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Hydrological changes and its impact on water resources of Bagmati watershed, Nepal

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Summary For long-term planning and management of water resources, future change in the pattern of landuse, water demand and water availability should be analyzed well in advance. The assessment of climate change impacts on the hydrological resources of a country is the most important assessment to be carried out, before planning any long-term water resources utilization program. Change in the hydrology of the Bagmati River is analyzed and its probable future implications are accessed. Trend analysis of seasonal flows and extreme events shows that monsoon seasonal floods are decreasing while other seasonal flows are constant. The magnitude of flood is decreasing but its frequency and duration are increasing. The hydrograph is shifting in time which is affecting water availability. In the changed scenario, hydropower production is likely to decrease in the future. Production of rice has decreasing trend while production of wheat has increasing trend. The proper modality of a water sharing agreement should be negotiated between the riparian countries Nepal and India before any conflict may arise, as the water volume is decreasing year by year. To address all the changing scenarios of the river hydrology an appropriate policy should be formulated for long-term water utilization.

Introduction

Local hydrology of every river in the world is likely to be affected by climate change in some way. In Nepal, major river basins such as the Karnali, Koshi, Gandaki and Bagmati may have already been affected by climate change. Climate change affects different aspects of local hydrology of river such as timing of water availability and quantity, as well as its quality. Changes in river hydrology will induce risks to water resources facilities that includes flooding, landslides, and sedimentation from more intense precipitation events (particularly during the monsoon) and greater unreliability of dry season flows that possesses potentially serious risks to water and energy supplies in the lean season.

For long-term planning and management of water resources, future change of the pattern of landuse, water demand and water availability should be analyzed well in advance. Understanding how a water resources system responds to changing trends and variability requires

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knowledge of how it is affected by those conditions today and how it might respond in the future if those conditions change (UNEP, 2001). Assessment of climate change helps to build resilience to the possible impacts of climate change through enhanced institutional flexibility and consideration of climate-related risks in the planning process.

The impact of climate change on water resources depends not only on changes in the volume, timing, and quality of streamflow and recharge but also on system characteristics, changing pressures on the system, how the management of the system evolves, and what adaptations to climate change are implemented. Non-climate changes may have a greater impact on water resources than climate change in managed basins but the unmanaged systems are likely to be most vulnerable to climate change. Climate change challenges existing water resources management practices by adding additional uncertainty. Developing countries are vulnerable to extreme weather events in present day climatic variability and this causes substantial economic damage (Monirul and Mirza, 2003).

A change in trend of water availability, spatially and temporally both, would critically impact the future of the national economy directly. The assessment of climate change impacts on the hydrological resources of a country is therefore the first and most important assessment to be carried out, before planning any long-term water resources utilization program. Water Resources, one of the top prioritized national issue in Nepal, is considered as the key natural resource for the development of the country.

Very few studies have been conducted on climate change impacts on water resources in South Asia (Monirul and Mirza, 1997) and there exists only limited knowledge concerning impact of climate change on water resources in the foothills and mountains of Nepal. It is general trend to assume that the impact of climate change on the Indian subcontinent and the Nepal are similar (Sontakke et al., 1993; Kripalani et al., 1996). Kripalani et al. (1996) examines the monthly rainfall data over Kathmandu for a 105 year period and reveals that Nepal's rainfall is well related with rainfall variations over northern and central parts of India. However, Shrestha et al. (1999, 2000) found general increasing temperature trends over Nepal but trends differ from those found in the Indian plains. The precipitation climatology in the northern part of the subcontinent (including the Himalayan region) is different from the rest of the subcontinent, and that the precipitation record from India as a whole (and generally excluding the Himalayan region) is not always a suitable representation for the region.

Yogacharya and Shrestha (1997) based on the GCM's results projected an overall increase in annual precipitation. Shakya (2003) however indicates that there are no definitive trends in aggregate precipitation, although there is some evidence of more intense precipitation events. A somewhat clearer picture emerges in stream flow patterns in certain rivers where there has been an increase in the number of flood days. Some rivers are also exhibiting a trend towards a reduction in dependable flows in the dry season, which has implications both for water supply and energy generation. Keshav et al. (2000a,b) concluded that the statistical analysis of homogeneity showed that the climatic as well as the hydrologic trends were more localized in nature lacking distinct basinwide significance. The statistical tests of hydrologic trends indicated an overall decrease in discharge on the Kosi River and its major tributaries. While it is virtually certain that there are changes in the quantity and distribution of precipitation and runoff in all basins of Nepal, there are significant uncertainties regarding the specific nature of the local impacts of climate change on hydrologic regimes that may varies from basin to basin.

The main objective of this paper is to see if there is a perceptible trend in the flow of Bagmati River, if so, how it will affect our present and future water-resources. Historical analogies give us some insight into climate change and corresponding responses by a water resources system. The Bagmati River is taken as a representative basin to study the change in characteristics of the runoff and its implication on different sectors of water utilization.

The Bagmati River is the most important river among all rivers of Nepal because water availability per population is lowest in this river basin. The capital city Kathmandu, which is located on the bank of the Bagmati River, is already affected by a water supply deficit. Even at the present demand level, the shortfall in supply during dry months is as much as 50% (Madan, 2001). Large parts of the basin are inundated every year by floods, while some parts are exposed to annual droughts. There is already a deficit of irrigation water supply, and the demand is increasing. From 1980 to 1992 agricultural landuse was increased by about 94% in the lower Bagmati watershed (BIWMP, 1999). Intra-annual and inter-annual variations of discharge are very high in the basin. The long-term mean monthly flows of July and August (around 480 m^3/s) are more than 22 times of the mean monthly flow of April (21.8 m^3/s) at Karmaiya gauging station. Long-term mean annual discharge of the river at the station is 151 m^3/s but the annual discharge has variation from 96.8 m^3/s on year 1977 to 252.3 m^3/s on year 1987 (DHM, 1998). Possible changes in climate might worsen the situation. This will pose more complexity for water resources planners and managers. Therefore, quantitative estimates of the hydrologic effects of climate change are essential for understanding and solving potential water resources problems associated with flooding, drought, agricultural and industrial uses and hydro-power generation for sustainable water resources utilization in the basin.

General description of Bagmati River basin

The Bagmati watershed lies in the middle mountain region of Nepal. The watershed encompasses nearly 3719 km^2 within Nepal and reaches the Ganges River in India. Watershed area draining to the Karmaiya station is called upper watershed area and below Karmaiya station is called lower watershed area. The upper watershed area which is 2720 km^2 covers the Kathmandu valley including the origin of the Bagmati River at Shivapuri and surrounding mountain ranges. This watershed also covers the Kulekhani sub-watershed, which is of national importance being the source of the country's second largest hydroelectric plant. The Lower Bagmati Watershed Area, below Karmaiya station, is the flat alluvial plain of the Terai which is famous for its agricultural fertile land. Since the flow from the tail race tunnel of the Kulekhani hydropower project is diverted to Rapti basin permanently, the area is considered as outside the Bagmati River basin. Fig. 1 shows the major river basins of Nepal within Ganges River basin, and a map of the Bagmati watershed.

The climate varies from sub-tropical in the valleys and foot slopes through warm temperate at the mid-elevation to cold temperate in the higher mountains. In the lowlands (<1000 m above msl), having subtropical climate, mean annual temperature is 20–30 °C. In the warm temperate climatic zone (1000–2000 m above msl) the temperature range is 15–20 °C and in the cold temperate climatic zone (2000–3000 m above msl) it is 10–15 °C. The mean relative humidity in the watershed varies between 70% and 86%. The higher mountains receive snowfall occasionally during the winter months. Average rainfall is 1500 mm per year with 90% of the precipitation occurring during the four months of June–September (Poudel, 2002).

Table 1 shows a more detailed division of land use in the watershed. The IUCN survey in 1994 in the Upper Bagmati Watershed did not find significant changes in the forest area since 1981 although a significant increase in agricultural land in the lower Bagmati area was seen (Poudel, 2002). It indicates that there is increasing demand of water in the lowland Terai below Karmaiya for agriculture.

Data of river flow were collected from Department of Hydrology and Meteorology of Nepal which collects river flow data throughout Nepal.

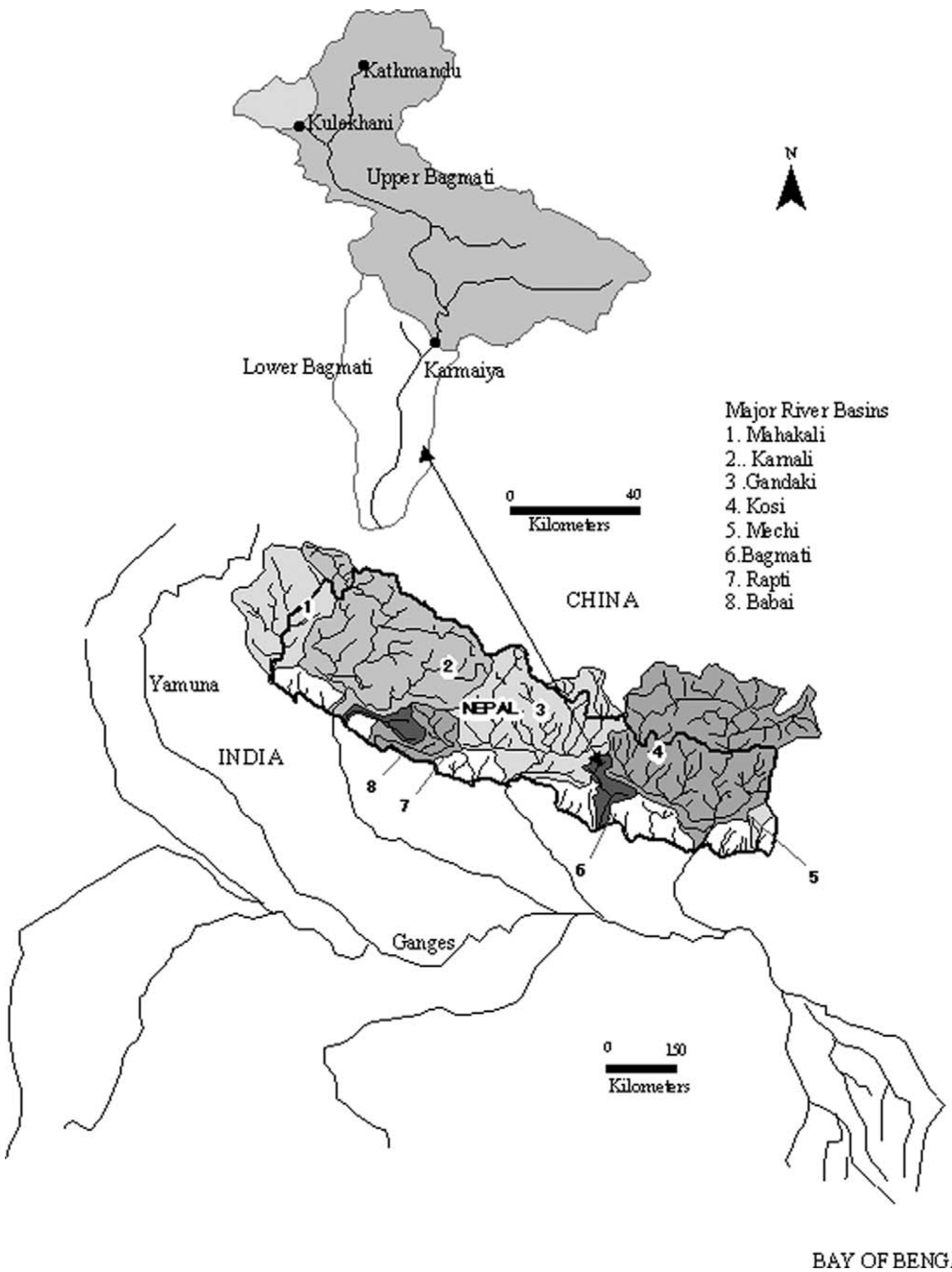

Figure 1 Location map of Bagmati watershed within Nepal.

Table 1 Areas of different landuse in the Bagmati watershed

Landuse	Whole Bagmati watershed	
	Area (km^2)	% Area
Forest	1888	51
Agriculture	1402	38
Shrub	134	4
Urban area	23	1
Grass	44	1
Others	228	6
Total	3719	100

Change in hydrologic characteristics of river flow

Trend of the river flow

Hydrological seasons in Nepal can be categorized in three different groups: (a) dry pre-monsoon season (March—May) with almost no rain; (b) rainy monsoon season (June—September); and (c) post-monsoon season (October—February) with little rain. Most of the agricultural water demands is by rice in the monsoon, by wheat in the post-monsoon and by maize in the pre-monsoon season.

The trend in river flow in each season was analyzed by regression analysis with time as the independent variable. Slope of the regression is taken as a representation of per year increase or decrease in stream flow. Monthly runoff data at Karmaiya gauging station of the Bagmati River from 1965 to 2000 was taken for the analysis.

A clear indication of decreasing monsoon flows is observed, but there is no significant change in the post- and pre-monsoon season (Fig. 2). Mean yearly flow of the river is also decreasing, since the contribution of the monsoon flow is very high compared to the flow in other seasons.

A decrease in the monsoon precipitation and an increase in evapotranspiration due to climate change may have caused the reduction in the flow in the monsoon season (UNEP, 2001). Ground water is the major contributor for the post and pre-monsoon flows. Enough infiltration supply is available in the monsoon season so the general trend of the flow has not been changed. Also the winter precipitation is increasing (UNEP, 2001), which also helps to maintain the post-monsoon and pre-monsoon flows, compensating for the increasing evapotranspiration.

Extreme flows

The trend of extreme flows, i.e., instantaneous maximum and instantaneous minimum flows was also analyzed. The trend analysis of annual maximum and minimum instantaneous discharges was done since it is a good indicator of

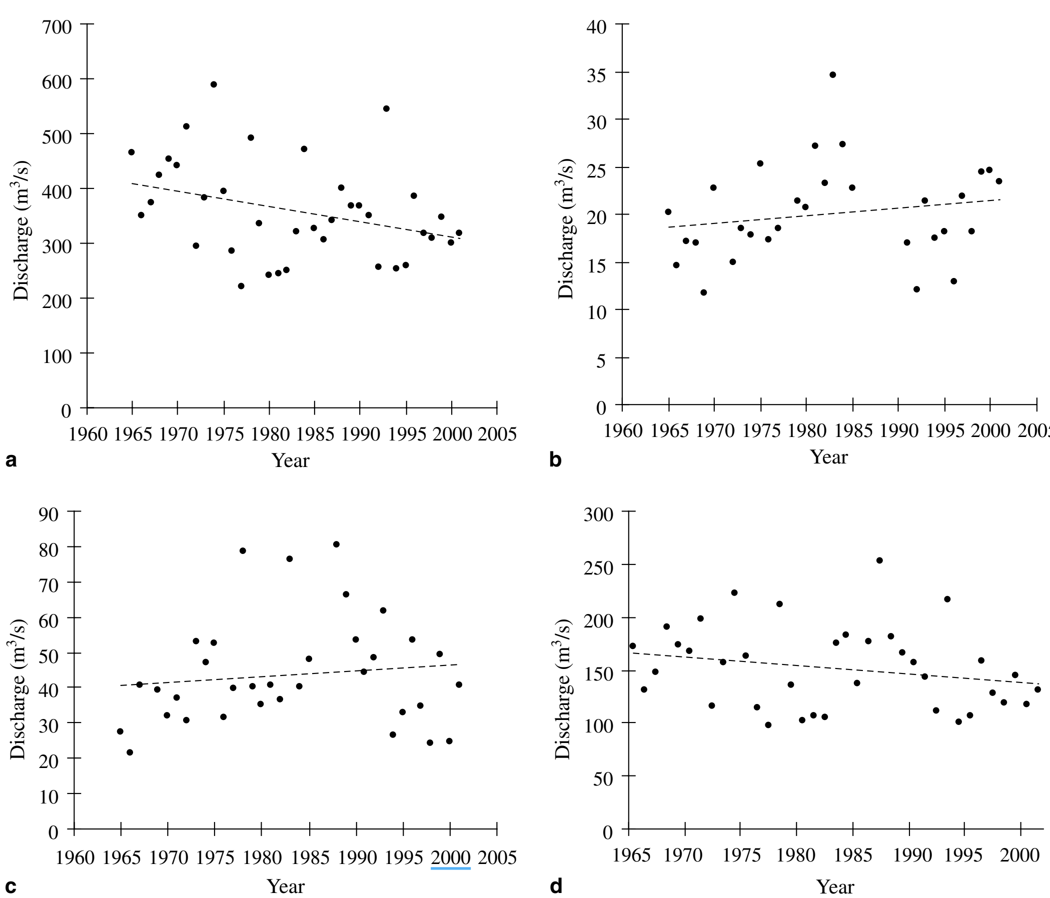

Figure 2 Trend of river flow. (a) Monsoon. (b) Pre-monsoon. (c) Post-monsoon. (d) Mean yearly (straight lines are regression lines).

the flood magnitude and drought, respectively, in the basin. A catastrophic flood occurred in 1993. Since the event is not associated with climate change but with a local phenomenon of cloud burst, it is excluded from the study as it alone has capacity to change the trend. Instantaneous data were available since the 1980s and daily data from the 1990s hence this time frame was used for the study of instantaneous min/max and flood characteristics analysis. Fig. 3 is presented to show the historical sequence of the annual maximum and minimum instantaneous discharges. It indicates that the instantaneous maximum discharge has the tendency to decrease which means that the magnitude of the flood is decreasing. Similarly instantaneous minimum discharge of the basin is increasing which entails that the water availability in the driest time is increasing.

The change in the magnitude of floods is a major impact associated with climate change. Besides its magnitude, frequency and duration are other major characteristic of floods. From the historical data defining which flow is the flood and which is not, are quite difficult. For this purpose, we defined the threshold as summation of long-term mean daily flow and one standard deviation ($\mu + \sigma$). If any daily flow event crosses the threshold we took that as a flood event. Analysis showed that the frequency and duration of small floods was most affected. Floods in the river seem to be more frequent and of longer duration although their magnitude is decreasing. Fig. 4 shows the clear indication of the increasing trend in the frequency and duration of the flood.

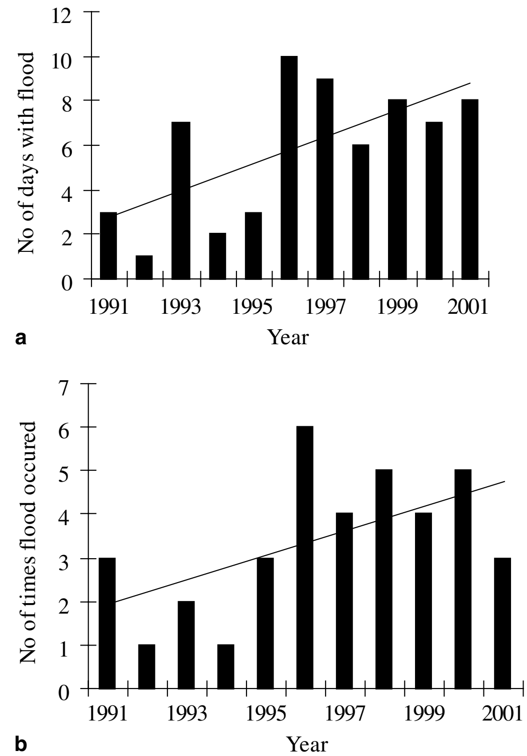

Figure 4 Trend of flood frequency and flood duration (straight lines show regression lines).

Late shifting of the hydrograph

Change in the timing of water availability is of great importance for water management and is also a good indicator of climate change. Different from the snow-fed rivers which have early shifting of hydrograph (Shrestha, 2004); the Bagmati River has late shifting of the hydrograph. Since long-term daily data were not available, monthly data were taken for analysis, despite the fact that a clearer transition of the hydrograph shift probably could be seen in daily data. Five year average monthly flow from 1965 to 2001 was taken for the hydrograph plot (Fig. 5). It can be seen that until the year 1984 peak lies in July but after 1985 the peak occurred in August indicating one month delay in peak flow.

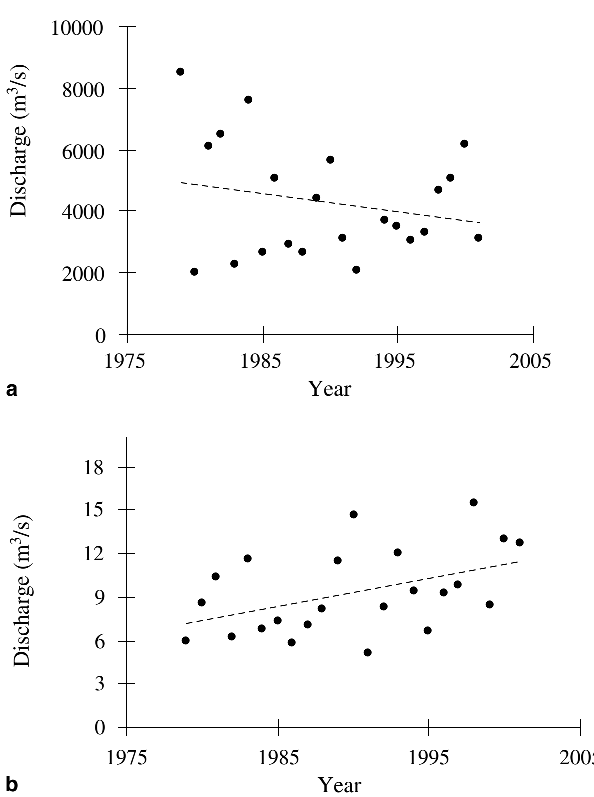

Figure 3 Instantaneous minimum and maximum flow (straight lines show regression lines).

Affected areas and adaptations

The changed scenario of water availability needs to be properly taken into account for the long-term basin scale water management. There would be change in hydroelectric power generation capacity of the power plants, change in the water quality and change in the water availability for agricultural, residential, and industrial uses. It is becoming more and more urgent for developing better ways to manage the water in the face of changing climate to meet the competing needs of hydropower, water supply, irrigation, and environmental quality. The scale of the impact due to climate change on different sectors needs to be assessed before formulating any management plan. In Bagmati River basin the hottest sectors that are likely to be affected are hydropower generation, water quality and irrigation. There

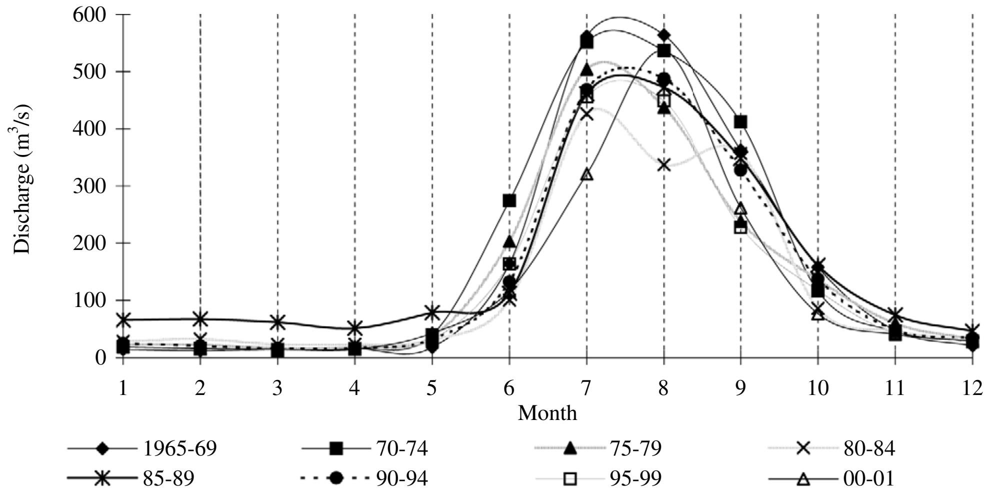

Figure 5 Shifting of hydrograph of Bagmati River.

Table 2 Predicted discharge and corresponding power generation and crop yield

Year	Flow (m^3/s)			Hydropower generation	Agricultural yield (ton/ha)	
Monsoon	Pre-monsoon	Yearly mean	(MWh/year)	Wheat	Rice	
2010	279.6	22.2	130.4	131,688	1.64	1.97
2020	251.5	23.0	122.5	125,991	1.67	1.87
2030	223.3	23.8	114.7	120,294	1.69	1.78

is not any system within the basin which draws water from the Bagmati River for water supply. So the decrease in the river runoff does not directly impact the water supply although it may have indirect impacts.

To quantify the hydrologic effects of climate change an estimate of future discharge for the Bagmati River was made (Table 2). This will give an idea of the possible changes in the magnitude of discharge and corresponding changing pattern in the hydropower production and agricultural yield. Three assumptions were made for the estimation: (1) the current trend of the yearly and seasonal flows will also be valid in the future; (2) the current relationships of river discharge with electric power, and discharge with crop yield remain the same; and (3) there will be no other significant physical change in the watershed, and the managerial system remains same.

Hydropower

Changes in the flows of rivers would have a direct impact on the amount of hydropower generation, because hydropower production decreases with lower flows. Hydroelectricity is the major source of electricity in Nepal; it meets more then 95% of electric demand. Thus, changes in hydropower production would lead to serious disruptions in the national power grid. Kulekhani hydropower plant is the second largest of Nepal in terms of production capacity hence the future production capacity of the plant with changed water availability is of prime importance. Assuming the trend of main Bagmati River flow is valid for all of its tributaries, a plot of relationship of the mean yearly discharge (June—May) and power production (Fig. 6) reveals how a decrease in volume of water causes a decrease in power production. There are other proposed hydropower plants in the river. Since the hydrology of the river is changing their design capacity should be revised as in the long run sufficient water may not be available. Table 2 shows the predicted discharge by the year 2010, 2020 and 2030. Since the mean yearly discharge rate is decreasing the hydropower production by the Kulekhani plant seems to be decreasing 4% every 10 years.

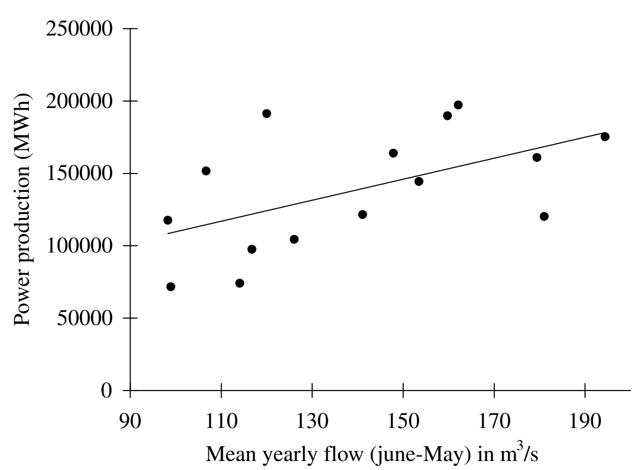

Figure 6 Relationship of mean yearly flow and mean yearly power production (straight line is regression line).

Water quality

Changing climate could impair water quality in the river system by reducing the flexibility of the existing water management system. Decreased river flows and higher temperatures could harm the water quality of the rivers. If the river flow decreases, pollution concentrations will rise because there will be less water to dilute the pollutants. To keep pollution concentrations from urban sewage below the standard, water pollution controls will have to be upgraded. Increased frequency of severe rainstorms could increase the amount of chemicals that run off from farms, lawns, and streets into the rivers.

Fig. 7 shows the increase of BOD_5 (five day biochemical oxygen demand) and chlorine concentration in the Bagmati River just downstream of Kathmandu City. Water quality in the River, however, is heavily dependent on direct and indirect human activities. Land-use and urban activities have a very significant effect on water quality, as do management actions to control point and nonpoint source pollution and to treat wastewaters discharged into the environment. The city is expanding very rapidly increasing more sewage load to river.The trend is more likely to be valid in future due to the rapid urbanization of the Kathmandu valley rather then the climate change. In this river, future water quality will be very dependent on future human activities, including water management policies; the direct effect of climate change may be very small in relative terms. But for the long-term pollution control policy formulation the trend of decreasing river flow should be taken into account.

Agriculture

Agriculture is most vulnerable to climate change. The overall agricultural production system in Nepal is very traditional, unmanaged and is too slow to adopt new technology. Change in water availability in the monsoon, the pre-monsoon and the post-monsoon season, and the shifting of the hydrograph have direct impact on the Nepalese agriculture which is totally unmanaged. Taking the runoff in the Bagmati River as an indicator of the water available in the catchment (Fig. 8) indicates that the agricultural yield is directly related to the water availability. In the driest years the yield of both rice and wheat are decreased, but there will not always be an increase in the yield if the river discharge is more than some limited range.

Table 2 shows the predicted discharge and crops yield by the year 2010, 2020 and 2030. Since the monsoon flow is decreasing, the production of rice is also decreasing due to reduction of water availability in the basin. Yield of wheat is likely to go up slightly as the pre-monsoon and post-monsoon flows have a tendency to increase. Current practice of crop calendar may have to be changed due to shifting of the hydrograph.

Water sharing between India and Nepal

There have been serious misunderstandings and conflicts between Nepal and India about the sharing of transboundary water resources as water demand in both countries is increasing mainly in the large river basins: Koshi, Gandaki, Karnali, Bagmati and Mahakali Rivers. There are also many conflicts in small river basins such as the Rapti and the Babai. As the population swells and incomes grow, demand of water for agricultural, residential and industrial purposes increases rapidly. With water becoming increasingly scarce and development of new sources of water becoming very

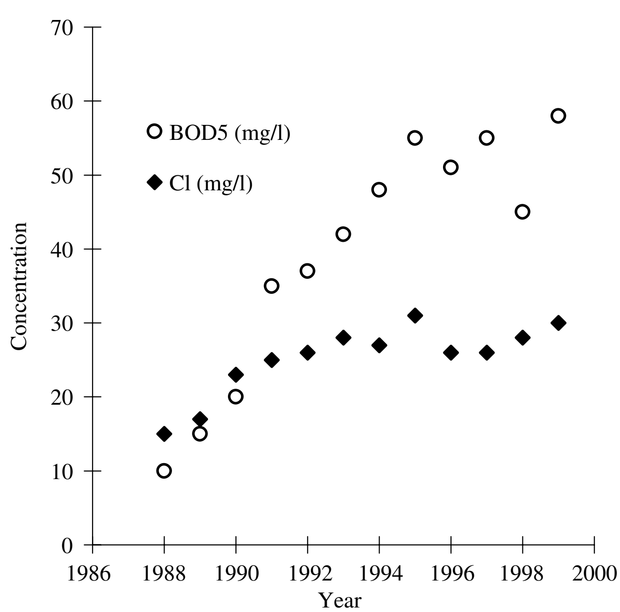

Figure 7 Yearly Cl-concentration and BOD_5 in Bagmati River just downstream of Kathmandu city.

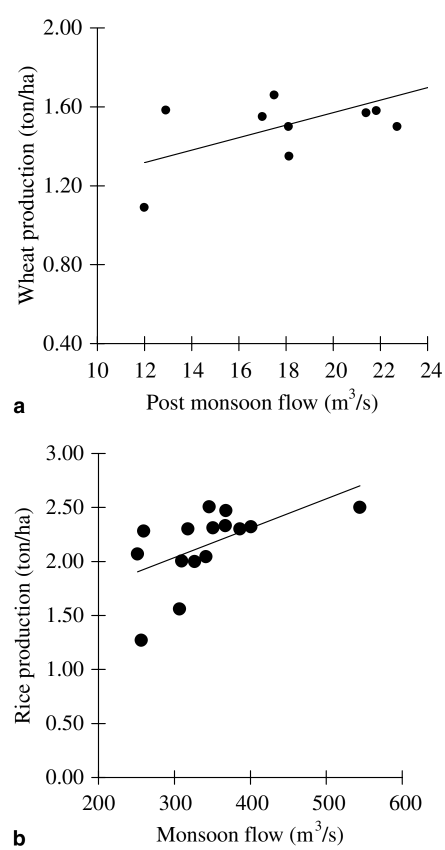

Figure 8 Relationship of discharge with rice and wheat yield.

costly, more national conflicts are expected to arise, pitting industry, urban centers, and agriculture against each other. The decrease in the river flow will even escalate the demand. Since the Bagmati River is a transboundary river, a change in the flow characteristics may introduce a new dimension in the water negotiation problem between Nepal and India. Both countries will have to design the modalities to properly share resources under the scenario of changed water availability. Unless mechanisms for incorporating climatic changes in the water sharing agreement can be worked out, changes in future flow may provoke further conflicts between these riparian countries.

Conclusion

Although climate change is a global phenomenon the trends and impact may be different on a local scale. Analysis should be done at the local level rather than at the large scale. The seasonal variability, timing of water availability and change in flood pattern are indicators of the impact of climate change on river hydrology. Mean yearly flow and monsoon season flow in the Bagmati River is decreasing significantly. Post-monsoon and pre-monsoon seasonal flows are more or less constant. If the current trend continues and no other management systems were adopted then it is likely that the power production from the Kulekhani hydropower plant is going to be reduced by 4% in every 10 years. Production of rice which is directly related to the monsoon season flow is going to be decreased but the production of the wheat may slightly be increased. The flood magnitude in the Bagmati River basin is decreasing but the duration of each flood and the frequency of the flood are increasing. The hydrograph is shifting which means the water will be available later in the season then it is now. Date of current practice of planting may have to be changed. Due to increasing demand and reduced supply water conflicts between India and Nepal are likely to increase in the future. A proper modality of water sharing should be designed in advance. Proper water management policy hence becomes an urgent need to address all the scenarios.

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