JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 11 2003

HYDROCHEMICAL STUDIES OF THE HINDON RIVER, INDIA: SEASONAL VARIATIONS AND QUALITY-QUANTITY RELATIONSHIPS

C.K. Jain*
D.C. Singhal**
M.K. Sharma*

* National Institute of Hydrology, Roorkee, India
** University of Roorkee, Roorkee, India

A hydrochemical study of the Hindon river system in western Uttar Pradesh (India) has been carried out with the objective to examine variation in water quality characteristics within the river system, and to establish water quality-quantity relationships to provide a proper basis for establishing water quality objectives for the basin. The river receives considerable amounts of municipal and industrial wastes which contaminate the receiving water, especially immediately downstream of the outfalls. Agricultural runoff also contributes to river pollution. The river shows annual chemical cycles for most parameters, with elevated values in summer and minimum values in the monsoon season. Nitrate concentration did not show a seasonal variation. Most constituents decreased with increasing discharge, and dissolved oxygen concentration increased. The overall low value of r^2 *between water quality constituents and discharge may be attributed to the irregular discharge of industrial effluents of different kinds, climatic and physiographic controls including temperature, seasonality, the rainfall/runoff ratio, rock type and vegetation.*

INTRODUCTION

The hydrochemistry of a river basin reflects the geochemical and hydrological characteristics of the basin that maintain the flow of the river and dissolved chemical constituents. The total dissolved salts generally increase downstream from the source region. Depending upon the degree of chemical weathering of various rocks exposed in the catchment and anthropogenic activities, the main stream displays significant temporal and spatial variations in chemistry at a particular station (Drever, 1982).

Urban settlements and growing industrial development, combined with rapidly increasing demand for water, are causing more and more water management problems. Ninety six percent of water pollution problems in India are due to indiscriminate discharge of municipal wastes (Chaudhary, 1981). These wastes are biodegradable and produce a series of directional but predictable changes in water bodies. Industrial effluents are responsible for pollution to a lesser extent but their effects may be more serious, as nature is often unable to degrade and assimilate them. Agriculture is also responsible for degrading the river water quality by generating runoff from animal husbandry units, which contain predominantly organic compounds from the use of mineral fertilizers and chemical pesticides (Jenkins et al., 1995; Collins and Jenkins, 1996). The seasonal variations in the intensity of rainfall cause both the quality and quantity of flow of rivers to vary widely. During the wet season, storm runoff conveys both suspended and dissolved matter into the rivers. In the dry season, many rivers and streams either dry up completely or have very little flow.

The knowledge of two interrelated factors, viz., the trend of water quality and the relationship of dissolved constituents to river discharge, is especially useful for planning, management and development of water resources (Dutta, 1983). Therefore, there is a strong demand for scientific investigations that can support efforts to maintain river water to standards of purity. In this paper a hydrochemical study has been carried on the Hindon river system in western Uttar Pradesh (India) with the objective to examine variation in water quality characteristics within the river system, and to establish water quality-quantity relationships to provide a proper basis for establishing water quality objectives for the basin.

STUDY AREA

The Hindon River is one of the important rivers in western Uttar Pradesh (India), having a basin area of about 7000 km^2. The catchment area is a part of the Indogangetic Plain, composed of Pleistocene and subrecent alluvium and it lies between latitude 28^o 30’ to 30^o 15’ N and longitude 77^o 20’ to 77^o 50’. The river originates in the Upper Shivaliks (Lower Himalayas) and flows through four major districts, viz., Saharanpur, Muzaffarnagar, Meerut and Ghaziabad in western Uttar Pradesh and covers a distance of about 200 km before joining the Yamuna river downstream of Delhi (Figure 1). Physiographically the area is generally flat, except for the Shivalik hills in the north and northeast. The area is devoid of relief features of any prominence, except for deep gorges cut by drains and rivers flowing through the area. The Ganga River in the east and the Yamuna River in the west bound the Hindon. The rivers generally flow from north to south, and during most of the non-monsoon season they carry water from groundwater storage.

The climate of the region is a moderate subtropical monsoon type. The average annual rainfall is about 1000 mm, the major part of which is received during the monsoon period. The major land use in the basin is agriculture and there is no effective forest cover. The soil type of the basin is alluvial, consisting of clay, silt and fine to coarse sand. The basin is densely populated because of the rapid industrialization and agricultural growth during the last few decades. The discharge from municipal and industrial areas, as well as runoff from agricultural areas, affects the quantity and quality of the

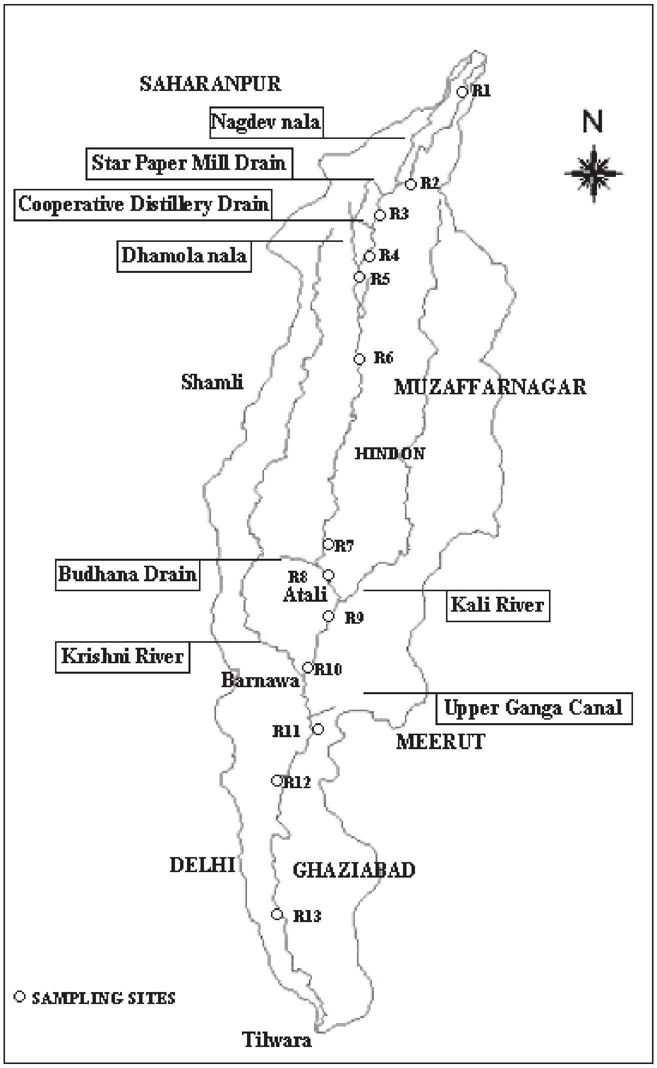

Figure 1. The Hindon river system showing location of sampling sites: R1-Khajnawar; R2-Beherki; R3-Santagarh; R4-Nanandi; R5-Sadhauli Hariya; R6-Maheshpur; R7-Budhana; R8-Chandheri; R9-Atali; R10-Barnawa; R11-Daluhera; R12-Surana; R13-Mahannagar.

river water. Due to the continuous pollution load, the river's environmental matrix has become very complex and needs systematic study.

SOURCES OF POLLUTION

The main sources of pollution in the Hindon River include the municipal waste of the Saharanpur, Muzaffarnagar and Ghaziabad districts and industrial effluents of sugar, pulp and paper, distilleries and other miscellaneous industries through tributaries as well as direct outfalls. In the summer months (April-June) the river is completely dry from its origin up to Saharanpur town. The effluents of Nagdev nala and Star Paper Mill at Saharanpur generate the flow of water in the river. The municipal wastewater generated from Saharanpur city is discharged to the river through the Dhamola nala. The industrial effluent from the Cooperative Distillery and municipal wastewater from Budhana town also join the river in this stretch.

The Kali River joins the Hindon on its left bank near the village of Atali, which is carrying municipal wastewater and effluents of industries located in Muzaffarnagar city. Another tributary, the Krishni, meets the Hindon on its right bank at Binouli village in the Meerut district and carries wastewater from a sugar mill and distillery. In the Ghaziabad district, downstream of Karhera village, the majority of river flow is diverted to the Hindon cut canal at Mohan Nagar, which outfalls into the Yamuna upstream of the Okhla barrage. Thereafter, the river receives wastewater through the Dhasana drain at Bisrakh village in Ghaziabad district. The Dhasana drain carries the wastewater of municipal as well as industrial establishments in Ghaziabad. The river flows further downstream and joins the Yamuna at Tilwara village.

A general plan of sampling locations with respect to different outfalls of municipal and industrial effluents in the Hindon River is shown in Figure 1. Thirteen stations (R1 to R13) in the river were selected in order to obtain general information on the longitudinal and seasonal variation of water quality along its course covering a total distance of 200 km.

METHODOLOGY

River water samples were collected from thirteen locations on a monthly basis using a Hydro-Bios standard water sampler for a period of two years (April 1997 to March 1999). At each station three samples were collected from 1/3, 1/2 and 2/3 width of the river along the transect and mixed together to obtain a composite sample. All the samples were collected from the upper 15 cm of the water surface and stored in polyethylene bottles fitted with screw caps. Determination of pH and conductance was performed on site using portable meters (WTW, Germany). For other parameters, samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at 4^oC for detailed chemical analysis. The physico-chemical analysis was performed following standard methods (APHA, 1985, Jain and Bhatia, 1987). The accuracy of the methods is greater than ± 10%. The discharge at all the sampling sites was also determined during each visit using a Seba current meter by the area-velocity method.

RESULTS AND DISCUSSION

The upper part of the river basin falls in the Saharanpur district, and has a large number of industries related to paper, milk products, distillery and small scale cottage industries pertaining to electroplating, paper board, chemicals, and rubber, etc. The waste effluents generated from these industries are released either directly on the lowlands or into the tributaries of the Hindon River in their vicinity. Much of these wastes contaminate the receiving water, especially in the stretches immediately downstream of their outfalls.

The main effluent discharge in the upper part of the river system is from the Star Paper Mill in Saharanpur. The chemical analysis of the waste effluent shows that the effluent is rich in organic substances as reflected by high BOD and COD values. In addition, the river has two major drains in its upper portion, viz., Nagdev nala and Dhamola nala, which join the Hindon near the village of Ghogreki and Sadhauli Hariya, respectively. The municipal wastewater generated from the Saharanpur city is discharged to Hindon river through Dhamola nala. There is no wastewater collection and treatment system in the city. In addition, the wastes from several small units such as textile factory, sugar factory, cigarette factory, cardboard factory and laundries etc. also transfer their wastes to the Hindon through the Dhamola nala. The industrial effluent from the Cooperative Distillery also joins the river in this stretch.

In the mid portion of the basin, the Kali river carries the municipal and industrial effluents of Muzaffarnagar district and joins the Hindon near the village of Atali. The Krishni River, receiving wastes from a sugar mill and distillery, joins the Hindon near the village of Barnawa. In addition, some local drains from villages and towns also join the river. There are no notable waste outfalls in the lower portion of the study area. The characteristics of the various waste effluents/tributaries discharged into the Hindon have been discussed in an earlier paper (Jain et al., 2000).

The Hindon has not been used at any place in its course of flow for organized water supply. The local fishermen use the river water for fishing, fish-seeds and fingerlings of several crops. The river is also utilized to flush the water of the Yamuna through the Hindon cut canal in Delhi. The water quality of the river has been monitored at 13 locations (Figure 1) on the basis of contribution of pollution load by point sources to assess the impact of waste effluents. The longitudinal variations of various constituents are shown in Figure 2.

The river water is clear and odorless at an upstream site (station R-1 and R-2) while that at station R-3 to R-6 the river has a foul and pungent organic odor due to the discharge of pulp and paper mill effluent. The odor becomes much more pronounced in the summer months. In addition to the floating froth and foam, the river water also becomes brown in color owing to the discharge of pulp and paper factory effluent. The water is dark brown at stations R-3 and R-4, and becomes light brown with a black tinge at stations R-5 and R-6. The brown color of the water decreases the penetration of light and affects the spectrum of the light wavelengths which penetrate into the river water. The change in the wavelength and its reduction in intensity limits the growth of phytoplankton and other aquatic plants which are of great importance, not only because they form an important link in the food chain cycle of aquatic habitats, but also because they produce oxygen by photosynthetic activity which plays an important role in re-aeration of streams and in natural self-purification processes.

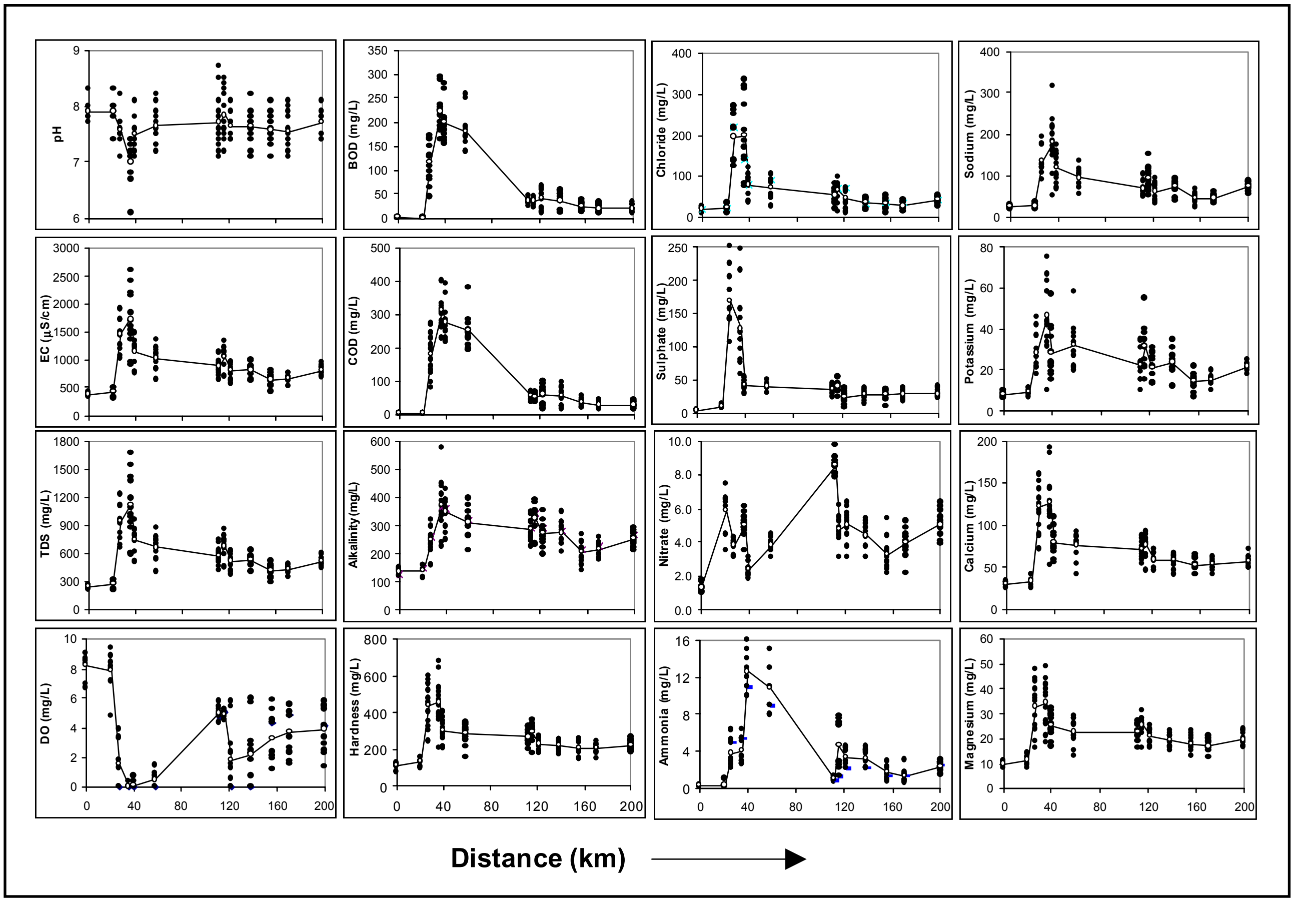

Figure 2. Longitudinal variation of various constituents.

The pH of the river water was always found towards the alkaline side except at station R-4, where the river water is acidic in nature. At station R-4, the pH value gets reduced due to the mixing of distillery effluent and then slightly increased from station R-5 to R-7 after the discharge of wastewater from Dhamola nala. The values of pH show almost the same trend in the downstream section between stations R-9 to R-13. The variation in pH at different sampling stations is well within the range of tolerance by fish.

The contents of total dissolved solids vary between 210 to 263 mg/L in the upstream section at Khajnawar village. They vary from 654 to 1233 and 599 to 1667 mg/L at station R-3 and R-4 respectively, mainly due to the mixing of effluent from the Star Paper Mill and Cooperative Distillery. The excess dissolved solids creates an imbalance due to increased turbidity and causes suffocation of fish even in the presence of high dissolved oxygen. The dissolved solids decreased considerably at station R-5, R-6 and R-7 due to the dilution effect of the Dhamola nala, which has significant flow throughout the year. A slight increase in dissolved solids was observed at station R-8 due to the discharge of wastewater from the Budhana drain, which then indicated a slight decreasing trend in the downstream section of the river.

The dissolved oxygen content in the upstream section at Khajnawar was quite satisfactory (6.7 to 9.0 mg/L), but a critical situation was observed at stations R-3 and R-4. The sudden fall in dissolved oxygen at stations R-3 and R-4 is attributed to the discharge of untreated municipal and industrial wastes from Nagdev nala, Star Paper Mill and Cooperative Distillery. However, the distribution of dissolved oxygen at all the stations is not the same. The dissolved oxygen content gets reduced to zero at station R-3 and R-4 during summer months so that a complete anaerobic condition is developed. This indicates that the river flow is mainly composed of the wastewater generated from industries. The DO values gradually improve from station R-5 to R-8 due to re-aeration and photosynthesis.

The Kali River, carrying wastewater of municipal and industrial establishments of Muzaffarnagar district, meets the Hindon at Atali village (Station R-9), thus augmenting the flow of the Hindon. A substantial amount of water is discharged in the Kali from the Upper Ganga Canal at Khatauli. The level of dissolved oxygen in the Hindon after the confluence with the Kali deteriorates further, and is observed to be nil during summer months. At Barnawa village, another tributary, the Krishni, joins the Hindon, which flows only during the sugar crushing season and remains stagnant for the rest of the year. In this stretch (Station R-9 to R-13), dissolved oxygen shows a large variation depending on the flow in the river. During summer months, dissolved even gets reduced to nil at stations R-9 and R-10. The quality of the river water in this stretch is controlled by the discharge of water from the Upper Ganga Canal through the Khatauli and Jani escapes.

The BOD values vary from 0.7 to 1.6 mg/L in the upstream section of the Hindon at the village of Khajnawar. However, a sudden rise in the BOD values was observed at stations R-3 and R-4 due to the discharge of paper mill and distillery effluents. The higher values of BOD observed at these stations indicate a high degree of organic pollution in this stretch of the river. The effluent of pulp and paper mill and distillery adds to the high concentration of organic matter in the river, which is responsible for a remarkable decrease in DO, along with increase in BOD, COD and TDS. From station R-4 to R-8, the oxygen condition improves significantly with the lowering of BOD values. Upstream of Atali village, the Hindon has little flow due to significant abstraction for irrigation by the farmers along its course. At Atali village (Station R-9), the Kali joins the Hindon and the water quality of the Hindon is controlled by the inputs from the Kali. The Kali also receives a significant amount of water from the Upper Ganga Canal through the Khatauli escape. At Atali village, the values of BOD and COD rise, while DO decreases due to the discharge of municipal wastes from Budhana drain and the Kali into the Hindon. From station R-9 to R-13, the BOD values show a slight decreasing trend due to re-aeration.

The COD values range from 1.4 to 2.8 mg/L in the upstream section at the village of Khajnawar. However, a sudden rise in COD values was observed at stations R-3 and R-4 due to the discharge of paper mill and distillery effluents. The COD values at the two stations vary from 78 to 274 and 230 to 404 mg/L respectively. The high values of COD observed at stations R-3 and R-4 indicate a certain degree of organic pollution in this stretch of the river. The effluent of the pulp and paper mill and the distillery add a high concentration of organic matter to the river, which is responsible for a remarkable decrease in DO, along with an increase in COD values. From station R-4 to R-8, the oxygen condition improves significantly due to re-aeration, resulting in the lowering of COD values. At station R-9 again, the values of COD rise while DO decreases due to the confluence of the Budhana drain and Kali into the Hindon. From station R-9 to R-13, the COD values show a slight decreasing trend due to the re-aeration and dilution effect of water from Upper Ganga Canal.

The concentration of ammonia in the upstream section at Khajnawar village is quite low (< 1 mg/L). However the content of ammonia increases significantly at Station R-5 due to the confluence of Dhamola nala, which is carrying the municipal waste of Saharanpur town, and has significant flow throughout the year. The maximum value of ammonia observed at Station R-5 was found to be 16 mg/L, which reduces to about 1 mg/L at Station R-7. Again at Station R-8, the concentration of ammonia increases up to 7.8 mg/L due to the confluence of Budhana drain, which carries municipal waste of Budhana town.

The maximum concentration of sulfate was found to be 250 mg/L at Station R-3 after the confluence of paper mill waste. The highest concentration of sulfate at Station R-3 is due the discharge of paper mill waste, which uses sodium sulfate as raw material in the manufacture of pulp and paper. The maximum concentration of phosphate was found to be 3.54 mg/L at Station R-8 after the confluence of wastewater from Budhana drain. This is due to the presence of soapy mixtures in the wastewater, which contain phosphate as one of the important constituents.

The river is sluggish except during the high flow period. It is evident that during a high flow period, there is no significant effect of pollution owing to a very high dilution of the effluent, but once the flow decreases, there is visible sign of pollution, specifically during summer months. From the above discussion it is evident that the pollution load generated from Saharanpur town and industrial establishments of this region, viz. Star Paper Mill, Cooperative Distillery, Nagdev nala etc., is mainly responsible for the water quality degradation in the upper stretch of the Hindon River. In the intermediate stretches, water quality shows a steady improvement due to re-aeration and photosynthesis. Improvement in the river water quality downstream of the confluence of Dhamola nala indicates a relatively better quality of water in Dhamola nala compared to the river water. The river water before the confluence of Dhamola nala is mainly the mixture of wastewater of Nagdev nala and effluent from pulp and paper factory and distillery waste. A further improvement in the river water quality was noticed downstream due to re-aeration. In the lower stretch, degradation of water quality is observed due to the discharge of wastewater from Budhana drain, the Kali River and the Krishni River. However, the water quality in this stretch is mainly controlled by the release of water from the Upper Ganga Canal through the Khatauli and Jani escapes.

It is recommended that the wastewater generated by the municipal areas of Saharanpur, Muzaffarnagar and Ghaziabad be treated and utilized for irrigation through an organized network.

The industrial units discharging their effluents directly into the river without any treatment should install effluent treatment plants.

Time Series Analysis

Time series analysis of flow and certain water quality constituents at selected sites is shown in Figure 3. The seasonal variations in the intensity of rainfall cause both quality and quantity of flow of the river to vary widely. During the monsoon season, agricultural runoff conveys nutrients into the river by overland flow (Morris and Fan, 1997; Rai and Sharma, 1998). The river has a maximum flow of about 65.7 $m^3 s^{-1}$ during the monsoon season and a minimum flow of 18.5 $m^3 s^{-1}$ during the summer season at the downstream site (Mohan Nagar) of the river. At the upstream site the flow in the river was almost negligible (< 0.3 $m^3 s^{-1}$) for most of the year. The increase in discharge between upstream and downstream sites is due to the municipal waste of Saharanpur and Muzaffarnagar towns, industrial effluents of sugar, pulp and paper, distilleries and other industrial units through its tributaries, as well as direct outfalls, the Kali and Krishni rivers, and release of the Upper Ganga Canal water in the river in addition to normal base flow, all of which add up to about 90 percent of the total flow in the river.

There is a strong seasonal pattern for various water quality constituents in the river water with elevated concentrations during summer and lower concentrations during monsoon periods. Almost all of the constituents follow the same time patterns except dissolved oxygen, which shows a reverse pattern. The electrical conductivity of the river water underwent pronounced seasonal fluctuations with minimum values in winter and maximum values in late summer. This is to be expected because

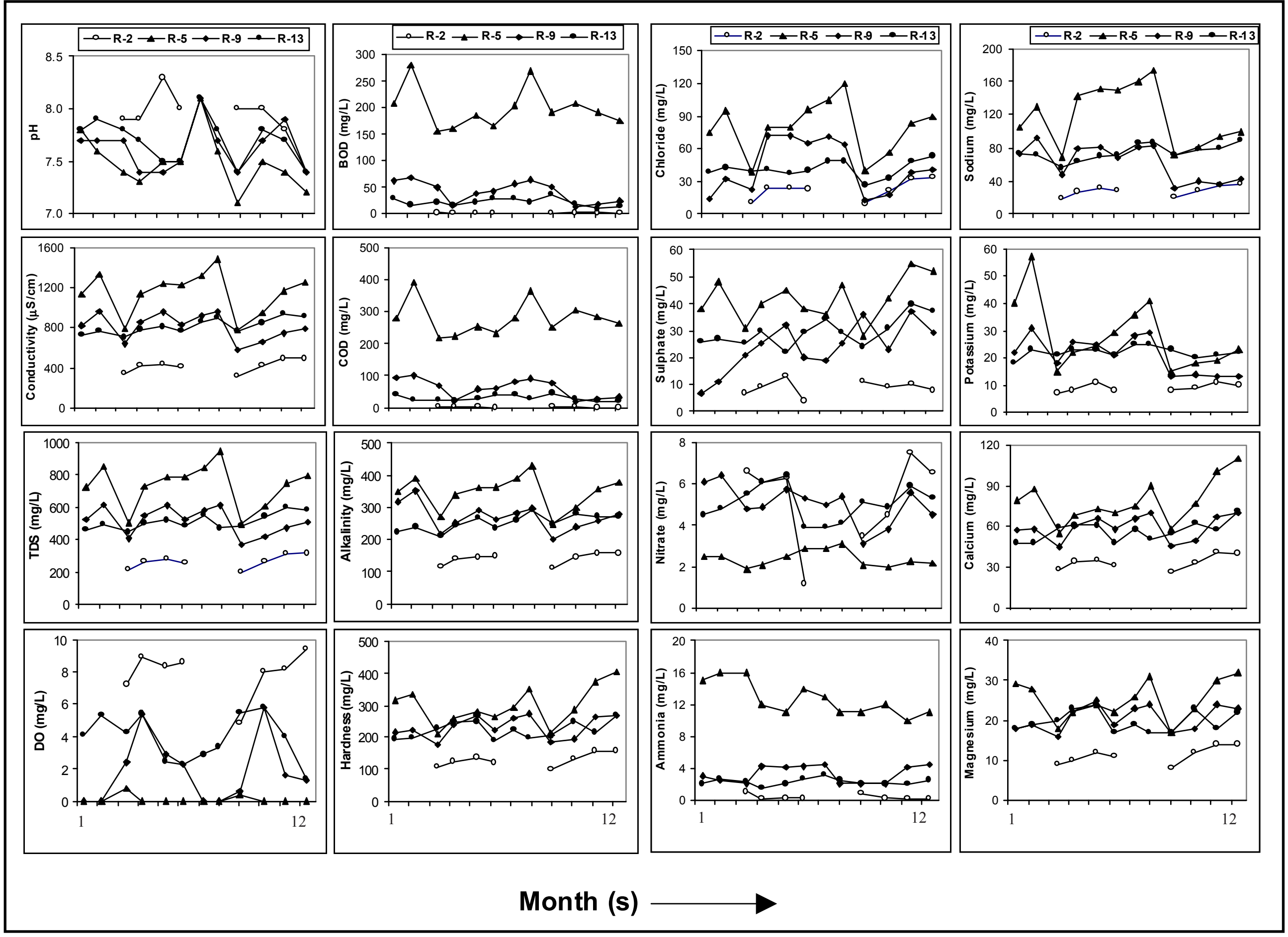

Figure 3. Time series of water quality constituents.

electrical conductivity was closely related to the sum of the concentrations of four major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) in the river water as well as that of three major anions (HCO_3^-, SO_4^{2-}, Cl^-) (Feller, 1975). Sodium, potassium, calcium, magnesium, chloride and sulfate ion concentrations showed clear seasonal variation, with maxima in summer months and minima in monsoon season at almost all the sites. This seasonal variation suggests that river water chemistry is influenced by annual cycles with biological and geological breakdown in the summer season leading to the accumulation of chemicals during dry periods, followed by dilution of those chemicals by monsoonal rainfall.

Nitrate displayed no consistent seasonal behavior, which may be attributed to biological activities caused by topographic, microclimatic and different amounts of wastes discharged to the river. Further, relatively low concentrations of nitrate observed in the river throughout the year are probably due to high levels of denitrification. Significantly, higher ammonia concentration in the monsoon months, at site R-5 in the river, reflects the leaching of nitrogenous fertilizers (e.g. ammonium sulfate) applied extensively to agricultural fields in the vicinity of the river. Similar findings were also observed by Feller and Kimmins (1979).

The dissolved oxygen content at the upstream site was quite satisfactory (> 5.0 mg/L) throughout the year, but a critical situation was observed at Sadhauli Hariya (< 1.0). The sudden drop in dissolved oxygen and abrupt rise in BOD values at this site is attributed due to the discharge of paper mill effluent from Star Paper Mill and municipal effluent from Dhamola nala. It may be stated that the maximum value of BOD for potable water is 2 mg/L and that for bathing it is 3 mg/L. The higher values of BOD and COD observed at this site indicate a high degree of organic pollution, rendering the water unsuitable even for bathing purposes throughout the year. The condition of dissolved oxygen improves in the downstream section due to dilution of river water with various tributaries and canal water. In rural and urban areas, nutrients are released in surface and groundwater and degrade the quality of water, causing various health problems to humans. Nutrients particularly are also of major concern because of eutrophication problems.

The maximum load of various constituents is contributed from the basin during the monsoon months, which seem to follow the general runoff pattern. This is mainly due to the contribution of agricultural runoff from the basin. In the rainy season, nitrogen, phosphorous and potassium are transported from the cropland to the river system, either by being adsorbed onto eroded soil particles or dissolved in runoff water.

Water Quality and Quantity Relationships

The interrelationship between river discharge and hydrochemistry provide a useful means for examining hydrological processes in a river system. Several approaches have been used to analyze the relationship between water quality constituents and river discharge. Regression equations have been developed between solute concentration and river discharge (Foster, 1978; Walling and Webb, 1983, 1986; Webb and Walling, 1992). During low flow, the origin of river water is generally believed to be solely groundwater, therefore the chemical signature should reflect the high concentration of solutes found in the deepest part of the groundwater system (Reynolds et al., 1987; Avila et al., 1992; Soulsby, 1995).

Variation in hydro-chemistry at a particular point are also correlated with changes in discharge and biological activity (Slack and Feltz, 1968; Johnson et al., 1969; Cleaves et al., 1970; Walling, 1975; Clayton and Megahan, 1986, Feller and Kimmins, 1979) but these spatial variations are controlled mainly by biogeochemical reactions which occur as water flows along various paths before discharging into a channel (Smith and Dunne, 1977). However, the nature of flow pathways in a catchment remains controversial (Pearce et al., 1986); the surface and shallow groundwater chemistry reflects the weathering reactions and alteration of silicate minerals, dissolution of carbonates and biological activity (Stallard and Edmond, 1983; Dethier, 1988).

The relationships between dissolved constituents and river discharge for the Hindon River are shown in Figure 4.

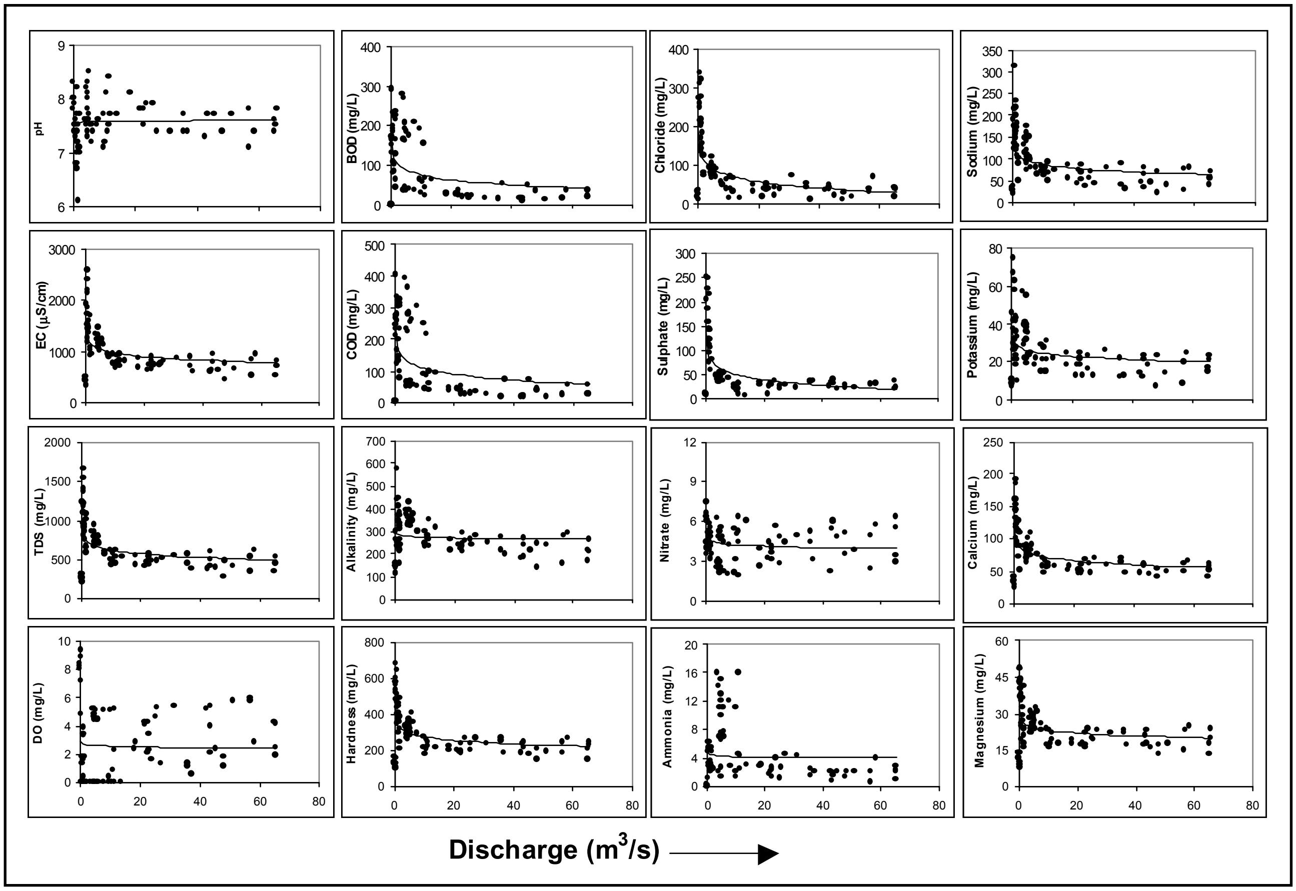

Figure 4. Water quality-quantity relationship.

In general the relationships are curvilinear and a decrease in various water quality constituents is observed with increasing discharge. The regression equations showing relationships of various water quality constituents with discharge are given in Table 1 along with a coefficient of determination. The

Table 1. Relations between Water Constituents and River Discharge

Parameter	**Regression Equation**	**r^2**
pH	no relation	-
Conductivity, µS/cm	Y = 1218.6 – 106.61 ln (X)	0.17
TDS, mg/L	Y = 779.9 – 68.224 ln (X)	0.17
Dissolved Oxygen, mg/L	no relation	-
BOD, mg/L	Y = 117.56 – 18.314 ln (X)	0.15
COD, mg/L	Y = 170.4 – 27.007 ln (X)	0.16
Alkalinity, mg/L	Y = 300.49 – 1.4636 (X)	0.12
Hardness, mg/L	Y = 340.45 – 28.174 ln (X)	0.16
Chloride, mg/L	Y = 128.08 – 23.491 ln (X)	0.28
Sulphate, mg/L	Y = 88.966 – 16.642 ln (X)	0.25
Nitrate, mg/L	Y = 4.5841 – 0.1509 ln (X)	0.04
Ammonia, mg/L	no relation	-
Sodium, mg/L	Y = 116.76 – 12.769 ln (X)	0.17
Potassium, mg/L	Y = 29.938 – 2.3367 ln (X)	0.09
Calcium, mg/L	Y = 92.225 – 8.6106 ln (X)	0.19
Magnesium, mg/L	Y = 26.84 – 1.6337 ln (X)	0.11

Level of significance = 5%

logarithmic relationship of water quality constituents with discharge has been established for many streams (Livingstone, 1963). The overall low value of r^2 between water quality constituents and discharge may be attributed to the discharge of irregular industrial effluents of different kinds, climatic and physiographic controls including temperature, seasonality, the rainfall/runoff ratio, rock type and vegetation. Within a single storm event, the conductivity value for a given discharge is higher on the rising limb of the hydrograph than on the falling limb, with minimum conductivity after the storm has peaked. This is partly due to the flushing of accumulations of leachable chemicals by the first wetting front of a storm and partly due to changes in the origin of the stream flow as the storm progresses.

CONCLUSION

The river Hindon is subjected to domestic and industrial pollution because of absence of, or poor enforcement, of water pollution control laws and regulations. The seasonal variations in the intensity of rainfall cause both the quality and quantity of flow of the rivers to vary widely. During the wet season, storm runoff conveys both suspended and dissolved matters into the rivers. It is recommended that the wastewater generated by the municipal areas of Saharanpur, Muzaffarnagar and Ghaziabad be treated and utilized for irrigation through an organized network. The industrial units discharging their effluents directly into the river without any treatment should install effluent treatment plants.

REFERENCES

APHA (American Public Health Association); (1985*)*. Standard Methods for the Examination of Water and Wastewater. 16th edn., APHA, Washington, DC, USA.

Avila, A., J. Pinol, F. Roda and C. Neal; (1992). Storm solute behaviour in a montane Mediterranean forested catchment. J. Hydrol., 140, 143-161.

Chaudhary, N.; (1981). The policy of water pollution control in India. Proc. Int. Symp. Water Resources Conservation pollution and Abatement, Univ. of Roorkee, Roorkee, pp. 27-40.

Cleaves, E. T., A. E. Godfrey and O. P. Bricker; (1970). Geochemical balance of a smaller watershed and its geomorphic implications. Geol. Soc. Am. Bull*.*, 81, 3015-3032.

Clayton, J. L. and W. F. Megahan; (1986). Erosional and chemical denudation rates in the southwestern Idaho Batholith. Earth Surface Processes Landforms, 11, 389-400.

Collins, M.A. and A. Jenkins; (1996). The impact of agricultural land use on stream chemistry in the middle hills of the Himalayas, Nepal. J. Hydrol*.,* 185, 71-86.

Dethier, D. P.; (1988). A hydrochemical model for stream chemistry, Cascade Range, Washington, USA. Earth Surface Processes Landforms, 13, 321-333.

Drever, J. J.; (1982). The Geochemistry of Natural Waters. Prentice-Hall, Englewood Cliffs, NJ, 388.

Dutta, P. S.; (1983). Trend analysis of water quality in the Sabarmati river at Ahmedabad for a decade (1969-1978). In: Dissolved Loads of Rivers and Surface Water Quantity/quality Relationships, IAHS Publ. No. 141, 71-77.

Feller, M. C.; (1975). Initial effects of clearcutting on the flow of chemicals through a forested watershed ecosystem. Ph. D. dissertation, Univ. of British Columbia, Vancouver, p.352.

Foster, I. D. L.; (1978). Seasonal solute behaviour of stream flow in a small agricultural catchment. Catena, 5, 151-163.

Jain, C. K. and K. K. S. Bhatia; (1987). Physico-chemical Analysis of Water and Wastewater. User's Manual, UM-26, National Institute of Hydrology, Roorkee, India.

Jenkins, A., W. T. Sloan and B. J. Cosby; (1995). Stream chemistry in the middle hills and high mountains of the Himalayas, Nepal. J. Hydrol., 166, 61-79.

Johnson, N. M., G. E. Likens, F. H. Bormann, D. W. Fisher and R. S. Pierce; (1969). A working model for the variation in stream water chemistry at Hubbard Brook Experimental Forest, New Hampshire. Wat. Resour. Res., 5, 1353-1363.

Livingstone, D. A.; (1963). Chemical composition of rivers and lakes. U. S. Geol. Surv., Prof. Pap.440-G:1-64.

Morris, G. L. and J. Fan; (1997). Sediment yield from watersheds. In: Reservoir Sedimentation Handbook, 7.1-7.44, McGraw-Hill, New York, USA.

O'Connor, D. J.; (1976). The concentration of dissolved solids and river flow. Wat. Resour. Res., 12, 279-294.

Pearce, A. J., M. K. Stewart and M. G. Sklash; (1986). Storm runoff generation in humid headwater catchments, 1. Where does the water come from? Wat. Resour. Res., 22, 1263-1272.

Rai, S. C. and E. Sharma; (1998). Hydrology and nutrient flux in an agrarian watershed of the Sikkim Himalaya. J. Soil Wat. Conserv., 53(2), 125-132.

Reynolds, B., M. Hornung and P. A. Stevens; (1987). Solute budgets and denudation rate estimates for a mid-Wales catchment. Catena,. 14, 13-23.

Slack, K. V. and H. R. Feltz; (1968). Tree leaf control on low water quality in a small Virginia stream. Environ. Sci. Technol., 2, 126-131.

Smith, T. R. and T. Dunne; (1977). Watershed Geochemistry: the control of aqueous solutions by soil materials in a small watershed. Earth Surface Processes Landforms, 2, 421-425.

Stallard, R. F. and J. N. Edmond; (1983). Geochemistry of the Amazon- II. The influence of geology and weathering environment on the dissolved load. J. Geophys. Res., 88(C14), 9671-9688.

Soulsby, C.; (1995). Contrasts in storm event hydrochemistry in an acidic afforested catchment in upland Wales. J. Hydrol., 170, 159-179.

Walling, D. E.; (1975). Solute variation in small catchment streams: some comments. Trans. Br. Inst. Geogr., 64, 141-147.

Walling, D. E. and B. W. Webb; (1983). The dissolved loads of rivers: A global review. In: Dissolved Loads of Rivers and Surface Water Quantity/quality Relationships, IAHS Publ. No. 141, 3-20.

Walling, D. E. and B. W. Webb; (1986). Solutes in river systems. In: Solute Processes (Ed. Trudgill, S. T.), John Wiley and Sons, Chichester, 251-327.

Webb, B. W. and D. E. Walling; (1992). Water Quality II. Chemical characteristics. In: The Rivers Handbook (Eds. Calow, P. and Petts, G. E.), Blackwell Scientific Publications, London, 73-100.

ADDRESS FOR CORRESPONDENCE
Dr. C. K. Jain
National Institute of Hydrology
Environmental Hydrology Division
Roorkee – 247 667, India

Email: ckj@nih.ernet.in