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A hydro-chemical study of a mountainous watershed: the Ganga, India

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Abstract

A hydro-chemical study has been carried out on a 37-km stretch of the River Ganga from Deoprayag to Rishikesh (India) during the period from April 1999 to March 2000. The assessment of sediment and nutrient load has been considered to evaluate the current state of pollution through real time measurements. The values of pH and conductance are well within the limits prescribed for drinking water. The maximum suspended sediment concentrations of 1405 and 2002 mg/L were recorded at Deoprayag and Rishikesh, respectively, during the rainy season. A large amount of sediment and nutrient load is transported from the watershed during the rainy season. Concentrations of NO_3–N and NH_3–N at Deoprayag varied from 0.30 to 0.50 and 0.02 to 0.12 mg/L, respectively, depending on season. Examination of the results showed clearly that NH_3–N was generally low as compared to NO_3–N. Depending on the pH and temperature of soils, NH_4^+ and NO_3^- ions are produced in the watershed through ammonification and nitrification of organic matter and mobilized into rivers through run-off. Dissolved N and P from fertilizer application, sewage and non-point source run-off contribute significant quantities of these nutrients in river water. The nitrate and phosphate are transported from the cropland either by being adsorbed on to soil particles that are subsequently eroded, or dissolved in runoff water from agricultural land. The data generated through the study will be useful for development and management planning of the hilly watershed. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Hydro-chemical; Watershed; Sediment load; Nutrient loading; Non-point source; Nitrate; Ammonium; Electrical conductivity

1. Introduction

The fast growing population in India and the use of mineral and organic fertilizers to increase crop yield and the conversion of upland grazing, scrub and forest to terraced agricultural land in mountainous regions is a cause of major concern from the point of view of environmental degradation [1,2]. Furthermore, as tourism is established as a major industry in mountainous and remote areas, human habitation and road transport will further impact on the natural environment [1]. Growing awareness of this situation [3] calls for sustainable development of natural resources so that ecosystem stability is maintained.

Non-point sources of water pollution have been recognized as often being of greater importance than point sources particularly in rural catchments [4–6]. This is due in part to the continuing efforts to reduce pollution from point sources over the past few decades, as well as recognition that non-point sources, such as storm water, may contain harmful contaminants [7]. In most cases, the sources and concentrations of non-point source pollutants are the result of land use interactions with the transport system. In rural areas, nutrients and pesticides are released in surface and ground water and may degrade the quality of drinking water and cause various health problems to humans [8]. Nutrients and pesticides, particularly, are of major concern because of

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eutrophication and high toxicity problems [9,10]. This has emphasized the need to identify and quantify major sources of nutrients and pesticides deposited within the river system. The assessment of nutrients is an example of a spatially and temporally complex, multidisciplinary environmental problem that exists over multiple scales [11].

The major factors influencing non-point source surface water pollution include soil erosion and sedimentation and erosion of stream banks, washing out nutrients and organic material from livestock wastes and agricultural land, storm runoff from urban areas and atmospheric deposition. Adsorption to the surface of sediment particles provides a mechanism for transport of many contaminants derived from agricultural fertilizers, pesticides and industrial wastes. Deposition of sediments carrying such loads in the channel or on the flood plain can have detrimental consequences for ecology and agricultural activities. The sediment released into the river system can promote channel instability and cause bed degradation [6].

In most cases the sources and concentrations of non-point source pollutants are the result of land use interactions with the transport system [12]. It is a source transport problem in which the hydrologic cycle provides the transport processes to move pollutants from the source to ground water, a stream, or a reservoir [13]. Non-point sources can be urban, industrial, or agricultural pollutants that are distributed over the surface.

Watershed management essentially relates to long-term soil and water conservation by proper land use, preventing deterioration of soil, increasing and maintaining soil fertility, reducing soil erosion, conserving water for drinking and other farm uses, increasing the availability of basic resources and achieving the optimum productivity of land uses [14]. Rai et al. [15] has described the traditional conservation practices and relationship with land use in Mamlay watershed in the Sikkim Himalaya. It was observed that the agricultural land area has considerably increased over the past 40 years [14,15]. Soils without tree cover on steep upland farming systems such as those associated with more intensive agricultural practices is vulnerable to erosion and reduced fertility [16].

Information on the hydrology and associated water quality is very important for evaluating management strategies at a watershed level. Unfortunately, there are no such data available for the Himalayan region of India. The present investigation was undertaken to understand the basic hydrology and associated water quality in a mountainous watershed of River Ganga so as to determine the contribution of nutrient and sediment loading from the catchment. In recent years exponential growth in population and fragmentation of farm families have caused a reduction in land holding size per family unit, consequently forcing the farmers towards more intensive cultivation practices [16]. The present study focuses on the contribution of nutrient loading from different land uses, considering the hilly portion of the watershed as a whole unit, which could be useful in development and management planning of the hilly region.

2. The river system

The River Ganga rises in the Gangotri glacier in the Himalaya Mountains at an elevation of 7138 m above mean sea level in the Uttar Kashi district in the state of Uttaranchal, India. At its source the river is called the Bhagirathi. It descends down to the valley to Deoprayag, where the Alaknanda, another hill stream rising from the Bhagirath Kharak and the Satopanth twin glaciers joins it. After the confluence with Alaknanda, the combined stream is called the Ganga. After covering a distance of about 220 km in the Himalaya, it enters the plains at Hardwar and meanders over a distance of about 2290 km across Uttar Pradesh, Bihar and West Bengal, before it joins the Bay of Bengal through a large number of deltaic branches flowing in India and Bangladesh (Fig. 1).

Physiographically the area is generally flat except for the Siwalik Hills in the north and north-east of the catchment. The area is devoid of any relief features except from deep gorges cut by drains and rivers flowing through the area. The River Ganga dominates the drainage pattern, which is the only river flowing through the area. The melt water of the glaciers in the upper Himalayas maintains a perennial supply of water in the River Ganga.

The climate of the region is characterized by moderate type of subtropical monsoonal climate. It has a cool dry winter season from October to March, a hot dry summer season from April to June and a warm rainy season from July to September. The average annual rainfall over the Ganga basin varies from 780 mm in the upper part, 1040 mm in the middle course and 1820 mm in the lower delta of Bangladesh [17]. Most of the rainfall occurs during the Southwest monsoon season. Several large-scale modern irrigation projects have been initiated during the last one hundred years and irrigation for food production is the main use of water from the Ganga River. The total cultivable area of the whole Ganga basin is 21,109 km^2.

Geologically, the area is a part of the west Indogangetic plain, which is composed mainly of Pleistocene and subrecent alluvium brought down by river action from the Himalayan region. At Hardwar, the sequence of sandstone and shales along with gravel beds and clays are grouped within the upper and middle Siwaliks. The soils of this region do not form a compact block. They

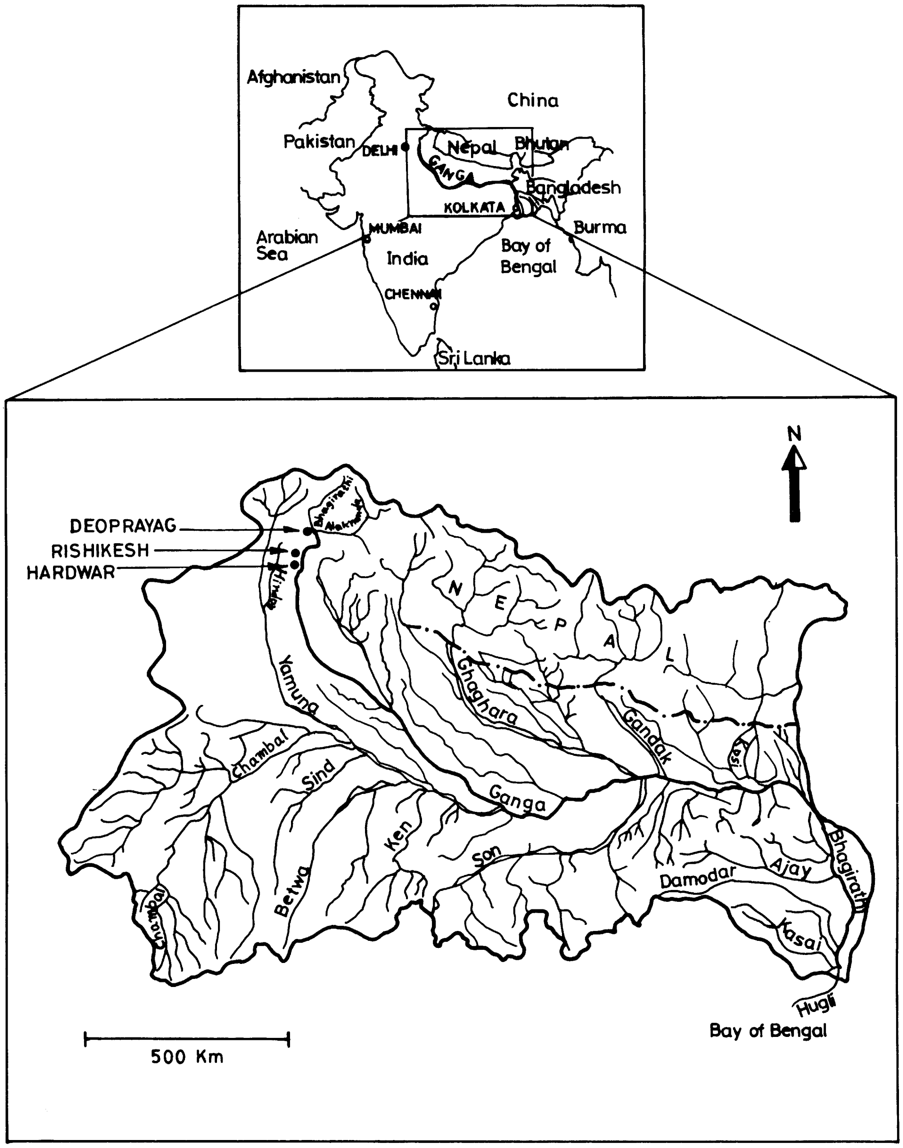

Fig. 1. The Ganga basin.

differ from valley to valley and slope to slope according to different ecological conditions. Soils of the upper Bhagirathi and Alaknanda are of mixed origin, i.e. glacial and fluvio-glacial. In the lower hilly region, soils mostly comprise forest soils and hilly soils. The problem of soil erosion in the basin is particularly serious in the Himalayan tract, since the soils in this region are often very thin and all exposed slopes are susceptible to severe erosion and to gullying. Lower down in the plains region, slopes are gentle, except in the vicinity of natural drainage where steep river bank slopes have been created through erosion spread over centuries. The bed of the river is rocky up to Hardwar. The soils of the area are predominantly loam to silty loam and are normally free from carbonates.

The present study has been carried out on the upper stretch of River Ganga (hilly region) from Deoprayag to Rishikesh. The study area has an elevation of 327–443 m above MSL, covering a total catchment area of 2200 km^2. The watershed area lies entirely in the mountainous zone. The area is typified by folded structures and varied lithology with older rocks occupying the upper structural levels. The major rock formations in the watershed are phylites. The drainage network map of the study area showing location of sampling points is shown in Fig. 2.

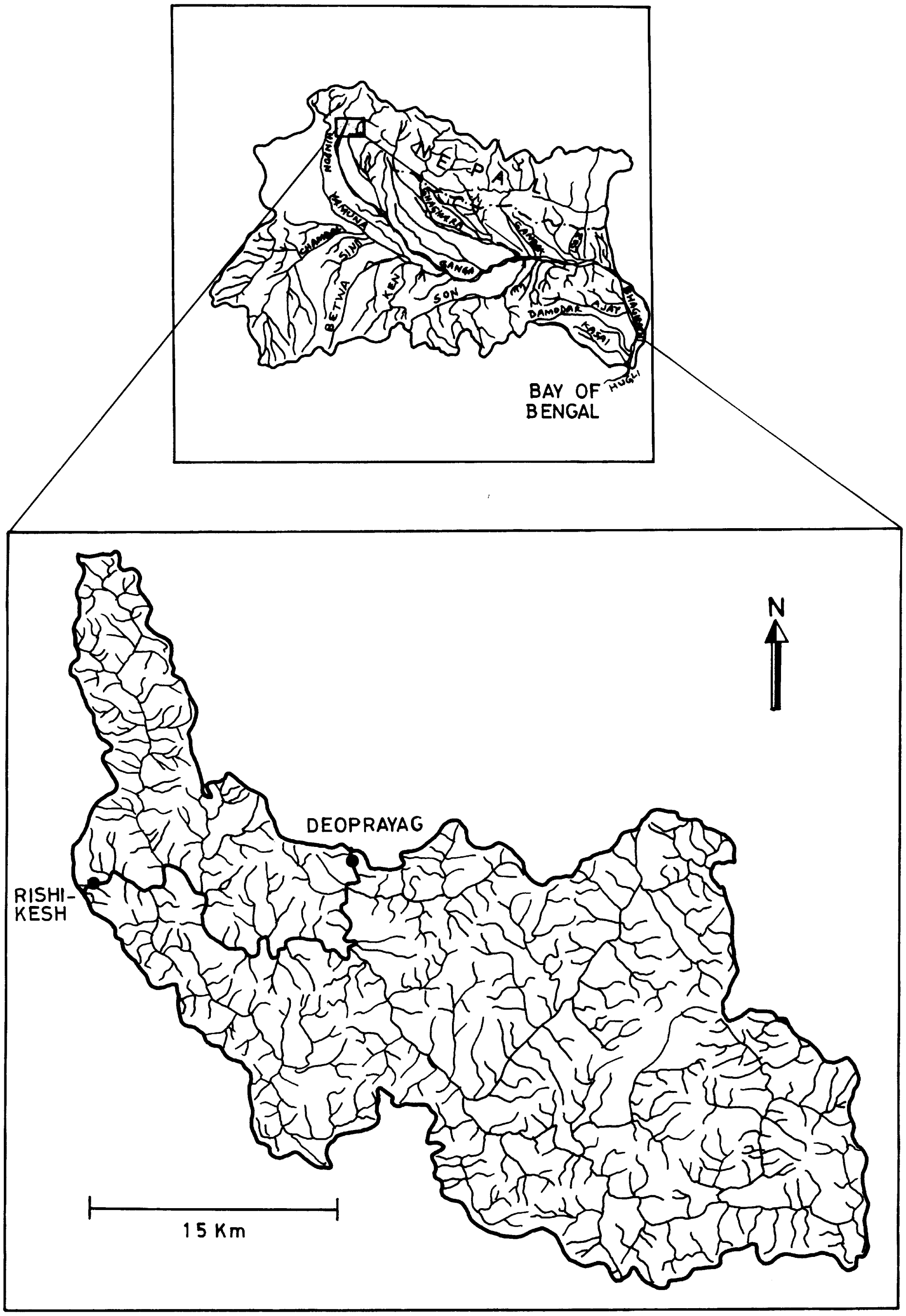

Fig. 2. Drainage network map of the study area showing location of sampling sites.

The daily rainfall pattern at the two sampling stations is shown in Fig. 3. It is clear from the figure that more than 70% of the rainfall occurred during the period from June to September. The daily maximum rainfall was observed to be 44.6 mm and 51.0 mm at Deoprayag and Rishikesh, respectively. Knowledge of precipitation distribution during individual months, seasons and the year is of vital importance for water quality assessment as well as for planning water resources projects and agricultural operations in a given river basin.

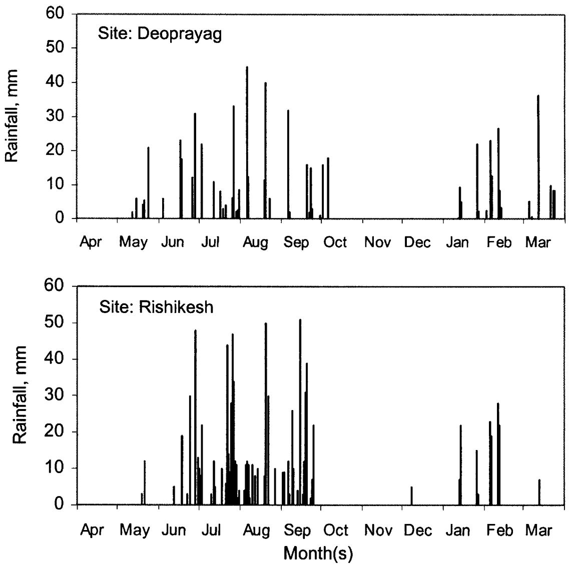

Fig. 3. Daily rainfall pattern at Deoprayag and Rishikesh.

3. Sampling stations

The two sampling stations, viz., Deoprayag and Rishikesh were monitored to determine nutrient and sediment loading from the mountainous portion of the watershed. Deoprayag is situated on the left bank of the River Ganga at an elevation of 443 m. The total catchment area including the upper reaches upto this site is 19,600 km^2. The geographical coordinates of the site are: longitude 78°36′E and latitude 30°08′N. Water samples were collected from the Central Water Commission (CWC) gauge and discharge site, located 1 km downstream from the confluence of the two rivers, Bhagirathi and Alaknanda. Bathing activities at this point are not very intense and the population is also small.

Rishikesh is an important religious and tourist centre with intense bathing activities. The sampling site is situated at Rishikesh on the right bank of River Ganga at an elevation of 327 m. The total catchment area of the river upto this site is 21,794 km^2 including upper reaches of Alaknanda and Bhagirthi. The river length from Deoprayag (below confluence of river Bhagirthi and Alaknanda) to Rishikesh is 37 km. The geographical coordinates of the site are: longitude 78°17′E and latitude 29°05′N. The water samples were collected from the CWC gauge and discharge site.

4. Experimental methodology

Water samples were collected from Deoprayag and Rishikesh at a frequency of 14 days (usually on alternate Wednesday or Thursday) for a period of one year from April 1999 to March 2000 by dip (or grab) sampling method. The samples were collected from 1/3, 1/2 and 2/3 width of the river and mixed together to obtain a composite sample. All the samples were collected from 15 cm depth using standard water sampler (Hydro Bios, Germany). The samples thus collected were stored in clean narrow-mouth polyethylene bottles fitted with screw caps.

In the field, two water quality parameters (pH, conductance) were measured by means of portable meters. For other parameters, samples were preserved by adding an appropriate reagent and water samples were brought to the laboratory in sampling kits maintained at 4°C for analysis. Physico-chemical analysis was conducted following standard methods [18]. All chemicals used in the study were obtained from Merck, India and were of analytical grade. Double-distilled water was used throughout the study. All glassware and other sample containers were thoroughly cleaned and finally rinsed with double-distilled water several times prior to use. A brief description of the analytical methods is given in Table 1.

Table 1
Analytical procedures

Parameter	Method
Temperature	Thermometric method
pH	Electrometric method
Conductivity	Electrical conductivity method
Total dissolved solids	Filtration through 0.45 μm membrane filter, filtrate dried at 103–105°C
Total suspended solids	Filtration through 0.45 μm membrane filter, dried at 103–105°C
Total solids	Gravimetric method, dried at 103–105°C
Nitrate–nitrogen	Chromotropic acid method for 0–5.0 mg/L range
Ammonia–nitrogen	Distillation followed by nesslerization for 0–5.0 mg/L range
Orthophosphate	Stannous chloride method for 0–1.0 mg/L range
Total phosphorous	Alkaline persulfate digestion of total phosphorous to orthophosphate, followed by stannous chloride method for 0–1.0 mg/L range

5. Results and discussion

All the major rivers in India originate in the Himalayas. The Indus, the Ganga and the Brahmaputra, which receive substantial amounts of flow as snow and glacier melt runoff from the Himalayas, are considered to be the life-line of the Indian subcontinent. The majority of the rivers have their upper catchments in the snow-covered areas and flow through steep mountain valleys. The perennial nature of these rivers and appropriate topographical settings provide excellent conditions for the development of hydropower resources. The role of these rivers and their tributaries in irrigation and water supply is also vital.

The water of the River Ganga has traditionally been regarded as an inexhaustible gift of nature. In recent decades rapid development of agriculture and industry in the Indian sub-continent have, however, put severe strains on the river and, to an extent, have resulted in degradation of its quality. Problems of water pollution have not only surfaced but also begun to assume serious dimensions in certain stretches of the long course of the River Ganga. Several examples highlighting the pollution status of the River Ganga have been described in an earlier report [19].

The investigations conducted in this study have been restricted in scope and dealt mainly with the assessment of nutrient loading from the mountainous region of the watershed. The total length of the river from Deoprayag to Rishikesh is 37 km, which covers a watershed area of 2200 km^2. Attempts have also been made to correlate the nutrient loads delivered from the watershed to the river with cultivable land and fertilizer application. This will provide necessary information to guide current and future decision-making.

5.1. Land use pattern and fertilizer inputs

Most parts of the River Ganga basin are densely populated (covers 37% of India's population). Intense agricultural practices are being followed through ages and the forest area is greatly reduced. About 47% of the total irrigated area in India is located in the Ganga basin alone [20]. The natural contrivances for restraining soil erosion are almost non-existent in the agricultural belts. Agricultural land is irrigated with water from the River Ganga and its tributaries. Each year, about 115,000 tonnes of fertilizers are washed away with the agricultural waste water and find their way into the River Ganga, of which nitrogen is 88,600 tonnes, phosphorous 17,000 tonnes and potassium 9200 tonnes [21].

The land use map of the Ganga basin from Deoprayag to Rishikesh has been prepared using remote sensing techniques and is shown in Fig. 4. On the basis of the land use map the study area can be demarcated into four categories (Fig. 5): agriculture (7.1%), grass/scrub (56.9%), forest (21.5%) and barren land (14.5%).

The total area of the watershed of River Ganga from Deoprayag to Rishikesh is about 2200 km^2. Out of which 155 km^2 of land, which constitute 7.1% of the total study area, is cultivated. Grassland covers an area of 1252 km^2, which constitute 56.9% of the study area. Non-arable land (barren land) in the study area covers an area of 320 km^2, which constitutes 14.5% of the total study area. This category of land comprises those areas, which cannot be put to agricultural or silvicultural uses because of their unproductive character. It also includes other types of land use, e.g., human settlements, roads, etc. The remaining 473 km^2 of the area, 21.5% of the study area, is under forest cover. At the basin level (Ganga basin as a whole) it may be mentioned that 14.3% of the total basin is under forest cover while at the national level 20% of total land is forested. Most of the forested land in the Ganga basin is severely degraded on account of over exploitation due to rapid progress in communication and commerce. There has been a constant increase in the urban areas along the River Ganga. As a result the river is no longer only a source of water but also a channel, receiving and transporting urban wastes away from the towns. Rampant deforestation in the last few decades has resulted in topsoil erosion and increased silt deposition in the catchment area, which in turn raise the river bed and lead to devastating floods in the rainy season and stagnant flow in the dry season [20].

Agriculture in the study area consists exclusively of terraced cultivation. Extensive application of fertilizers in the form of farmyard manure and inorganic nitrogen and phosphorous compounds are common in these fields. About 311 metric tonnes of chemical fertilizers comprising nitrogen 68.5%, phosphorous 23.6% and potassium 7.9% were applied in the study area during the year 1999–2000. A major portion of this is believed to finds its way into the river due to steep slopes.

5.2. Flow characteristics

The flow in the River Ganga at the two sampling strations, Deoprayag and Rishikesh, varies from 122 to 1775 and 132 to 2000 m^3/s, respectively, during the period of sampling. Temporal variability in flow is one of the important features of Himalayan rivers. The flow in these rivers can be distinguished in four well-marked seasons. In the winter season flow is basically from surface flow due to seasonal rains, sub-surface flow and ground water contribution. In the pre-monsoon season, snowmelt and glacier waters produces high flows in mid or late summer. Some times, rainfall also contributes to the flow in this season. During monsoon months, the flow is augmented by monsoon rains to produce higher discharges and occasional peak floods. In the post-

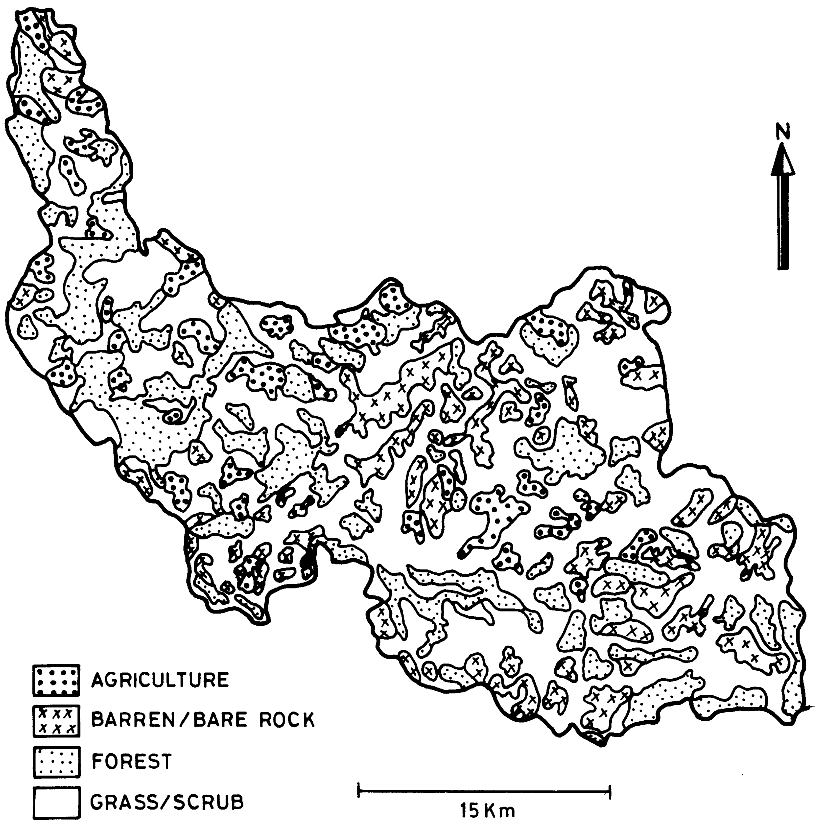

Fig. 4. Land use map of the study area.

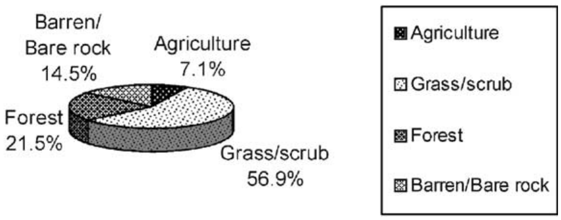

Fig. 5. Land use classification.

monsoon season, the flow is believed to be primarily from glaciers and occasional rainfall events in the basin. Generally, the glacier contribution starts in the month of July when accumulated seasonal snow on the glaciers in the preceding winter season is melted and continues till September/October. Glacier melt runoff in the streams coincides with the monsoon period. Snow and glacier melt runoff make these rivers perennial in nature, though with distinct seasonal patterns of flow. The flooding in these rivers results from heavy rainfall. Sometimes, a combination of rainfall and excessive snowmelt also cause floods. According to the study conducted by Singh et al. [22], the seasonal distribution of the flow at Deoprayag using 10 years of flow data was found to be 1.2% during October–December, 5.6% during January–March, 20.0% during April–June and 63.2% during July–September. It has also been reported that, on average snow and glacier melt contributes 28.7% of the average annual flow in the Ganga River at Deoprayag, whilst rainfall contributes the remaining flow. On average, about 41% of the total drainage area of the Ganga basin upto Deoprayag is covered by snow in the month of March/April, whilst some 19% of the catchment remains covered by perpetual snow and glaciers.

5.3. Hydro-chemical characteristics

The temporal variations of various constituents at Deoprayag and Rishikesh are graphically presented in Fig. 6. A pH range of 6.5–8.5 is normally acceptable as per guidelines suggested by BIS and WHO [23,24]. The pH values at Deoprayag and Rishikesh vary from 7.23 to 8.50 and 7.83 to 8.40, respectively, indicating the alkaline nature of the river water at both the stations. The pH values observed at both the stations are well

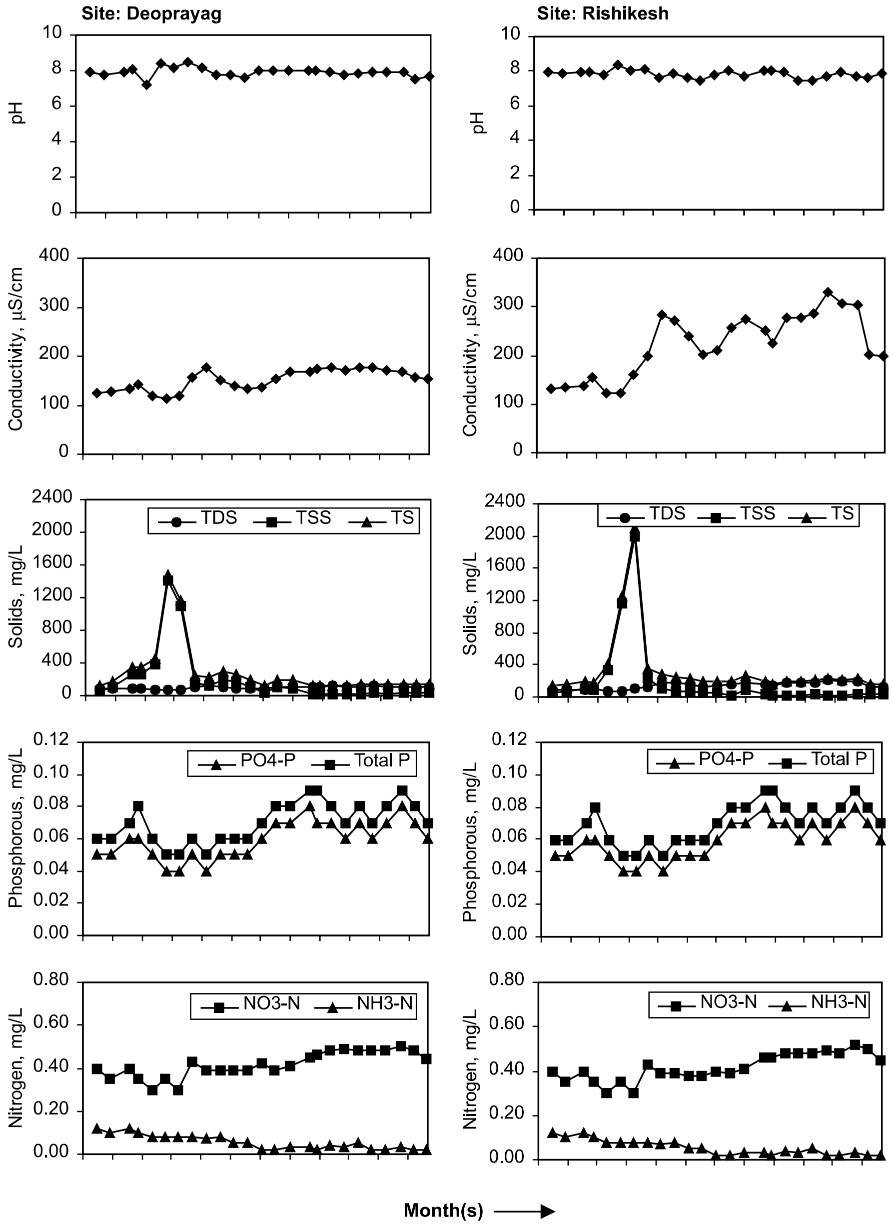

Fig. 6. Temporal variations of various constituents at Deoprayag and Rishikesh.

within the limits prescribed by BIS and WHO for drinking water. Stream chemistry is well buffered within the observed pH range.

Conductivity is used as a criterion for expressing the total concentration of soluble salts in water. The conductivity values at Deoprayag and Rishikesh vary from 114 to 178 and 123 to 330 µS/cm, respectively. Higher values of conductivity were observed in low flow periods at both the stations (Fig. 6). Slightly higher values of conductivity at Rishikesh appear to be due to the contribution of dissolved solids from the watershed.

Total dissolved solids (TDS) indicate the general nature of water quality or salinity and is usually related to conductivity. Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralised water may be used where better quality water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water [23]. The TDS content at Deoprayag and Rishikesh varies from 73 to 114 and 79 to 211 mg/L, while total suspended solids vary from 11 to 1405 and 12

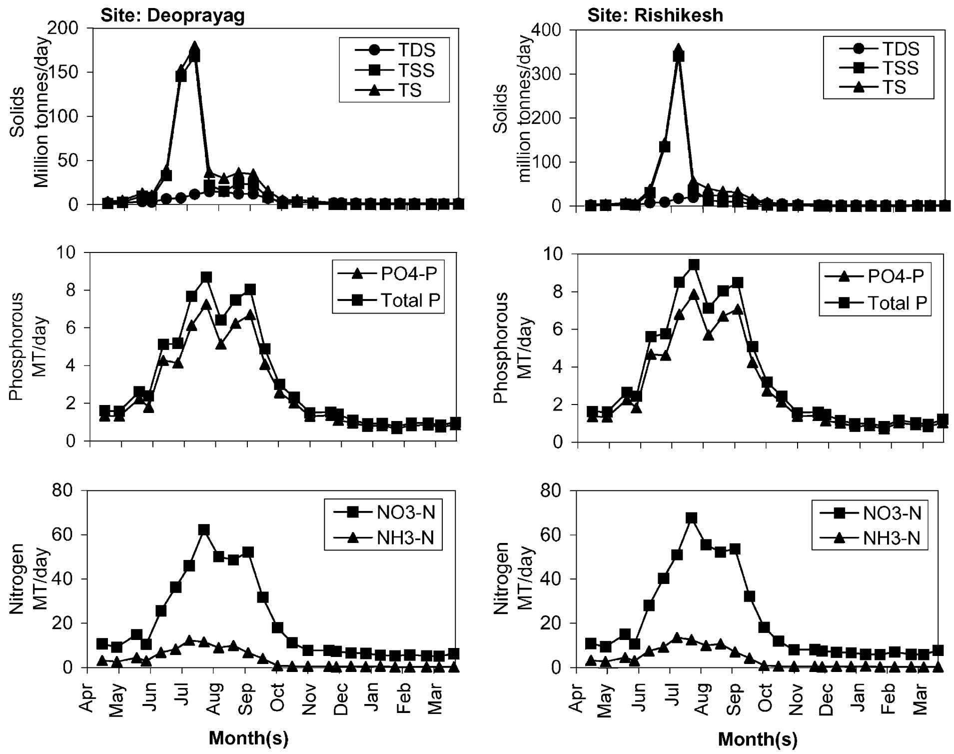

Fig. 7. Temporal variation of sediment and nutrient loadings at Deoprayag and Rishikesh.

to 2002 mg/L, respectively. Higher values of dissolved solids at Rishikesh (Fig. 6) may be attributed to the contribution of the watershed due to the dissolution or weathering of rocks and soils as water passes over or percolates through them [12]. As expected the maximum total suspended solids were observed during the monsoon season at both the stations (Fig. 6). A large amount of sediment load is transported from the watershed during the rainy season (Fig. 7). The highest sediment concentration in the rainy season may be attributed to high rainfall during this period and steep slopes of the land. Similar findings were also reported by Rai and Sharma [2] for Sikkim Himalaya.

Concentrations of NO_3–N and NH_3–N at Deoprayag varied from 0.30 to 0.50 and 0.02 to 0.12 mg/L depending on season. Examination of results clearly showed that NH_3–N was generally low as compared to NO_3–N (Fig. 6). A limit of 45 mg/L as nitrate (10 mg/L as NO_3–N) has been prescribed by BIS [23] for drinking water supplies. Its concentration above 45 mg/L in drinking water may prove detriment to human health, particularly to infants [23,24].

NO_3–N concentrations showed a clear seasonal pattern (Fig. 6). The seasonal differences can be accounted for by variations in the amount of readily leachable NO_3–N within the soil profile [25]. Mineralisation of soil nitrogen usually continues after uptake by an arable crop has ceased and often after harvest, causing an accumulation of NO_3 in the soil during the late summer, autumn and early winter [25]. Autumn sown crops utilise only a small quantity of NO_3, the remainder being exposed to leaching throughout late autumn, winter and early spring period when the soil moisture content is at field capacity. The highest losses due to leaching occur during the cold winter months, when the autumn sown crop ceased to absorb NO_3 from the soil profile. During the summer months, plant uptake is high and effective runoff is low relative to the other seasons, resulting in greatly reduced leaching losses from the soil system.

PO_4–P and total P concentrations ranged from 0.04 to 0.08 and 0.05 to 0.09 mg/L at Deoprayag. Almost the same trend was observed at Rishikesh. This may be due to increased weathering and breakdown of the soil structure and addition of mineral fertilizers [1]. However, more detailed studies are needed specifically at agricultural catchments of similar geology to confirm these observations.

Various pathways are employed in the transport of N and P into a river system. Depending on the pH and temperature of soils, NH_4^+ and NO_3^- ions are produced in the watershed through ammonification and nitrification of organic matter and mobilized into rivers through run-off [17]. The weathering of apatitic rocks is the major natural source of PO_4^{3-}. Rain can be a source of dissolved N and S. N, P and S from fertilizer application, sewage and non-point source run-off contribute significant quantities of dissolved species of N, P and S near human habitation [17].

Comparison of the water quality data at Deoprayag and Rishikesh provides evidence of agricultural impacts. This pattern is entirely consistent with the expected impacts of agricultural land use. The nitrate and phosphate are transported from the cropland either by being adsorbed on to the eroded soil particles or dissolved in runoff water from agricultural land. Modern high-yielding crops also require the addition of fertilizers resulting in the possibility of increased NO_3–N losses from terrestrial systems into water courses through surface runoff and/or by leaching through the soil profile [26].

The area under study contains a relatively small human population and there is no industrial activity. Therefore the N and P inputs to the river from domestic, industrial sources and atmospheric from fuel burning may be considered negligible. The fertilizer application rates have increased over the last two-three decades [27] and uptake efficiencies by crops are often relatively poor, approximately 50% and 20% for N [28] and P [29], respectively. It may be stated therefore that in the mountain environment with low agricultural activities, the stream chemistry is greatly influenced by the agricultural practices carried out on the terraced land.

The quantification of nutrients contributed from different land uses, point and non-point sources and process mechanisms causing the change in the water chemistry of the river could not be quantified due to a paucity of fertilizer application data at an appropriate scale. More detailed studies are needed to provide the necessary baseline data against which to assess the extent of anthropogenic influences, in particular, the impact of land use and land cover on stream chemistry should be quantified so that the sensitivity of these systems to anthropogenic pollution can be assessed. This is particularly important in view of the need to maintain ecosystem stability and bio-diversity in the face of continued development of these areas in response to increasing population and tourism pressure in the hilly regions.

5.4. Sediment load

The Ganga basin is by far the largest in India, with a geographical area of 861,404 km^2 within India. As compared to the river Nile (6650 km) or Amazon (6500 km) the total length of the Ganga is only 2525 km, but it carries the highest quantity of sediment (2.4 billion metric tonnes per year) which is greater than that carried by any other river of the world. The Ganga has also acquired a unique position among other major rivers of the world by possessing the largest delta, which was formed with deposition of these sediments through the ages. It is these sediments that keep enlarging the delta and extending sea-wards.

The enormous sediment load of the Ganga may be attributed to the following factors: (1) The Himalayas, the birth place of Ganga is made up of unstable rocks with a high erosion rate, (2) the size of the drainage basin is enormous with steep angle of elevation in the Himalayan region, (3) there are numerous tributaries flowing through the basin and by their joint action soils from all over the basin are transported to the main stream [21].

The distribution of instantaneous loads for total, dissolved and suspended solids at Deoprayag and Rishikesh is given in Fig. 7. As is evident from the results that the maximum suspended load is transported from the watershed during the monsoon season at both the stations. The higher value of suspended load at Rishikesh is due to the contribution from the watershed. The maximum suspended load of 1405 and 2002 mg/L were observed at Deoprayag and Rishikesh, respectively, during the monsoon season.

5.5. Nutrient load

One of the most important aspects of river water quality management is the determination of the input mass loading, that is, the total mass of a material discharged per unit time into a specific body of water. For defined sources, the instantaneous input load is given by the equation

$$L(t) = Q(t)C(t),$$

where $C(t)$ is the concentration of the input, $Q(t)$ is the input flow and $L(t)$ is the mass rate (load) of input, all quantities occurring simultaneously at given time t. In metric units, the concentration and flow are often expressed in mg/L and m^3/s, respectively.

The instantaneous nutrient loads were accordingly calculated at two sites by multiplying concentration values from samples taken at the gauging sites and flow values at the time of sampling. The temporal variations of nutrient loads transported at the two sampling sites are shown in Fig. 7. It is clear from the results that the loading of various constituents varies widely from month to month and season to season, with the maximum load being transported during the monsoon season. The result suggests that significant quantities of nutrient loads are transported from the watershed during the monsoon period. Similar findings were also reported by various authors [30–32].

The fluxes of nutrients induced by excessive human activities have begun to exceed the natural fluxes in

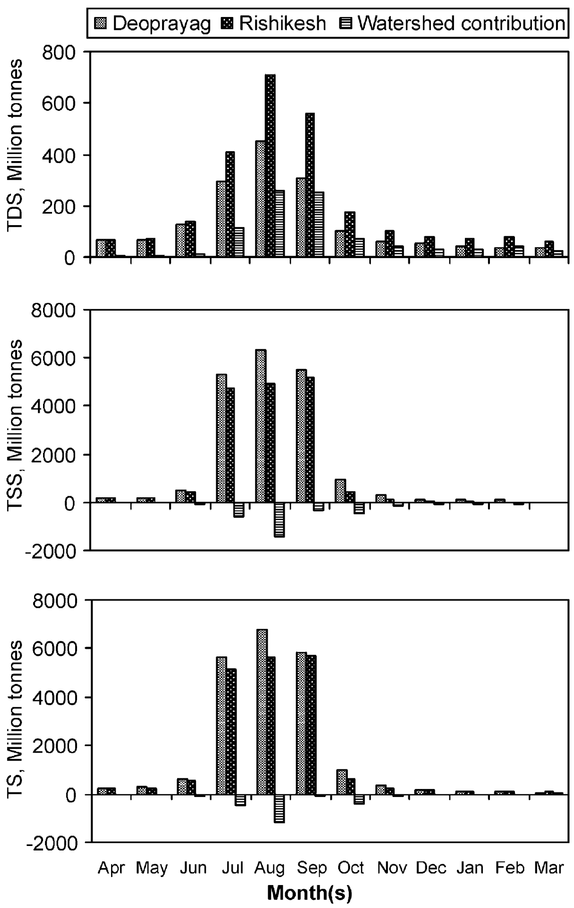

Fig. 8. TDS, TSS and TS loadings from the watershed.

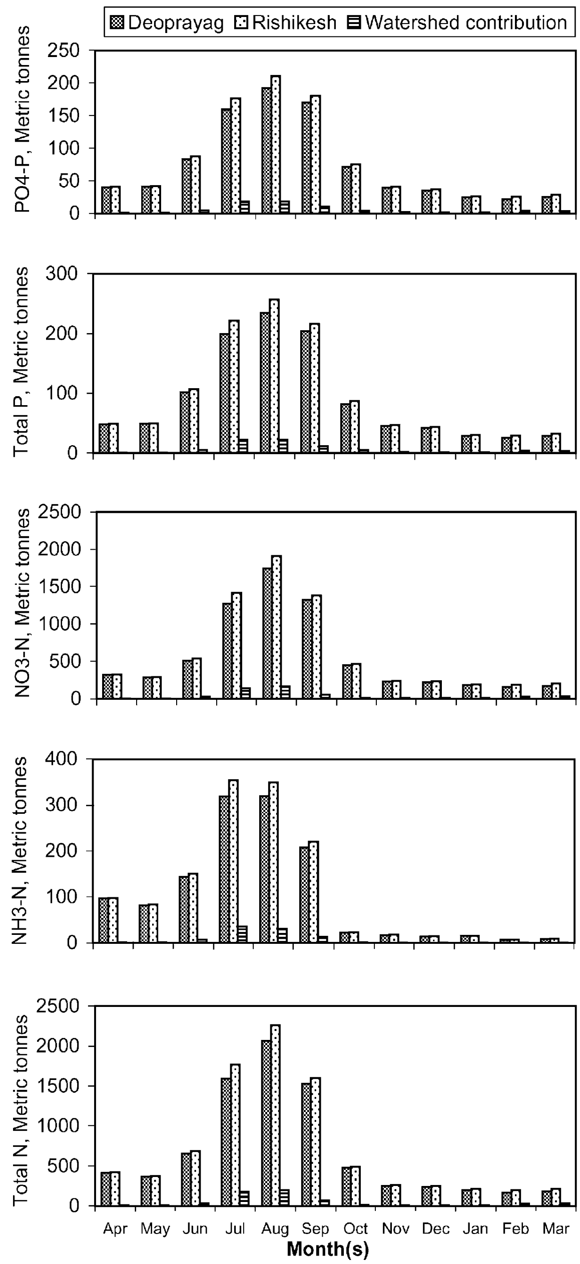

Fig. 9. Nutrient loadings from the watershed.

many parts of the world [33]. It is reported that the increase of dissolved nitrogen fluxes in rivers represents 30% of the nitrogen fixed annually by man during combustion processes and fertilizer production. For phosphorous the increase is only 15% of the total phosphorous mined annually. The increased biological activity due to the entry of N and P in rivers had led in some cases to anoxia and consequent fish mortalities.

The monthly variations in cumulative loads for dissolved solids, suspended sediment and nutrients transported from the watershed (from Deoprayag to Rishikesh) are shown in Figs. 8 and 9. It is clearly evident from the figures that maximum dissolved solids and nutrient loads are transported from the watershed during the monsoon months. An unusual negative contribution of sediment load is observed from the watershed during monsoon months (Fig. 8). This may be attributed due to deposition of substantial amount of suspended sediment within the river reach due to river diversion/topography.

5.6. *Nutrient control*

The control of nutrients is an important issue throughout the world, both from a public health perspective and to keep natural waters free from eutrophication. The most widely used water quality standard for nitrate is the 50 mg/L limit adopted by WHO as a precautionary level to safeguard babies from the risks of contracting methaemoglobinaemia [24].

The reduction of nitrogen and phosphorous from agriculture relies upon changes to farming practices because they give rise to diffuse sources. Ploughing of grassland and other crops, particularly during autumn, leads to the release of large quantities of soil nitrogen and, therefore, a general move towards permanent pasture regimes assists in lowering nitrate leaching. When this is not possible, the use of short-term rotational crops to take up nitrogen followed by their harvesting and subsequent removal from the catchment is helpful. Animal wastes should be used carefully, avoiding overuse and direct washoff into water courses, but wherever possible they should be used in place of synthetic fertilisers. Use of all types of fertilisers should be carefully controlled and matched to crop requirements.

In addition to agricultural sources, rural sanitation practices and the input of nutrients from animal dung also result in considerable quantities of nutrients entering the rivers. The practice of washing clothes in rivers, particularly in rural areas, is quite common in India and also provides an important pathway for detergent entry to river systems. One of the most important aspects of controlling phosphorous inputs from agriculture is the need to prevent erosion from field surfaces. Phosphates tend to bind to soil particles which, washed from fields into watercourses, become a source of phosphate in suspended form and in deposited sediments. Sediments act as a long-term source of phosphate by releasing it (i.e. by redissolution) under certain environmental conditions. Physical removal of the sediment layer, in order to remove the bound phosphate from the catchment, has been tried in a number of locations around the world [34]. Some success has been achieved in lowering phosphate levels in the Norfolk Boards in England by a combination of the diversion of effluents containing phosphorous out of the area, phosphorous stripping at sewage treatment works, and by the dredging of sediment. Concentrations below the target of 100 μg/L of phosphorous were reached [34]. Therefore, control of nutrients not only require management strategies at agricultural watershed label but it has to be strategic in approach keeping in view all other factors, which are likely to have an impact on the river system.

6. Conclusion

It is concluded that in a mountain environment with low agricultural activities, the stream chemistry is greatly influenced by the agricultural practices carried out on the terraced land. A large amount of sediment and nutrient load is transported from the watershed during the rainy season. Nutrients are particularly transported from cropland either by being adsorbed onto eroded soil particles or dissolved in runoff water. The assessment of nutrients is a perfect example of a spatially and temporally complex, multidisciplinary environmental problem that exists over multiple scales. In order to identify non-point source pollution and its relationship with land use activities, a geographical information system may be useful to relate data associated with land use (e.g. cropping intensity, vegetation clearance and soil erosion information). Further studies in this direction are being planned so that water quality data may be processed to estimate the effects of agricultural activities on water quality and to devise pollution control policies for the hilly watershed.

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