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Review Article

A new ecohydrological approach for ecosystem service provision and sustainable management of aquatic ecosystems in Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

Ecohydrology provides a framework for aquatic ecosystem management based on the interplay between different biota and hydrology. Bangladesh being situated in the world's largest delta is suffering from rapid degradation of its aquatic ecosystems. The ever increasing population pressure and intensive agriculture together with diversion of upstream water flows by India and climate induced changes make this ecosystem even more vulnerable. Using information from diverse sources, this paper explores the current state of the art on aquatic ecosystems of Bangladesh, their management, key problems, and introduces a new ecohydrology-based management approach for sustainable management of aquatic ecosystems in the country. Integration of both physical measures and policy actions are indispensable for greater ecosystem service provision from country's aquatic ecosystems. A cross-disciplinary action plan and appropriate strategies to bring policies into action is also essential for the sustainable management of aquatic ecosystems in the country.

1. Introduction

Bangladesh, being situated in the largest deltaic floodplain in the world is one of the most vulnerable countries to the projected sea level rise due to global climate change (Agrawala et al., 2003; Hossain et al., 2013). According to the Ramsar Convention's definition more than two-thirds of the land mass of Bangladesh can be classified as an aquatic ecosystem (FAO, 1988). These consist of a wide variety of water bodies, including lakes, oxbow lakes, rivers, flood plains, coastal wetlands, paddy fields and ponds (Craig et al., 2004). Ninety percent of the aquatic ecosystems of Bangladesh are dependent on the flow from three major rivers, but are now threatened by diversion of water from the Ganga–Padma River system in India (Gopal and Wetzel, 1995). All of these aquatic ecosystems form a unique mosaic of habitats with an extremely rich diversity of flora and fauna. They support the livelihood of millions of people in activities as diverse as fishing and collecting honey. They have also supported in agriculture and provide materials for thatching and fuel for domestic use (Mukul et al., 2014). Unfortunately, these aquatic ecosystems are either vanishing or have become degraded as a consequence of overexploitation of both ground and surface water, anthropogenic pressure and ill-planned flood control and irrigation

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infrastructures that cause habitat destruction in flood plains. These also cause loss and destruction of fish breeding grounds and favors siltation in river basins and flood plain areas (Hussain, 2010). In addition, present government policies with regard to wetland management are somehow inadequate and responsible for the degradation of aquatic ecosystems in Bangladesh.

Ecosystem services, is the collective term for the goods and services produced by ecosystems that benefits humankind, and have traditionally been undervalued as they often fall outside conventional markets (NRC, 2005). They have broadly been classified as provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005). This concept has much earlier origins in the context of aquatic ecosystem research where it has been embedded in the ideas of ecosystem functioning and the consequent human values (Maltby, 1986). In fact, aquatic ecosystems are associated with a diverse and complex array of direct and indirect uses. Direct uses include the use of the aquatic ecosystem for water supply and the harvesting of aquatic products such as fish and plant resources. Indirect benefits are derived from environmental functions such as flood water retention, groundwater recharge, nutrient, abatement, depending on the type of wetland, also on soil and water characteristics and associated biotic influences (Mitsch and Gosselink, 1993). Flood plain wetlands are particularly associated with groundwater recharge or discharge and individual floodplains may exhibit either or both of these functions (Thompson and Hollis, 1995). These functions are highly influenced by over exploitation of ground water resources (Rassam et al., 2009). However, the degradation and loss of aquatic ecosystems all over the world, together with the subsequent recognition of the ecological value of the services they provide, has made the restoration of aquatic ecosystems a top priority (Tong et al., 2007).

The dynamics of aquatic ecosystem depends on climate, geomorphology, plant cover and nutrient flow. In contrast to this its modification and degradation depends on the harmonization of population density, agriculture, urbanization, industrial development and hydrotechnical infrastructure with ecosystem potential. In the Anthropocene, the environment is dominated and transformed by socio-ecological processes and, for this reason, the existing traditional management strategy in Bangladesh is not sufficient to reverse the degradation of the aquatic ecosystem. In the traditional management approach, governments are creating unplanned infrastructure (flood control, drainage and irrigation) (Hussain, 2010) which hampers the connectivity of water flow. For the effluent treatment from the industry, government proposed to establish treatment plant which is very costly (DoE, 2008). The result is industries still do not feel interest to add this treatment plant. For water deficiency or drought control the government still has no specific plan or policy (GoB, 2010). However, in the National Plan for Disaster Management report 2010–2015 they have suggested to manage this issue with more surface water utilization projects such as barrages across the rivers and installation of pumping plants for lifting water from the rivers. This is not a sustainable solution and will definitely hamper the natural flow of the river and fishery resources. The government has recently adopted a new policy to restrict shrimp farming (Dhaka Tribun, 2014), which may have deleterious impacst on the livelihoods of so many people. All these policys are somewhat responsible for the degradation of aquatic ecosystem of Bangladesh. Therefore, reversing the degradation of the biosphere requires solutions based on an integrative science. Ecohydrology is a growing progress in water resource managemet sector, which increases the carrying capacity of the ecosystem under current population pressure keeping future climate change into consideration (Zalewski, 2010). Ecohydrology uses hydrology to shape biota, and uses ecosystem properties as a management tool to increase the carrying capacity of the aquatic ecosystem (Zalewski, 2000). Ecohydrology also uses the concept of ecological engineering (Mitsch, 1993) to solve environmental problems. Incorporating this ecohydrology concept in the traditional water resource management will increae the carrying capacity of degraded aquatic ecosystem. This paper sheds light on the ecosystem service values of the aquatic ecosystem of Bangladesh in detail with specific causes and consequences of ecosystem service degradation, and the state of art of the present management of aquatic resources. A holistic approach based on the ecohydrological approach to the aquatic ecosystem management in Bangladesh has been discussed in detail in the latter part.

2. The aquatic ecosystem of Bangladesh and their management

The abundance of water and wetlands has always been the geographical and historical destiny of Bangladesh, and the country is located within the three major river basins of the world – the Ganges–Brahmaputra–Meghna basin. About 6.7% of Bangladesh is permanently under water over the year, 21% is deeply flooded (more than 90 cm) and 35% experiences shallow inundation during the rainy season (FAO, 1988). The average discharge of water in the Bangladesh delta in the flood season is more than 141,584 m^3/s. The wetlands in Bangladesh encompass a wide variety of dynamic ecosystems, including rivers (7497 km^2), flood plains (45,866 km^2), Kaptai Lake (man-made reservoir, 688 km^2), ponds (1469 km^2), oxbow lakes (1197 km^2), brackish-water farms (72,899 km^2), estuaries and mangrove swamps (6102 km^2) (Akonda, 1989).

The government has taken several initiatives to manage its aquatic resources and associated problems, such as flood control, drainage and irrigation projects. However, flood-control infrastructure that has been initiated by the government has often seen ineffective because of improper planning. Bangladesh has developed a National Water Policy and an Integrated Water Management Plan (IWMP) for 2000–2025 on 1999. The 1999 Water Policy assigns water-allocation decisions to local administrative authorities. The IWMP addresses three major issues: (1) efficient use of water in the face of increasing scarcity; (2) providing all people with access to sufficient, good-quality water; and (3) ecologically sustainable use of the resources (Gupta et al., 2005). The draft national water control code of Bangladesh has been formulated since 2010, but not yet been enacted into law. There is also no linkage between national development plans with aquatic ecosystem management, which creates conflict among various policies and stakeholders. Moreover, up to now, there is no integration of forest policy with water policy, which is essential for proper watershed management. Although, in practice, there is no river basin planning in Bangladesh, a major obstacle for integrated water resource management (IWRM) process during the flood season is that government does not have control over the catchment areas of the major rivers, and no secured environmental flow in the area during the dry season.

3. Major ecological problems faced by the aquatic ecosystem and their effect

The problems faced by the aquatic ecosystems of the country are diverse and mostly due to anthropogenic pressure on the ecosystem. The problems and their subsequent effects are described hereafter.

3.1. Overexploitation of water resources

With its growing population, Bangladesh has more and more difficulty managing its limited water resources. An average Bangladeshi uses approximately 40 l of water per day for household use, and the demand for irrigation water is gradually increasing (Rashid and Kabir, 1998). The growing population causes an increase in demand for food. This has led Bangladesh to irrigate more crops which in turn generates a need for more water. Rice production for every individual requires over 800 m^3 of water (Rashid and Kabir, 1998). When the total population of Bangladesh is considered, water demands can become enormous. Moreover, to accommodate and to fulfill the demand of human population, unplanned urban areas and industries are growing rapidly. As a result, the conversion of aquatic habitat into urban and industrial areas accelerates the degradation of the ecosystem.

3.2. Effects of unplanned infrastructure development

In the last two decades, an accelerated expansion of physical infrastructure (i.e. flood control drainage and irrigation infrastructure (FCDIs), road and building structure) occurred in the flood plains and oxbow lake areas. These infrastructures were often implemented without proper planning or without proper attention to natural water flows. The impacts of FCDI on aquatic ecosystem are the connectivity losses of water, biota and materials. There are two aspects of connectivity. Lateral connectivity is the ability of biota, water and materials to move from one distinct system, such as a flood plain lake, to another such as a river and/or tree swamp. Longitudinal connectivity is the 'upstream-downstream', or within system connectivity that is important for the movement of species within the wetland. A loss of connectivity can result in decreasing water quality. The duration and timing of periods of connection can be very important in order to allow opportunities for spawning, dispersal and migration of fish and young individuals. Species that migrate between wetland systems as part of their life cycle, such as diadromous fish, are particularly susceptible to the loss of lateral connectivity (Wetlandinfo, 2012). In Bangladesh, these poorly planned infrastructures played a major part in reducing valuable aquatic ecosystem resources, especially fish that cover almost 63% of the animal protein intake of the country's population (Hussain, 2010). Halls et al. (1998, 1999) found that in Bangladesh, fish yields were 50% lower inside FCDIs compared with outside where 25 species of fish are absent or less abundant. The area under flood control and irrigation is expected to be 5.74×10^6 ha in 2010 causing a loss of 151,300 t of fish in the flood plain areas of Bangladesh (Craig et al., 2004).

3.3. Pollution problems faced by the aquatic ecosystem

Pollution problems originate from the extensive use of pesticides and fertilizers in agricultural landscape which results in severe eutrophication in the aquatic ecosystem. In Bangladesh, the use of fertilizers increased rapidly from the mid 1960s with the introduction of modern varieties and the development of irrigation facilities. The annual urea (nitrogen-releasing fertilizer) consumption in Bangladesh was 2 million tons in the 1980s. From 1989/1990 to 1996/1997, urea consumption grew rapidly, registering an average growth rate of 7% per year (MoA, 2003). Excessive N-fertilizer application is therefore very common, especially in intensive rice, wheat, bean and vegetable producing areas. So the occurrence of nitrate pollution might be expected in groundwater and surface water. In the rivers of Bangladesh, the amount of dissolved nitrate is 13.26 mg/l (Subramanian, 2008). According to WHO recommendations, the maximum allowable concentration of nitrate nitrogen should not exceed 10 mg/l (WHO, 1971). The aquatic ecosystem of the whole country is the dumping ground for contaminated sediments and pollutants. However, flushing out of materials to the sea is quite slow. The result is a serious deterioration of the aquatic resources, eutrophication for example (Fig. 1). The addition of high concentration of nitrogen (N), phosphorus (P) and other pollutants from point sources and nonpoint sources increases algal growth. When the algae is decomposed it converts the organic matter into inorganic form. The decomposition process of algae consumes oxygen, which creates an oxygen deficiency (Fig. 1) in water, resulting in unsuitable habitat for fish and other aquatic organisms.

Most of the industries and factories are situated either on the river banks or very close to a river system and the effluents and waste are mostly thrown directly into the river water without any treatment. The industrial effluent containing acids, heavy metals, ammonia, toxic substances, etc., are thrown directly and untreated into the water together with agrochemical substances (insecticides, pesticides, fertilizers. etc.) with the huge quantity of domestic waste making the situation worse.

3.4. Unsustainable shrimp cultivation in coastal zone

Bangladesh is blessed by goods and services provided by the coastal zone. Among all of these, shrimp aquaculture

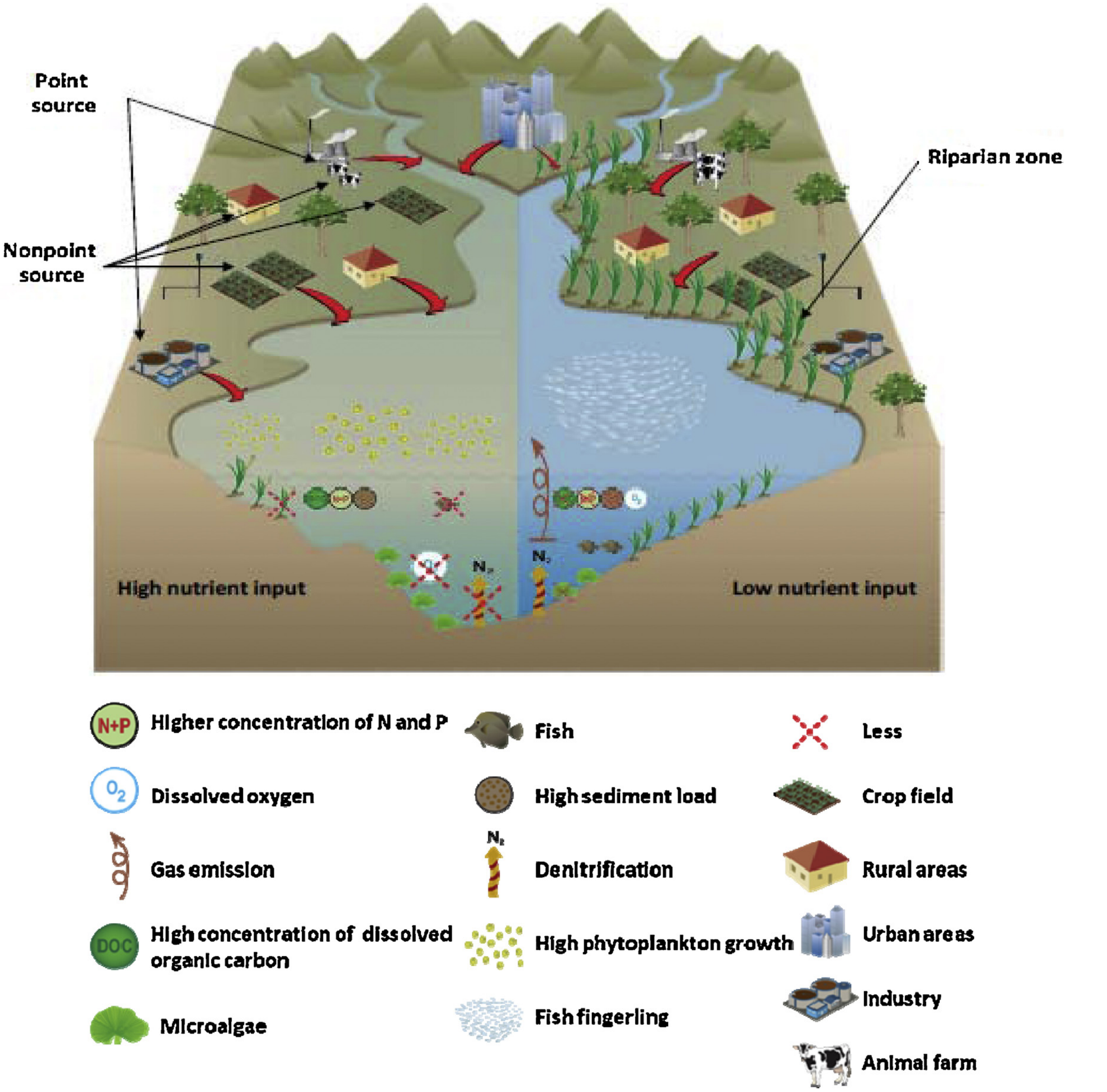

Fig. 1. Conceptual model of eutrophication problem showing increased inputs of nutrients and other pollutants in the left side of the illustration with consequent declines in water quality.
(Source: Authors).

is the fastest growing economic activity in coastal areas and Bangladesh was the 8th largest producer in the world in the year 2000 (FAO, 2002). There are 1.2 million people employed in prawn and shrimp production and a further 4.8 million household members are associated with the sector (DoF, 2009). However, the rapid expansion of shrimp farm development during the last decade, along with poor production technology, has caused growing concern. Its adverse effect on the coastal environment and socio-economic conditions are now responsible for the unsustainability of this sector. This farming system, requiring large land areas, has contributed most to the encroachment of agricultural land and mangrove clearance with the increased intrusion of salinity, degradation of land and destabilization of coastal eco-systems. Many scholars have already addressed these environmental issues and therefore, a question is being raised about the sustainability of coastal shrimp aquaculture (Chowdhury et al., 2006; Primavera, 1997). The rapid expansion of shrimp farming has caused extensive destruction of mangrove ecosystems (Chowdhury et al., 2006) as well as superseding other forms of land-use like agriculture (Paul and Vogl, 2011). Case studies demonstrate that prolonged shrimp farming increases the soil salinity, acidity, and depletes soil Ca, K, Mg, and organic C content which leads to soil degradation (Ali, 2006). In addition, the directly discharged effluents can easily pollute the surrounding water and soil quality (Deb, 1998). Fig. 2 summarizes the overall impact of coastal shrimp farming in Bangladesh.

3.5. Impact of water diversion from upstream

Bangladesh's topography is formed by three of the largest river systems in the world. It occupies the greater part of the Bengal Basin which was slowly built up by alluvial deposits carried from the adjoining mountains of the Himalayas by the Ganges–Brahmaputra river system. It is a riverine country with 230 tributaries and distributaries. The Ganges–Brahmaputra–Meghna river systems drain a total area of about 1.72 million km^2 (Ahmad et al., 2001) in India, China, Nepal, Bhutan and Bangladesh, hence the name Ganges–Brahmaputra–Meghna (GBM) river basin. A lower riparian located at the lowermost reaches of the three large rivers, Bangladesh itself, makes up only 7–8% of the watershed (Ahmad et al., 2001). The construction of the Farakka dam in India in 1974 has drastically reduced the natural flow of the Ganges water downstream in Padma, Bangladesh. This reduced water flow causes drought and the drying of ponds, a condition which leads to a drop in groundwater levels. It is therefore a matter of great concern. Diversion of low flows at Farakka has increased the inland penetration of salinity. Salinity levels increase rapidly and curve northwards in the area affected by the withdrawal of Ganges water in the low-flow season. This condition would lead to a massive loss of agricultural production, which would trigger the migration of at least 20 million people (Islam, 2008). Reduction of the Ganges flow through the Farakka dam has severely affected the downstream river regime of the Ganges–Padma. For the Ganges–Padma River at Hardinge Bridge, the ratio of maximum and minimum discharge during pre-Farakka days and post-Farakka days are roughly 70% and 27%, respectively, which is far greater than the ratio of 10% of the maximum discharge required for maintaining a stable river regime (Rashid and Kabir, 1998). The reduced flow of river water has reduced the major carp (*Cyprinus carpio carpio*) habitats in the Ganges River Basin in Bangladesh (Tsai and Ali, 1985) which is one of the most important sources of fish. The proportion of freshwater carps in total fish production was about 35% in 2008–09 (FSYB, 2010). Another potential fish source was hilsa hich (*Tenualosa ilisha*), which is also affected by water diversion from upstream. Significant reductions in catches of around 1600 tons or 13% over 10 years were found at Allahabad and on the Ganges (Padma) in Bangladesh (Payne et al., 2004).

3.6. Global climate change impacts

Climate change is expected to increase the average temperature and spatio-temporal variability in precipitation, as well as cause a rise in sea level (Ellison, 1994). The increase in temperature and variability in rainfall will put further pressure on freshwater resources and hence alter

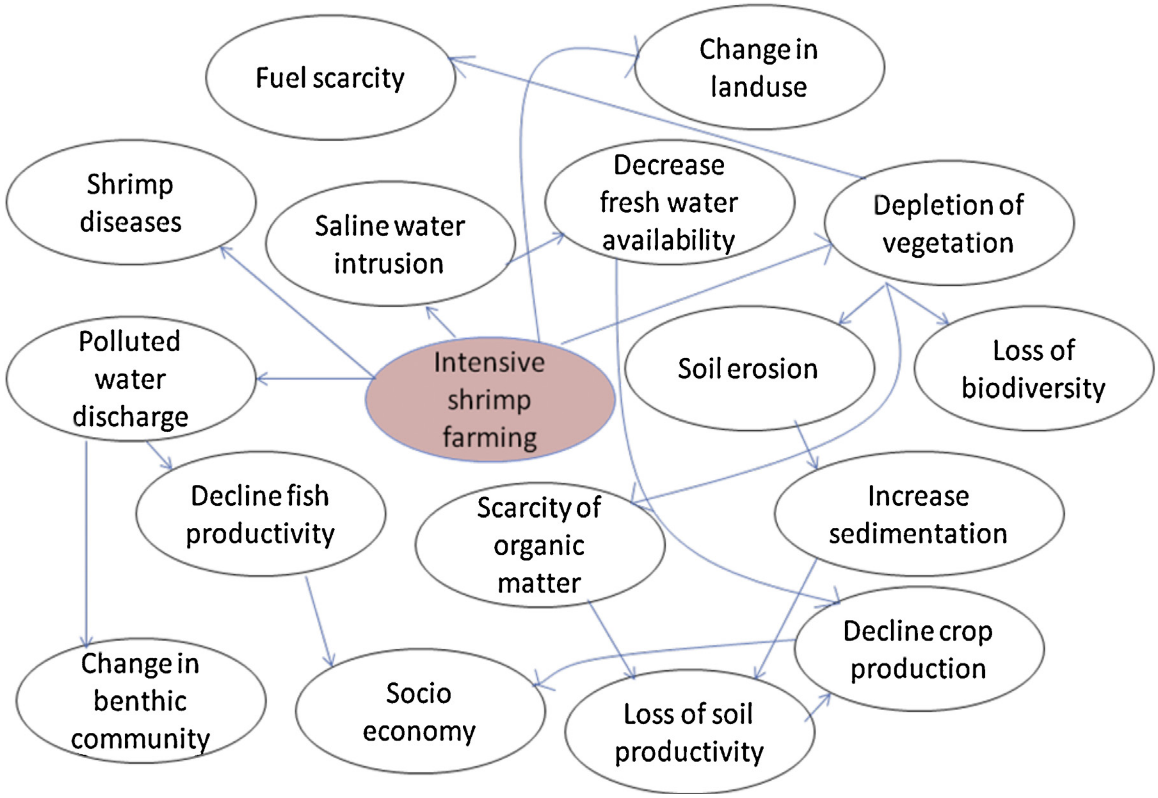

Fig. 2. Illustration of the many impacts of coastal shrimp farming and some of the influences between them.
(Source: after Sohel and Ullah, 2012).

the freshwater inflows to the mangroves. Alteration of aquatic ecosystems due to low rainfall and high temperature has direct and indirect adverse effects on fish through their reproduction, migration and survival (Hussain, 2010). This adverse climatic effect creates a water deficiency in agriculture, which ultimately causes more water extraction from the aquatic ecosystem during the dry season (Halls et al., 2001; Shankar et al., 2004, 2005). Climate change also presents an increased frequency of tropical cyclones and storm surges, which may cause further changes in freshwater-seawater interactions, thereby affecting the mangroves (Ali, 1995). Changed hydrological extremes due to climate change will have important implications for the design of future hydraulic structures, floodplain development, and water resource management (Cunderlik and Simonovic, 2005). Maintaining hydrology, reducing pollution, controlling exotic vegetation, and protecting wetland biological diversity and integrity are important activities to maintain and improve the resilience of wetland ecosystems so that they continue to provide important services under changed climatic conditions (Ferrati et al., 2005).

4. Toward sustainable management of aquatic ecosystems based on ecohydrological approach

To manage the aquatic ecosystems of Bangladesh in a sustainable and ecologically sound manner the following measures should be taken into consideration by government, policy makers and overall by the small-holder farmers and land-use practitioners.

4.1. Minimizing environmental effects of intensive agriculture

Majority of the arable lands in the country is used for agriculture where uses of fertilizer for higher yield, herbicide and pesticide application for weed and pest control are common. They are also located just after the wetlands for irrigation and/or linked with aquatic ecosystem. Following are some ways which can be used for the minimization of agricultural effects on aquatic ecosystems of Bangladesh.

4.1.1. Creation of ecotone zone for controlling diffuse pollution

Loss of nutrients from agricultural land to surface waters can cause environmental harm to fish and other aquatic organisms. Vegetated buffer zones between agricultural land and surface waters have proved to be effective filters for trapping diffuse pollutants (Syversen, 2002).

4.1.2. Implementation of ‘‘Denitriphication wall’’ to protect groundwater in agricultural areas

Already, maximum allowable concentration of nitrate nitrogen (10 mg/l) in potable water of Bangladesh exceeds 13.26 mg/l (Subramanian, 2008). Until today no initiatives have been taken to control this pollution. To solve this problem of water pollution, ecohydrology, a transdisciplinary science introduced different ecological biotechnologies (Zalewski, 2009) and ‘‘Denitrification wall’’ is one of them. This is a low-cost and effective tool for diminishing the nitrate inputs into groundwater and surface water (Schipper et al., 2005). Therefore, ‘‘Denitrification wall’’ could be excellent biotechnological tools to reduce nitrate pollution in Bangladesh.

4.1.3. Water deficiency control in agricultural landscape

Water shortage is observed in many regions of the world where low precipitation and high evapotranspiration occur and global climate change makes this condition more severe. To overcome water deficiency in the agricultural field, proper water management in a landscape can improve these unfavorable conditions. This can be attained mainly through the creation of small water retention (Fig. 3) which increases the water retention capacity of the surrounding soil and also, particularly increases groundwater retention in the adjoining area (Jain, 2006). Soil water holding capacity can also be increased by applying organic matter (Zalewski et al., 2004). Besides, to reduce evaporation in the agricultural landscape during the dry season, which becomes worse due to climate change, strip plantation or shelterbelt (Fig. 3) can be very effective because of its ability to break the wind force which helps to reduce evapotranspiration. Through this mechanism, strip plantation improves water availability in the agricultural landscape (Ryszkowski and Kędziora, 2007; FAO, 1989). Moreover, to reduce the irrigation water demand an improved irrigation system can be adopted for agri-crop cultivation. Irrigation systems like sprinklers can save water by about 35–40% when compared with flood irrigation method. The systems are suitable for almost all field crops such as wheat, gram, pulses as well as vegetables, cotton, soybean, tea, coffee, tobacco, sugar cane, and other fodder crops and can be installed in residential and industrial units, hotels, resorts, public and government enterprises, playgrounds, and racecourses. While in the bed and furrow method, water is applied only in furrows. Another kind of irrigation system is drip irrigation, which also uses water rationally as its target area of watering is root zone (IUCN, nd). For rice, rice intensification system (i.e. preparing high-quality land, developing nutrient-rich and unflooded nurseries, using young seedlings for early transplantation, transplanting the seedlings singly, ensuring wider spacing between seedlings, preferring compost or farmyard manure to synthetic fertilizers, weeding frequently) can be adopted as it is focused on rice cultivation by maintaining soil moisture rather than the flooded irrigation method (Fig. 3). In this method 25–50% less water is needed than in conventional rice cultivation methods (WWF, 2007).

4.2. Reducing the impact of flood control drainage and irrigation (FCDI) infrastructure

To reduce the impact of FCDI on the aquatic ecosystem, especially on fish, adaptive management of sluice gates is essential to improve fish access to flood plain areas. Taking this into consideration, Halls et al. (1998, 1999) suggests to maximize the flow of water during the flooding period,

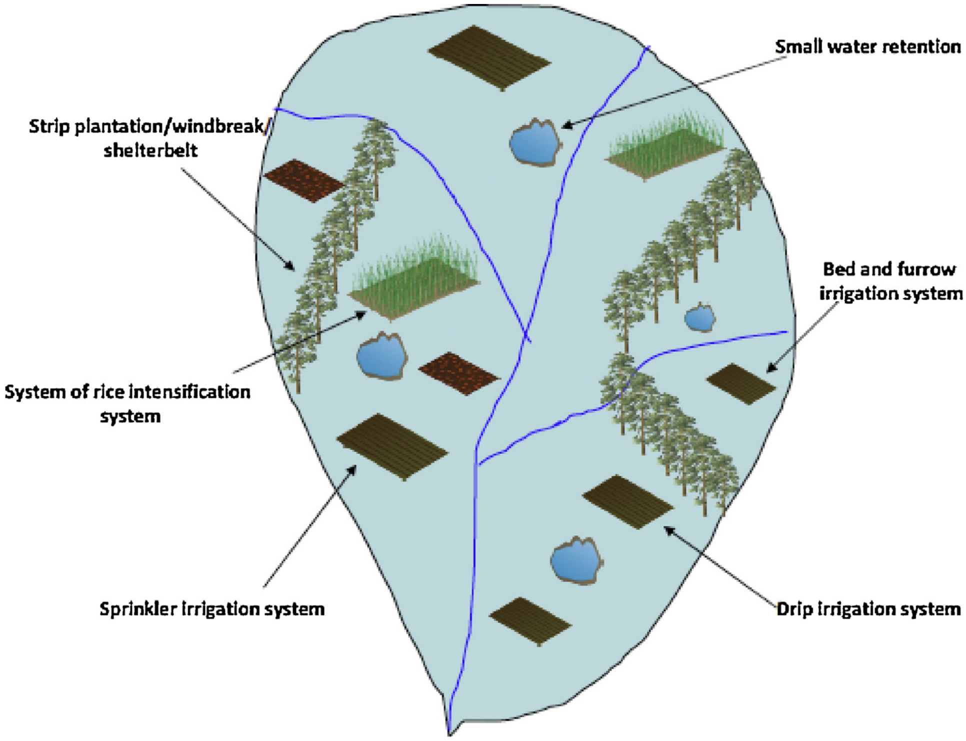

Fig. 3. Conceptual model of water deficiency control in agricultural landscape at catchment scale.

which aids passive inward migration of fish in the floodplain areas, to open the sluice gates more frequently in order to reduce the turbulence of water outside the gates during the flooding period which accelerates the smooth passage of fish and controls ebb flow from the sluice gate to attract more fish. It suggests that the best attraction velocity is about 0.1 ms^{-1}. Halls et al. (2001) and Shankar et al. (2004, 2005) have predicted that raising water levels during the dry season by as little as 0.25 m, could increase fish production by about 9% at a loss of only 8 ha of rice production, mainly from marginal, low-lying land. Another potential strategy is to make changes to land use practices. In the dry season Boro rice production is highly dependent upon irrigation water from dry season water bodies. Switching to other dry season crops such as wheat and vegetables that are harvested several weeks before boro rice, and greater emphasis on more flood-tolerant Aman rice would also allow for earlier, more frequent opening of sluice gates for longer periods during the rising flood (Shankar et al., 2004, 2005). Apart from this, in order to reduce irrigation structure impact, various kinds of effective irrigation systems (sprinkler irrigation system, drip irrigation system) could be adopted (Fig. 3). This strategy would help to reduce the pressure on the large demand for irrigation water. Application of such irrigation strategies is likely to become increasingly necessary in the face of climate change (Halls, 2005). Such adaptive strategies are increasingly necessary where precipitation is predicted to increase during the flood season, but to decrease during the dry season in response to climate change (Halls, 2005).

4.3. Overcoming the impact of coastal shrimp aquaculture

Technologies involves with higher cost is a barrier to adoption by the local farmer and policy makers in developing countries. Such barrier can be minimized by applying ecohydrology-based shrimp farming (ESF). Sohel and Ullah (2012) proposed a low cost technology (Fig. 4) for the sustainable development of shrimp/prawn farming through ecohydrology based approach. In ESF system nitrogen, phosphorus, organic matter and sediment load occur at a lower rate due to fish bivalve pond, sedimentation pond and constructed wetland also stimulated lower level of macroalgal and phytoplankton (chlorophyll-a). Lower level of chlorophyll-a will allow high light penetration that will help well growth of submerged aquatic vegetation. This will also circulate more oxygen that is suitable for fish and other aquatic organism. The buffer zone in the ESF system will protect nearby freshwater and agricultural land from salt. Sediment from the sedimentation pond can be used as fertilizer (Fig. 4). Overall lower level of nutrients, organic matter and sediment load make the shrimp pond more hygiene, which will increase shrimp production as well as beneficial for the coastal water quality of the surrounding shrimp farm. Steps should be taken to implement this technology as soon as possible to make this industry sustainable.

4.4. Waste water treatment by creating constructed wetland

Constructed wetlands (CWs) are among the recently proven efficient technologies for wastewater treatment.

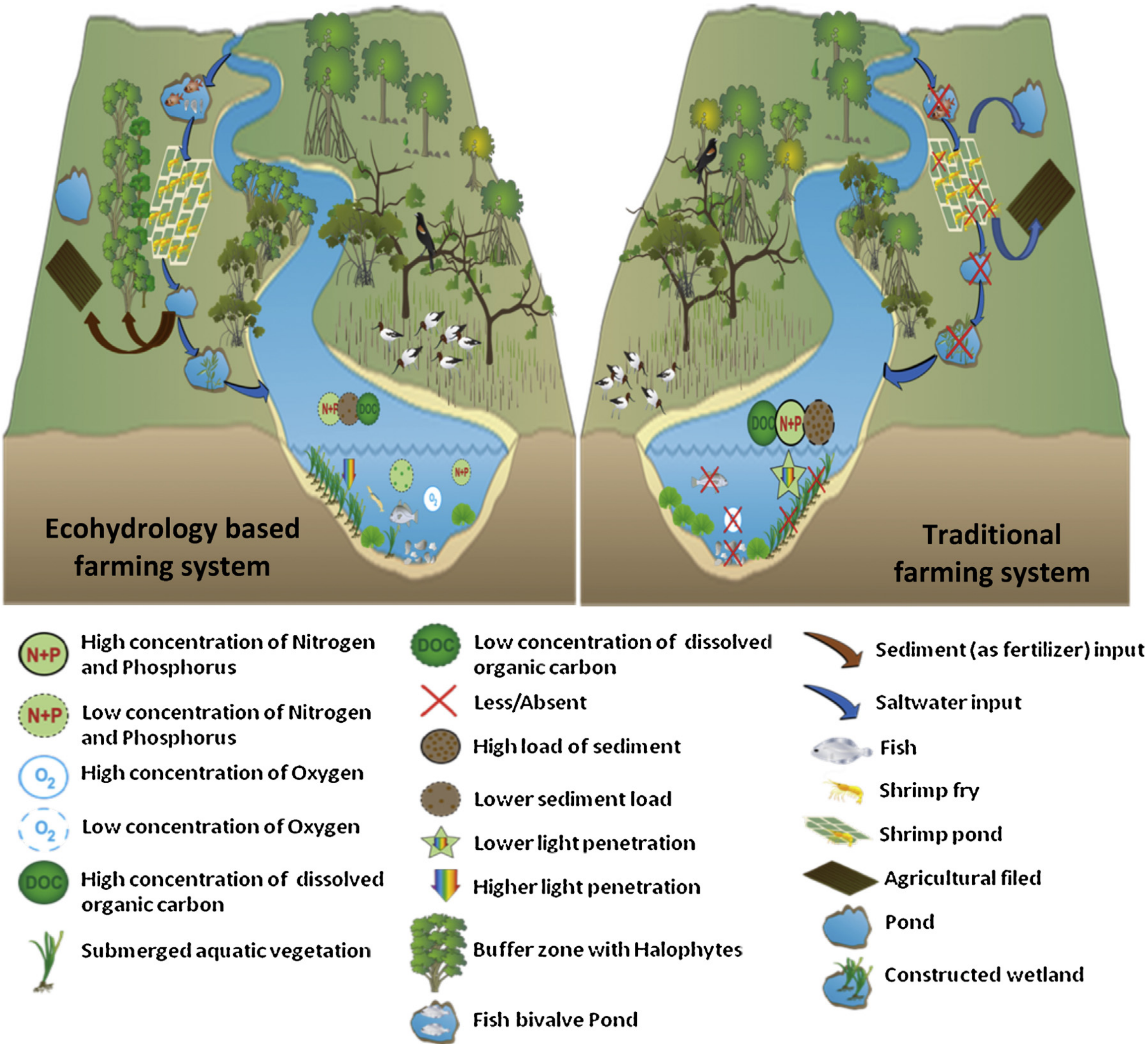

Fig. 4. Conceptual model of ESF (ecohydrology based shrimp farming) system and traditional (e.g. intensive and semi-intensive) farming system illustrating potential reductions in nutrient, organic matter, and sediment loads when ecohydrological biotechnologies are applied.
(Source: after Sohel and Ullah, 2012).

Compared with conventional treatment systems, constructed wetlands are low cost, easily operated and maintained, and have a strong potential for application in developing countries. In most developing countries, there are very few wastewater treatment facilities. This is mainly due to high costs of treatment processes and lack of effective environmental pollution control laws or law enforcement. CWs (Fig. 5) for wastewater treatment involve the use of engineered systems that are designed and constructed to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated shellfish, microorganisms to remove contaminants from wastewater effluents (EPA, 1993) (Fig. 5). In developed countries, CWs are used for treating various wastewater types, e.g. domestic wastewater (Cooper et al., 1997; Schreijer et al., 1997), agricultural wastewaters (Rivera et al., 1997), landfill leachate (Trautmann et al., 1989), urban storm water (EPA, 1993). CWs are also used for treating eutrophic lake waters (D'Angelo and Reddy, 1994), and for the conservation of nature (Worrall et al., 1997). CWs can be an alternative for treating nitrate contaminated aquifers, denitrification of nitrified sewage effluents and irrigation return flow (Baker, 1998).

4.5. Probable solution (water retention) to reduce the impact of Farakka dam of India

Bangladesh–Nepal (Ministry of Water Resources) joint investigation report on environmental impact assessment studies in 1989, suggests to build seven water storages in the upstream of the Ganges. These seven rivers of Nepal can supply 71% of fresh water annually at the Farakka Barrage in the dry season. It has been estimated that after construction of these proposed water storages in Nepal, Bangladesh can achieve extra 1274 m^3/s water from upstream in the dry season (Islam, 2008).

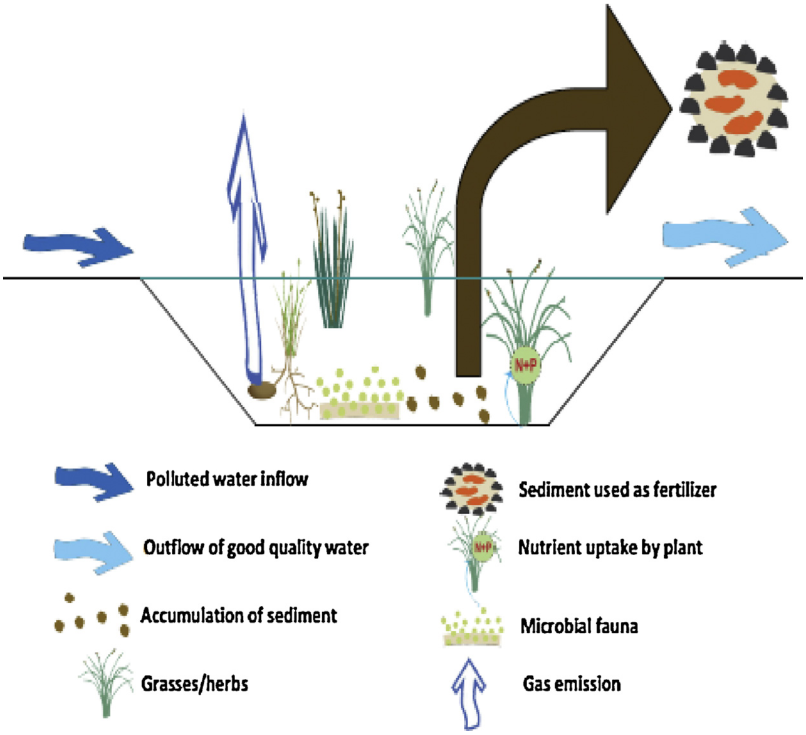

Fig. 5. Constructed wetland systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated shellfish, micro-organisms to remove contaminants from wastewater effluents (EPA, 1993).
(Source: Authors).

4.6. Facing urbanization impact

A broad range of direct and underlying effects of increasing urban pressures threaten the ability of aquatic habitats to provide various ecosystem services (Millennium Ecosystem Assessment, 2005). These services depend to a great extent on the functioning of aquatic ecosystems and their ability to cope with high impacts, determined among others by the size and distribution of available "green areas". Therefore introduction of water sensitive urban design (WSUD) can harmonize the urban built environment and the urban water cycle. This approach embraces an interdisciplinary cooperation of water management, urban design, and landscape planning in order to achieve integrated water resource management goals (SWITCH, 2010). Adoption of ecohydrological solution for urban storm water management is such an example (Fig. 6).

5. The prospects of adopting ecohydrology based ecosystem management approach in Bangladesh

Although existing management and policy guidelines have gone through extensive review and become more comprehensive than before, environmental degradation is still continuing in Bangladesh. This may be due to the absence of proper policies and techniques on waste treatment, pollution abatement and irrigation techniques. The traditional water resource management approach is much more mechanistic and unsustainable because of financial and energy constraints. In many situations this mechanistic approach seriously reduces the role of ecological processes in moderating the water cycle. Hence intervention of the ecohydrology approach will enhance the carrying capacity of an aquatic ecosystem which will be helpful in better water resources management. In this context, it is expected that this new management approach would be cordially encouraged by the government from its policy point of view. In Bangladesh, most of the industries and shrimp farm land is operated by national and multinational investors who have access to the technology and the necessary capital to adopt new technology to gain benefits. On the other hand, most of the owners of the agricultural land are large farmers who can easily minimize the environmental effects of intensive agriculture by adopting low-cost ecohydrology technologies. If industries, farm owners and infrastructure development authorities adopt a new approach where a small portion of land is devoted to ecohydrological compensatory measures, it is expected that they will be accepted by them for two reasons. Firstly, adopting such technology will ensure the sustainability of aquatic ecosystem functions and reduce the environmental degradation which is key concerns of the relevant department of the state. This means large-scale owners should benefit from the government in terms of greater subsidies and greater availability of state financial services. Secondly, because of environmental degradation from industry, agricultural

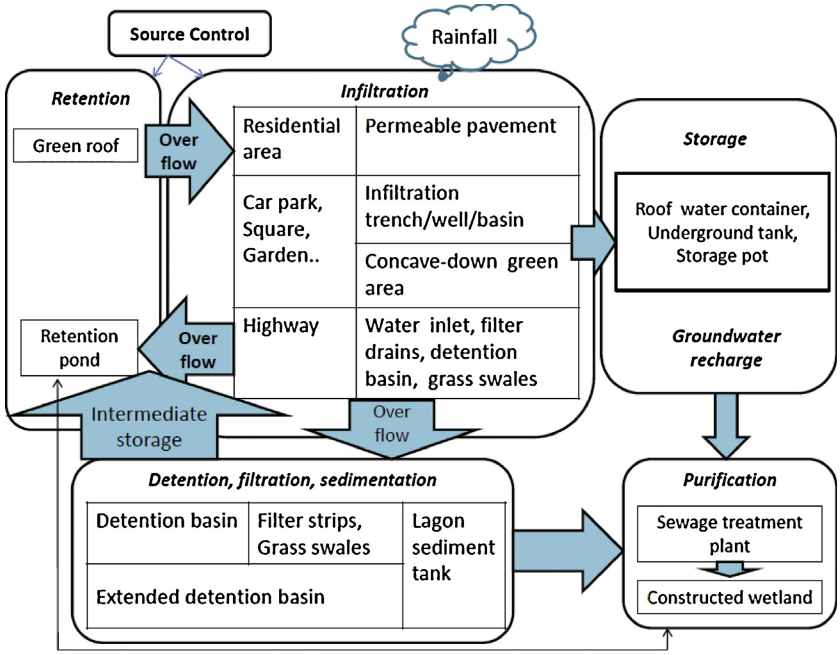

Fig. 6. An example of different methods of urban storm water management integrated into the systematic ecohydrological solution with good urban design. (Source: Li, 2012).

land, shrimp farm, unplanned urban development and irrigation infrastructure, aquatic ecosystem has faced huge financial loss over the past years where a cost-effective management approach is demanded. Here government can formulate policies to adopt such technologies. Therefore, adoption of an ecohydrology based management approach (Table 1) will be helpful to reverse the environmental degradation of the aquatic ecosystem.

Table 1
Potential benefits and perceived constraints of the ecohydrology based approach.

Factor	Traditional approach	Ecohydrology based approach
Influent treatment	Absent	Present
Effluent treatment	Absent	Present
Salinity intrusion in freshwater & agricultural field	High	Might be lower
Diseases because of low water quality	Moderate to high	Might be low
Sediment trap pond	Absent	Alternatively can be used as fishery production & sediment can be used as fertilizer in agri crop production
Constructed wetland	Absent	Source of bioenergy and biodiversity
Buffer zone of halophytes (salt accumulator halophytes)	Absent	Source of bioenergy, biodiversity, protect from cyclone and climate change effect
Fish-bivalve pond	Absent	Source of fishery production & poultry feed production
Small water retention pond in agricultural filed	Absent	Source of fishery production
Shelterbelt/strip plantation	Absent	Source of fuelwood, biodiversity. Could be a source of fruits if planted with fruit bearing trees
Irrigation system (sprinkler, bed and furrow, drip)	Absent	Can consume less water for irrigation
Denitrification wall	Absent	Can reduce water pollution from agriculture filed
Social Implications	Moderate to high	Can be Less
Sustainability issue	Moderate to low	Can be high
Policy issue	Based on existing Policy	Need modification of policy like waste treatment, pollution abatement, land use plan for ecohydrology based approach
Environmental impact	Moderate to high	Less
Development costs	Moderate to high	Probably high but once installed return can be more from fishery production from treatment pond
Water sensitive urban design	Absent	Improve urban water cycle

6. Concluding remarks

The fundamental aspect of any ecosystem based management approach depends upon a proper understanding of how the system works, how it is organized or structured, what the damaging factors are, and what the impact of those damaging factors is. Ecohydrology gives better understanding of the interplay between biota and hydrology, and therefore provides a balanced framework of how to use ecosystem properties as a management tool for integrated water resource management. Moreover, the ecohydrology based aquatic/water resources management approach sustains the health of aquatic ecosystem services provisions, and therefore should be adopted for the sustainable management of aquatic ecosystem and associated resources in the country. In this paper, the concept of ecohydrology is introduced for the sustainable management of aquatic ecosystems of Bangladesh. The immediate action measures for the betterment of country's aquatic ecosystem should be: control of water pollution, check the degradation of aquatic habitats, control sedimentation, protect salinity intrusion, monitor nutrient loading, conserve the mangrove ecosystem and maintaining river flow from the upstream. A cross-disciplinary policy development and strategies to bring policies into action is also essential for the sustainable management of aquatic ecosystem of the country.

Conflict of interest

None declared.

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