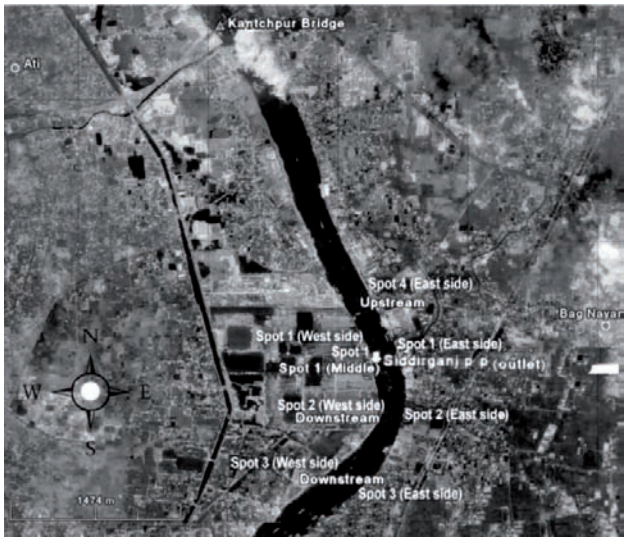

Figure 1: Google Earth image of the study area.

Modeling

Methods

Modeling thermal effluent discharge plume

Presence of a number of steam turbine power plants within a short stretch of the river necessitates the assessment of the water quality of the Sitalakhya River due to the combined effect of thermal discharges from these power plants. These include the existing 210 MW power plant within the Siddhirganj complex, CDC Globeleq 360 MW power plant, and the Haripur power plant (not in operation currently). Assessment of present water quality of the Sitalakhya river and probable changes in river water quality due to the thermal effluents from the existing and proposed plants may provide insight in the ecology of the river based on the macroinvertebrates.

The assessment of river water quality of Sitalakhya river and the impact of thermal discharge presented here builds on two major thermal plume studies carried out for two different power generators, namely, the Siddhirganj Power Plant and the CDC Globeleq.

The hydrodynamics of an effluent continuously discharging into a receiving water body can be conceptualized as a mixing process occurring in two separate regions (Fischer et. al., 1979). In the first region, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. This region is usually known as the "near-field", and it encompasses the buoyant jet flow and any surface, bottom or terminal layer interaction. As the turbulent plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due ambient turbulence. This region is usually referred to as the "far-field".

Tidal fluctuations in a water body, such as an estuary, coastal water or tidally fresh river, usually form an unsteady ambient flow field. The rate reversal (time gradient of tidal velocity) near these slack tides is of considerable importance for the concentration build-up in the transient discharge plume, as tidal reversal is likely to reduce the effective dilution of a discharge by re-entraining the discharge plume remaining from the previous cycle. Thus, it is essential to conduct a critical time variable analysis at different time steps within a tidal cycle. CDC Globeleq Private Limited is situated on the bank of the Sitalakhya River opposite to the Siddhirganj Power Plant, with the objectives to generate and supply power to the Bangladesh Power Development Board for a period of 22 years. The power plant is under full operation with a total capacity of 360MW (a steam turbine of capacity 130MW and gas turbine 230MW). The steam turbine uses cooling water at a rate 37,200 m^3/hr (max.) drawn from the Sitalakhya River. The thermal effluent passes through a small stilling basin within the plant. Then it is discharged into the river through a single-port submerged diffuser.

To determine the effect of the thermal effluent disposal on the Sitalakhya River and to set the macroinvertebrate sampling locations a data collection scheme was adopted to generate primary data on the temporal and spatial variation of temperature data at the outfall and at locations 100m and 500m

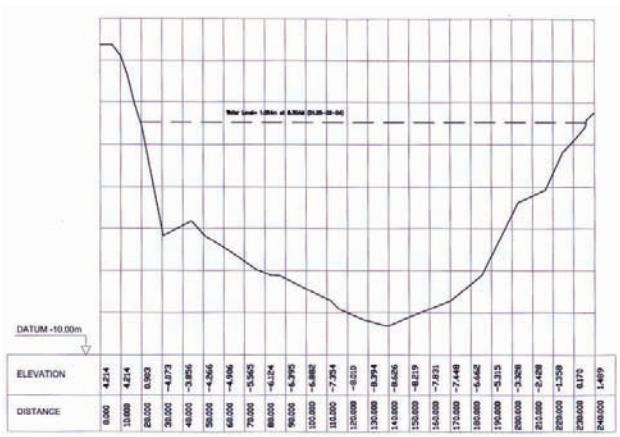

Figure 2: Cross-section along the plume origin.

upstream and downstream of the outfall during a tidal cycle. In addition, velocity and depth of flow of the river Sitalakhya during the collection of temperature data were recorded.

Temperature of river water was measured at different depths at three different transects, namely, at the outfall, at 100m and 500m upstream and at 100m and 500m downstream of the outfall in the month of November, 2008.

Temperature data at different stages of the tidal cycle at the outfall and 100m and 500m downstream of the outfall were collected over a tidal cycle once in each month.

Velocity and depth of flow were measured at the transects just upstream of the outfall over a tidal cycle. Wind velocity data were collected from secondary sources.

The study area was surveyed to identify the study stretch and the bathymetry along the cross section of the river at the plume origin was determined using an echo-sounder (Figure 2).

Simulation of the CDC Globeleq thermal effluent discharge

A length-scale model for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharge into diverse water bodies recommended by the USEPA was used to simulate the effects of thermal effluent discharge from CDC Globeleq in the Sitalakhya River.

The bathymetric data collected during the preliminary campaign were used in schematizing a bounded river cross-section approximating a rectangular channel from the considerations of equal hydraulic radius and later modified for non-uniform conditions.

The reach of the river within the study area has some irregularity in cross-section and has a moderate downstream meander with a relatively straight reach. The ambient geometry and the flow field data include an average river width of 180m. The average depth is 7.5 to 7.9m and the average depth at discharge is 8.45 to 8.85m. For the model simulation the Manning's roughness coefficient was assumed to be 0.03 for that of a clean and fairly straight natural river. The wind speed data was collected from the CDC Globeleq records and an average of 3m/s was used. The river was considered to have uniform density stratification with fresh water flow. Filed data on water temperature were colleted at different sampling campaigns and recorded for use during simulation. From the field data during the tidal period were found to be semi-diurnal (12.4hrs). The critical (minimum) dilution occurs near, and during the low velocity periods immediately following slack tide. Therefore, it necessitates multiple simulations at these junctures to estimate the mixing zone boundaries. Thus, it was decided that the simulations will be conducted at 3hr, 2hr, and 1hr before and after both the High Water Slack (HWS) and the Low Water Slack (LWS) and also at slack periods. The field data show a maximum tidal velocity of 0.334 m/s (an average of two maxima irrespective of their directions). The instantaneous velocities at different intervals ranged from a minimum of 0.013m/s to 0.334m/s.

Ambient river water is drawn from the bottom of the Sitalakhya River by the CDC Globeleq Power (pvt.) Ltd., approximately five meters below the mean water level to cool the plant. As the ambient river water passes through the power plants cooling system, its temperature increases by approximately 3-5°C prior to discharge. This heated ambient river water is discharged back into the river at a rate of 10.83 m^3/sec at maximum generating capacity. The outfall port is located downstream of the ambient river water intake structure in order to minimize the potential for recirculation of the heated discharge water. The outfall pipe extends ten meters from the site boundary to the riverbank and runs an additional 70 meters along the river bottom. The discharge port has a diameter of 2.5m and discharges horizontally at an angle of 90° with the direction of the ambient flow. The centerline of the discharge port remains 2.2m above the bed level and the port was designed to remain submerged in the river flow at all times.

The simulations were performed for comparison against the World Bank guidelines of 3°C below the ambient temperature at a distance of 100m up and downstream from the outfall. For all the simulations, the model was run for a region of interest of 2000m from the outfall.

Model results and discussion

The simulation was initiated with the input data for the condition representing 3 hour before HWS (Fig. 3). The nearest bank was, thus, located on the left of the direction of flow.

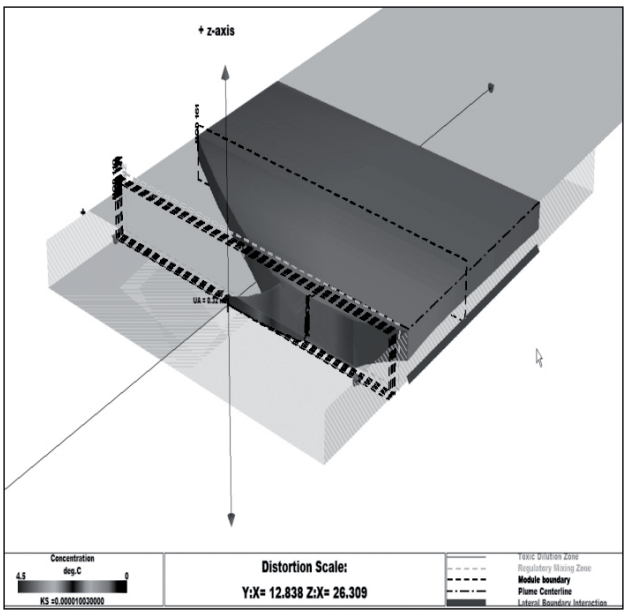

Figure 3: Plume at 3 hours before HWS.

The plume centerline temperature drops below the standard immediately after discharge. There is a possibility of dynamic bottom attachment. The near-horizontal discharge flow will dynamically attach to the nearby bottom in the near-field of the discharge (Coanda attachment). At the Regulatory Mixing Zone (RMZ), i.e. 100m from the outfall, the temperature is 0.40°C above the ambient temperature and the width of the plume is 65.5m and has a thickness of 6.09m. The plume hugs the near bank (the right bank) at 194m from the outfall. The plume becomes laterally fully mixed at the end of the buoyant spreading regime at 827m from the outfall.

Simulation at 2 hours before HWS shows that the temperature of the plume drops to a value of 0.34°C above the ambient temperature immediately after the disposal. However, the plume changes the direction and the right bank becomes the nearest bank. There is a possibility of dynamic bottom attachment. The near-horizontal discharge flow will dynamically attach to the nearby bottom in the near-field of the discharge (Coanda attachment). At the Regulatory Mixing Zone (RMZ), i.e. 100m from the outfall, the temperature is 0.40°C above the ambient temperature and the width of the plume is 61m and has a thickness of 6.36m. The plume becomes attached to the near bank (the right bank) at 217m from the outfall and becomes laterally fully mixed at the end of the buoyant spreading regime at 874m from the outfall. Immediately following the disposal, the plume becomes vertically well mixed and later due to lower density becomes positively buoyant at 1 hour before HWS flow condition (Figure 4).

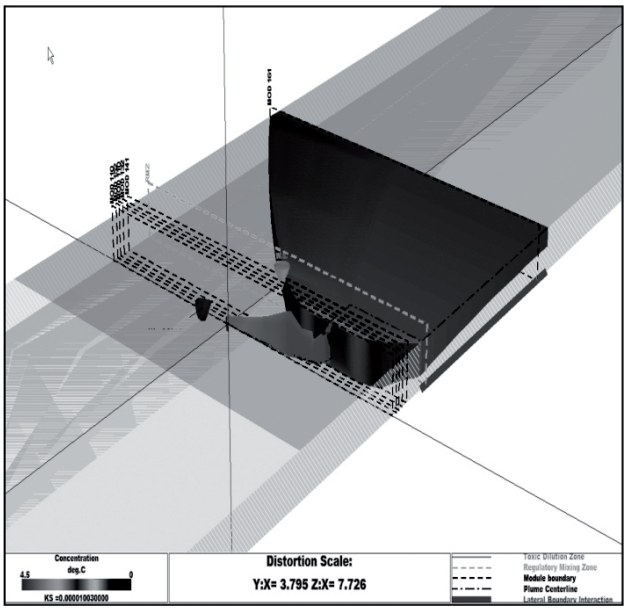

Figure 4: Plume at 1 hour before HWS.

Because of the immediate vertical mixing, there exists a possibility of benthic high temperature conditions. The plume becomes attached to the near bank at 83.4m and becomes laterally fully mixed at 475m downstream. Although there is tidal reversal, heat entrapment is unlikely to occur. At 1 hour after HWS the plume behaves the same as before. However, it changes direction and the left bank becomes the near bank. Subsequently, the temperature at the boundary of the mixing zone drops to 0.5°C above the ambient temperature. The plume becomes attached to the left bank at 112m and fully laterally mixed at 455m (Figure 5).

At 2 hours before the LWS the plume becomes vertically well mixed at the disposal point. However, it becomes re-stratified and does not become fully mixed in the vertical plane even at the far-field (Fig. 6). At the end of the RMZ the mixed temperature drops to 0.46°C above the ambient temperature, well below the regulatory limit. It becomes attached to the near bank (left bank) at 116m and becomes completely laterally mixed at 593m. During the flow condition at 1 hour

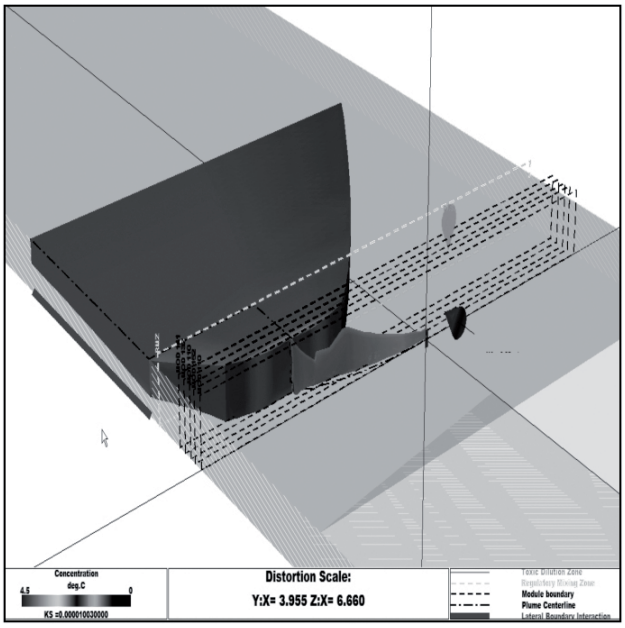

Figure 5: Plume at 1 hour after HWS.

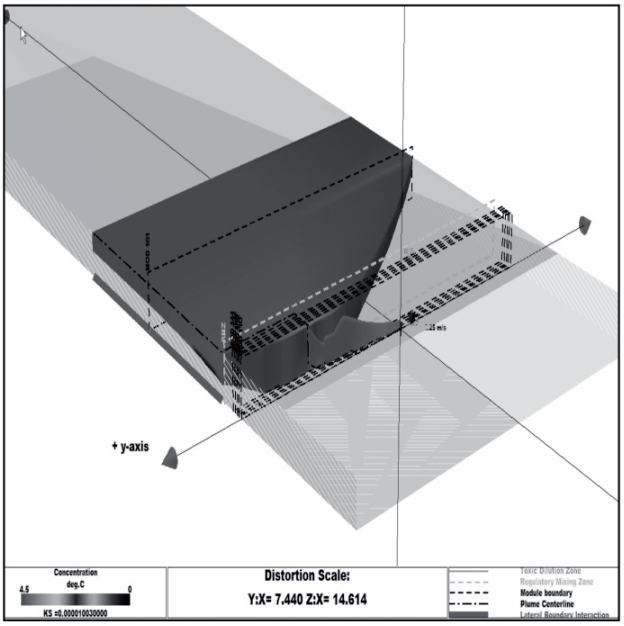

Figure 6: Plume at 2 hours before LWS.

after LWS the plume changes position and comes closer to the right bank. Some boundary interaction occurs at the end of the near-field. This may be caused by the very low ambient velocity, which may lead to some heat entrapment. At 50m downstream from the outfall the plume becomes attached to the right (near) bank. This is the situation where the temperature rises to the highest level of 1°C above the ambient temperature at the end of the regulatory mixing zone. It also becomes laterally fully mixed at a distance 177m downstream from the outfall (Figure 7).

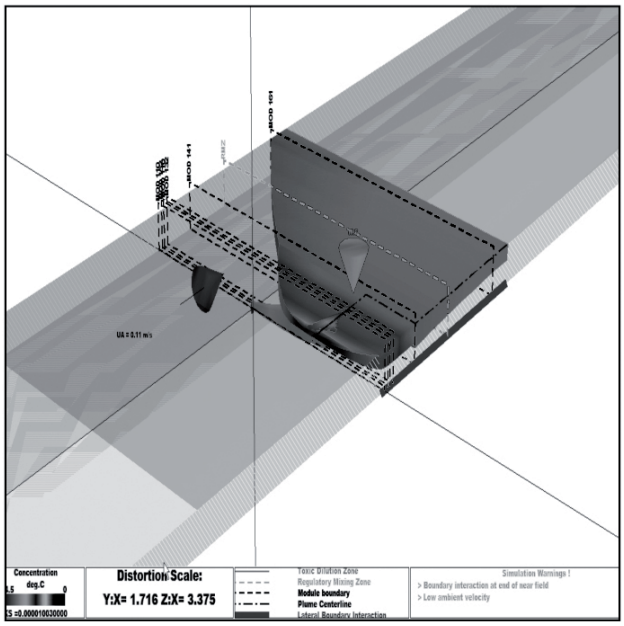

Figure 7: Plume at 1 hour after LWS.

Verification of CDC Globeleq simulation

The results of the model analyses were verified by comparing the simulation results with actual field data. It is apparent from the Fig. A-1 (in Appendix) that the model predicts the field conditions very well and actually follows the trend of immediate reduction in temperature in the near-field and subsequent steady trend to the far-fields.

Figure 8: Siddhirganj Power Plant thermal discharge outfall.

Simulation of the Siddhirganj 210MW ST thermal discharge

A 210MW Steam Turbine unit has been installed at the Siddhirganj power plant that uses water drawn from the Sitalakhya River for cooling purpose. The design include withdrawal of cooling water from the upstream of the plant and disposal of the used water into a concrete open channel, which drains into a closed conduit running along the river up to a designated length before ultimate disposal in the Sitalakhya River. Since the Sitalakhya River is influence by semidiurnal tide, the worst-case scenario for the disposal of cooling water following once-through cooling is the low-flow period subjected to river backflow induced by tide. With the hydrologic, bathymetric and wind velocity data collected a comprehensive simulation was performed to analyze the effects of the side-bank discharge of the thermal effluents in the Sitalakhya River.

Although the effluent discharged into the open channel at the boundary of the plant travels some distance the heat dissipation from the disposed water during the course of travel between the outlet (with initial temperature of 42.7 °C) and the final outfall is minimal. This is due to the fact that the total travel time for a water particle between these two points is only about 15 minutes. In addition, a major portion of this channel is a closed conduit virtually preventing any transfer of heat from rapidly flowing water and the surrounding environment.

Numerical modeling

The numerical modeling analysis was performed for the option where cooling fluid is used for 1 x 210 MW + 50 MW TPS and disposed off at a location 450m downstream of the intake location. The discharge channel is protruding 25m inside the river at a 45° angle from the right bank looking at the downstream direction. The width of the discharge channel is 7.5m and a depth of 2.5m. The rate of discharge for this condition is 10.7 m^3/sec (38,500 m^3/hr) (Figure 8).

The modeling was performed at every hour within the entire tidal cycle. The worst case scenario with respect to the temperature at the intake location was considered for the selection of the disposal point. Description of the worst case scenario run for this option is given below (Fig. 9a-b).

The effluent density is less than the surrounding ambient water density of 995 kg/m^3 at the discharge level. Therefore, the effluent is positively buoyant and will rises towards the surface within the near field. The temperature within the plume axis at the edge of the near field (99.8m from the disposal location) is +3°C above the maximum ambient temperature. The plume is become vertically fully mixed in the far field. During the simulation, the Region of Interest was considered

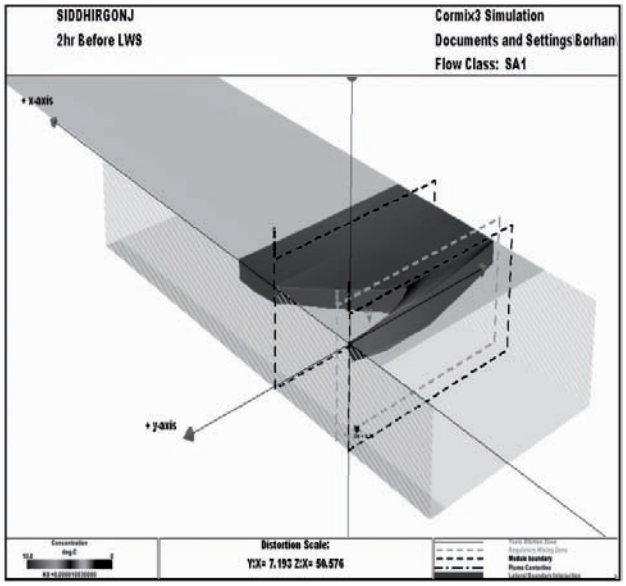

Figure 9a: Simulation of thermal plume of the Siddhirganj Power Plant in Sitalakhya.

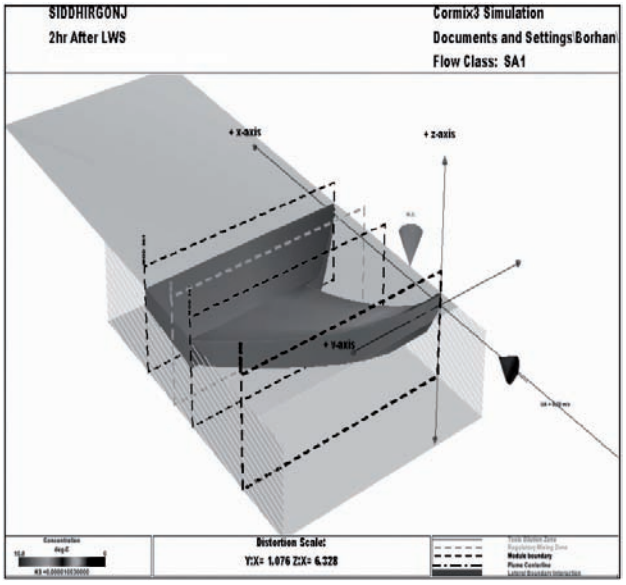

Figure 9b: Simulation of thermal plume of the Siddhirganj Power Plant in Sitalakhya.

to be 2500m. Within this region the location and trajectory is represented by the steady state analysis and are not limited by any tidal restrictions. For this condition, after tidal reversal, mixed water from the previous half-cycle become re-entrained into near field of the discharge, increasing the temperature compared to the steady state predictions. A pool of mixed water formed at slack tide is advected downstream in this phase.

Verification of Siddhirganj Power Plant Simulation

The mixing zone model was also applied for assessing the impact of the newly installed 210-MW power generation unit at the Siddhirganj Power Plant. However, given the model limitations for using two simultaneous thermal input in the same region of a river it was impossible to simulate the actual condition of the river at present. Thus, an individual simulation with only the present conditions was performed. Therefore, the model outputs for such a case are only indicative. Figure A – 2 (in Appendix) shows the simulation results of the Siddhirganj outfall. The field data show considerable differences with the simulated results in the nearfield but follows the trend of the data in the farfield. This difference in the nearfield may be attributed to the fact that the model can only simulate the effects of one thermal input in the river reach, whereas, the field data are the combined effects of both the plants. Although the Siddhirganj Power Plant is within the Bangladesh Standard (ECR 1997) standards for thermal effluent discharge, it sometimes exceeds the World Bank Guidelines of 3°C at 100m from the outfall.

Table A-1 (in Appendix) shows the water temperature data collected on December 05, 2007 at different depths near the Siddhirganj Power Plant outfall and at a distance of 100m up and downstream from the outfall. Even during the relatively high flow condition of the Sitalakhya River the water temperature has risen to 40.2°C at a location close to the outfall and the same at location 100m up and downstream from the outfall the water temperature varies between 31.4°C to 40.2°C. Therefore, it is likely that the river water temperature will increase significantly during the low flow periods. In addition, the model simulation suggests that entrainment of heat caused by heat carried over from one tidal cycle to the next may lead to substantial increase in water temperature in the vicinity of the side-bank discharge outfall. It is also apparent that a submerged discharge is more efficient than a side bank discharge in dissipating heat from thermal discharge. However, siltation over a prolonged period may cause the submerged discharge port to work inefficiently over in the long run.

The submerged buoyant jet such as the CDC Globeleque plume dissipates a large quantity of heat on its way upward before it takes the form of surface thermal plume, while in surface buoyant jet such as that of Siddhirganj Power Plant, heat is dissipated only when it starts mixing with the surface water after discharge. This is why there is an abrupt decrease in temperature after discharge for submerged jets while in surface jets, even with the same effluent characteristics, the temperature decrease occurs over a larger distance. However, the condition changes due to tidal nature of the flow. Heat entrapment along the depth of the river near the discharge point may occur in both the cases. This may lead to increase in ambient temperature.

The model analysis shows that although the ECR 1997 (GoB, 1997) guideline values for thermal discharge has not been exceeded during dry season, at times the World Bank Guideline limit of maximum of 3°C increase in ambient temperature could not be achieved by the Siddhirganj Power Plant. As mentioned, the effect of surface disposal persists over a

long distance and the plume travels more than 1000m before laterally full-mixed condition prevails. The increase in ambient temperature may also be enhanced due to entrapment of heat during each tidal cycle. Therefore, it will not be advisable to allow additional thermal discharge within the distance of 1.5km upstream and 1.5km downstream of the present discharge point of the Siddhirganj Power Plant.

Macroinvertebrate sampling and analysis

Methods

ASSESS-HKHbios Score methodology was used for assessing the water quality of Sitalakhya river. The water quality assessment system using benthic macroinvertebrates as bio-indicators play an important role of river ecosystem management. Biotic Score indicate the ecological status of water-bodies based on the study of the benthic macroinvertebrates. Such score-based assessment methods are based on higher taxonomic bio-indication units (order, family and genus). This is an easy way of making judgments on surface river quality.

Freshwater macroinvertebrates require dissolved oxygen as well as microhabitats to survive and to build sustainable populations. The assemblage of species reflects the overall condition of a given site. The number and type of taxa provides an indication of the overall ecological status. Benthic invertebrate taxa are scored according to their sensitivity to stressors.

A total of nine locations along the stretch of the Sitalakhya River near the power plants have been selected for macroinvertebrate and water quality sampling and analysis. Near the banks samples were collected using a 45cm wide x 30cm long D-frame with a 500µm mesh net. The net is thoroughly rinsed in water by hand, ensuring that all pieces of substrate have been removed and rubbed clean of attached organisms. In deeper water a 25cm x 25cm Ekman grab sampler was used to collect samples representative of the overall biological integrity within a stream reach. Aquatic plants, sticks, branches, stones and other unwanted materials were removed and after rinsing inspected for the sessile organisms. Samples were transferred from the net to sample containers and preserved with formalin (4% concentration of formaldehyde) after field sorting. Airtight sample containers were labeled with the name of the river, site code and date of sampling as per the sampling protocol of the ASSESS-HKH. All samples were processed at the Environmental Engineering Laboratory of the Department of Civil Engineering, BUET. Processing includes sorting of the organisms according to taxonomic groups, identifying organisms up to family level following ASSESS-HKHbios Score methodology.

Macroinvertebrates are ranked using a ten point scoring system as per HKHbios assessment system. Tolerance values range from 10 for organisms very intolerant of organic wastes and 1 for organisms very tolerant of organic wastes. The scores reflect the sensitivity of taxa to organic pollution (oxygen depletion), chemical pollution as well as on hydromorphological deficits. Taxa with high scores indicate high sensitivity to stressors and taxa with low scores indicate high tolerance to stressors. Tolerances values decrease as water quality decreases.

Bio-monitoring results and discussion

In the present study 13 physico-chemical parameters of Shitalakhya River were measured. The results have been presented in Table A - 2. It is apparent that the river water is devoid of any dissolved oxygen and the ammonia concentration is relatively high. The secchi depth was found to be about 50cm indicating very low light penetration level.

During the period of study 18 families of aquatic macroinvertebrates were identified from nine locations in the Sitalakhya River. They are Tubificidae, Naididae, Nereididae, Nephthydae, Bithyniidae, Viviparidae, Thiaridae, Sphaeriidae, Corbiculidae, Amblemidae, Unionidae, Chironomidae, Culicidae, Lebellulidae, Potamidae, Palaemonidae, Atyidae, and Noteridae.

Table 1: Distribution of benthic sampling locations by water quality class.

		Water quality class (WQC)				
	Sample sites	I	II	III	IV	V
1.	Spot-1 (center of outfall)	--	--	--	1	--
2.	Spot-1(u/s of plume)	--	--	1	--	--
3.	Spot-1(mid river)	--	--	1	--	--
4.	Spot-1(d/s of plume)	--	--	1	--	--
5.	Spot-2 (d/s of plume)	--	--	1	--	--
6.	Spot-2 (d/s of outfall inside plume)	--	--	--	1	--
7.	Spot-3 (d/s outfall outside plume)	--	--	1	--	--
8.	Spot-3 (d/s of outfall inside plume)	--	--	--	1	--
9.	Spot-4 (u/s of outfall inside plume)	--	--	--	1	--
	Total	--	--	5	4	--

Based on species abundance and richness numerical scores were assigned to potential water quality classes (shown in Table 1), viz. Class I (none to very slight organic pollution), Class II (moderate pollution), Class III (critical pollution), Class IV (heavy pollution), and Class V (very heavy to extreme pollution). Findings of the present study according to the river water quality class at each location have been presented in Table 1.

Physico-chemical conditions of the Sitalakhya River indicate that the river has little or no dissolved oxygen. This extremely low level of oxygen in dry periods makes it impossible for the larvae of Ephimeroptera and Trichoptera to survive in this water. The findings of present study indicate that although the physcico-chemical quality do not change along the stretch of the river the water quality class changes from Class III to Class IV which has been confirmed by the presence of the more tolerant species.

Aquatic worms under the phylum of Annelids are tolerant of bad or poor water quality and common in critical to heavy pollution. Many aquatic worms can tolerate low dissolved oxygen and found in large numbers in organically polluted habitats. Tubificidae and Naididae family found in the samples under the class of Oligochaeta have the greatest indicator value. The species of these families were found in water quality Class III and even in heavily polluted running waters of Class IV. Nereididae and Nephthydae families under the class of Polychaeta were found in the sand and mud substrate of river bed. The species of these families have also been found in water quality Class III and even in heavily polluted running waters of Class IV. Bithyniidae, Viviparidae and Thiaridae families under the order of Prosobranchia indicates moderately tolerant of organic enrichment. Thiaridae, Sphaeriidae, Amblemidae, Unionidae and Corbiculidae families under the order Eulamellibranchia are abundant in waters enriched with organic nutrients and low in dissolved oxygen. Some species of these families are very tolerant of poor water quality. The species of these families usually are indicator species for critical to heavy pollution. Chironomidae and Culicidae families under the order of Diptera are poor tolerant of organic and inorganic pollution. Chironomidae commonly known as midges, are the most common of aquatic invertebrates of rivers and indicate multiple stressors. Mosquitoes of Culicidae, found in the samples, are not important water quality indicators as they are common in river water, therefore, not considered in classifying the stretch. Lebellulidae family under the order of Odonata found in a number of samples exhibits a range of sensitivity to pollution. The larvae of Lebellulidae, which have been found outside the thermal plume, are intolerant of pollution and indicate moderate water quality. Potamidae, Palaemonidae and Atyidae are intolerant or moderately tolerant of organic pollution. Most species of these families found in water quality Class II and even in critically polluted running waters of Class III. Noteridae family under the order of Coleoptera is common in well oxygenated and swiftly running waters. The species of Noteridae are usually indicative of clean water and sensitive to organic and inorganic pollutants. Noteridae larvae can survive in moderately polluted water.

Table 1 describes the water quality classes in terms of pollution per sampling spots. It shows that the sampling locations within the plume showed a inferior class (Class IV) indicating heavier level of pollution. Field survey of the stretch of the river revealed that there is no significant organic loading along both banks. It is evident taht the deterioration of water quality from Class III to Class IV occurs when the sampling points are within the thermal plume. The reason for such deterioration in water quality may be attributed to the presence of more thermotolerant species. It is also evident from the species found in the samples collected from near the outfall.

Conclusions

The Sitalakhya River is currently being used as the source of drinking water for the inhabitants of Dhaka City. It also provides cooling water for the thermal power plants situated on its banks. Rampant discharge of untreated domestic and partially treated industrial wastes has already deteriorated the quality of the river water. Recent installation of thermal power plants discharging their hot cooling water directly into the river have cause appreciable increase in ambient water temperature. Benthic macroinvertebrates as Bio-indicators are susceptible to degradation of water and habitat and serve as good indicators of localized environmental conditions. From the macroinvertebrate sampling, conducted following the ASSESS-HKHbios protocol, shows that river water quality deteriorates even further within the region covered by the thermal plume.

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Table A-1: Water temperature of the Sitalakhya river (°C)

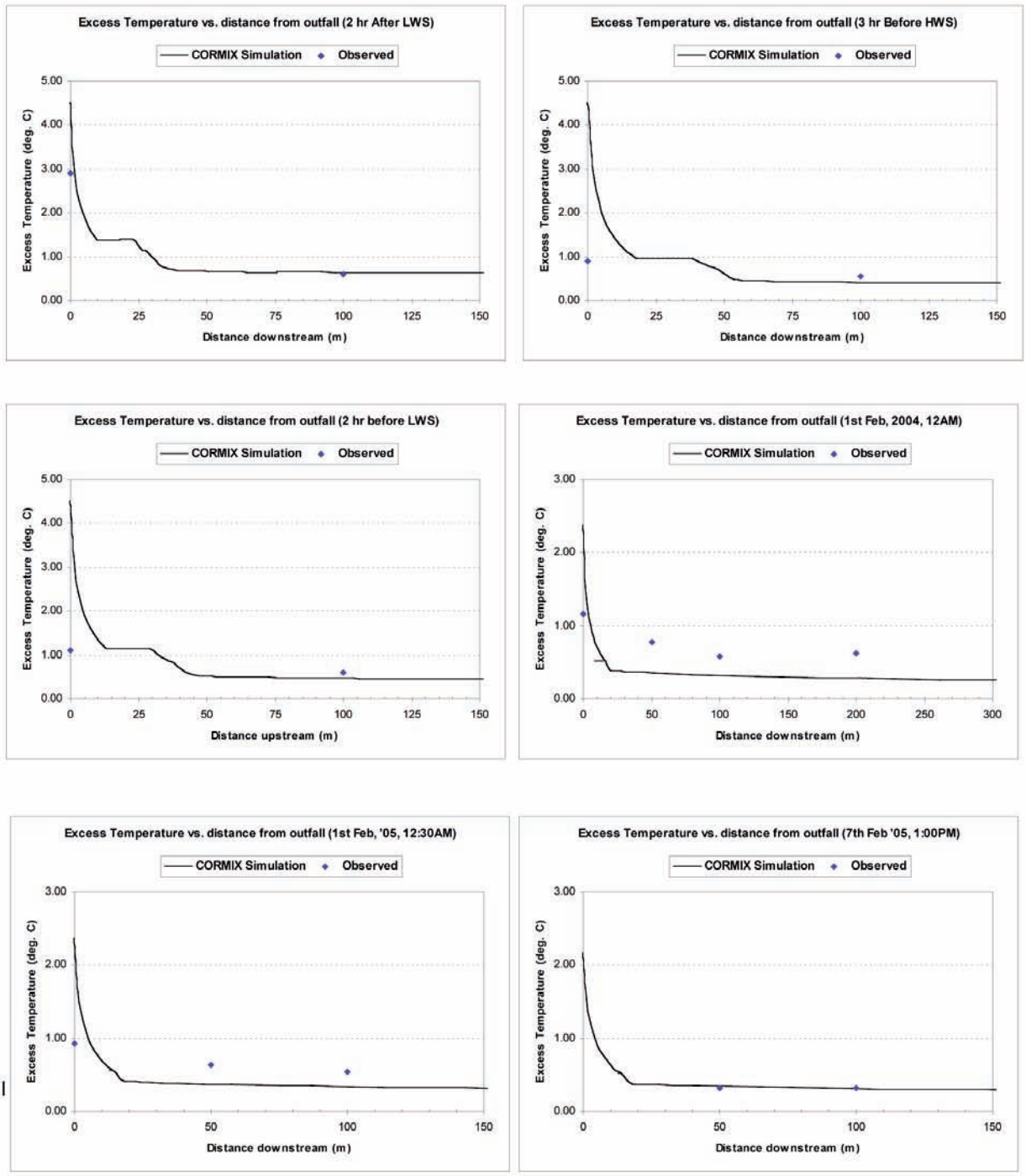
Date: 5 Dec 2007 Start time: 09:25 am End time: 10:30 am

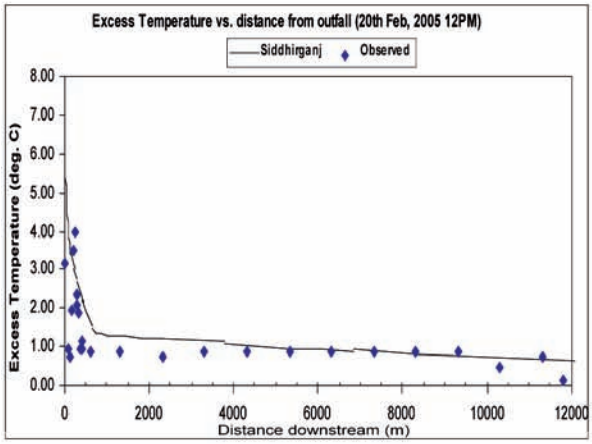
Site no.	Distance (m) → / Depth (cm) ↓	X1 (Intake point)		X2 (100m N from discharge)		X3 (Discharge point)		X4 (100m S from discharge)	
		3.0m	0.0m	3.0m	0.0m	3.0m	0.0m	3.0m	0.0m
1	0	31.7	31.6	32.7	33.1	33.5	36.6	32.3	32.2
2	10	31.5	31.4	32.7	33.3	34.9	35.8	32.3	32.2
3	20	31.5	31.4	32.6	32.5	34.4	33.5	32.0	31.9
4	30	31.4	31.3	32.3	32.5	32.5	32.4	31.8	31.8
5	40	31.5	31.4	32.6	32.7	32.3	32.2	32.0	32.0
6	60	31.4	31.3	32.5	32.6	32.7	32.7	31.9	32.0
7	0	31.9	32.1	32.7	32.9	37.2	40.2	33.8	34.0
8	10	31.7	31.6	32.4	32.3	36.2	37.4	33.6	33.5
9	20	31.7	31.8	32.4	32.2	33.9	35.1	33.0	32.9
10	30	31.8	31.6	32.4	32.3	32.9	33.9	32.6	33.0
11	40	31.9	31.9	32.3	32.3	32.9	33.3	32.2	32.1
12	60	32.0	32.0	32.2	32.3	33.0	33.2	32.3	32.1

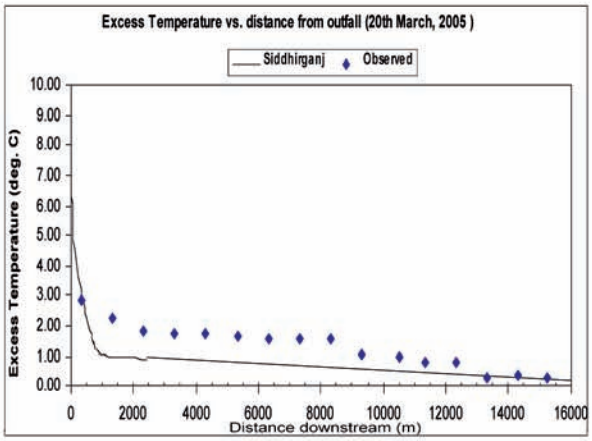
Table A-2: Physico-chemical parameters of Sitalakhya river

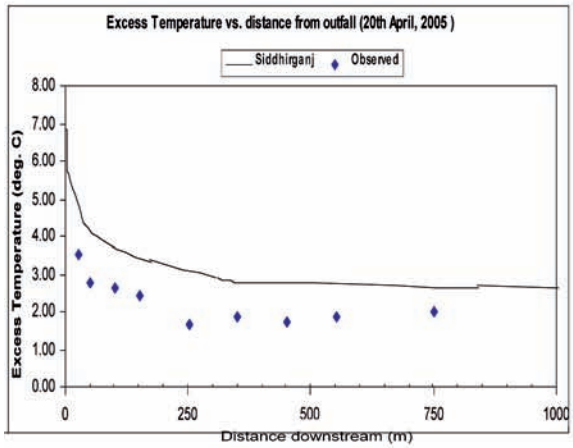
Sample ID	pH	Temp. (°C)	Cond.	O_2 Cont.	O_2 Satura.	Alkal.	Hard.	Cl^-	BOD5	NH_3 (mg/l)	NO^{2-} (mg/l)	NO^{3-}	Ortho PO_4^{3-}
Spot-1 (center of outfall)	7.25	27	271	0.32	4.1	105	43	11	1.6	2.19	0.11	0.4	0.618
Spot-1 (mid river)	7.32	26.6	281	0.66	6.9	112	44	11	3.2	2.23	0.03	2.1	0.678
Spot-2 (d/s of plume)	7.36	26.6	289	0.45	5.2	109	43	16	0	2.16	0.01	0	0.634
Spot-2 (d/s of outfall inside plume)	7.36	26.1	300	0.72	7.3	111	44	26	0	2.19	0.01	0.2	0.645
Spot-3 (d/s outfall outside plume)	7.39	26.8	295	0.35	4.3	111	41	22	1.6	2.3	0.02	0.2	0.66
Spot-3 (d/s of outfall inside plume)	7.32	27.4	275	0.29	3.4	106	45	19	1.6	2.18	0.05	0	0.437
Spot-4 (u/s of outfall inside plume)	7.23	25.6	273	0.16	1.8	102	51	17	2.6	1.48	0.08	0.5	0.459

Figure A-2: Verification of Siddhirgonj Power Plant model results with field data.




Excess Temperature vs. distance from outfall (20th Feb, 2005 12PM)
Siddhirganj
Observed
Excess Temperature (deg. C)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
2000
4000
6000
8000
10000
12000
Distance downstream (m)


Excess Temperature vs. distance from outfall (20th March, 2005)
Siddhirganj
Observed
Excess Temperature (deg. C)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
2000
4000
6000
8000
10000
12000
14000
16000
Distance downstream (m)


Excess Temperature vs. distance from outfall (20th April, 2005)
Siddhirganj
Observed
Excess Temperature (deg. C)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
250
500
750
1000
Distance downstream (m)

Otto Moog, Daniel Hering, Subodh Sharma, Ilse Stubauer & Thomas Korte (eds.) (2008)
ASSESS-HKH: Proceedings of the Scientific Conference "Rivers in the Hindu Kush-Himalaya – Ecology & Environmental Assessment"

Biological monitoring of water quality in India – needs and constraints

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Abstract

Fast urbanization and industrialization in India is leading to steep increase in waste generation. The waste management is not adequately addressed resulting in large part of uncollected and untreated wastes getting into water courses. This situation coupled with steep increase in water demand leading to degradation of water quality. India's water stressed economy is slowly becoming a water scarce economy. The maintenance of water quality is a Herculean task which bacons us. To meet these challenges, the country has taken up several positive steps through formulation of national policies and regulatory frameworks, its implementation along with a well designed water quality monitoring system including data analysis and dissemination. Due to growing diversity of pollutants, it is increasingly becoming difficult to measure all the pollutants. Many of the pollutants which are not regularly monitored may be very important due to their environmental significance. In such situation biomonitoring is becoming more important. In applying biomonitoring in the water quality monitoring program, the major constraint was specialized knowledge required to identify the organisms exist in water. Such knowledge was not available with the monitoring agencies. To overcome such problem Central Pollution Control Board (CPCB), which is an apex body for management of water quality in the country and maintaining a well designed network of water quality monitoring, initiated a program to develop methods for biological assessment of water quality in Dutch collaborated project. The outcome of the project was a well designed integrated method of water quality assessment including biological and chemical parameters. This paper attempts to highlight the method and its applicability in different parts of the country and different types of water bodies.

Key words: biomonitoring, chemical monitoring, pollution, legislation.

Introduction

Water is most essential but scarce resource in our country. Presently the quality & the availability of the fresh water resources is the most pressing of the many environmental challenges on the national horizon. The stress on water resources is from multiple sources and the impacts can take diverse forms. Geometric increase in population coupled with rapid urbanization, industrialization and agricultural development has resulted in high impact on quality and quantity of water in our country.

The situation warrants immediate reprisal through radically improved water resource and water quality management strategies. In order to achieve sustainable economic growth, the requirement of water management strategy includes interrelated programs, policies, and legislation designed to protect and improve aquatic environment. Rational planning of any water quality management program required adequate knowledge on nature and magnitude of water quality degradation.

To acquire such knowledge a well designed water quality monitoring is essential. Monitoring supports the implementation of water quality management program by providing feedback on the status of aquatic resources and the performance of policies, programs, and legislation.

Central pollution control board's present water quality monitoring program

The national water quality-monitoring network is operated under a three-tier program i.e. Global Environment Monitoring System (GEMS), Monitoring of Indian National Aquatic Resources System (MINARS) and State Level Programs. CPCB in collaboration with concerned SPCBs/PCCs established a nationwide network of water quality monitoring comprising 1019 stations in 27 states and 6 union territories. The monitoring is done on monthly or quarterly basis in surface waters and twice in a year for ground water. The monitoring network covers 200 rivers, 60 lakes, 5 tanks, 3 ponds, 3 creeks, 13 canals, 17 drains and 321 wells.

Among the 1019 stations, 592 are on rivers, 65 on lakes, 17 on drains, 13 on canals, 5 on tanks, 3 on creeks, 3 on ponds and 321 are groundwater stations. Water samples are being analysed for 28 parameters consisting of 9 core parameters and 19 other physico-chemical and bacteriological parameters apart from the field observations. Besides this, 9 trace metals and 22 pesticides are also analysed in selected samples. Biomonitoring is also carried out on specific locations. In view of limited resources, limited numbers of sample are analysed once in a year for micro pollutants (toxic metals & POPs) to assess the water quality. The water quality data are reported in the water quality status year book.

Need for biomonitoring in India?

Legal and policy considerations

Water pollution in India is regulated under the provisions of Water (Prevention and Control of Pollution) Act, 1974. The pollution control boards formed under the Act are responsible for its implementation in the country. The basic objective of the Act as stated in its preamble is to maintain and restore the wholesomeness of the aquatic resources in the country. Thus, the long term objectives for pollution control boards must essentially be that all natural waters should be free from harmful effects to man and aquatic environment caused by waste discharges. This means that wholesome ecological systems should be maintained in the aquatic systems of India. In order to advance towards fulfilment of this goal, pollution control boards must strive to minimize the adverse effects that discharges may cause in water bodies. Most of the policy documents and legal provisions on water resources protection and management in India emphasize protection of human health and living creatures. Water Act, 1974 emphasizes 'wholesomeness' and under its sections stresses on protection of human health and living creatures. Similarly, Environment (Protection) Act, 1986 emphasizes protection of environment including air, water, land, living creatures and their relationships. The Policy Statement for Abatement of Pollution (1992) and National Conservation Strategy and Policy Statement on Environment and Development, 1992 stresses on protection of wildlife and ecosystems. Similarly, recently notified National Environment Policy, 2006 also strongly emphasizes on protection of wildlife, fisheries and other living being. Even the National Water Policy, 2002 of Ministry of Water Resources also emphasized on ecological requirement of water and felt the need for ecological flows in different rivers in the country. All the above mentioned facts reveals that protection of aquatic life is an important intention under the law and policies of the government of India and thus biological monitoring is essential in order to ensure such a goal.

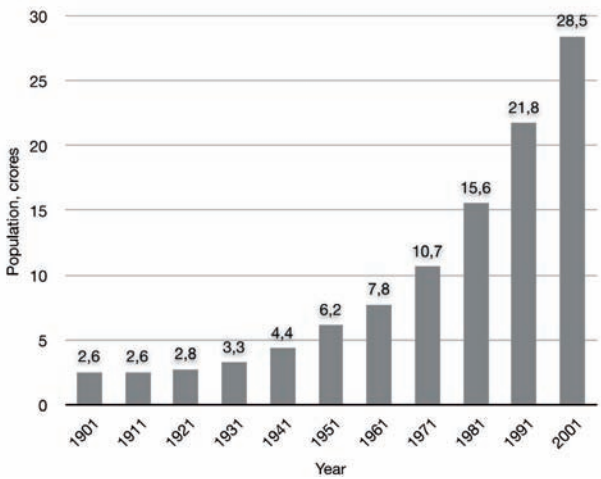

Figure 1: Increase in urban population.

Increasing diversity of pollution

Fast economic growth, urbanization, industrialization and agricultural advancement in India led to increase in pollutants diversity. Some of the facts related to urban, industrial and agricultural growth are presented below:

Urbanization

The growth of urban population becomes very steep in the last 3-4 decades (Figure 1). It is predicted that the growth would be much more steeper in future.

Industrialization

Soon after independence, the Government of India embarked upon a planned approach of socio-economic development for self-reliance. There was a tremendous euphoria for rapid economic growth using modern technological development through the process of massive industrialization of the country, especially the development of heavy and basic industries. It was important that the industries continue to get high priority. Industrial production increased at an average rate of 7.8% in the decade following 1955. This rate of growth fell to 4.0% in the decade 1966-75. Aggregate industrial output has increased to five folds over a period of 39 years since the independence giving a compound rate of growth 6%. This growth rate was tried to maintain till recently. This has resulted in fast industrialization of the country. India ranks today amongst the first 10 industrial nations of the world. The Indian economy has never been in such good shape as it is now with the liberalization measures initiated in 1991 become effective. The continued impressive performance of the agricultural sector and a significant improvement in the industrial production since September 1993 have enabled the rate of growth of the Gross Domestic Product (GPD) rise from 0.8 percent in 1991-92 to 5.1 percent in 1992-93, 5 percent in 1993-94, 6.3 percent in 1994-95, seven percent in 1995-96, 7.5 percent in 1996-97, which has continuously increased to 9 percent in 2006-07.

Agriculture

India ranks second worldwide in farm output. Agriculture and allied sectors accounted for 18.6% of the GDP in 2005, employed 60% of the total workforce and despite a steady decline of its share in the GDP, is still the largest economic sector and plays a significant role in the overall socio-economic development of India. Yield per unit area of all crops have grown since 1950, due to several efforts to augment the agricultural production. Apart from massive efforts to augment irrigation potential in the country, use of chemicals has also grown steeply. For example: fertilizer consumption has grown from 0.3 million tonnes/year in 1960 to 20.3 million tonnes/ year in 2006 (68 times increase in 46 years), pesticides consumption has grown from 2353 tonne/year in 1955 to 75418 tonnes/year in 1990.

Water availability

Although India is wettest country in the world, with annual average rainfall of 1170 mm, still water is a scarce commodity. This is mainly due to highly uneven distribution of rainfall with time and space. With fast industrialization and urbanization the demand of water is steeply increasing. This is leading to severe problem of water availability in several part of the country. The water scarcity is very important cause of water quality problems.

Complexity of chemicals in water

Due to fast economic growth, urbanization, industrialization and agricultural development followed by water scarcity, a large number of chemicals are getting into the environment. Recognition is growing that in order to achieve and maintain water quality objectives, pollution control boards lack, in many cases, an essential tool: the ability to assess the level and cause of adverse environment effects due to discharges of pollution, also to assess the magnitude and persistence of the toxic effects of effluents on receiving waters. Chemicals can, and do, reach the aquatic environment by many routes i.e. discharge from the industries, sewage, storm water, and urban and industrial runoffs, leaching from the soils, agricultural areas and atmospheric deposition. The effluents can be extremely complex in quality and individual in their properties. Several hundreds or thousands of chemical may be discharged in an industrial or urban effluent. While a limited number of these compounds are well known chemical products and reactants used in industrial processes, many are unintended by-products which are far less likely to be identified. Although many of these chemicals and by-products are present as trace pollutants they may still be toxic even in low concentrations.

This has compounded the complexity in water quality monitoring and management strategies. A ppredominant argument to apply bio-monitoring technique in pollution control is the incompleteness of the analytical techniques. This relates to the impossibility to develop analytical methods for each pollutants as well as to the unavailability in practice of complete series of instruments covering all the polluting substances. Furthermore, simple techniques for determining what fraction of the contaminant is actually biologically active, are not available. Also technical know how to interpret all the results may not be sufficiently available. Therefore, although monitoring chemical variables is often considered to be simple, in many cases it is not simple and effective and certainly not cheap. The only option to overcome such complexity is use of biological system to monitor water quality. Considering these arguments selective bio-monitoring is a most efficient method for pollution control and measurement on environment.

Biomonitoring

Biomonitoring relies on the fact that environmental stresses will cause change in the physical and chemical environment of the water and that those changes will disrupt the ecological balance of the system. Thus, by measuring the extent of the ecological upset, the severity of the impact can be estimated.

The species most commonly used for the investigation of water quality are the larger and more easily visible invertebrate animals which colonize the substrata of all the rivers. Such animals are collectively referred as macroinvertebrates, of which the main constituents are young aquatic stage of certain insects. Within this bottom dwelling community, the sensitivity and tolerance to pollution varies considerably from species to species. Thus, for example, some species are very sensitive to reduction in dissolved oxygen and will not be found in the area where oxygen levels are not consistently high. On the other hand, some species are very tolerant in this respect. Like-wise some species require particular physical conditions in order to survive and thrive e.g. clean gravel and clean surface interstices. Any change in conditions such as silting will significantly reduce or even completely eliminate such species. This is a characteristic feature of polluted environments where reduction in overall community diversity of tolerant species will be observed. Thus, the quality of water can be assessed by means of a field inspection of the macroinvertebrate communities inhabiting the substratum, noting the relative proportions of sensitive, less sensitive, tolerant and most tolerant species and comparing the result found with the expected ratios from unpolluted habitats of a similar type.

There are several methods of assessing water quality using biological structure (Trivedi 1981). Each method has its own particular application, advantages and disadvantages. These are summarized in the table 1, from which it will be seen

Table 1: Advantage and disadvantage of different water quality monitoring techniques.

Realm	Performance of chemical monitoring	Performance of biological monitoring
Precision (i.e. polluant concentration assessment)	Good	Poor
Discrimination (what kind of pollution)	Good	Poor
Reliability (how representative is a single or a limited number of samples)	Poor	Good
Measure of ecological effects	No	Yes
Cost	Relatively high	Relatively low

that a combination of both techniques is preferable to either alone. Physico-chemical methods measure the concentration of pollutants only at the time of sampling and can not detect the pollutants discharges that are either irregular or surreptitious. These are also relatively expensive in terms of the equipment needed and number of analyses required to achieve results with a comparable reliability to those achieved by biological surveillance. Their particular advantage is that the analyses involves are precise, discriminating and quantitative. The physico-chemical methods provide such data as required by the Pollution Control Boards for assessment of compliance with prescribed standards.

On the other hand, the biological methods could be useful for such assessing the overall impact of pollutants on the ecosystems. Such impact are generally independent of the time(s) during which the pollutants were discharged and therefore this approach could help in integrated assessment of the water quality. This is an important advantage of biological techniques. They do, however, suffer from the limitation of being poor in terms of their precision and discrimination of the pollutants involved (Table 1).

Options for biomonitoring

There are as many methods as the number of scientific groups working on biomonitoring in the world. The details of these methods are widely referred in the literature. Thus it becomes difficult to select appropriate method for a situation. In order to find suitable method for Indian conditions and within capability of Indian regulatory authorities, Central Pollution Control Board has carried out a three year pilot study on the Yamuna river under Indo-Dutch collaborative project and developed a method for evaluation of water quality combining both the chemical and biological evaluation to make it more scientific and useful for the pollution control agencies in India. The method integrates the individual parameters in an index. The methodology developed involves large number of physico-chemical measurements, although it has a flexibility to be used even if limited parameters of local importance are measured. For any beginner measurement of all the parameters used in the above methodology may be difficult. The complete details of the methodology are available elsewhere (de Kruijf et al.1992, Trivedi et al.1993, de Zwart & Trivedi, 1995). A brief description is provided below:

The yardstick

The adopted river water quality yardstick is based on measured chemical, bacteriological and ecological data. The individual measurement are integrated to a number of indices which are graphically presented in a so called AMOEBA - figure. The AMOEBA (abbreviation for a method of ecological and biological assessment) depicts the actual quality status, together with the deviation from target objectives. The individual indices are related to identifiable aspects of pollution, and therefore they can be used for water quality management. For the time being 8 different indices are specified:

Pollution Load (strain) Indices:
- Bacterial Pollution Index (BPI)
- The Nutrient Pollution Index (NPI)
- The Organic Pollution Index (OPI)
- The Industrial Pollution Index (IPI)
- The Pesticide Pollution Index (PPI)

Effect (stress) Indices:
- The Benthic Saprobity Index (BSI)
- The Biological Diversity Index (BDI)
- The Production Respiration Index (PRI)

Each of these indices is derived from a set of one or more water quality monitoring parameters which may vary according to regional requirements. The details of the methodology is described elsewhere (Trivedi et al 1993, de Zwart & Trivedi, 1995)

Amoeba presentation

All the eight individual indices as explained earlier are expressed on a scale from 0 to 100, where 0 indicates the worst imaginable condition and 100 stands for a totally natural environment. The target level does not necessarily be 100 since compromise between development and environmental protection leads to the acceptance of some degree of deterioration. For each index a different target value may be selected, depending on local conditions. The targeted values of each individual indices is rescaled so as to fall on a circle, "AMOEBA" (Ten Brink et al 1991). Thus one can immediately see which index is falling short of or exceeding the target.
The sector size can also vary according to the weightage of the corresponding index, and may depends on the local regional or national values and views. For the time being the weightage of the indices are kept equal.

Application of amoeba in water pollution control

Rational formulation of any pollution control program for a water body needs to define water quality objectives (target) for that water body in a sound scientific manner. These objectives are used as yardstick to identify the areas in need of restoration, extent of pollution control needed, prioritization of pollution control programme and effectiveness of pollution control efforts. Using the Yamuna River's 3 years data on the water quality the indices are calculated and presented in the "AMOEBA" form. The suggested target values for NPI, OPI, IPI, PPI, BSI, BDI and PRI are 90, 80, 60, 80, 80, 70, 70 and 80 respectively. These targets are suggested based on various water quality objectives identified by the CPCB under its various pollution control programmes. An example of how the proposed yardstick can be applied in the field of pollution control is given in Table 2.

This yardstick so developed is proposed to be validated in other river systems of India during the year 1992-93.If found suitable the yardstick is proposed to be introduced in the legislative framework of pollution control in India.

Table 2: Example of application of yardstick in pollution control.

Stretch	Value not fulfilling the target	Major cause for degradation	Action required
Palla to Wazirabad	BPI	Faecal coliform	Control of sewage from drain no.8 in Haryana
Hindon from Ghaziabad to confluence with Yamuna	BPI, BSI, PRI, NPI, OPI, PPI	Sewage and industrial wastes	Control of sewage and industrial wastes from Ghaziabad
Wazirabad Barrage to Okhla Barrage	BPI, NPI, OPI, PRI, BSI, BDI	Sewage and industrial wastes.	Control of sewage and industrial waste of Delhi
Okhla Barrage to Chambal Confluence	BPI, NPI, OPI, PRI, BSI, BDI	Sewage and Industrial wastes	Control of Shahadara Drain and Mathura-agra drains
In the city limits of Mathura, Agra and downstream of Delhi (20-30 km stretches)	BPI, NPI, PRI, OPI, BSI, BDI	Sewage and industrial wastes	Control of Shahadara and Mathura Agra sewage inflows

Biological mapping of water bodies

Water quality mapping is the most important exercise for the Pollution Control Boards to establish magnitude of water quality degradation in different water bodies in the country. It helps in the identification of water bodies which are in need of improvement, as well as the extent of pollution control needed. It also helps in formulation of pollution control programs in a rational manner. Giving a proper advise to Central and State Government in various pollution control policies is also supported by such mapping activities. CPCB has attempted mapping of some of the rivers in the country using biological information.

Major constraint in implementation of biomonitoring

The yardstick methodology is now validated on many water bodies in the country. Now 14 states have adopted the biomonitoring in their monitoring programme. However, many state are not able to adopt it or carry it on regular basis due to the following main constraints:

– Lack of taxonomic skill in many State Polution Control Boards
– Lack of manpower
– Lack of resources
– Lack of awareness.

Conclusion

Biomonitoring has several advantages. It can help in evaluation of environmental damage caused by an activity. is important to use biomonitoring techniques in environment impact assessment. It is less expensive, more informative and convincing. Biomonitoring results can be used to:

– identify environmental problems.
– establish priorities for pollution control efforts.
– set discharge limits for effluents.
– identify & implement appropriate control measures.
– monitoring compliance with regulatory limits on ecosystem degradation.

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Aquatic macroinvertebrates as bio-indicators: A new approach for river water quality assessment in Bangladesh

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Abstract

Aquatic macroinvertebrates are insects and non-insects that live on the bottom of the stream and river bed. Aquatic macroinvertebrates as bio-indicators are unique environmental indicators to provide a signal of the biological condition in a watershed and used as an early warning of pollution in an ecosystem. This study introduces Multi Habitat Sampling (MHS) (Moog 2007) and Rapid Field Bio-monitoring protocol (Hartmann and Moog 2008) and HKHBIOS score (Ofenböck et al. 2008) for assessing the river water quality. The results derived from the ASSESS-HKH project (funded by the European Union (Contract number: INCO-CT-2005-003659). The benthic macroinvertebrates analysis has been carried out at 34 sites on 25 North-west regional rivers of Bangladesh. The selected sites represent a gradient of river pol-lution from less polluted to moderate polluted to severely degraded stretches of rivers to be able to as-sess biodiversity and thereby the health of rivers. 74 families, 5 sub families, 12 genus and 3 species of aquatic insects and non-insects have been studied using correspondence analysis. These species are af-fected by various short-term environmental stressors throughout their different life stages. Some of these stages are more sensitive than others to particular stressors. They respond quickly to stress in a sensitive life stage. Mayflies and caddisflies are generally intolerant of pollution. Large number of these insect in a sample indicates good water quality. On the other hand, pollution-tolerant organisms such as non-biting midges, worms and some molluscan present in a sample signify bad water quality. This study is pre-sented the sensitivity and tolerances levels of these macroinvertebrates to type of pollution. Bio-indicators focus on biological points of view to guide water quality assessment.

Key words: aquatic macroinvertebrates, stream and river bed, bio-indicators, environmental stressors, pollution, water quality.

Introduction

Aquatic macroinvertebrates are backboneless and visible without the use of a microscope. These animals are diverse organisms with varying tolerances for pollution from chemicals, toxins, nutrients, and sediment making them well suited as indicators for determining river and stream health and water quality. They are susceptible to degradation of water, sediment, and habitat. That is why they serve as good indicators of localized environmental conditions.

Freshwater benthic macroinvertebrate includes mainly three phyla, such as Annelida, Arthopoda, and Mollusca. Aquatic macroinvertebrates comprises the insects of Ephemeroptera (mayflies), (Trichoptera (caddisflies), Odonata (dragonflies/ damselflies), Heteroptera (true bugs), Coleoptera (beetles), Diptera (flies / midges) and Lepidoptera (caterpillars). Ephemeroptera, Trichoptera, Odonata and Heteroptera have aquatic larvae. The remaining Coleoptera, Diptera and Lepidoptera are mostly terrestrial, but their larval stages are aquatic or several species or entire families are adapted to aquatic environments. Aquatic macroinvertebrates also include crustaceans (e.g., copepods, crayfish and amphipods), molluscan (gastropods and bivalvia) and aquatic worms (polychaetes, oligochaetes and hirudinea).

Aquatic macroinvertebrates are affected by various short-term environmental stressors throughout their different life stages. Some of these stages are more sensitive than others to particular stressors. They respond quickly to stress in a sensitive life stage. A macroinvertebrate complete its life cycle from egg to adult, either complete or incomplete metamorphosis. There are four stages in complete metamorphosis (holometabolis), such as – egg, larvae, pupa and adult. They include beetles, caddisflies and true flies. Many of these macroinvertebrate are aquatic for the egg and larval stages, but not in the adult stage. On the other hand, there are three stages in incomplete metamorphosis (hemimetabolis), such as – egg, nymph and adult. They include mayflies and dragonflies. Many of these macroinvertebrate do not live in an aquatic system as adults form, such as – dragonflies. Other macroinvertebrate, such as – True bugs (e.g., water boatmen, water scorpions and backswimmers) go through a gradual metamorphosis (paurometabolis) with an egg, nymph, and adult. A macroinvertebrate can survive less than two weeks, such as- some midges and mosquitos. On the other hand, some dragonflies can survive more than two years. This complicated life cycles that allow them to reflect overall ecological status of rivers.

The present study is to identify the number of different types of macroinvertebrate and used them as bioindicator to assess

the ecological status of selected rivers in Bangladesh. It is expected that greater taxa richness generally indicates better water quality. Many types of benthic macroinvertebrates are sensitive to pollutants such as organic wastes. Mayflies and caddisflies are generally intolerant of pollution. If a large number of these insect types are collected in a sample, the water quality in the river or stream is likely to be good. If only pollution-tolerant organisms such as non-biting midges and worms are found, the water is likely to be polluted. Therefore, aquatic macroinvertebrates were selected as the bio-indicators for the following reasons:

1. Aquatic macroinvertebrates are good indicators of localized conditions of water quality due to their limited mobility.

2. They have a wide range of pollutant tolerances among the various species.

3. They are well suited for the assessment of site-specific pollution impacts.

4. When monitored together with relevant chemical/ physical parameters, benthic macroinvertebrate can be used to identify sources of impairment.

5. There are a large number of species that are sensitive to environmental impacts from both point and non-point sources of pollution.

6. A biologist who is experienced in macroinvertebrates identification, able to assess the environment whether the river water quality has been degraded by identifying changes in the aquatic species structure of the river water resource.

7. Sampling procedure is relatively easy, not expensive and does not adversely affect other organisms.

8. Sampling process under rapid field bio-assessment protocol requires few people and minimal equipment.

9. Macroinvertebrate serves as the primary food source for many species of fish and fisheries. Thus, they provide information about disturbances in nutrient cycling throughout the aquatic ecosystem.

Methods

ASSESS-HKH Methodology Manual used as biological assessment method which is HKHbios: Score Bio-assessment method (Ofenböck et al. 2008). This score-based assessment method based on higher taxonomic bio-indication units (order, family and ge-nus). Taxa composition provides an indication of the overall ecological status of a site. A research entitled "Development of an Assessment System to Evaluate the Ecological Status of selected Rivers in the Hindu Kush-Himalayan Region" (ASSESS-HKH) is underway with participation of researchers of BUET to-gether with scientists from several countries in Asia and Europe.

Aquatic life samples are collected upstream and downstream of all selected rivers as well as from relatively undisturbed and unpolluted water bodies. Samples have been collected in two seasons: pre-monsoon (March/April) and post-monsoon (Novem-ber/ December) 2006. 34 sites were selected for samples on 25 regional rivers (Shown in table 3) in the north-eastern region of Bangladesh. The sam-pling procedure follows the multi-habitat approach that is the distributions of sampling units follow the distribution of habitats (Moog 2007). Twenty units samples were collected for multi-habitat sampling for the assessment of river water quality. Sampling starts from the most downstream point of the in-vestigated section to avoid a self made turbidity which would hamper the sampling.

Table 1: ASSESS-HKHbios score index for Bangladesh.

Ephemera sp., Ephemeridae, Potamanthidae, *Prosopistoma sp.*	10
Baetis sp., Hydropsychidae, Hydroptilidae, Limnocentropodidae, Synlastidae	9
Baetiella sp., Brachycentridae, Glossosomatidae, Glossosomatinae, Lepidostomatidae Neritidae, Orthocladiinae, *Platybaetis sp.*, Scirtidae, Talitridae, Tipulidae	8
Caenidae, *Caenis sp.*, Corydalidae, Ephemerellidae, Gyrinidae, Microchaetidae, *Pisidium sp.*, Potamidae, Pyralidae, Simuliidae, Sisyridae, Tabanidae	7
Atyidae, *Brachycentrus sp.*, Ecnomidae (*Ecnomus sp.*), *Gyraulus labiatus*, *G. convexicusculus*, Haliplidae, Libellulidae, Mesoveliidae, Mysidae, Nepidae, Nereididae, Palaemonidae, Parathelphusidae, *Pila globosa*, Planorbidae, Pleuroceridae, Psychodidae (black), *Sigara sp.*, Sphaeriidae, Unioniidae, Viviparidae	6
Bithyniidae, Cloeoninae, Coenagrionidae, Corduliidae, Dipseudopsidae, *Lamellidens sp.*, Nephthydae, Protoneuridae	5
Corbiculidae, Glossiphoniidae, Lymnaeidae, Noteridae, Thiaridae, Tanytarsini	4
Naididae, Notonectidae, Salifidae	3
Ceratopogonidae, Dolichopodidae, Oligochaeta, Physidae	2
Chironomidae (red), Ephydridae, Psychodidae (White), Syrphidae,Tubificidae	1
Amblemidae, Ampulariidae, Belostomatidae, Corixidae, Culicidae, Curculionidae, Dytiscidae, Gammaridae, Gerridae, Hydrophilidae, Micronectidae, *Micronecta sp.*, Pleidae, Ranatrinae, Velliidae	0

Table 2: Transformation table of HKHbios values to describe the saprobic water quality.

For lowland HKHbios/ ASPT value obtained	Water quality classes	Ecological status classification	Colour code	WQ characteristics degree of organic pollution
6.00-10.00	I	High	Blue	None to very slight organic pollution
5.00-5.99	II	Good	Green	Moderate pollution
4.00-4.99	III	Moderate	Yellow	Critical pollution
2.50-3.99	IV	Poor	Orange	Heavy pollution
1.01-2.49	V	Bad	Red	Very heavy to extreme pollution
No higher aquatic life		Severe	Black	Severe organic pollution

Each sample unit is regularly emptied into a white tray before the sample unit from the next habitat is added. Macroinvertebrate were sorted and put a variety of them into a Petri dish. Leaves and twigs are thoroughly washed into the bucket and poured through the recommended net. Then samples were preserved in container with formaldehyde in the field. The container was marked with a label that contains the name of the sampling site, sampling code, river name and date. After one week of fixa-tion, samples were sorted, identified up to the low-est taxonomic levels in the lab and additional taxa were included in the taxalist that was prepared in the field. The sorting procedure followed Hartmann et al. 2007).

Results

During the period of study both in 1st and 2nd sampling 74 families, 5 sub families, 12 genus and 3 species of aquatic macroinvertebrates were identified from 34 sites in 25 rivers. The HKHbios Score of the identified taxa have been presented in Table1. The benthic macroinvertebrates as bio-indicators were used to determine the water quality status and classify the rivers in Class I, II, III, IV or V based on ASSESS-HKHbios Score Index. Water quality classes, classification of ecological status and colour code with WQ characteristics/degree of Organic Pollution shown in Table 2.

For assessment the communities have been divided into five groups – very sensitive organisms, sensitive organisms, medium tolerant organisms, tolerant organisms and extremely tolerant organisms. These indicator species are one kind of biological resources that were used to assess environmental condition. Individual family is used as an effort to assess water quality conditions. Less polluted river and streams generally have a higher Mayfly and caddisfly richness. The Mayfly and caddisfly richness are a useful indicator of river and stream health.

The HKHbios scores were applied for assessment of river water quality status. Pollution tolerance values are specifically assigned to each major group of organisms. Different types of macroinvertebrates have a different tolerance to pollution.

Discussion

Rivers of North-west region are critical pollution to very heavy to extreme pollution due to industrial effluents, wastewater, municipal sewage disposal, faecal contamination, agrochemicals and large amount of suspended sediments carried by upstream flow. In 1st sampling the table data shows that 53% of the total sample sites lie in WQC II, followed it by WQC III. There are five sites falling in WQC I and a single sample site belonging to WQC IV. Similarly, in 2nd sampling 50% of the total sample sites lie in WQC III and 35.3% followed in WQC IV. There are two sites falling in WQC IV and V respectively and a single sample site belonging to WQC I. This indicates that most of the river water is moderate to critically polluted. Among the sampled rivers, the Tarai, Boraghat, Chellyakhali, Bhogai and Banar are none to very slight organic polluted in 1st sampling. But the water quality of these rivers became moderately polluted in 2nd sampling due to agricultural runoff. Most of the rivers (given in table 3) contain all water quality classes, ranging from II to III. It has been observed that the rivers are found to be polluted by faecal contamination, agro-chemicals, washing and bathing. The condition of Buriganga being the worst with fowl smell. Water of such a river is not suitable for any useful purpose except navigation.

Tolerance levels are the ability of the benthic macroinvertebrate to tolerate various forms of stress, such as - low dissolved oxygen, high amounts of siltation and varying amounts of toxic chemicals. Taxa are associated with pollution tolerances. The levels of tolerance are the observation of the predominance of certain taxa in specific water quality conditions. Gastropoda and Bivalvia tolerate a wider range of organic pollution. Ampulariidae, Planorbidae, Viviparidae, Pleuroceridae, Sphaeriidae and Unionidae indicate moderately tolerant of organic enrichment. The species of these families were found in water quality class III and even in heavily polluted running waters of class IV. Bithyniidae, Lymnaeidae, Thiaridae and Corbiculidae are abundant in waters enriched with organic nutrients and low in dissolved oxygen. Some species of these families are very tolerant of poor water quality and used as indicators of pollution. The species of these families usually found in class III to IV water, an indicator species for critical to heavy pollution. Physidae was found in

water quality class IV and even in very heavy to extremely polluted running waters of class V.

Aquatic worms under Annelids are very common in streams and rivers. They are tolerant of bad or poor water quality and very heavy to extreme pollution. Many aquatic worms tolerate low dissolved oxygen and found in large numbers in organically polluted habitats. Family Nephthydae under Polycaeta found in the sand and mud substrate of river bed and found in water quality class III and even in heavily polluted running waters of class IV. Oligochaetes under annelids are common in most freshwater habitats and display the greatest diversity and have the greatest indicator value. The species of Microchaetidae family are moderate water quality indicator with critical organic pollution. Two families, Naididae and Tubificidae form 80 to 100% of the annelid communities in the benthos of most streams and lakes at all trophic levels (Mackie, 2001). Tubificidae are deposit feeders

Table 3: River name, site name and water quality class of 1st and 2nd sampling.

		1st sampling		2nd sampling	
River name	Site name	Site code	WQ class	Site code	WQ class
Balu	Ichhapura	B01BA014	III	B01BA021	IV
Turag	Ashulia	B01TU014	III	B01TU021	III
Old Brahmaputra Br.	Olipura Dn.	B01TJ014	II	B01TJ021	III
Sutia	Kaoraid	B01SA014	II	B01SA021	III
Khiru Up	Kaoraid	B01KA014	III	B01KA021	III
Khiru Dw	Dhamsur	B01KB014	III	B01KB021	III
Rangsha	Tarakanda	B01RA014	III	B01RA021	II
Khuria Dw	Amuakanda	B01KX014	II	B01KX021	III
Khuria Up	Dew Gram	B01KY014	II	B01KY021	III
Boraghat Dw	Haluaghat Dn.	B01BX014	II	B01BX021	III
Tarai	Munshir Hat	B01TA014	I	B01TA021	III
Gangina	Gangina Par	B01GA014	II	B01GA021	III
Melang	Mazracora	B01ME014	II	B01ME021	II
Boraghat Up	Butiapara Up.	B01BZ014	I	B01BZ021	II
Jhenai Dw	Charpolisha	B01JA014	II	B01JA021	II
Jhenai Up	Chandra	B01JB014	II	B01JB021	III
Chellyakhali	Shonnyashi Vita	B01CH014	I	B01CH021	II
Bhogai	Noyabil Hatipagar	B01BO014	I	B01BO021	I
Bhogai Rb Dw	Jamirakanda	B01BP014	II	B01BP021	V
Bhogai Ra Up	Jamirakanda	B01BQ014	II	B01BQ021	II
Bhaitkamari	Tallukpara	B01BH014	III	B01BH021	II
Katakhali	Garaikuti	B01KC014	III	B01KC021	III
Banar	Harinatala	B01BR014	I	B01BR021	II
Bongshai Dw	Modhupur	B01YB014	III	B01YB021	V
Bongshai Up	Modhupur	B01XB014	III	B01XB021	III
Fotikjani	Hamidpur	B01FO014	II	B01FO021	II
Lohojang	Gunotia	B01LO014	II	B01LO021	II
Pungli	Pungli village	B01PU014	II	B01PU021	III
Lohojang	Korotia	B01LP014	II	B01LP021	IV
Bongshi branch	Pushto Kamzi	B01BB014	III	B01BB021	II
Bongshi	Shutrapur	B01BS014	II	B01BS021	III
Old Brahmaputra Br.	Olipura Up	B01TV014	II	B01TV021	II
Tributary to Old Br.	Olipura	B01TC014	II	B01TC021	III
Buriganga	Postogola	B01BG014	IV	B01BG021	no

N.B.: B-Country name: Bangladesh; 01-Ecoregion: lower Gangetic Plains (IM0 120); BA-River name: Balu; 01-1st sampling and 4-Post monsoon (winter); 02-2nd sampling and 1-Pre monsoon (summer).

and most commonly found in soft sediments rich in organic matter. Some species under Tubificidae family live in sites that receive organic pollution and tolerate anoxic conditions. They are usually found in class IV to V water, a good indicator species for high pollution and tolerate higher organic pollution. Aquatic worms of Naididae family are ecologically diverse and common in both running and standing waters. Many species of these worms are sediment dwellers, surviving on organic detritus.

The species of family Glossiphoniidae found attached to stones and floating substrate macrophytes in river and found in water quality class III and class IV. Salifidae is common in very heavy to extremely polluted river and stream and indicates water quality class V.

Crustacea are intolerant or moderately tolerant of organic pollution. Atyidae, mysidae, palaemonidae, potamidae, parathelphusidae and talitridae live in clean water and moderately tolerant of pollution. Most species of these families found in water quality class II and even in critically polluted running waters of class III.

Ephemeroptera commonly known as mayfly nymphs are often abundant wherever the water is clean. They are sensitive to various types of water pollution, including low dissolved oxygen, ammonia, biocides, and metals. Baetidae commonly known as small minnow mayflies indicates moderately tolerant of organic enrichment. The presence of *Cloeon sp.* in large numbers is usually an indication of good water quality. Ephemeridae popularly known as common burrowers, are moderately tolerant of organic pollution, but are sensitive to low dissolved oxygen levels. *Ephemera sp.* is very intolerant of pollution and indicates good water quality. Most larvae of Caenidae are intolerant to moderately intolerant of organic pollution. *Brachycercus sp.* and *Caenis sp.* are fairly good water quality indicators. The larvae of prosopistomatidae are intolerant to moderately intolerant of organic pollution. *Prosopistoma sp.* is fairly good water quality indicators.

The larvae of odonata exhibit a range of sensitivities to pollution, depending on genus or species. Some are good water and some are moderate water quality indicators. Synlestidae, coenagrionidae, corduliidae, libellulidae and protoneuridae larvae are intolerant of pollution and are moderate water quality indicators.

Some species of heteroptera are very pollution tolerant and some species are sensitive. Belostomatidae, corixidae, gerridae, veliidae, micronectidae and pleidae are not very useful indicators of water quality as they are common in river and streams. Mesoveliidae and nepidae are moderately tolerant of organic pollution and indicates moderate water quality indicators. Some species of notonectidae are very tolerant of pollution.

Coleoptera commonly known as beetle's larva those are common in well oxygenated and swiftly running waters. Many species of coleoptera are known as "riffle beetles." They are usually indicative of clean water and sensitive to organic and inorganic pollutants. The species of curculionidae are common in river and streams and they are not very useful indicators of water quality. Dytiscidae are less informative for river and stream water quality, because both adults and larvae breathe air. The beetles of gyrinidae are moderately intolerant of organic pollution. Haliplidae beetles indicate moderate ecological status. The species of hydrophilidae are not considered important water quality indicators. Noteridae larvae live in fairly clean water and they are only moderately tolerant of pollution.

Trichoptera commonly known as caddisfly larvae, many of which build portable cases of stones, sticks, sand and other detritus. They are intolerant of water pollution and their presence indicates good water quality. The larvae of dipseudopsidae are very intolerant of organic pollution and are good water quality indicators. The larvae of ecnomidae are intolerant of organic pollution and they are also good water quality indicators. The larvae of hydropsychidae are moderately tolerant of organic pollution but a few are sensitive to pollution. The larvae of hydroptilidae are intolerant of organic pollution and indicate a good water quality. The larvae of leptoceridae are moderately intolerant of organic pollution.

Most larvae of pyralidae under lepidoptera are intolerant or moderately intolerant of organic pollution, making them good water quality indicators.

Diptera are moderately tolerant to very tolerant of organic and inorganic pollution. Some species are very pollution tolerant and some species are very sensitive. Chironomidae commonly known as midges, are the most common of aquatic invertebrates of rivers and streams. Many species are very tolerant of pollution and midge larvae may indicate multiple

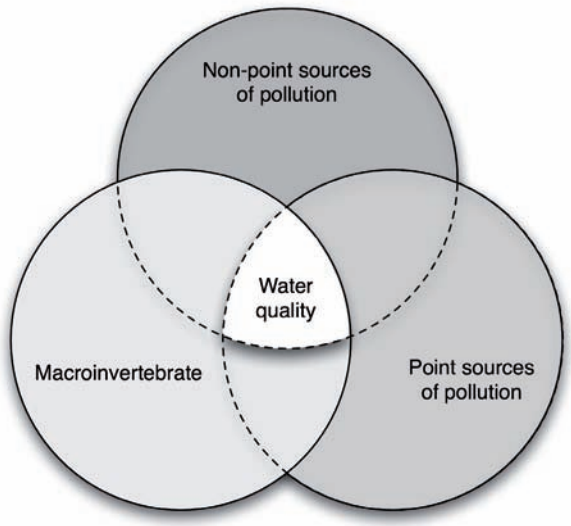

Figure 1: Interrelationship among macroinvertebrate, pollution and water quality.

stressors. Mosquitoes of culicidae are not considered important water quality indicators. Dolichopodidae are tolerant of organic pollution and indicates poor river water quality. Ephydridae are tolerant of organic pollution and indicates bad river water quality. Psychodidae are moderately tolerant of organic pollution and indicates moderate river ecological status. Syrphidae are very tolerant of poor water quality. Tabanidae are moderately tolerant of organic pollution and indicates good river water quality status.

Bioindicators are the groups of benthic macroinvertebrate that indicates symptoms that they are affected with environmental degradation due to human activities. Benthic macroinvertebrates respond to a change in aquatic environment conditions. Biological monitoring method told how healthy the water body is based on the amount and types of aquatic macroinvertebrates living in a water body. The amount and types of macroinvertebrates living there change when water bodies are polluted. For example, a polluted stream often lack pollution-sensitive organisms like mayflies and caddisflies and have more pollution-tolerant organisms like snails and leaches. Adjustments are possible in practices and structure of ecosystem to project/changes of aquatic environment. Some benthic macroinvertebrates are modified their morphological and physiological structures to adapt with the changing environment.

Aquatic ecosystem depends on sensitivity of aquatic organisms and ability to adapt to a new environment. Polluted water damage and harm aquatic organisms. Tolerable benthic macroinvertebrates survive in polluted water and intolerable macroinvertebrates unable to survive in polluted water. Therefore. It is proved that macroinvertebrates survivility depends on point and non-point sources of pollution and availability of macroinvertebrates reflect overall water quality of rivers shown in figure 1.

Conclusions

Bio-indicators were used to assess the health of streams and rivers by evaluating the composition of aquatic benthic macroinvertebrate. This method indicates how healthy the water body is based on the amount and types of aquatic macroinvertebrates living in a water body. The amount and types of benthic macroinvertebrates living there change when water bodies are polluted. Lower taxa are sensitive to habitat changes.

Oxygen, toxic chemicals, nutrients and habitat quality are the factors that affect the benthic macroinvertebrates. The chemical measures of river water quality are indirect ways to determine the health of a water body. Beside these, traditional measures sometimes create effects on aquatic life. From this point of view, bio-indicator is the best way for detecting aquatic life impairments and assessing their relative severity. Bio-indicators play an integral role as unique environmental indicators to provide a signal of the biological condition in a watershed and used as an early warning of river water pollution in an ecosystem. Some types of coleoptera may actually be found in waters that are not so clean, and likewise some types of worms and midges can be found in cleaner waters. So it is important to understand the decisions methods to determine whether waters are healthy or polluted for aquatic life.

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River water quality pressures, impacts and policies in the Hindu Kush-Himalaya

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Abstract

Water is the most important natural resource for the environmental conservation and development in the Hindu Kush-Himalayan countries including Bangladesh, Bhutan, India, Nepal and Pakistan. Most of the large rivers are originating from the Himalayas and they therefore are perennial rivers. Over the last few decades the river stretches in the Hindu Kush-Himalayan countries have experienced a variety of pressures due to use of river water in different types of development activities such as drinking and bathing, irrigation, fishing, transport, hydro electricity, industries, and socio-cultural activities. Intensity of these activities has been increased due to rapid growth of population, haphazard urbanization, agricultural production, wastes dumping, direct discharge of effluents, etc. As a result, the river ecology has been degraded in most cases due to loss of biodiversity (animal species) and diminishing of aesthetic value of the river environment. Efforts of the governments of the HKH countries have been made towards conservation and development of the river stretches in terms of environmental policies, acts and programmes. These efforts however appear to be inadequate.

Key words: conservation, Himalayas, perennial, haphazard, urbanization, river ecology.

Background

The Hindu Kush-Himalaya (HKH) region in the South Asia consists of three major river systems, such as the Indus, the Ganges and the Bramhaputra. These rivers drain the South Asia's five countries, including Bangladesh, Bhutan, India, Nepal, and Pakistan. This watershed region stores one of the largest freshwaters in the world, supplying the needs of about 1500 million people living in the South Asia. The three rivers also contain sacred places for religious and cultural importance.

The watershed region is characterised by permanent snow, lofty mountain peaks, and glaciers. The permanent snow line begins from about 5,000 m, the highest elevation in the earth. The region has lofty mountain peaks, including the Mt. Everest with elevation of 8,848 m of Nepal, the highest peak in the world. Some of the longest glaciers in this region include the Batura glacier in Karakoram of Pakistan. With these features, the region offers a unique potential of river water development.

Further, the HKH region is also characterised by change in altitude within a short horizontal distance, which provides both advantages and problems in terms of river water resource development. The south-west monsoon is one of the sources of water of the rivers of HKH region, which is however seasonal in character, bringing precipitation with about 80 percent in few summer months (June – September) and the other months of the year remain dry. Since the monsoon rainfall is orographic in nature, the eastern part of the region that encounters first with this moist laden monsoon wind gets abundant precipitation and the amount decreases as it moves west ward. Thus, there is a great variation in the water supply to the rivers from this wind. The western HKH region however receives showery precipitation caused by the western disturbances during the dry months from November to March. Thus, the whole activities dependent on the river water in the HKH region have to cope with either 'too much' or 'too little' water in different seasons of every year.

On the other hand, the HKH region has one of the highest population densities in the world. The growth of population is rapid and the number and size of urban areas are also growing rapidly. Large urban areas are growing rapidly in a haphazard manner. Along with this, the use of river water is intensified for different purposes such as drinking, irrigation, industry, and transportation, as well as for dumping places for wastes and effluents. The intent of this paper to portray the state of the HKH region's river stretches, including

the Indus, the Ganges, and the Bramhaputra in the HKH countries in the framework of pressure, impact and policy components.

Methods

The paper is based on the methods and tools adopted for the project development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region (ASSESS-HKH), jointly by the Asian and European partners (Moog et al. 1999, Moog & Sharma 2005). The project consists of eight work packages to achieve its all activities. Of these, the Work Package 3 is to analyse the overview of driving forces or pressures and impacts on the rivers and the policy measures undertaken by the respective HKH countries towards development and conservation of the river stretches in their own areas. This paper draws on information of the study reports on the river stretches prepared as a part of the Work Package 3 by the HKH countries during the preparation of Work Package 7 of the project. The methodology thus adopted is made compatible among the partner countries.

Analysis of the river stretches

General features of the HKH countries

The five countries including Bangladesh (BG), Bhutan (BT), India (IN), Nepal (NP), and Pakistan (PK) represent extreme conditions in terms of area and population, as well as in the availability of water resources. India is the largest both in terms of area and population, whereas Bhutan is the smallest in both cases (Table 1). Bangladesh has the highest density of population (969/km²), while Bhutan has the largest forest coverage (72.5%), but lowest population density of only 17 persons per km². Bangladesh has the largest coverage of agricultural land, but the least coverage of forest. There is largest soil loss in India, which is 5.3 billion tons per year. Both Nepal and Pakistan lie in between these extremities.

Table 2 indicates that, though the total annual renewable surface water availability is the lowest in Bhutan, its per capita availability is highest, which is due to relatively small population size with its area. Two larger countries, India and Pakistan have very low per capita renewable surface water, the amount being ≤2,000 m³/year, as compared to other three smaller countries, Bangladesh, Bhutan and Nepal. However, annual per capita renewable water availability is misleading, because 80 percent of water flows during monsoon season, which is neither being used nor stored, especially in a flat country like Bangladesh. Instead, if the seasonal per capita water were available, it would have better depicted the situation of the river water renewable. Bhutan has not only the highest per capita withdrawal of water, but also a fair distribution of use of water among the three important sectors, such as domestic, industry and agriculture. Nepal has the least proportion of water withdrawal for industry, among the five countries.

The state of the socioeconomic parameters in the HKH countries is shown in Table 3. It is known that the HKH countries are primarily rural countries, with over 70 percent people residing in the rural areas. In other words, the HKH countries are the least urbanised countries in the world. The urbanised ratio among the HKH countries ranges from 14 percent in Nepal to 29 percent in Pakistan. Not a single country of the HKH region has 100 percent coverage of drinking water

Table 1: State of area, population and some resources of HKH five countries. Sources: SOE Bangladesh (2001), SOE Bhutan (2001), SOE India (2001), SOE Nepal (2001), SOE South Asia (2001).

HKH Countries	Area (x10³ km²)	Forest coverage (%)	Agricultural land (%)	Population		Soil loss (billion tons/year)
				Growth %	Density/km²	
Bangladesh	148	11.0	64.2	1.4	969	2.40
Bhutan	40	72.5	7.7	3.1	17	-
India	2,973	21.9	47.0	2.0	336	5.30
Nepal	147	29.5	20.0	2.1	156	0.64
Pakistan	803	3.0	35.0	1.8	187	NA

Table 2: Surface water availability and its use in the five HKH countries. Sources: SOE Bangladesh (2001), SOE Bhutan (2001), SOE India (2001), SOE Nepal (2001), SOE South Asia (2001), ICIMOD/ASSESS-HKH (2005).

Description	BG	BT	IN	NP	PK
Total annual renewable water availability (km³/y)	1,134	39	1960	224	171
Per capita renewable water (m³/y)	9,000	58,930	2,000	10,300	1,309
Total annual withdrawal (km³/y)	34	0.8	350	16.7	186.2
Per capita withdrawal (m³/y)	275	1200	359	760	NA
Domestic % withdrawal of total	3	36	3	3.4	4.3
Industry	1	10	4	0.3	0.7
Agriculture	96.0	54.0	93.0	96.3	95.0

Table 3: Water supply and sanitation indicators, HKH countries. Source: UNICEF (2004).

Indicators		BG	BT	IN	NP	PK
Population (2002)	Total (million)	146.7	0.67	1,065.5	25.2	153.6
	Rural (%)	75	85	72	86	71
	Urban (%)	25	15	28	14	29
	Popn/km^2	994	17	358	171	191
Water supply coverage (2002)	Total (%)	75	62	86	84	90
	Rural (%)	72	60	82	82	87
	Urban (%)	82	86	96	93	95
Sanitation (2002)	Total (%)	48	70	30	27	54
	Rural (%)	39	65	18	20	32
	Urban (%)	75	70	58	68	92

supply. Pakistan has the highest water supply coverage with 90 percent, while Bhutan has the lowest with 62 percent. In all HKH countries, the water supply coverage in the urban areas is higher than that in the rural areas. The urban water coverage ranges from 86 percent in Bhutan to 96 percent in India. The performance of sanitation coverage also is poor in the HKH countries, showing 27 percent in Nepal to 70 percent in Bhutan. In case of the urban areas, it is highest in Pakistan with 92 percent (SOE South Asia 2001, UNICEF 2004). Despite the largest fresh water reserve, the HKH countries have poor capacity in the exploitation of water for household supply, which is the basic essential of the people. The water and sanitation can be related to the demographic features of the HKH countries. The health status of the people can be measured by state of the water supply, which in turn determines the demographic pattern. Table 4 shows that HDI, including parameters such as literacy, mortality, access to facilities, etc., is at around 0.5 for four countries except India which has around 0.6. This means that on the whole, the HKH countries are poor in showing basic social and economic indicators.

Impacts of the environmental components

The major environmental priority areas as shown in Table 5 are derived from State of the Environment Report, 2001 of each of the HKH countries. All HKH countries have considered the priority areas of the first three environmental components such as water pollution, air pollution, and forest depletion, whilst they differ in other components. While Pakistan has given priority to all 12 types of environmental components as listed in Table 5, Bhutan has given to only first five components. Nepal has six priority areas, including first five components like Bhutan with adding up of solid waste management.

River water pressure

Three broad pressure factors are: (a) land use change (b) waste and (c) climate change related to GLOF, which have been obtained from the SOE reports of HKH countries. Under these broad types, a total of 12 main pressure factors of river water quality are shown in Table 6. The common pressure factors for all countries are rapid and haphazard urbanization, hazardous waste, and domestic effluents followed by industrial and agricultural effluents. If an index is made, eight out of 12 (8/12 = 0.67) pressure factors exist in three countries such as Bangladesh, Nepal and Pakistan, whereas Bhutan has relatively better index value (5/12 = 0.42).

River water quality impacts

It is mentioned in the earlier section above in Table 6 that Bhutan has relatively fewer factors than other four HKH countries, but in terms of impacts on the river water quality, it has the largest number of factors that have affected the river water. Nepal with similar geographical features of Bhutan such as mountainous and landlocked has also the same number of impacts on its river quality. Both countries have index value of 0.7 (7/10), whereas Bangladesh and India have an index value of 0.3. Table 7 lists a total of 10 impacts under four broad groups. The impact of river water quality and quantity is shown by the occurrence of water borne diseases in all the five countries followed by eutrophication and depletion of water sources and aquatic biodiversity (Table 7).

River water conservation policy measures

The counties of the HKH region are the signatories of many global conventions. It seems that the international convention especially the Earth Summit held in Rio in 1992 has

Table 4: Demographic indicators of HKH countries. Sources: SOE Bangladesh (2001), SOE Bhutan (2001), SOE India (2001), SOE Nepal (2001), SOE South Asia (2001).

Indicators	BG	BT	IN	NP	PK
Mortality < 5 per 1000 live births	69	85	87	82	103
Maternal mortality rate/10000 live births	380	260	540	740	500
Life expectancy at birth	62	63	59	60	61
Gross national income per capita (US$)	400	660	530	240	470
Adult literacy rate - male (%)	49	61	68	59	57
Adult literacy rate - female (%)	30	34	45	24	28
Human Development Index (HDI)	0. 547	0.579	0.619	0.532	0.551
Population below poverty line (%)	36	NA	35	38	13

Table 5: Comparison in major environmental priority areas, HKH countries. Note: 1= yes, - = not applicable. Sources: SOE (2001), Kahlown & Azam (2004), ICIMOD/ASSESS-HKH (2005).

Environmental components	BG	BT	IN	NP	PK	Total
Water quality/pollution	1	1	1	1	1	5
Air pollution	1	1	1	1	1	5
Forests/depletion	1	1	1	1	1	5
Land degradation/soil erosion	1	1	1	1	1	5
Bio-diversity	1	1	1	1	1	5
Marine resources incl. inland fisheries	1	-	-	-	1	2
Solid waste management	1	-	1	1	1	4
Energy /renewable/alternate	-	-	-	-	1	1
Climatic variation	-	-	-	-	1	1
Hazardous wastes	1	-	1	-	1	3
Salinity	1	-	-	-	1	2
Water logging	1	-	-	-	1	2
Total	10	5	7	6	12	40

Table 6: Pressures on the river quality, HKH Region. Note: 1 = yes, - = not applicable. Sources: SOE (2001), ICIMOD/ASSESS-HKH (2005).

Pressure factors		BG	BT	IN	NP	PK	Total
Land use	Rapid and haphazard urbanization	1	1	1	1	1	5
	Increase in slums/squatter settlements	-	1	-	1	-	2
	Increment in industrial activities	1	-	-	-	1	2
	Intensive use of agriculture land	-	1	1	-	-	2
Waste	Hazardous waste	1	1	1	1	1	5
	Industrial effluent	1	-	1	1	1	4
	Domestic effluents	1	1	1	1	1	5
	Agricultural effluents	1	-	1	1	1	4
	Solid waste	-	-	1	1	1	3
	Seaports-oil and lube spillage	1	-	-	-	-	1
	Salinity intrusion	1	-	-	-	1	2
Climate change	Glacial lake outburst floods (GLOF)	-	-	-	1	-	1
Total		8	5	7	8	8	36

Table 7: Impacts on the river water quality, HKH Region. Note: 1= yes, - = not applicable. Sources: WRA (1992), WAPRO (1999), NDHS (2001), SOE (2001), GON/UNDP (2002), RGOB (2002), NEC (2004), RGOB (2004), UNICEF (2004).

Impacts on river stretches		BG	BT	IN	NP	PK	Total
Water quality	Eutrophication	1	-	1	1	1	4
	Destructed fish and marine aquaculture	1	1	-	-	-	2
	Disturbed aquatic bio-diversity	-	1	-	1	1	3
	Threatened/displaced fishing, boating occupants	-	1	-	1	-	2
Water quantity	Depleted water sources	-	1	1	1	-	3
	Emerged water-borne diseases	1	1	1	1	1	5
Land degradati on	Degraded land	-	1	-	-	-	1
	Decreased agricultural productivity	-	-	-	1	1	2
	Increased runoff, erosion & sedimentation	-	-	-	1	-	1
Energy source	Increase in alternate energy sources	-	1	-	-	-	1
Total		3	7	3	7	4	24

Table 8: Policy responses of river quality. Source: GOI (1974), MOWR (2000), NWP (2000), RGOB (2000), SOE (2001), DWSS (2002), NWRS (2002), CPCB (2003), GOP (2005).

Bangladesh
National Environment Policy (1992), Environment Conservation Act (1995), Environment Conservation Rules (1997), The Environment Court Act (2000), EIA Guidelines for Industries (1997), The National Policy for Safe Water Supply and Sanitation (1998), National Environment Management Action Plan (1995), National Fisheries Policy 1998, Environment Conservation Act, 1998 , EIA Guidelines for water resources (1992)
Bhutan
Set up of NEC Secretariat (1997), Water quality Baseline data (1997), Monitoring major rivers (2001-2003), Land Act (1979), Forest and Nature Conservation Act (1995), Environment Assessment Act (2000), Electricity Act (2001), Environment Assessment Act (2000), Environmental Clearance and Environmental Assessment Strategic (2002)
India
National River Conservation Plan – the Ganga and the Yamuna Rivers (1995), Water Prevention and Control of Pollution Act (1974), Water Prevention and Control of Pollution Cess Act (1977), River Boards Act (1956), Environment Protection Act (1986), Environment Protection Rules (1986), Hazardous Waste Rules (1988), and Municipal Waste Rules (1999)
Nepal
Water Resources Act (1992) and its Rules (1993), WRA (1992), Environmental Protection Act (1996) and its Rules (1997), Solid Waste Management Act (1987) and its Rules (1989), Electricity Act (1992) and its Rules (1993), Soil and Watershed Conservation Act (1982), Aquatic Animals Protection Act (1965), Patent, Design and Trademark Act (1965), Nepal Water Resources Strategy (2002), National Water Plan (2005), Nepal Water Supply Corporation Act (1989), Drinking Water Regulation (1998), Industrial Enterprises Act (1992), Irrigation Regulation (2003)
Pakistan
Environmental Protection Act (1997), National Environmental Quality Standards and Rules (2000)

Table 9: Water policy instruments. Note: 1 = yes, (1) = Not clear; IE = ineffective. Source: GOI (1974), MOWR (2000), NWP (2000), RGOB (2000), SOE (2001), DWSS (2002), NWRS (2002), CPCB (2003), GOP (2005).

Description	BG	BT	IN	NP	PK
National water policy					
National water development plan	1	1	1	1	1
Water management plan	1	(1)	1	(1)	1
Protection					
Environmental/water law	1	(1)	1	1	1
Water quality standards	1	1	1	1	1
EIA	1	1	1	1	1
Water quality monitoring programs	1	(1)	1	1	1
Implementation	IE	IE	IE	IE	IE

Table 10: Implementation mechanism of river water policy measures.
Source: SOE Bangladesh (2001), SOE Bhutan (2001), SOE India (2001), SOE Nepal (2001), SOE South Asia (2001).

Institutional framework	BG	BT	IN	NP	PK
No. of governmental organizations	several	1	several	several	several
No. of executive institutions	1	1	>2	several	1
No. of monitoring institutions	1	1	>2	>2	1
Involvement of NGOs	1	1	1	1	1
Community participation	weak	weak	weak	medium	weak
Enforcement of measures	weak	weak	weak	weak	weak
Coordination and integration	weak	weak	weak	weak	weak

forced all the signatory countries, including HKH countries to prepare Environmental Action Plan that demanded policies and laws. Table 8 lists the major policy measures related to water resources adopted and implemented by the HKH countries. It is to be noted that most of the policies, acts, rules and programs are found to be prepared by them after 1992. Though it is late, we must appreciate the efforts by the government of HKH countries to safeguard their water resources, including river. Development is inevitable and the policies made have given focus on the sustainable use of natural resources, especially river water.

Some of the HKH countries have policies and acts even before 1992 but their implementation modalities have not been effective to conserve the river water quality. Therefore, though formulating and adopting policy measures are starting point, the most important is to implement them to see their visual impacts.

The water policy instruments adopted by the HKH countries are summarized in Table 9. All HKH countries have made national water development plan, water quality standards, and water quality monitoring programmes, but not clear in other three instruments. However, whatever instruments are made, their effectiveness in implementing is found weak.

Another important aspect of policy measures is to adopt implementation mechanism. The information given in Table 10 shows that there are government organizations, as well as non-governmental organizations involved in the implementation of the policy measures formulated by the countries of HKH region. Monitoring is an important instrument for the effective implementation and achievement of the programmes' goals. All HKH countries have monitoring institutions. But they are weak in enforcement of measures, coordination and integration among different agencies, and participation of local communities.

Discussions and conclusions

Water, the nature given, is the most important resource for overall development of the countries. The HKH region's countries are rich in river as freshwater source. But ironically, they are one of the poorest regions in exploiting the water resource in the world. This indicates that the countries with plentiful nature resources are fortunate only when they exploit their natural resources for the benefit of their inhabitants in a sustainable manner.

While the freshwater source – rivers are described in terms of framework of pressures, impacts, and responses (policy measures), the state is found to be varied among the countries of HKH region. Uncontrolled population growth is seen as a major common problem, but an increased pressure on the natural resources, including river by the accelerated growth of population is the more acute problem. What is found is that the river water has been used in inappropriate manner. The conspicuous impacts are that the quality of river water is deteriorated by a variety of effluents and solid wastes and that there is virtually broken down the river ecological system and complete loss of aquatic animals, particularly when the rivers pass through the large urban areas.

The state of the river water quality in the countries of HKH region is poor indeed. The policy measures formulated and adopted by the countries are adequate and address most the basic problems related to river environment and ecological conservation, to a larger extent. But the ineffective implementation mechanism is the common problem among the countries of HKH region. There is seen a weak participation of all stakeholders, including the communities in the river water resource management.

The state of environment reports of each of the HKH countries indicates that there is lack of implementation of the formulated policy measures (programmes, acts and regulations). Further, the policy measures have grossly ignored the awareness about formulating and adopting of river water conservation among the mass people of the partner HKH countries. On top of them, there is lack of commitment of the responsible agencies to implement the policy tools in each country of the HKH region. So, it is worthwhile to develop mechanisms in such a way that the existing measures of the river water resource be implemented, rather than to formulate additional policy measures.

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River management strategy in the Hindu Kush-Himalayan Region

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Abstract

Hindu Kush-Himalaya (HKH) region including Bangladesh, Bhutan, India, Nepal, and Pakistan is the largest reserviour of freshwater in the world. River is one of the principal natural resources for different development activities, viz. drinking, sanitation, irrigation, hydro-electricity, fishing, recreation, and cremation in the HKH region. Since the last few decades, the rivers have been degraded environmentally and ecologically due to the interactive processes between human activities, water resource and environment. Efforts have been made by the HKH countries' governments to conserve and develop the river basins in terms of policy measures, programmes, acts, and implementation. Twelve major river basins representing each of the five HKH countries have been considered in this study. On the whole, the major river stressing factors include effluents, human activities and infrastructure, environmental conservation and ecological disturbances, and personal hygiene and sanitation. There exists a relationship between the types of stressing factors and five river quality classes, which is indicated by an increase in intensification of anthropogenic impacts along with the ascending order of poor water quality classes. The strategies for each of stressing factors are provided. The responsible agencies for each strategy are also provided. The results of differential impacts of the stressing factors in the case river basins provide valuable information to the river environmentalists for conserving river stretches. The methodology adopted here can be a model for conservation planning of river basins in other countries.

Key words: Hindu Kush-Himalaya, freshwater, stressing factors, strategy, anthropogenic.

Background

Three major river systems in the Hindu Kush-Himalayan (HKH) region of South Asia are the Indus, the Ganges, and the Bramhaputra. Five countries that fall within these river systems are Bangladesh, Bhutan, India, Nepal, and Pakistan. Major river basins and their watershed boundaries are shown in Figure 1.

The HKH region is one of the largest storehouses of freshwater in the world supplying the need of about 1,500 million people living in South Asia. These rivers are not only sources meeting the peoples' water needs but are also major foci for both religious and cultural activities. The mountain areas with over 5,000 m under ice and snow are located on the highest elevations of the earth. The Himalayan range contains the world's highest three peaks, including Mt. Everest with an elevation of 8,848 m, the highest peak.

All the rivers of HKH countries are originated from the mountains. They are rain-fed and snow-fed. All HKH's five countries lie in the monsoon climatic regime. Since the monsoon rainfall is erratic and over 80 percent of total precipitation occurs during the four summer months (June through September), the volume of water in the rivers fluctuates.

The HKH five countries represent extreme conditions in terms of area and population, and so is the availability of water resources. India is the largest both in terms of area and population, whereas Bhutan is the smallest in both cases (Table 1). Bangladesh has the highest density of population (969 persons/km^2), while Bhutan has the largest forest coverage (72.5%), but lowest population density with only 17 persons/km^2. Bangladesh has the largest coverage of agricultural land, but least coverage of forest. There is largest soil loss in India, which is 5.3 billion tons per year (Table 1).

Table 2 indicates that, though the total annual renewable surface water availability is the lowest in Bhutan, its per capita availability is highest, which is due to mountainous country with lowest population size. Two larger countries, India and Pakistan have very low per capita renewable surface water, the amount being ≤2,000 m^3/year, as compared to other three smaller countries. However, annual per capita renewable water availability is misleading, because 80% of water flows during monsoon season (June - October) which can neither

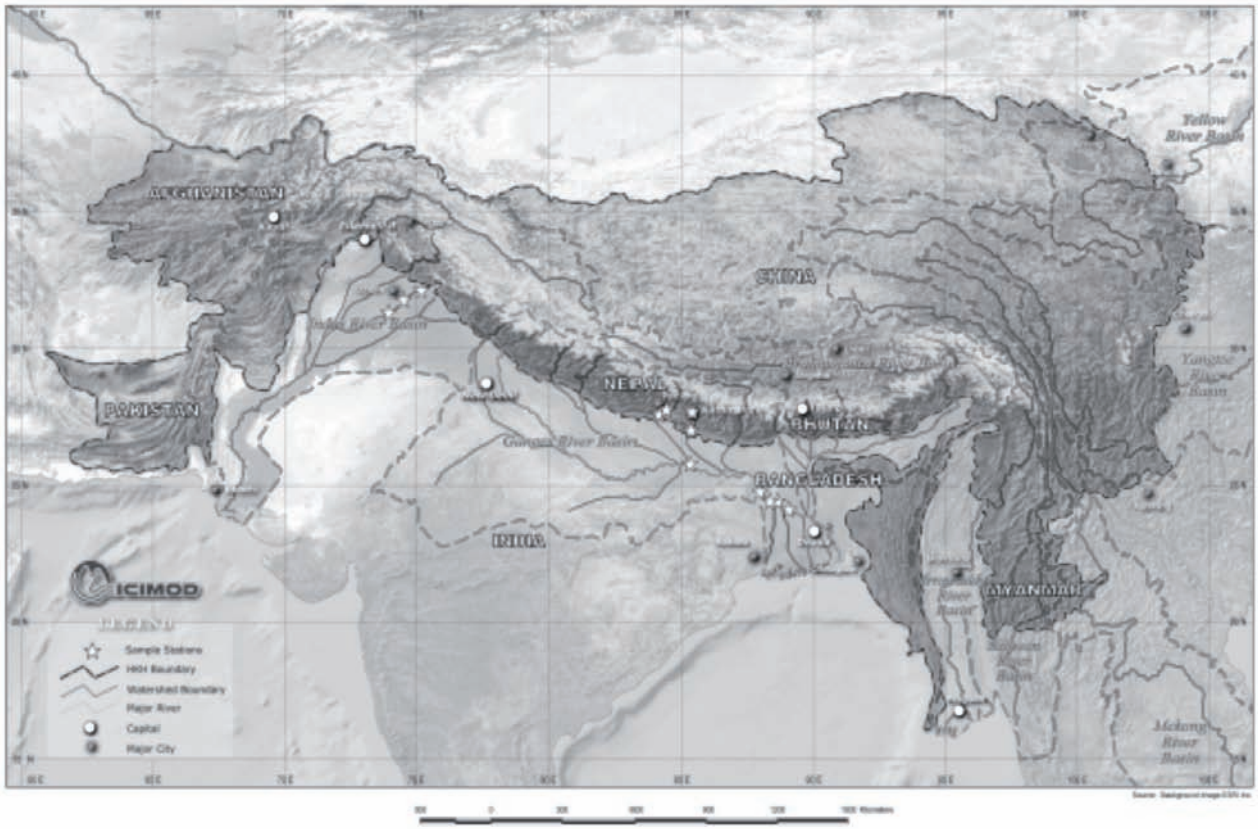

Figure 1: Major River Basins in South Asia.

Table 1: State of area, population and some resources of HKH five countries. Sources: SOE: Bangladesh 2001, SOE: Bhutan 2001, SOE: India 2001, SOE: Nepal 2001, SOE: South Asia 2001, PCRWR 2004, ICIMOD/ASSESS-HKH 2005.

HKH Countries	Area ($x10^3$ km^2)	Forest coverage (%)	Agriculturalland (%)	Population		Soil loss (billion tons/year)
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Table 2: Surface water availability and its use in the five HKH countries (SOE: South Asia 2001).

Description	BG	BT	IN	NP	PK
Total annual renewable water availability (km^3/y)	1,134	39	1960	224	171
Per capita renewable water (m^3/y)	9,000	58,930	2,000	10,300	1,309
Total annual withdrawal (km^3/y)	34	0.8	350	16.7	186.2
Per capita withdrawal (m^3/y)	275	1200	359	760	NA
% withdrawal of total					
Domestic	3	36	3	3.4	4.3
Industry	1	10	4	0.3	0.7
Agriculture	96.0	54.0	93.0	96.3	95.0

be used nor stored, especially in flat country like Bangladesh. Instead seasonal per capita water availability would better depict the actual situation. Bhutan has not only the highest per capita withdrawal, but also fairly distributed its use among the three important sectors, such as domestic, industry and agriculture. Nepal has the least withdrawal percent for industry, among the five countries.

River water is one of the principal natural resources being used in different development activities in the mountains of HKH region. The water as a resource is being used for drinking, sanitation, irrigation, hydro-electricity, fishing, recreation, cremation, etc. Since the last few decades, the rivers have been degraded environmentally and ecologically, which is however by no means inevitable result of natural processes. It has emerged from the interactive processes between human (development) activities, water resource, and environment.

Though river water is the basis for planning, development, and management of both rural and urban areas, this resource has received considerable stress due to rapid growth of population and urbanisation, coupled with the manner in which it has been used. In most cases, particularly in urban areas, such practice has led to the accelerated deterioration of river environment at local and regional levels such as depletion of water sources and degradation of water quality, destruction of hydrological systems, flash floods and siltation, etc. The most crucial consequence of these environmental trends is the inappropriate and inefficient use of the river water.

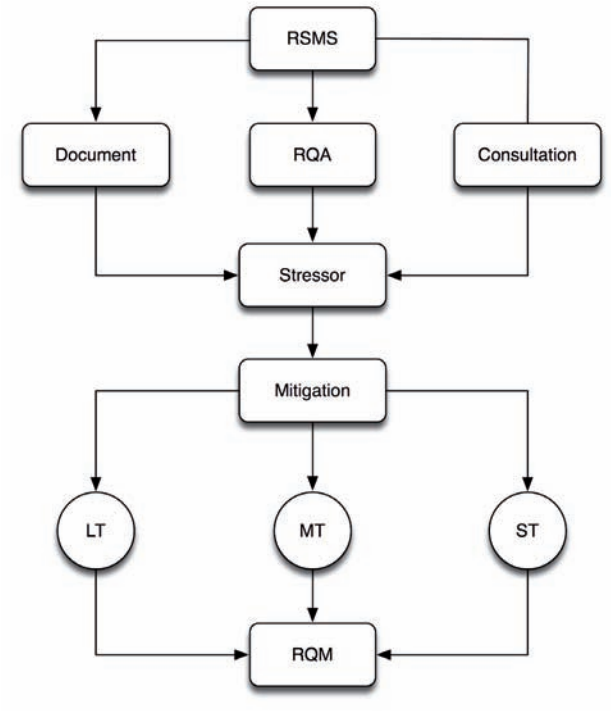

Figure 2: Conceptual Framework for River Sustainable Management Strategy. RSMS = River Sustainable Management Strategy LT = Long term, MT = Medium term, ST= Short term, RQM = River Quality Management, RQA = River Quality Assessment.

Efforts have been made to conserve and develop the river basins in terms of policy measures, programmes, acts, and implementation by the governments of HKH countries in collaboration with international and non-governmental organisations, community based organisations and local people participation. However, they have not been successful for a desired sustainable management of the river basins.

Objectives of the study

This paper has two-fold aims: first, to identify the stressing factors of river water resource and secondly, on the basis of the identified factors to provide sustainable management strategies for the river basins.

Methods

The project "Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region (ASSESS-HKH) activities are divided into 8 work packages (WP). The present paper is fulfilling the objective of WP 7 (ICIMOD/ASSESS-HKH 2007b).

Based on the experiences gained during WP5 (Methodology Development) and WP6 (Eco-data Management Tool) from the extensive field work conducted in the regions, as well as adapted from the methods of the European rivers, the "rapid field assessment screening methodology" (Moog et al. 1999, Moog & Sharma 2005) has been used for the river quality assessment of the HKH region, and the data and information generated by this methodology has been used in the river quality mapping. Each of the individual partner countries of the HKH region has carried out survey in its selected river stretches based on the screening methodology and prepared river quality maps.

Methods of analysis of stressing factors

As the water of the rivers along their stretches is found to be used for different purposes like drinking, washing, bathing, irrigation, fishing, transportation, hydropower generation, sand and pebble quarrying, industries, cremation and wastes dumping, its quality is also changed, in most cases being deteriorated. So, it is worthwhile to identify stressing factors that pollute quality of the river water.

The observation protocol sheet was also used to record and locate the type of stressing factors along the river stretch. Thus, total stressing factors for each river stretch have been obtained, and then grouped into a maximum of four broad general groups such as (i) effluents, (ii) activities and facilities, (iii) hydromorphological degradation, and (iv) ecological disturbances and personal hygiene and sanitation. Sub-sets under each broad group were also identified. The frequency of each type of stressing factors was computed, and the relative importance of each type has been identified in terms of frequency, i.e. the higher the frequency, the greater is the importance of particular stressing factor to be considered. In

Table 3: The names and sites of sample river quality assessment in the HKH countries. Sources: Field study 2007.

Description	BG	BT	IN	NP	PK
Sample sites	20	17	26	115	42
River Name	1. Turag 2. Balu 3. Buriganga 4. Shitalakkhya 5. Dhaleshwari	1. Paro 2. Ha	1. Kosi	1. Bagmati 2. Seti	1. Soan
Name of cities	Dhaka	Thimphu	Rampur & Kashipur	KTM & Pokhara	Islamabad & Rawalpindi

Table 4: Classification of river stressing factors in HKH-countries. Note: 0 = absence; and 1 = presence
Sources: Field study 2007, ICIMOD/ASSESS-HKH (2007a, b).

Stressor groups	Stressing factors	BG	BT	IN	NP	PK	Total
Effluents	Sewage discharge	1	1	1	1	1	5
	Industrial effluents	1	1	1	1	1	5
	Agricultural runoff	1	1	0	1	0	3
	Solid wastes	1	0	1	1	1	4
	Cremation	0	0	0	1	0	1
	Poultry waste	0	0	0	0	1	1
	Hospital waste	0	0	0	0	1	1
Sub-total		4	3	3	5	5	20
Activities & facilities	Navigation	1	0	0	0	0	1
	River crossing	0	1	0	1	0	2
	Vehicle washing	0	1	0	0	1	2
	Squatter settlements	0	0	0	1	0	1
	Military camp in upstream	0	0	0	1	0	1
	Water mills in upstream	0	0	0	1	0	1
	Picnic spots close to river	0	0	0	1	0	1
	Littering by picnic goers	0	0	0	1	0	1
	Open defecation	0	0	0	1	0	1
Sub-total		1	2	0	7	1	11
Environmental & ecological disturbances	River dams	0	1	0	1	1	3
	Mining	0	1	1	0	0	2
	Deforestation	0	0	1	0	0	1
	Sand/gravel extraction	1	0	0	1	0	2
	Channel embankment & weir	0	0	0	1	0	1
	Flood	0	0	0	1	0	1
	Bank cutting	0	0	0	1	0	1
	Irrigation	0	0	0	1	0	1
	Landfill leachate	0	0	0	1	0	1
	Fishing & boating	0	0	0	1	0	1
	Construction	0	0	0	0	1	1
	Landslides	0	0	0	0	1	1
	Animal washing & wallowing	1	0	0	0	0	1
Sub-total		2	2	2	8	3	17
Personal hygiene & sanitation	Bathing and washing	1	0	0	1	0	2
TOTAL		8	7	5	21	9	50

Table 5: Existing efforts on mitigating effluents. Sources: MOWR (2000), RGOB (2000), NWMP (2001), CPCB (2003), NEC (2004), PCRWR (2004), NWP (2005).

Stressing groups/factors	BG	BT	IN	NP	PK
Safe water supply and sanitation					
Clean–up and rehabilitation of pollution hotspots	1	0	0	0	1
Salinity intrusion in surface and groundwater	1	0	0	0	1
Effluents standards	1	1	1	1	1
Treatment plant	1	1	1	1	1
Water cess act and rules	1	1	1	1	1
Hazardous waste rules	0	0	1	0	0
Demarcation of groundwater quality zones	0	0	0	0	1
Development of low cost water testing kit	0	0	0	0	1
Prohibition of direct discharge into water bodies by municipality	0	0	0	1	1

Table 6: Proposed mitigating measures of effluents. DU = development unit. Source: Field survey 2007.

Stressing factors	Mitigation programs	Responsible agencies	Years of period
Waste dumping	Prohibition of dumping	Municipality/local govt	Short
	Provision of waste collection points	Municipality/local govt	Short
	Roads along the river banks & embankment		
	Awareness to locals	Municipality/Department of roads	Long
		Municipality/NGOs	Long
Sewerage	Prohibition of direct discharging	Municipality	Short
	Treatment plants	Municipality/environment	Medium
	Awareness to locals	Municipality/NGO	Long
Agricultural effluent	Reduce amount of chemical fertilizer & pesticides through encouraging manure	Municipality/Department of Agriculture/environment	Medium
Industrial effluent	Prohibition of direct discharging	Municipality/industries	Short
Cremation	Electric furnace	Municipality/DU	Long

Table 7: Efforts on mitigating anthropogenic activities and provision of facilities. Sources: GOI (1992), MOWR (2000), RGOB (2000), PCRWR (2004).

Stressors	BG	BT	IN	NP	PK
Ecological balance through protecting and improving environment	1	1	1	1	1
Identify water polluted activities and regulate them	0	1	0	0	0
Public toilets	1	1	1	1	1
Rehabilitation of squatters	0	0	0	1	0

Table 8: Strategies for mitigating activities and facilities stressing factor. Source: Field survey 2007.

Stressing factors	Mitigation programs	Responsible agencies	Years of period
Open defecation	Prohibition of open defecation Provision of community toilets Awareness to local	Municipality/DU Municipality/locals Municipality/NGOs	Short Medium Long
Vehicle crossing along river	Build bridges and/or cause ways	Municipality/Dept of roads/ NGOs/Locals	Medium
Littering at around picnic spots by picnic goers	Prohibition of littering Provision of litter containers Awareness	Municipality/DU Municipality/Locals Municipality/NGOs	Short Short Long
Others (squatter settlements, water mills & military camp in upstream and picnic spots close to river)	Control of squatting and building of water mills, military camps in upstream Prohibition of picnic spots close to river & upgrading of slums Awareness	Municipality/Defence ministry Municipality/DU Municipality/NGOs	Short Short+ medium Long

Table 9: Existing efforts on environmental and ecological disturbances. Sources: WRA (1992), NWMP (2001), CPCB (2003), NEC (2004), NWP (2005).

Stressing groups/factors	BG	BT	IN	NP	PK
Environment conservation a ct	1	1	1	1	1
Polluters pay principle	1	1	1	0	1
Sand quarrying and stone mining	1	0	0	0	0
River conservation	0	0	1	0	0
Water prevention and pollution control acts	1	1	1	1	1
River corridor roads	0	0	0	1	0
Prohibition of sand quarrying near bridges	0	0	0	1	0

Table 10: Mitigation strategies for conservation of river. Source: Field survey 2007.

Stressing factors	Mitigation programs	Responsible agencies	Years of period
Water for irrigation	Building eco-dam for allocation of water for drinking and irrigation	Municipality/ Dept. of Drinking Water & Irrigation	Medium
Reservoir & impoundment along rivers	Prohibition of building impoundments Regulation of community drinking water as top priority	Municipality/Local Department of Drinking Water	Short Short
Embankment & weir	Demarcation of river course/bank Prohibition of encroaching river banks Awareness	Municipality/Survey Department Municipality/Locals Municipality/ NGOs	Medium Short Long
Flood	Protection of watershed by planting trees/grasses Building of embankment Awareness	Municipality/Dept. of Forestry/ User group Municipality/Local Municipality/NGOs	Long Medium Long
Bank cutting	Embankment of river banks	Municipality/Local	Medium
Quarrying sand & stone	Prohibition of quarrying sand & stone Construction of embankment Prohibition of stone crushing factories at the river banks Awareness	Municipality Municipality/NGOs/Locals Municipality/NGOs Municipality/NGOs	Short Long Short Long
Chemical poisoning & blasting in fishing	Prohibition of using chemical poisoning & blasting Awareness	Municipality and fishery department	Short Long

Table 11: Efforts to mitigate bathing and washing in the rivers. Source: WSP 1998, NWRS 2002, CPCB 2003.

Stressing Groups/factors	BG	BT	IN	NP	PK
Prohibition of throwing and dumping wastes	1	1	1	1	1

Table 12: Strategies for mitigating river water stressing activities. Source: Field survey 2007.

Stressing factors	Mitigation programs	Responsible agencies	Years of period
Bathing	Prohibition of bathing in terms of sanitation viewpoint at hot spots	Municipality	Short
	Provision of adequate community taps	Municipality/Dept. of Drinking Water Supply	Medium
	Awareness	Municipality/NGOs	Long
Washing clothes, vegetables	Prohibition of washing clothes and vegetables at hot spots	Municipality	Short
	Provision of adequate community taps	Municipality/Dept. of Drinking Water Supply	Short
	Awareness	Municipality/NGOs	Long
Treated wastewater use in agriculture	Canalization of waste water for irrigation	Municipality/Dept. of Irrigation	Medium
Display of river water quality maps at public place of importance	Awareness program on the importance of RWQM	Municipality	Short
	Advocacy against the direct discharge of effluents and domestic and hazardous waster	Municipality/Dept of Drinking Water Supply/NGOs	Long

addition, other features like settlement density and land uses have also been used in each stressing factor. This analysis has been used later for identifying mitigation options and designing strategies for sustainable river management.

Methods of river sustainable management strategies (RSMS) preparation

RSMS is discussed in terms of four major elements, such as stressing factors, mitigating program, responsible agencies, and duration of years (Figure 2). The stressing factors of each of the rivers under study have been obtained from the reports prepared by partner countries for this project. The relative importance of each stressing factor is described in cases wherever the information is available. Here, the mitigation strategies are proposed ones, which are defined in terms of three broad periods, such as short-term, medium-term, and long-term. The strategies for each broad class and its individual cases are described in terms of order of relative importance of stressing. The responsible agencies for each strategy are identified and described. In some cases, some particular strategies described against the particular stressing factors are also used for other related stressing factors. The description of the four elements of RSMS is dependent on the information supplied by the partner countries.

Results

A total of 11 rivers and their 220 sample sites were considered for the preparation of the sustainable river strategy management of the HKH region (Table 3). Among the countries, Bangladesh has covered the largest number of rivers for this study, whereas Nepal study has covered the highest number of sample sites from two rivers.

Water quality map is prepared based on the analysis of the field data by each partner country. Stressing factors responsible for the deterioration of the river water quality were analysed. Table 4 represents an example of the stressors as per the river quality classes. Table 5 shows the description of river stressing factor of all HKH partner countries.

River stressing factors

There are 21 stressing factors in Nepal, followed by Pakistan with 9 and Bhutan with 8. Table 5 shows that, two stressing factors such as sewage discharge and industrial effluents are common in all five HKH countries. The presence and absence of stressing factors by country are indicated by logical expression such as 1 and 0 respectively.

The table 4 indicates that, in terms of observation, the relative influence of effluent is the largest stressing factor, followed by environmental and ecological disturbance.

River sustainable management strategies

Here, the river sustainable management strategies (RSMS) are related to the stressors of the rivers described in Table 4 above. RSMS is described in terms of existing policy efforts

and formulation of proposed strategies. However, the existing policy efforts differ remarkably among the partner countries; there are very few policy efforts commonly adopted by these countries. The proposed mitigation strategies are defined in three broad periods, such as short-term, medium-term, and long-term. They are defined as 5, 15, and 25 years respectively. The strategies for each broad class and its individual cases are described in terms of order of relative importance of stressing. The responsible agencies for each strategy are also provided. Each of the four major groups of stressors is described as follows:

Effluents as a stressor

There are seven types of effluents as mentioned in Table 4 above, of which sewage and industrial effluents are the largest. Those effluents are being observed along the rivers under consideration, despite the policy efforts as shown in Table 5. Table 5 describes 10 different policy efforts to mitigate effluents in the HKH countries. Three policy efforts such as effluent standards, treatment plant, and water cess acts and rules are common to all five countries, whilst the other differ among them. As these policy efforts have not been effective, the followings are the proposed mitigation measures on effluents.

Proposed mitigation measures of effluents

Table 6 summarises proposed strategies for mitigating each of the effluents and its possible responsible agencies. In all cases, however, a well formulated monitoring and evaluation mechanism (system) should be adopted by the respective responsible agencies.

Anthropogenic activities and facilities as stressor

The second group of river stretch stressing factor includes the environmental and ecological disturbances. All HKH partner countries have made some efforts with this regard. However, the type and nature differ among them (Table 7).

There are nine stressors listed under this category. Of these, vehicle crossing and washing over and in the rivers are relatively more two stressors than others. However, these all stressors are responsible for deteriorating river water quality, resulting in dysfunction of ecological system (IWMI 2002, IWMI 20064, WHO 2006). This might be due to the rivers flowing through the big cities that have more anthropogenic activities. Proposed Mitigation Measures for Anthropogenic activities and development works Table 8 lists the proposed strategies to mitigate the above mentioned stressors.

Environmental and ecological disturbances as stressors

The efforts being made by HKH countries to mitigate environmental and ecological disturbance factors are shown in Table 9. Despite those efforts as listed in Table 9, environmental degradation has been continued in and around the rivers of HKH region. On the one hand, resources from the rivers such as sand and pebbles have been continued to meet the increasing demand of urban growth and development activities, whereas on the other hand, the livelihood of the traditional communities has been lost and displaced from their original areas, both causing the loss of biodiversity in and around the rivers.

Proposed mitigation measures for environmental and ecological disturbances

The proposed strategies for each stressing facility are provided in Table 10.

There is largest number of stressors under this category as described above. River dam is found the most stressor for disturbing river ecology, as it is observed in three countries. Two other stressors are stone mining from the hills, which also act as water sources of river, and sand and gravel quarrying from the rivers. Both belong to the rapid urbanization phenomena. The stone mining has also given rise to the establishment of an increased number of stone crushers.

Bathing and washing in the rivers as stressors

This group of stressing factors contains only one type (Table 11). The HKH countries have to formulate more policy measures, if this is a serious problem.

One of the crucial health problems now associated with the use of polluted water of the river, basically for cleaning vegetables, washing, and bathing. The people of this region have to depend on the river water for domestic activities, due to limited supply of tap water.

Proposed mitigation measures for bathing and washing

Table 12 provides proposed strategies for each stressing facility.

Conclusion

This paper has made an attempt to provide framework for analysing and devising strategies for the sustainable river water management, considering the information generated through rapid screening field protocol. The protocol has been effective to assess river quality and its stressors. More importantly, local people were involved in the identification of stressing factors along the river of their own area. So the stressing factors are the realistic ones. In formulating strategies, however, their involvement has been ignored and therefore, the river management strategies are being made without their participation. It is yet to see whether the river management would be effective and sustainable in real sense or not. Though the methodology adopted here by all partner countries was based on the workshop in order to make comparison and compatible among them. However, the information has not been to the same extent as it is supposed to be. Therefore,

there has been a bit imbalance in analysing the problems and policy measures among the countries.

The rivers are found to be used for different development sectors such as dams, embankments, reservoir, roads along the rivers, etc. and in some cases the water of the rivers has been over-exploited. All the HKH countries are facing challenge to maintain the quality of water of the rivers and to conserve the riverine ecology. In some cases, the pollution loads of the rivers flowing through the large cities have already reached to a maximum.

Despite several policy measures and implementation mechanisms exist in the partner countries, there is no improvement of water quality of the rivers to a desired level. The results of this study shown through matrix tables indicate cautious to the partner countries to formulate policy measures and programmes, as practical as possible.

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Sustainable water resources management strategies in India

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Abstract

Water is the most essential but scarce resource & the quality and the availability of fresh water resource is becoming one of the pressing environmental challenges of the country as a whole. The rapid increase in multiple water uses coupled with rapid growth of population, urbanization, industrialization and agricultural development has resulted in high impact on the quality and quantity of water. The situation demands immediate redressal through water quality management strategies. The present paper aims to overview the water quality of river basin of India, water quality assessment and monitoring programme, evaluation of impacts/causes of pollutional stressors, management strategies adopted at state and central government level, overview of technologies available for management, role of public participation and institutions through awareness and education, role of environmental laws, acts, rules etc. constraints in sustainable management of conservation of water resources will also be discussed.

Key words: water pollution, water quality, pollutional stressors, management techniques, environmental regulations.

Introduction

The purpose of Sustainable Water Management (SWM) is simply to manage our water resources while taking into account the needs of present and future users. SWM attempts to deal with water in a holistic fashion taking into account the various sectors affecting water use including political, economic, social, technological and environmental considerations.

The current understanding of SWM is based primarily upon the principles devised in Dublin during the International Conference on Water and the Environment (ICWE) in 1992 namely:

– Freshwater is a finite and valuable resource essential to sustain life, the environment and development.
– The development and management of water resources based on a participatory approach, involving users, planners and policy makers at all levels.
– Women's central role in the management and safeguarding of water resources.
– Economic value of water as an economic good.
– These principles reflect the importance of water in our daily lives and the need for proper communication, gender equity, and economic and policy incentives to manage the resource properly.

The present paper aims to overview the water quality of river basin of India, water quality assessment and monitoring programme, evaluation of impacts/causes of pollutional stressors, management strategies adopted at state and central government level, overview of technologies available for management, role of public participation and institutions through awareness and education, role of environmental laws, acts, rules etc. The constraints in sustainable management of conservation of water resources will also be discussed

Sustainable water management in India

The rapid population growth, urbanization and industrialization lead to greater demand for an increasingly smaller supply of water resources in the area. In India, the two most important issues are how to balance the country's rapid economic growth with the need to ensure equitable distribution to all sectors, in particular, the urban and rural drinking water supply. The three issues limiting the sustainable management of water resources are:

Policy failures and institutional weaknesses: Inadequate policy and regulation combined with a non-transparent and non-participatory process is at the root of many of the water management problems plaguing the region. Until recently, water management projects have been the almost exclusive domain of government agencies. Government led and funded water development projects have seldom involved the private and volunteer sectors to ensure that the needs of the public are met. Furthermore, full funding of the projects has resulted in low cost recovery and an unrealistic valuation of users' willingness to pay leading to continued abuse of water resources. No or little cooperation exists between the various agencies responsible for the management of water resources in different sectors such as environment, health and agriculture. The result is a planning process that does not take into account the needs of different interest groups and a lack of accountability on the part of any Government agency. Many of the pollution control measures are based on "end of pipe" principles rather than a minimization/prevention approach. Most of the current policies still encourage developing supplies of water resources rather than encouraging demand management. Competition for water: Increasing competition for dwindling water resources continue to pose a greater threat to national and international security between neighbouring countries or states and between different user groups within a watershed. Already, the urban, agricultural and industrial

demands for water are greater than the available supplies. The traditional approach to solve competition issues has been to develop water supplies with the construction of dams, reservoirs or other engineered structures. Therefore, there is a need to optimize the use and distribution of the current supplies to meet the needs of all users. This would include implementing conservation measures such as reduced wastage and leakage, demand regulations, low-flow technologies, wastewater reclamation and reuse etc.

Health and environmental needs: Increased prevalence of mosquitoes and other disease vectors, displacement and over-riding of property rights/ownership, waterlogging and salinization of agricultural land, intrusion of salt water into aquifers, destruction of wetlands and loss of biodiversity in riparian and coastal areas are some of the negating impacts of water resources management.

The poor success of past projects can be attributed to insufficient data on the links between health and water quality as well as little or no public involvement in the decision-making process. In addition, the needs of the ecosystem to maintain its functions has often been omitted from water-balance budgets. The result has been the projects that do not fully address the needs of the public or the environment.

Water resource of India

Although India received about 1170 mm rainfall annually, which is not evenly distributed with time and space. Nearly 85% of rain occurs only in three to four months in a year. On an average, there are only 40 rain days and most of rainfall occurs within 15 days or more precisely within less than 100 hours. Our demand for water has been increasing steeply especially during last 4-5 decades due to fast growth in agricultural activities urbanization & industrialization. The over-exploitation of groundwater and surface water is widespread across the country and is growing. To feed our growing population and to become self-sufficient in food, Govt. of India has focused its attention on development of agriculture. The inappropriate land use practices, fast and deforestation prevalent in the country limit the groundwater recharge potential. With given situation, future water demands can be met in absolute quantity & quality terms

Table 1: Basin-wise availability of utilizable surface and ground water. Source: CWC 1993: CGWB 1995

		Surface water		Ground water	
Site no.	Name of river basin	Mean flow (bcm)	Utilisable (bcm)	Replenishable (bcm)	Utilisable (bcm)
1	Indus	73.31	46.00	26.50	24.3
2a	Ganga	525.02	250.00	171.00	156.80
2b	Brahmaputra	629.05	24.00	26.55	24.40
2c	Barak	48.36	-	8.52	7.80
3	Godavari	110.54	76.30	40.64	37.20
4	Krishna	69.81	58.00	26.40	24.20
5	Cauvery	21.36	19.00	12.30	11.30
6	Sabemarekha	12.37	6.80	1.80	1.70
7	Brahmani-baitami	28.48	18.30	4.05	3.70
8	Mahanadi	66.88	50.00	16.50	15.10
9	Pennar	6.32	6.90	4.93	4.50
10	Mahi	11.02	3.10	7.20	6.60
11	Sabarmati	3.81	1.90	-	-
12	Narmada	45.64	34.50	10.80	9.90
13	Tapi	14.88	14.50	8.27	7.60
14	West flowing rivers between Tapi to Tadri	87.41	11.90	17.70	16.20
15	West flowing between Tadri to Kanyakumari	113.53	24.30	-	-
16	East flowing rivers between Mahanadi & Pennar	22.52	13.10	11.22	10.30
17	East flowing rivers between Pennar & Kanyakumari	16.46	16.70	18.80	17.20
18	West flowing rivers of Kutch & Saurashtra & Luni	15.10	15.00	0.00	0.00
19	Area of inland drainage in Rajasthan	0.00	-	-	-
20	Minor rivers draining into Bangladesh	31.00	-	18.12	16.80
	Total	1952.87	690.30	431.32	395.60

only through pragmatic planning that includes highest priority to water conservation, recycling-reuse of municipal and industrial wastewater and increase efficiently in various uses. Water Scarcity has resulted in many water quality problems in India. The 14 major river basins in India drain 85% of surface run-off cover 83% of country's area supporting about 80% of the population. To feed the ever growing population of the country, agricultural development is on top priority of the government. Although India is the wettest country in the world receiving average 1170 mm rainfall annually. Many settlements in India rely on groundwater, and quite a few of them withdraw water from aquifers at rates higher than natural rates of replenishment, leading to mining of groundwater. Unlike surface storage, the groundwater is slow in accumulation. Groundwater has two components i.e. one a static part, and the other dynamic, which comprises annual additions due to recharge. The quantum of yearly use needs to be limited by the quantum of this addition. During deficit years, a part of static component is drawn for use expecting recuperation during the next surplus year. The basin-wise availability of utilizable surface and ground water is given in Table 1.

Water demand

The demand for fresh water has been assessed by the Ministry of Water Resources as the quantity of water required to be supplied for specific use and includes consumptive as well as non-consumptive users. The total water withdrawal/utilization for all uses in 2002 was about 634 billion cubic meter (bcm) or 609 m^3/capita/year. Estimates for water requirements, through iterative and building lock approach, have been made for the years 2010, 2025 and 2050 for total national requirements (Table 2) based on a 4.5% growth in expenditure and median variant population projections of United Nations. The country's total water requirement by the year-2050 would become 1422 bcm, which would be much in excess of total utilizable average water resources of 1086 bcm.

In India, consumptive uses (eg. irrigation) far outweigh non-consumptive ones (eg. industrial). However, the non-consumptive use is rising with increase in population coupled with rapid urbanisation and industrialisation. India's water use has significantly increased over the last five decades. Under given situation, future water demands can be met in absolute quantity and quality terms only through pragmatic planning that includes highest priority to water conservation, recycling-reuse of municipal and industrial wastewater, and inter-basin/inter-regional transfers of water.

Major causes for water quality degradation

Domestic wastewater

Discharge of untreated domestic wastewater is predominant source of pollution of aquatic resources in India. Large urban centers contribute most of the sewage generation in the country. The smaller towns and rural areas do not contribute significant amounts of sewage due to low water supply & under developed conditions. The wastewater generated in these areas normally percolates in the soil or evaporates.

The estimated sewage generation from 423 Class I cities and 499 Class II towns (as per 2001 census) is 29129 millian litres/day (MLD), which is expected to be 33212 MLD at present assuming 30% decadal growth in urban population. Against this, there exist STPs having 6190 MLD capacity while another 1743 MLD capacity is being added. Thus, the existing treatment capacity is just 18.6 % of present sewage generation and another 5.2% capacity is being added. The actual capacity utilization of STPs is only 72.2% and as such only 13.5% of the sewage is treated. This clearly indicates dismal position of sewage treatment, which is the main cause of pollution of rivers and lakes. To improve the water quality of rivers and lakes, there is an urgent need to increase sewage treatment capacity and its optimum utilization.

Table 2: Water requirement for different uses (BCM).
Source: MoWR 2002.

Use/year	2000	2010	2025	2050
Irrigation	541	536	688	1008
Domestic	42	41.6	52	67
Industries	8	37	67	81
Energy	2	4.4	13	40
Inland navigation	-	-	4	7
Flood control	-	-	-	-
Afforestation	41	33	67	134
Ecology	-	5	10	20
Evaporation	-	36	42	65
Total	634	693	942	1422

Status of sewage treatment plants: As per the survey conducted by CPCB, there are about 269 STPs exist in the country, out of which only 231 are operational. The performance study carried out on 115 STPs indicated that the STPs could utilise only 72% of the capacity. The performance was also poor. Average performance was around 70%. This is mainly due to poor operation and maintenance. A large number of STPs created under Central Funding schemes like Ganga Action Plan, Yamuna Action Plan or National River Action Plan are not fully utilised/satisfactorily operated thus jeopardising its objectives.

Industrial wastewater

It is estimated that the total wastewater generated from all major industrial sources is about 15438 MLD out of which treatment facilities are available for about 9000 MLD wastewater. The remaining wastewater is mostly generated from small scale industries, majority of them are located in congested residential areas. Agro based industries like Distilleries,

Sugar mills and Paper mills are major contributors of organic pollution, whereas the industries generating chemical pollution can be divided in two categories i.e. i) those generating high TDS bearing wastes like pharmaceuticals, rayon plants, chemicals, caustic soda, soap and detergents, smelters etc. (ii) those which generates toxic wastes e.g. pesticides, smelter, inorganic chemicals, organic chemicals, steel plants, pharmaceuticals and tanneries etc. There are large number of small-scale industries being promoted by government to generate employment and economy. Many of such industries have come-up as clusters in our country. Due to lack of knowledge, resources, these industries do not have proper treatment for their wastewater. Their solid wastes and sludge get scattered-around or dumped in unlined pits and effluents flow to streams through storm-drains or stagnate in depressions to percolate, leach or get washed-off during next rainy season. Even some of the large and medium industries also do not have proper disposal arrangements for their wastes and thus find its way into watercourses. Common effluent treatment plants (CETPs) are established for many clusters of small scale industries.

Status of CETPs: As mentioned earlier, the small scale industries (SSI) are not able to comply with the pollution control norms. In order to help the SSI, Ministry of Environment and Forests (MoEF), Govt. of India has initiated a technical and financial support scheme to promote common facilities for treatment of effluents generated from SSI units located in clusters. Under the financial assistance scheme, 50% subsidy on project capital cost - 25% share each of Central and State Governments- was provided. As a result, 88 CETPs having total capacity of 560 MLD have been set up throughout India covering more than 10000 polluting industries. CPCB carried out performance study of these treatment plants and observed that operation and maintenance is most important problem.

Rural and slum population

Rural and slum population, which is lacking the piped water supply and sewered sanitation facilities, uses open field for defecation, with a few using pit-latrines or septic-tanks. Thus, generation of liquid effluents would be minimal and all wastewater generated is soaked into the nearby land. However, much of the bathing and washing (clothes, utensils etc.) may be in or near the water-body reducing abstraction and transport of water but causing in-situ non-point pollution.

Pollutants in agricultural run-off and drainage water

Application of chemicals like fertilizers and pesticides in agriculture is increasing steeply for increasing the agricultural production. Residues of these chemicals are transported to water courses through surface run-off during heavy rains and through percolation to the groundwater and pollute them. Drainage waters from irrigated agricultural land are always high in salts, since they also have to carry the salts originally contained in the trans- evaporated fraction of the irrigation water.

Deposition of air-pollutants

Atmospheric pollutants may deposit directly on surface waters. The pollutants depositing on vegetation and soils may get leached or washed- over to water bodies.

Present approach to water quality management

Legal and institutional provision

Water Act 1974 and the nvironment Protection Act 1986: The government enacted the Water (Prevention and Control of Pollution) Act, 1974 with the primary objective of prevention and control of water pollution. The Act established the Central Pollution Control Board and the State Pollution Control Boards for its implementation. The Water Act empowers the pollution control boards to lay down and maintain water standards. The actual provisions for enforcement such as penalties, imprisonment etc. are largely confined to source-specific standards for individual polluters. The Environment Protection Act, 1986 is an umbrella act providing for the protection and improvement of environment and for matters connected therewith. It authorizes the central government to intervene. The nature of penalties allowed under this act are similar to those authorized under the Water Act. Supported by recent legislative, administrative and judicial initiatives, environmental regulations in India are becoming more comprehensive. The new regulations cover noise, vehicular emissions, hazardous wastes and chemicals, hazardous microorganisms and transportation of toxic chemicals. Stringent penalties were introduced in the old pollution control laws. The licensing regime is supplemented by "citizen suits" provision and besides, a statutory "right to information" now enables an aggrieved citizen to directly prosecute a polluter after examining the government records and data. Rules have been notified for environmental auditing of all the industries which may cause water or air pollution or generate solid or hazardous wastes.

The Ministry of Environment and Forests has adopted a "Pollution Abatement Policy which includes adoption of clean technology, conservation of resources, change of concentration-based standards to mass-based standards, incentives for pollution control, public participation, environmental auditing and Eco-marking on environment friendly products.

Control of pollution at sources is the immediate short-term objective adopted by all the state pollution control boards. For this, the industries must know the extent up to which their effluent or emission must be treated/controlled so that they can discharge the treated effluent to receiving environment without significant effect. The cost of treatment should be such that the industry is able to take the burden. The Central Pollution Control Board has evolved industry specific Minimum National Standards (MINAS)

National water policy 2002: As demand for freshwater is increasing and the availability is gradually reducing due to

erratic monsoons, it is essential to make judicious allocation of the available water resources. The National Water Policy formulated by the Government of India in 2002 accords top priority to drinking water supply in the allocation of water resources for various beneficial uses. After drinking water, the list includes irrigation, hydropower, navigation and industrial & other uses. These priorities, however, might be modified if necessary, particularly with reference to area-specific considerations.

Constraints in implementation of water quality management plans

Water scarcity: In the recent past due to over use of surface and ground waters to fulfill the ever increasing demand of agriculture, industrial and domestic uses, the water level in our aquatic resources is gradually decreasing. As a result, the assumption of 10 times dilution is no more valid in many parts of the country.

Thus, it has become necessary to achieve progressive reduction or elimination of effluent discharges. It implies adoption of no waste or low waste technologies through new treatment methods.

Inadequate resources with local authorities: The responsibility of wastewater management lies with local authorities. In most of the cases, the local authorities are lacking the resources to handle the ever increasing problem of wastewater. They do not have any effective system to generate resources. Unfortunately "polluter pays" principle is not effectively applied in India.

Polluter pay principle: Pollution control should be the primary responsibility of polluter. The "Pollution Abatement Policy 1992" of Govt of India clearly specifies it. Indian judiciaries also emphasized it in many of their orders. Thus the cost incurred on urban wastewater management should be born by the urban population. This is not adequately applied in India.

High organic and dissolved solid bearing industrial wastes: In spite of massive efforts from certain categories of industries, adequate success could not be achieved due to special characteristics of the wastewater being generating like distilleries (due to high organic load), pharmaceutical, pesticide and rayon plants (due to high TDS).

Large number of small scale industries: Small scale industries in India are facing great difficulty in achieving the MINAS due to variety of problems. The most important one is their location. Many of these industries are located in residential areas, congested areas in the city, due to easily availability of infrastructure, labour, raw material, transport and market. In such areas, treatment facilities can not be established. The other important factor is the financial hardship. It is difficult for small scale industry to afford the cost of the conventional treatment. Secondly, even if they establish a treatment system they can not run it properly due to lack of skill which is very important for running such plants.

Operation and maintenance of created treatment facilities

The maintenance of the sewage system, namely, sewers, rising mains, intermediate pumping stations, etc. should be entrusted to the nodal agencies identified for the maintenance of the sewage treatment plants and sufficient funds and staff provided for them. Facilities like community toilets, electric crematoria, etc. should be maintained by the local bodies. Also the issue of resource recovery by way of raising the revenue through sale of treated effluent for irrigation, of sludge as a manure and biogas utilization for power generation, wherever provision exist, needs to be addressed. Biogas generation, pisciculture from sewage as envisaged in the Ganga Action Plan is still in the starting stages. The problem of dead bodies can be addressed by including the police department in the cleaning efforts. Police must be instructed to take dead bodies to the electric crematorium, and additional funds must be provided above and beyond the current inadequate level. Provision should also be made for the disposal of dead animal bodies. Various target groups such as villagers, industrialists, dhobis, fishermen, Doms, boatmen, pandas should be identified and their problems addressed.

Characteristics of effluents: Amongst others, inadequacy in the design of treatment plants leads to a host of problems that are being faced in construction, operation and maintenance. This is due to the fact that the characteristics of wastewater actually reaching the plant are much different than the design criteria. The plant designs are based on population based estimated BOD load, which is much higher than the BOD actually reaching to the plants. Similar situations prevail in industries also. Thus the plants were overdesigned or underdesigned. The treatment plants lack skilled staff for operation and maintenance, besides being energy and cost intensive. All these factors may result in malfunctioning of the Sewage/effluent treatment plants and jeopardize the very objective of the pollution control efforts.

Need for strengthening present approach

Augmentation of sewage treatment capacity: As mentioned above, the huge gap between sewage generation and its treatment, is the main cause of pollution of rivers and lakes. To restore the water quality of rivers and lakes, there is a urgent need to increase sewage treatment capacity and its optimum utilization. Treatment of wastewater requires enormous resources, which cannot be provided without public support. There should be separate fund for waste management, which should come from the public as waste-tax.

In most of the cities/towns, adequate wastewater collection systems are not existing/functioning, leading to accumulation of wastewater in the urban areas, percolating in the ground and polluting the groundwater. To protect the groundwater pollution, it is very important to establish proper collection system and maintain it.

A large number of small-scale industries of urban residential areas are compounding the problem by discharging industrial effluent in sewer line. Since wastewater contains large amount of organic matter & nutrients, it is worth to convert into energy & fertilizer that hampers the biological system in majority of sewage treatment plants. Keeping in view of the future scenario of wastewater generation for the year 2050, a definite road map needs to be prepared by all concerns. Effort needs to be focused on use of wastewater for agriculture & recover energy from it as far as possible.

Maintenance of sewage treatment plants: Operation and maintenance of existing plants and sewage pumping stations is a neglected field, as nearly 39% plants are not conforming to the general standards prescribed under the Environmental (Protection) Rules for discharge into streams as per the CPCB's survey report. STPs are usually run by personals that do not have adequate knowledge of running the STPs and know only operation of pumps and motors. The operational parameters are not regularly analyzed, hence the day-to-day variation in performance is not evaluated at most of the STPs.

Thus, there is a need that persons having adequate knowledge and trained to operate the STPs be engaged to manage STPs and an expert be engaged to visit the STPs at least once a month and advice for improvement of its performance. In a number of cities, the existing treatment capacity remains underutilized while a lot of sewage is discharged without treatment in the same city. Auxiliary power back-up facility is required at all the intermediate (IPS) & main pumping stations (MPS) of all the STPs. It is very essential that they be efficiently maintained by the State Governments whose properties and charge they are. The maintenance of the sewage system, namely, sewers, rising mains, intermediate pumping stations, etc. should be entrusted to the nodal agencies identified for the maintenance of the sewage treatment plants and sufficient funds and staff provided to them. Facilities like community toilets, electric crematoria, etc. should be maintained by the local bodies. Biogas generation, pisciculture from sewage as envisaged in the Ganga Action Plan is still in the starting stages.

Use of alternative simpler technology: Simpler technology should be adopted for sewage treatment. Treatment scheme based on series of Waste Stabilization Ponds (WSP) is quit rugged, one of the most economical ones and suitable for small towns where sufficient land is easily available. Multiple stage ponds (at least three) with first pond as anaerobic one is the most widely used and suitable configuration. Sewage collection and treatment is the primary responsibility of state governments.

The Goverment has not provided funding for internal sewerage in cities whereas it has funded sewage interception, pumping and treatment plants. Sewage can be found flowing in open drains in most of the cities, as these do not have full sewerage. STPs funded by the Govt. of India under various river action plans receive sewage by tapping these open drains carrying sewage. Low strength sewage received from open drains is not ideal for anaerobic biological treatment as recovery of use full byproduct, biogas, is meager. Simpler option of treatment such as series of waste stabilization ponds may prove to be cost effective in such conditions.

There is scope to reduce the cost of the material used for laying down the sewers. Use of low volume flushing tanks will help in reducing waste water volume and thereby the cost of sewerage and sewage treatment. For low income housing colonies either two pit pour flush water seal latrines or a shallow sewer could a possible option. Co-operative group housing societies, multi storied housing complexes, big hotels etc. need to set up appropriate on-site waste water treatment facilities for recycling of waste water for gardening and other non-domestic uses to the extent feasible. Renovation of existing drainage system and dovetailing the renovated drainage system to appropriate forestry programme or tree plantation, will reduce sewage treatment cost. The options which are available for cost-effective and environmentally compatible sewage treatment include land treatment, waste stabilization ponds, constructed wetlands, duck-weed pond, aerated lagoon, rotating biological contractors, up-flow anaerobic sludge blanket system and root zone treatment.

The use of biotechnology could be another option for waste treatment under NRCD, particularly with respect to organic pollution. Inorganic pollutants like nitrogen and phosphorus can also be removed by this technology.

Reuse/recycling of treated domestic sewage: Discharged wastewater from Cities/towns should be treated suitably for land application to the maximum extent possible. In cases, where waste water is to be discharged into a water body, the degree of treatment needs to be higher, keeping in view the low quantity of available water for dilution and abstraction points downstream, etc. If the city does not have adequate land for irrigation due to increased urbanisation, the neighboring states may be approached. The fresh water so saved from irrigation could be utilised for meeting the drinking water requirements or for ensuring minimum flow in river. It is felt that the dilution of effluents is not a practical and economically viable solution to the problem that domestic and industrial effluents be adequately treated for re-use, for irrigation, industries, etc. Where irrigation from treated sewage is not feasible, the possibility of recharging ground water aquifer by sewage, treated to a certain desirable level, may be explored by taking up some experimental studies.

Pollution from industrial sources

Pollution control at source: Emerging technologies such as aerobic composting, vermiculture, ferti-irrigation, etc. as secondary treatment should be adopted for the organic wastes by the industries. Recently, the root-zone technology has also been advocated as another alternative for energy saving for treatment of industrial wastewaters.

Incentives more encourage the industries to undertake pollution control measures. The water cess rates being low, the rebate available to polluters installing pollution control measures has not served as much of an incentive so far. It is important to assess the effectiveness of this measure and work out other measures which would serve as effective incentives for pollution control.

Waste minimization and clean technologies

It may be noted that by recycling techniques the waste concentrations may increase and the total load remain the same. The concentration of waste strength would help the economical conversion of spent wash to biofertilizer. Waste strength reduction can be achieved by adopting in plant control measures such as reduction of spillages of wastes, elimination of process failures, use of proper equipment for handling and dry cleaning techniques etc. This is often termed as clean technologies and it does not add to the cost of production and in fact industry gains from it.

Innovation in pollution prevention/waste minimization efforts on the part of the industries needs to be sternly promoted. Pollution prevention/ waste minimization, in our country at least, is done only for product quality improvement, energy saving or other economic reasons and any reduction in pollution is only incidental.

All organic wastes are best source of energy. A number of anaerobic technologies are now available for treatment of organic industrial effluents. Spent wash, black liquor (pulp mill), dairy effluents, sugar factory effluents and press mud etc. are some of the organic wastes tried for energy recovery. The energy recovery will incidentally solve the air pollution problem, as biogas is a cleaner fuel compared to baggasse, rice husk or coal. It is essential to introduce energy audit in all the industries so hat cost-benefit ratio can be established in each case.

Bio-fertilizers are now prepared from organic rich wastes by admixing filler materials. Spent wash is converted to manure by addition of press mud, bagasse cillo, agricultural residues etc. In this technology the entire liquor effluent is converted into solid mass and it can be termed as "Zero-discharge" technology.

Suggested water conservation measures

Surface Storage: Storage of water by construction of various water resource projects have been one of the oldest measures of water conservation. The scope of storage depends on region to region depending on water availability and topographic conditions. The environmental impact of such storage also needs to be examined for developing an environment friendly strategy.

Conservation of rain water: Rain water has been conserved and used for agriculture in several parts of country since ancient time. The infrequent rains if harvested over a large area, can yield considerable amount of water. It consists of rows of rocks placed along the contour of steps. Contour terraces have been found in use in various parts of the world. Runoffs captured by these barriers also allows for retention of soil, thereby, serving as erosion control measures on gentle slopes. This technique is especially suitable for areas having rainfall of considerable intensity, spread over large part i.e. in Himalayan area, North-East states and Andamon and Nicobar Islands.

Ground water conservation: As pointed out order, out of total 4000 BCM, precipitation in India, about 450 BCM percolates as a ground water flow. It may not be possible to tap the entire ground water resources. Looking at limited ground water availability, it is very important that should be used it economically and judiciously and conserve it to maximum possible. Some of the techniques of ground water management and conservation are described below:

Artificial recharge: In water scarce areas, where there is a low and erratic rainfall, there is a increased dependence on ground water. The water table declines quickly, as the main source of recharging the ground water is rainfall. In its absence, the only alternative to replenish the ground water is by artificial means. Studies have been taken up in the states of Maharashtra, Gujarat, Madhya Pradesh and Andhra Pradesh. There are various techniques to develop and manage ground water artificially. In one of the methods, water is spread over ground to increase area and length of time for water to remain in contact with soil, to allow maximum possible quantity of water to enter into the ground. The artificial recharging can also be done by digging recharge wells which admit water from the surface to fresh water aquifer.

Percolation tank method: Percolation tanks are constructed across the water course for artificial recharge. Many states like Maharashtra, Rajasthan, Andhra Pradesh and Karnataka have used percolation tanks. The studies conducted in Maharashtra indicates that on an average, area of influence of percolation of 1.2 km2, the average ground water rise was of the order of 2.5 m and the annual artificial recharge to ground water from each tanks was 1.5 hactare meter.

Catchment area treatment (CAT): Catchment area treatment plans are usually called Watershed Protection or Management Plans. These are adopted as an important measure to conserve and protect the quality and quantity of water in a watershed. It helps in withholding runoff water albeit temporarily by a check bund constructed across the streams on hilly terrain, which delays the runoff so that greater time is available for water to seep underground. Such methods are in use in North-East states, in hilly areas of tribal belts. This technique also helps in soil conservation. Afforestation in the catchment area is also adopted for water and soil conservation.

Inter-basin transfer of water: A broad analysis of water and land resources and population statistics of various river basins in the country reveals that areas in Western and Penninsular region have comparatively low water resources/culturable land ratio. Northern and Eastern region, which are drained by Ganga and Brahmaputra, have substantial water resources. Because of resources, the scheme of diverting water from region with surplus water to water deficit region can be adopted. Ganga-Cauveri link would enable transfer of vast quantities of Ganga basin flood water running out to sea, to west and south-west India. The transfer of the surplus Ganga water would make up for the periodical shortage in the Sone, Narmada, Godavari, Krishna and Cauveri. The National Water Grid envisages diversion of part of the surplus discharge in the Ganga near Patna during the high flood period.

Adoption of drip sprinkler irrigation: Surface irrigation methods, which are traditionally used in our country, are unsuitable for water scarce areas, as large amount of water is lost through percolation in this method. Drip irrigation where a limited area near plant is irrigated could be the suitable method of irrigation in water scarce areas. This method is particularly useful in row crops. Similarly sprinkler method is also suitable for such water scarce areas. About 80% water consumption can be reduced by this method, whereas the drip irrigation can reduce water consumption by 50 to 70%.

Management of growing pattern: In water scarce areas, the crop selection should be based on efficiency of the crop to utilize the water. Some of the plants suitable for water scarce areas are (i) plant having shorter growth period; (ii) high yielding plants that require no increase in water supply; (iii) plants with deep and well trenched roots and (iv) plants which can not tolerate surface irrigation.

Selection of crop varieties: Crop performance and yield are the results of genotype expression as modulated by continuous interactions with the environment. Generally, the new varieties of crop do not require more water than the older ones. However, they require timely supply of water because their productivity is high. Frequent light irrigation is more conducive than heavy irrigation at large intervals for obtaining high yields.

Nutritional management: Potassium plays a major role under stress conditions by improving the tissue water potential by osmoregulation mechanism and ultimately increasing the water use efficiency. Experiments conducted at the Water Technology Centre, Coimbtore, indicated that foliar application of 0.5% potassium chloride can reduce the moisture stress in soyabean, sorghum and groundnut.

Role of antitranspirants: Nearly 99% of irrigation water applied to the plant is lost by transpiration. Application of antitranspirants reduces transpiration thereby maintaining the tissue water potential. Antitranspirant can prolong the irrigation intervals by slowing down soil water depletion. Application of Kaolin (3%) and lime wash (2%) could maintain the water balance of plant and resulted in normal yield in sorghum under moisture stress condition. Certain growth regulators reduce the plant's susceptibility to water stress. Application of cycoel, a growth retardant by delaying senescence increases the ability to withstand the drought. The cycoel application also reduces production of gibberellic acid which leads to closing of stomata, and thus, the transpiration losses depleted.

Reducing evapotranspiration: Evapotranspiration losses can be reduced by reducing the evaporation from soil surface and transpiration from the plants. In arid zones where low humidity prevails, considerable amount of water is lost in evaporation from soil surface. This can be prevented by placing water tight moisture barriers or water tight mulches on the soil surface. Non-porous materials like papers, asphalt, plastic foils or metal foils can also be used for preventing evaporation losses. Transpiration losses can be reduced by reducing air movement over a crop by putting wind breaks, evolving such types of crops which are having xerophytic adaptations. Such crops have tendency to reduce the water losses in transpiration. Destroying the unwanted plants from the farm, removing unproductive leaves from the crops and enclosing crops with such structures so that transpired water can be collected and reused.

Reducing evaporation: The quantity of water lost through evaporation is very high in many areas in the country. It is estimated that 10,000 ha of land loses about 160 Mm3 of water each year. The water losses through evaporation from storage tanks, reservoirs, irrigation tanks, rivers and canals reduce the water available for various uses. A number of techniques have been used to reduce evaporation from water bodies. The methods are: installing wind breaks, reducing energy available for evaporation, constructing artificial aquifers, minimising exposed surface through reservoir regulation, reducing ratio of volume of water bodies, locating reservoirs at higher altitudes and applying monomolecular films.

Recycling of wastewater: The wastewater from industrial or domestic sources can be used after proper treatment, for irrigation, recharging ground water, and even for industrial or municipal use. If agricultural lands are available close to cities, municipal waste water can be easily used for irrigation. Many industries are already practicing recycling of waste water after proper treatment in their own processes. Industrial waste water can also be used for irrigation.

Conservation of water in domestic use: There is a large scope of conserving water at household level. Closing of taps while not in use alone can save lot of water. A general awareness among the people about the importance of water and its availability, and need for preservation can help to a large extent in minimising wastage. Losses during water supply also need to be prevented by reducing the leakage.

Conclusions

Looking at the serious pollutants loading of rivers & streams of India due to growing population, industrialization and urbanization, the water quality of these rivers & streams is deteorating rapidly resulting in scarce availability of water for drinking, irrigation, industry & other uses. Ministry of Environment and Forest, Government of India under its National River Conservation & National Lake Conservation plan, a number of conservation measures are being taken at state & central government level. These measures are being monitored with respect to large number of environmental laws, policies, acts and regulations. The impacts of these measures have not been found upto the mark owing to administrative & financial reasons. Public participation & capacity building has been found to play a key role in implementing conservation measures in true spirit. The water quality assessment based on macroinvertebrates may be considered as a valuable tool to assess ecological status of the above water bodies with minimum time & much less efforts and costs. The outcome of ASSESS-HKH project may prove as one of the valuable assets in evaluating the quality of water & preparation of water quality of a given river stretch which will help the decision makers, policy makers and scientists to find the exact causes and full proof conservation methodologies.

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Water resource management in the foothills of N-W Himalayas of India for sustainable farming: An overview

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Abstract

In foothill region of Siwaliks in North-Western Himalayan tract of India, the water management is serious issue affecting the agricultural production and livelihood of the dwellers. Opportunities and challenges to research this goal can be grouped in five major areas viz. overcoming constraints to technology adoption, managing conflict, balancing local economic and environmental services and strengthening organizational and learning processes. A recently conducted study demonstrated that the construction of series of small water harvesting structures in the form of earthen dams across the seasonal streams for managing runoff during the monsoon season is helping in improving water availability in lower Siwaliks of northern India. Some evidences showed that the recharge is merely 20-50 per cent of existing level in N-W tract of India in the state of Punjab, which mean that even the rainwater is not able to compensate the extraction. It is important to involve stakeholders in seeking their partnership at addressing the local and other serious problems from water management point of view in the upper watersheds. It is a matter of concern to follow the integrated water management options and their sustainable combinations will be the key to future agricultural economic growth and social wealth etc. The constraints in the adoption of rainwater management practices are topographical problem, followed by lack of technical knowledge and ignorance of rainwater management practices etc. in rainfed foothill region of Punjab and Jammu & Kashmir. However managing resources at local levels requires ability to negotiate solutions and to resolve conflicts among stakeholders ranging from contractors to landless laborers should be viewed seriously. It is also important to refine the existing indigenous technical knowledge systems in a scientific way in rainfed foothill region from moisture conservation point of view. The lessons learnt from the successful watershed projects in Punjab need to be replicated in other states following participatory approach of the people. Understanding the importance of collective action of farming communities and of jointly framing the rules for resource access and use, improved institutional arrangement of land and water resources in upper watersheds is of immediate concern.

Key words: sloping lands, Siwalik, Jammu, ITK.

Introduction

People in reality, rarely manage watersheds deliberately, but they manage different components of watersheds in isolation viz. land, water or vegetation or livestock. However, the management decisions are rarely made keeping in view needs of the people, variations in rain, land, soil and vegetation parameters and with different objectives in mind. Also, the combined outcomes of these independent decisions, with their often highly dependent economic and ecological consequences, determine the overall watershed function. For varied reasons, top down watershed management strategies ignored multiple uses and users of watershed resources have not been successful. However, in order to improve watershed management and services including the availability and quality of water, the benefits of which could be accrued by the farming community by following participatory approach. It may also require encouraging people to think beyond individual resources or plot/ community level to consider the implications of their actions at the watershed scale. For example the integrated watershed management options have been quite successful in the foothill region of Punjab (Sur and Toor, 2002). Also in an on farm applied research projects, monitoring, evaluation and geographic information system experts were involved. Jain (1995) reviewed and highlighted experiences from some of these projects. It was felt that there are still serious issues affecting these programmes and limiting their success and sustainability.

Temporal and spatial dimensions of technology adoption

Technology adoption decisions are often perceived or modeled as being individual decisions, where benefits and costs are assessed and actions taken on the basis of net expected impacts. This model is appropriate where the benefits and costs of an action are well understood and where they are mainly felt by decision maker himself/ herself where internalities are significant, the sum of individual decisions may not lead to optimal social outcomes.

It is likely to be the case for management of upper watersheds. For technologies, such as improved varieties, temporal and spatial scales are not likely to influence adoption since the benefits can be realized at the plot level in a short period of time, by adoption by individual. Other technologies, such as land and soil management, may only yield benefits in the medium to long term, which means the farmers must consider temporal dimensions in making adoption among

farmers is effective if groups of farmers agree to adopt them on contiguous plots. It can be visualized that on an average 4cm of more soil water storage can be achieved by treating the land with conservation measures in foothill region of Punjab (Table 1; Hadda and Sur, 1987).

Table 1: Soil water storage in untreated and treated fields at Hoshiarpur (Hadda and Sur 1987).

Day	Soil water storage in 180 cm soil profile (cm)	
	Untreated	Treated
0	30.5 ± 1.4	34.3 ±1.5
2	20.7 ±1.3	23.2 ±1.1
4	19.6 ±1.4	22.0 ±1.0
17	28.0 ±1.4	32.0 ±2.0
19	19.1 ±1.6	26.1 ±2.0
Mean	23.5	27.5

It is thus imperative that the watershed management technologies and practices generally yield benefits over the long term and to be effective, they must be adopted on a large scale through community participation or in small groups. For example, an irrigation dam built at Karoran, District Ropar in a participatory mode during the year 1984 have the following features as listed in Table 2.

The catchments area of the dam is 17.3 ha, however the command area is 20 ha. The earth fill core wall dam is expected to generate runoff volume of capacity 5.7 ha m. It involved total cost of 2.50 lakh of rupees. The underground irrigation pipeline (950m length of 250 mm size and 132 m length of 150mm size) system was laid in the command area. The suitable outlets were provided to ensure equal distribution of water. The studies (Jindal et al., 1990) conducted on rainfall –runoff (during the years; 1985-89) indicated that the rainfall becomes runoff to the tune of 36.4 per cent. The seepage rate reduction occurred to the tune 60 per cent during this period without applying any treatment to the reservoir bed. This reduction in seepage occurred due to deposition of silt on the bed and sealing of soil pores. The average silt load was observed to be 48 t/ha/yr during the years 1984-87. The availability of the water in the dam observed to vary from 208 mm to 253 mm (average of 1985 -1989 years) in the beginnings of months of November and December respectively. It was found that the sufficient quantity of water is available to apply one, pre-sowing irrigation of 5 cm depth in all the 20 ha command area.

This showed that both secure property rights and effective collection are important for their adoption. Since the watershed management is generally the outcome of many individual watershed resources and number of stakeholders acting in a participatory mode. In the light of inherent uncertainties about impacts of land management or hydrologic function, especially at different geographic scales, the answers to these questions may only emerge over time due to participatory and adoptive learning process (Johnson et al. 2001).

Table 2: Salient features of the dam at village Karoran District Ropar, Punjab (Jindal et al. 1990).
Source: The perusal of data in table 3 showed that the watershed treatments resulted in significant reduction of sediment loss from 140t/ha to 18 t/ha in Sukhna lake of 4207 ha catchments area over a period of ten years (Samra, 2002).

Attribute	Values	
Average rainfall for the monsoon	935 mm	
Catchments area	17.3 ha	
Runoff	35 %	
Expected runoff volume during monsoon	5.7 ha-m	
Designed storage capacity	5.7 ha-m	
Dead storage capacity	0.4 ha-m	
Type of dam	Earth fill, core wall	
Height of dam	11.0 m	
Top width of dam	5.0 m	
Side slope on the u/s and d/s sides	3 : 1, 2 : 1	
Estimated runoff for spillway	225 m	
Slope on spillway on sides	1.5 : 1	
Cost of dam	Rs. 1.50 lakh	Total cost 2.5 lakh
Cost of irrigation system	Rs. 1.00 lakh	
Cost of storage, per m^3	Rs. 2.70	
Total command area	20 ha	

Table 3: Effect of watershed measures and social protection in Sukhna Lake catchments (4207 ha) on sediment and water yield.
* values in parenthesis indicate times reduction.
Source: Samra (2002).

Particulars	Pre-treatment (Avg. 1970-79)	Post-treatment (Avg. 1979-89)
Average annual		
Monsoon rainfall (mm)	1003	953
Monsoon water yield (mm)	295	63 (4.7*)
Runoff (% of monsoon rain)	29	7
Monsoon sediment yield (t/ha)	140	18
	Avg. 1958-78	(7.8)

Challenges to improve water management in upper watersheds

Properly managed upper watersheds result in optimal allocation and use of water and land in upland areas to advance social objectives. Equity considerations dictate that the poor be targeted for benefits and protected from adverse impacts. The major challenge for research is to identify circumstances under which poor water management is a major impediment in achieving these objectives. It is also important to

specifically identify the pro-poor approaches for improving the contribution of water to rural livelihoods. One of the outstanding developmental challenges in the rainfed regions of India is wide adoption of the well known rainwater management practices. Improvement in the management of the rainwater has a vital role in the reduction of livelihood and enterprises risks caused by climatic variability. The agriculture sector is by far the largest user of water in the world. About 80-90 per cent of all the water is used in agriculture. Unfortunately, water use efficiency in this sector is very poor not exceeding 45 per cent with more than 50 per cent water is not being utilized, thereby enormous water saving could be achieved in the agricultural sector comparable with the other sectoral water uses (IWMI, 2002).

The fear of occurrence of large-scale famine cannot be dispelled easily. According to experts, on an average, water is being exploited more than the normal threshold level. Hydro-geologists from groundwater board of the state of Punjab opine that Punjab might be desert by 2025 if the groundwater table is exploited in the ongoing rampant manner (Hadda and Arora, 2003). Some reports indicate, reckless installation of tubewells by the private and government agencies, incentives to the farmers in the form of free power, discharge of effluents by industrial houses, faulty cropping pattern, lack of will to harness rainwater and above all empty government coffers. Thus, each factor is adversely affecting the groundwater table.

In the 300 km long and 30 km wide foothills area of Punjab state of India, which more or less meets the boundary of the Siwalik range, the water level fluctuation is immense. Some reports indicated that between 1995-1996, the water table has gone down by more than 7 m in the Balachaur block located in district Nawanshahr. However, the recharge is merely 20-50 per cent of existing level in Hoshiarpur and Gurdaspur districts, which mean that even the rainwater is not able to compensate the extraction (Hadda and Arora, 2003). It is apprehended that the people of Punjab are sure to face an acute scarcity of drinking water, leaving aside water for irrigation purposes and Punjab, the land of five rivers is likely to turn into a desert like conditions.
Therefore, keeping these points in view, some drastic corrective measures need to be taken up. The percentage of the area irrigated by tube wells increased form 23 to 60 per cent in 1995 to 1998 (in plains). It is thus imperative to use the canal water in conjunction with the tube well water wherever possible as indicated by irrigation engineers of Punjab Agricultural University, Ludhiana. Nearly, 75 per cent of the cultivated land in Punjab is under water intensive cropping pattern of wheat–rice monoculture. There is need to educate the farmers about the effect of over withdrawal of water. The early transplanting of paddy should be discouraged and there is need to look for other means of not only harvesting roof top water but also adopting artificial recharging technologies, harvesting the rainwater either in impounding or excavating or Makkhowal type of water harvesting tanks in the foothills of Siwaliks depending upon catchments area, probable rainfall, cultivated area, cropping sequences and type of soils, etc. Sur et al. (1999) advocated the construction of a series of small water harvesting structures (WHS) in the form of earthen dams across the seasonal streams for managing runoff during the monsoon season, that could improve the water availability in the lower Siwaliks of the northern India. Three water harvesting structures (core wall type of earthen dams) having catchment's areas of 77.2, 6.6 and 17.3 ha were constructed : one at village Ballowal Saunkhari and Takarla each in district of Nawanshahr and one at Karoran in district of Ropar, Punjab in 1983-84. The study showed that 73, 77 and 85 per cent of the total summer monsoon rains could produce runoff with runoff coefficients of 0.22±0.03, 0.37±0.04 and 0.35±0.05 at the respective sites. On an average, 1211, 2712 and 2769 m^3 of water was harvested per hectare in these structures. The major mode of water loss was through seepage, which varied from 61 to 86 per cent at these sites. The water harvesting structures lost their gross storage capacity by 1.3, 1.1 and 1.2 per cent with siltation rate of 31, 37 and 47 t/ha of catchments area at Ballowal Saunkhari, Takarla and Karoran respectively.

Opportunities and challenges for water management in upper watersheds can be grouped in five major areas: overcoming constraints to technology adoption, managing conflict; balancing local economic and environmental services; and strengthening organizational and learning processes. Recently Leach et al. (2002) indicated that public policy making and implementation in the United States are increasingly handled through local consensus seeking partnerships involving most affected stakeholders. The stakeholders perceive that their partnerships have been most effective at addressing local and other serious problems.

Recently, Hirji and Pamella (2002) indicated that the systematic integration of environmental flow requirements in water resources management decision-making and policy reforms is a complex task and still a developing field on which agreement does not yet exist, even in industrialized countries. However, the complexity is compounded by lack of data and weak institutional capacity. In addition environmental flow assessments i.e. the process of determining environmental flow requirements, can be costly and may yield uncertain results with limited utility to decision-makers. The paper concludes with recommendations for improving the integration of environmental flow consideration into water resources development and management.

Because of uneven distribution of water resources and population densities worldwide, water demands already exceed supplies in nearly 80 countries with more than 40 per cent population of the world (Qadir et al., 2003). Consequent to further population increase in these countries, supplies of good quality irrigation water will further decrease due to increased competition in water use in between agricultural and non-agricultural uses. These facts reveal that the time has come for the sustainable management of available water resources based on global, regional and site-specific strategic

options. The integrated water management approaches can be followed and their sustainable combination will be the key to future agricultural and economic growth, social wealth, particularly in the region that are deficient in fresh water supplies and are expected to become more deficient.

Overcoming constraints to technology adoption

Many appropriate technologies have been developed for supplemental irrigations and water harvesting. These technologies are widely used in countries such as Burkina fiaso, Kenya and India by group of farmers. However, developed technologies are not being adopted due to variety of constraints. While the causes of lack of adoption may be similar across sites, site specific solutions may be required based on solutions, social, economic, biophysical and political environments. A survey of two districts of submontane region of Jammu, indicated that the constraints in adoption of rainwater management practices included topographical problem (90 %), lack of technical knowledge (78 %), ignorance of rainwater management practices (58 %), non availability of agricultural machinery and implements for water harvesting (51 %) and non-availability of labour (32 %) (Table 4, Sharma et al., 2004).

Table 4: Constraints in adoption of rainwater management practices (Sidhu 2002).

Sr. No.	Constraints in adoption of rain water management practices	Farmers	%
1	Non-availability of labour	48	32.0
2	Non-availability of agricultural machinery and implements used for rainwater harvesting	77	51.3
3	Lack of technical knowledge	117	78.0
4	Topographical problems	135	90.0
5	Ignorance of rainwater management practices	88	58.7

In an on-farm experiment conducted in foothills of Siwaliks, there was 13.2 per cent increase in grain yield of maize in T4 treatment as compared to treatment T1 (farmers practice). The grain yield in other treatments viz. T2 and T3 was 3.2 and 7.3 per cent higher over control (Table 5, Arora and Hadda et al., 2003).

Managing conflicts

In the absence of clear and widely accepted rules for access and norms for use, multiple uses and users of resources can often lead to conflict. For example in N-W tract of India, the residents of watersheds are resource poor, posses small land holdings and suffer from vagaries of nature. Since time immemorial, land clearing and farming by those farmers is seen as a threat to the integrity of the watershed functions produced by those forest lands.

Often conflicts frequently occur; more convert conflicts are also common. It is a matter of concern and cause to reduce conflicts between upland farm communities and state forest departments and other public agencies concerned with water and watershed management (Tomich et al., 1998; Swallow et al., 2002).

Decentralization of government services, NGOs and devolution of responsibilities with field functionaries for natural resources management are creating new opportunities for resources management as per requirements and needs of local people. However managing resources at the local level requires the ability to negotiate solutions and to resolve conflicts among stakeholders ranging from contractors to landless laborers should be viewed seriously and not underestimated (Sur and Toor, 2002).

Table 6: Environmental and productive impacts of participatory integrated watershed management at Fakot in UP Hills. Source: Samra (2002).

Attributes	Pre-project (1974-75)	During project (1975-86)	Post-project (1987-95)
Total foodgrain Production (qtls)	86.6	421	515
Average family income at constant price ('000 Rs.)	3.7	20.5	24.5
Male migration (%)	26.6	9.3	0.7
Runoff (%)	42	18	13
Soil loss (t/ha/yr)	11.2	4.9	2.0
Role of women in decision making (%)	10	25	45
Animal grazing	Heavy	Partial	Stall feeding

Table 5: Effect of different treatments on grain yield of maize following participatory approach in a micro-watershed during the year 2002, Arora and Hadda (2003).

Treatments	Grain yield (kg ha^{-1})
Farmers practice (T1)	2270.5
Improved variety + recommended dose of fertilizer (RDF) (T2)	2344.4
T2 + 25 % N replacement through farm yard manure (FYM) (T3)	2435.6
T3 + addition of Zn as per recommendation + herbicides (T4)	2570.2
LSD < 0.05	87.4

Balancing local economic and environmental objectives

In many developing countries, there are clear trade offs between the revenues generated by those enterprises and deterioration of quality and quantity of water for downstream users of water. These affected users are often the poor, who are least able to defend their right to clear water. An important question is need to be addressed, how the rights of the poor can be safe guarded in the processes of demographic, economic, political and global changes that are shaping the developing regions. The adoption of indigenous technologies and their refinement in a scientific way is a need of the hour in rain fed foothill region of Punjab.

Following the participatory integrated watershed management approach at Fakot, UP Hills, there was considerable reduction in soil loss from 11.2 t/ha/yr to 2 t/ha/yr (Table 6). Also, there was tremendous reduction in heavily grazing to stall feeding after managing the watershed. It has generated the income source at a place where participatory watershed approach has been adopted as evidenced by reduction in male migration from 26.6 to 0.7 percent in the area (Samra, 2002).

Sustainability and replicability

Sustainability is hard to define in absolute terms because it is a complex and contested concept. To some, it implies persistence and capacity to continue something for a long time. To others, it means resilience and ability to bounce back after unexpected resources. Some emphasize in activities concerning environment, others talk of economics to be sustainable. It is now well recognized that in any discussion on sustainability, it is important to clarify what is being sustained, for how long, for whose benefit, at whose cost, over what area and measured by what criteria. In the World Bank aided Project (IWDP) in Punjab, Haryana, Himachal Pradesh and J&K, the issue of sustainability received a good attention. The major concern was on the sustainability of resources created during the project like water harvested, fodder, fuel, crops and milk produced. It was emphasized that project area should work as demonstration to be simulated and replicated beyond the project area. Major lesson learnt from this project was that the task of replicability and sustainability is huge and cannot be solved without people's participation (Sur and Toor, 2002). The same study showed that the runoff was reduced from 45 to 22 percent in arable watersheds compared to non-arable watershed where it reduced from 45 to 18 percent due to adoption of soil conservation treatment. The reduction in runoff observed was more in non-arable compared to arable because of better vegetation status and less disturbances caused by human, and livestock's, etc. (Table 7).

Table 7: Runoff as affected by soil and water conservation treatment in foothills of Siwaliks. Figures in parenthesis are for runoff coefficient (Sur and Toor 2002).

	Rainfall (mm)	Untreated (mm)	Treated (mm)
Arable	3160	1438 (0.45)	693 (0.22)
Non-arable	10597	4733 (0.45)	1889 (0.18)

People's participation

People's participation holds the key in sustainable management of water resources in watershed by proper and purposeful execution, replicability and sustainability. Lessons learnt during the implementation of IWDP (Hills) Project (Sur and Toor, 2002) showed that the people's participation could be ensured through

a) adoption of need based, scientifically sound technology,
b) involving people during various phases of project implementation like planning, decision making and execution,
c) proper training and extension efforts,
d) changing and adjusting approaches which infuse in people the confidence and reliance in the project works and workers both,
e) transparency of accounts,
f) getting more and more works executed through beneficiary proved useful in this regard,
g) including a good portion of works with quick returns helped in attracting peoples attention and their interest in activities of the project,
h) People should be encouraged to contribute in term of labor and/or money in various activities of the project,
i) The technical practices should be evaluated properly for their cost-benefit ratio point of view. Moral and ethical commitment on the part of those directly involved in execution of works is vital for the successful implementation of project. Evaluation of works have been reported which brought out remarks like "physical and financial target achieved but none of the sub-watersheds rehabilitated effectively and completely" (Singh et al., 1993).

Strengthening organizational and learning processes

Understanding the importance of collective action of farmer's communities and of jointly framing rules for resource access and use, improved institutional arrangements for better management of land and water resources in upper watersheds are needed urgently. Collective action and institutional arrangements at different scales do not generally emerge spontaneously. Kerr et al. (1996) analyzed some watershed projects in India and those watersheds which were implemented through partnerships between NGO's and government organizations had the highest rate of success.

Also it is needed to assess the advantages and disadvantages of catchments management entities from community user group to large scale NGO's or centralized organizations for basin management. However, some of the questions addressed by challenge programme document on food and

water (IWMI, 2002) of realizing increased potential for sustainable water management in upland watersheds are :

What types of organizations are most effective in which circumstances?
What are the transaction costs of different organizational mechanisms?
What is the best way to facilitate the emergence and sustainability of these organizations, or to support existing organizations to take a new function?
How can it be ensured that the poor participate and the powerful vested interests do not dominate?
How can biophysical research best support collective decision making, especially in the context of a participatory adaptive learning process?

Conclusions

Where the potential for improved water use exists, how can it be realized? Often, actual benefit is obstructed by complex problems such as uncertainty of gain, lack of institutions to implement changes and possible conflicts between the diverse groups of people. This will require identification of factors that influence people to engage in a long term, adaptive process of water resource management.

People organize themselves in response to a variety of influences, including social, economic, political, technological and biophysical influences. In upper catchments, biophysical implications of individual decisions may not be considered due to high degree of uncertainty, externalities or overriding economic or social pressures. As a result, many of the institutions and policies that influence how people use resources in upper catchments/watersheds are not designed to maximize benefits from water. Yet, top-down, engineering approaches to watershed management have generally not been effective precisely because they do not take into account the multiple uses and users of resources in the upper watersheds.

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A study on water quality parameters of Karnafully river of Bangladesh

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Abstract

The river Karnafully is one of the Himalayan River originating from Lushai Hills in India. The catchments of the Karnafully and its allied streams cover 5500 (14000 km^2) square miles. The estimated peak discharge at Rangamati point on 12th July 2003 was 213,000 cumecs, which on reaching Chittagong was estimated to have been augmented to around 256,000 cumecs. Water samples were collected from Karnafully River along different points and analyzed for various physiochemical quality parameters during winter. Effects of industrial wastes, municipality sewage and agricultural runoff on the river water were investigated. The study was conducted between the Kaloorghat Bridge and Potenga estuary including Chittagong port. This area is most polluted due to the presence of many chemical fertilizers, iron, leather and pharmaceutical industries. All these industries discharge their untreated toxic waste water directly into the river Karnafully. The study involved determination of physical and chemical parameters of surface water at different points. The mean values of Water Temperature, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Solids (TS), Turbidity, Dissolved Oxygen (DO), Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Electric Conductivity and Total Alkalinity were 230C, 365.87 mg/L, 8018.8, 8518.33 mg/L, 31.54 FTU, 1.55 mg/L, 6.65 mg/L, 13961 µs/cm, 247.47 mg/L, 560.27 mg/L and 4.8 mg/L respectively.

Key words: physiochemical parameters, winter season, monsoon season, DO, BOD.

Introduction

Water is essential for all living beings and man is no exemption. So that most of the human civilization has developed on the banks of rivers, lakes or seas. Today, nearly 40 percent of the world's food supply is grown under irrigation, and a wide variety of industrial processes depends on water (BCAS 2000). Bangladesh is a land of rivers. Around 230 rivers flow in the country including 53 international rivers. Most of the big cities and settlements developed near those water bodies. Simultaneously this urbanization becomes main reason of pollution for these rivers and other water bodies (DOE, 2001). Several studies (DOE 1993, Hossain 2001) showed that surface water quality of the rivers of the country is getting highly polluted day by day. Karnafully River the largest and most important river in Chittagong and the Chittagong hill tracts, originating from South Lushy Hills, a lofty range of Hills of Assam in India at Latitude 23° 53/ N and Longitude 92° 27/ E. The Karnafully river enters into the Chittagong in the west and South-west direction and finally falls after a course of 180 km, into the Bay of Bengal in 22° 14/ N and 91° 47/ E at Potenga, leaving the city of Chittagong on its right bank, about 10 miles away from the mouth. Before that it travels through mountainous wilderness making a narrow loop at rangamati and then follows a zigzag course before it forms two other prominent loops, the Dhuliachhari and the kaptai. The hydroelectric dam is situated just before the entrance of the river into the Kaptai loop. In Chittagong the Karnafully made a most significant change in its course from Kalurghat downwards. The change has been taking place for more than a century. Formerly, the river had a western and southwestern course from Kalurghat and flowed by Sampanghata, Suloop Bahar, Kapashgola, Chowk Bazar, Roomghata, Ghat Farhadbeg, Boxirhat, Patharghata on its rightbank. But gradually it receded to the left throwing up vast and extensive alluvial lands along its rightbank, now known as Char Bakalia, Chandgaon, Char Chaktai, etc. The above ghats and bazars which once dotted the right bank of the Karnafully along the eastern limits of the town are now important localities in and outside the municipality, far away from the present course of the river. For centuries has shaped the lives of the people living along its banks. With marked rise in population and consequent increase in irrigation and a flurry of industries, the demand for pure natural water is increasing. Incongruously, growing urban population is producing greater loads of urban waste and the industries that need so much clean water are throwing out their effluents directly or indirectly into Karnafully. Industrial wastes are known to adversely affect natural life by direct toxic action or indirectly through qualitative alterations in the character

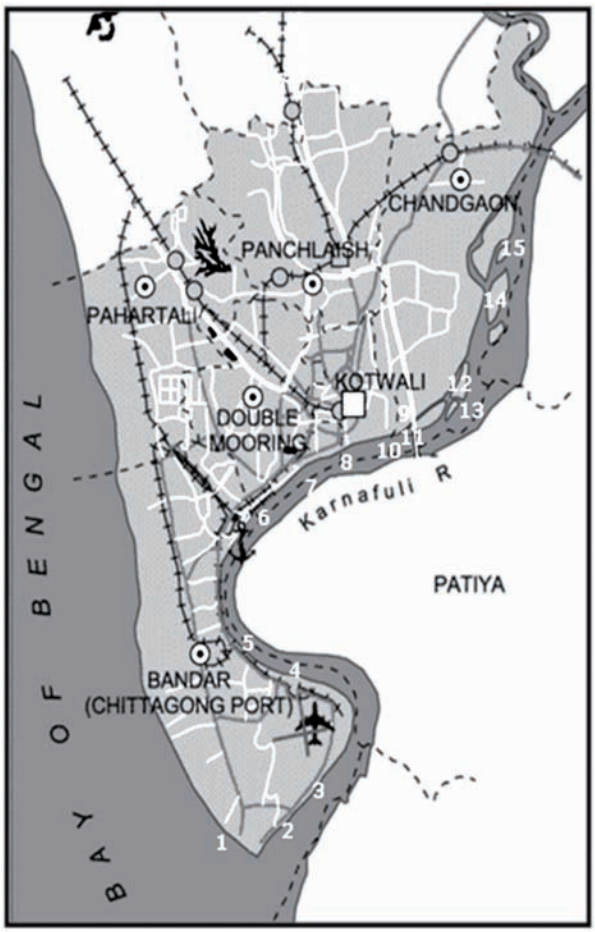

Figure 1: Showing the study area and sampling points.

of the water as well as that of the streambed (Ahmed & Reazuddin 2000). Urban wastes, on the other hand, cause organic enhancement and spread pathogens of devastating and serious sickness. The study was conducted between the Kaloorghat Bridge and Potenga estuary including Chittagong port. This area is most polluted due to the presence of many chemical fertilizers, iron, leather and pharmaceutical industries. All these industries discharge their untreated toxic waste water directly into the river Karnafully. Thus the study involved determination of physical and chemical parameters of surface water at different points. The objectives of the study are To assess the present water quality, through analysis of some selected water quality parameters like Color, Odor, Temperature, pH, TSS, TDS, TS, BOD, COD, DO, Turbidity, EC and Salinity etc. and to compare the results with the international and Bangladeshi standards.

Methods

Water samples were collected from the Karnafully River during dry seasons in January 2003 and later on in January 2008 and tested for physical qualities, chemical contents. 1.5 liter polypropylene bottles were used for water sample collection. Prior to sample collection, all bottles were washed with dilute acid followed by distilled water and were dried in an oven. Before taking final water samples, the bottles were rinsed three times with the water to be collected. The sample bottles were labeled with date and sampling source. Fifteen sampling points were selected. Methods used in the study of the physicochemical parameters are being listed in Table 1 and analytical equipment and materials used in the study are being listed in Table 2. The study area is shown in Figure 1 and the sampling locations were shown in Table 3.

Results and discussion

Water samples were collected from the Karnafully River during winter seasons and tested for physical and chemical parameters. Fifteen sampling points were selected. The sampling conditions were discussed in the Table 3. The important water quality parameters, such as Color, Odor, Temperature, pH, TSS, TDS, TS, BOD, COD, DO, Turbidity, EC and Salinity etc. were analyzed.

Table 1: Methods used in the study of the physicochemical parameters.

S/No	Parameters	Methods
1	Color	Visual inspection
2	Odor	By smelling
3	Temperature	Thermometer (graduated 0°C to 100°C)
4	Total Suspended Solid (TSS)	Gravimetric method
5	Total Dissolved Solid (TDS)	EC meter (HANNA instruments: H 19143)
6	Total Solid (TS)	Gravimetric method
7	Dissolved Oxygen (DO)	HANNA instruments: H 19143, (Dissolved Oxygen Meter, Portugal)
8	Hydrogen-ion-concentration (pH)	Jenway pH meter, model no. 3305
9	Electrical Conductivity (EC)	EC meter (HANNA instruments: H 19143)
10	Salinity	Salinity meter (HANNA instruments: H 19143)
11	Turbidity	Turbidity meter
12	Biochemical Oxygen Demand (BOD)	5-Day BOD test
13	Chemical Oxygen Demand (COD)	Closed reflux, titrimetric method.

Table 2: Analytical equipment and materials used in the study.

S/no	Equipment/material	Model/type	Manufacturer
1	Thermometer	Mercury/ Celsius	-
2	Conductivity meter	EC: 10/1990	HANNA
3	pH meter	Single Electrode	HANNA
4	Dissolved oxygen meter	H 19143	HANNA
5	Turbidity meter	C-114	HANNA
6	Electronic balance	WA 210 Rev-B	-
7	Water de-ionizer	B-114	Elgacan
8	Desiccators	-	-

Table 3: Shown the sampling locations.

Site no	Sampling sites/sources	Sample ID	Condition
1	Patenga Sea Beach	S-1	High tide
2	Patenga Nevay Academy	S-2	High tide
3	Nevay Academy Jetty	S-3	High tide
4	15 no ghat, opposite of the KUFCO	S-4	High tide
5	Dry Dock	S-5	High tide
6	Shipping Corporation	S-6	High tide
7	Chaktai New Bridge	S-7	High tide
8	Karnafully River in front of Chaktai Khal	S-8	High tide
9	Chaktai Khal (Chawkbazar)	S-9	High tide
10	Firingibazar Khal (at outfall to Karnafully River)	S-10	Low tide
11	Firingibazar Khal (up stream)	S-11	Low tide
12	Monohar Khal (low tide starting, east of Sadarghat)	S-12	High tide
13	Monohar Khal (at outfall to Karnafully River)	S-13	High tide
14	Mazhirghat (main drain)	S-14	Low tide
15	Mazhirghat (outfall to Karnafully River)	S-15	Low tide

Color, order and temperature

The river water should be colorless. As show in the Table 4, 7 samples are nearly colorless, 1 muddy, turbid color, 3 turbid color, 2 light green and 1 oily & black color. The observation showed that as near the estuary as good in color. The river water should be odorless. As show in the Table 4, 8 water samples are odorless, 1 pungent, 4 high pungent, 2 smile pungent. The observation showed that as near the estuary as good in odor. In the case of temperature, standard for sustaining aquatic life is 20-30 °C and as it was winter all the sample complies with the national standard. Figure 2 graphically shows the temperature data of sampling points.

TSS, TDS and TS

Bangladesh Standard for TSS in terms of inland surface water is 150 mg/L. The mean total suspended solids concentrations in Karnafully river was found to be 365 mg/L which is ranges from 120 to 590 mg/L is stated in Table 4. In fig. 3 graphically shows the total dissolved solids concentrations of sampling points. In case of TDS Bangladesh Standard in terms of inland surface water is 1000 mg/L. The mean total dissolved solids concentrations in Karnafully river was found to be 8018 mg/L which is ranges from 292 to 18530 mg/L is stated in Table 4. In fig. 4 graphically shows the total dissolved solids concentrations of sampling points. The mean total dissolved solids concentrations in Karnafully river was found to be 8518 mg/L which is ranges from 472 to 19210 mg/L is stated in Table 4. Following Figure 5 graphically shows the total dissolved solids concentrations of sampling points. Higher values of total solids are mainly due to the presence of silt and clay particles in the river water.

DO, BOD and COD

In the case of dissolve oxygen(DO), standard for sustaining aquatic life is 4 mg/L, whereas for drinking purposes it is 6 mg/L. DO value for Karnafully river, along our particular reach lies in between 0.10 mg/L to 3 mg/L (winter) as shown in Table 4. Following Figure 7 graphically shows the DO data of fifteen sampling points. While in the case of biochemical

Table 4: Physical and chemical parameters of Karnafully River water.

Sample id	Color	Odor	Temp. (°C)	TSS (mg/L)	TDS (mg/L)	TS (mg/L)	Turb. (FTU)	DO (mg/L)	pH	EC (µs/cm)	BOD (mg/L)	COD (mg/L)	Sal (mg/L)
S-1	nearly colorless	odorless	21	590	13200	13990	42.00	3.0	7.0	19920	163	390	6.20
S-2	nearly colorless	odorless	21	560	17500	18300	50.10	2.6	6.9	31340	178	380	6.50
S-3	nearly colorless	odorless	22	610	16100	16850	49.45	2.7	6.9	29900	195	420	9.20
S-4	nearly colorless	odorless	23	513	18530	19210	48.23	2.9	7.0	31300	160	350	7.0
S-5	nearly colorless	odorless	23.5	360	15000	15490	38.54	2.5	6.9	29200	195	423	9.9
S-6	nearly colorless	odorless	23.5	490	12590	13193	45.00	2.3	6.8	20700	200	425	6.7
S-7	muddy	pungent	22	480	510	1120	40.50	0.70	6.7	1080	290	635	0.40
S-8	turbid color	high pungent	22.5	190	421	695	16.20	0.20	6.6	820	397	865	0.40
S-9	turbid color	high pungent	23	120	292	472	14.00	2.10	6.6	552	198	510	1.50
S-10	light green	high pungent	24	230	999	1320	19.71	0.35	6.4	1806	370	755	5.20
S-11	oily & black	high pungent	24.5	380	6920	7441	23.33	0.65	6.2	11570	285	623	5.10
S-12	turbid color	odorless	24	175	910	1167	18.45	0.40	6.4	1712	273	600	1.40
S-13	nearly colorless	odorless	24	305	7510	7932	22.00	1.50	6.5	12880	243	590	5.10
S-14	light green	smile pungent	23.5	210	3500	3910	19.50	0.10	6.4	6190	310	743	2.70
S-15	turbid color	smile pungent	23.5	275	6300	6685	26.10	1.20	6.5	10450	255	695	4.70
BD stnd.	colorless	odorless	20-30	150	2100	-	-	4.5-8	6-9	1200	50	200	-

oxygen demand (BOD), standard for drinking purpose is 0.2mg/L, sewage effluent 20 mg/L which is exceeded to a great extent as shown by the mean values of 247 mg/L in Table 4. Figure 8 graphically shows the BOD data of fifteen sampling points. Chemical oxygen demand (COD) is other important parameter of water quality assessment. A standard for drinking purposes is 4 mg/L, which are not acceptable in-terms of Karnafully river water sample analyzed value as stated in Table 4. Figure 9 graphically shows the COD data of fifteen sampling points.

pH, turbidity, EC and salinity

pH is the indicator of acidic or alkaline condition of water status. The standard for any purpose in-terms of pH is 6.5-8.5; in that respect the value Karnafully River water are 6.2 to 7.0. In Table 6 indicates slightly acidic water. Following Figure 10 graphically shows the pH data of sampling points. The mean Turbidity of Karnafully River was found 31 FTU which is range from 14 to 50.1 FTU. Figure 6 graphically shows the Turbidity data of sampling points. The mean value of electrical conductivity (EC) of Karnafully River were found to be 13961 which is ranges 552 µs/cm to 31340 µs/cm whereas Bangladesh Standard for EC in terms of inland surface water is 1200 µs/cm. Figure 11 graphically shows the pH value of fifteen sampling points. The mean Salinity of Karnafully River were found 4.8 mg/L with a range from 0.4 to 9.2 mg/L. Figure 12 graphically shows the Salinity data of sampling points.

The results from data analysis show that, the water is certainly unfit for drinking purposes without any form of treatment recommended by EU (Claes 1997, EC 1986) and BD (Bangladesh Gazzet 1997) but for various other surface water usage purposes, it still could be considered quite acceptable. But as we know, once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So few years from now, serious water quality deterioration could take place.

Table 5: Standards for drinking water in Bangladesh (DOE, 1997).

Sl. no.	Parameter	Unit	Standards
1	Aluminum	mg/l	0.2
2	Ammonia (NH_3)	mg/l	0.5
3	Arsenic	mg/l	0.05
4	BOD	mg/l	0.2
5	Boron	mg/l	1.0
6	Cadmium	mg/l	0.005
7	Calcium	mg/l	75
8	Chloride	mg/l	150 – 600
9	Chromium (total)	mg/l	0.05
10	COD	mg/l	4
11	Color	Hazen	15
12	Copper	mg/l	1
13	DO	mg/l	6
14	Hardness (as $CaCO_3$)	mg/l	200 – 500
15	Iron	mg/l	0.3 – 1.0
16	Lead	mg/l	0.05
17	Magnesium	mg/l	30 – 35
18	Manganese	mg/l	0.1
19	Nitrate	mg/l	10
20	Odor	mg/l	odorless
21	pH	-	6.5 – 8.5
22	Sodium	mg/l	200
23	Suspended particulate matters	mg/l	10
24	Total dissolved solids	mg/l	1000
25	Temperature	°C	20-30

Table 6: Number of industrial in the bank of Karnafully.

Sl. no.	Industry	Number
1	Tanary	11
2	Textile	26
3	Oil refinery	01
4	T.S.P. plant	01
5	Uria plant	02
6	D.D.T. plant	01
7	Chemical industry	02
8	Fish processing plant	20
9	Asphalt bitumen plant	01
10	Still mill	01
11	Paper and reonmil	01
12	Soft drinks industry	03
13	Cement factory	03
14	Soop and diterjent	02
15	Insect killer production plant	02
16	Paint and x-ray production unit	04
17	Others industry	75
18	Total	156

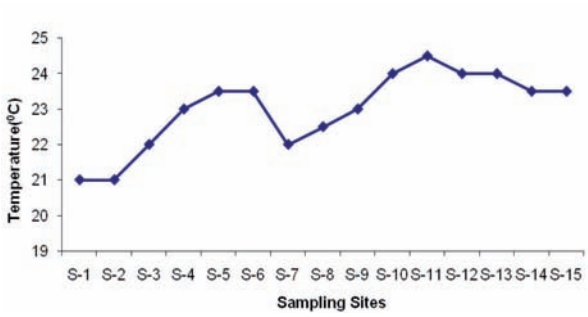

Figure 2: Temperature at different sampling sites.

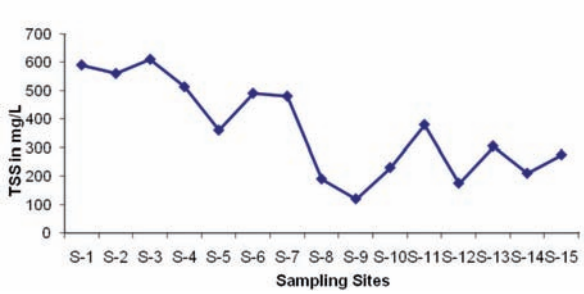

Figure 3: TSS at different sampling sites.

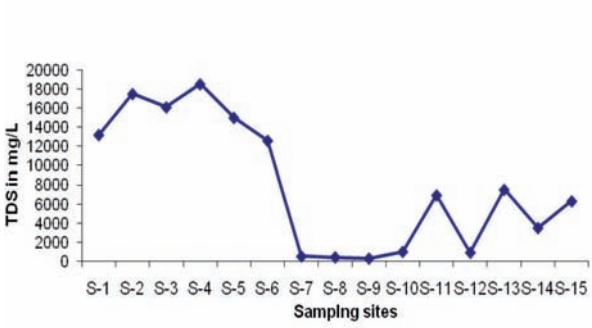

Figure 4: TDS at different sampling sites.

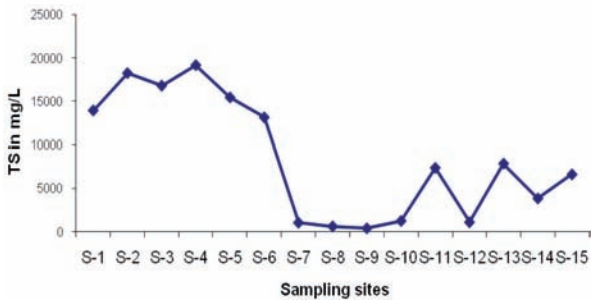

Figure 5: TS at different sampling sites.

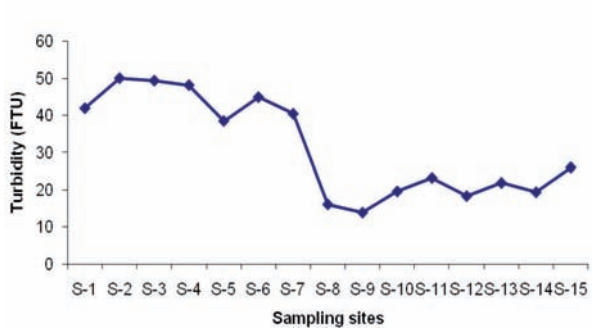

Figure 6: Turbidity at different sampling sites.

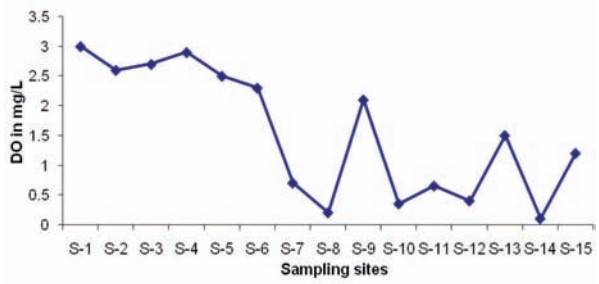

Figure 7: DO at different sampling sites.

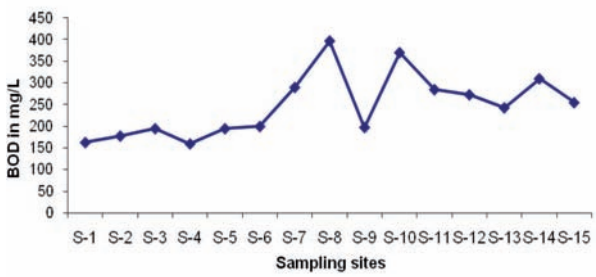

Figure 8: BOD at different sampling sites.

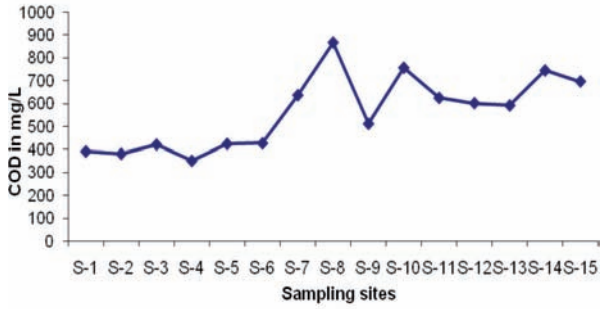

Figure 9: COD at different sampling sites.

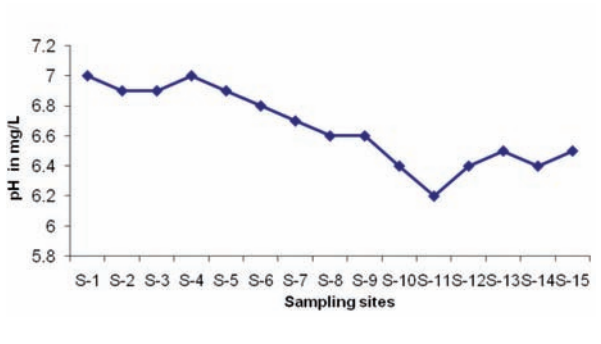

Figure 10: pH at different sampling sites.

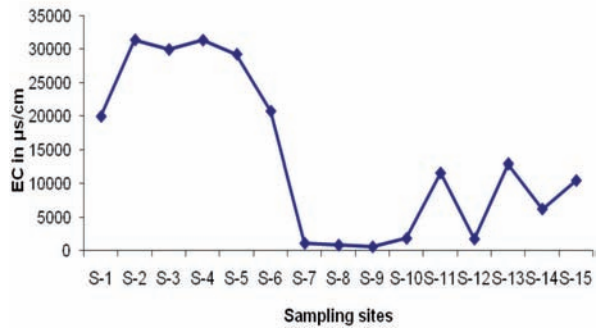

Figure 11: EC at different sampling sites.

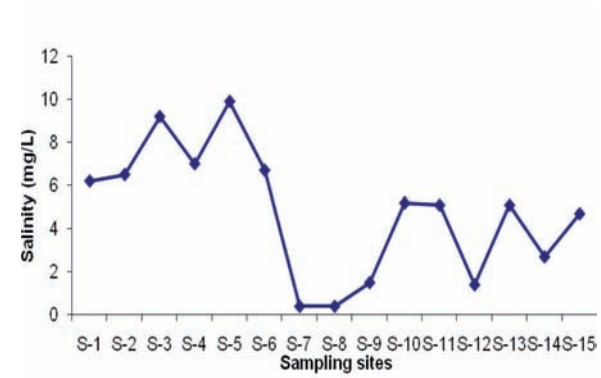

Figure 12: Salinity at different sampling sites.

Figure 13: Chemicals in T.K leather industry near Karnafully.

Figure 14: KAFCO fertilizer industry in the bank of Karnafully.

Figure 15: Water pollution by timber and sow mills.

Figure 16: The industrial waste water going to Karnafully.

Figure 17: Chittagong sea port in Karnafully River.

Table 7: Location of the water pollution responsible industries.

Location	Numbers
Kaloorghat	98
Mohra	85
Chandraghona	10
Chaktai	76
Sadarghat	71
Firingibazar	60
Fisheryghat	69
Dry-dock	89
Katgore	40
Jaldia	30
Gohira	20
Port	65
Total	713

However, there could be gross differences in the test results of some samples at different laboratories in the country, which could limit the use of these data for sensitive policy issues. The differences might be attributed to the approach adopted by laboratories in sample preservation, quality of chemicals used, testing method applied or qualification or expertise of the technicians or test performers.

Conclusions

Karnafully is very important for the Chittagong region. It is called the mother of Chittagong city because it feeding the city in many ways and also contents the all kinds of garbage of that city and it play an important role in the communication system of the whole region. From the beginning the importance of the river was very remarkable and increasing day by day. But at present that river is under pollution. Like other city belt river Karnafully is losing its water quality day by day. From the above chemical analysis we saw that most of the water parameters have already exceeded there tolerates limits. Still it has the time to control the pollution of the Karnafully. So it is very much necessary to more research on this river and has to raise awareness among the people about the pollution. Otherwise after few years we will not find our historical river, which is feeding the city.

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The authors are thankful to Professor Subodh Sharma and Dr. Roshan Man Bajracharya, Associate Professor, Aquatic Ecological Center (AEC) of Kathmandu University to financially support to present this paper in "International Conference on River in the Hindu Kush-Himalaya Region", Kathmandu, Nepal. Also thankful to Professor Dr. M. Shahidul Islam and Professor Shafique Haider Chowdhury for valuable advice, discussion and important paper. The authors express thanks to the authority of DoE, Chittagong, specialty Junior Chemist Md. Ashadul Hoque, and authority of COSED specialty to the Mr. Jabber and Mr. Kabir. Very special thanks to Shohid, Regan, Mahmood, Rana, Tapas and Shohag for their help during sampling and land-use survey.

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Water quality mapping of Kosi river using benthic macroinvertebrates

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Abstract

The water quality maps are valuable tools to identify sources and causes of pollution of rivers and help to take remedial measures to mitigate impacts under the existing environmental laws, policies and acts (ICIMOD 2007). As part of ASSESS-HKH project (funded by the European Union, contract number: INCO-CT-2005-00365), Kosi River covering three different ecoregions (according to Olson et al. 2001, Sharma and Moog 2005) and taking organic pollution as the major stressor, has been selected for water quality mapping based on benthic macro-invertebrates. The rapid field bioassessment method (Hartmann & Moog 2008) has been applied at 26 locations on Kosi river and its tributaries from Rudradhari (near Kausani, District Almora, Uttarakhand) upto Ramganga river (Near Patwai, District Rampur, Uttar Pradesh). The results have indicated that water quality class-I have been found at 13; class-II and III each at 5 and Class-IV and V at 1 location each. The water quality classes at different locations based on macro-invertebrate available taxa has also been validated using National Sanitation Foundation water quality index (NSFWQI). The water quality map was prepared on Google map base using five different colours indicative of different water quality classes. The water quality map clearly explains the quality of water at various stretches which can be used by the policy/decision makers at Government level to go for mitigation to improve the health of water body. The present paper reviews the concept of river typology (Sharma & Moog 2005a), selection of ecoregions and stressors of pollution (Moog & Sharma 2005), pre-classification of sites of different water quality classes (Moog and Sharma 2005), Multi Habitat Sampling (Moog 2007), preservation and identification of macro-invertebrates (Hartmann et al. 2007), development of rapid field bioassessment protocol (Hartmann & Moog 2008) and its application at 26 locations over the course of Kosi River.

Key words: biomonitoring, India, bioassessment, index, pollution.

Introduction

Management of quality of water bodies requires the information with respect to the nature and extent of existing water quality. It has been observed that the major rivers of the country have retained pristine water quality in their upper stretches and as the rivers enter the plains, they start getting exploited for irrigation and drinking purposes and are used as recipient of industrial and domestic waste water in addition to pollution from non-point sources. Further, the nature and extent of pollution has been changing with rapid urbanization and industrialization. Hindu Kush-Himalayan (HKH) region is not only the world's highest mountain range but also most popular region covering about 3500 km length over 8 countries from Afganistan in the west to Myanmar in the east. The HKH region is the store house of water, timber, firewood & medicinal plants, minerals etc that supports life sustaining activities of population living in the plains as well in river basins. Himalayan rivers are snow fed and flow is high to medium throughout the year with additional flows caused by heavy rainfall during the monsoon months from June to September when the catchments area is prone to flooding.

The water quality monitoring is conventionally based on the measurement of the physico-chemical and biological parameters which is not only time consuming but cost intensive too requiring lot of efforts and manpower & is faced with the problems of sensitivity of instruments with respect to low concentration of pollutants. Assessment of streams and rivers health using rapid approaches produces the results that are easily understandable by water resources managers and general public in short period of times potentially, over large areas and at a lower cost than more traditional quantitative methods. Large number of biological communities have been used to assess the quality of aquatic systems eg. macroinvertebrates (Armitage et al. 1983, Hellawell 1986, Galay 1987, Sehgal 1988, Rosenberg & Resh 1993, Griffith et al. 1994, Chessman 1995, Rosenberg & Resh 1996, Growne et al. 1997, Turak et al. 2000, Metzelling 2001, Hering et al. 2004, Verdonschot & Nijboer 2004).

Different groups of macroinvertebrates have different behaviour with respect to alternations and thus the tolerant or non-tolerant species can be found (Frey 1975, Galay 1987, Rosenberg & Resh 1993, Hering et al. 2004). In general, Stoneflies, Trichoptera and Ephemeroptera are considered non-tolerant, while Tubificidae or red Chironomidae are considered tolerant. In fact, the beginning of the use of macroinvertebrates to assess water quality was based on the concept of Indicator organisms and still remains in some biomonitoring methods. Some species can inhabit clearly polluted waters (Sehgal 1988). Thus, instead of just using the presence or absence of an indicator organism, the concept has been broadened to include indicator communities (Hellawell 1986).

According to Hellawell (1986), the macroinvertebrates are suitable as bioindicators because of the following reasons: (a) they constitute a heterogeneous assemblage of animal phyla and consequently it is probable that some members will respond to whatever stresses are placed upon them; (b) many are sedentary, assist and in detecting the precise location of pollutant sources while some have relatively long life histories (measurable in years) and provides the effect of prolonged exposure to intermittent discharges or variable concentrations of pollutants. (c) Qualitative sampling of benthic macroinvertebrates is relatively easy, well developed and equipment does not need to be elaborate; (d) taxonomic keys are available for most groups although certain 'difficult' taxa exist and (e) perhaps the most useful feature of this group is that many methods of data analysis including pollution indices and diversity indices have been devised.

The present paper outlines the water quality mapping of Kosi river based on the samplings, sorting, identification and assignment of water quality classes at 26 locations spread over the stretch of Kosi River. The work involves the selection of eco-regions (according to Olson et al. 2001) river typology (Sharma & Moog 2005a), selection of stressors, pre-classification of sites of different water quality classes (Sharma & Moog 2005a, Sharma & Moog 2005b), multihabitat sampling (Moog 2007), identification of macro-invertebrates, preparation of water quality maps of kosi river in Uttarakhand and upper gangetic plains. The results have indicated that water quality class-I have been found at 13; class-II and III each at 5 and Class-IV and V at 1 location each. The water quality classes at different locations based on macro-invertebrate available taxa has also been validated using National Sanitation Foundation water quality index (NSFWQI). The water quality map was prepared on Google map base using five different colours indicative of different water quality classes. The developed water quality map clearly explains the quality of water at various stretches which can be used by the policy/decision makers at Government level to go for mitigation to improve the health of water body.

Methods and results

Criteria for pre-classifying the sites

Out of many stressors like organic pollution, water abstraction (river damming and residual flow) & morphological degradation due to river engineering, only organic pollution has been selected as the main stressor of pollution. The

Table 1: Saprobic Water Quality Classes. Class I: None to very slight organic pollution; Class II: Moderate Pollution; Class III: Critical Pollution; Class IV: Heavy Pollution and Class V: very heavy to extreme pollution (Moog & Sharma 2005).

		Saprobic water quality classes				
S. no.	Parameters	I	II	III	IV	V
1.	Extent of pollution	No	Moderate	Visible load of organics	High organic load	Very heavy load of organic matter
2.	Quality of water	Clear	Natural turbidity	Slightly turbid	Turbidity	Considerable turbidity
3.	DO (mg/l)	8 or more	>6	4	Low 2-4 (to 2)	<1
4.	Oxygen saturation (%)	95-110	70-125	50-150	25-200	10-200
5.	BOD5 (mg/l)	<2	2-6	6-10	10-15	15
6.	COD (mg/l)	<5	5-12	12-18	18-25	>25
7.	Phosphorous (µg/l)	<35	36-81	82-200	201-300	300-1000
8.	Reduction phenomenon	Absent	Little	Black spots beneath the stones	Black reduction spots beneath the stone	-
9.	Substrate cover	Diatoms mosses	Algae, mosses, macrophytes	Macrophytes filamentous algae	Filamentous algae, sewage fungi	Reduced algal cover sulphur bacteria
10.	Macro-organisms (Insect fauna)	Highly diverse	Many groups highly diverse of high abundance	Sponges, mosses, crustaceans, molluscs, insect larvae	Poor fauna of high abundance	-
11.	Invertebrate fauna	-	-	-	Few groups e.g. Chironomus, tubificid worms	-
12.	Fish kills	-	-	Possible (high reaches produce high fish yield)	-	Balanced fish population not possible
13.	Sewage bacteria	-	-	Can be recognized	Colonies of sewage fungi can be seen by naked eye	Sludge deposits in lentic areas and Chironomidae and tubificid worms

saprobic quality water classes can be assigned on the basis of parameter given in Table 1.

The decision support was finally used to pre-classify the impact of organic pollution stressor at various locations. To delineate proper geographical area for ASSESS-HKH region, the rivers within one ecoregion were characterized on the basis of altitude range, climate, substrate composition, flow conditions and land cover (Sharma & Moog 2005a). These major abiotic parameters provide the hydromorphological matrix for river basins and control the development of the pristine (natural) benthic community.

A total of four common and wide-spread ecoregions were chosen for ASSESS-HKH and the focus was placed on the comparability, i.e. an ecoregion should be shared by at least two partner countries. For example the 'Subtropical Pine Forests' was used as "core ecoregion", as it is shared by four out of five countries namely Bhutan, India, Nepal and Pakistan and covers a large geographical area which helped in proper pre-selection of different river catchments in each country.

The following ecoregions were selected for India in state of Uttarakhand and adjoining part of Uttar Pradesh:

1. Himalayan Subtropical Pine Forests (IM0301)
2. Western Himalayan Broad-leaf Forests (IM0403)
3. Gangetic Plains Moist Deciduous Forests
   Upper Gangetic Plains (IM0166)
   Lower Gangetic Plains (IM0120)

Pre-selection of sampling sites

The pre-selection of sampling sites being a stepwise process, involved the use of an ecoregion map to identify appropriate river basins within the ecoregion. All available abiotic and biotic data were used to roughly define the estimated river quality of suitable river reaches. Sites were selected by fulfilling the defined criteria: ecoregion, altitude range, catchment size, anthropogenic impact (organic pollution vs. stagnation), availability of discharge even during dry season and site accessibility.

Pre-classification of sampling sites

After site selection, pre-classification of sites was carried out to assign the site to a water quality class between high (reference) and bad. A five water quality class scheme has been used to help combined abiotic and biotic pre-classification

Table 2: Criteria for reference site selection in selected ecoregions. X: moderate impacts, XX: severe impacts (Moog & Sharma 2005).

Basic criteria for reference site selection		IM0301	IM0120	IM0166
A	Land use practices in the catchment area			
	Effects of agriculture (Nitrate-N)	X	XX	XX
	Effect of herbicides and pesticides (consulting local inhabitants)	X	XX	XX
	Effects of villages, towns	X	XX	XX
	Effects of silviculture	No	No	No
B	River channel and habitats (related to at least 500 meter upstream and downstream of sampling site)			
	Substrate removal from riverbed, riverbank and floodplain	No	No	No
	Removal of debris (e.g. logs) from river	No	No	No
	Engineering structures in the river	No	No	No
	Migration barriers	No	No	No
C	Riparian vegetation and floodplain (related to at least 500 meter upstream and downstream of sampling site)			
	Riparian vegetation (percentage present)	25%	No	No
D	Hydrologic conditions and regulation			
	Impoundments, weirs, damming upstream	No	No	No
	Water abstraction and diversion	No	No	No
E	Physical and chemical conditions of water			
	Organic pollution affecting the site (BOD measurement)	6 mg/L	5 mg/L	5 mg/L
	Eutrophication affecting the site	No	No	No
	Diffuse inputs affecting the site	No	No	No
	Sign of salinity	No	No	No
F	Biological conditions			
	Disturbance by invasive plants or animal species	No	No	No

of the impact of organic pollution in the field. According to the pre-defined pre-classification scheme, four sites each were chosen representing a high and good status and three sites each representing a moderate, poor, and bad status summing up to a total of 17 sites per stream (4+4+3+3+3) (Moog and Sharma 2005). The pre-selection of sites was focused in the two states of Uttarakhand and Uttar Pradesh. The majority of rivers in IM0301 are located in Uttarakhand like Sarju, Pindar, and Kosi, all of which are tributaries to River Ganga in the Upper Gangetic Plains. The rivers are characterized by mineral subtrates ranging from megalithal (bedrock, large boulders) to silt. Organic pollution and waste disposal was common at many sites, Electrical conductivity ranged between 90 and 180 µS/cm, reflecting the absence of significant pollution. Initially, the Lower Gangetic Plains (IM0120) were selected for India, but finally, the Upper Gangetic Plains of Uttar Pradesh (IM0166) were chosen. A total of 35 candidate sites were selected in post monsoon period. It was found that there were lack of clear bad sites for IM0301 and reference sites for IM0166 ecoregion pre-classified. To get some severely polluted sites, sewage drains were taken into consideration, even though the drains were below the targeted catchment size range of 100–500 km² for this stream type.

Criteria of a reference stream

Criteria such as land use practices in the catchment area, river channel and habitats, riparian vegetation, floodplain, hydrologic conditions and water regulation, physical, chemical and biological conditions were mostly considered for selecting a reference stream. The criteria for reference site selection is given in Table 3 below.

Methodology

A rapid bio-assessment protocol with slight modifications for different river types in different ecoregions was used in decision making with reference to sites (Moog & Sharma 2005, Hartmann & Moog 2008). The catchment size and accessibility of sampling sites were used as selection criteria. Total of 12 reference sites were selected on the basis of the above criteria with 4 sites in Himalayan Subtropical pine forests (IM0301) (Almora hills in the Kumaon Himalaya), 4 sites in Western Himalayan Broadleaf forests (IM0403) (The Shimla hills in Dhauladhar range) and 4 sites in Upper Gangetic Plains moist deciduous forests (IM0166) (Siwaliks/Tarai).

Stream typology

The classification of rivers was based on three approaches eg., the longitudinal zonation, catchment based approach and the regional (geographic, physiographic) approach, the later is a comparatively new approach in aquatic sciences. Most of the new biological assessment systems for freshwater ecosystems are based on reference conditions (Verdonschot & Nijboer 2004). To describe reference conditions and to conduct a reference based quality assessment, a typological framework was applied (Rosenberg & Resh 1996). The comparison of impaired sites with undisturbed sites allows the definition and classification of different stages of degradation which must be river type specific. A river type is a constructed ecological entity with limited internal variation in its biotic and abiotic components which indicate a minimal and constant biotic and abiotic discontinuity in comparison to other entities. Such river types might serve as 'units', to which an assessment system can be applied.

A river type should always be defined on the basis of natural or near natural reference sites. The comparison with undisturbed sites of a certain river type allows to define and classify different stages of degradation. Biological assessment requires sufficiently stable and integrated river typologies that consider both abiotic and biotic criteria. The most prominent abiotic factors are river morphology, geochemistry, altitude, river size and hydrology. The river typologies can generally be designed following either 'top-down' or 'bottom up' approaches. The major difference between these approaches is the reliability of criteria (either environmental parameters or organism groups). Research on the importance of scale and ecological relevancy of parameters shows that even small-scale landscape units may only partially explain the distribution of species and communities.

Ecoregion approach

Ecological regions are defined as areas of relative homogeneity in ecological systems and relationships between organisms and their environment (Griffith et al. 1994). From the point of water quality assessment, it is seen as a great advantage for developing and applying a methodology. Within these areas, natural variability is expected to be comparatively low and ecological expectations relatively uniform. Thus ecoregions are regarded as a basic element of river typology.

Table 3: Details of sites and number of samples.
Out of total 35 sites, two sites were dropped as these were found dry during post monsoon period.

S. No.	Ecoregions	Area considered	No. of sites	No. of samples collected
1.	Himalayan Subtropical Pine Forests (IM0301)	Almorah Hills/Kumaon	16	32
2.	Upper Gangetic Plains moist deciduous Forests (IM0166)	Haridwar and east	17	34

Ecoregions selected

The following ecoregions were selected in India:

Upper Gangetic Plains moist deciduous forests (IM0166)

The upper Gangetic plains moist deciduous forest ecoregion lies along river Ganga. Originating in the western Himalayas, the river flows east along most of the length of the long mountain range to eventually join with the Brahmaputra River and head to the Bay of Bengal in south. The ecoregion extends from the upper reaches of the Ganga River across the states of Uttar Pradesh, Haryana, and Bihar. The main river systems in this ecoregions are River Khoh, Dehla, Ramganga and Kosi, all are tributaries to River Ganga. The alluvial substrate deposited in the river is clayey and poorly drained, the soil tends to be more sandy with only local clay patches more stable yet flood-prone riverine flats.

Lower Gangetic Plains moist deciduous forests (IM0120)

The lower Gangetic Plains moist deciduous forest ecoregion lies along the confluence of two of Asia's largest rivers, the Ganga and Brahmaputra River. It supports one of the most dense human populations on Earth and the fertile alluvial plains have been cleared and intensely cultivated. The human activities, that date back thousands of years have reduced the natural biodiversity of the ecoregion and many species have disappeared from the ecoregion.

Himalayan subtropical pine forest (IM0301)

The Himalayan subtropical pine forests are the largest forest in the Indo-Pacific regions. They stretch over 3,000 km length of the world's youngest and highest mountain range. It is believed that climate change and human disturbance are causing lower-elevation oak forest to be gradually degraded and invaded by the drought-resistant Chir pine (*Pinus roxburghii*), the dominant species in the subtropical pine forests which extends as a long, disjunct strip from Pakistan in the west through the states of Jammu and Kashmir, Himachal Pradesh and Uttar Pradesh in northern India upto Nepal and Bhutan.

Selection of core stream type

The core stream were selected on the basis of the following criteria: (i) The catchment area of the stream should be between 100-500 km^2 and (ii) Altitude range between 45-250m from sea level.

Procedure for sampling

Multihabitat sampling (MHS) technique a fundamental technique of multimetric assessment approach, has been used to evaluate the ecological status of running waters. The methodology is based on the Rapid Bioassessment protocols (Karr 1981, Armitage et al. 1983, ISO7828 1985, Chessman 1995, AS 1997, Growne et al. 1997, Barbour et al. 1999, Chessman et al. 1999, Kingsford 1999, Moog et al. 1999, Murray-Bligh 1999, WRC 1999, John 2000, Turak et al. 2000, Burns & Ryder 2001, Metzelling 2001, AQEM 2002, AQEM & STAR 2002, Halse et al. 2002, Parsons et al. 2002, Roshier et al. 2002), the Austrian Guidelines for the Assessment of the Saprobiological Water Quality of Rivers and Streams (Murray-Bligh 19999), ISO 7828 (Moog et al. 1999), the AQEM sampling manual (ISO7828 1985), the AQEM & star (AQEM 2002) and Austrian Standards (AQEM & STAR 2002).

The method focuses on a multi-habitat scheme designed for sampling major habitats in proportion to their presence within a sampling reach. A sample consists of 20 "sampling units" taken from all habitat types at the sampling site, each with a shar e of at least 5% coverage. A "sampling unit" is a sample performed by positioning the net and disturbing the substrate in a quadratic area that equals the frame-size upstream of the net. Sediments must be disturbed to an adequate depth to ensure capture of all species present depending on substrate diameter, compactness and shape. The sampling procedure covers a sampled area of approximately 1.25 m2 of the stream bottom.

The sampling site (river reach) should be representative for the river-segment (Austrian Standards M6232 1997). The sampled stretch of about 100m of length should reflect the typical situation (at least two riffle-pools sections) along a

Table 4: Streams with stresses and water quality classes.

Site no.	Stream name	Stressors	WQC
1	Sai	Deforestation, mineral removal, waste dumping and organic pollution from villages	2
2	Bitchula	Deforestation, mineral removal and minor organic pollution	1
3	Shrota	Deforestation, mineral removal and minor organic pollution	1
4	Swal	Deforestation, mineral removal and organic pollution	2
5	Uttarvahini (Ramgad)	Deforestation, mineral removal and organic pollution	1
6	Pathri	Deforestation, mineral removal and organic pollution	3
7	Bahalla	Deforestation, mineral removal, organic pollution and industrial effluents	5

section of one to several kilometers. The length of the investigated river reach should increase with the size (stream order) of the river. Sampling should be started at the downstream end of the stretch and proceeds upstream. The river section to be sampled should not be disturbed by physical contact when sampling the "sampling units" with the hand-net a controlled sampling by hand is the preferred method. The sampling area should cover a quadratic area in the front of the opening of the net (25×25cm). If kick-sampling is necessary (e.g. in deep sections), the net should be held vertically with the frame at a right angle to the current and disturb the stream bed vigorously by kicking or rotating the heel of boot to dislodge the substratum and the fauna.

After at least every three sampling units, rinse the collected material by running clean stream water through the net two to three times. The material is transferred into a large (white) tray or a bucket. The final multi-habitat sample consisted of 20 pooled sampling units. The table 4 gives no. of sites and samples collected during post monsoon and pre-monsoon season.

The macroinvertebrates were identified to the best level possible. Selected taxa groups and site characteristics were entered into software for data storage (HKHdip) and macroinvertebrate samples were sent to Austria from both reasons for identification upto species and the results are awaited.

HKH Eco-Data Management Tool (ECODAT)

It consists of a (i) catalogue of macroinvertebrate taxa of the HKH region and ecological information needed for data analysis and (ii) an analysis software and database for processing the ecological assessment data. It has four sub data files: (i) HKHdip (data input programme) for site protocol and taxa data entry and storage (ii) HKHscreening (screening field assessment) for evaluation of field observations regarding the ecological status of a river (iii) HKHbios (biotic score) for calculation of a HKH specific biotic score and (iv) HKHindex (multi-metric index): for calculation of a variety of metrics and a HKH specific multi-metric index.

Based upon the results of assessment from sites sampled during post & pre-monsoon seasons, the next step was to select a river passing through the selected ecoregions and accordingly Kosi River was selected for water quality mapping.

Water quality mapping of Kosi river

The river Kosi has been selected as a representative river for Water quality mapping using screening methodology. The river is a major tributary of the river Ganga and is the third largest river in the Himalayas with the Brahamputra & Indus rated first & second respectively. The river originates from rain fed spring source at Rudradhari, (District: Almora, Uttarakhand) joins Ramganga river near village Chamraul (Rampur district) has a catchment area of 3420 km^2 and length of 290 km and pass through the ecological regions including Himalayan subtropical pine forest ecoregion (IM0301)- the core ecoregion, Tarai Dwar Savanna ecoregion (IM0701) and Upper gangetic plains ecoregion (IM0166). It is an important river flowing at the foot hills of the Kumaon region and it drains the central part of the Almora district and western part of Nainital District of Uttarakhand. Figure 1 shows the ecoregions through which Kosi River passes and the catchment area of the river respectively.

Table 5: Distribution of sampling sites by WQC in India.

	Sampling sites	
WQC	No.	%
I	14	53.8
II	5	19.2
III	5	19.2
IV	1	3.9
V	1	3.9
	26	100.00

The Figure 1 shows that a third ecoregion Terai–Duar Savanna and grasslands also falls between IM0301 and IM0166. The ecoregion has also been sampled. The river is found to be used for various purposes such as drinking water source, washing & bathing, fishing, waste dumping (solid waste, domestic waste water, industrial waste water, cremation waste etc.), Irrigation and power generation purposes and Industrial uses as raw water & cooling water. However in downstream, the water can be used directly for domestic purposes as the sites are contaminated with domestic and industrial effluents. The Table 5 gives the various types of stressors over the course of Kosi River.

Sampling at Kosi River

A total of 26 sample sites were selected along the course of Kosi River Stretching from its origin at Rudrapur to just before the confluence with Ramganga River in Rampur village. Based upon the available macroinvertebrate taxa, NEPBIOS (Sharma 1996) keys were applied to assign water quality classes to the sampling sites. These water classes were validated using National Sanitation Foundation water quality index (NSFWQI). Based on the rapid field bio-assessment, five water quality classes were obtained for Kosi River as per details given in table 6 which shows that largest sample sites (nearly 54%) lie in WQC-I followed by WQC-II & WQC-III. In the upstream of the Kosi river, most of the sample sites belongs to WQC-I. As the river passes through the urban areas, it is polluted by direct sewage discharge and waste dumping.

Water quality mapping of Kosi River

The river water quality maps for 5 WQC were prepared for Kosi River on google map using 5 different indicative colours (Figure 2). These maps are easily readable & understandable

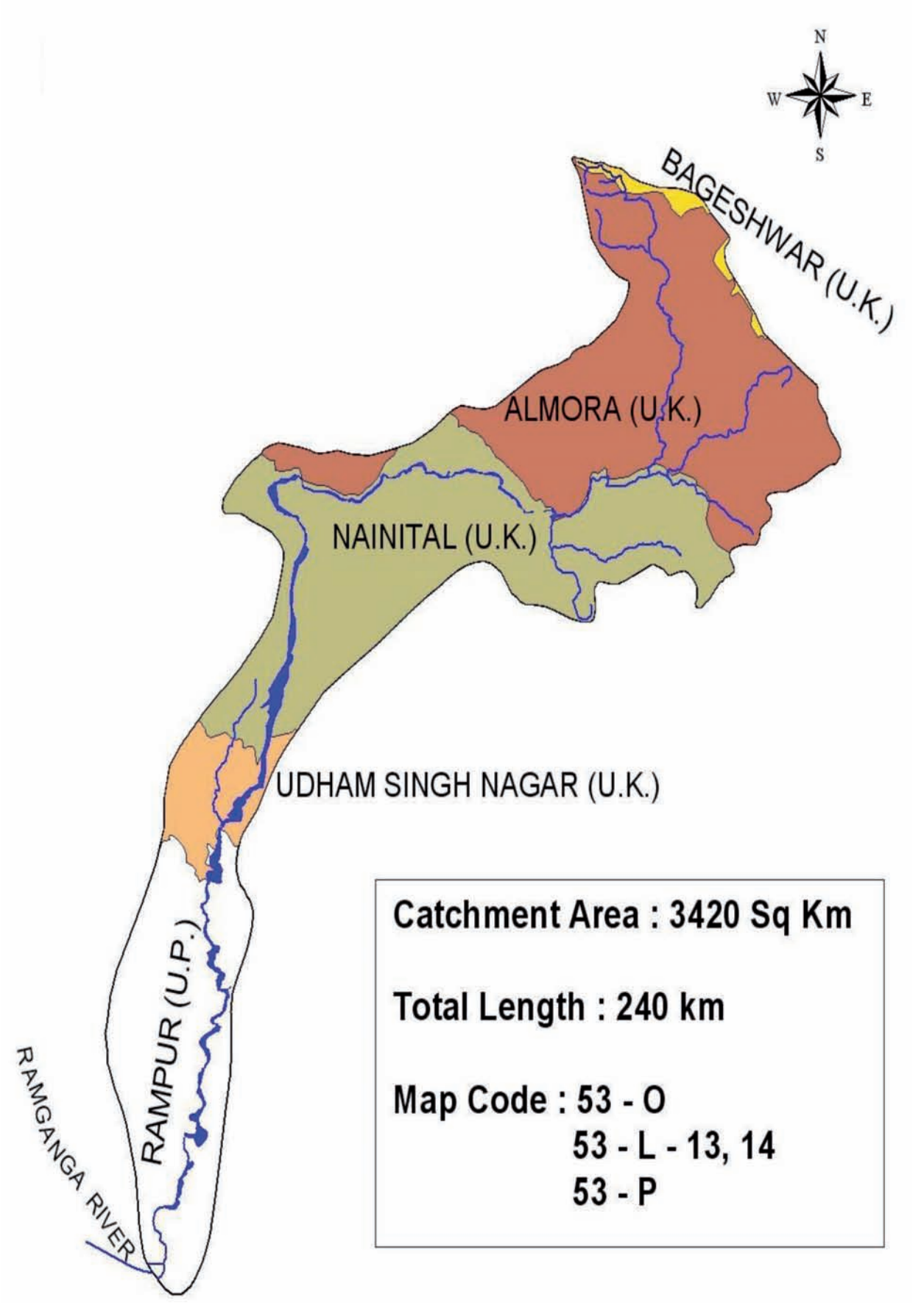

Figure 1: Kosi River catchment.

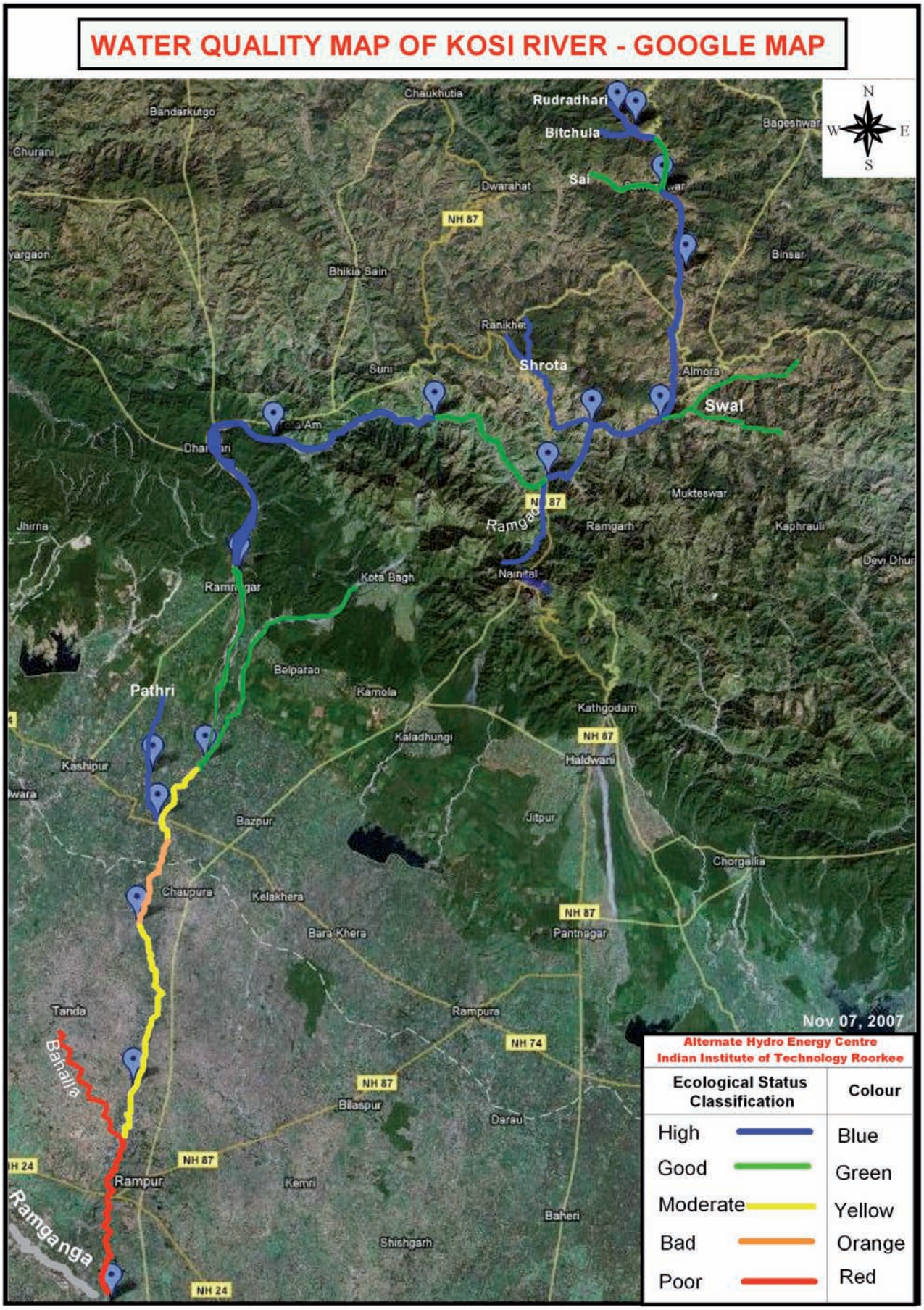

Figure 2: Water quality map of Kosi River.

to identify the hot spots along with the river stretches & show locations of sites where immediate action is requested. These maps can also be used as a basis for supplying information to strengthen sustainable management strategies in selected river stretches. The mapping outputs can also be used as a valuable in dissemination activities.

Conclusions

Looking at the serious pollutants loading of rivers & streams of India due to growing population, industrialization and urbanization, the water quality of these rivers & streams is deteorating rapidly resulting in scarce availability of water for drinking, irrigation, industry & other uses. Ministry of Environment and Forest, Government of India under its National River Conservation & National Lake Conservation plan, a number of conservation measures are being taken at state & central government level. These measures are being monitored with respect to large number of environmental laws, policies, acts and regulations. The impacts of these measures have not been found up to the mark owing to administrative & financial reasons. Public participation & capacity building has been found to play a key role in implementing conservation measures in true spirit. The water quality assessment based on macroinvertebrates may be considered as a valuable tool to assess ecological status of the above water bodies with minimum time & much less efforts and costs. The outcome of ASSESS-HKH project may prove as one of the valuable assets in evaluating the quality of water & preparation of water quality of a given river stretch which will help the decision makers, policy makers and scientists o find the exact causes and full proof conservation methodologies.

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Water quality mapping of the Bagmati river basin, Kathmandu valley

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Abstract

The Bagmati river together with its tributaries is the main source of water for domestic, irrigation and industrial uses for more than 2.5 million people of the Kathamndu valley. It is also a river of high religious significance of Nepal. A total of 77 sampling sites in the Bagmati river and its tributaries in the Kathmandu valley were analysed. The sites were classified into different quality classes based on the Saprobic approach. Water quality classes from I (none to very slight organic pollution) to V (very heavy to extreme pollution) were determined in the field by using a Field Screening protocol. In addition, physico-chemical parameters of water such as water temperature, dissolved oxygen, pH, electrical conductivity and biochemical oxygen demand (BOD5) were also measured in order to support the biologically determined water quality classes. In most of the urban core areas the river water quality is found to be extremely polluted with class V. The river stretches of water quality class I are found in the upstream part of the rivers/streams which are mostly covered with dense, protected forest and not easily accessible to human beings. The river water quality deteriorates rapidly as the river pass through semi urban and urban areas. A total of 21 stressing factors for degradation of the Bagmati river basin were identified. The major stressors were categorized as domestic and industrial effluents, solid waste disposal, washing/bathing and substrate abstraction. From the field data analysis a water quality map has been prepared which identifies the hot spots. This paper provides how to use the Screening methodology for biological water quality assessment and produces a water quality map of the Bagmati river basin.

Key words: bio-monitoring, macroinvertebrates, screening protocol, stressors, water quality map.

Introduction

The degrading water quality of the Bagmati river basin in the Kathmandu valley is largely due to human activities especially direct discharge of domestic, industrial and agricultural effluents, dumping wastes and quarrying sands. The consequences of the activities, the biological, physico-chemical and hydro-morphological characteristics of the river have deteriorated to such an extent, that the chances of recovery to the desire level are less.

Biological water quality assessment is one of the reliable, affordable and field based tools that can be used to evaluate the health status of the river/stream (Moog 1995). The biological assessment can detect cumulative physical, chemical, and biological impacts of stream-degrading activities (Karr & Chu 1999). Macroinvertebrates are commonly used in biological assessment because they are wide-spread, provide a spectrum of responses to disturbances, and can show sensitive response to the change of water quality (Rosenberg & Resh 1993).

The quality of Bagmati River water has received the most consistent attention compared to other river systems of the country (Shrestha 1980; Upadhyaay and Roy 1982; Pradhanang et al. 1988; DISVI 1988; RONAST 1988; Karmarcharya 1990; Shrestha 1990; Moog and Sharma 1998; DHM 1996; Pradhan 1998, Juettner et al. (2003) and several development project works). The studies have analysed the water quality of the Bagmati river basin considering different parameters inclusing benthic macroinvertebrates.

Shrestha (1980) studied the water quality of Bagmati biologically, using aquatic insects as bio-indicators. This was one of the first applied research work where aquatic insects were used to assess the water quality of rivers of Nepal. The biological index concept in surface water quality monitoring was introduced by DISVI (1988), the basis was Extended Trent Biotic Index. Moog & Sharma (1998) carried out the first systematic and detailed study on the water quality status of the Bagmati River and its tributaries in Kathmandu Valley introducing the use of saprobic system in monitoring surface water quality. Pradhan (1998) investigated microbial population density and their biomass with respect to saprobic water quality classes. Pradhan (2002) assessed the water quality of Bagmati River using mayflies as bio-indicators and suggested higher taxonomic identification for better precision of water quality classes. All the studies have shown that the water quality of the Bagmati River in the Kathmandu Valley have been deteriorated when it passes through the core area (Sharma et al. 2006).

ASSESS-HKH (Contract No: INCO-CT-2005-003659) is a three years project in which a methodology has been

developed known as the Field Screening Protocol for the assessment of river water quality of the Hindu Kush-Himalayan Region. This study was conducted to apply the screening protocol to develop water quality maps for identifying the hot spots in the Kathmandu Valley, Bagmati Basin.

Materials and methods

Study area

The study was carried out in the Bagmati river basin which is situated at 1,300 masl and is located between 27032'13" and 270 49'10" N latitudes and 85011'31" and 85031'38 E longitudes. The valley area is about 665 square kilometers (ICIMOD 2007). It is surrounded by the Mahabharat mountain range on all sides. The Phulchowki hill is in the south, Chandragiri/Champadevi in the south-west, Shivapuri in the north-west and Nagarkot in the north-east. The valley is drained by a multitude of tributaries that feed the main channel of the Bagmati River. The Bagmati River originates from the Southern slope of Shivapuri lekh (ridge) at an elevation of about 2650 meters, north of Kathmandu basin & flows straight south – west cutting the Mahabharat range. The present nature of rivers came into existence in Pleistocene times when the Kathmandu lake disappeared (Sharma, 1977).

In the upstream region near Sundarijal, two streams: the Nagmati and the Syalmati come to join this rivers. The length of the Bagmati River from its origin Shivapuri ridge to the Chovar gorge which is the outlet from the Kathmandu Valley is about 35 kilometers. The valley basin begins some kilometers below Sundarijal over which it flows to the south, turns to the west and again turns to the south and the west and then finally to the south-west. In the valley basin, the Manohara River with its tributaries such as the Salinadi, the Ghatte (Naldum), the Manamati, the Mahadev, the Hanumante, Godavari and the Kodku khola, joins the Bagmati River at Sankhamul Dovan. Before the Bagmati turning to the south at Teku, joins with other tributaries like the Dhobi khola (Rudramati), the Tukucha (Ichchhumati) and the Bishnumati which drains heavily populated areas. Three other tributaries such as the Balkhu, the Nakhu and the Bosan join the Bagmati River before leaving Chobar gorge (Pradhan 1998).

Methodology

Sample sites: A total of 77 sites were investigated in 26 rivers/streams of the Bagmati basin (Table 1). Sampling was conducted during premonsoon (May 2007) period. In each selected site, one hundred meters stretch as the part of the river was selected for study. The site selection was based on the point of effluent discharge, landuse, solid waste disposal, bank condition, substrate composition and meeting of tributaries.

Field Screening protocol (Moog 2007a): The protocol consists of several parameters like physico-chemical parameters, the sensory features, ferrosulphide reduction, bacteria, fungi, periphyton and composition and abundance of benthic macroinvertebrates were noticed and filled as per the instruction given in the protocol (annex 1). A more detailed description of the Field Screening methodology give Hartmann & Moog (2008).

Sampling

The sampling followed the multi-habitat approach (Moog 2007b) i.e. the distribution of sampling units followed the distribution of habitats. The distribution of habitats in the stretch was estimated and used it as a basis for selection of sampling units. About ten sampling units were taken in order to cover all possible habitats. However, more sample units were taken when some targeted organisms were still missed or less samples in case of heavily deteriorated rivers with a poor fauna. Benthic macroinvertebrates samples were collected with sampling net of 500µm mesh size from the most downstream point of the investigated section to avoid a self made turbidity. Each sample unit was regularly emptied into a white tray and identified up to family level with abundance in each sample unit. The successive samples were taken for further addition of taxa. Finally, the Field Screening protocol provides sum up values that determines the water quality class of the study section directly on the spot.

When the sample units from all microhabitats were taken, the sediments were stirred in the bucket, and poured the organic part through a net (500 micron mesh size) to reduce the amount of the sampled material. This sample was preserved in 4 % formaldehyde in the field which was well labeled. The samples were further processed in the lab through sorting and identification based on keys (Nesemann et al. 2007, Yule et al. 2004, unpublished keys 2006 of ASSESS-HKH project). The identified macroinvertebrates were assigned with NEPBIOS (Sharma & Moog 1996) and ASPT was calculated in order to obtain final numerical values which determined WQC (water quality class) and was verified with field water quality classes resulted from the Field Screening protocol.

Corridor survey

For the selected river stretch, the sketch of the river section was drawn. The features of the river such as bank condition and structure, bed materials, riparian vegetation, flood plain land use, flow conditions like pool, riffles, runs, rapids, water fall, slacks, transverse structures like bridge, weirs, dams, sediment bar and stressors like sewage discharge, substrates abstraction, water abstraction, solid waste disposal, washing, bathing and river engineering were noted down. This corridor survey reflects the present riverine environment including the current stressors to the riverine ecosystem and their impacts.

Table 1: Sampling sites in different rivers/streams of Bagmati.

Rivers	Total sites	Rivers	Total sites
Bagmati	10	Khasang khusung	3
Balkhu	4	Kodku khola	6
Basuki	1	Lele khola	2
Bishnumati	4	Mahadev I (Lele ward no 4)	2
Chakhu	1	Mahadev II (Bramhakhel)	1
Chharchhare	1	Manohara	7
Dhobi khola	2	Manamati	1
Ghatte I (Katunje)	1	Manamatta	1
Ghatte II (Matatirtha)	2	Nallu	3
Ghatte Khola (Naldum)	1	Samakhusi	1
Godavari	4	Sangle	2
Hanumante	8	Sano Khola	2
Kalka khola	1	Tukucha	1
		Total	77

Table 2: Distribution of macroinvertebrates by saprobic water quality class. Source: Field survey & laboratory analysis, 2007.

	Average number of families				
Group	I	II	III	IV	V
Ephemeroptera	4	3	2	1	1
Plecoptera	2	2	0	0	0
Trichoptera	5	2	2	1	1
Coleoptera	3	2	2	1	1
Heteroptera	2	1	2	2	1
Odonata	3	3	2	1	2
Diptera	6	5	5	3	3
Megaloptera	1	1	1	0	0
Lepidoptera	1	0	1	0	1
Decapoda	1	1	1	0	0
Tricladida	1	1	1	1	1
Oligochaeta	1	2	2	2	2
Bivalvia	1	1	1	1	1
Gastropoda	1	2	3	1	1
Taxa range	23-39	15-38	10-23	8-15	1-8

Table 3: Sensory features in sample sites. Source: Field survey, 2007.

		Sensory features (expressed in %)									
WQC	No. of sample sites	Foam	Odour	Waste dumping	Non-natural colour	Non-natural turbidity	Sewage fungi	Stone with algal veg.	% thick, significant layers of algae	Filamentous green algae	Reduction
I	12	0	0	41	0	0	0	67	25	8	0
II	18	17	0	73	0	34	0	28	28	22	12
III	16	57	0	94	0	57	13	0	38	50	44
IV	13	75	25	100	34	59	33	33	25	25	58
V	18	95	79	100	84	95	74	5	37	11	100

Table 4: Classification of river water quality stressing factors. Source: Field survey, 2007.

Groups	Stressing factors	f	%
A	1. Agricultural effluent	7	
	2. Industrial effluent	6	
	3. Sewerage	10	
	4. Waste dumping	35	
	5. Cremation site	2	
	Sub total	60	40.3
B	6. Squatter settlements	1	
	7. Water mills in upstream	1	
	8. Picnic spots close to river	3	
	9. Littering by picnic goers	1	
	10. Vehicle crossing along river	6	
	11. Military camp in upstream	1	
	12. Open defecation	15	
	Sub total	28	18.8
C	13. Bank cutting	1	
	14. Flood	3	
	15. Embankment & weir	4	
	16. Water for irrigation	9	
	17. Reservoir & impoundment	4	
	Sub total	21	14.1
D	18. Bathing & washing	18	12.1
E	19. Minimum disturbances	12	8.1
F	20. Stone quarrying & crushing	4	
	21. Sand quarrying	6	
	Sub total	10	6.7
	Total	149	100

Results and discussion

Response of benthic macroinvertebrates

The Bagmati River and its tributaries flow through diverse environments in the Valley and have diverse aquatic macroinvertebrates. Altogether 4 Phylum, 6 Classes, 16 Orders and 86 Families of macroinvertebrates were recorded from 77 sites of the Bagmati basin (Figure 1). Insecta was dominating by 86% among all benthic invertebrates. The number of benthic animals varies considerably between upstream and downstream. Sensitive taxa are gradually replaced by moderately to heavily tolerant taxa. The diversity and abundance of benthic animals are indicative of water quality class.

Most of EPT taxa (Ephemeridae, Ephemerellidae, Heptageniidae, Perlidae, Nemouridae, Leptophlebiidae, Leptoceridae, Rhyacophilidae, Lepidostomatidae, Calamoceratidae, Uenoidae) were only dominated in WQC I to II and non of them recorded in WQC IV and V except Baetidae and Hydropsychidae (Table 2). These two families were found in all the water quality classes except few sites. Presence of Salifidae (more than naturally occurring) indicated WQC III. High abundance of Chironomidae red, Psychodidae (white), Salifidae, Physidae were recorded in WQC IV and presence of Syrphidae together with either high abundance of Tubificidae and Culicidae or very low abundance of animals resulted into WQC V. The Bagmati river and most of its tributaries' head region are protected and have WQC I with sensitive taxa. These water sources are being used as drinking water. However, Manohara Khola in the upstream which flows through the cultivated land and accessible to human activities at Lapsephedi, had high sensitive faunal composition with WQC I. The number of taxa range varried significantly from WQC I to WQC V (Table 2). Only eight taxa was recorded in Nallu khola (WQC II) at Tika Bhairav before confluence with Lele khola was due to daily vehicle crossing along the river and sediment extraction.. Similary only six taxa were recorded from Hanumante River at reservoir, Telkot (WQC III) may be due to bank sampling as well as stagnacy of water body with deposition of fine particles.

Sensory features

The presence of foam gradually increased from WQC II to V (Table 3). Foam was recorded only in three sites among 18 sample sites of WQC II which was resulted mainly from sparse waste thrown (in terms of Manohara Khola at Phedi and Hanumante Khola upstream to drinking water reservoir) and discharge from nearby settlement in Godavari khola inside Botanical garden. Among twelve sample sites of WQC I, fourty one percentage of sites was recorded with few plastic and wrappers thrown due to human accessibility. Foam, odour, non natural colour, sewage fungi and reduction were resulted significantly from WQC III to V due to waste dumping on banks, domestic sewage, agricultural flow, industrial discharge, washing/bathing and open defecation directly into the rivers. Highest percentage (67 %) of stone with thin algal vegetation was recorded in WQC I and nil in WQC III may be due to frequent human activities.

River corridor survey

Presence of occasional human disturbances such as washing/ bathing, picnic spot, cultivated land on surrounding etc resulted WQC II in all river stretches (for example Bagmati river after confluence with Nagmati, Hanumante at third and fifth site, Nallu midle at Bhardeo, Godavari khola inside Botanical garden, Kodku at Harisidhhi). Regular washing/ bathing, agricultural flow and discharge from scattered householdes resulted WQC III before entering to urban areas which have deteiorated to WQC IV and V after entering into urban areas respectively.

The major stressors that degraded the water quality of the Bagmati basin are domestic and industrial effluents, solid waste disposal, substrate abstraction, vehicle washing and river crossing, river bank encroachment, no to low residual flow (environmental flow), river embankment and river impoundment. The classification of the river stressing factors

has been obtained from the field data and information that were processed.

The stressing factors obtained for each sample site have been grouped into six broad classes (each class includes related individual factors) as shown in table 4, and the frequency against each class has been obtained, and its relative importance has been computed in terms of percentage sharing. The major stressing factor under group A "River effluents" which broadly includes agricultural effluents, industrial effluents, sewage, waste dumping and cremation sites has the highest frequency in the Bagmati basin.

Physico-chemical parameters analysis

DO was recorded high (8.5 mg/l) in WQC I and gradually decreased to WQC V (0 mg/l). Similarly, BOD was very low in WQC I (0.3 mg/l) and increased to 163 mg/l in WQC V. DO and BOD varied highly in different WQC as well as within the same class (figure 2).

Field and laboratory verification

The samples that were collected were further checked and verified in the lab. The minute distinguishing characteristics of macroinvertebrates through binocular & microscope that was not easily distinguishable in the field has brought changes in the number of taxa (Figure 4). Through lab verification, the increase of taxa number ranges from 22 percentage to 8 percentage.

Water quality map

The water quality map of the Bagmati basin within the Kathmandu valley (figure 3) is prepared. Different colours are used for different water quality class such as blue for WQC I, green for WQC II, yellow for WQC III, orange for WQC IV and red for WQC V. Most of the rivers in the Kathmandu valley are of water quality class V and few rivers are of water quality class I, II, III and IV. The river waters with water quality class I were found in the upstream part of the rivers/streams which are mostly forest streams and not easily accessible to human whereas these water quality deteriorate rapidly as they pass through the human settlements and became water quality class V when passes through the semi-urban and urban areas.

Table 5: Water quality class with description and uses.

WQC	Description	Uses
I	Not polluted	Recommended for drinking after simple treatment
II	Slightly polluted	Drinking possible after intensive treatment
III	Moderately polluted	Hazardous
IV	Heavily polluted	Unsuitable for human use
V	Extremely polluted	Unsuitable for any purpose

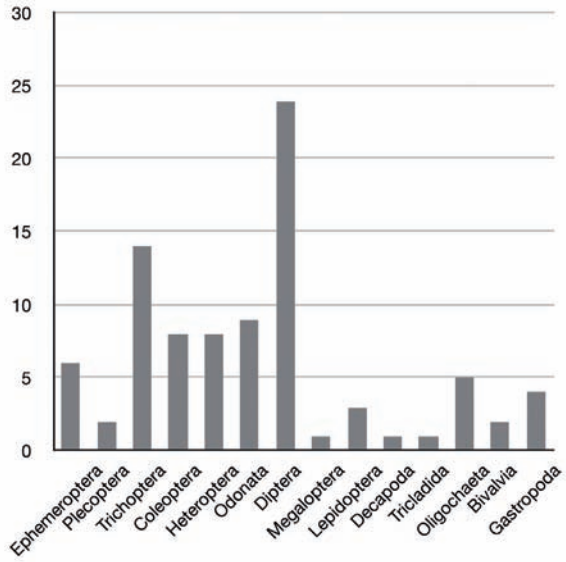

Figure 1: Macroinvertebrates diversity in Bagmati basin, Kathmandu Valley.

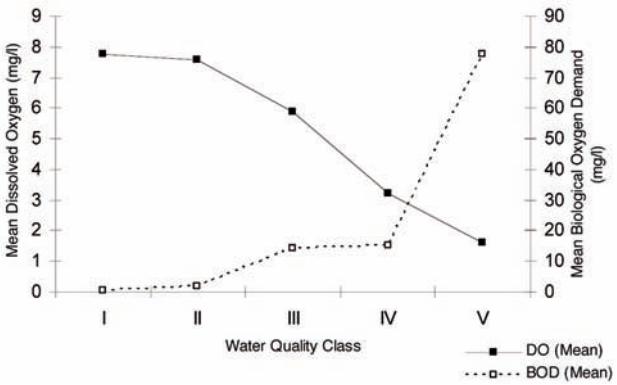

Figure 2: Mean DO and BOD at different water quality classes.

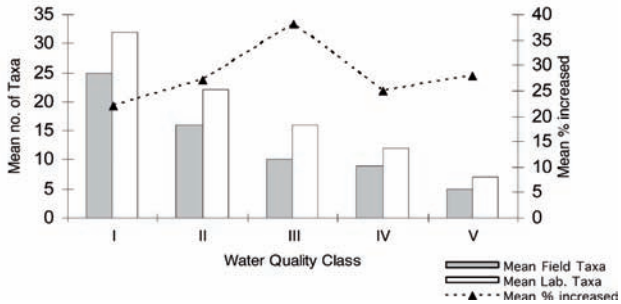

Figure 4: Increased % of taxa in laboratory verification.

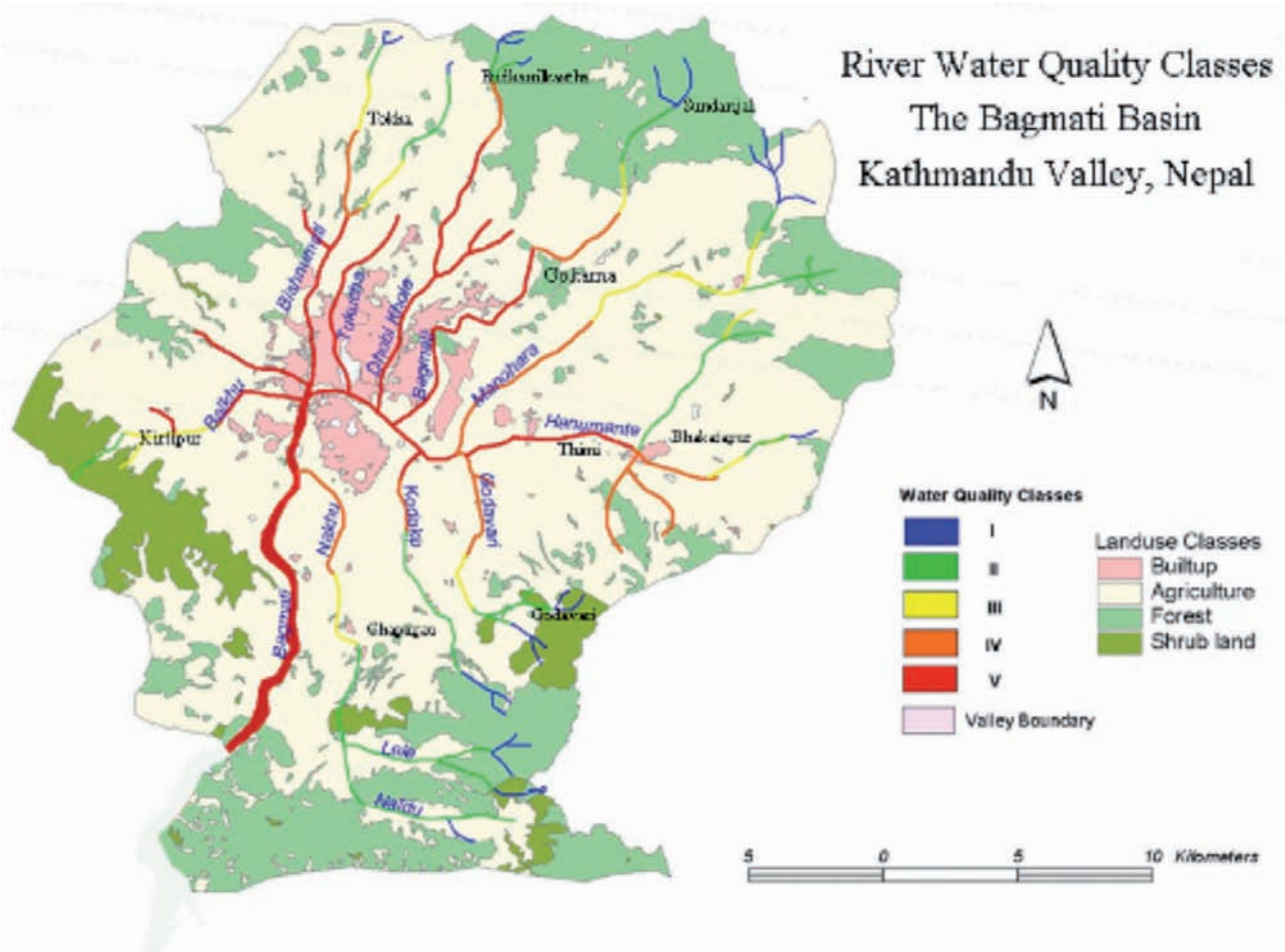

Figure 3: Water quality map of the Bagmati Basin.

Among twenty nine investigated streams and rivers, only two streams namely Nagmati and Basuki khola are of water quality class I for the entire river stretch whereas other streams have different water quality classes in different sections and particularly class V is observed in twelve streams at least at some river sections. The water quality class with its description and uses is presented in Table 5.

Conclusion

Kathmandu valley is drained by a number of tributaries that feed the main channel of the Bagmati River. Based on the Field Screening method, all five water quality classes have been obtained in the rivers of the Bagmati Basin. The water from the rivers across the river stretches is found to be used for multiple purposes like drinking, washing, bathing and irrigation. In all five water quality classes irrigation and washing are commonly used, the river water is found to be used for drinking in class I through class III. A total of 21 stressing factors of degradation of river water quality have been identified. Water quality class I have no or minimal anthropogenic impacts. The water quality map of the Bagmati basin within the Kathmandu valley is prepared.

A total of 86 families of macroinvertebrates was recorded from the Bagmati basin. The number of benthic animals varied considerably between upstream and downstream. Upstream sites have shown the diversity and range of benthic animals with 23-39, which has decreased along with the poorer water quality classes to 1-8 in class V. In addition to the field identification, lab identification is also necessary for identifying the macroinvertebrates the increase of taxa number in each site ranges from 22 percentage to 38 percentage in the present investigation.

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***Screening Protocol* for assessing the river quality of streams in the ASSESS-HKH (version Moog 12/03/07)** exceptive Gangetic Plains

River:	River system:		Date/Time:
Site:	Next village:		Surveyor:
N:	E:		Altitude (m):
Temperature water:	Conductivity:	O_2 (mg/l):	O_2 %:

DECISION SUPPORT TABLE	WATER QUALITY CLASSES				
Multiple choices possible	I	II	III	IV	V
Sensory features	**To be ticked/counted if not in accordance with natural river type**				
Non natural turbidity, Suspended solids			+	+	++
Non natural colour		+	+	+	++
Foam		+	+	+	+
Odour (water)		+	++	++	++
Waste dumping		+	+	+	+
Ferro-sulphide reduction – (water velocity< 0,25 m/s)	-				
Mud reduced but with aerobic surface		+	+++	++	
Mud reduced but with anaerobic surface				++	+++
Lower surface of stones (% cover black dots)		< 25 %	25-75 %	75-100 %	100 %
Upper & lower surfaces of stones (% cov. black dots)				+	++
Ferro-sulphide reduction – (water vel.) 0,25-0,75 m/s)	-	-			
Mud reduced but with aerobic surface			+	+++	+
Mud reduced but with anaerobic surface				+	++
Lower surface of stones (% cover black dots)			< 50 %	50-100 %	100 %
Upper & lower surfaces of stones (% cov. black dots)					+++
Ferro-sulphide reduction – (water velocity > 0,75 m/s)					
Lower surface of stones (% cover black dots)			< 25 %	25-50 %	50-100 %
Upper & lower surfaces of stones (% cov. black dots)					+++
Bacteria, fungi, periphyton					
Sewage fungi & bacteria (visible to the naked eyes)	(-)	(-)	few	medium	many +++
Sulphur bacteria (visible to the naked eyes)	(-)	(-)	(-)	+	+++
Stones with algal vegetation (periphyton) in thin layers	++	++			
% of thick, significant layers of algae	< 25 %	25-75 %	75-100 %	75-100 %	few
Filamentous green algae	none to few	filaments, tufts	large tufts	(large) tufts	+
Benthic macro-invertebrates					
Species richness	medium/high	(very) high	medium	few	very few**
Dominance of very sensitive organisms (8 to 10)*)	+++				
Dominance of sensitive organisms (6 to 8)*)	+	+++	+		
Dominance of medium tolerant organisms (4 to 6)*)			+++	+	
Dominance of tolerant organisms (3 to 4)*)			+	+++	+
Dominance of extremely tolerant organisms (1 to 2)*)					+++
Potamidae	++	++	+		
Perlidae	++	+			
Plecoptera	++	+			
Heptageniidae	+++	++	+		
Rhithrogena spp.	+++	++			
Ephemerellidae	+	++	+		
Euphaeidae	++	+			
Stenopsyche spp.	+	++			
Lepidostomatidae	+	++	+		
Rhyacophila spp.	++	+			
Simuliidae	+	++	++		
Tabanidae		+	++	++	
Hydropsyche spp. (medium to many)		+	+++	+	
Physa spp. (medium to many)			+	++	
Leeches (more than naturally occurring)	-	-	+	+++	+
Chironomids with red colour		very few	few	medium	+++many**
Bezzia-Group				+	++
Psychodidae white				+	+++
Air-breathing animals, e. g. rat-tail maggots					+++
Oligochaeta / Tubificidae (mud-worms)	0 to very few	few	few/medium	medium/many	many**
Sum of columns					

*) check scores in the Original NEPBIOS on the back page **) abundances may decline to 0 if oxygen depletes

TAXON / NEPBIOS		Abd	TAXON / NEPBIOS		Abd	HABITAT	%
Aeshnidae	6		Limnocentropodidae	9		**Mineral**	
Aphelocheiridae	7		Limoniidae	8		Hygropetric	
Athericidae	10		Lymnaeidae	6		Boulders	
Baetidae	7		Micronecta	4		Cobbles	
Bezzia-Group	2		Muscidae	3		Stones	
Bithyniidae	5		Naucoridae	4		Pebbles	
Blephariceridae	10		Nemouridae	9		Gravel	
Brachycentridae	7		Neoephemeridae	9		Sand	
Caenidae	6		Nepidae	4		Sandy mud	
Calopterygidae	4		Noteridae	4		Mud	
Chironomidae *red*	1		Notonectidae	3		Clay	
Chironomidae *not red*	5		Odontoceridae	5			
Chlorocyphidae	9		Palaemonidae	4		**Biotic**	
Chloroperlidae	5		Peltoperlidae	10		Micro algae	
Coenagrionidae	4		Perlidae	8		Macro algae	
Corbiculidae	5		Perlodidae	9		Submerged macroph.	
Corduliidae	4		Philopotamidae	7		Emerged makrophyte	
Corixidae	6		Physidae	3		Living terrest. plants	
Corydalidae	2		Planariidae			Wood	
Culicidae	5		Planorbidae	4		CPOM	
Dryopidae	4		Pleuroceridae	4		FPOM	
Dytiscidae	6		Polycentropodidae	7		Debris	
Ecnomidae	8		Potamidae	7		Sewage bacteria	
Elmidae	7		Protoneuridae	5			
Ephemerellidae	6		Psephenidae	7			
Ephemerellidae (*Drunel.* sp.)	7		Psychodidae (white)	2			
Ephemeridae	10		Psychomyiidae	6			
Epiophlebiidae	8		Ranatridae	4			
Euphaeidae	7		Rhyacophilidae	8			
Gammaridae	4		Salifidae	3			
Gerridae	4		Scirtidae	8			
Glossiphoniidae	7		Simuliidae	7			
Glossosomatidae	9		Siphlonuridae	10			
Goeridae	4		Sphaeriidae	5			
Gomphidae	6		Stenopsychidae	6			
Gyrinidae	10		Stratiomyidae				
Helicopsychidae	10		Taeniopterygidae	10			
Heptageniidae	10		Tabanidae	2			
Heptageniidae (*Epeorus* sp.)	9		Thiaridae	4			
Heptageniidae (*Iron* sp.)	9		Tipulidae	8			
Hept. (*Rhithrogena* sp.)	8		Tubificidae	1			
Hydraenidae	6		Veliidae	4			
Hydraenidae (*Ochthebius* sp.)	10						
Hydrobiosidae	10		**Other Taxa ⇩**				
Hydrometridae	6						
Hydrophilidae	6						
Hydropsychidae	6						
Hydroptilidae	10						
Lepidostomatidae	5						
Leptoceridae	7						
Leptophlebiidae	10						
Leuctridae / Capniidae	6						
Libellulidae	6						
Limnephilidae	9						

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Comparison of macroinvertebrate feeding strategies in streams from Asia, South America and Europe

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Abstract

Historical events and environmental conditions are regarded as the most important factors driving community composition, structure and function. Functional structure of benthic fauna is considered to be more similar across biogeographic regions than taxonomic composition. However differences in trophic structure and longitudinal patterns of benthic fauna are documented between temperate and (sub)tropical streams. Community characteristics based on biological and ecological traits became a stable part of assessment anthropogenic impacts. Feeding strategies indicate predominantly inputs of organic matter and nutrients. Dataset consists of sites from sub(tropical) zone in South America and Hindu Kush-Himalayan region and temperate Central Europe. Two and four seasons were sampled in Asian and European streams respectively. Macroinvertebrate data were adjusted to same identification level – family. Trophic patterns of macroinvertebrates across gradients of altitude, stream size and anthropogenic stress were compared among continents and zones. These findings were discussed in relation to the River Habitat Templet theory. Present study contributes to the understanding of tropical and temperate streams ecology and use these knowledge for assessment of anthropogenic impacts.

Key words: feeding strategies, macroinvertebrates, temperate, subtropical, impairment.

Introduction

Functional feeding groups provide analyses of functional structure of macroinvertebrate communities. Simplified classification linked to taxonomic level more general than species allow comparing benthic fauna from regions where lack of knowledge complicate detailed identification. Referring to River Continuum Concept (Vannote et al., 1980) describing patterns of feeding strategies along the river course there have been published comments introducing deviation from this concept (e.g. Statzner & Resh, 1993). Differences between temperate and tropical/subtropical regions were reported from Asia (Dudgeon, 1994) and South America (Tomanova et al., 2006). Composition of functional feeding groups is related to natural gradients of environmental parameters and it reflect also anthropogenic impairment of river ecosystems. Channel slope, width, shading, erosion-sedimentation, characteristics of riparian corridor, landuse of floodplain and catchment are interacting with intensity of eutrophication, organic pollution and morphological degradation. Habitat pattern, dynamics and availability of food resources form conditions for realization of ecological traits of macroinvertebrates.

Aim of study was identification of dominant drivers of macroinvertebrate feeding strategies and their tresholds arranged in regression trees. Results of different regions were compared.

Methods

Study sites

We collected dataset of 852 macroinvertebrate samples taken in running waters of South America (154 samples), Europe (457 samples) and Hindu Kush-Himalayian region in Asia (241 samples). Sampling and laboratory methodology of European samples collected within AQEM and STAR projects in period 2000-2003 were described by Hering et al. (2004) and Furse et al. (2006). Multihabitat sampling design was also adopted for samples collected from Asia during ASSESS-HKH project in period 2006-2007.

South American dataset is more heterogeneous in used methods due to combination of results from various studies (Buss et al. 2002; Callisto et al. 2004; Miserendino 2004; Moya et al., 2007; Miserendino & Pizzolon 2003; Boyero & Bosch 2004; Fernandez et al. 2001; Fossati et al. 2001; Moya et al., 2003; Tomanova et al. 2006; Rocabado & Wasson 1999; Campero 1998; Claros 1999; Arévalo 2000).

Feeding strategies

Taxonomic level of all macroinvertebrate data was adjusted to family level. Feeding strategies in form of preferences within categories used in Moog (1995) were estimated for all families present in dataset based on existing databases (e.g. Euro-limpacs Consortium, 2007) and literature search (Yule & Hoi Sen, 2004; Dudgeon, 1999; Tachet et al., 2000). The supplemental information was completed from Wilke et al. (2000), Rutter & Klemm (2001), Pereira & García (2001), Nesemann et al. (2003), Wantzen & Wagner (2006) and Tomanova & Usseglio-Polatera (2007). Combining 10 point preference system and relative abundance of individual taxa (families) a share of feeding strategies in samples were calculated.

Analyses

The relationships between community characteristics – percentage of individual feeding strategies (as a dependent variable) and environmental parameters were analysed by means of regression trees (Breiman et al., 1984). It find hierarchical decision rules to provide optimal separation between observations with regard to a continuous criterion variable, based on splits on one or more continuous and/or categorical predictor variables. To avoid over fitting, we adopted ten-fold cross-validation for estimating the best tree size and the tree with the minimum cross-validation cost was chosen as the optimal tree. For each tree the relative importance of predictors was computed; the differences among samples groups linked to branches of trees were tested using standard procedures (Kruskal-Wallis test; K-W, Mann-Whitney test; M-W). The analyses were computed using Statistica 8.0 (Statsoft, Inc., 2007).

Results

Data analyses of dataset combining samples from all three continents were limited to near natural sites with known information about Strahler stream order, distance to source, altitude, channel width. Additionally sites were classified into stream types or related to regional attributes. More environmental characteristics were available when data from individual continents were analyzed separately. Samples from Europe and Asia were classified to 5-class ecological status based on assessment systems developed in projects AQEM, STAR and ASSESS-HKH.

Comparing only pristine or minimally degraded sites from all three regions together (595 samples) statistically the most significant differences among continents were found for gathering collectors (lower values in Europe) and miners being higher in South America. Similar pattern was recorded if only sites closer than 20 km to source have been included. Regression trees analyses exhibited clear differentiation of shredders proportion in samples according stream types (regions). In the first branch samples with relatively low values (SH 2.9%) were specified by central European lowland rivers, Mediterranean rivers and streams in tropic/subtropic zone of South America. In the second branch combination

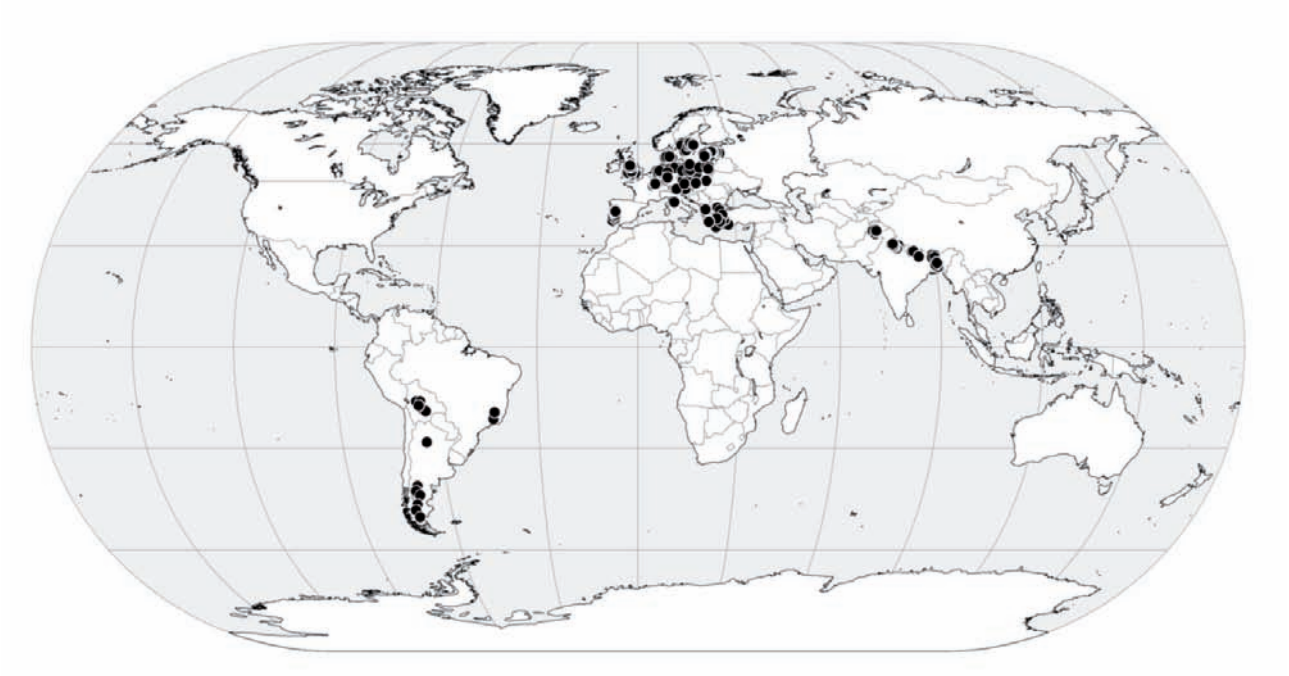

Figure 1: Location of studied areas.

of distance to source (treshold 11.9 km), altitude (treshold 1263 m a.s.l.), 1st stream order and stream type (higher values in European Alpine rivers) differentiated samples in relation to share of shredders. Significantly lower share of gathering collectors (CO 35.4 %) differentiated all Asian, South American and Mediterranean rivers from remaining European rivers (CO 19.9 %). In the next division the temperate samples from South America (CO 50.6 %) were separated by higher values from Himalayan Subtropical Broadleaf Forests, Upper Gangetic Plains Moist Deciduous Forests and tropic/subtropic South American samples. Within remaining Asian ecoregions the channel width treshold of 14.5 m, altitude treshold 865 m a.s.l. and distance to source at 22 km were important.

Europe

The most dominating feeding strategies in 457 samples collected across Europe and during four seasons were gathering collectors followed by collectors and passive filtrators. High proportion of shredders (Fig. 2) was recorded at sites in altitude above 999 m a.s.l. (SH 13.5 %). In lower altitudes relatively high share of shredders was associated with pristine sites of central European mountain rivers (SH 9.6 %). Within degraded sites shredders declined when cropland share in catchment was higher than 25 % (SH 1.3 %). Mean slope of the valley floor was primary factor dividing samples in terms of relative abundance of grazers. Slope treshold value was 1.2 %.

Asia

Samples from pre-monsoon and post-monsoon seasons were analyzed separately. In pre-monsoon season the land use characteristics of floodplain and catchment played important role. Samples with high proportion of shredders (Fig. 2) have been divided by more than 75 % of naturally unvegetated floodplain (17.3 %). Higher share of shredders within the opposite branch is associated either with small streams with catchment area below 8 km2 and channel width less than 1.35 m (SH 16.3 %) or streams with catchment larger than 8 km2 located in the ecoregion of moist deciduous forest in Lower Gangetic Plains and having more than 15 % of coniferous native forest in catchment (SH 12.5 %). The most dominated feeding strategy in 123 samples taken during post-monsoon season was gathering collectors followed by grazers. High share of shredders were associated with first order stream having more than 65 % of forest in catchment (SH 18.3 %). Fourth stream order was important for proportion of gathering collectors separating samples into two groups with mean values 33.2 % (stream order ≤4) and 64.7 % (stream order >4). First group was further divided based on altitude and catchment land use.

South America

Since standardized assessment of impairment wasn't available for this dataset only sites with no or very minor degradation were included in analyses (118 samples). Percentage of shredders was split to temperate and tropic/subtropic streams indicated by average values of 9.1 % and 2.2 % respectively (Fig. 2). Higher proportion of shredders within temperate streams was recorded at localities being located closer than 33.5 km from their source (SH 11.9 %) and in altitudes above 412.5 m a.s.l. (15.2 %). Relatively low proportion on shredders in tropic/subtropic streams can be additionally splited by tresholds of channel width (42.5 m) and 2nd stream order. In contrast to temperate streams in Europe the channel width had opposite effect on slightly higher share of shredders in tropical streams wider than 42.5 m in South America (K-W; $p<0.05$).

Discussion

Effects of temperature and flow regimes on functional structure of macroinvertebrates were obvious in different patterns in temperate and tropic/subtropic regions of South America. Low proportion of shredders in tropical rivers in Asia and South America is explained by possible trophic flexibility (Tomanova et al., 2006), misclassification caused by rough identification and lack of autecological information. It could be also related to limited stream retentiveness for leaf litter, role of mycoflora in litter breakdown (Padget, 1976; Irons et al., 1994) and different palatability of leaves in tropical streams (Stout, 1989). Our results indicated relationships of trophic structure of communities with stream zonation parameters (altitude, distance to source, stream order, channel width) and differences among climate regions. Anthropogenic impact modify characteristics of streams, fllodplain and their catchments. Effect of proportion cropland in catchment on the shredder quantity was found for degraded European streams. Riparian vegetation and shading are important factors forming community structure (Dudgeon, 1989). Prediction based on if-then conditions can be applied to analyze dependance of community features on combination of categorical and continuous environmental factors. It could be possible to development of models predicting proportion of feeding strategies. However it also indicated categories (stream types) within them would be efficient to evaluate the effect of local-scale factors and anthropogenic degradation.

Conclusions

Feeding strategies of macroinvertebrates are useful indicator of anthropogenic modification of stream ecosystems. It was found that some driving factors are operating in similar way among regions/continents but also significant differences in trophic patterns were recorded. More detailed identification, knowledge about traits of macroinvertebrate taxa and using biomass instead of simple number of individuals would improve indication value of these methods.

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