Report No.

ASSESSMENT OF WATER QUALITY IN HINDON RIVER BASIN

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PREFACE

Water quality problems are caused by pollution and over-exploitation. The rapid pace of urbanization, industrialisation and greater emphasis on agricultural growth combined with financial and technological constraints and non-enforcement of laws have led to generation of large quantities of waste and pollution. Water quality is affected by both point and non-point sources of pollution viz; sewage discharge, discharge from industries, run-off from agricultural fields and urban run-off. Lack of proper underground sewerage system in most of the area of the country further aggravates the problem of water quality. Water quality can also arise from lack of awareness and education among users specially rural population. The need for user involvement in maintaining water quality and looking at other aspects like hygiene, environment sanitation, storage and disposal are critical elements to maintain the quality of water resources.

River Hindon, an important tributary of river Yamuna flowing through the districts of Western Uttar Pradesh, is subjected to varying degree of pollution caused by numerous untreated and/or partially treated waste inputs of municipal and industrial effluents. The toxic pollutants from these wastes will ultimately reach the ground water and enter in the food chain posing a threat to human health because of their carcinogenic nature. The pollution matrix in some stretches of the river becomes so complicated that anaerobic and septic condition prevails during the lean period due to joining of effluents to the river from different kind of industries operating in the region.

Keeping in view of the above fact, a study on water quality assessment of surface and ground water resources in Hindon river basin was conceived in the work program 2011-12 of division for a period of three years. The aim of the study was to monitor and assess of water quality of Hindon river and point sources contributing to it, to study DO deficit with estimation of re-aeration and de-oxygenation coefficients in different reaches of the river, to examine the suitability of ground water in the vicinity of the river for various designated uses and to explore possible remedial measures for improvement of river water quality. The report titled "Assessment of Water Quality in Hindon River Basin" has been prepared by Dr. M. K. Sharma, Scientist 'C' and Sri Omkar Singh, Scientist 'E' under the guidance of Dr. C. K. Jain, Scientist 'F' & Head, Environmental Hydrology Division of the institute during the year 2013-2014.

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ABSTRACT

An extensive field survey in Hindon river basin was carried out and three wastewater samples from Nagdev Nala, Star Mill Drain and Dhamola Nala, water samples from river Kali and Krishni, eleven water samples from different stretches of river Hindon and sixty eight groundwater samples from hand pumps of different locations in the Hindon river basin were collected in pre- and post-monsoon seasons during 2012 and analysed for physico-chemical and bacteriological parameters, metal concentrations and organochlorine pesticides. Maximum value of BOD (261 mg/L) was observed in Star Paper Mill Drain. The higher values of BOD and COD observed in the drains and river Hindon indicate high degree of organic pollution rendering the water unsuitable even for bathing purpose. At almost all sites of the upstream and mid-section of the river Hindon, DO was observed to be nil because of high organic load in the river water. The values of re-aeration coefficients and de-oxygenation coefficients for different stretches of river Hindon were computed and the results of estimated BOD at different sampling sites are well in agreement with observed values. The DO Sag analysis (using Streeter & Phelps, 1925 and differential equations of DO Sag) can be successfully used to predict the DO level at different location of the river.

Ground water quality data has been processed as per BIS and WHO standards to examine the suitability of water for drinking purpose. Degraded water quality zones have been identified based on water quality parameters not conforming the drinking water standards. Water quality standards have been violated for TDS, hardness, alkalinity, Ca and Mg at few locations. Nitrate concentration in few of the ground water samples exceeded the maximum permissible limit of 45 mg/L, which may be attributed to contamination by domestic waste disposal. Bacteriological contamination was observed in few ground water samples in the vicinity of river Hindon, which may be attributed to unorganized sewerage system in the study area. The concentrations of Fe, Mn, Ni, Cr, Pb and Cd in few ground water samples exceeded the permissible limit prescribed for drinking purpose, which may be attributed to the leaching of effluent containing wastes from different industries operating in the basin. The concentration of α-BHC, γ-BHC and Methoxychlor were detected in few ground water samples of the study area, which may be attributed to extensive use of these pesticides in agricultural practice in the study area, which might have leached to ground water system. Almost all collected groundwater samples from Hindon river basin falls in rock dominance zone suggesting evolution of water chemistry influenced by water-rock interaction. The scatter plot of (Ca+Mg) vs TZ^+ and high (Ca+Mg)/(Na+K) ratio indicate that carbonate weathering is a major source of dissolved ions in the groundwater of the study area. Assessment of suitability of the groundwater of the study area for irrigation purpose on the basis of total soluble salts, SAR, RSC and heavy metals revealed that these waters are of medium to good quality for irrigation purpose. The chemical data of ground water samples of the study area has been processed using per Piper trilinear diagram, Chadha's diagrams and Durov's diagram for classification and majority of the ground water samples of the study area belong to Ca-Mg-HCO_3 hydrochemical facies in both pre- and post-monsoon seasons. Water type C3-S1 as per U. S. Salinity Laboratory Classification and fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline water as per alkalinity classification as per Gupta's classification were observed. The water quality of river Hindon at all sites in both season was found to be bad and most of the ground waters were found in the good to excellent category type on the basis of Water Quality Index. Possible remedial measures have also been discussed and recommendations for preventing the deterioration of ground water quality have been suggested.

1.0 INTRODUCTION

The Hindon River, historically known as the Harnandi River, has been a major source of water to the highly populated and predominantly rural population of Western Uttar Pradesh. The river was once considered to be so clean that its water was believed to cure the Kaali Khansi (bad cough). However, now the water quality of the river Hindon has been drastically deteriorated due to discharge of industrial/domestic sewage and application of chemicals/pesticides in agriculture during past years. This heavy loading of industrial effluent discharge directly into the Hindon River places an intolerable burden on the river's natural ability to assimilate pollutants (Janhit Foundation, 2007).

The main sources of pollution in River Hindon include municipal and industrial (sugar, pulp and paper, distilleries etc.) wastes from Saharanpur, Muzaffarnagar and Ghaziabad urban areas. The water quality of the River Hindon gets further deteriorated due to confluence of River Kali and River Krishni. The river is highly influenced due to heavy metals, pesticides, which enter the river system, by direct discharges of municipal and industrial effluents and surface runoff. These toxic pollutants will ultimately reach the ground water and will enter in the food chain posing a threat to human health because of their carcinogenic nature. A number of studies regarding pollution aspects of river Hindon and its tributaries have been carried out by different workers (Verma and Mathur, 1971; Verma and Dalela, 1975; Verma et al., 1980; Patel et al., 1985; Singhal et al., 1987; Joshi et al., 1987; Seth, 1991; Seth and Singhal, 1994; Khare, 1994; Kumar, 1994; Lokesh, 1996; Jain, 1996, 2000; Kumar, 1997; Jain and Ali, 2000; Jain and Ram, 1997a, 1997b; Jain and Sharma, 2001a, 2002, 2006; Jain et al., 1997, 1998a, 1998b, 2002, 2003, 2004a, 2004b, 2005, 2007; Sharma, 2001; Sharma et al., 2009a, 2009b).

The amount of dissolved oxygen (DO) in water is one of the most commonly used indicators of a river's health. As DO drops below 4 mg/L, the forms of life that can survive, begin to reduce. In the extreme case, when anaerobic conditions exist, most higher forms of life are killed or driven off. Noxious conditions, including floating sludges, bubbling, odorous gases, and slimy fungal growths, then prevail. Therefore, the water quality modeling is necessary to estimate downstream DO deficit in different stretches using Streeter-Phelps oxygen sag equation if DO deficit is greater as wells as river water attaining minimum DO level below limit (4.0 mg/l) for survival of aquatic life. Accordingly, it will be necessary to determine the possible reduction in wastewater BOD load through trial and error process to achieve a more desirable level. A little attempt has been made to estimate DO deficit in river Hindon (Seth, 1991; Patel et al., 1985; Sharma et al., 2009(b)). Therefore, it is essential to estimate DO deficit in different reaches of the river Hindon.

Ground water plays an important role in our life support system as it is being used for different designated uses specially for drinking purpose. But due to unplanned urban development and growth in industrial and agricultural sectors, groundwater quality has deteriorated. Diffusion of urban sources like runoff from city streets, gardening and commercial activities in urban environment and effluents from industrial sites also aggravate the problem of ground water pollution.

Jain and Sharma (2001b) assessed the groundwater quality of adjoining areas of river Yamuna in Delhi to see the suitability of groundwater for irrigation and domestic application and reported higher concentration of TDS, electrical conductivity, nitrate, sulphate and sodium violating the water quality standards. The presence of bacterial contamination in groundwater was observed. More than 50% samples fall under water type C3-S1 (high salinity and low SAR) such water can not be used on soils with restricted drainage as per U S Salinity Laboratory Classification of irrigation water. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

Singh et al. (2005) discussed the groundwater regime, the sources of pollution, the groundwater quality and suitable site-specific control measures for the cities of Lucknow, Kanpur, Ghaziabad and Faridabad and reported that high concentration of iron, chromium, mercury and arsenic at few locations, presence of high counts of total and faecal coliforms indicating poor sanitary conditions were observed in the groundwater of the study area.

Kumar et al. (2009) attempted a comparative assessment of groundwater quality in NCT Delhi through consumer perception survey and standard quality guidelines and reported that the classifications based on different water quality criteria show that present status of groundwater in Delhi is unsuitable, not only for drinking but also for irrigation. Statistical analysis based on logistic regression indicates that water source type, educational background, socioeconomic status and the geographic location of consumer in the NCT have a significant impact on the consumer perception. There is a clear correlation between the quality parameters studied and perceived quality in terms of satisfactory taste responses which obtained at electrical conductivity (EC) values higher than the maximum threshold acceptable limit.

Singh and Dev (2010) evaluated chemical quality of ground water of Saharanpur and adjoining area, Uttar Pradesh for human consumption by collecting ground water samples from the shallow dug and bore wells existing in the vicinity of Saharanpur and reported that ground water is of Ca-Mg-CO3-HCO3 type and favourable for human domestic applications, except the concentration of Ca, Mg and SO4 at some localities requires proper treatment of purification before water supply.

Dhakyanaika and Kumara (2010) studied the effect of pollution of River Krishni on the quality of ground water abstracted through shallow and deep hand pumps placed in the village Chandenamal situated in the close vicinity of River Krishni and inferred that hand pumps abstracting water from shallow and deep unconfined aquifers have been found to deliver polluted water in terms of colour, organics and coliform bacteria.

Hydrogeochemical studies relevant to the water quality explain the relationship of water chemistry to aquifer lithology. Such relationship would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry.

Kumar et al. (2006) also studied the hydrogeochemical processes in NCT Delhi to identify the geochemical processes and their relation with groundwater quality as well as to get an insight into the hydrochemical evaluation of groundwater and reported that salinity and nitrate are two major problem from drinking point of view. The prevailing hydrochemical processes operating in the study area are simple dissolution, mixing, weathering of carbonate minerals (kankar) and of silicate, ion exchange, and surface water interaction. Limited reverse ion exchange has been noticed in a few parts of the study area especially in post-monsoon periods. Periodic seasonal switch-over has been clearly noticed in these hydrogeochemical processes that control groundwater quality of the area.

Reddy and Kumar (2010) carried out hydrogeochemical studies in Penna-Chitravahi river basins in Southern India to identify and delineate the geochemical processes responsible for the evolution of chemical composition of ground water and reported that the groundwater in general is of Na^+-Cl^-, Na^+-HCO_3^-, Ca^{2+}-Mg^{2+}-HCO_3^- and Ca^{2+}-Mg^{2+}-Cl- type . Na^+ among cations and Cl^- and/or HCO_3^- among anions dominate the water; Na^+ and Ca^{2+} are in the transitional state with Na^+ replacing Ca^{2+} and HCO_3^- Cl^- due to physicochemical changes in the aquifer and water rock interactions. Further, Gibbs plots indicate that the evolution of water chemistry is influenced by water-rock interaction followed by evapotranspiration process.

Vijaykumar et al. (2010) studied hydrogeochemistry in the part of Ariyalur region, Perambalur district, Tamil Nadu, India and reported that Ca+Mg, SO_4+Cl and HCO_3+CO_3 are high facies during pre- and post-monsoon season and evaporation process dominates the groundwater chemistry as explained by Gibbs plot. The quality of water for irrigation was estimated by USSL classification indicating high salinity and low sodium hazard, satisfactory for plants having moderate salt tolerance on soils.

Obiefuna and Orazulike (2011) characterized groundwater in semiarid Yola area of northeastern Nigeria employing chemical indicators and reported that alkaline earths (Ca+Mg) significantly exceed the alkali (Na+K) and week acids (HCO_3+CO_3) exceed the strong acids (Cl+SO_4), suggesting dominance of carbonate weathering followed by silicate weathering. Chemical fertilizers and anthropogenic activities are contributing to sulphate, nitrate and chloride concentrations in surface and ground water of the study area.

Srinivasamoorthy et al. (2012) made an attempt to identify the major geochemical process activated for controlling the ground water chemistry of Sarabanga minor basin of river Cauvery, situated in Salem district, Tamil Nadu, India and inferred that water chemistry is guided by complex weathering process, ion exchange along with influence of Cl ions from anthropogenic impact.

Water quality index (WQI) is a means to summarize large amounts of water quality data into simple terms for reporting to management and the public in a consistent manner. It tells us whether the overall quality of water bodies poses a potential threat to various uses of water. Different workers have used WQI to assess the surface water quality and ground water quality (Singh, 1992; Subba Rao, 1997; Naik and Purohit, 2001; Mishra and Patel, 2001; Avvannavar and Shrihari, 2008; Kumar and Dua, 2009; Kumar et al., 2009, Singkran et al., 2010).

In view of above, assessment of the present status of surface water quality and ground water quality in the Hindon River Basin is carried out with the following objectives:

i) Monitoring and assessment of water quality of Hindon river
ii) Characterize different point sources contributing river Hindon
iii) To estimate re-aeration and de-oxygenation coefficients in different reaches of Hindon River
iv) To estimate downstream DO deficit in different stretches of river using Streeter-Phelps oxygen sag equation
v) To examine the suitability of ground water in the vicinity of river Hindon for various designated uses
vi) To explore possible remedial measures for improvement of river water quality

2.0 STUDY AREA

The river Hindon is among one of the important rivers in western Uttar Pradesh (India) having a basin area of about 7000 km^2 [Fig. 1(a)]. The study area is a part of Indo-gangetic Plains, composed of Pleistocene and subrecent alluvium. The catchment area of the river lies between latitude 28^o 30' to 30^o 15' N and longitude 77^o 20' to 77^o 50' E. The river originates from Upper Shivaliks (Lower Himalayas). The basin area falls in the districts of Saharanpur, Muzaffarnagar, Shamli, Meerut, Baghpat, Ghaziabad and Gautambudh Nagar in western Uttar Pradesh and covers a distance of about 200 km before joining the river Yamuna downstream of Delhi.

2.1 Physiography and Drainage

Physiographically, the area is generally flat except Shivalik hills in the north and north east. The area is devoid of relief features of any prominence except deep gorges cut by nalas and rivers flowing through the area. The river Hindon and its tributaries generally flow from north to south. These rivers carry base flow from ground water storage during the non-monsoon season. The important tributaries include river Krishni and river Kali. Apart from these rivers, the Upper Ganga Canal also drains the area.

2.2 Geology and Hydrogeology

The Hindon river basin can be divided into three parts based on the geological and hydrogeological formations as under [Fig. 1(b)]:

i) Upper part of Hindon river Basin

Most of the upper part of Hindon river Basin falls in the district Saharanpur of Uttar Pradesh. The soil of the upper portion of the Hindon river basin is of alluvial type. Lithologically it consists mainly of clay, silt and fine to coarse sand. The area is a part of the Gangetic plain, which has been divided into three belts viz; Bhabhar belt, Terai belt and alluvial plain. Bhabhar formation is chiefly made up alluvial fan deposits consisting of sand and gravel beds with cobbles and boulders. The zone is characterised by steep ground slope and deep water table lying between 5 to 37 m depth below the ground surface. The southern limit of the Bhabhar generally forms a spring line which also defines the northern limit of the Terai tract. The Terai tract lies immediately south of the Bhabhar zone. It is a transition zone between the Bhabhar and the Alluvial plain. It is composed of alternate layers of clay and sand often having marshy conditions covered with grass and thick forest. In the Terai, ground slope varies from mild to steep and water table is at very shallow depth. The width of the belt varies from 5.5 to 8 km. Baring a northern peripheral zone, the upper portion of the basin lies in the alluvial plain, which is almost a level with gentle slope from NW to SE. Lithologically, the Gangetic plain has thick alluvial deposits consisting of unconsolidated deposits of sands, clay and kankar.

The groundwater in the study area occurs under both the un-confined and confined conditions. Groundwater conditions in the alluvial terrains are considerably influenced by varying lithology of subsurface formations. The rainfall is main recharge source of groundwater body besides infiltration from river, canals and return flow from irrigation. The existence of a three-tier aquifer system in the upper part of the basin was observed. The first aquifer (sand thickness is about 88 m with 64% of sand) system lies down to 147 m bgl. The second aquifer (granular material is found upto 64 m thickness with 54% sand) starts from 167 to about 267 m bgl and third aquifer (sand range upto 63%) is at depth below 290 m bgl.

ii) Mid part of Hindon river Basin

The mid part of Hindon river Basin falls in the districts Muzaffar Nagar, Meerut and Baghpat of Uttar Pradesh. The mid part of the basin is a flat terrain falling in middle Ganga plain. Rivers Kali and Krishni also joins river Hindon at Atali and Barnawa respectively in this part of the basin. The entire area underlains by the quaternary alluvium deposited by Ganga and Yamuna river system. Lithologically, the alluvial sediments comprise of sand, silt, clay and kankars in varying proportions.

The top sandy clay bed 3-75 m in thickness covers the entire area. After top clayey layer, first aquifer starts and with varying thickness at different places continues down to 185 m bgl. The second aquifer occurring at varying depths between 115 and 235 m bgl is separated by 10-15 m thick clay layer from the first upper aquifer. The third aquifer is separated by second aquifer by thick clay layer ranges in thickness between the depths 255 to 329 m bgl.

iii) Lower part of Hindon river Basin

The down part of Hindon river Basin falls in the districts Ghaziabad and Gautam budh Nagar of Uttar Pradesh. The area is a part of Ganga-Yamuna doab, eastern boundary is marked by Ganga river and the river Yamuna defines the western western boundary. The older alluvium occupies the entire upland and interfluves area occurring between major drainage ways. The area is underlain by quaternary sediments. The thickness increase from west to east and also towards north east.

Three-tier aquifer system in the down part of the basin has been identified down to a depth of 450 m bgl. The first aquifer extends down to 125 m bgl. The second aquifer occurs varying depths between 170 and 350 m bgl. The third aquifer occurs below 350 m and continues down to depth explored of 450 m.

2.3 Landuse

The major landuse in the basin is agriculture and there is no effective forest cover. The basin is densely populated because of the rapid industrialization and agricultural growth during last few decades. Several industries related to paper, sugar, distillery and many small scale cottage industries related to electroplating, paper board, food processing, milk products, chemicals and rubber etc., located in the western part of U.P., release their waste effluents into the river through various open drains. Due to the continuous pollution load, the river's environmental matrix has become very complex.

2.4 Climate

The climate of the region is moderate subtropical monsoon type. 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 is about 1000 mm, major part of which is received during the monsoon period (June to September). The daily maximum rainfall was observed to be 122 mm in the basin. Significant diurnal variations in hydrometeorological parameters like precipitation, temperature and relative humidity also exist. The daily maximum temperature varies from 10 to 43^{O}C and minimum temperature varies from 4.6 to 29.2^{O}C.

2.5 Sources of Pollution

The main sources of pollution in river Hindon include municipal wastes from Saharanpur, Muzaffarnagar, Ghaziabad and Gautambudh Nagar urban areas and industrial effluents of sugar, pulp and paper, distilleries and other miscellaneous industries through tributaries as well as direct outfalls. In summer months the river is completely dry from its origin upto 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 the Saharanpur city is discharged to the Hindon river through Dhamola nala. The municipal wastewater from Budhana town also join the river in this stretch.

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

2.6 Sampling Stations

A general plan of the surface water and ground water sampling locations within Hindon river basin is shown in Fig. 1(a) & (b).

2.6.1 Surface Water Sampling Stations

The location of main sources of pollution has also been indicated in Fig. 1(a). In all, 5 stations in the waste effluents and tributaries (D-1 to D-3, K-1 and KR-1) joining the river Hindon and 11 stations in the river Hindon (R-1 to R-11) were selected for monitoring various water quality constituents. Each sampling station can be characterized as follows:

Station D-1 (Nagdev Nala), is located in the Nagdev nala at village Beherki, through which industrial effluents of some of the industries located in Saharanpur is discharged into the Hindon river.
Station D-2 (Star Paper Mill), is located in the Star Paper Mill effluent drain at village Paragpur.
Station D-3 (Dhamola Nala), is located in the Dhamola nala at village Nanandi, through which municipal waste of Saharanpur city is discharged into the Hindon river.

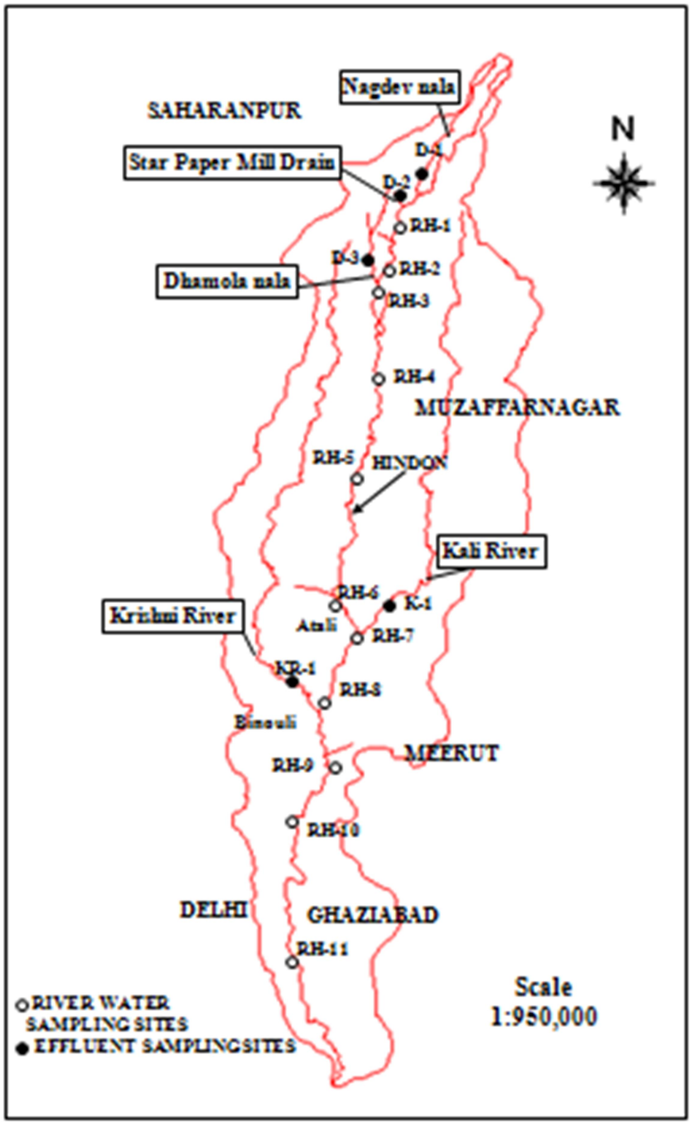


Fig. 1(a) Map showing locations of surface water sampling sites in Hindon river basin

Station K-1 (Kali River), is located in the Kali river at village Ratanpuri downstream of the bridge over the Budhana-Khatouli road, through which municipal and industrial waste effluents of Muzaffarnagar city is discharged into the river Hindon.

Station KR-1 (Krishni River), is located in the Krishni river downstream of the bridge at village Barnawa, through which industrial effluent of sugar mill and distillery is discharged into the river Hindon.

Station RH-1 (Kapasa), is located downstream of Star Paper Mill at village Kapasa. The water is brown with oozing substratum. The pulp fibres are found lying in the bed and on the bank of the river.

Station RH-2 (Nanandi), is located near village Nanandi before the confluence of Dhamola nala. The river banks are steep with black muddy and oozing substratum which is full of pulp fibers.

Station RH-3 (Sadhauli Hariya), is located near cremation ghat at village Sadhauli Hariya. The substratum is oozing and muddy. The colour of the water is brown black. The banks on both the sides have plain surface.

Station RH-4 (Maheshpur), is located near the village of Maheshpur downstream of the bridge on Deoband road.

Station RH-5 (Charthawal), is located near the village of Charthawal. The banks are high with sandy soil.

Station RH-6 (Chandheri), is located downstream of Budhana drain at village Chandheri. The banks are high with sandy soil.

Station RH-7 (Atali), is located near the village of Atali, just after the confluence of river Kali. The river is wide with high banks. The water is light brown in colour. The soil is sandy mixed with clay. A large quantity of water from Upper Ganga Canal is released into the river Kali through Khatauli escape.

Station RH-8 (Barnawa), is located near the village of Barnawa downstream of bridge before the confluence of Krishni river. The water is light brown in colour. The soil is sandy mixed with clay.

Station RH-9 (Daluhera), is located near the village of Daluhera after the confluence of Krishni river and Jani Escape of Upper Ganga Canal. The water is mostly clear with sandy and stony bed. This station assumes significance from the point of view of significant changes in water quality. Just upstream of this location, large quantity of water from Upper Ganga Canal is released into the river through Jani escape to supplement the discharge in Yamuna river.

Station RH-10 (Surana), is located near the village of Surana. The water is mostly clear with deep pools.

Station RH-11 (Mohannagar), is located just before Hindon cut canal, upstream of Hindon bridge at Mohannagar. Lot of human activities (washing and dying of clothes, direct disposal of human ash alongwith offerings) can be seen at this point. The river is quite wide at this place. The station is important since the water regulatory works (barrage and canal diversion point) are situated just downstream of this point. Because of barrage across the river, the water is stagnant at this point for extended periods.

2.6.2 Ground Water Sampling Stations

Sixty eight groundwater samples from different depths and different locations in the basin (handpumps) were collected [Fig. 1(b)]. The details of the ground water sampling locations are given in Table 1.

Table 1. Description of ground water sampling locations in Hindon River Basin					
S.No.	**Location**	**Source**	**Depth (m)**	**Water Use**	**Land Use/Specific Activity**
1	Fatehpur	HP	40	Domestic	Residential
2	Gagalheri	HP	40	Domestic	Residential
3	Kailashpur	HP	40	Domestic	Residential
4	Naugazapeer	HP	50	Domestic	Residential
5	Mahipura	HP	40	Domestic	Residential
6	Beherki	HP	33	Domestic	Residential
7	Ghogerki	HP	36	Domestic	Residential
8	Paragpur	HP	17	Domestic	Residential
9	Paragpur	HP	33	Domestic	Residential
10	Hasanpura	HP	36	Domestic	Residential
11	Hasanpura	HP	32	Domestic	Residential
12	Kapasa	HP	36	Domestic	Residential
13	Kapasa	HP	13	Domestic	Residential
14	Tapri	HP	36	Domestic	Residential
15	Tapri	HP	25	Domestic	Residential
16	Shekhpura Kadim	HP	36	Domestic	Residential
17	Lakhnaur	HP	36	Domestic	Residential
18	Mubarikpur	HP	36	Domestic	Residential
19	Mubarikpur	HP	15	Domestic	Residential
20	Nanandi	HP	36	Domestic	Residential
21	Sadauli Hariya	HP	36	Domestic	Residential
22	Sadauli Hariya	HP	13	Domestic	Residential
23	Bargaon	HP	36	Domestic	Residential
24	Maheshpur	HP	36	Domestic	Residential
25	Deoband	HP	15	Domestic	Residential
26	Deoband	HP	36	Domestic	Residential
27	Charthawal	HP	36	Domestic	Residential
28	Charthawal	HP	20	Domestic	Residential
29	Biralsi	HP	36	Domestic	Residential
30	Thanabhawan	HP	36	Domestic	Residential
31	Thanabhawan	HP	27	Domestic	Residential
32	Muzaffar Nagar city	HP	15	Domestic	Residential
33	Muzaffar Nagar city	HP	36	Domestic	Residential
34	Tawli	HP	20	Domestic	Residential
35	Tawli	HP	40	Domestic	Residential
36	Shahpur	HP	40	Domestic	Residential

37	Shahpur	HP	40	Domestic	Residential
38	Budhana	HP	40	Domestic	Residential
39	Budhana	HP	36	Domestic	Residential
40	Jogiyakhera	HP	83	Domestic	Residential
41	Atali	HP	12	Domestic	Residential
42	Atali	HP	46	Domestic	Residential
43	Nirpura	HP	46	Domestic	Residential
44	Bamnauli	HP	66	Domestic	Residential
45	Barnawa	HP	66	Domestic	Residential
46	Sardhana	HP	15	Domestic	Residential
47	Sardhana	HP	27	Domestic	Residential
48	Kankarkhera	HP	40	Domestic	Residential
49	Surana	HP	10	Domestic	Residential
50	Surana	HP	40	Domestic	Residential
51	Muradnagar	HP	40	Domestic	Residential
52	Daluhera	HP	40	Domestic	Residential
53	Daluhera	HP	10	Domestic	Residential
54	Muradnagar	HP	23	Domestic	Residential
55	Basantpur Sainthali	HP	40	Domestic	Residential
56	Harbansnagar	HP	40	Domestic	Residential
57	Mohannagar	HP	40	Domestic	Residential
58	Bisrakh	HP	26	Domestic	Residential
59	Bisrakh	HP	12	Domestic	Residential
60	Kulesra	HP	40	Domestic	Residential
61	Kulesra	HP	13	Domestic	Residential
62	Surajpur	HP	17	Domestic	Residential
63	Surajpur	HP	33	Domestic	Residential
64	Jaitpur Vaishpur	HP	40	Domestic	Residential
65	Dadha	HP	36	Domestic	Residential
66	Dadri	HP	15	Domestic	Residential
67	Badalpur	HP	13	Domestic	Residential
68	Badalpur	HP	40	Domestic	Residential
HP = Handpump					

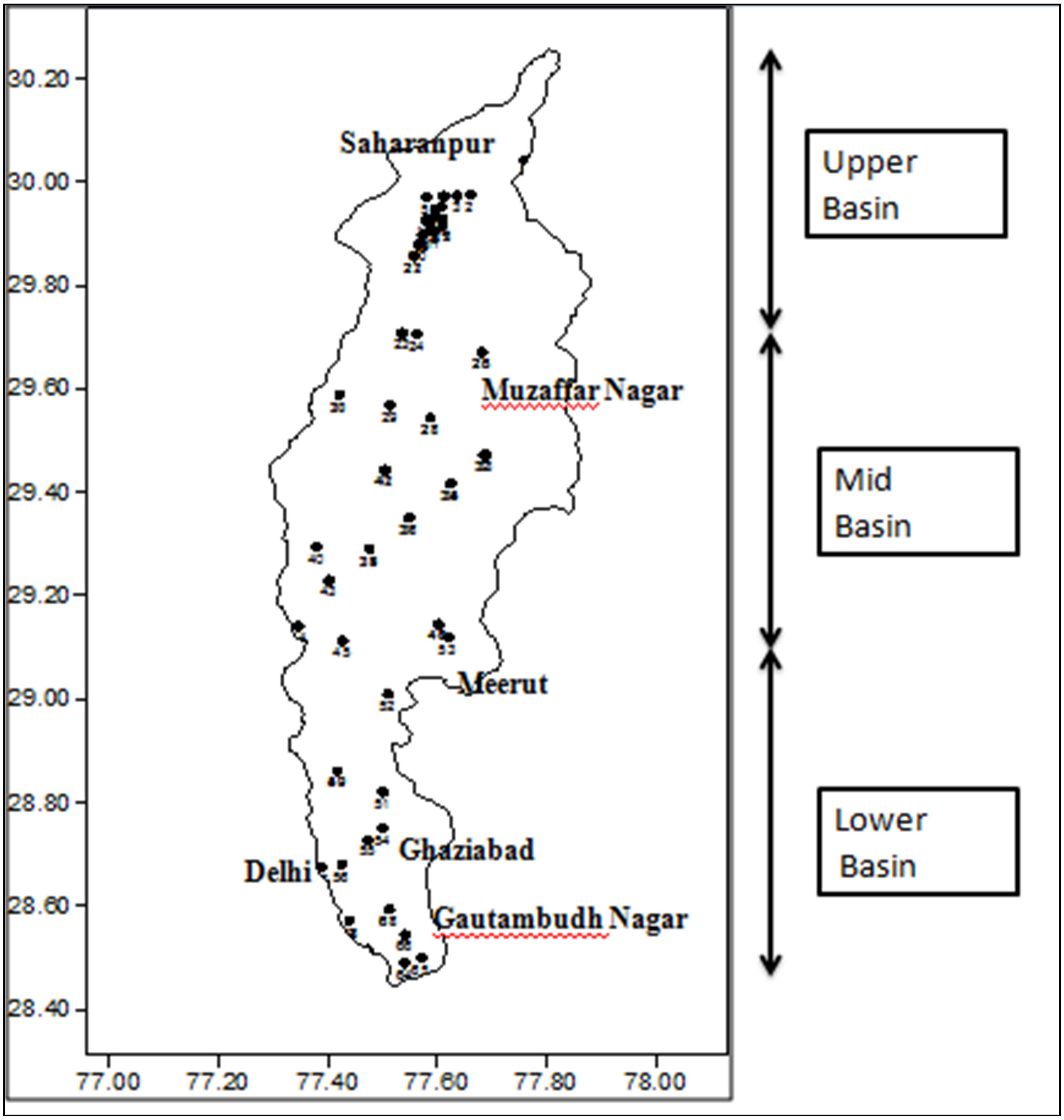


Fig. 1(b) Map showing locations of ground water sampling sites in Hindon river basin

3.0 MATERIALS AND METHODS

To meet the objectives of the study, the following action plan/methodology was approved by the working group:

i) Sampling of river Hindon and point sources contributing to river and ground water sources in the vicinity of the river in pre-monsoon and post-seasons.
ii) Analysis of the samples for Physico-chemical parameters, Bacteriological parameters, Toxic (Heavy) Metals and Pesticides
iii) It was proposed to apply a simple model of the oxygen resources in a river having two key processes (i) the removal of oxygen by microorganisms during biodegradation, and (ii) the replenishment of oxygen through re-aeration at the surface of the river. Rate of re-aeration in different stretches of the Hindon River would be determined using equation given by O' Connor and Dobbins (1958)
$k_r = (3.9u^{1/2})/(H^{3/2})$, where, u is average stream velocity (m/s) and H is average stream depth (m).
iv) The de-oxygenation rate constant (k_d) is often assumed to be same as the (temperature adjusted) BOD rate constant (k) obtained in standard laboratory BOD test (typical values for the BOD rate constant k at 20 ^oC in accordance with Davis and Cornwell (1985) is $k = k_{20}\theta^{(T-20)}$.
v) Modelling of BOD
Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The term also refers to a chemical procedure for determining this amount. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water (Clair et. al, 2003). The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. In this study, modelling of biochemical oxygen demand (BOD) was attempted assuming first order reaction and its governing equation is given below (Masters, 1995):

$$dL_t/dt = -k_d.L_t$$

The solution of the above equation may be written in the following form:

$$L_t = L_{0e}^{-kdt}$$

Where L_t = BOD remaining
L_0 = Ultimate BOD (just after mixing waste water drain with river water)

vi) Estimation of downstream DO deficit in different stretches will be carried out using Streeter-Phelps oxygen sag equation

$$D = (k_d L_0/k_r - k_d)(e^{-kd.t} - e^{-kr.t}) + D_0\, e^{-kr.t}$$ (Streeter and Phelps, 1925)

Where D = Dissolved oxygen deficit (DO_s-DO)
DO_s=Saturated value of dissolved oxygen
DO = Actual dissolved oxygen at a given location in the river
k_d=de-oxygenation rate constant (day^{-1})

L_0 = initial BOD of the mixture of streamwater and wastewater (mg/L)
k_r = re-aeration constant ($time^{-1}$)
t = elapsed time between discharge point and distance x downstream = (x/u)
u=stream speed

vii) Processing of data for different seasons as per BIS and WHO standards to examine the suitability of ground water for drinking purpose and irrigation purpose on the basis of total soluble salts, SAR, RSC.
viii) Classification of ground water using Piper trilinear diagram, Durov plots, Chadha's diagram, U S Salinity Laboratory Classification and Gupta Classification.
ix) Identification of degraded ground water quality locations using spatial distribution map.
x) Identification of degraded water quality stretches of the river Hindon using Water Quality Index

3.1 Sampling and Analysis

Wastewater samples from Nagdev Nala, Star Mill Drain and Dhamola Nala, water samples from river Kali and Krishni, eleven water samples from different stretches of river Hindon and sixty eight groundwater samples from hand pumps of different locations in the Hindon river basin [Fig. 1(a) and (b)] were collected in pre- and post-monsoon seasons during 2012. The sampling bottles were washed thoroughly, rinsed with distilled water several times and finally rinsed with the sample to be sampled. The samples for physico-chemical parameters were collected and stored in clean narrow mouth polyethylene bottles fitted with screw caps. The samples for bacteriological analysis were collected in wide mouth sterilized high density polypropylene bottles covered with aluminium foils as per the standard methods (APHA, 1995). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 mL/lit.). Samples for pesticide analysis were taken in glass bottles. Some parameters like pH and electrical conductance were measured on the spot by means of portable meters (HACH, USA). For other parameters, samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at $4^{o}C$ for detailed chemical and bacteriological analysis.

3.2 Chemicals and Reagents

All chemicals and standard solutions used in the study were obtained from Merck, India/Germany and were of analytical grade. Bacteriological reagents were obtained from HiMedia. Deionised water was used throughout the study. Aqueous solutions were prepared from the respective salts. Double distilled water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use. All glassware and reagents used for bacteriological analysis were thoroughly cleaned and sterilized before use.

3.3 Physico-chemical Analysis

The physico-chemical and bacteriological analysis was performed as per standard methods (Jain and Bhatia, 1988; APHA, 1995). Ionic balance was calculated, the error in the ionic balance for majority of the samples was within 5%.

3.4 Metal Ion Analysis

Perkin-Elmer Atomic Absorption Spectrometer (model 3110) using air-acetylene flame was used for metal analysis of water samples. Average values of five replicates were taken for each determination. Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis. The detection limits for iron, manganese, copper, nickel, chromium, lead, cadmium and zinc are 0.003, 0.001, 0.001, 0.004, 0.002, 0.01, 0.0005 and 0.0008 mg/L respectively.

3.5 Pesticide Analysis

The groundwater samples for organochloropesticide analysis were extracted with n-hexane three times and the combined extract was concentrated using Kuderna Danish assembly under reduced vacuum. The moisture from the extracts was removed by using anhydrous sodium sulphate. The analysis of the pesticides was carried using Aimil Nucon Gas Chromatograph with the ^{63}Ni selective electron capture detector (ECD). This detector allows the detection of contaminants at trace level concentrations in lower ppb range in the presence of multiple of compounds extracted from the matrix to which the detector does not respond. The column used was EQUITY-5, 30 m with internal diameter of 0.25mm. Nitrogen gas was used as carrier gas at 2.0 ml/min with 28 ml/min as makeup gas. The temperatures of the oven was kept at 150^0C with a hold time of 1 minute, then from 150^0C to 200^0C at a rate of 10^0C/minute with a hold time of 1 minute and then from 200^0C to 250^0C at a rate of 1^0C/minute with a hold time of 1 minute and finally to 280^0C at a rate of 10^0C/minute with a hold time of 4 minutes. The detector was maintained at 285^0C. The qualitative and quantitative determination of the organochloro pesticides were carried out by comparing the retention time and peak area of the pesticides. The confirmation of the pesticides in the water samples was achieved by using standard internal addition method. Recovery experiment was performed and recovery was about 75% - 103% for organochlorine pesticides. The reproducibility of the results for all pesticides was 95% and above for all samples. Further, the mean average reading of an individual sample analyzed in triplicate has been taken for reporting the results.

4.0 RESULTS AND DISCUSSIONS

The wastewater samples from Nagdev Nala, Star Mill Drain, Dhamola Nala, water samples from river Hindon and its tributaries, river Kali and Krishni and groundwater samples from hand pumps in the Hindon river basin [Fig. 1(a) and (b)] were collected during pre- and post-monsoon seasons of 2012 and analysed for physico-chemical parameters, bacteriological parameters, concentration of metal and organochlorinated pesticides.

4.1 Surface Water Quality of Hindon River Basin

4.1.1 Point Sources

The physico-chemical characteristics of the identified drains and tributaries are given in Table 2 & 3 and Fig. 2.

Drains

Three effluents drains namely Nagdev Nala, Star Paper Mill Drain and Dhamola Nala join the river Hindon in upper section. The Nagdev nala receives municipal wastewater of the adjoining villages and industrial effluents from various industrial units. The Star Paper Mill is located near Saharanpur railway station and manufactures several varieties of paper used in writing, printing, craft wrapping and wall papers. The raw materials used in the manufacturing processes include wood, bamboo, jute sticks, straw, hemp, sawai and sabal grass. The important chemicals used are sodium sulphate, sodium hydroxide, sodium sulphide, sodium carbonate, calcium hypochlorite and magnesium bisulphite. The wastes from different processes and manufacturing units flow separately for some distance but finally join at one point and form the composite waste of pulp and paper mill. The composite effluent from the factory is discharged almost without any treatment into the river through an open channel. The channel is about 3 km in length and outfalls on the right bank of river Hindon near the village of Paragpur with a considerable force. Due to the presence of caustic soda and other alkaline mixtures, a soapy and fibrous froth is continuously generated at the point of discharge. A characteristic smell of sulphate mercaptan and sulphide is all pervading in the mixing zone and is strongly felt in the area. Due to these factors, dirty black subsoil with foul odour is also found in the nearby area and a dark brown colour is imparted to the river water, which allows easy distinction between the effluent and the river water. Other sources of pollution in Hindon river are the sewage of Saharanpur town and several other wastes from textile mill, sugar mill, cigarette factory, card board factory, laundary and other small industrial units which discharge their waste effluents into Dhamola nala which in turn opens into Hindon river.

The determination of pH serves as a valuable index which shows whether the waste is acidic or alkaline in nature. The pH of the wastewater of identified drains varies from 7.6 to 8.4 in pre-monsoon season and 7.0 to 7.4 in post-monsoon season. Total Dissolved Solids (TDS) create an imbalance due to increased turbidity and cause suffocation to the fish life even in the presence of high dissolved oxygen. The TDS value in wastewater varies from 671 to 2054 mg/L in pre-monsoon season and 232 to 1466 mg/L in post-monsoon season. Maximum value of TDS was observed in the wastewater of Star paper mill drain which contains mixture of different kind of wastes from different operations of paper industries. Sharma (2001) observed TDS from 1381 to 1550 mg/L during April 1997 to February 1999 in the effluents of Star paper Mill Drain.

The higher values of BOD indicate high degree of organic pollution. Maximum value of BOD (261 mg/L) was observed in Star paper mill drain in post-monsoon season. 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 in the drains indicate high degree of organic pollution rendering the water unsuitable even for bathing purpose. Sharma (2001) also reported higher values of BOD (190 to 310 mg/L) and COD (270 to 464 mg/L). The discharge of the composite effluents results in depletion of dissolved oxygen even zero, generation of an objectionable odour and colour due to lignin, the formation of bottom deposits and formation of slime and foam.

Tributaries

The portion of the Hindon catchment in the vicinity of Muzaffarnagar is not directly contributing municipal and industrial effluent to the river Hindon as the local industries are discharging their waste effluent either in river Kali or river Krishni. The river Kali is subjected to varying degree of pollution caused by numerous untreated outfalls of municipal and industrial effluents. The main sources which create pollution in the river Kali include municipal wastes of Muzaffarnagar city, industrial waste from a variety of industries (such as steel, rubber, ceramic, chemicals, plastic, dairy, pulp and paper and laundries) and Mansurpur sugar mill and distillery waste. On the otherhand, the wastes of Shamli sugar factory and distillery pollute the river Krishni. The waste effluents stagnate in the river Kali for a long time, because of which the biological action starts and obnoxious condition soon develop in the region. This septic condition results in the production of hydrogen sulphide gas imparting black colour to the river water. River Kali opens into river Hindon near the village of Atali and river Krishni near Sardhana. The water samples were taken upstream of the confluence of the two rivers with the Hindon river.

River Krishni was dry during pre-monsoon season. The pH values of the two rivers indicate that there is not much variation in the pH of the two rivers. The value of conductivity of the two river indicates that water of river Krishni is having higher dissolved solids as compared to Kali river water. The overall high values of BOD and COD clearly indicate large scale disposal of untreated industrial effluent in the two rivers. The same findings were also reported by Sharma (2001). A large quantity of water from Upper Ganga Canal is released into the river Kali through Khatauli escape thereby diluting the water of river Kali. It can be inferred from the results that the discharge of the two rivers into the river Hindon is hazardous due to the high values of BOD, COD and other constituents.

4.1.2 River Hindon

The river Hindon rises in the Saharanpur district from Shivalik hills. In summer months, the river is dry from its origin upto Saharanpur town. In effect, the effluents of Nagdev nala and Star Paper Mill generate the flow of water in the river. In the course of its flow, it also receives the municipal wastewater from Saharanpur and Muzaffarnagar towns. The first tributary, i.e., Western Kali meets river Hindon on its left bank near the village of Atali, which carries the municipal and industrial wastewater of Muzaffarnagar district. Another tributary, Krishni, meets river Hindon on its right bank near the village of Barnawa in Meerut district and carries the wastewater from sugar industries. In Ghaziabad district, downstream of Karhera village, majority of flow of the river is diverted to Hindon cut canal at Mohan Nagar which outfalls into river Yamuna upstream of Okhla barrage.

The river water at station Kapasa to Maheshpur has foul and pungent organic smell due to the discharge of pulp and paper mill effluent. The odour becomes much more pronounced in summer months. In addition to the floating froth and foam, the river water also becomes brown in colour owing to the discharge of effluent of pulp and paper factory. The water is dark brown at stations RH-1 and RH-2, becoming light brown with black tinge at stations R-3 and R-4. The brown colour of the water reduces the penetration of light and affects the spectrum of the wavelength, which penetrates 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 they also produce oxygen by photosynthetic activity which plays an important role in reaeration of streams and in natural self-purification process.

The physico-chemical characteristics of the water of river Hindon are given in Table 2 and 3 and Fig. 3(a) and (b). The pH of the river Hindon water varies from 6.7 to 7.5 in pre-monsoon season and 6.8 to 7.5 in post-monsoon season. The electrical conductivity in the water of the River Hindon varies from 232 to 3273 μS/cm in pre-monsoon season and 307 to 3250 μS/cm in post-monsoon season. Conductivity measurements are directly related to the concentration of ionized substance in water and commonly used to determine the purity of de-mineralized water and total dissolve solids in boiler, cooling tower water, irrigation and domestic supply. Salinity is measured in terms of electrical conductivity. The total dissolved solids value in the water of the River Hindon varies from 149 to 2095 mg/L in pre-monsoon season while 197 to 2080 mg/L in post-monsoon season. Higher values of TDS (>2000 mg/L) were observed in upstream section of the river Hindon which may be attributed to the mixing of wastewater from star paper mill and Dhamola nala.

The dissolved oxygen (DO) concentration depends not only on the relative dilutions but on the rate of oxidation of organic material and re-aeration. More is the oxygen, better is the quality of water. DO concentration in the water of river Hindon river varies from 0 to 5.0 mg/L in pre-monsoon season while 0 to 2.2 mg/L in post-monsoon season. At almost all sites of the upstream and mid-section of the river Hindon, DO was observed to be 0 mg/L because of high organic load in the river water.

The demand of oxygen from water to break down of organic and inorganic wastes and sewage is known as biochemical oxygen demand (BOD). The more oxygen taken out from water the less becomes the content of dissolved oxygen, thus, increasing the pollution in the river with a high BOD load. The amount of dissolved oxygen needed by bacteria to decompose the wastes determines the quality of wastewater. The problem arises when demand for dissolved oxygen exceeds available supply. Thus, BOD is a measure of oxygen required to sustain organisms like aerobes, protozoa etc. BOD concentration varies from 3.3 to 65 mg/L in pre-monsoon season while 0 to 139 mg/L in post-monsoon season. High values of BOD were observed in upstream section of the river Hindon which may be attributed to the mixing of wastewater from Star Paper Mill and Dhamola nala with river Hindon water.

Chemical Oxygen Demand (COD) is a measurement of the oxygen requirement equivalent of organic matter that is susceptible to oxidation with the help of a strong chemical oxidant. It is an important, rapidly measured parameter as a means of measuring organic strength for streams and polluted water bodies. COD in the river water varies from 28 to 338 mg/L in pre-monsoon season while 24 to 388 mg/L in post-monsoon season.

The presence of carbonates, bicarbonatess and hydroxides are the main cause of alkalinity in natural waters. The alkalinity value in the river Hindon varies from 180 to 1440 mg/L in pre-monsoon season while 110 to 700 mg/L in post-monsoon season. The total hardness value in the water of the river Hindon varies from 200 to 830 mg/L in pre-monsoon season while 120 to 850 mg/L in post-monsoon season.

Table 2. Physicochemical characteristics of surface water in Hindon river basin (Pre-monsoon 2012)									
Drain Sample									
S.No.	Location	pH	EC	TDS	Hardness	Alkalinity	DO	BOD	COD
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
D-1	Nagdev Nala	8.4	1493	956	350	144	0	14.7	216
D-2	Star Paper Mill Drain	8.2	3210	2054	384	196	2.3	29.3	439
D-3	Dhamola Nala	7.6	1049	671	349	344	0	47.3	130
Tributary Sample									
K-1	River Kali	7.4	1410	902	472	156	0.4	56	72
KR-1	River Krishni	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
River Hindon Sample									
RH-1	Kapasa	6.9	3153	2018	800	550	0	29	338
RH-2	Nanandi	7.1	3273	2095	830	800	0	25	230
RH-3	Sadauli Hariya	7.4	1383	885	360	530	0	51	322
RH-4	Maheshpur	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RH-5	Charthawal	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RH-6	Chandheri	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RH-7	Atali	7.1	2013	1288	500	1160	0	65	88
RH-8	Barnawa	7.5	2513	1608	600	1440	5	59	84
RH-9	Daluhera	6.7	259	166	200	190	0	3.3	28
RH-10	Surana	6.7	232	148	240	180	0	35	112
RH-11	Mohannagar	7.4	244	156	265	198	0.8	44	118

Table 3. Physicochemical characteristics of surface water in Hindon river basin (Post-monsoon 2012)									
Drain Sample									
S.No.	Location	pH	EC	TDS	Hardness	Alkalinity	DO	BOD	COD
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
D-1	Nagdev Nala	7.4	362	232	328	130	0	31	356
D-2	Star Paper Mill Drain	7.0	690	442	850	420	0	261	356
D-3	Dhamola Nala	7.0	2290	1466	304	650	0	3.1	56
Tributary Sample									
K-1	River Kali	7.3	330	211	130	120	1.5	0.1	56
KR-1	River Krishni	7.0	335	214	160	106	6.5	1.1	46
River Hindon Sample									
RH-1	Kapasa	7.1	3010	1926	770	610	0	139	374
RH-2	Nanandi	7.3	3250	2080	850	630	0	99	334
RH-3	Sadauli Hariya	7.3	1283	821	350	400	0	61	324
RH-4	Maheshpur	7.5	1915	1226	460	650	0	113	388
RH-5	Charthawal	7.5	1648	1055	420	700	0	129	302
RH-6	Chandheri	7.4	1730	1107	500	620	0	97	228
RH-7	Atali	7.2	393	252	146	230	0.2	7.1	46
RH-8	Barnawa	7.5	433	277	178	156	0	0	52
RH-9	Daluhera	7.4	307	196	120	110	0	0	24
RH-10	Surana	6.8	358	229	130	114	1.8	0	36
RH-11	Mohannagar	7.4	362	232	120	130	2.2	0	44

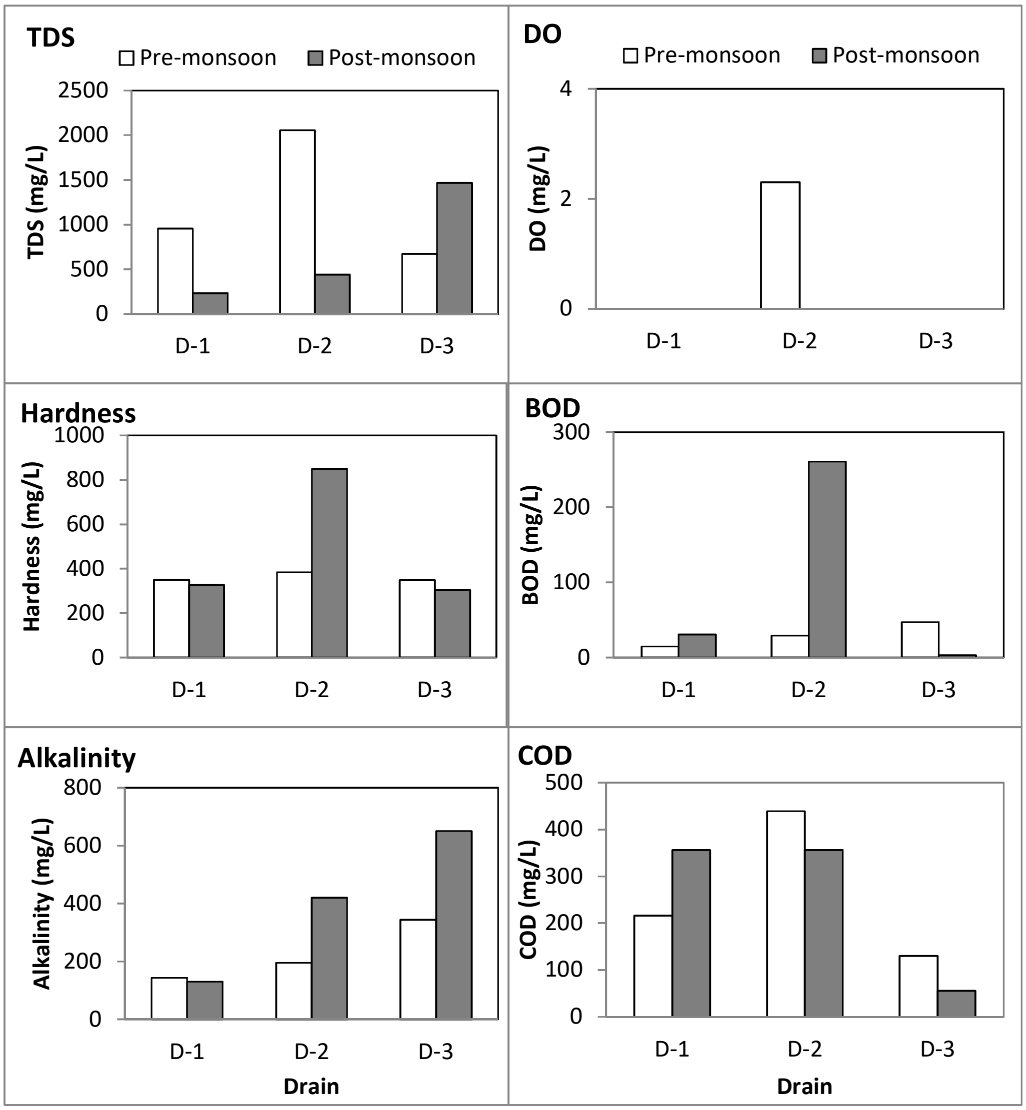


Fig. 2 Physico-chemical characteristics of Drains

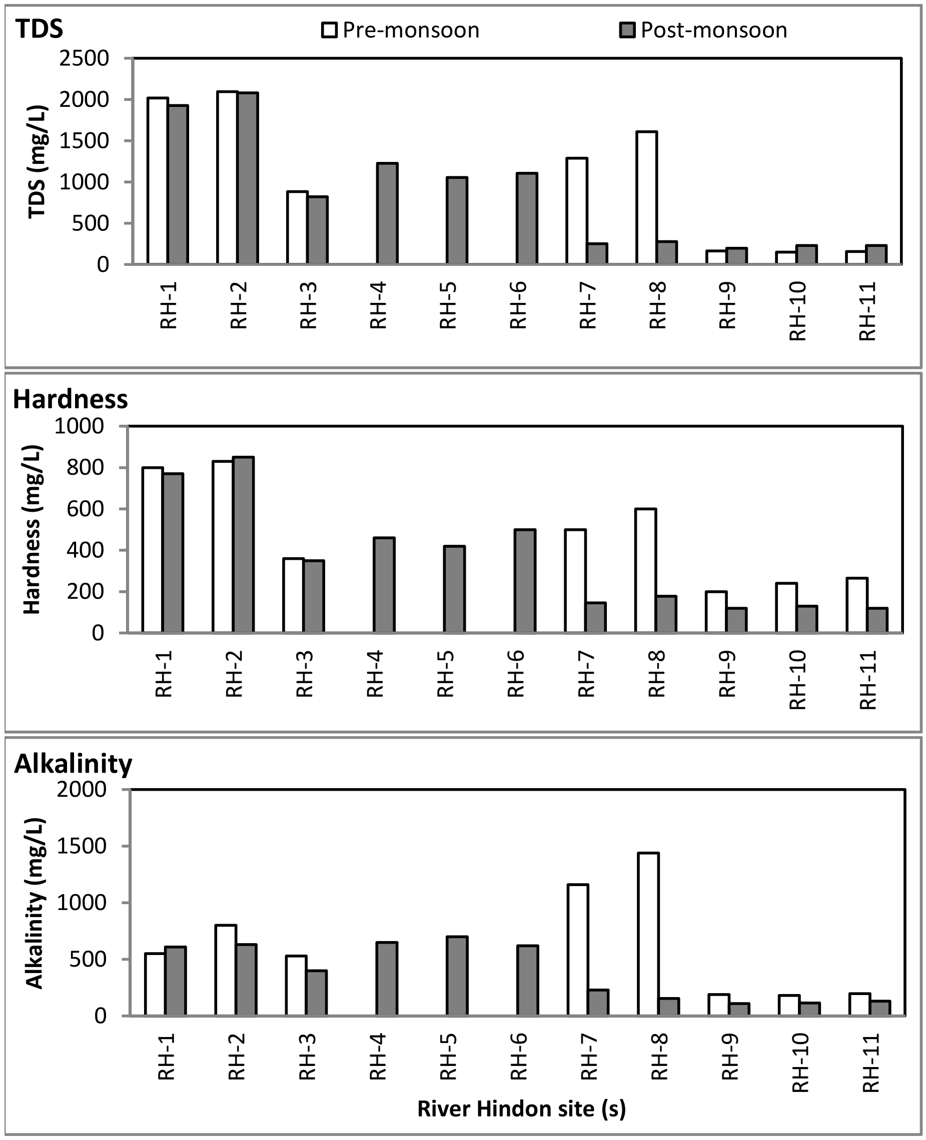


Fig. 3(a) Longitudinal variation of physico-chemical parameters along river Hindon

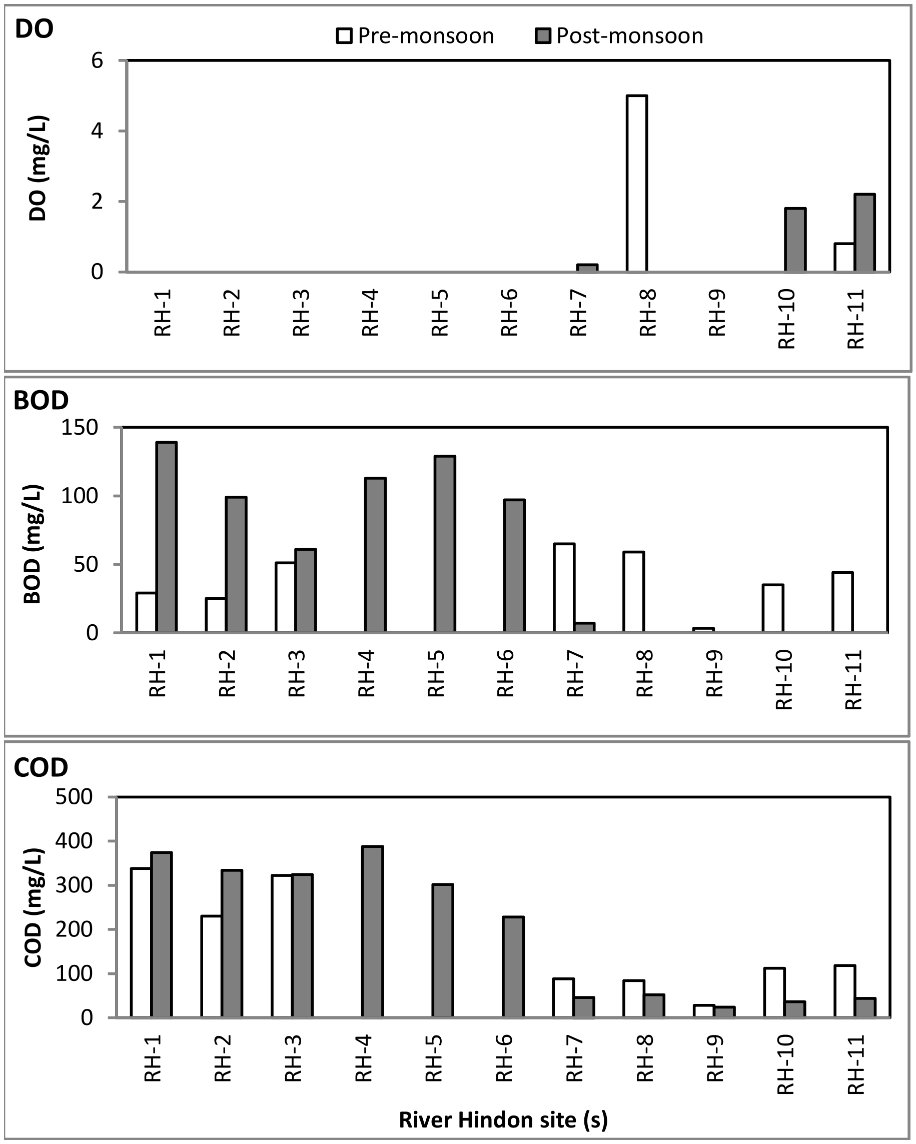


Fig. 3(b) Longitudinal variation of physico-chemical parameters along river Hindon

4.2 Estimation of Re-aeration (k_r) and De-oxygenation (k_d) Coefficients

For this aspect of the study, water quality monitoring was carried out from the Hindon River (including its tributaries Kali, Krishni as well as open drains carrying domestic/industrial sewage) during June 2012, October 2012 and January 2013. The cross sections, flow velocities and water temperature were also measured during the water quality monitoring programs to estimate re-aeration and de-oxygenation coefficients of the Hindon River. Based on these investigations, the flow of water at respective monitoring locations in the river was computed. A relationship between mean stream depth (m) and discharge (cumec) obtained at various locations in the Hindon River (including drains/tributaries) was developed for October 2012 (Fig. 4). The R^2 of the developed Equation ($y=11.204\ x^{2.2918}$) was found 0.65.

The results of water quality obtained during June, 2012 show that the dissolved oxygen (DO) varies from 0 to 5 mg/L and Bio-chemical Oxygen Demand (BOD) from 3.3 to 65 mg/L respectively during June 2012 in the surface water of the Hindon river (including drains/tributaries). However, during October 2012, DO and BOD was found to vary from 0 to 4 mg/L and 3 to 170 mg/L, respectively (Figs. 5&6). Subsequently, inferences made separately for 3 different water/waste water sources (viz. domestic/industrial drains, tributaries and main course of Hindon River) reveals that dissolved oxygen (DO) was found to vary from 0 to 2 mg/L for drains carrying industrial/domestic effluents, 0 to 4 mg/L for tributaries of Hindon River and 0 to 3 mg/L for Hindon River. Similarly, BOD varies from 9.9 to 35 mg/L for drains carrying industrial/domestic effluents, 7 to 170 mg/L for tributaries of Hindon River and 3 to 120 mg/L for Hindon River.

During October 2012, the re-aeration coefficients vary from 3.36 to 14.07 for drains carrying industrial/domestic effluents, 3.68 to 16.34 for tributaries of Hindon River and 3.45 to 26.8 for Hindon River. The de-oxygenation coefficients were estimated and vary from 0.42 to 0.55 for drains carrying industrial/domestic effluents, 0.38 to 0.42 for tributaries of Hindon River and 0.38 to 0.53 for Hindon River (Fig. 7). The BOD modelling was attempted using simple first order BOD reaction equation. The results are given in Table 4. The results of estimated BOD were compared with observed BOD at different sampling sites in the Hindon River for the month of October, 2012. The results of predicted and observed BOD were plotted in Fig. 8, which indicate a very good agreement (R^2=0.948) between observed and predicted values of BOD under this study. Similarly, the results of estimated BOD and observed BOD at different sampling sites in the Hindon shown in Fig. 9 (R^2=0.735). The results of re-aeration coefficients and de-oxygenation coefficients are given in Figs. 10 and 11 respectively.

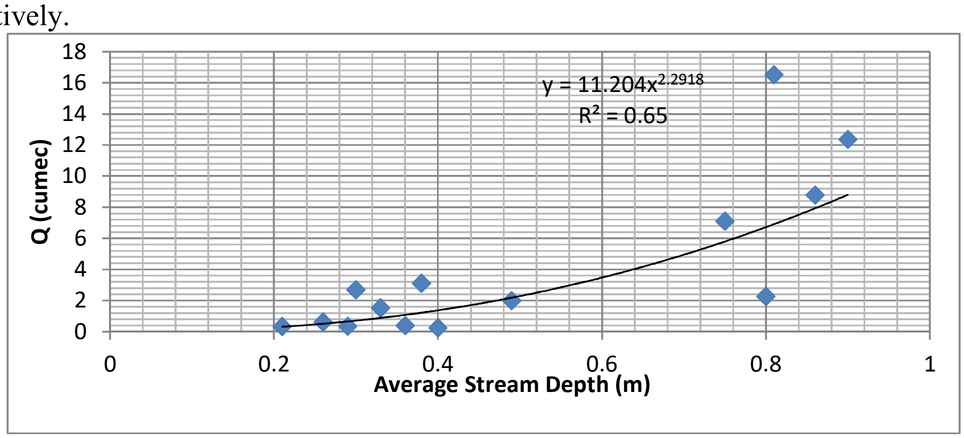


Fig. 4 Relationship between average stream depth and discharge in Hindon River (October 2012)

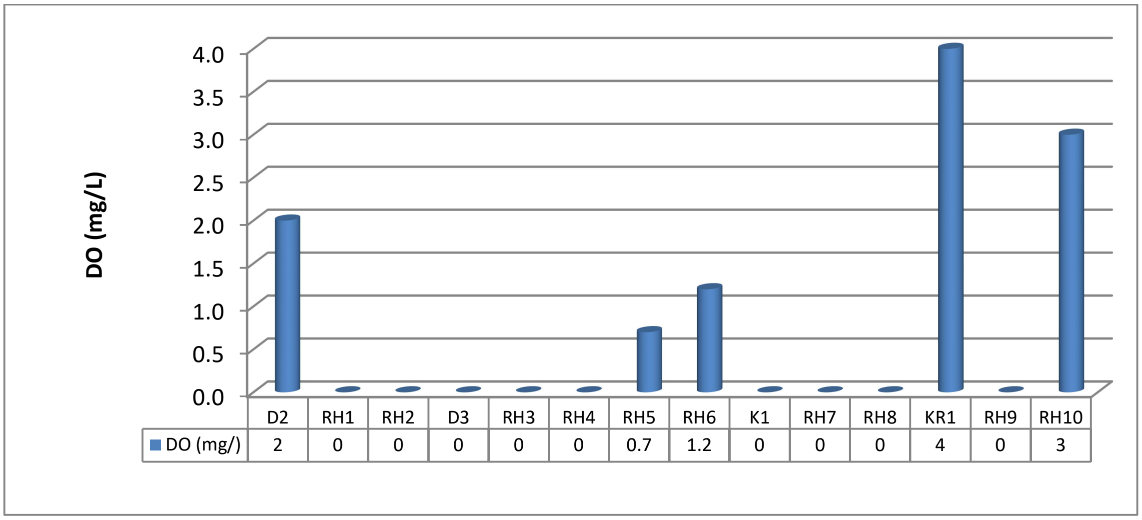


Fig. 5 Variation of DO (mg/L) in Hindon River (October 2012)

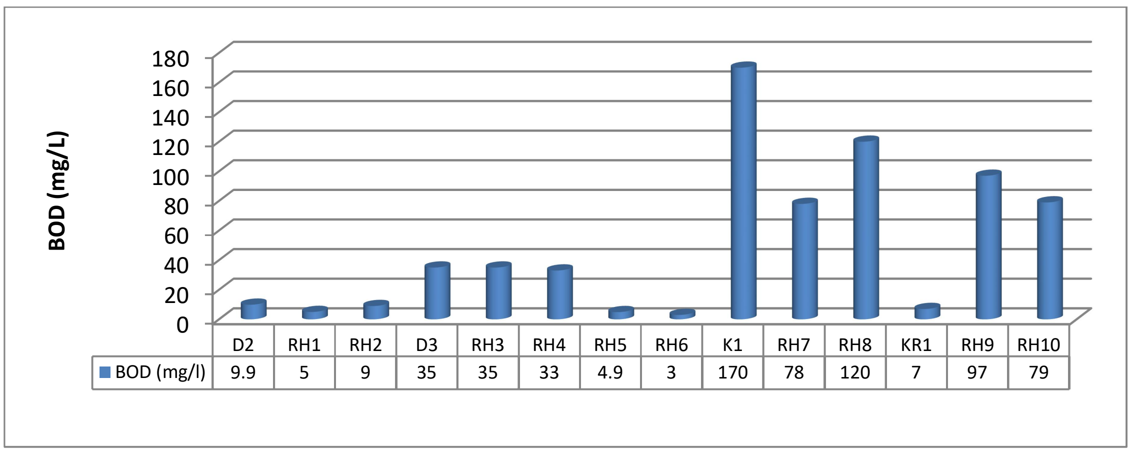


Fig. 6 Variation of BOD (mg/L) in Hindon River (October 2012)

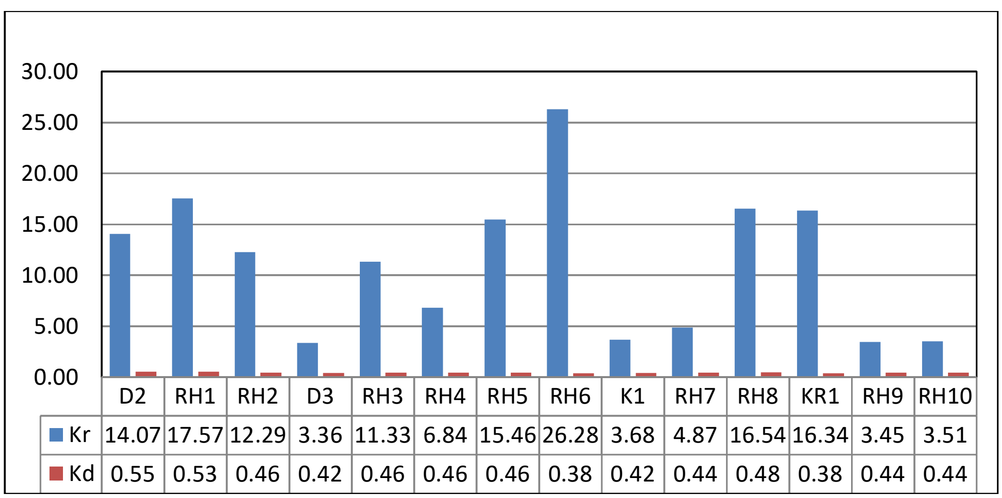


Fig. 7 Computed values of Re-aeration (k_r) and De-oxygenation(k_d) Coefficients for Hindon River (October 2012)

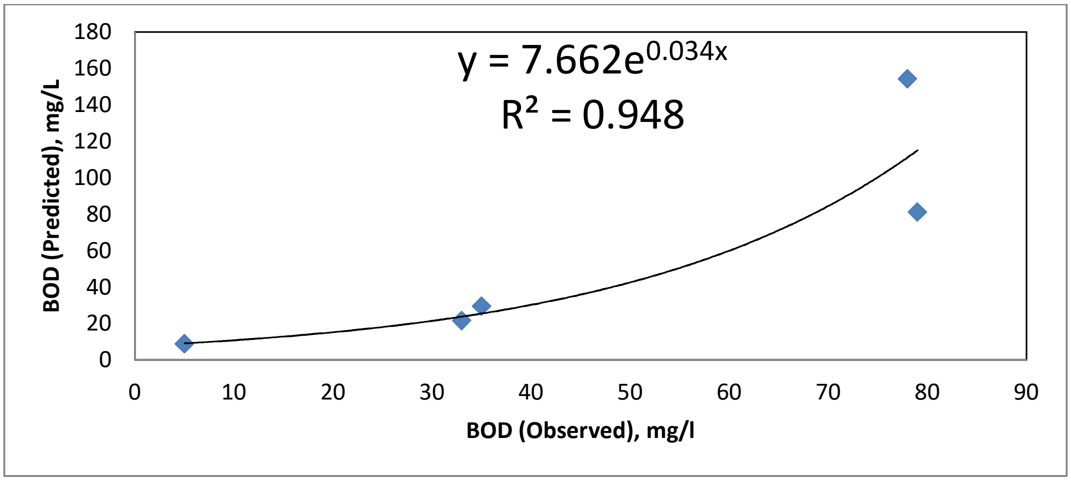


Fig. 8 Observed and predicted BOD in Hindon River (October 2012)

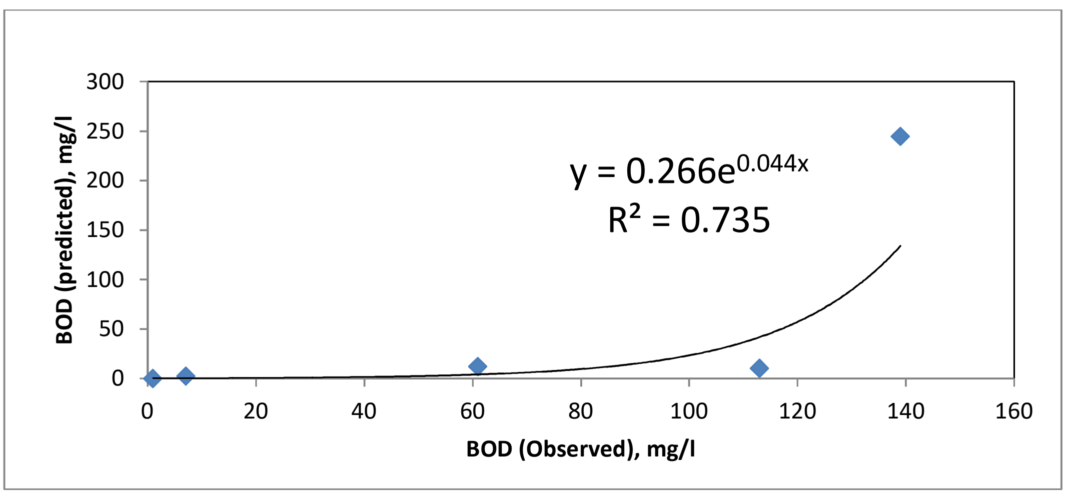


Fig. 9 Observed and predicted BOD in Hindon River (January 2013)

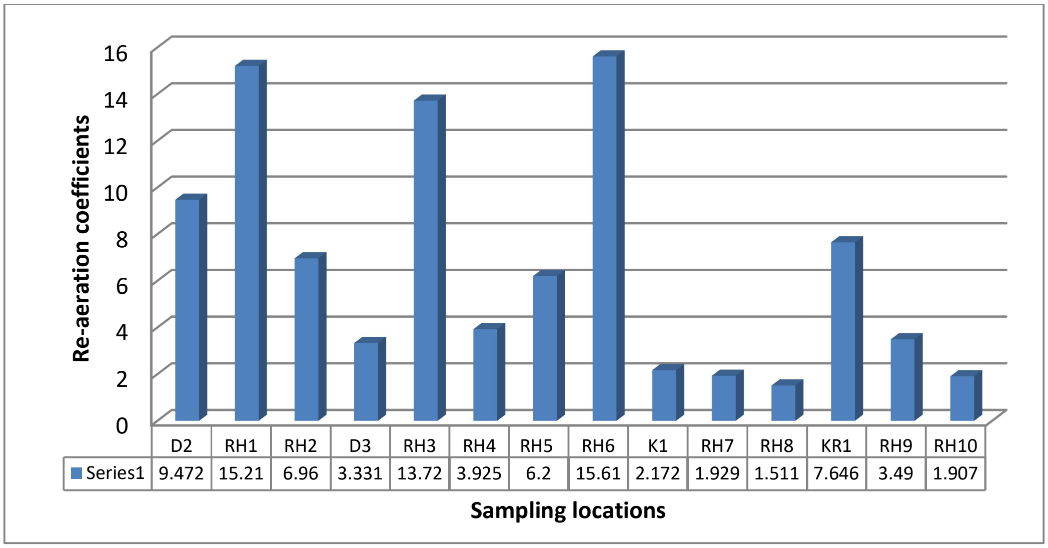


Fig. 10 Computed values of Re-aeration (k_r) Coefficients for Hindon River (January 2013)

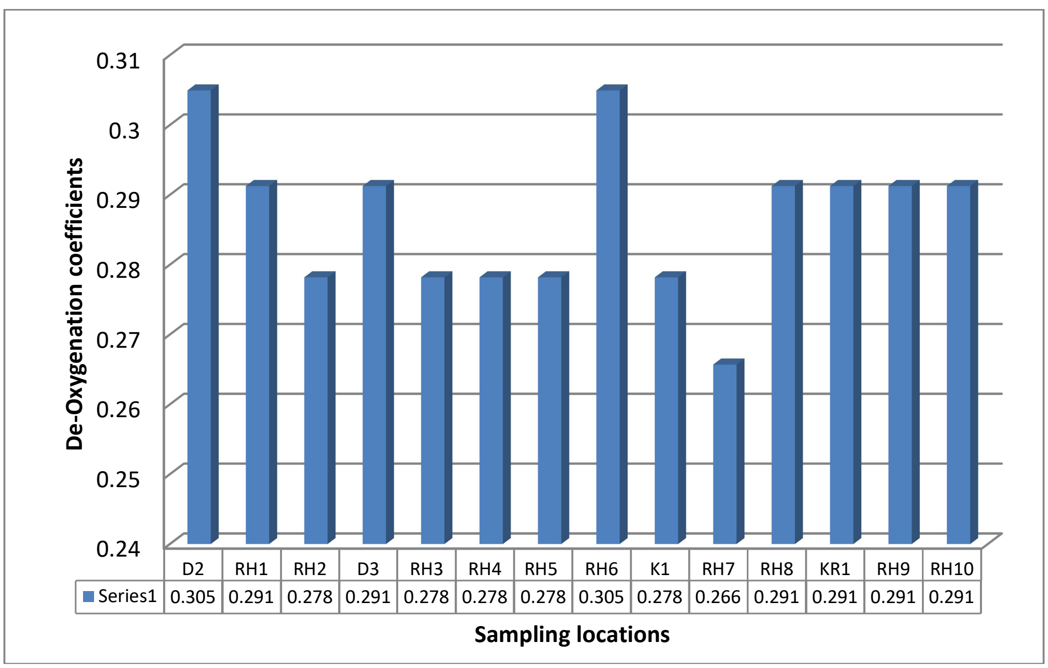


Fig. 11 Computed values of De-oxygenation (k_d) Coefficients for Hindon River (January 2013)

Table 4. Observed and estimated BOD in Hindon River (October 2012)

Sampling Sites		K_d	Observed BOD (mg/L)	Estimated BOD (L_t) afte travel time t (mg/L)
D2	Star Paper Mill	0.55	9.9	-
RH1	Kapasa	0.53	5	8.79
RH2	Nanandi	0.46	9	-
D3	Dhamola Nalla	0.42	35	-
RH3	Sadauli Haria	0.46	35	29.49
RH4	Maheshpur	0.46	33	21.62
RH5	Charthawal	0.46	4.9	-
RH6	Chandheri	0.38	3	-
K1	Kali River	0.42	170	-
RH7	Atali	0.44	78	154.33
RH8	Barnawa	0.48	120	-
KR1	Krishni River	0.38	7	-
RH9	Daluhera	0.44	79	81.17

4.3 DO Sag Analysis

The DO sag analysis of Hindon River was carried out using Ponce Calculator (http://ponce.sdsu.edu/onlinedo.php) by two different models (Streeter & Phelps, 1925 and differential equations of DO Sag) in this study. The data of DO, BOD, stream discharge, stream velocity, water temperature monitored during October 2012 was used in the study. The values of K_r (=0.6) and K_d (=0.2) of the Ponce Calculator were used in the analysis. The Hindon River was divided into 4 segments from origin (Beherki, Saharanpur) to Surana/Mohannagar (Ghaziabad). The details of the sections are given below (Table 5).

Table 5. Details of Sections/Reaches in Hindon River (From Origin to Mohannagar)

Section Number	Name	Length (Km)	Main Effluent Stream
1	Beherki-Nandini	15	Star Paper Mill & Nagdeva Nalla
2	Nanandi-Chandheri	80	Dhamola Nala
3	Chandheri-Barnawa	22.5	Kali River
4	Barnawa-Mohannagar	61.5	Krishni River

The section-1, which is demarcated from Beherki to Nanandi (15 km), mainly receives industrial effluents from Star Paper Mill and effluents through Nagdeva Nalla. The section-2 extends from Nanandi to Chandheri (80 km) mainly receives effluents from Dhamola Nala. The section-3 extends from Chandheri to Barnawa (22.5 km) receives mainly effluents from Kali River. The section-4 was considered from Barnawa to Mohannagar (61.5 km) and mainly receives effluents through Krishni River. A line diagram showing main effluent streams are given in Fig. 12.

DO Sag analysis using two different models (Model-1: DO Sag differential equations of Ponce Calculator, Model-2: Streeter & Phelps, 1925) for section 1 to 4 was carried out and the results are given in Tables 6-9 respectively. The behaviour of DO sag curves plotted using both DO prediction models (Model 1 are Model 2) for section 1 to 4 are shown in Figs. 13-16 respectively.

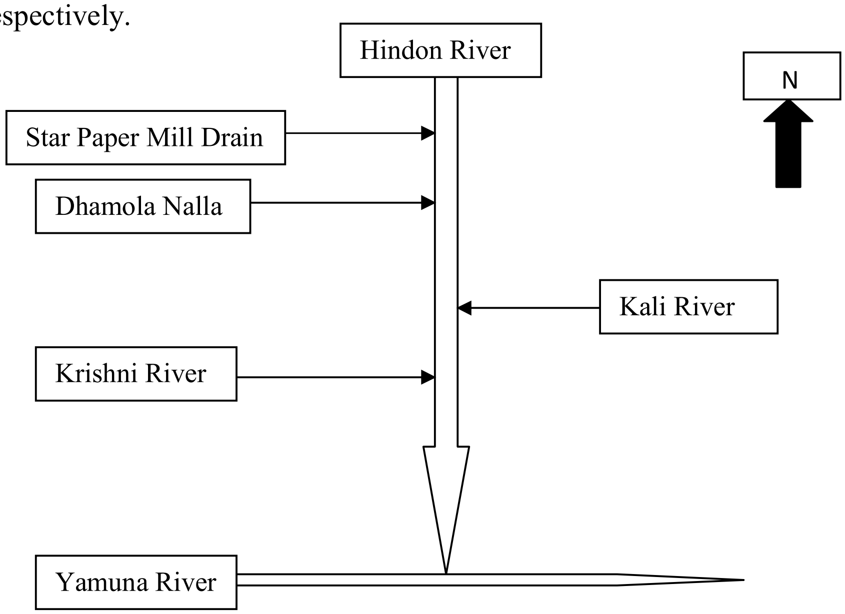


Fig. 12. Line diagram showing main effluents streams in Hindon River

Table 6. Predicted DO for Section 1 (Beherki to Nanandi) of the Hindon River

Space interval j	Distance (km)	Model-1 (DO Sag Diff. Eqn.) DO (mg/L)	Model-2 (Streeter-Phelps) DO (mg/L)	DO difference (mg/L)
0	0.000	0.57	0.57	0.00
1	1.500	0.53	0.53	0.00
2	3.000	0.49	0.49	0.00
3	4.500	0.45	0.45	0.00
4	6.000	0.42	0.42	0.00
5	7.500	0.40	0.39	0.00
6	9.000	0.38	0.37	0.01
7	10.500	0.36	0.35	0.01
8	12.000	0.34	0.34	0.01
9	13.500	0.33	0.32	0.01
10	15.000	0.32	0.31	0.01

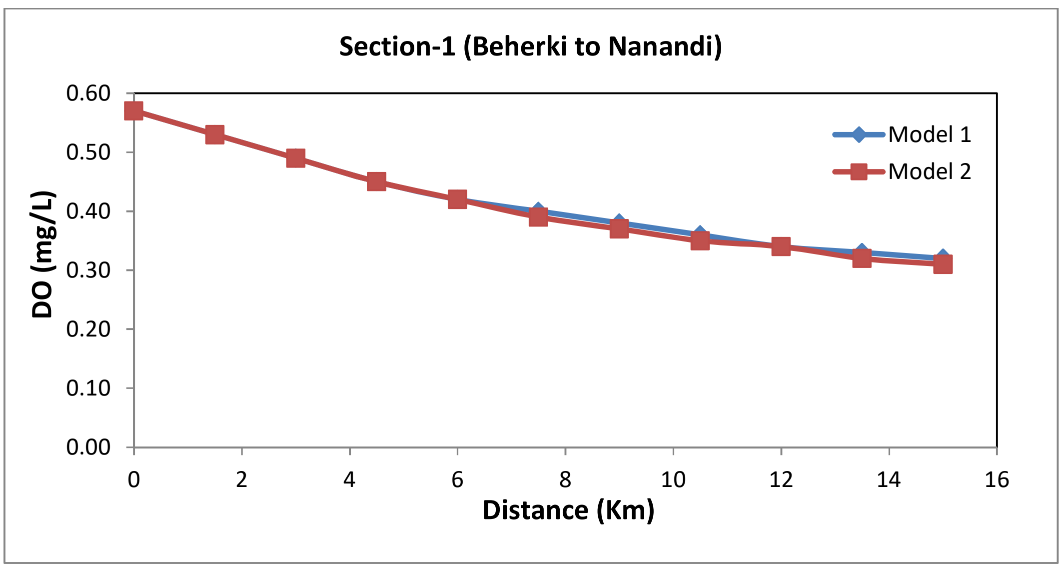


Fig. 13. DO Sag curves for Section-1 of the Hindon River

Table 7. Predicted DO for Section-2 (Nanandi to Chandheri) of the Hindon River

Space interval j	Distance (km)	Model-1 (DO Sag Diff. Eqn.) DO (mg/L)	Model-2 (Streeter-Phelps) DO (mg/L)	DO difference (mg/L)
0	0.000	0.00	0.00	0.00
1	8.000	0.00	0.00	0.00
2	16.000	0.00	0.00	0.00
3	24.000	0.07	0.00	0.07
4	32.000	0.19	0.05	0.15
5	40.000	0.36	0.19	0.16
6	48.000	0.55	0.37	0.18
7	56.000	0.76	0.57	0.19
8	64.000	0.99	0.79	0.20
9	72.000	1.24	1.02	0.21
10	80.000	1.49	1.26	0.22

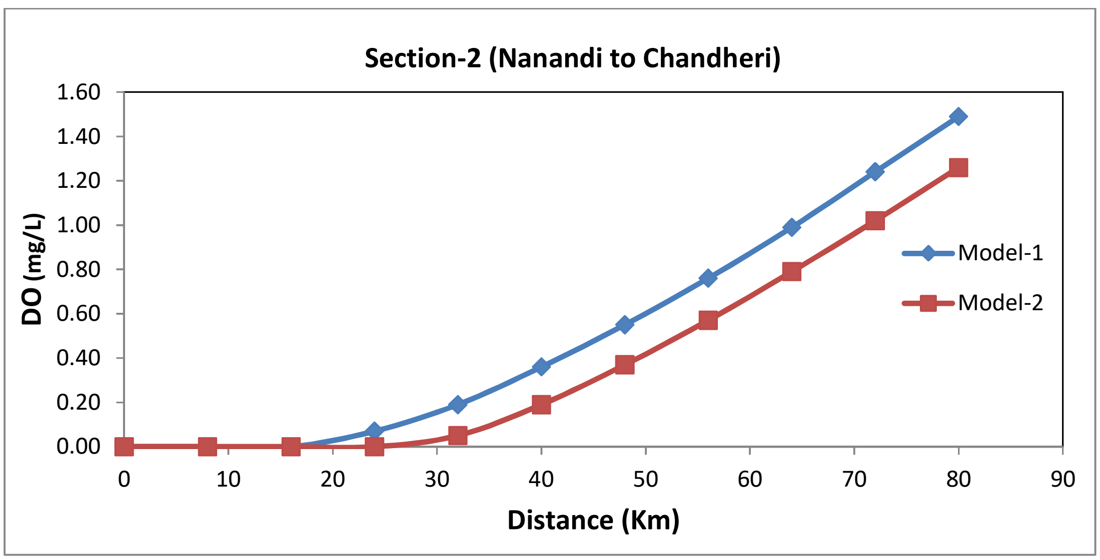


Fig. 14. DO Sag curves for Section-2 of the Hindon River

Table 8. Predicted DO for Section-3 (Chandheri to Barnawa) of the Hindon River

Space interval j	Distance (km)	Model-1 (DO Sag Diff. Eqn.) DO (mg/L)	Model-2 (Streeter-Phelps) DO (mg/L)	DO difference (mg/L)
0	0.000	0.04	0.04	0.00
1	2.250	0.00	0.00	0.00
2	4.500	0.00	0.00	0.00
3	6.750	0.00	0.00	0.00
4	9.000	0.00	0.00	0.00
5	11.250	0.00	0.00	0.00
6	13.500	0.00	0.00	0.00
7	15.750	0.00	0.00	0.00
8	18.000	0.00	0.00	0.00
9	20.250	0.00	0.00	0.00
10	22.500	0.00	0.00	0.00

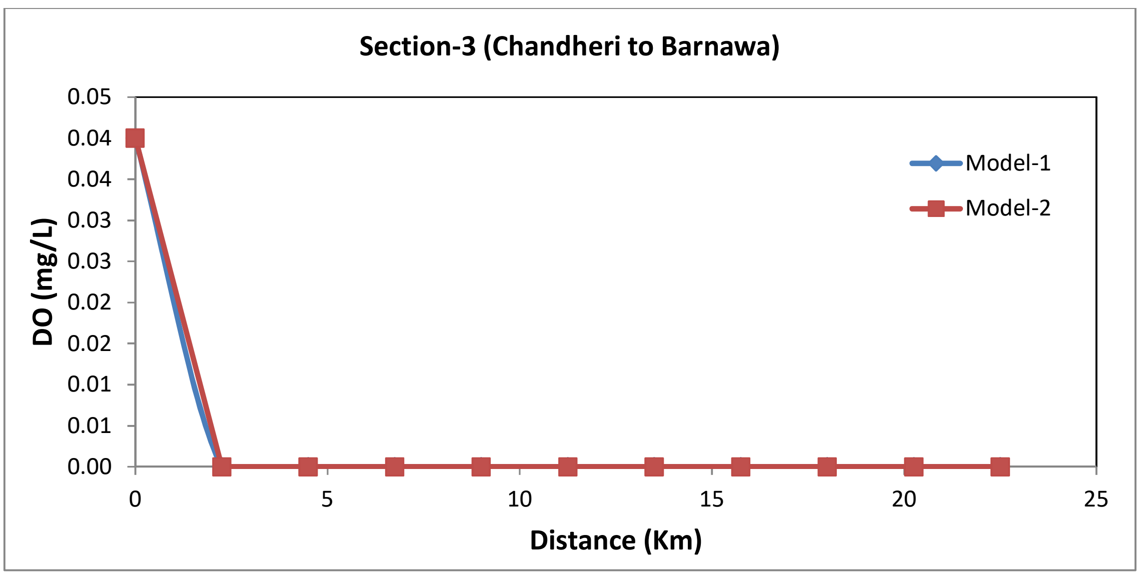


Fig. 15. DO Sag curves for Section-3 of the Hindon River

Table 9. Predicted DO for Section-4 (Barnawa to Mohannagar) of the Hindon River

Space interval j	Distance (km)	Model-1 (DO Sag Diff. Eqn.) DO (mg/L)	Model-2 (Streeter-Phelps) DO (mg/L)	DO difference (mg/L)
0	0.000	0.00	0.00	0.00
1	6.150	0.92	0.87	0.05
2	12.300	1.73	1.63	0.10
3	18.450	2.44	2.31	0.13
4	24.600	3.07	2.92	0.15
5	30.750	3.62	3.45	0.17
6	36.900	4.11	3.93	0.18
7	43.050	4.54	4.35	0.18
8	49.200	4.92	4.73	0.18
9	55.350	5.25	5.07	0.18
10	61.500	5.54	5.36	0.18

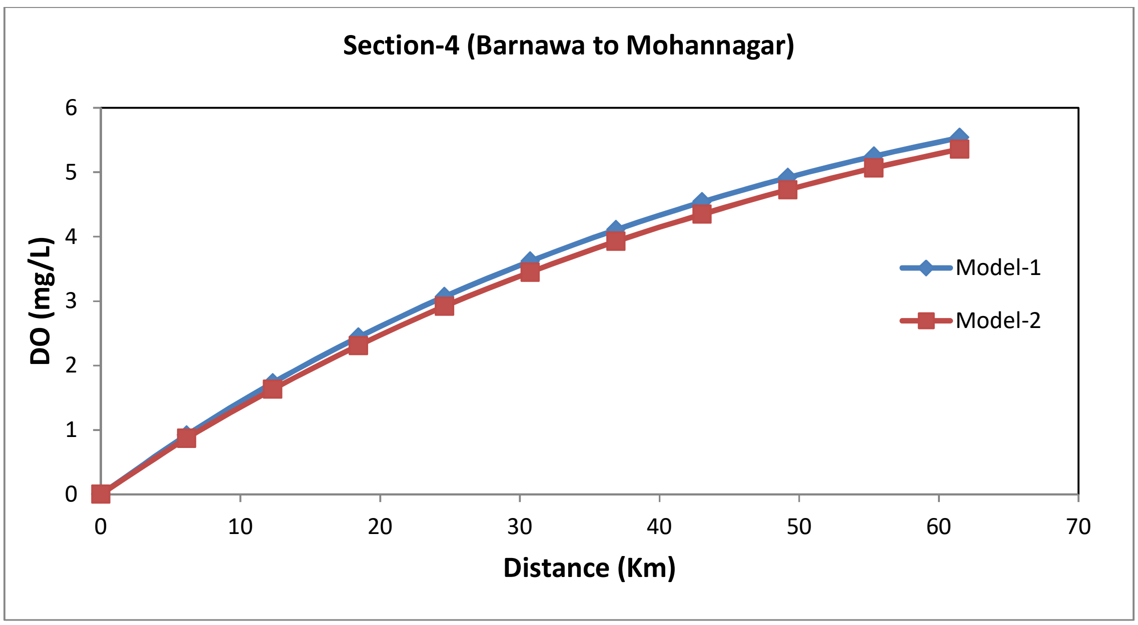


Fig. 16. DO Sag curves for Section-4 of the Hindon River

The performance of the above said models for prediction of DO level at different locations of the river Hindon has been depicted in the Fig. 17 and 18. It is revealed from these figures that DO level can be predicted using these models successfully.

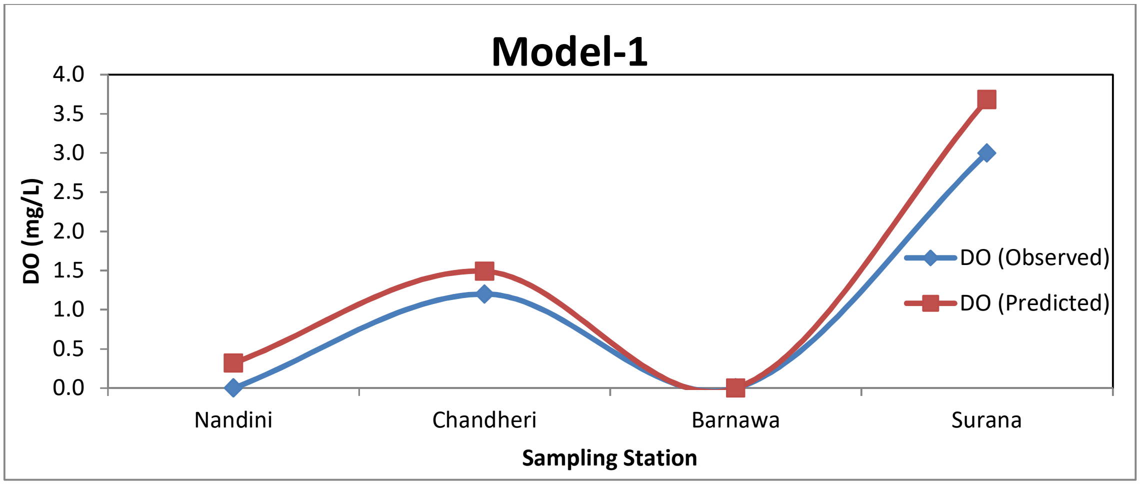


Fig 17. Comparison between observed and predicted values of DO by Model-1 (DO Sag)

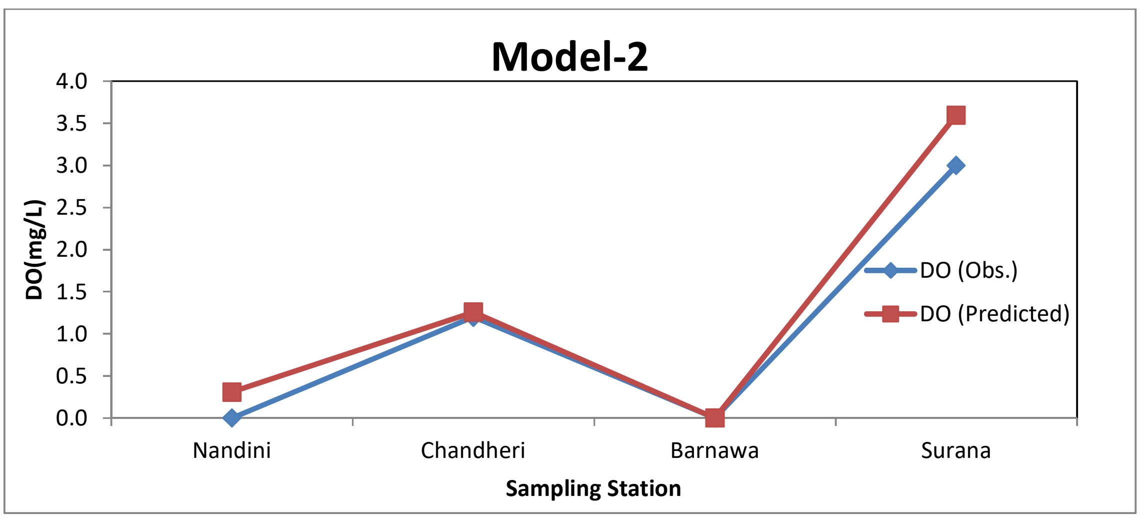


Fig 18. Comparison between observed and predicted values of DO by Model- 2 (Streeter & Phelps, 1925)

4.4 Ground Water Quality of Hindon River Basin

In order to see the impact of various industrial effluents on ground water quality, sixty eight ground water samples [Fig. 1(b)] in pre- and post-monsoon seasons were collected and analyzed for various physico-chemical parameters, bacteriological parameters, metal concentrations and organochlorinated pesticide. The hydro-chemical data for the two sets of ground water samples collected during pre- and post-monsoon seasons is presented in Table 5. Spatial distribution maps of different water quality constituents are presented in the form of contour diagrams in Figs. 19 (a)&(b) to 27(a)&(b).

4.4.1 General Characteristics

The pH values in the collected ground water samples of study area fall within the range 6.5 to 7.8 during pre-monsoon and 6.9 to 8.2 during post-monsoon. The pH values for almost all of the samples are well within the limits prescribed by BIS (2012) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the study area vary from 635 to 3310 μS/cm during pre-monsoon season with more than 60% of the samples having conductivity value above 1000 μS/cm and 362 to 3329 μS/cm during post-monsoon season with about 50% of the samples having conductivity value above 1000 μS/cm. The maximum conductivity value of 3329 μS/cm was observed in the hand pump of village Paragpur, which may be attributed to leaching of wastewater generated from Star paper mill.

The TDS values in the ground water varies from 406 to 2118 mg/L during pre-monsoon season and 232 to 2131 mg/L during post-monsoon season with more than 70% of the samples having TDS values above the acceptable limit of 500 mg/L. Water containing more than 500 mg/L of TDS is not considered acceptable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the acceptable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 2012). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 2012).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water of study area varies from 180 to 650 mg/L during pre-monsoon season and 140 to 702 mg/L during post-monsoon season. Six samples exceed the maximum permissible limit of 600 mg/L during pre-monsoon season while only three samples exceeded the permissible limit during post-monsoon season.

Hardness of water is due to carbonates, sulphates and chlorides of calcium and magnesium. A limit of 200 mg/L as acceptable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 2012). The total hardness values in the study area range from 108 to 818 mg/L during pre-monsoon season and 69 to 950 mg/L during post-monsoon season. The ground water samples of Paragpur, Kapasa, Surana, Muradnagar, Mohannagar and Bisrakh crosses the permissible limit of 600 mg/L.

In ground water of the study area, the values of calcium range from 22 to 217 mg/L during pre-monsoon season and 13 to 123 mg/L during post-monsoon season and the values of magnesium vary from 21 to 225 mg/L during pre-monsoon season and 4.0 to 112 mg/L during post-monsoon season. The acceptable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 2012). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, ground water samples of Kapasa, Charthawal, Surana and Muradnagar exceed the maximum permissible limit of 200 mg/L for calcium and ground water sample of Village Bisrakh exceeds the maximum permissible limit of 100 mg/L for magnesium.

The concentration of sodium in the study area varies from 4.8 to 378 mg/L during pre-monsoon season and 19 to 456 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the study area may be attributed to base-exchange phenomena and causes sodium hazard. Ground water with such high sodium is not suitable for irrigation purpose.

Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. The concentration of potassium in ground water of the study area varies from 1.9 to 365 mg/L during pre-monsoon season and 1.5 to 94 mg/L during post-monsoon season The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, ground water samples of Kapasa, Charthawal, Muzaffar Nagar city, Atali, Kankarkhera, Surana, Muradnagar, Daluhera, Mohannagar, Bisrakh, Kulesra, Surajpur, Dadha and Dadri exceed the guideline level of 10 mg/L in pre-monsoon season.

The concentration of chloride varies from 0 to 482 mg/L during pre-monsoon season and 0 to 620 mg/L during post-monsoon season. Three samples of the study area exceed the acceptable limit of 250 mg/L during both pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as acceptable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 2012). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride.

The concentration of sulphate in the study area varies from 0 to 410 mg/L during pre-monsoon season and 1.7 to 250 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the acceptable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, only one sample exceeds the maximum permissible limit of 400 mg/L during pre-monsoon season and none of the samples during post-monsoon season. The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium.

Nitrate content in drinking water is considered important for its adverse health effects and moderately toxicity. A limit of 45 mg/L has been prescribed by BIS (2012) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases. The nitrate content in the study area varies from 0 to 311 mg/L during pre-monsoon season and 0 to 271 mg/L during post-monsoon season with more than permissible limit of 45 mg/L in eighteen ground water, which may be attributed to contamination by industrial/domestic waste disposal.

The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water. The fluoride content in the ground water of the study area varies from 0.16 to 4.56 mg/L during pre-monsoon season and 0 to 3.60 mg/L during post-monsoon season. Ground water samples of Barnawa, Sardhana,Surana, Muradnagar, Surajpur, Jaitpur Vaishpur and Badalpur exceed the maximum permissible limit of 1.5 mg/L during post-monsoon season which may be attributed to localized geogenic/anthropogenic activities.

From the above discussion, it is clearly indicated that in the study area, the concentration of total dissolved solids was observed above the acceptable limit of 500 mg/L in more than 70% of the samples and exceeded the maximum permissible limit of 2000 mg/L in two samples during pre-monsoon season. The hardness values also observed to exceed the permissible limit in ground water samples of Paragpur, Kapasa, Surana, Muradnagar, Mohannagar and Bisrakh. The concentration of nitrate exceeded the permissible limit in eighteen samples. The concentration of fluoride exceeded the permissible limit in the ground water of Barnawa, Sardhana,Surana, Muradnagar, Surajpur, Jaitpur Vaishpur and Badalpur. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

Table 10. Hydro-chemical characteristics of ground water in Hindon river basin

S. No.	Parameter	Minimum	Maximum	Mean
1.	pH	6.5 (6.9)	7.8 (8.2)	7.0 (7.3)
2.	Conductance, µS/cm	635 (362)	3310 (3329)	1446 (1224)
3.	TDS, mg/L	406 (232)	2118 (2131)	925 (783)
4.	Alkalinity, mg/L	180 (140)	650 (702)	388 (348)
5.	Hardness, mg/L	108 (69)	818 (950)	348 (346)
6.	Chloride, mg/L	0.0 (0.0)	482 (620)	70 (63)
7.	Sulphate, mg/L	0.0 (1.7)	410 (250)	71 (55)
8.	Nitrate, mg/L	0.0 (0.0)	311 (271)	44 (25)
9.	Phosphate, mg/L	0.0 (0.0)	0.14 (0.24)	0.05 (0.03)
10.	Fluoride, mg/L	0.16 (0.00)	4.56 (3.60)	0.89 (0.52)
11.	Sodium, mg/L	19 (4.8)	456 (378)	128 (87)
12.	Potassium, mg/L	1.9 (1.5)	365 (94)	20 (11)
13.	Calcium, mg/L	22 (21)	217 (225)	78 (74)
14.	Magnesium, mg/L	13 (4.0)	123 (112)	37 (39)

(Values given in parenthesis are post-monsoon values)

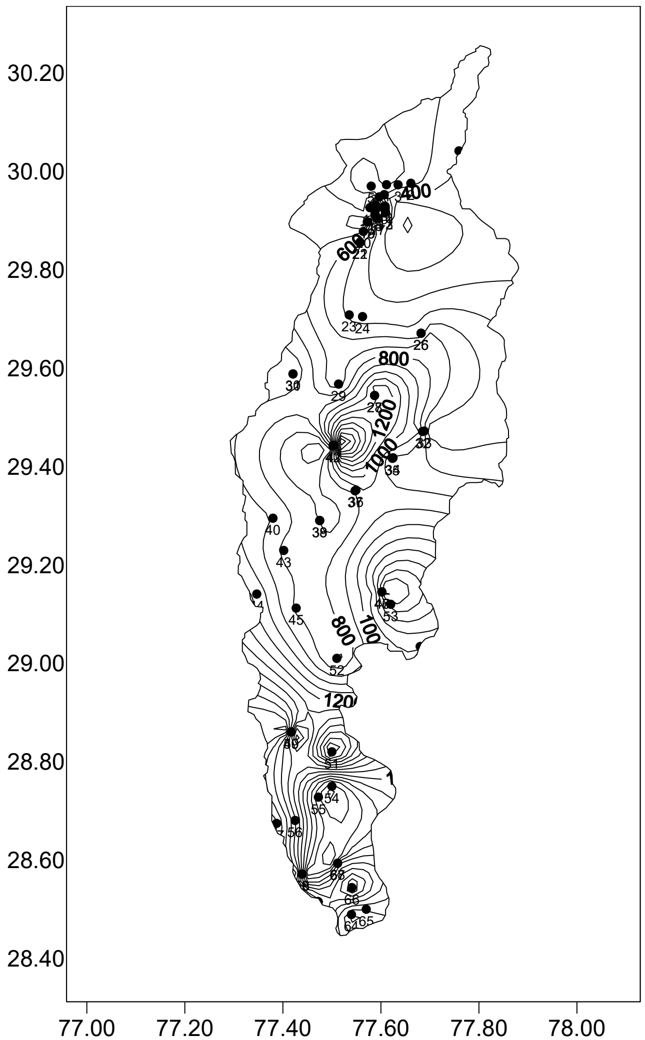


Fig. 19(a) TDS distribution in ground water (Pre-monsoon)

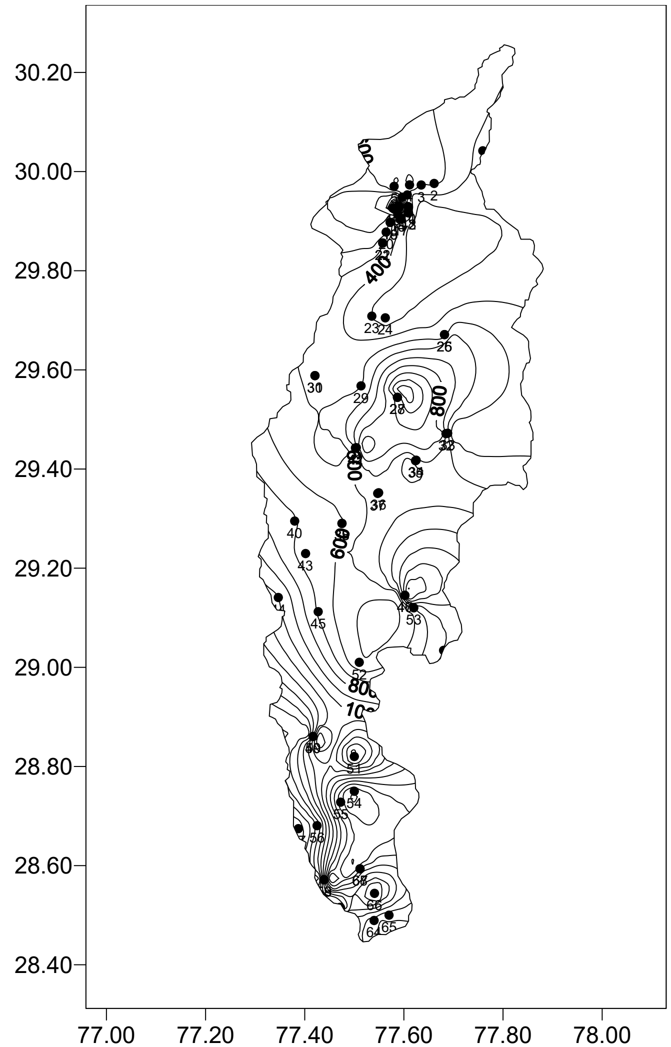


Fig. 19(b) TDS distribution in ground water (Post-monsoon)

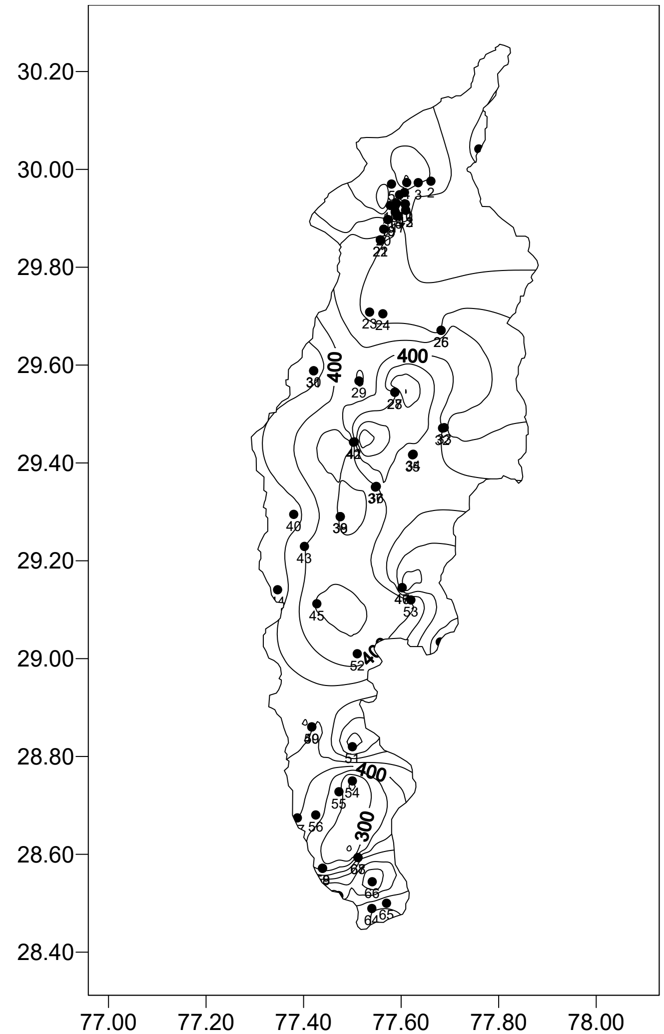


Fig. 20(a) Alkalinity distribution in ground water (Pre-monsoon)

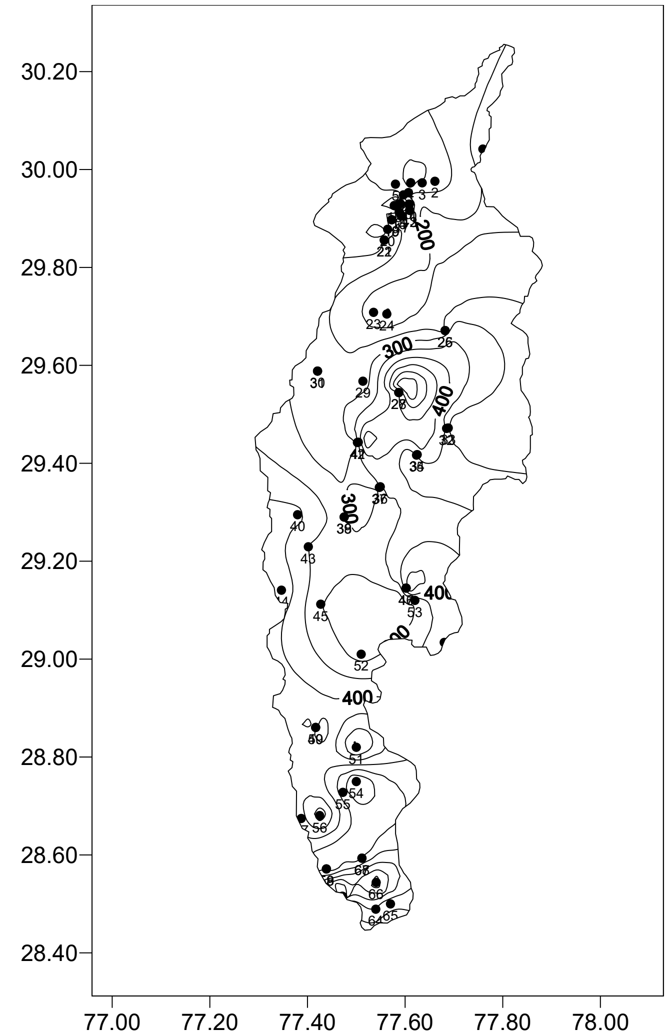


Fig. 20(b) Alkalinity distribution in ground water (Post-monsoon)

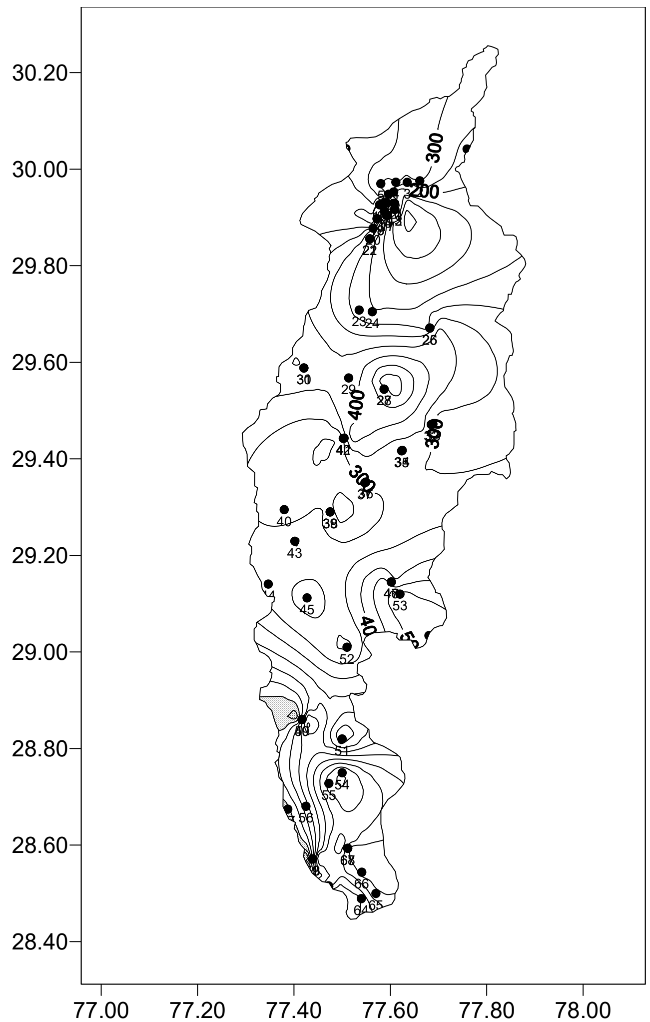


Fig. 21(a) Hardness distribution in ground water (Pre-monsoon)

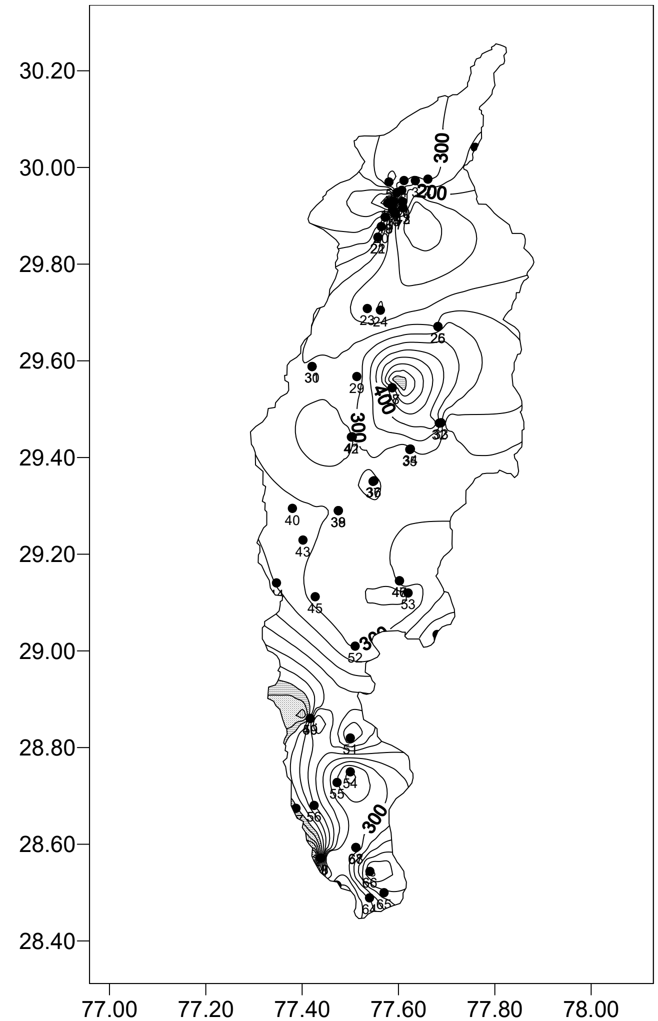


Fig. 21(b) Hardness distribution in ground water (Post-monsoon)

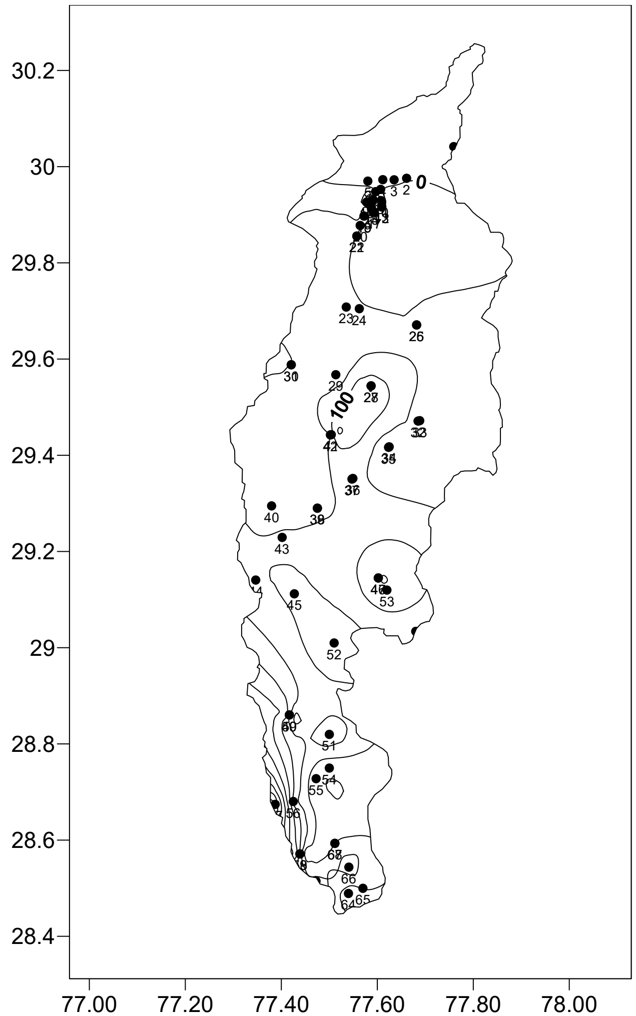


Fig. 22(a) Chloride distribution in ground water (Pre-monsoon)

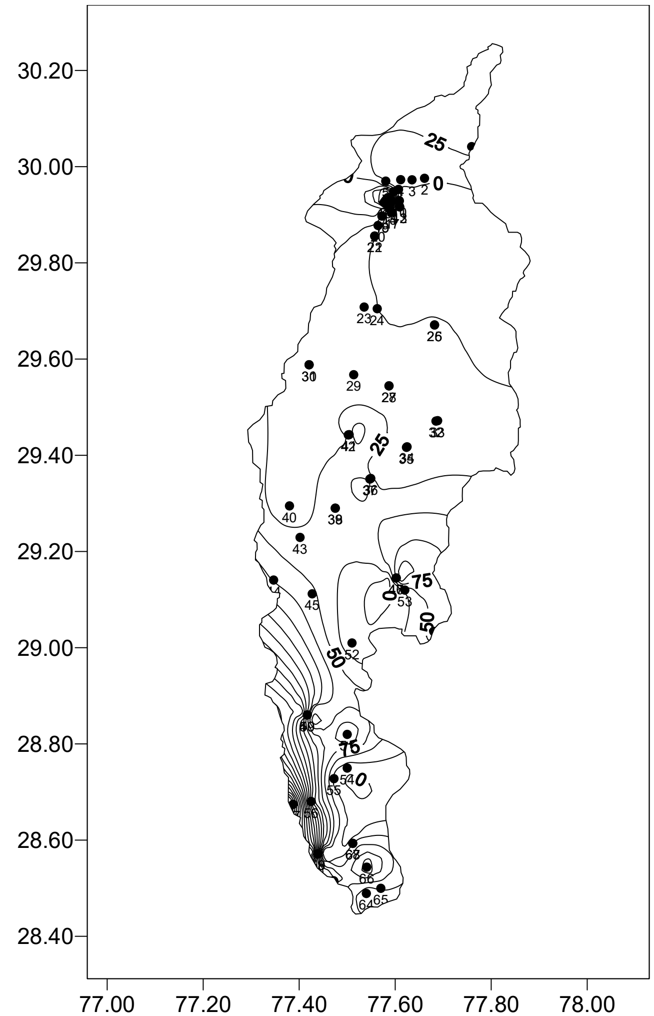


Fig. 22(b) Chloride distribution in ground water (Post-monsoon)

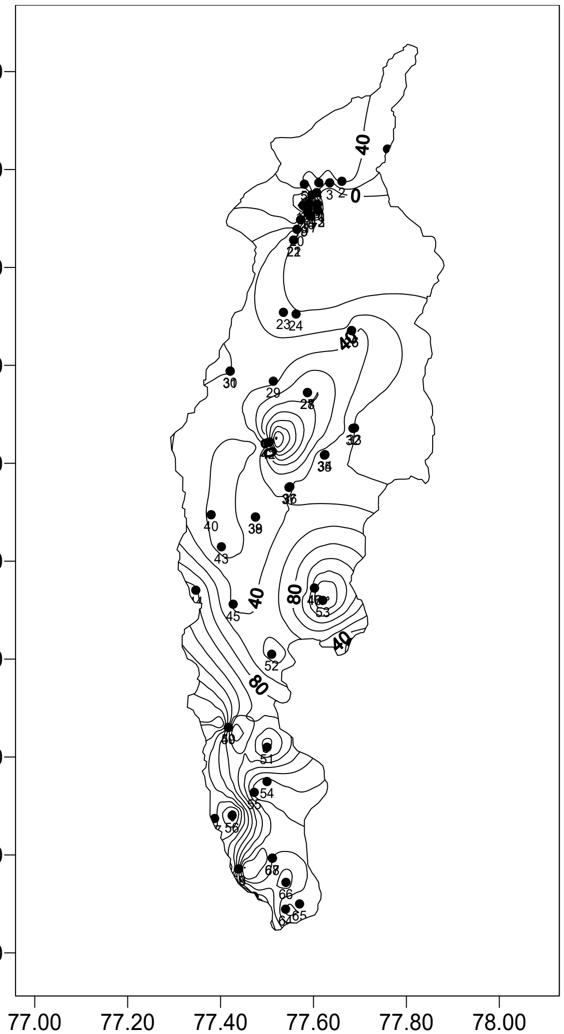


Fig. 23(a) Sulphate distribution in ground water (Pre-monsoon)

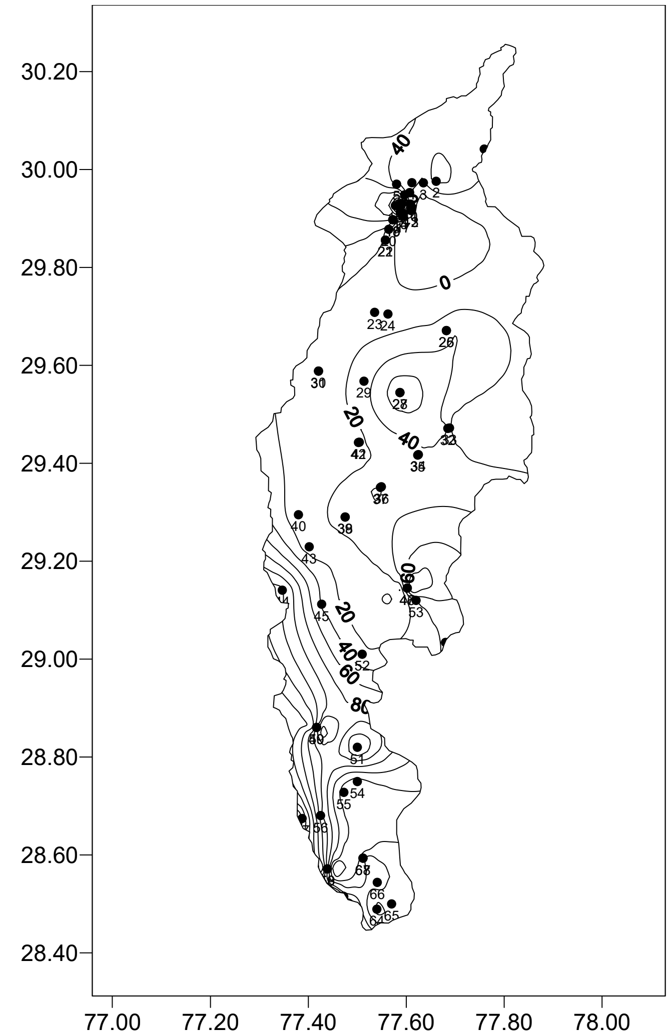


Fig. 23(b) Sulphate distribution in ground water (Post-monsoon)

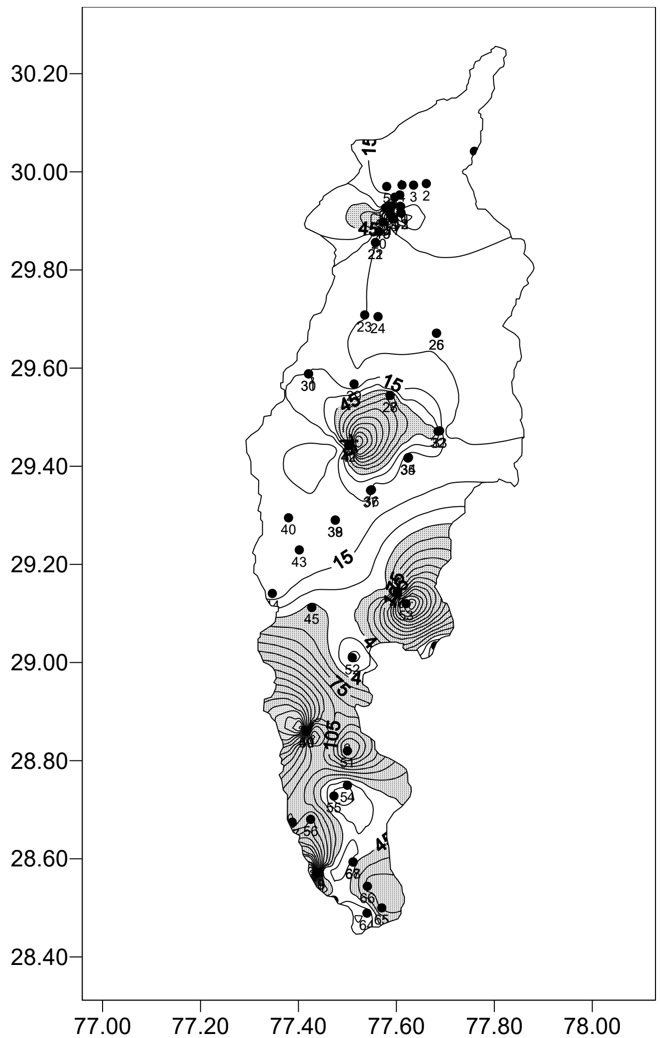


Fig. 24(a) Nitrate distribution in ground water (Pre-monsoon)

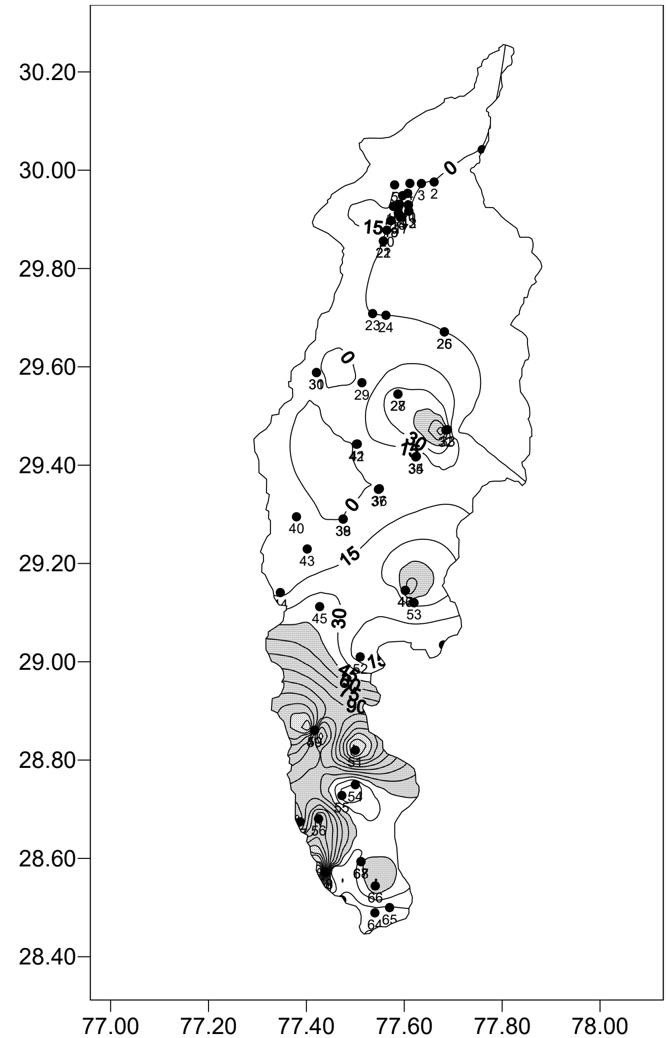


Fig. 24(b) Nitrate distribution in ground water (Post-monsoon)

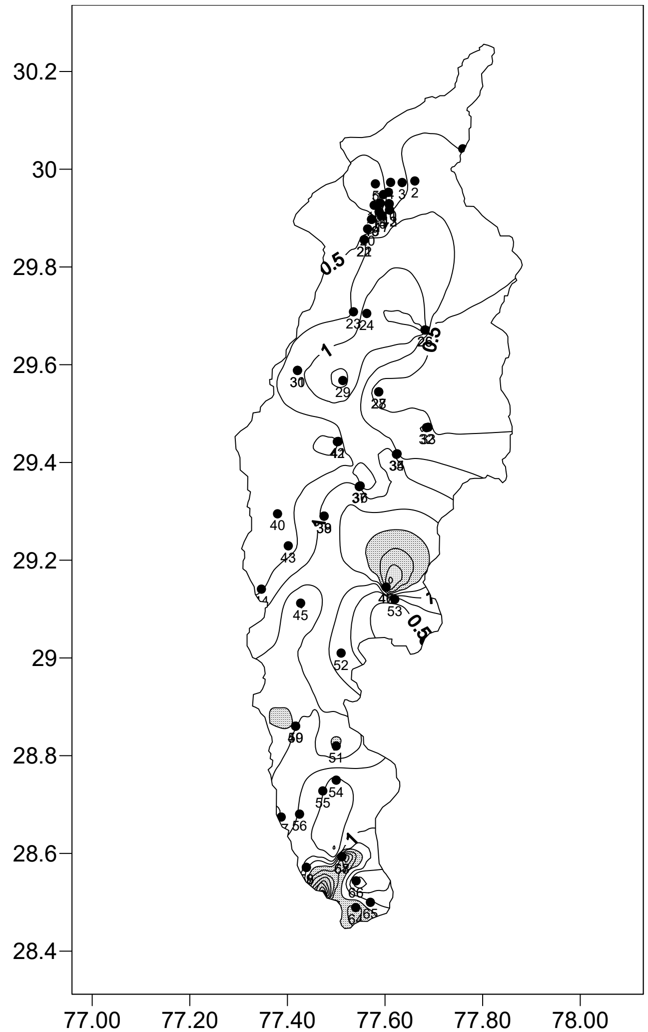


Fig. 25(a) Fluoride distribution in ground water (Pre-monsoon)

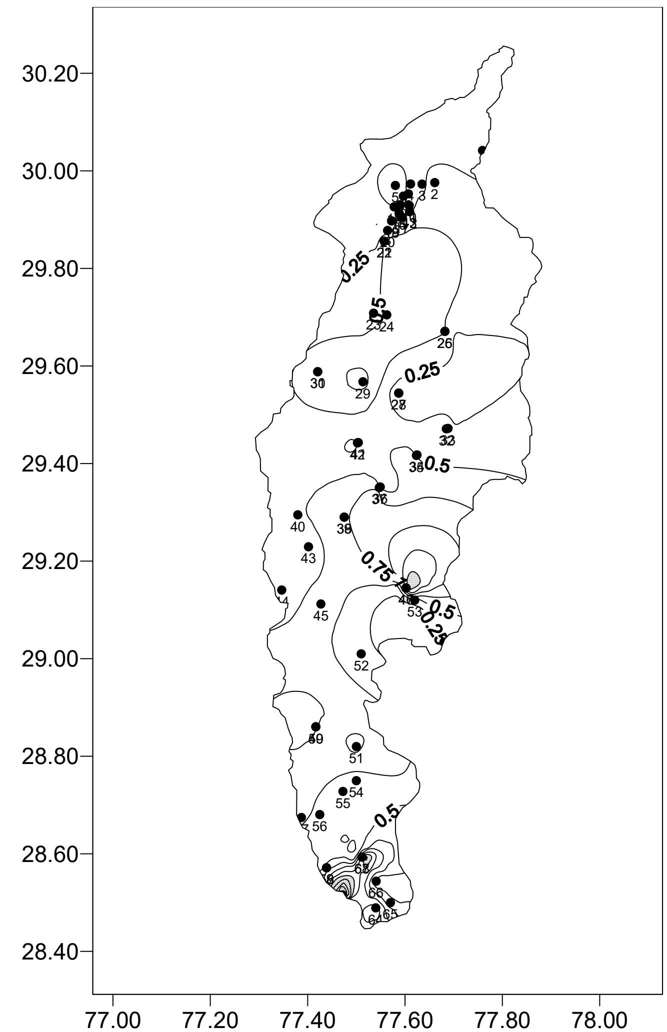


Fig. 25(b) Fluoride distribution in ground water (Post-monsoon)

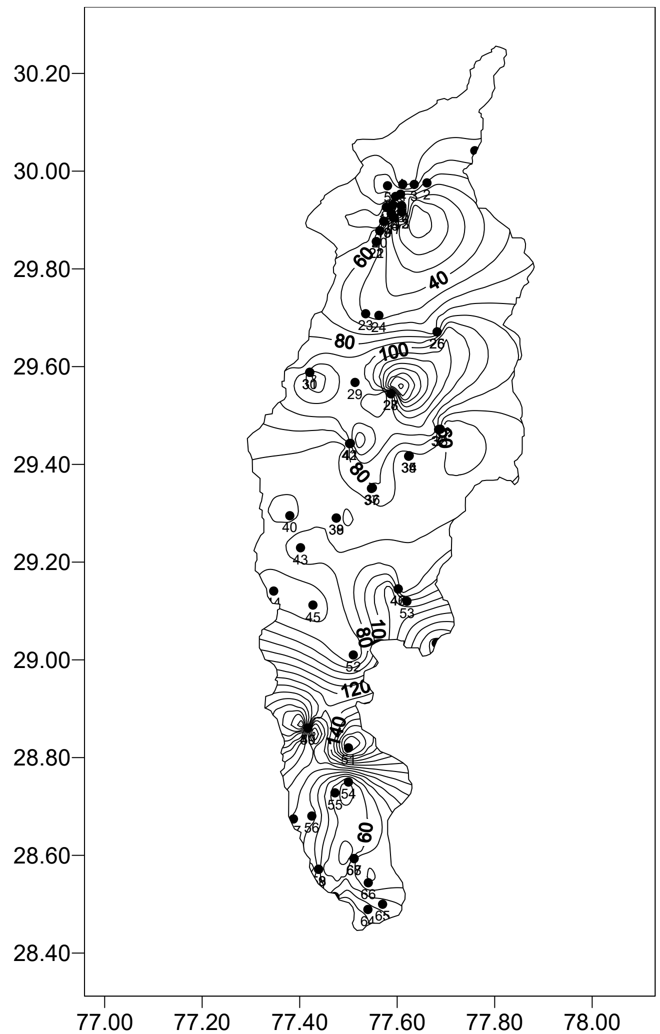


Fig. 26(a) Calcium distribution in ground water (Pre-monsoon)

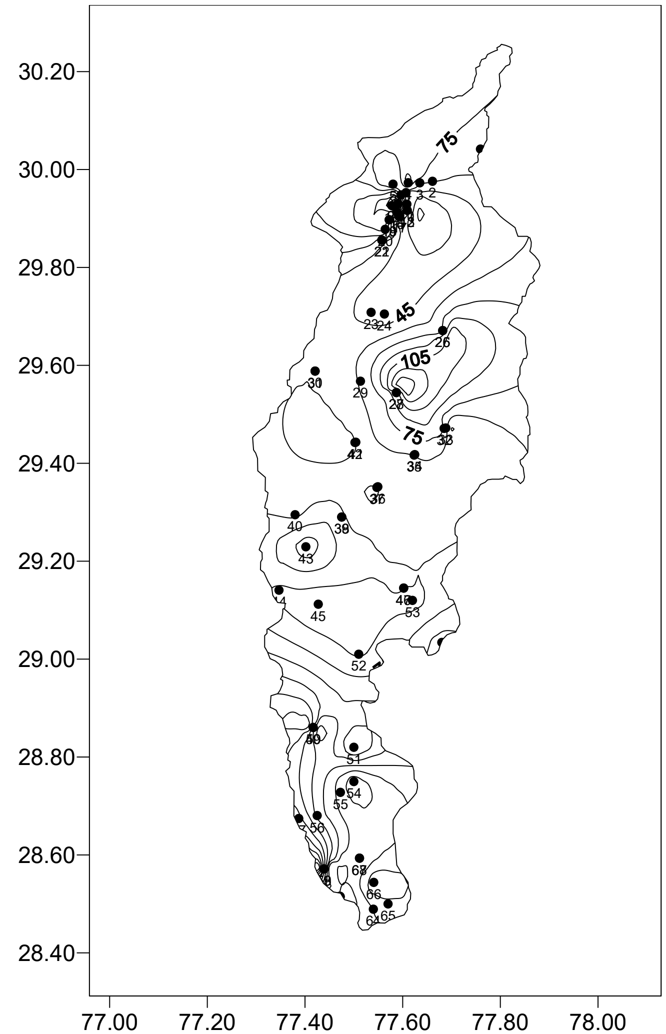


Fig. 26(b) Calcium distribution in ground water (Post-monsoon)

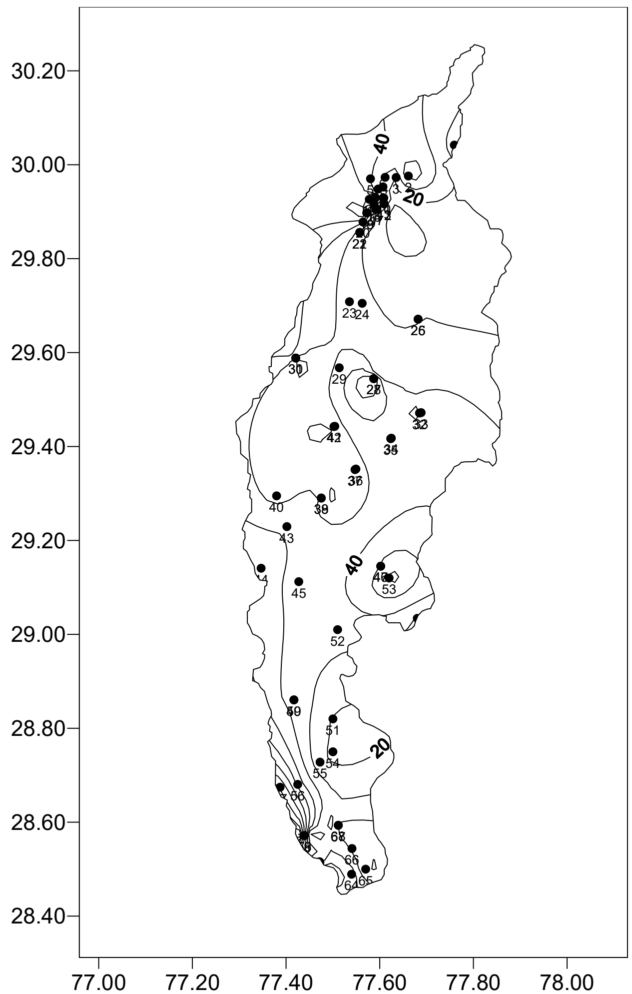


Fig. 27(a) Magnesium distribution in ground water (Pre-monsoon)

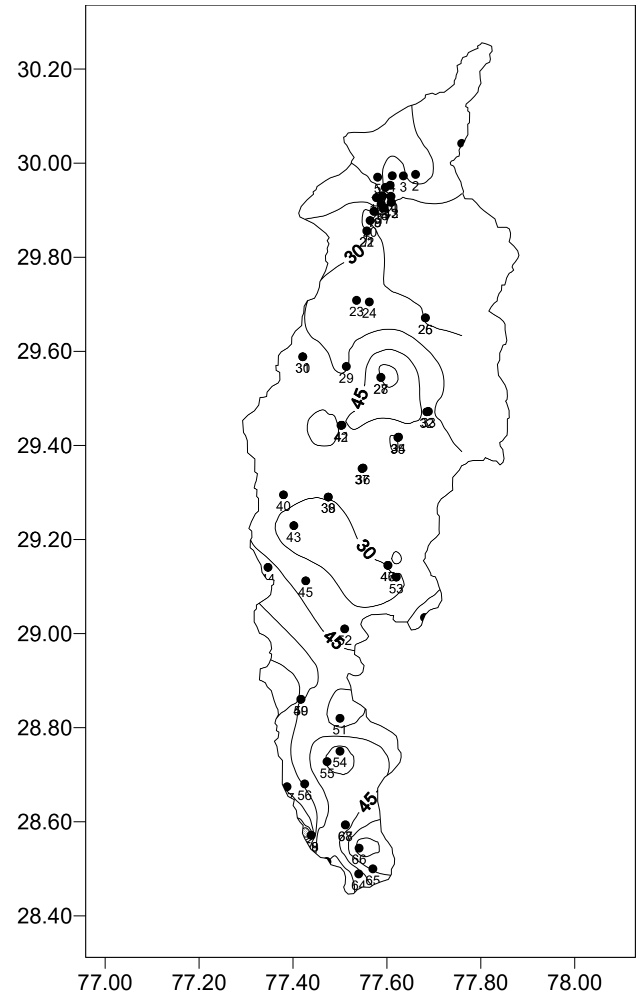


Fig. 27(b) Magnesium distribution in ground water (Post-monsoon)

4.4.2 Bacteriological Parameters

In water quality control technology, the principal indicator of suitability of water for domestic, industrial or other uses is the coliform group of bacteria. The density of coliform group is the criteria for the extent of contamination and has been the basis for bacteriological water quality standard. Further, the presence of faecal colifirms in water is the indicator of a potential public health problem, because faecal matter is a source of pathogenic bacteria and viruses. The faecal coliform bacteria contaminate water through percolation from contamination sources (domestic sewage and septic tank) and also because of poor sanitary system. The indiscriminate land disposal of domestic waste on surface and improper disposal of solid waste further aggravate the problem of bacterial contamination in water. The collected samples were analysed for bacteriological parameters viz; Total Coliform and Faecal Coliform. The result of bacteriological analysis is given in Table 11. The result shows that the bacterial contamination in thirteen ground water samples during pre-monsoon season and in five ground water samples during post-monsoon seasons exceeds the permissible limit.

Table 11. Bacteriological contamination in ground water of River Hindon Basin (Pre- and Post-monsoon 2012)							
S.No.	**Location**	**Source**	**Depth**	**Pre-monsoon**		**Post-monsson**	
			m	**Total Coliform**	**Feacal Coliform**	**Total Coliform**	**Feacal Coliform**
				per 100 ml	per 100 ml	per 100 ml	per 100 ml
1	Fatehpur	HP	40	ND	ND	ND	ND
2	Gagalheri	HP	40	ND	ND	ND	ND
3	Kailashpur	HP	40	ND	ND	ND	ND
4	Naugazapeer	HP	50	ND	ND	ND	ND
5	Mahipura	HP	40	ND	ND	ND	ND
6	Beherki	HP	33	ND	ND	ND	ND
7	Ghogerki	HP	36	ND	ND	ND	ND
8	Paragpur	HP	17	ND	ND	ND	ND
9	Paragpur	HP	33	ND	ND	ND	ND
10	Hasanpura	HP	36	ND	ND	ND	ND
11	Hasanpura	HP	32	ND	ND	ND	ND
12	Kapasa	HP	36	ND	ND	ND	ND
13	Kapasa	HP	13	ND	ND	ND	ND
14	Tapri	HP	36	ND	ND	ND	ND
15	Tapri	HP	25	ND	ND	ND	ND
16	Shekhpura Kadim	HP	36	ND	ND	ND	ND
17	Lakhnaur	HP	36	ND	ND	ND	ND
18	Mubarikpur	HP	36	ND	ND	ND	ND
19	Mubarikpur	HP	15	ND	ND	ND	ND
20	Nanandi	HP	36	ND	ND	ND	ND
21	Sadauli Hariya	HP	36	ND	ND	ND	ND
22	Sadauli Hariya	HP	13	ND	ND	ND	ND
23	Bargaon	HP	36	23	ND	ND	ND
24	Maheshpur	HP	36	ND	ND	ND	ND
25	Deoband	HP	15	9	9	ND	ND
26	Deoband	HP	36	ND	ND	ND	ND
27	Charthawal	HP	36	4	4	ND	ND
28	Charthawal	HP	20	ND	ND	ND	ND
29	Biralsi	HP	36	ND	ND	ND	ND
30	Thanabhawan	HP	36	9	9	ND	ND
31	Thanabhawan	HP	27	23	9	ND	ND
32	Muzaffar Nagar city	HP	15	ND	ND	ND	ND
33	Muzaffar Nagar city	HP	36	ND	ND	ND	ND
34	Tawli	HP	20	ND	ND	ND	ND
35	Tawli	HP	40	ND	ND	ND	ND
36	Shahpur	HP	40	240	240	23	23
37	Shahpur	HP	40	ND	ND	ND	ND
38	Budhana	HP	40	ND	ND	ND	ND
39	Budhana	HP	36	ND	ND	ND	ND
40	Jogiyakhera	HP	83	ND	ND	ND	ND
41	Atali	HP	12	ND	ND	ND	ND
42	Atali	HP	46	ND	ND	ND	ND
43	Nirpura	HP	46	ND	ND	ND	ND
44	Bamnauli	HP	66	ND	ND	ND	ND
45	Barnawa	HP	66	ND	ND	ND	ND
46	Sardhana	HP	15	23	23	ND	ND
47	Sardhana	HP	27	ND	ND	ND	ND
48	Kankarkhera	HP	40	ND	ND	ND	ND
49	Surana	HP	10	ND	ND	ND	ND
50	Surana	HP	40	ND	ND	ND	ND
51	Muradnagar	HP	40	93	93	ND	ND
52	Daluhera	HP	40	ND	ND	ND	ND
53	Daluhera	HP	10	ND	ND	ND	ND
54	Muradnagar	HP	23	ND	ND	ND	ND
55	Basantpur Sainthali	HP	40	ND	ND	ND	ND
56	Harbansnagar	HP	40	ND	ND	ND	ND
57	Mohannagar	HP	40	23	23	ND	ND
58	Bisrakh	HP	26	ND	ND	ND	ND
59	Bisrakh	HP	12	1100	1100	240	240
60	Kulesra	HP	40	ND	ND	ND	ND
61	Kulesra	HP	13	ND	ND	ND	ND
62	Surajpur	HP	17	2400	2400	240	240
63	Surajpur	HP	33	460	460	240	240
64	Jaitpur Vaishpur	HP	40	23	23	ND	ND
65	Dadha	HP	36	93	93	460	460
66	Dadri	HP	15	ND	ND	ND	ND
67	Badalpur	HP	13	ND	ND	ND	ND
68	Badalpur	HP	40	ND	ND	ND	ND
HP = Handpump, ND = Not detected							

4.4.3 Heavy Metals

Heavy metals in ground water have a considerable significance due to their toxicity and adsorption behaviour. Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. Despite the presence of trace concentrations of Cr, Mn, Co, Cu and Zn in the aquatic environment, which is essential to a number of life processes, high concentrations of these metals become toxic. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the study area is given in Table 12. The distribution of different metals graphically is shown in Fig. 28 to 35. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

Iron (Fe): The concentration of iron in the ground water of the study area ranges from 0.002 to 3.197 mg/L during pre-monsoon season and 0.006 to 0.263 mg/L during post-monsoon season. The Bureau of Indian Standards has recommended 0.3 mg/L as the acceptable limit and no relaxation has been given for the maximum permissible limit for iron in drinking water (BIS, 2012). WHO has prescribed 0.3 mg/L as the acceptability threshold value for iron (WHO, 2011). It is evident from the results that 20% of the samples of the study area exceed the acceptable limit of 0.3 mg/L during both pre- and post-monsoon season. The maximum concentration of iron at Paragpur may be attributed to leaching of wastes from Nagdev nala and Star paper mill drain during pre- and post-monsoon seasons.

It is a known fact that iron in trace amounts is essential for nutrition. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity. The objection to iron in the distribution system is not due to health reason but to staining of laundry and plumbing fixtures and appearance. Taste and order problems may be caused by filamentous organism that prey on iron compounds (frenothrix, gallionella and leptothrix are called iron bacteria), originating another consumer's objection (red water). The presence of iron bacteria may clog well screens or develop in the distribution system, particularly when sulphate compounds in addition to iron may be subjected to chemical reduction.

Manganese (Mn): The concentration of manganese ranges from 0.002 to 0.975 mg/L during pre-monsoon season and 0.008 to 1.492 mg/L during post-monsoon season. Manganese is an essential trace nutrient for plants and animals, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water. A concentration of 0.1 mg/L has been recommended as a acceptable limit and 0.3 mg/L as the permissible limit for drinking water (BIS, 2012). WHO has prescribed 0.1 mg/L as the acceptability threshold value and 0.4 mg/L as health based value (WHO, 2011). It is evident from the results that 60% of the samples of the study area fall within the acceptable limit of 0.1 mg/L and nine samples exceeds the maximum permissible limit of 0.3 mg/L during pre-monsoon season while 30% of the samples fall within the acceptable limit of 0.1 mg/L and twelve samples exceeds the maximum permissible limit during post-monsoon season. The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

Copper (Cu): The concentration of copper ranges from 0.004 to 0.619 mg/L during pre-monsoon season and 0.001 to 0.798 mg/L during post-monsoon season. The Bureau of Indian Standards has recommended 0.05 mg/L as the acceptable limit and 1.5 mg/L as the permissible limit in the absence of alternate source (BIS, 2012). Beyond 0.05 mg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2.0 mg/L as the provisional guideline value for drinking purpose (WHO, 2011). In the study area, five samples exceed the acceptable limit of 0.05 mg/L in pre-monsoon season and four exceeds in post-monsoon season.

Nickel (Ni): The concentration of nickel ranges from 0.001 to 0.057 mg/L during pre-monsoon season and 0.002 to 0.061 mg/L during post-monsoon season. The Bureau of Indian Standards has recommended 0.02 mg/L as the acceptable limit (BIS, 2012). World Health Organization has recommended 0.07 mg/L as the guideline value for drinking purposes (WHO, 2011). In this range it is not harmful in drinking water. In the study area, about 25% of the samples in pre-monsoon season and 15% samples in post-monsoon season exceed the acceptable limit of 0.2 mg/L.

Chromium (Cr): The concentration of chromium ranges from 0.002 to 0.082 mg/L during pre-monsoon season and 0.002 to 0.066 mg/L during post-monsoon season. A concentration of 0.05 mg/L has been recommended as a acceptable limit for drinking water (BIS, 2012). WHO has also prescribed 0.05 mg/L as the guideline value for drinking water (WHO, 2011). In the study area, the concentration of Cr in ground water samples of Nirpura, Bisrakh, Kulesra and Surajpur exceed permissible limit for drinking water during pre-monsoon season, which may be attributed to leaching of chrome bearing waste from industries. During post-monsoon season, the concentration of Cr in almost all the ground water samples of study area falls within the permissible limit for drinking water.

Hexavalent chromium has a deleterious effect on the liver, kidney, and respiratory organs with hemorrhagic effects, dermatitis, and ulceration of the skin for chronic and subchronic exposure. Municipal wastewater release considerable amount of chromium into the environment. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges. The pathways of chromium contribution to ground water are that the chromium containing industrial effluent discharged into stream, the hexavalent state chromium may be reduced to trivalent state and later adsorbed on the suspended particulate. In case, it could not be adsorbed, the chromium remain in the form of colloidal suspension, may precipitate and become part of stream sediment, from where it may reach to ground water through percolation containing shallow aquifers.

Lead (Pb): In the study area, the concentration of lead was not observed during pre-monsoon season but ranges from ND to 0.160 mg/L during post-monsoon season. The Bureau of Indian Standards has prescribed 0.01 mg/L lead as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 0.01 mg/L as guideline value for drinking water (WHO, 2011). In the study area, all the samples fall within the acceptable limit for drinking water as prescribed by BIS (2012) during pre-monsoon season and about 75% of samples exceeded the limit during post-monsoon season.

Lead is not considered an essential nutritional element and is a cumulative poison to humans. Acute lead poisoning is extremely rare. The typical symptoms of advanced lead poisoning are constipation, anemia, gastrointestinal disturbance, tenderness and gradual paralysis in muscles, specifically arms with possible cases of lethargy and moroseness. The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. It may be noted that the use of soft water of slightly acidic pH and the use of lead pipes in service and domestic water lines may provide higher concentrations of lead at the consumers's tap, particularly when the water use is minimal in the household (overnight still water in pipes).

Cadmium (Cd): The concentration of cadmium ranges from 0.001 to 0.010 mg/L during pre-monsoon season and 0.001 to 0.008 mg/L during post-monsoon season. The Bureau of Indian Standards has prescribed 0.003 mg/L cadmium as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 0.003 mg/L cadmium as the guideline value for drinking water (WHO, 2011). The drinking water having more than 3 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. In the study area, more than 40% samples during pre-monsoon season and about 25% of samples during post-monsoon season exceeded the acceptable limit for drinking water as prescribed by BIS (2012).

Zinc (Zn): The concentration of zinc in the study area ranges from 0.009 to 1.842 mg/L during pre-monsoon season and 0.001 to 1.347 mg/L during post-monsoon season. The Bureau of Indian Standards has prescribed 5.0 mg/L zinc as the acceptable limit and 15 mg/L as the permissible limit for drinking water (BIS, 2012). WHO has prescribed 3.0 mg/L as the guideline value for drinking water (WHO, 2011). In the study area, all the samples were found within the acceptable limit prescribed by BIS (2012) and WHO (2011).

From the above results, it is quite clear that the presence of heavy metals has been recorded in many location and the water quality standards have been violated for iron (15 samples), manganese (12 samples), Nickel (17 samples), chromium (4 samples), lead (51 samples) and cadmium (31 out of collected 68 samples during pre- and post-monsoon seasons.

Table 12. Metal concentration of ground water in Hindon river basin

S. No.	Metal	Minimum	Maximum	Mean
1.	Fe, mg/L	0.002 (0.006)	3.197 (2.632)	0.248 (0.209)
2.	Mn, mg/L	0.002 (0.008)	0.975 (1.492)	0.150 (0.205)
3.	Cu, mg/L	0.004 (0.001)	0.619 (0.798)	0.022 (0.030)
4.	Ni, mg/L	0.001 (0.002)	0.057 (0.061)	0.014 (0.014)
5.	Cr, mg/L	0.002 (0.002)	0.082 (0.066)	0.036 (0.012)
6.	Pb, mg/L	ND (ND)	ND (0.160)	ND (0.067)
7.	Cd, mg/L	0.001 (0.001)	0.010 (0.008)	0.004 (0.003)
8.	Zn, mg/L	0.009 (0.001)	1.842 (1.347)	0.246 (0.200)

(values given in parenthesis are post-monsoon values)

4.4.4 Pesticides

During present investigation, ground water samples collected from the Hindon river basin were analysed for nine organo-chlorinated pesticides (Aldrin, α-BHC, β-BHC, γ-BHC, δ-BHC, DDD, DDE, Endosulphan and Methoxychlor) which are used in the study area. The result of pesticides analysis is given in Table 13&14. Out of the nine chlorinated pesticides analysed, only one pesticide γ-BHC has been detected in the ground water of Thanabhawan and Muzaffarnagar city more than the permissible limit of 2.0 μg/L in pre-monsoon season. Three pesticides α-BHC, γ-BHC and Methoxychlor were detected in the ground water of Hasanpura, Shekhpura Kadim, Muradnagar and Dadha in post-monsoon season with concentration of α-BHC exceeding the permissible limit of 0.01 μg/L. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water.

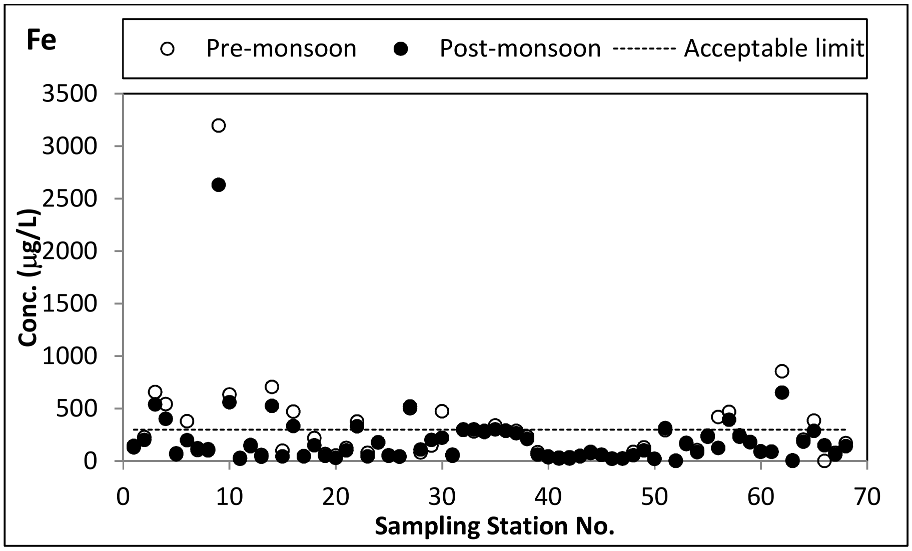


Fig. 28 Distribution of iron at different sampling locations

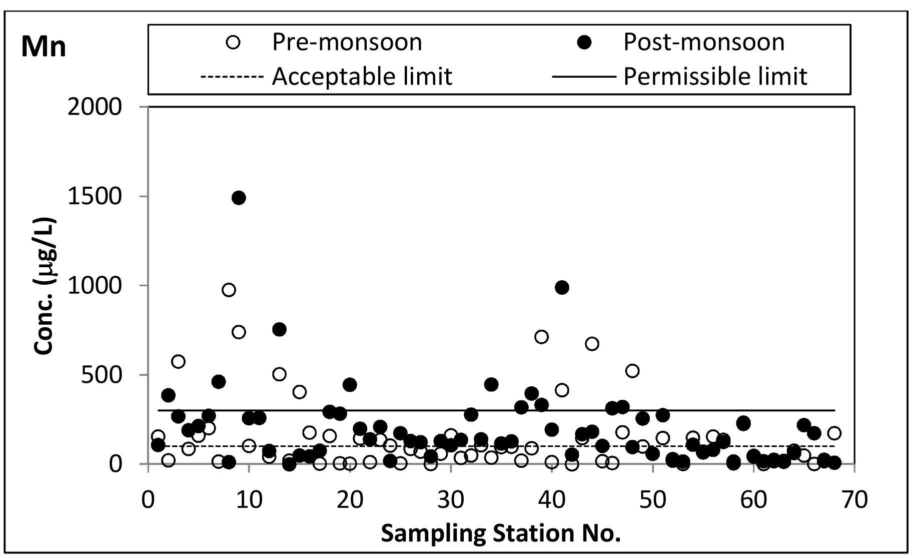


Fig. 29 Distribution of manganese at different sampling locations

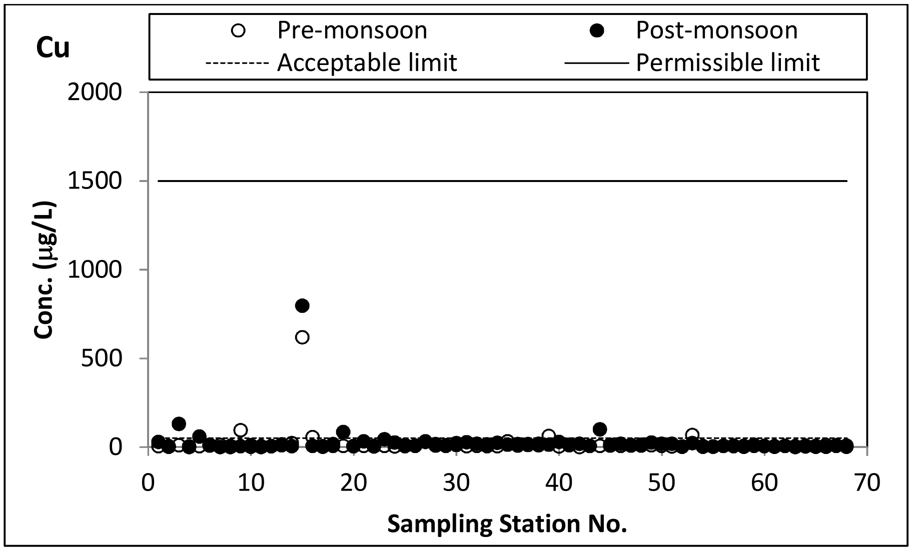


Fig. 30 Distribution of copper at different sampling locations

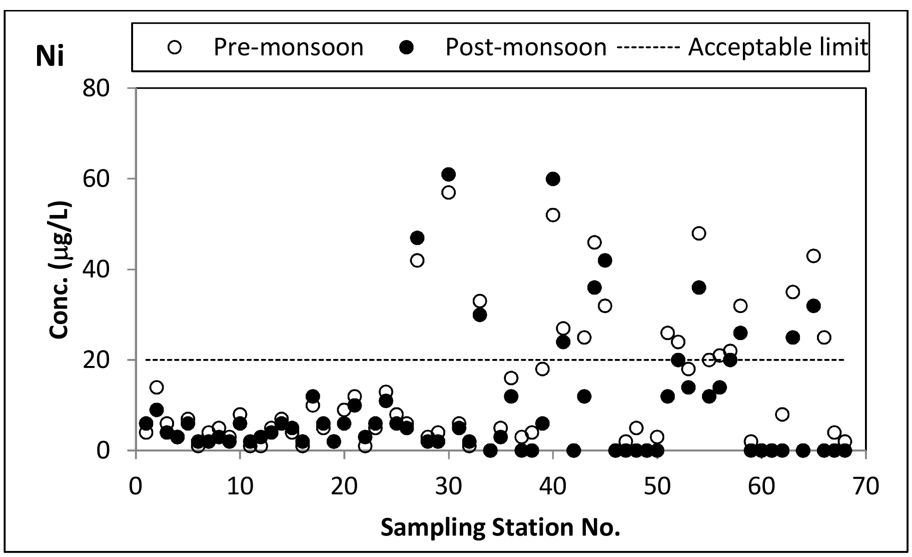


Fig. 31 Distribution of nickel at different sampling locations

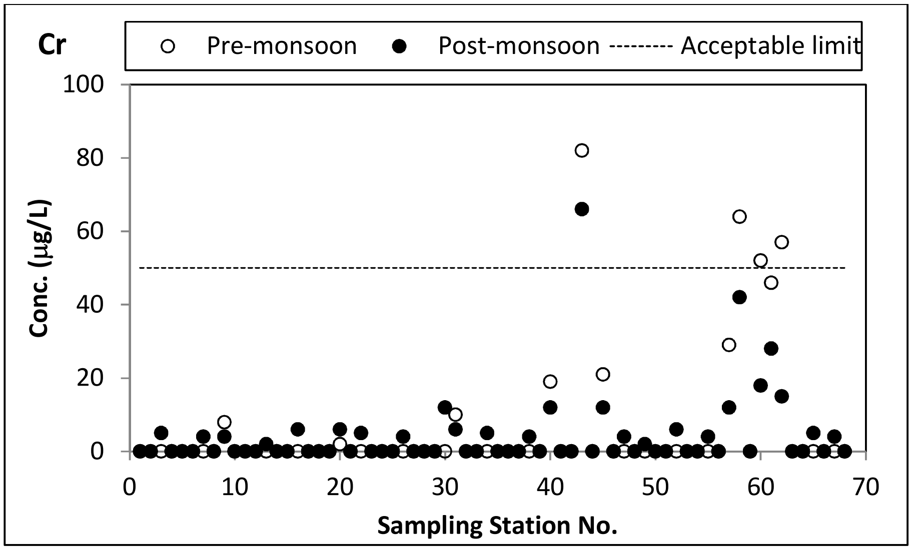


Fig. 32 Distribution of chromium at different sampling locations

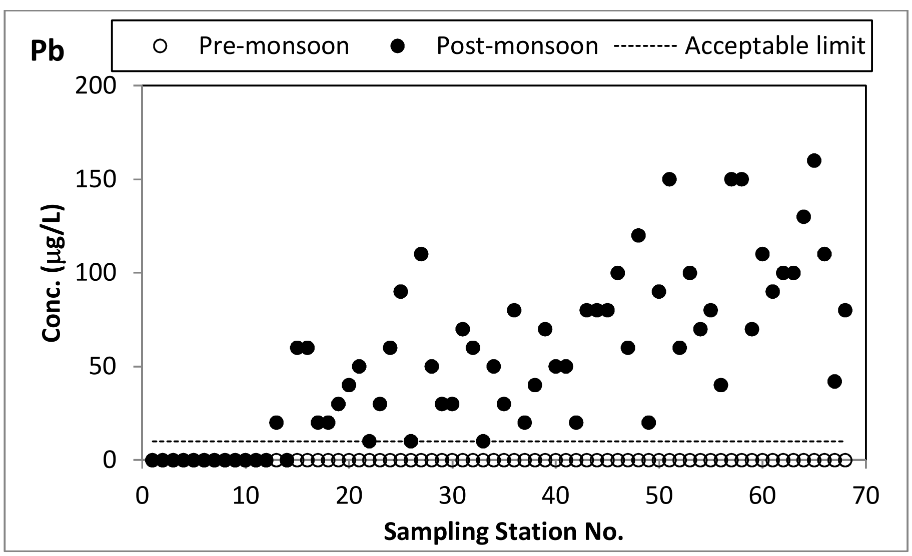


Fig. 33 Distribution of lead at different sampling locations

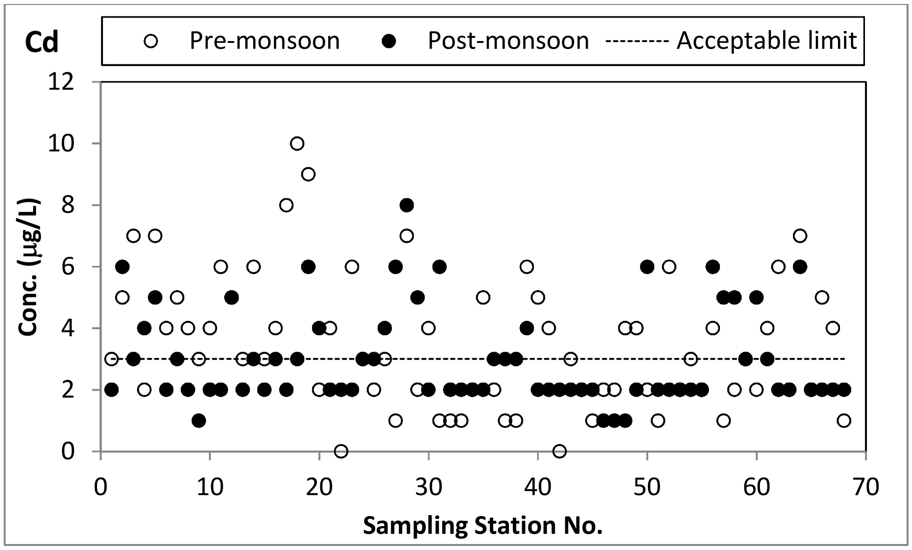


Fig. 34 Distribution of cadmium at different sampling locations

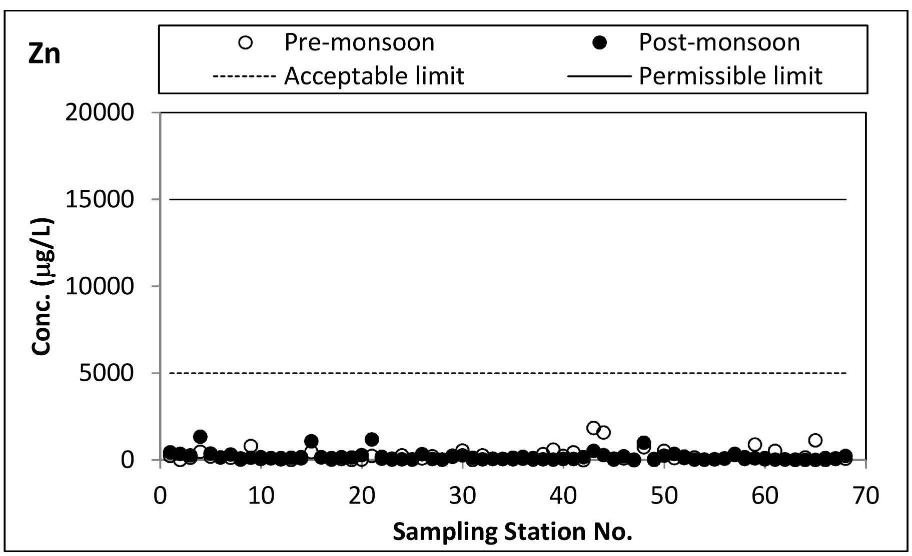


Fig. 35 Distribution of zinc at different sampling locations

Table 13. Pesticides contamination in ground water of Hindon river basin (Pre-monsoon 2012)

S.No.	Location	Source	Depth	Organo-chlorinated Pesticides (µg/L)								
				Aldrin	α-□BHC	β-BHC	γ-BHC	δ -BHC	Endosulphan	DDD	DDE	Methoxychlor
1	Fatehpur	HP	40	~	~	~	~	~	~	~	~	~
2	Gagalheri	HP	40	~	~	~	~	~	~	~	~	~
3	Kailashpur	HP	40	~	~	~	~	~	~	~	~	~
4	Naugazapeer	HP	50	~	~	~	~	~	~	~	~	~
5	Mahipura	HP	40	~	~	~	~	~	~	~	~	~
6	Beherki	HP	33	~	~	~	~	~	~	~	~	~
7	Ghogerki	HP	36	~	~	~	~	~	~	~	~	~
8	Paragpur	HP	17	~	~	~	~	~	~	~	~	~
9	Paragpur	HP	33	~	~	~	~	~	~	~	~	~
10	Hasanpura	HP	36	~	~	~	~	~	~	~	~	~
11	Hasanpura	HP	32	~	~	~	~	~	~	~	~	~
12	Kapasa	HP	36	~	~	~	~	~	~	~	~	~
13	Kapasa	HP	13	~	~	~	~	~	~	~	~	~
14	Tapri	HP	36	~	~	~	~	~	~	~	~	~
15	Tapri	HP	25	~	~	~	~	~	~	~	~	~
16	Shekhpura Kadim	HP	36	~	~	~	~	~	~	~	~	~
17	Lakhnaur	HP	36	~	~	~	~	~	~	~	~	~
18	Mubarikpur	HP	36	~	~	~	~	~	~	~	~	~
19	Mubarikpur	HP	15	~	~	~	~	~	~	~	~	~
20	Nanandi	HP	36	~	~	~	~	~	~	~	~	~
21	Sadauli Hariya	HP	36	~	~	~	~	~	~	~	~	~
22	Sadauli Hariya	HP	13	~	~	~	~	~	~	~	~	~
23	Bargaon	HP	36	~	~	~	~	~	~	~	~	~
24	Maheshpur	HP	36	~	~	~	~	~	~	~	~	~
25	Deoband	HP	15	~	~	~	~	~	~	~	~	~
26	Deoband	HP	36	~	~	~	~	~	~	~	~	~
27	Charthawal	HP	36	~	~	~	~	~	~	~	~	~
28	Charthawal	HP	20	~	~	~	~	~	~	~	~	~
29	Biralsi	HP	36	~	~	~	~	~	~	~	~	~
30	Thanabhawan	HP	36	~	~	~	20.148	~	~	~	~	~
31	Thanabhawan	HP	27	~	~	~	~	~	~	~	~	~
32	Muzaffar Nagar city	HP	15	~	~	~	6.345	~	~	~	~	~
33	Muzaffar Nagar city	HP	36	~	~	~	5.559	~	~	~	~	~
34	Tawli	HP	20	~	~	~	~	~	~	~	~	~
35	Tawli	HP	40	~	~	~	~	~	~	~	~	~
36	Shahpur	HP	40	~	~	~	~	~	~	~	~	~
37	Shahpur	HP	40	~	~	~	~	~	~	~	~	~
38	Budhana	HP	40	~	~	~	~	~	~	~	~	~
39	Budhana	HP	36	~	~	~	~	~	~	~	~	~
40	Jogiyakhera	HP	83	~	~	~	~	~	~	~	~	~

41	Atali	HP	12	~	~	~	~	~	~	~	~	~
42	Atali	HP	46	~	~	~	~	~	~	~	~	~
43	Nirpura	HP	46	~	~	~	~	~	~	~	~	~
44	Bamnauli	HP	66	~	~	~	~	~	~	~	~	~
45	Barnawa	HP	66	~	~	~	~	~	~	~	~	~
46	Sardhana	HP	15	~	~	~	~	~	~	~	~	~
47	Sardhana	HP	27	~	~	~	~	~	~	~	~	~
48	Kankarkhera	HP	40	~	~	~	~	~	~	~	~	~
49	Surana	HP	10	~	~	~	~	~	~	~	~	~
50	Surana	HP	40	~	~	~	~	~	~	~	~	~
51	Muradnagar	HP	40	~	~	~	~	~	~	~	~	~
52	Daluhera	HP	40	~	~	~	~	~	~	~	~	~
53	Daluhera	HP	10	~	~	~	~	~	~	~	~	~
54	Muradnagar	HP	23	~	~	~	~	~	~	~	~	~
55	Basantpur Sainthali	HP	40	~	~	~	~	~	~	~	~	~
56	Harbansnagar	HP	40	~	~	~	~	~	~	~	~	~
57	Mohannagar	HP	40	~	~	~	~	~	~	~	~	~
58	Bisrakh	HP	26	~	~	~	~	~	~	~	~	~
59	Bisrakh	HP	12	~	~	~	~	~	~	~	~	~
60	Kulesra	HP	40	~	~	~	~	~	~	~	~	~
61	Kulesra	HP	13	~	~	~	~	~	~	~	~	~
62	Surajpur	HP	17	~	~	~	~	~	~	~	~	~
63	Surajpur	HP	33	~	~	~	~	~	~	~	~	~
64	Jaitpur Vaishpur	HP	40	~	~	~	~	~	~	~	~	~
65	Dadha	HP	36	~	~	~	~	~	~	~	~	~
66	Dadri	HP	15	~	~	~	~	~	~	~	~	~
67	Badalpur	HP	13	~	~	~	~	~	~	~	~	~
68	Badalpur	HP	40	~	~	~	~	~	~	~	~	~
~ = Below Detection Limit												

Table 14. Pesticides contamination in ground water of Hindon river basin (Post-monsoon 2012)

S.No.	Location	Source	Depth	Organo-chlorinated Pesticides (μg/L)								
				Aldrin	α-BHC	β-BHC	γ-BHC	δ -BHC	Endosulphan	DDD	DDE	Methoxychlor
1	Fatehpur	HP	40	~	~	~	~	~	~	~	~	~
2	Gagalheri	HP	40	~	~	~	~	~	~	~	~	~
3	Kailashpur	HP	40	~	~	~	~	~	~	~	~	~
4	Naugazapeer	HP	50	~	~	~	~	~	~	~	~	~
5	Mahipura	HP	40	~	~	~	~	~	~	~	~	~
6	Beherki	HP	33	~	~	~	~	~	~	~	~	~
7	Ghogerki	HP	36	~	~	~	~	~	~	~	~	~
8	Paragpur	HP	17	~	~	~	~	~	~	~	~	~
9	Paragpur	HP	33	~	~	~	~	~	~	~	~	~
10	Hasanpura	HP	36	~	~	~	1.025	~	~	~	~	~
11	Hasanpura	HP	32	~	~	~	~	~	~	~	~	~
12	Kapasa	HP	36	~	~	~	~	~	~	~	~	~
13	Kapasa	HP	13	~	~	~	~	~	~	~	~	~
14	Tapri	HP	36	~	~	~	~	~	~	~	~	~
15	Tapri	HP	25	~	~	~	~	~	~	~	~	~
16	Shekhpura Kadim	HP	36	~	~	~	~	~	~	~	~	0.602
17	Lakhnaur	HP	36	~	~	~	~	~	~	~	~	~
18	Mubarikpur	HP	36	~	~	~	~	~	~	~	~	~
19	Mubarikpur	HP	15	~	~	~	~	~	~	~	~	~
20	Nanandi	HP	36	~	~	~	~	~	~	~	~	~
21	Sadauli Hariya	HP	36	~	~	~	~	~	~	~	~	~
22	Sadauli Hariya	HP	13	~	~	~	~	~	~	~	~	~
23	Bargaon	HP	36	~	~	~	~	~	~	~	~	~
24	Maheshpur	HP	36	~	~	~	~	~	~	~	~	~
25	Deoband	HP	15	~	~	~	~	~	~	~	~	~
26	Deoband	HP	36	~	~	~	~	~	~	~	~	~
27	Charthawal	HP	36	~	~	~	~	~	~	~	~	~
28	Charthawal	HP	20	~	~	~	~	~	~	~	~	~
29	Biralsi	HP	36	~	~	~	~	~	~	~	~	~
30	Thanabhawan	HP	36	~	~	~	~	~	~	~	~	~
31	Thanabhawan	HP	27	~	~	~	~	~	~	~	~	~
32	Muzaffar Nagar city	HP	15	~	~	~	~	~	~	~	~	~
33	Muzaffar Nagar city	HP	36	~	~	~	~	~	~	~	~	~
34	Tawli	HP	20	~	~	~	~	~	~	~	~	~
35	Tawli	HP	40	~	~	~	~	~	~	~	~	~
36	Shahpur	HP	40	~	~	~	~	~	~	~	~	~
37	Shahpur	HP	40	~	~	~	~	~	~	~	~	~
38	Budhana	HP	40	~	~	~	~	~	~	~	~	~
39	Budhana	HP	36	~	~	~	~	~	~	~	~	~
40	Jogiyakhera	HP	83	~	~	~	~	~	~	~	~	~

41	Atali	HP	12	~	~	~	~	~	~	~	~	~
42	Atali	HP	46	~	~	~	~	~	~	~	~	~
43	Nirpura	HP	46	~	~	~	~	~	~	~	~	~
44	Bamnauli	HP	66	~	~	~	~	~	~	~	~	~
45	Barnawa	HP	66	~	~	~	~	~	~	~	~	~
46	Sardhana	HP	15	~	~	~	~	~	~	~	~	~
47	Sardhana	HP	27	~	~	~	~	~	~	~	~	~
48	Kankarkhera	HP	40	~	~	~	~	~	~	~	~	~
49	Surana	HP	10	~	~	~	~	~	~	~	~	~
50	Surana	HP	40	~	~	~	~	~	~	~	~	~
51	Muradnagar	HP	40	~	0.644	~	0.104	~	~	~	~	~
52	Daluhera	HP	40	~	~	~	~	~	~	~	~	~
53	Daluhera	HP	10	~	~	~	~	~	~	~	~	~
54	Muradnagar	HP	23	~	0.514	~	~	~	~	~	~	~
55	Basantpur Sainthali	HP	40	~	~	~	~	~	~	~	~	~
56	Harbansnagar	HP	40	~	~	~	~	~	~	~	~	~
57	Mohannagar	HP	40	~	~	~	~	~	~	~	~	~
58	Bisrakh	HP	26	~	~	~	~	~	~	~	~	~
59	Bisrakh	HP	12	~	~	~	~	~	~	~	~	~
60	Kulesra	HP	40	~	~	~	~	~	~	~	~	~
61	Kulesra	HP	13	~	~	~	~	~	~	~	~	~
62	Surajpur	HP	17	~	~	~	~	~	~	~	~	~
63	Surajpur	HP	33	~	~	~	~	~	~	~	~	~
64	Jaitpur Vaishpur	HP	40	~	~	~	~	~	~	~	~	~
65	Dadha	HP	36	~	0.581	~	~	~	~	~	~	~
66	Dadri	HP	15	~	~	~	~	~	~	~	~	~
67	Badalpur	HP	13	~	~	~	~	~	~	~	~	~
68	Badalpur	HP	40	~	~	~	~	~	~	~	~	~
~ = Below Detection Limit												

4.4.5 Mechanism Controlling the Groundwater Chemistry

Geo-environmental conditions have a marked influence on the groundwater quality. Hydrogeochemical studies relevant to the water quality explain the relationship of water chemistry to aquifer lithology. Such relationship would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry. Gibbs (1970) proposed a hypothesis to elucidate the major natural mechanisms controlling world water chemistry. Three mechanisms – atmospheric precipitation, rock dominance and the evaporation-crystallization process – are the major factors controlling the composition of dissolved salts of the world waters. Other second-order factors, such as relief, vegetation and composition of material in the basin dictate only minor deviations within the zones dominated by the three prime factors.

Gibbs plot is a diagrammatic representation of the mechanisms responsible for controlling the chemical composition of various bodies of water on the surface of the earth. The major cations that characterize the end-members of the world surface waters are Ca for freshwater bodies and Na for high-saline water bodies. Gibbs plotted the weight ratio Na/(Na+Ca) on the x-axis and the variation in total salinity on the y-axis (Fig. 36). This ordered arrangement can serve as a basis for discussion of the several mechanisms that control world water chemistry.

The first of these mechanisms is the atmospheric precipitation. The chemical compositions of low-salinity waters are controlled by the amount of dissolved salts furnished by precipitation. These waters consist mainly of the rivers having sources in thoroughly leached areas of low relief in which the rate of supply of dissolved salts to the rivers is very low and the amount of rainfall is high – much greater in proportion to the low amount of dissolved salts supplied from the rocks. In addition, the composition of this precipitation differs from that of rock-derived dissolved salts.

The second mechanism is the rock dominance controlling world water chemistry. The waters of this rock-dominated end-members are more or less in partial equilibrium with the materials in their basins. Their positions within this grouping are dependent on the relief and climate of each basin and the composition of each basin.

The third major mechanism that controls the chemical composition of the earth's surface waters is the evaporation-fractional crystallization process. This mechanism produces a series extending from the Ca-rich, medium-salinity (freshwater), 'rock source' end-member grouping to the opposite, Na-rich, high-salinity end-member.

Almost all collected groundwater samples from Hindon river basin in both seasons fall in rock dominance zone suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals. Few samples are away from this zone reflecting the contribution of anthropogenic activity responsible for chemical composition of ground water of the study area specially in upper and lower part of Hindon river basin (Fig. 37&38).

4.4.6 Scatter Plots between Ions

The scatter plot of (Ca+Mg) vs TZ^+ shows that all the points fall above 1:1 equiline [Fig. 39(a)&(b)]. The relatively high contribution of (Ca+Mg) to the total cations (TZ^+) and high (Ca+Mg)/(Na+K) ratio indicate that carbonate weathering is a major source of dissolved ions in the groundwater of the study area [Fig. 40(a)&(b)] .

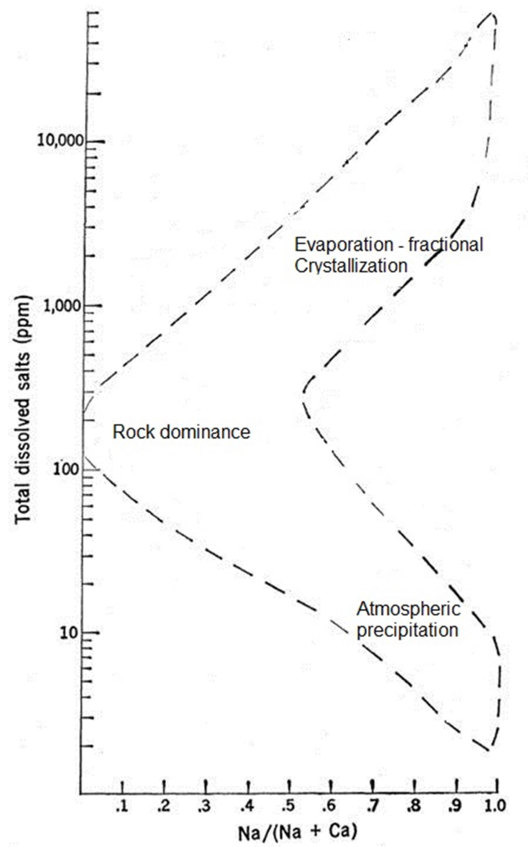


Fig. 36 Gibbs plot (Source: Gibbs, 1970)

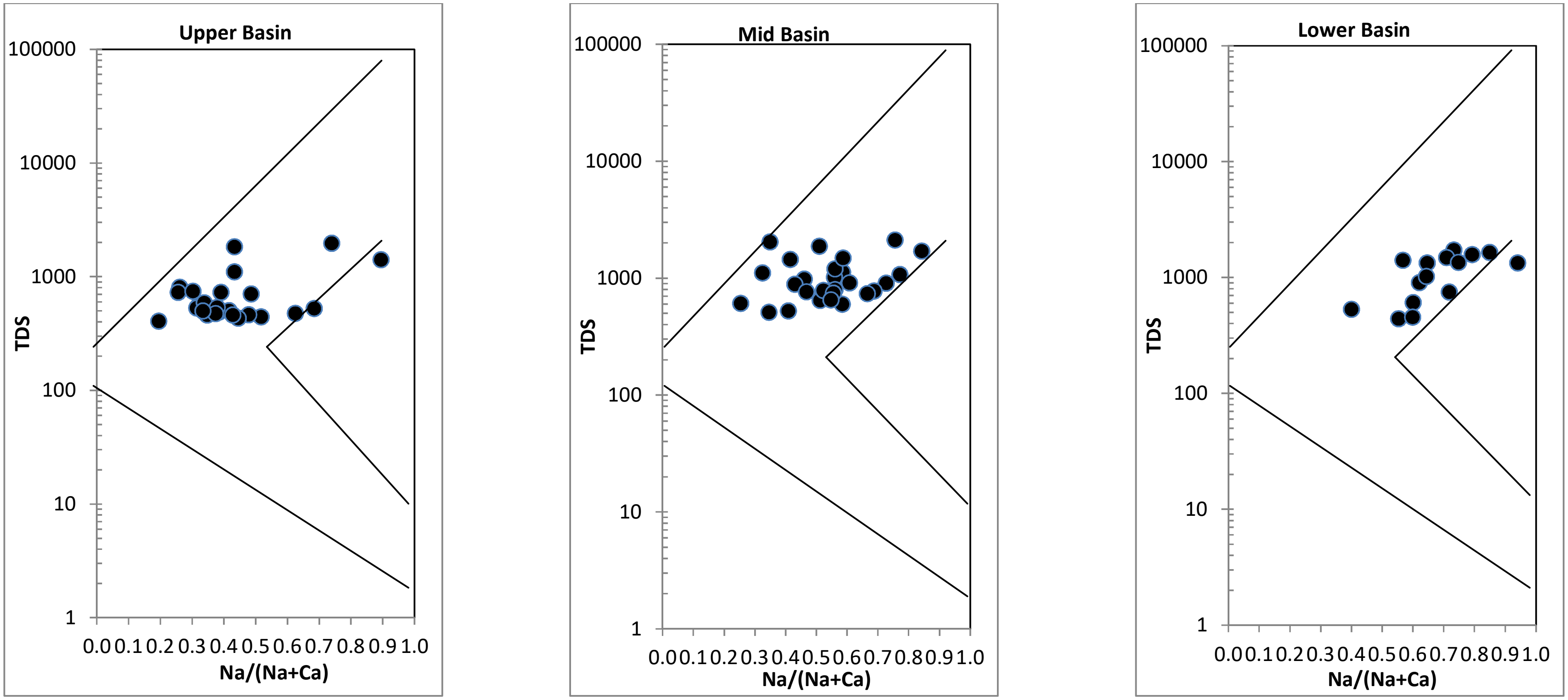


Fig. 37 Gibbs plot for mechanism controlling the groundwater chemistry (Pre-monsoon 2012)

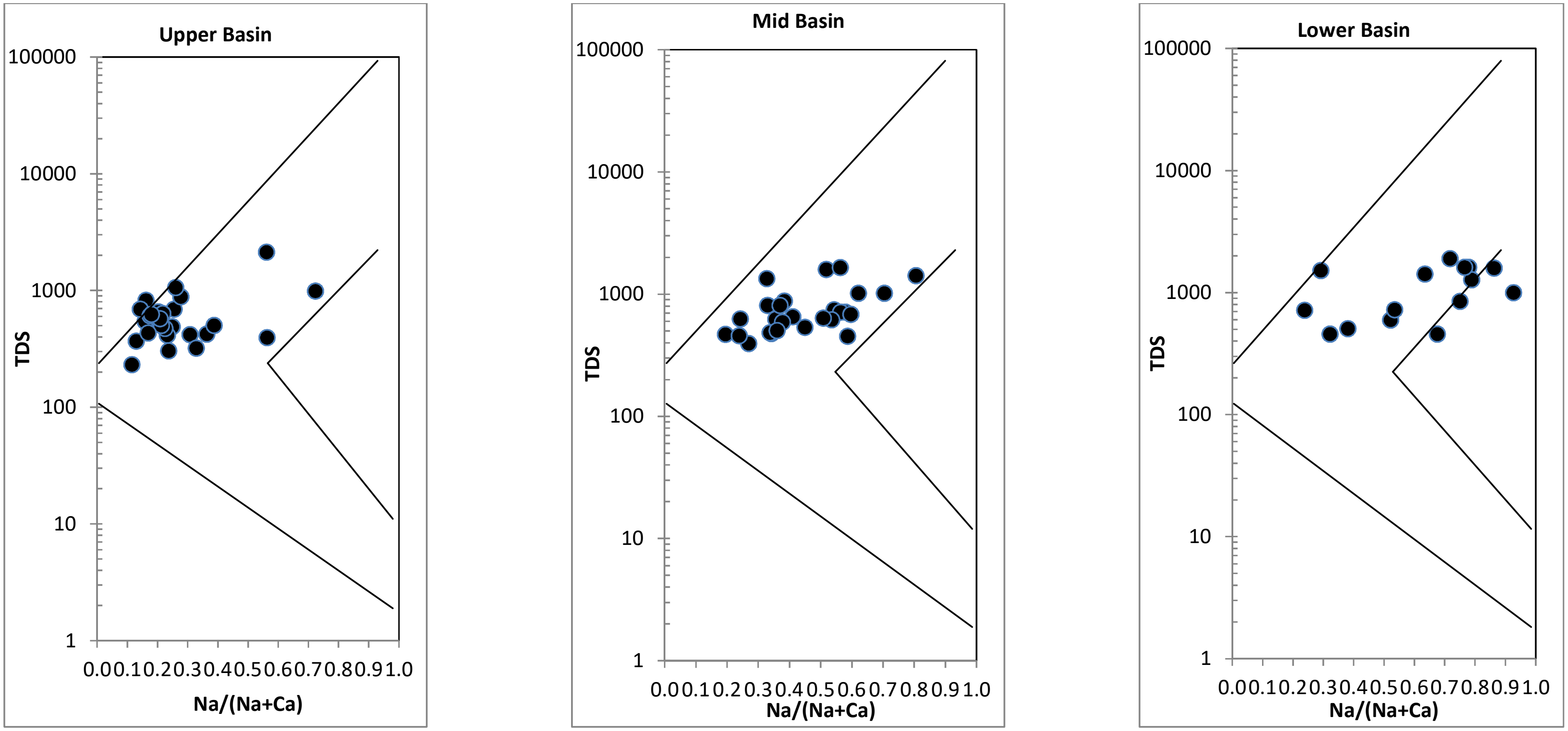


Fig. 38 Gibbs plot for mechanism controlling the groundwater chemistry (Post-monsoon 2012)

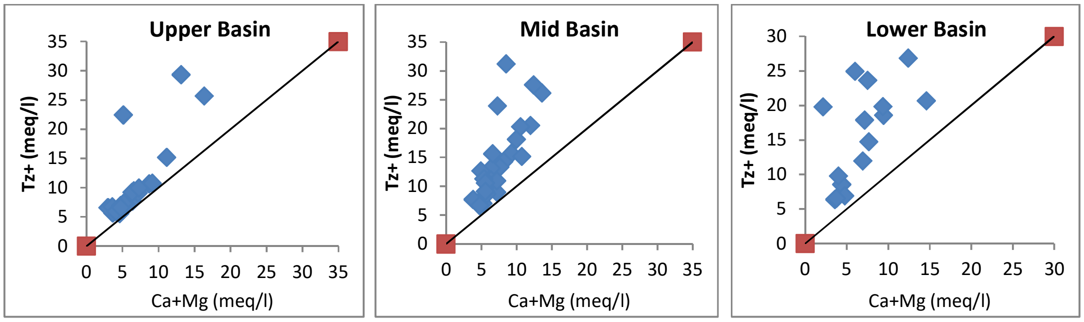


Fig. 39 (a) Scatter plot of (Ca+Mg) vs TZ$^+$ (Pre-monsoon season 2012)

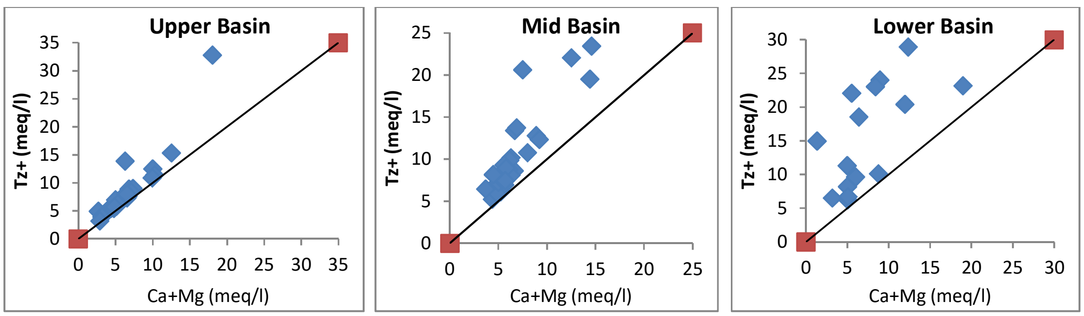


Fig. 39 (b) Scatter plot of (Ca+Mg) vs TZ$^+$ (Post-monsoon season 2012)

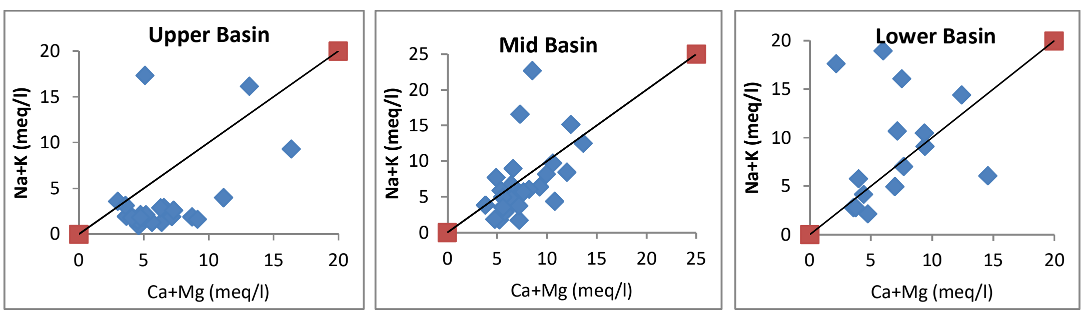


Fig. 40 (a) Scatter plot of (Ca+Mg) vs (Na+K) (Pre-monsoon season 2012)

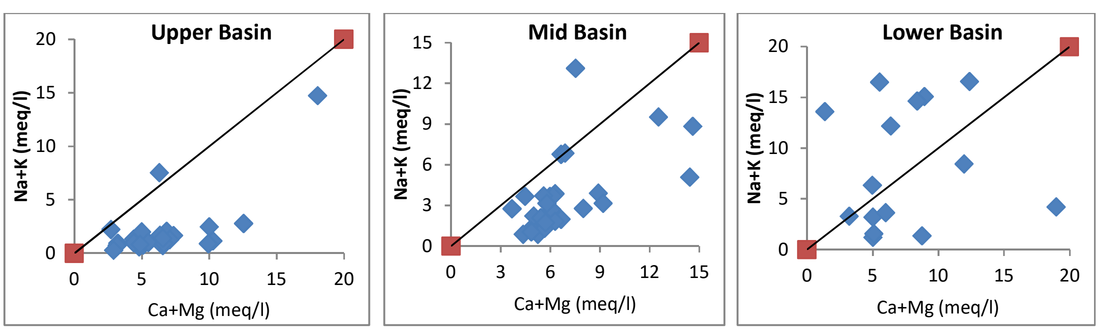


Fig. 40 (b) Scatter plot of (Ca+Mg) vs (Na+K) (Post-monsoon season 2012)

The scatter plot of (Na+K) vs TZ+ shows that all the points fall above 1:1 equiline with a low ratio indicating a relatively low contribution of dissolved ions from silicate weathering [Fig. 41(a)&(b)]. Na^{+}, K^{+} and dissolved silica in the drainage basin are mainly derived from the weathering of silicate minerals, with clay minerals as by-products.

The plot of (Ca+Mg) vs HCO_3 for most of the samples in mid and lower part of the basin indicates an access of alkalinity over Ca+Mg content [Fig. 42(a)&(b)]. The excess of Ca+Mg over HCO_3 in some of the sample of the upper part of basin indicate an extra source of Ca and Mg. This requires that a portion of the (Ca+Mg) has to be balanced by other anions like SO_4 and/or Cl.

The plot of (Ca+Mg) vs HCO_3+SO_4 is a major indicator to identify the ion exchange process activated in the study area. If ion exchange is the process, the points shift to right side of the plot due to excess of HCO_3+SO_4. If reverse ions exchange is the process, points shift left due to excess Ca+Mg. Plot of (Ca+Mg) vs HCO_3+SO_4 shows that most of the plotted points clusters around the 1:1 equiline and fall in HCO_3+SO_4 indicating the ion exchange process which may be due to the excess bicarbonate [Fig. 43(a)&(b)].

The plot of Na vs Cl indicates most of the points lie below the 1:1 equiline reflecting contribution of silicate weathering through the release of Na [Fig. 44(a)&(b)].

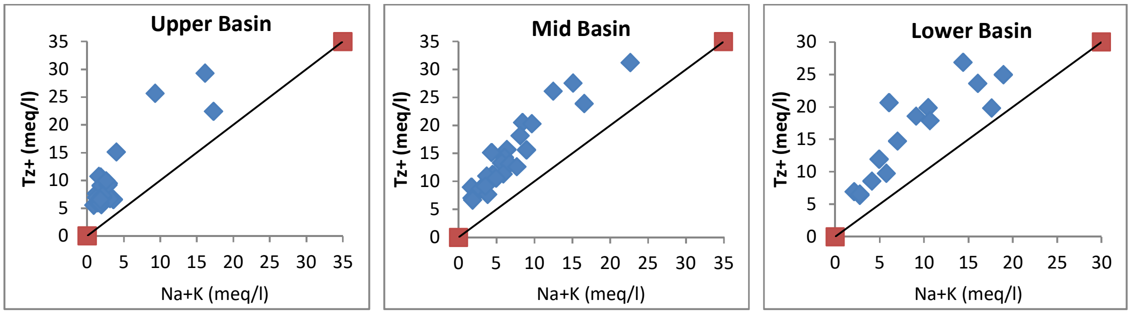


Fig. 41(a) Scatter plot of (Na+K) vs TZ^+ (Pre-monsoon season 2012)

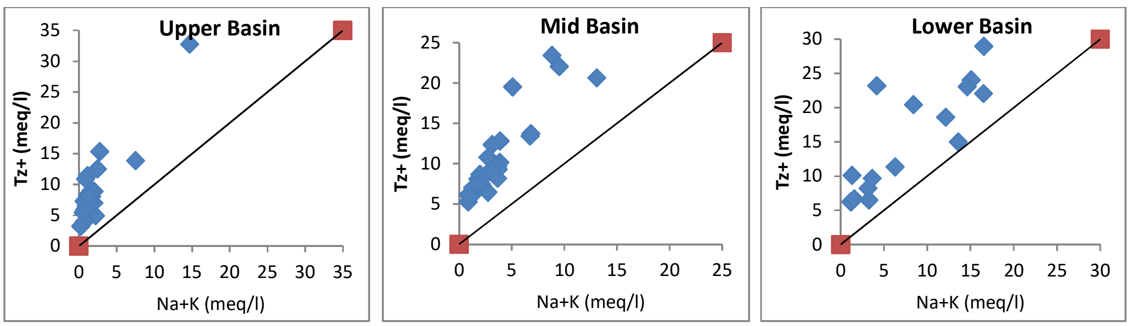


Fig. 41(b) Scatter plot of (Na+K) vs TZ^+ (Post-monsoon season 2012)

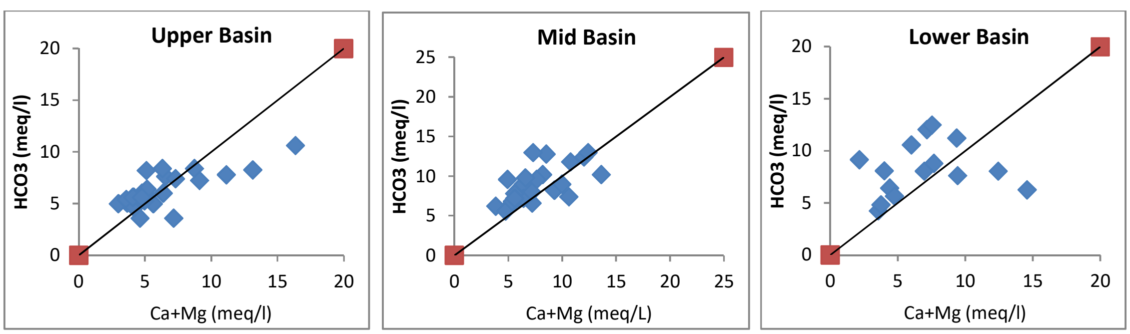


Fig. 42(a) Scatter plot of (Ca+Mg) vs HCO_3 (Pre-monsoon season 2012)

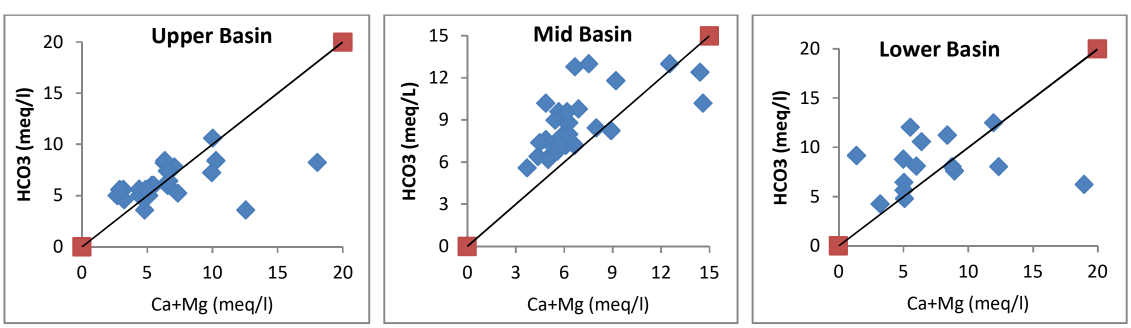


Fig. 42(b) Scatter plot of (Ca+Mg) vs HCO_3 (Post-monsoon season 2012)

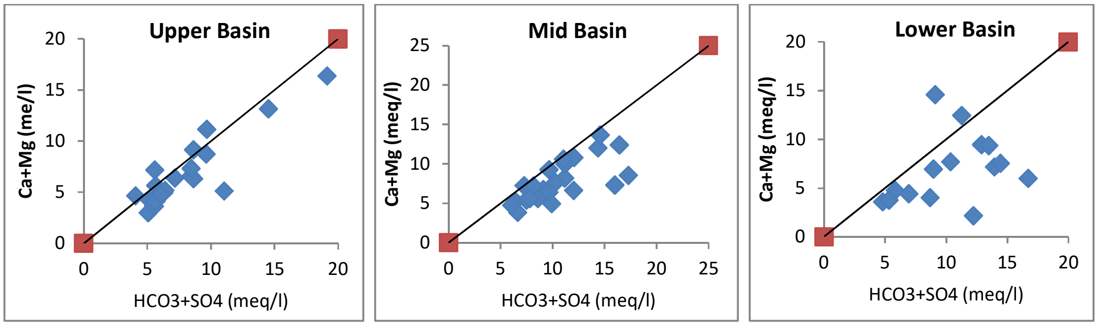


Fig. 43(a) Scatter plot of (Ca+Mg) vs HCO_3+SO_4 (Pre-monsoon season 2012)

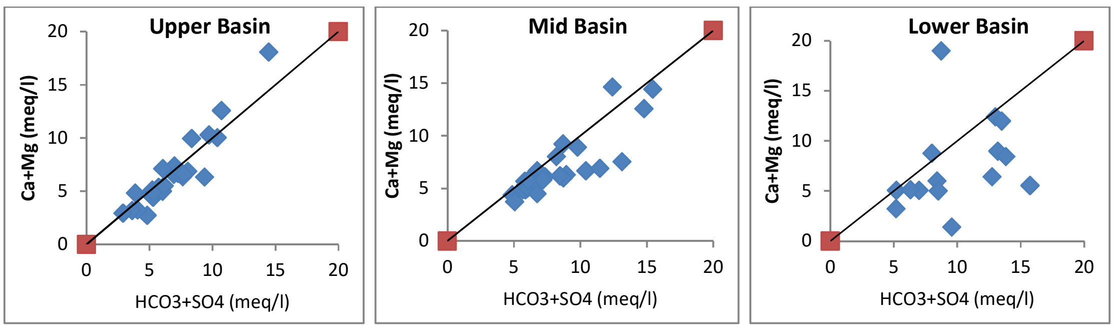


Fig. 43(b) Scatter plot of (Ca+Mg) vs HCO_3+SO_4 (Post-monsoon season 2012)

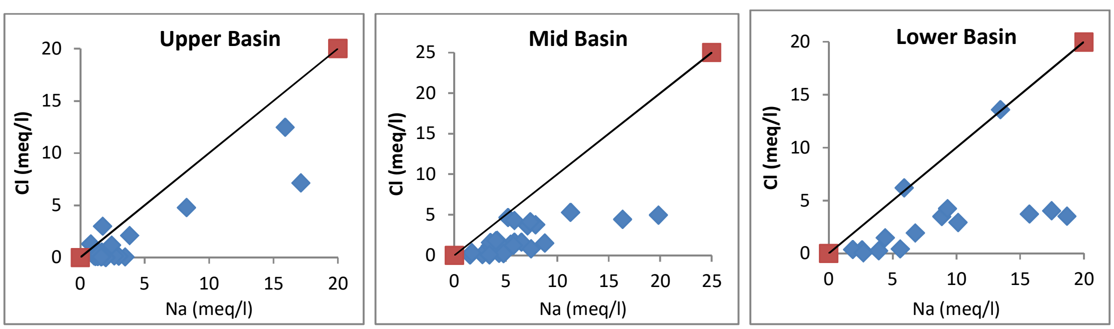


Fig. 44(a) Scatter plot of Na vs Cl (Pre-monsoon season 2012)

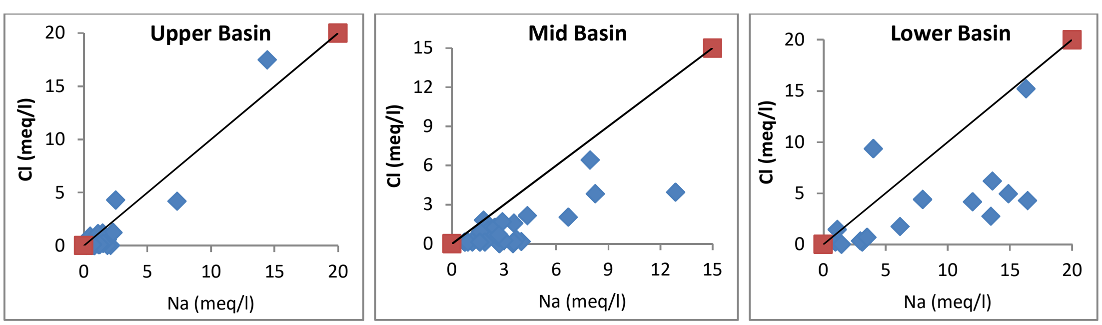


Fig. 44(b) Scatter plot of Na vs Cl (Post-monsoon season 2012)

4.5 Irrigation Water Quality

Water quality plays an important role in irrigated agriculture. Many problems arise during inefficient management of water for agriculture use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Under good soil and water management practices, good quality water has the ability to cause maximum yield. The quality of irrigation water is assessed by the following characteristics:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Heavy metals

4.5.1 Salinity

Salinity is expressed in terms of total dissolved solids (TDS) and thereby electrical conductivity (EC). If the salt concentration in water increases, the soil salinity also increases, it is difficult for plants to extract water. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solid content of the residual water in the root zone also has to be maintained within limits by proper leaching. The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 15. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels.

Table 15. Safe limits of electrical conductivity for irrigation water

S.No.	Nature of soil	Crop growth	Upper permissible safe limit of EC, μS/cm
1.	Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately well drained	Semi-tolerant	1500
		Tolerant	2000
2.	Having textured soils having clay contents of 20-30% soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3.	Medium textured soils having clay 10-20% internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4.	Light textured soils having clay less than 10% soil that have excellent internally and surface drainage system	Semi-tolerant	6000
		Tolerant	8000

Source: CGWB and CPCB (2000).

4.5.2 Relative Proportion of Sodium to other Cations

The clay minerals in the soil absorb divalent cations, lke calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conductive for plant growth. Sodium reacts with soil to reduce its permeability. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter. Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

4.5.3 Residual Sodium Carbonate

Water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate, changing the residual water to high sodium water with sodium bicarbonate in solution. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation.

The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 16. The values of sodium percentage (Na%), SAR and RSC were calculated for ground water samples collected from different sources in the different months and are given in Table 17. The electrical conductivity value in the study area varies widely from 635 to 3310 μS/cm during pre-monsoon season and 362 to 3329 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern. The values of SAR in the study area ranged from 0.54 to 16.80 during pre-monsoon season and 0.17 to 16.24 during post-monsoon season. The sodium percentage in the study area was found to vary from 15.0 to 89.1% during pre-monsoon season and 8.4 to 90.8% during post-monsoon season. Almost all samples have SAR values below 10 indicating excellent quality for irrigation purpose. Only ground water of Paragpur, Kulesra and Surajpur exceed SAR value of 10 during pre-monsoon season indicating medium hazard from sodium in these areas. About 10% of sample exceed the recommended value of percentage of sodium of 60% for irrigation during both pre- and post-monsoon seasons and is not suitable for irrigation purpose. About 40% of sample exceeds the recommended RSC value of 1.25 and 15% of sample exceed RSC value of 2.50 in pre-monsoon season making unsuitable these waters unsuitable for irrigation.

Table 16. Guidelines for evaluation of irrigation water quality

Water class	Na, %	EC, μS/cm	SAR	RSC, meq/l
Excellent	< 20	< 250	< 10	< 1.25
Good	20-40	250-750	10-18	1.25-2.0
Medium	40-60	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	> 26	2.5-3.0
Very bad	> 80	> 4000	> 26	> 3.0

Source: CGWB and CPCB (2000).

Table 17. SAR, Na% and RSC values in ground water of Hindon river basin(Pre- and Post-monsoon 2012)

S.No.	Location	Source	Depth	Pre-monsoon			Post-monsoon		
			m	SAR	Na (%)	RSC	SAR	Na (%)	RSC
1	Fatehpur	HP	40	0.54	16.81	-1.03	0.34	11.02	-1.33
2	Gagalheri	HP	40	0.58	16.83	-0.38	0.34	9.68	-0.72
3	Kailashpur	HP	40	1.05	27.00	1.01	0.64	17.51	0.24
4	Naugazapeer	HP	50	1.49	30.58	1.02	1.01	23.02	0.52
5	Mahipura	HP	40	0.70	18.87	-0.64	0.38	12.70	-0.47
6	Beherki	HP	33	1.35	34.94	1.37	0.79	22.76	0.37
7	Ghogerki	HP	36	1.08	27.29	0.27	0.77	18.45	-1.66
8	Paragpur	HP	17	10.7	77.21	3.09	4.13	54.36	1.12
9	Paragpur	HP	33	6.21	55.16	-4.90	4.80	44.91	-8.73
10	Hasanpura	HP	36	1.18	30.64	1.47	0.59	18.29	0.79
11	Hasanpura	HP	32	0.90	24.49	1.07	0.54	15.92	0.67
12	Kapasa	HP	36	2.84	54.59	2.01	1.83	45.06	2.04
13	Kapasa	HP	13	2.89	36.25	-5.77	1.03	19.79	-1.86
14	Tapri	HP	36	0.81	17.71	-0.33	0.42	9.99	-1.84
15	Tapri	HP	25	0.73	15.01	-1.90	0.39	8.36	-4.59
16	Shekhpura Kadim	HP	36	0.92	21.02	-3.57	1.01	18.11	-4.12
17	Lakhnaur	HP	36	2.24	46.53	1.80	1.18	28.42	0.80
18	Mubarikpur	HP	36	1.11	29.55	0.39	0.61	21.94	0.36
19	Mubarikpur	HP	15	1.62	26.43	-3.35	0.60	15.20	-2.54
20	Nanandi	HP	36	1.49	31.15	2.08	0.85	21.00	1.05
21	Sadauli Hariya	HP	36	1.30	31.22	1.23	0.52	15.33	0.34
22	Sadauli Hariya	HP	13	1.22	29.14	1.23	0.48	12.32	0.18
23	Bargaon	HP	36	0.95	25.77	1.07	0.48	18.38	0.34
24	Maheshpur	HP	36	1.16	30.53	1.51	0.17	8.86	-0.11

25	Deoband	HP	15	1.27	26.19	0.08	0.70	17.64	0.23
26	Deoband	HP	36	1.04	27.57	0.84	0.45	14.37	-0.08
27	Charthawal	HP	36	2.91	41.39	0.38	1.49	26.02	-0.63
28	Charthawal	HP	20	2.42	40.81	-1.03	1.30	30.40	-0.71
29	Biralsi	HP	36	0.82	19.43	-0.62	0.46	14.14	-0.02
30	Thanabhawan	HP	36	2.88	42.56	1.99	0.75	21.18	0.93
31	Thanabhawan	HP	27	2.80	42.82	1.97	0.70	18.70	0.02
32	Muzaffar Nagar city	HP	15	1.90	40.07	1.71	1.02	25.64	-0.80
33	Muzaffar Nagar city	HP	36	0.94	25.63	1.17	0.50	16.61	0.46
34	Tawli	HP	20	2.42	41.35	2.37	2.08	37.98	1.90
35	Tawli	HP	40	1.61	33.41	1.80	0.59	17.58	0.41
36	Shahpur	HP	40	3.64	51.13	2.59	2.03	37.97	2.25
37	Shahpur	HP	40	2.41	42.29	1.19	1.00	22.89	-0.90
38	Budhana	HP	40	2.64	50.13	2.37	1.32	30.76	0.59
39	Budhana	HP	36	2.48	42.17	0.78	1.42	30.48	0.51
40	Jogiyakhera	HP	83	4.76	60.97	4.67	2.03	37.41	2.13
41	Atali	HP	12	9.60	72.68	4.27	2.38	50.32	3.41
42	Atali	HP	46	1.10	28.24	0.84	1.98	42.63	1.30
43	Nirpura	HP	46	1.86	34.27	0.80	0.93	22.28	0.66
44	Bamnauli	HP	66	4.83	57.62	3.18	3.61	49.80	1.90
45	Barnawa	HP	66	3.50	52.38	1.41	2.13	39.82	0.40
46	Sardhana	HP	15	8.55	69.43	5.69	6.63	63.51	3.27
47	Sardhana	HP	27	3.54	45.03	-0.97	1.16	27.61	1.15
48	Kankarkhera	HP	40	1.74	28.88	1.02	1.36	25.47	-1.37
49	Surana	HP	10	4.33	47.84	-3.44	2.94	37.66	-5.41
50	Surana	HP	40	2.86	47.01	2.20	1.76	35.16	0.84
51	Muradnagar	HP	40	2.34	54.99	0.59	3.30	43.12	-0.95
52	Daluhera	HP	40	2.03	38.78	1.61	0.95	23.21	-0.16
53	Daluhera	HP	10	3.21	47.81	-3.21	1.80	44.98	1.51
54	Muradnagar	HP	23	1.95	43.79	0.66	2.47	50.54	1.42
55	Basantpur Sainthali	HP	40	2.64	48.48	2.04	1.89	38.64	1.43
56	Harbansnagar	HP	40	4.08	49.15	-1.84	7.03	62.74	2.05
57	Mohannagar	HP	40	5.40	53.65	-4.40	6.55	57.18	-4.18
58	Bisrakh	HP	26	1.21	31.09	0.87	0.63	19.19	-0.01
59	Bisrakh	HP	12	2.19	29.4	-8.34	1.31	18.12	-12.9
60	Kulesra	HP	40	10.79	75.94	4.56	6.71	65.52	1.16
61	Kulesra	HP	13	4.30	52.79	1.87	6.64	63.49	3.59
62	Surajpur	HP	17	5.35	59.86	4.87	9.87	74.83	8.49
63	Surajpur	HP	33	16.80	89.07	6.99	16.24	90.79	5.66
64	Jaitpur Vaishpur	HP	40	3.96	59.06	4.08	2.03	37.80	1.84
65	Dadha	HP	36	2.38	41.66	1.08	0.54	13.24	-1.72
66	Dadri	HP	15	8.10	68.06	4.94	3.27	41.32	0.06
67	Badalpur	HP	13	3.46	47.81	1.12	3.90	55.82	2.04
68	Badalpur	HP	40	1.96	42.62	1.03	0.93	23.55	0.74
HP = Handpump									

4.5.4 Heavy metals

There are certain specific trace elements, which have varying effects on plant growth. These trace elements include those occurring naturally in irrigation water, those introduced by man's activities and those which enter the soil through interaction between the soil and irrigation water. Some of these elements are essential for plant growth, other may be non-essential and sometimes harmful. The metal concentration ranges observed in ground water of the study area during pre-monsoon and post-monsoon seasons 2012 with their tolerance limits for irrigation waters are presented in Table 18. Almost all ground water samples were found having all the metal concentration except manganese within the tolerance limit for irrigation purpose for all soils in continuous use.

Table 18. Metal concentration ranges in ground water (mg/L)

Metal	Metal concentration range in ground water (mg/L)		Metal concentration tolerance limit (mg/L) for irrigation purpose	
	Pre-monsoon	Post-monsoon	Acid soils or all soils in continuous use	Fine textured Alkaline soils
Iron	0.002-3.197	0.006-0.263	5.00	20.00
Manganese	0.002-0.975	0.008-1.492	0.20	10.00
Copper	0.004-0.619	0.001-0.798	0.20	5.00
Nickel	0.001-0.057	0.002-0.061	0.20	2.00
Chromium	0.002-0.082	0.002-0.066	0.10	1.00
Lead	ND	ND-0.160	5.00	10.00
Cadmium	0.001-0.010	0.001-0.008	0.01	0.05
Zinc	0.009-1.842	0.001-1.347	2.00	10.00

Source: CGWB and CPCB (2000); FAO (1985).

4.6 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. Piper trilinear (Piper, 1944), Chadha's diagrams (1999) and Durov's diagram (1948) are used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) and Gupta's classification (1979) have been used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop.

4.6.1 Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. The chemical analysis data of ground water samples of the study area have been plotted on trilinear diagram for both the surveys [Fig. 45(a)&(b)] and results have been summarized in Table 20. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-HCO_3 or Na-K-HCO_3 hydrochemical facies in both pre- and post-monsoon seasons.

4.6.2 Chadha's Diagram

Modified version of the piper trilinear diagram is developed by Chadha (1999). In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The chemical analysis data of ground water samples of the study area have been plotted on Chadha' diagram [Fig. 46(a)&(b)] and results have been summarized in Table 20. It is evident from the results that majority of the samples of the study area belong to Group 5 (Ca-Mg-HCO_3) or Group 8 (Na-K-HCO_3) hydrochemical facies in both pre- and post-monsoon seasons.

4.6.3 Durov's Diagram

The trilinear Durov diagram is based on the percentage of major ion milli equivalents. The cation and anion values are plotted on two separate triangular plots and the data points are projected onto a square grid at the base of each triangle. The Durov plot is an alternative to the Piper plot. Since the data points are projected along the base of the triangle, which lies perpendicular to the third axis in each triangle, information about the concentration of the vertex elements (third element) is lost in the square grid. Changing the orientation of the elements in both triangles may improve the ability to detect distinct groups. The durov plots for the pre- and post-monsoon seasons are shown in [Fig. 47(a)&(b)]. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-HCO_3 or Na-K-HCO_3 hydrochemical facies in both pre- and post-monsoon season.

4.6.4 U. S. Salinity Laboratory Classification

Sodium concentration plays an important role in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The U.S. Regional Salinity Laboratory has developed a diagram for use in studying the suitability of ground water for irrigation purposes with reference to sodium adsorption ratio (SAR) as an index for sodium hazard S and electrical conductivity (EC) of water expressed in μS/cm as an index of salinity hazard C. The quality classification of irrigation water is given in Table 19.

The chemical analysis data of ground water samples of the study area has been analysed as per U.S. Salinity Laboratory classification for the two sets of data [Fig. 48(a)&(b)] and the results have been summarized in Table 20. It is evident from the results that the majority of ground water samples of the study area falls under water types C3-S1 followed by C2-S1 in both pre- and post-monsoon season. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. The C2-S1 type water (medium salinity and low SAR) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

4.6.5 Gupta's Classification

Gupta (1979 a,b) suggested a new classification for evaluation of quality of irrigation waters in arid and semi-arid zones of India. The classification has been adopted by ICAR Centres of the Coordinated Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture. It can be stated with certainty that both RSC and SAR influence the physical properties of soil in integrated manner. Whereas in low salinity waters, the effect of RSC is more prominent, in high salinity waters, it is SAR. However, it will be desirable to determine RSBC in waters having EC less than 3 dSm^{-1}, RSC and SAR for waters having EC between 3 and 5 dSm^{-1} and SCAR for waters having EC greater than 5 dSm^{-1}. RSC/RSBC and SAR/SCAR both should not be high. RSBC up to 10.0 $meqL^{-1}$ is permissible provided that SAR is less than 10 and SAR up to 20 and 30 is permissible provided that RSC is less than 5 and 10 $meqL^{-1}$, respectively., It seems to be difficult to suggest a single parameter for RSC/RSBC and SAR/SCAR which could be used for practical purposes with precision. The recommended classification with respect to electrical conductivity, RSC/RSBC and SAR/SCAR are given below:

	Non saline/sodic /alkaline water	Normal water	Low Salinity/ Sodicity/ Alkalinity water	Medium Salinity/ Sodicity/ Alkalinity water	High Salinity/ Sodicity/ Alkalinity water	Very high Salinity/ Sodicity/ Alkalinity water
Salinity (EC) (µS/cm)	<200	200-1500	1500-3000	3000-5000	5000-10000	>10000
Sodicity (SAR/SCAR)	<5	5-10	10-20	20-30	30-40	>40
Alkalinity (RSC/RSBC) (meq/L)	-ve	0	0-2.5	2.5-5.0	5-10.0	>10.0

Where $SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$ $SCAR = \frac{Na}{\sqrt{Ca}}$

$RSC = (HCO_3) - (Ca+Mg)$
$RSBC = HCO_3 - Ca$

All values are taken in meq/L.

The chemical analysis data of ground water samples of the study area has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 21**.** It is evident from the results that the majority of ground water samples of the study area fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline water as per alkalinity classification**.**

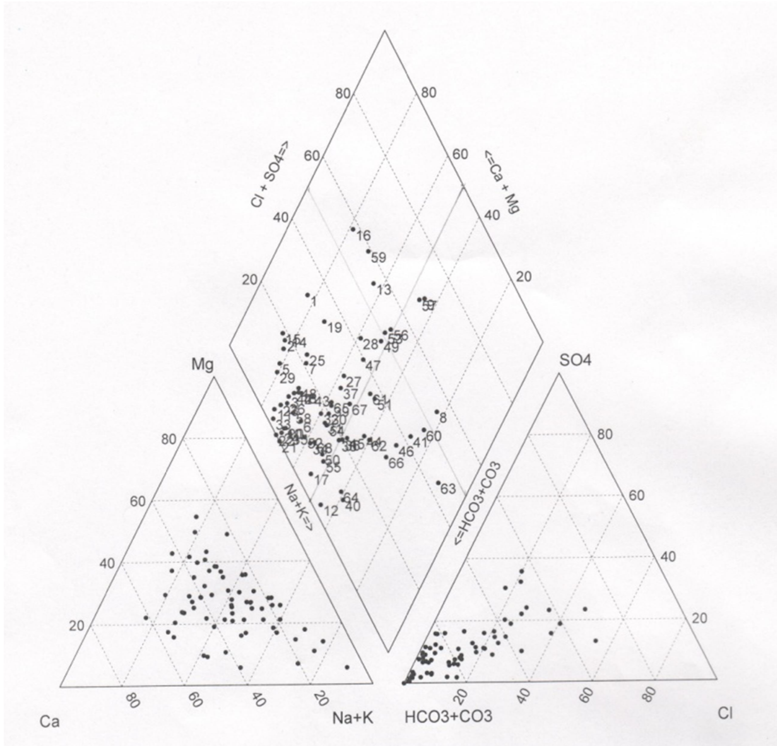


Fig. 45(a) Piper Trilinear diagram for ground water (Pre-monsoon, 2012)

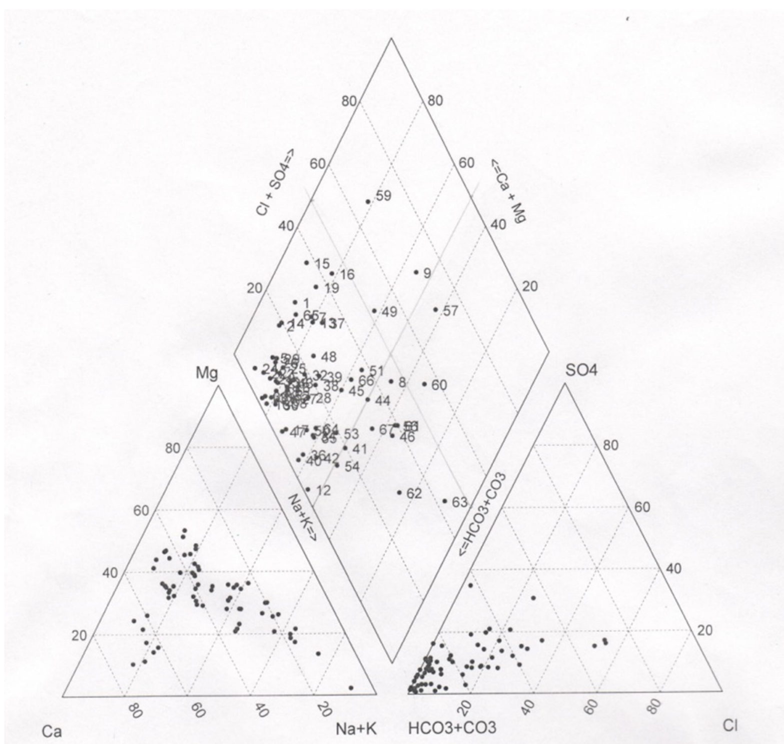


Fig. 45(b) Piper Trilinear diagram for ground water (Post-monsoon, 2012)

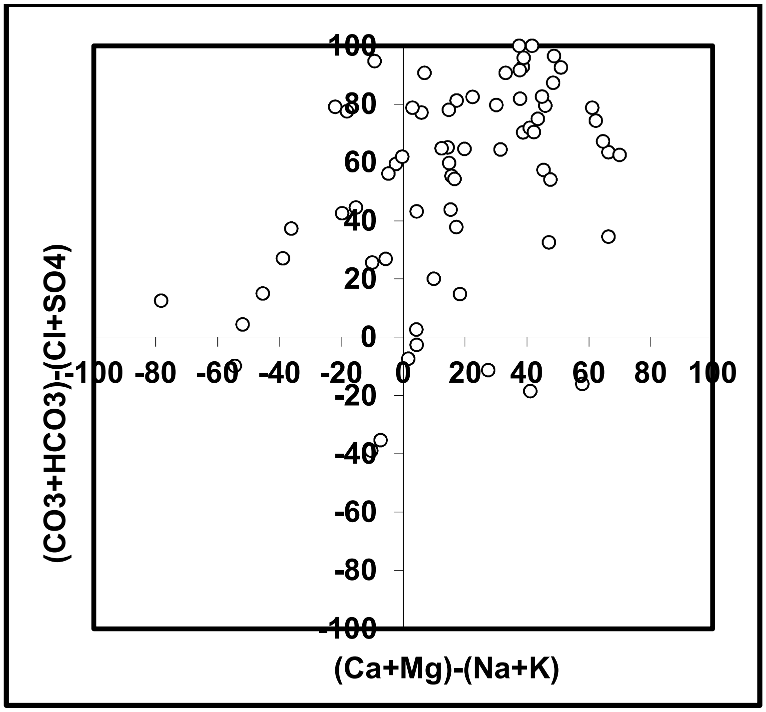


Fig. 46(a) Chadha's diagram for ground water (Pre-monsoon, 2012)

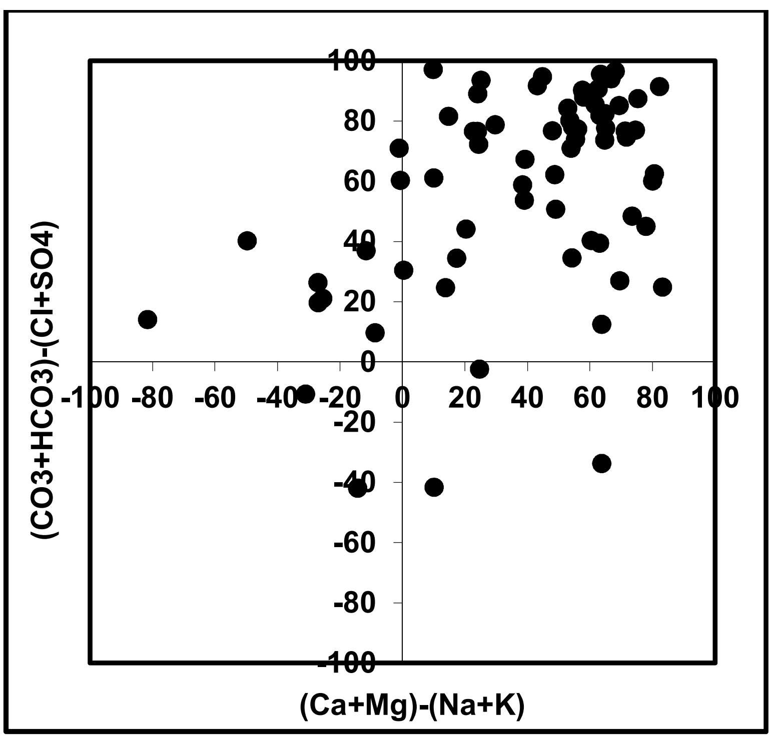


Fig. 46(b) Chadha's diagram for ground water (Post-monsoon, 2012)

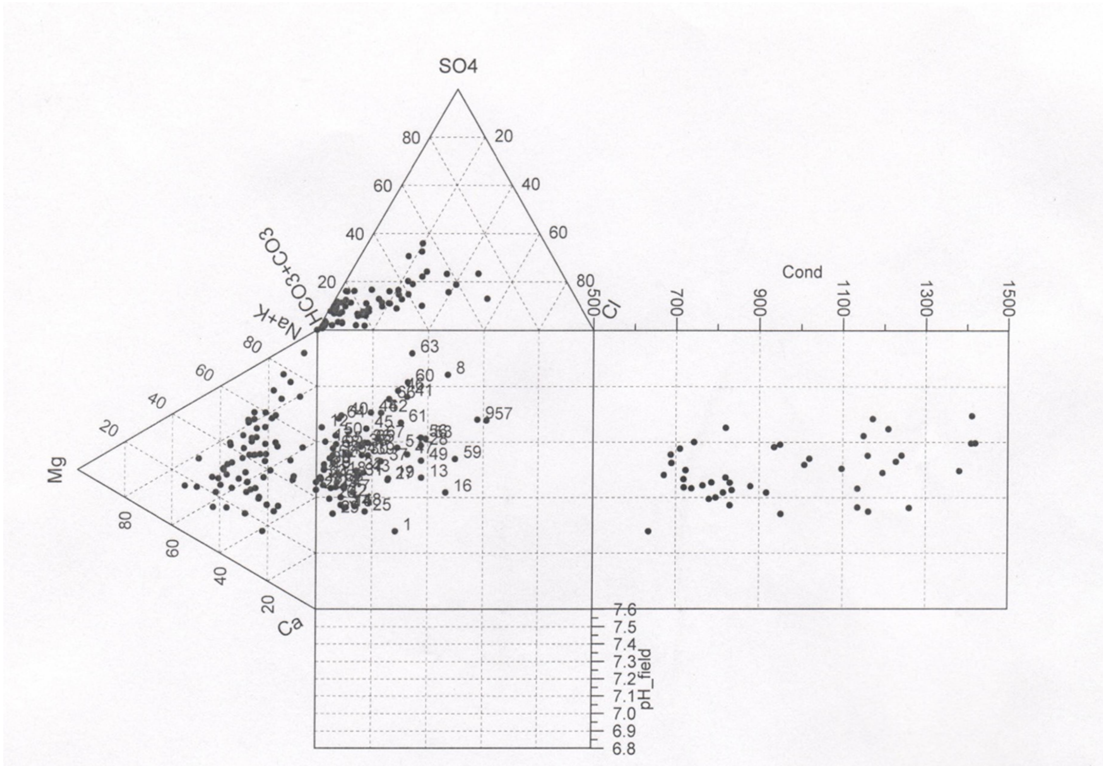


Fig. 47(a) Durov plot for ground water (Pre-monsoon, 2012)

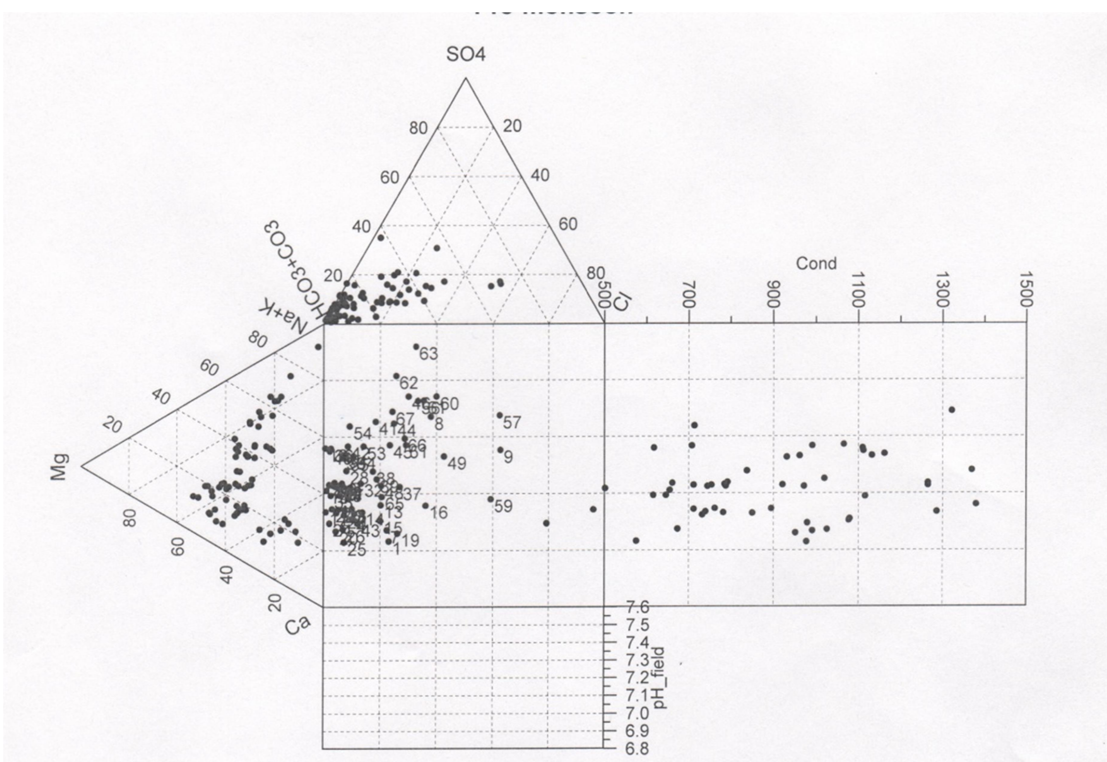


Fig. 47(b) Durov plot for ground water (Post-monsoon, 2012)

Table 19. U.S. Salinity Laboratory classification

Salinity	
Low Salinity (C1)	Low salinity water (C1) can be used for irrigation with most crops on most soils.
Medium Salinity (C2)	Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
High Salinity (C3)	High salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected.
Very High Salinity (C4)	Very high salinity water (C4) is not suitable for irrigation water under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate and irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.
SAR	
Low SAR (S1)	Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.
Medium SAR (S2)	Medium sodium water will present an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability.
High SAR (S3)	High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions.
Very High SAR (S4)	Very high sodium water is generally unsatisfactory for irrigation purposes.

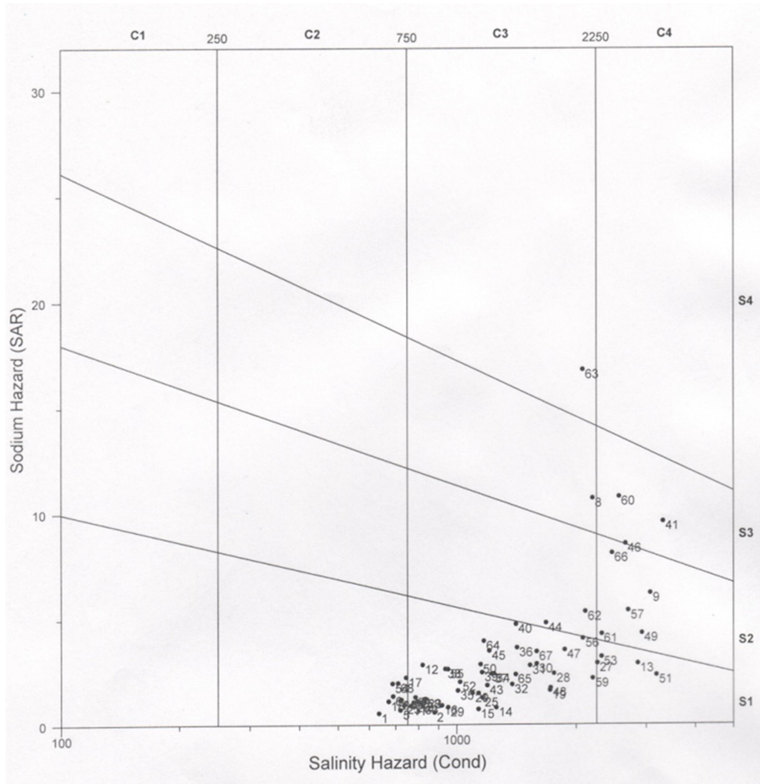


Fig. 48(a) U. S. Salinity Laboratory diagram for ground water (Pre-monsoon, 2012)

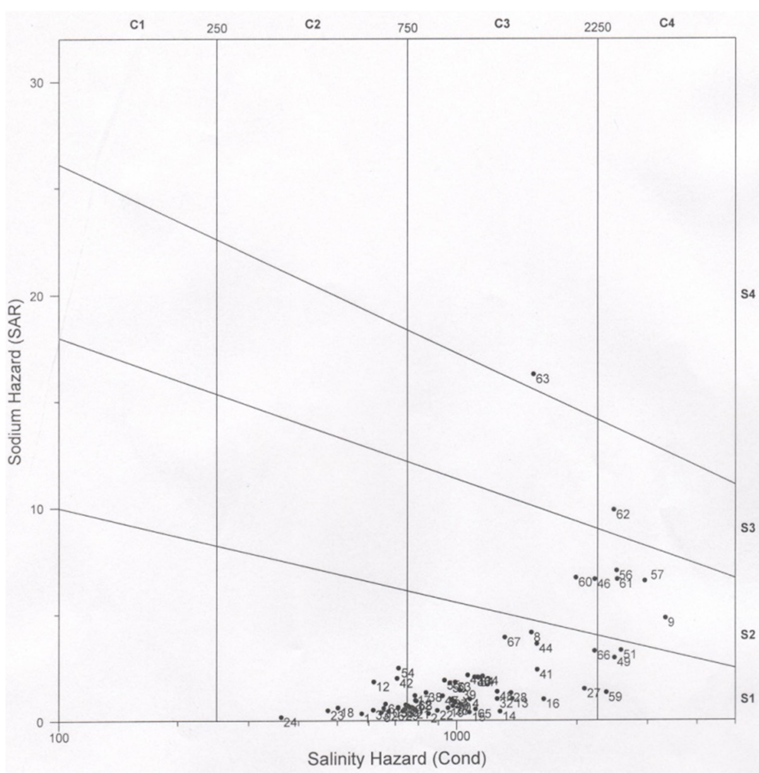


Fig. 48(b) U. S. Salinity Laboratory diagram for ground water (Post-monsoon, 2012)

Table 20. Summarized results of water classification for ground water

Classification/Type	Sample numbers	
	Pre-monsoon 2012	Post-monsoon 2012
Piper Trilinear Classification		
Ca-Mg-HCO_3 (Group 5)	1,2,3,4,5,6,7,10,11,14,15,17,18,19, 20,21,22,23,24,25,26,27,28,29,30, 31,32,35,37,38,39,42,43,45,47,48, 49,50,52,54,55,58,60,67,68	1,2,3,4,5,6,7,10,11,12,13,14,15, 16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30,31,32,33,34,35, 36,37,38,39,40,42,43,45,47,48, 50,52,55,58,61,64,65,68,68
Ca-Mg-Cl-SO_4 (Group 6)	13,16,53,56,59	9,49,59
Na-K- Cl-SO_4 (Group 7)	8,9,57	57,60
Na-K-HCO_3 (Group 8)	12,33,34,36,40,41,44,46,51,61,62, 63,64,65,66	8,41,44,46,51,53,54,56,62,63,67
Chadha's Diagram		
Ca-Mg-HCO_3 (Group 5)	1,2,3,4,5,6,7,10,11,14,15,17,18,19, 20,21,22,23,24,25,26,27,28,29,30, 31,32,35,37,38,39,42,43,45,47,48, 49,50,52,54,55,58,60,67,68	1,2,3,4,5,6,7,10,11,12,13,14,15, 16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30,31,32,33,34,35, 36,37,38,39,40,42,43,45,47,48, 50,52,55,58,61,64,65,68,68
Ca-Mg-Cl-SO_4 (Group 6)	13,16,53,56,59	9,49,59
Na-K- Cl-SO_4 (Group 7)	8,9,57	57,60
Na-K-HCO_3 (Group 8)	12,33,34,36,40,41,44,46,51,61,62, 63,64,65,66	8,41,44,46,51,53,54,56,62,63,67
U. S. Salinity Laboratory Classification		
C1-S1	-	-
C2-S1	1,4,5,6,16,17,21,48,50	1,3,6,10,12,18,23,24,26,29,42,48, 50,52,54
C2-S2	-	-
C2-S3	-	-
C2-S4	-	-
C3-S1	3,7,10,11,12,14,15,18,19,20,22,23, 24,25,26,28,29,30,31,32,33,34,35, 36,37,38,39,40,41,42,43,45,47,52, 54,55,56,58,59,64,65,67,68	2,4,5,7,8,11,13,14,15,16,17,19, 20,21,22,25,27,28,30,31,32,33, 34,35,36,37,38,39,40,41,43,44, 45,47,53,55,58,64,65,66,67,68
C3-S2	44,62	46,60
C3-S3	8	-
C3-S4	63	63
C4-S1	13,27,51,53	49,51,59
C4-S2	9,49,57,61,66	9,56,57,61
C4-S3	41,46,60	62
C4-S4	-	-

Table 21. Results of Gupta's classification for ground water (Pre- and Post-monsoon 2012)									
S. No.	Location	Source	Depth	Pre-monsoon			Post-monsoon		
			m	EC	SAR/ SCAR	RSC/ RSBC	EC	SAR/ SCAR	RSC/ RSBC
1	Fatehpur	HP	40	635	1.21	-5.15	576	1.21	66.57
2	Gagalheri	HP	40	879	0.83	-0.10	850	0.99	-0.27
3	Kailashpur	HP	40	830	1.20	0.42	762	1.08	0
4	Naugazapeer	HP	50	1136	1.13	0.30	1080	1.26	0.27
5	Mahipura	HP	40	720	0.88	-0.23	646	0.88	-0.18
6	Beherki	HP	33	690	0.96	0.41	662	0.96	0.14
7	Ghogerki	HP	36	814	1.10	0.12	1026	1.26	16.57
8	Paragpur	HP	17	2198	0.88	0.50	1540	0.94	0.24
9	Paragpur	HP	33	3072	0.92	-1.86	3329	1.12	4.53
10	Hasanpura	HP	36	724	0.94	0.39	655	0.94	0.24
11	Hasanpura	HP	32	765	0.97	0.31	740	1.08	0.24
12	Kapasa	HP	36	820	1.03	0.59	618	1.10	0.66
13	Kapasa	HP	13	2856	1.15	28.87	1380	1.09	-0.86
14	Tapri	HP	36	1260	1.05	-0.09	1286	0.98	-0.53
15	Tapri	HP	25	1136	1.00	-0.71	1078	1.02	-28.71
16	Shekhpura Kadim	HP	36	918	0.97	-17.85	1652	1.07	-3.19
17	Lakhnaur	HP	36	744	1.00	0.50	785	1.09	0.28
18	Mubarikpur	HP	36	672	0.97	0.15	502	0.99	0.18
19	Mubarikpur	HP	15	1720	0.95	-1.20	952	1.22	3.44
20	Nanandi	HP	36	1098	0.94	0.37	992	1.31	0.54
21	Sadauli Hariya	HP	36	786	1.08	0.39	782	1.08	0.13
22	Sadauli Hariya	HP	13	835	1.11	0.39	895	1.00	0.05
23	Bargaon	HP	36	738	1.03	0.33	474	1.11	0.22
24	Maheshpur	HP	36	719	1.04	0.45	362	1.05	-0.09
25	Deoband	HP	15	1162	1.24	0.04	978	1.32	0.22
26	Deoband	HP	36	780	1.16	0.35	674	1.18	-0.05
27	Charthawal	HP	36	2260	1.29	0.16	2088	1.07	-0.11
28	Charthawal	HP	20	1760	0.89	-0.23	1370	0.99	-0.19
29	Biralsi	HP	36	952	1.13	-0.31	732	1.08	-0.01
30	Thanabhawan	HP	36	1592	1.06	0.36	745	0.96	0.26
31	Thanabhawan	HP	27	1532	1.30	0.62	754	0.90	0.01
32	Muzaffar Nagar city	HP	15	1382	1.17	0.45	1265	1.02	-0.26
33	Muzaffar Nagar city	HP	36	820	0.92	0.28	616	0.96	0.16
34	Tawli	HP	20	1242	1.03	0.44	1162	0.99	0.37
35	Tawli	HP	40	1008	0.95	0.36	712	1.09	0.17
36	Shahpur	HP	40	1420	1.14	0.54	1110	0.92	0.39
37	Shahpur	HP	40	1228	1.12	0.35	972	1.00	-0.37
38	Budhana	HP	40	936	1.17	0.66	838	1.01	0.19
39	Budhana	HP	36	1160	1.05	0.21	1020	1.08	0.17
40	Jogiyakhera	HP	83	1412	1.07	0.69	1112	0.94	0.38
41	Atali	HP	12	3310	1.22	0.67	1592	0.89	0.46

42	Atali	HP	46	796	1.16	0.35	708	1.01	0.42
43	Nirpura	HP	46	1196	1.05	0.20	980	1.28	0.37
44	Bamnauli	HP	66	1680	0.89	0.44	1588	0.90	0.32
45	Barnawa	HP	66	1210	0.98	0.34	1066	0.93	0.11
46	Sardhana	HP	15	2660	0.91	0.57	2214	0.91	0.43
47	Sardhana	HP	27	1872	1.12	-0.35	922	1.08	0.33
48	Kankarkhera	HP	40	1726	1.25	0.30	1265	1.04	-0.47
49	Surana	HP	10	2926	1.26	5.29	2482	1.01	-3.01
50	Surana	HP	40	1150	0.93	0.41	962	0.95	0.21
51	Muradnagar	HP	40	3186	1.32	0.28	2575	1.01	-0.18
52	Daluhera	HP	40	1020	1.00	0.37	788	1.00	-0.06
53	Daluhera	HP	10	2315	0.99	-1.46	992	1.08	0.45
54	Muradnagar	HP	23	688	1.08	0.31	714	0.97	0.45
55	Basantpur Sainthali	HP	40	950	1.09	0.53	932	1.04	0.38
56	Harbansnagar	HP	40	2080	1.01	-0.67	2512	0.97	0.30
57	Mohannagar	HP	40	2702	0.89	-1.40	2956	1.02	-2.32
58	Bisrakh	HP	26	830	1.08	0.31	712	0.91	0.00
59	Bisrakh	HP	12	2202	0.79	-4.79	2365	1.02	3.42
60	Kulesra	HP	40	2562	1.05	0.63	1990	1.00	0.27
61	Kulesra	HP	13	2318	0.90	0.25	2520	0.99	0.46
62	Surajpur	HP	17	2108	0.97	0.56	2472	0.97	0.74
63	Surajpur	HP	33	2080	1.01	0.87	1558	1.23	0.95
64	Jaitpur Vaishpur	HP	40	1172	1.05	0.69	1132	1.01	0.38
65	Dadha	HP	36	1410	0.88	0.20	1116	0.91	-0.50
66	Dadri	HP	15	2462	1.04	0.59	2212	0.88	0.01
67	Badalpur	HP	13	1592	0.99	0.22	1322	0.91	0.41
68	Badalpur	HP	40	710	0.98	0.34	792	0.97	0.21
Hp = Handpump									

4.7 Water Quality Index

Water quality index (WQI) is a means to summarize large amounts of water quality data into simple terms for reporting to management and the public in a consistent manner. It tells us whether the overall quality of water bodies poses a potential threat to various uses of water. WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption.

4.7.1 Water Quality Index of Surface Water Quality of River Hindon

WQI is a set of standards used to measure changes in water quality in a particular river reach over time and make comparisons from different reaches of a river. A WQI also allows for comparisons to be made between different rivers. This index allows for a general analysis of water quality on many levels that affect a stream's ability to host life. The WQI was first developed by Horton in the early 1970s, is basically a mathematical means of calculating a single value from multiple test results. The index result represents the level of water quality in a given water basin, such as lake, river or stream. After Horton a number of workers all over the world developed WQI based on rating of different water quality parameters. Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Miller et al., 1986). For the evaluation of water quality, WQI was applied to river water (Singh, 1992; Naik and Purohit, 2001; Kumar and Dua, 2009; Kumar et al., 2009, Singkran et al., 2010). Atleast 30 water quality Indices are being used over the world, with the number of variables ranging from 3 upto 72 .

Water quality index was calculated for assessing the water quality of river Hindon at different sites in pre- and post-monsoon seasons. WQI of River Hindon was calculated as proposed by Tiwari and Mishra (1985). It was done by considering eight important physico-chemical properties using Central Public Health Environmental Engineering Organisation (CPHEEO), 1991 and Indian Council of Medical Research (ICMR), 1975 standards. In order to calculate WQI, eight important parameters viz; pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), Total Alkalinity (Alk), Total hardness (Hard), calcium (Ca) and magnesium (Mg) were used. These parameters maximum contribute for the quality of river. The steps for WQI are:

Weightage

Factors which have higher permissible limits are less harmful because they can harm quality of river water when they are present in very high quantity. So weightage of factor has an inverse relationship with its permissible limits. Therefore

$W_i \propto 1/X_i$ or $W_i = k/X_i$

Where, k = constant of proportionality
W_i = unit weight of factor
X_i = maximum permissible limits as recommended by Indian Council of Medical Research / Public Health Environmental Engineering Organization. Values of k were calculated as:

$$k = \frac{1}{\sum_1^8 (\frac{1}{X_i})}$$

$$\sum_{1}^{8}\left(\frac{1}{X_i}\right) = \frac{1}{X_i(pH)} + \frac{1}{X_i(DO)} + \frac{1}{X_i(EC)} + \frac{1}{X_i(TDS)} + \frac{1}{X_i(Alk)} + \frac{1}{X_i(Hard)} + \frac{1}{X_i(Ca)} + \frac{1}{X_i(Mg)}$$

The weightage of all the factors were calculated on the basis of the above equation and given in Table 22.

Table 22. ICMR/CPHEEO Standards and Assigned Unit Weights

S. No.	Water Quality Factors	ICMR/CPHEEO Standards (X_i)	Unit Weight (W_i)
1.	pH	7.0-8.5**	0.322
2.	Dissolved Oxygen	>5*	0.548
3.	Electrical Conductivity	<300*	0.009
4.	Total Dissolved Solids	<1500**	0.002
5.	Total Alkalinity	<120*	0.023
6.	Total Hardness	<600**	0.005
7.	Calcium	<75*	0.037
8.	Magnesium	<50*	0.055

*ICMR Standards (1975); **CPHEEO Standards (1991)

Rating Scale

Rating scale (Table 23&24) was prepared for range of values of each parameter. The rating varies from 0 to 100 and is divided into five intervals. The rating $X_r = 0$ implies that the parameter present in water exceeds the standard maximum permissible limits and water is severely polluted. On the other hand $X_r = 100$ implies that the parameter present in water has the most desirable value. The other ratings fall between these two extremes and are $X_r = 40$, $X_r = 60$ and $X_r = 80$ standing for excessively polluted, moderately polluted and slightly less polluted respectively. This scale is modified version of rating scale given by Tiwari and Mishra (1985).

Water Quality Index Calculation

Essentially, a WQI is a compilation of a number of parameters that can be used to determine the overall quality of a river. WQI is calculated for different sites of River Hindon in pre- and post-monsoon season. The parameters involved in the WQI are pH, Dissolved Oxygen, Electrical Conductivity, Total Dissolved Solids, Total Alkalinity, Total Hardness, Calcium and Magnesium. The numerical value is then multiplied by a weighting factor that is relative to the significance of the test to water quality. The sum of the resulting values is added together to arrive at an overall water quality index i.e.

$WQI = W_i \times X_r$

$W_i \times X_r = W_i(pH) \times X_r(pH) + W_i(DO) \times X_r(DO) + W_i(EC) \times X_r(EC) + W_i(TDS) \times X_r(TDS) + W_i(\text{Total Alkalinity}) \times X_r(\text{Total Alkalinity}) + W_i(\text{Hardness}) \times X_r(\text{Hardness}) + W_i(Ca) \times X_r(Ca) + W_i(Mg) \times X_r(Mg)$

The values of X_i, W_i and X_r are given in Tables 22 and 23. Hence by multiplying Wi and Xr we can get the value of WQI. The WQI result represents the level of water quality in a given water basin such as lake, river or stream. Similar WQI was given by Akkaraboyina and Raju (2012) using eight water quality parameters.

Table 23. Rating Scale for Calculating WQI

Water Quality Parameter				Ranges	
pH	7.0–8.5	8.6 - 8.7	8.8 – 8.9	9.0 – 9.2	>9.2
		6.8 - 6.9	6.7 – 6.8	6.5 – 6.7	< 6.5
Dissolved Oxygen	> 7.0	5.1 - 7.0	4.1 – 5.0	3.1 – 4.0	<3.0
E. Conductivity	0 – 75	75.1–150	150.1 –225	225.1 - 300	>300
Tot. Dissolved Solids	0 -375	375.1–750	750.1-1125	1125.1–1500	>1500
Total Alkalinity	21-50	50.1- 70	70.1 – 90	90.1 – 120	>120
		15.1 – 20	10.1 – 15	6 – 10	<6
Total Hardness	0 -150	150.1 – 300	300.1– 450	450.1 – 600	>600
Calcium	0 – 20	20.1 – 40.0	40.1 – 60.0	60.1 – 75.0	>75
Magnesium	0 – 12.5	12.6 – 25.0	25.1 – 37.5	37.6 -50	>50
Xr	100	80	60	40	0
Extent of Pollution	Clean	Slight Pollution	Moderate Pollution	Excess Pollution	Severe Pollution

Table 24. Rating Scale for Quality of Water

Value of WQI	Quality of Water
90 – 100	Excellent
70 – 90	Good
50 – 70	Medium
25 - 50	Bad
0 - 25	Very Bad

Water quality Indices for water quality at different sites of river Hindon in pre- and post-monsoon seasons were calculated and are given in Table 25. The water quality of river Hindon at all sites in both season was found to be bad.

Table 25. Water Quality Index and Quality of River Water

River Site	Location	Pre-monsoon		Post-monsoon	
		WQI	Quality of Water	WQI	Quality of Water
RH-1	Kapasa	25.76	Bad	32.20	Bad
RH-2	Nanandi	34.40	Bad	32.20	Bad
RH-3	Sadauli Hariya	35.92	Bad	35.92	Bad
RH-4	Maheshpur	Dry	-	32.48	Bad
RH-5	Charthawal	Dry	-	34.82	Bad
RH-6	Chandheri	Dry	-	32.52	Bad
RH-7	Atali	32.48	Bad	40.26	Bad
RH-8	Barnawa	65.28	Medium	40.16	Bad
RH-9	Daluhera	27.64	Bad	42.28	Bad
RH-10	Surana	26.54	Bad	28.30	Bad
RH-11	Mohannagar	38.68	Bad	41.36	Bad

4.7.2 Water Quality Index of Ground Water Quality in Hindon River Basin

Water Quality Index (WQI) is an important parameter for demarcating groundwater quality and its suitability for drinking purposes (Subba Rao, 1997; Mishra and Patel, 2001; Avvannavar and Shrihari, 2008). The standards for drinking purposes as recommended by BIS (2012) and WHO (2011) have been considered for the calculation of WQI. For computing WQI, three steps are followed. In the first step, each of the 16 parameters (TDS, HCO_3, Cl, SO_4, NO_3, F, Ca, Mg, Na, K, Fe, Mn, Ni, Cr, Pb and Cd) has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes.

The maximum weight of 5 has been assigned to the parameters like nitrate, total dissolved solids, chloride, fluoride, sulphate and heavy metals due to their major importance in water quality assessment (Srinivasamoorthy et al., 2008; Vasanthavigar et al., 2010). Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, magnesium, sodium and potassium were assigned weight between 1 and 5 depending on their importance in water quality determination. In the second step, the relative weight (W_i) is computed from the following equation:

$$W_{i}=w_i / \sum_{i=1}^{n} w_i$$

Where

W_i = relative weight

w_i = weight of each parameter

n = number of parameters

Calculated relative weight (W_i) values of each parameter are given in Table 26.

Table 26. Relative Weight of Chemical Parameters

Chemical parameters	Indian Standard (BIS 10500, 2012)	Weight (wi)	Relative weight $W_{i}=w_i / \sum_{i=1}^{n} w_i$
Total dissolved solids (mg/L)	500	5	0.0735
Bicarbonate (mg/L)	244	1	0.0147
Chloride (mg/L)	250	5	0.0735
Sulphate (mg/L)	200	5	0.0735
Nitrate (mg/L)	45	5	0.0735
Fluoride (mg/L)	1.0	5	0.0735
Calcium (mg/L)	75	3	0.0441
Magnesium (mg/L)	30	3	0.0441
Sodium (mg/L)	200	4	0.0588
Potassium (mg/L)	10	2	0.0294
Iron (mg/L)	0.3	5	0.0735
Manganese (mg/L)	0.1	5	0.0735
Nickel (mg/L)	0.02	5	0.0735
Chromium (mg/L)	0.05	5	0.0735
Lead (mg/L)	0.01	5	0.0735

Cadmium (mg/L)	0.003	5	0.0735

In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS (2012) and the result multiplied by 100.

$$q_i = \left(\frac{C_i}{S_i}\right) x100$$

Where
q_i = quality rating
C_i = Concentration of each chemical parameter in each water sample (mg/L)
S_i = Indian drinking water standard for each chemical parameter (mg/L) according to the guidelines of the BIS 10500 (2012)

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i x q_i$$

$$\boldsymbol{WQI = \sum_{i=1}^{n} SI_i}$$

Where
SI_i = Sub-index of ith parameter
q_i = rating based on concentration of ith parameter
n = number of parameters

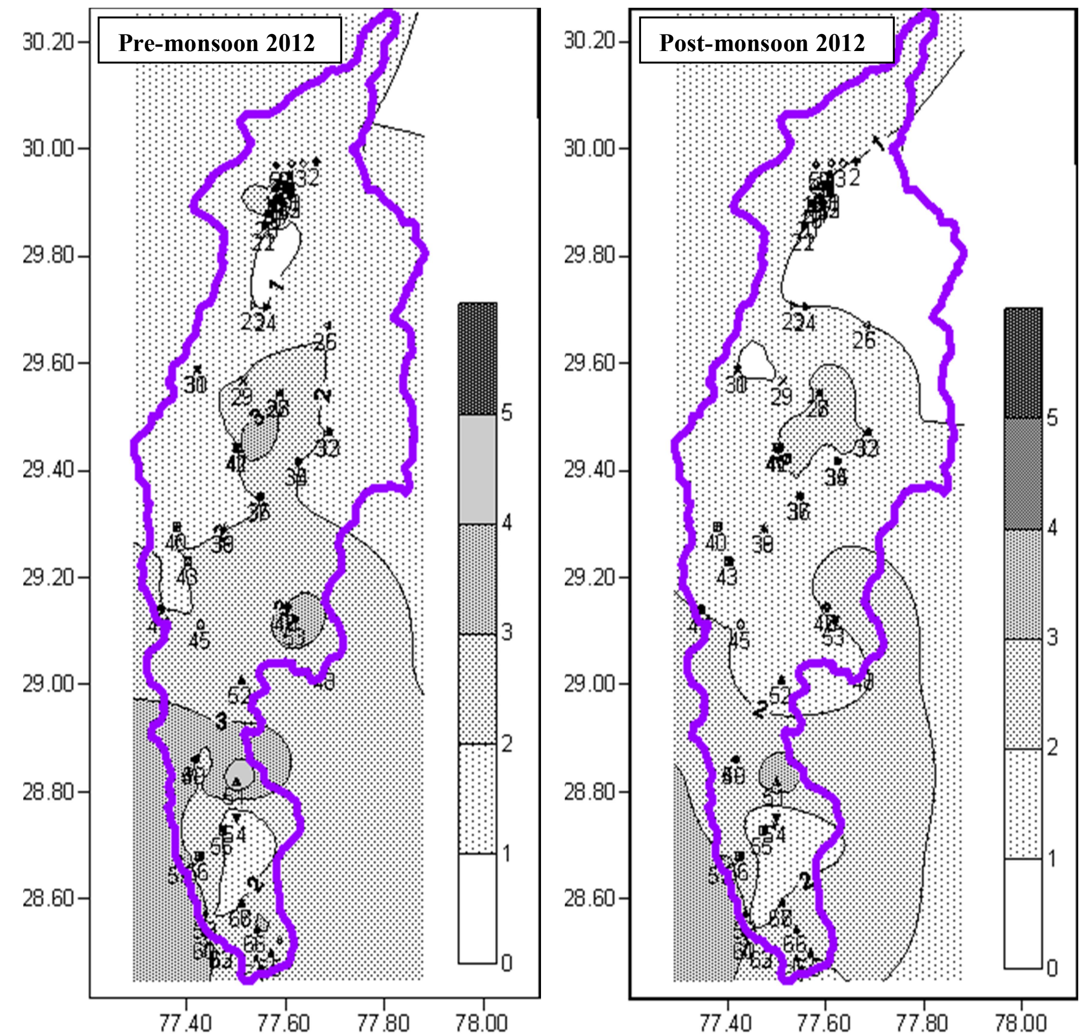
Water quality types can be determined on the basis of WQI. The WQI range and type of water can be classified as

Range	Type of water
<50	Excellent water
50-100.1	Good water
100-200.1	Poor water
200-300.1	Very poor water
>300	Water unsuitable for drinking purposes

Water quality indices for different ground water sources in Hindon river basin were calculated for pre- and post-monsoon season, the type of water was classified and given in Table 27 and Fig. 49. It was observed that most of the ground waters fall between good to excellent type. In post-monsoon season, the quality of ground water was observed to be improved.

Table 27. Water Quality Index of ground water in Hindon River Basin							
S.No.	Location	Source	Depth (m)	Pre-monsoon		Post-monsoon	
				WQI	Type of Water	WQI	Type of Water
1	Fatehpur	HP	40	46.49	Excellent water	47.81	Excellent water
2	Gagalheri	HP	40	56.54	Good water	96.96	Good water
3	Kailashpur	HP	40	100.59	Poor water	78.98	Good water
4	Naugazapeer	HP	50	60.93	Good water	87.77	Good water
5	Mahipura	HP	40	58.81	Good water	69.12	Good water
6	Beherki	HP	33	54.10	Good water	64.19	Good water
7	Ghogerki	HP	36	45.86	Excellent water	106.58	Poor water
8	Paragpur	HP	17	152.29	Poor water	90.62	Good water
9	Paragpur	HP	33	261.58	Very poor water	368.68	Unsuitable for drinking purposes
10	Hasanpura	HP	36	57.07	Good water	72.07	Good water
11	Hasanpura	HP	32	55.03	Good water	59.66	Good water
12	Kapasa	HP	36	54.03	Good water	51.09	Good water
13	Kapasa	HP	13	154.60	Poor water	148.35	Poor water
14	Tapri	HP	36	75.13	Good water	92.20	Good water
15	Tapri	HP	25	80.27	Good water	122.62	Poor water
16	Shekhpura Kadim	HP	36	70.69	Good water	155.21	Poor water
17	Lakhnaur	HP	36	47.46	Excellent water	69.13	Good water
18	Mubarikpur	HP	36	64.60	Good water	76.94	Good water
19	Mubarikpur	HP	15	103.55	Poor water	122.88	Poor water
20	Nanandi	HP	36	39.32	Excellent water	117.19	Poor water
21	Sadauli Hariya	HP	36	54.59	Good water	108.97	Poor water
22	Sadauli Hariya	HP	13	34.32	Excellent water	75.52	Good water
23	Bargaon	HP	36	52.19	Good water	71.03	Good water
24	Maheshpur	HP	36	51.02	Good water	88.05	Good water
25	Deoband	HP	15	41.98	Excellent water	135.36	Poor water
26	Deoband	HP	36	46.76	Excellent water	68.30	Good water
27	Charthawal	HP	36	109.45	Poor water	255.11	Very poor water
28	Charthawal	HP	20	93.58	Good water	158.55	Poor water
29	Biralsi	HP	36	50.48	Good water	94.89	Good water
30	Thanabhawan	HP	36	102.61	Poor water	105.61	Poor water
31	Thanabhawan	HP	27	59.27	Good water	124.32	Poor water
32	Muzaffar Nagar city	HP	15	70.80	Good water	176.04	Poor water
33	Muzaffar Nagar city	HP	36	55.06	Good water	72.71	Good water
34	Tawli	HP	20	49.09	Excellent water	136.44	Poor water
35	Tawli	HP	40	65.31	Good water	86.62	Good water
36	Shahpur	HP	40	62.53	Good water	137.67	Poor water

37	Shahpur	HP	40	56.56	Good water	111.18	Poor water
38	Budhana	HP	40	47.53	Excellent water	119.84	Poor water
39	Budhana	HP	36	114.61	Poor water	146.05	Poor water
40	Jogiyakhera	HP	83	75.79	Good water	135.48	Poor water
41	Atali	HP	12	199.76	Poor water	241.71	Very poor water
42	Atali	HP	46	23.53	Excellent water	55.47	Good water
43	Nirpura	HP	46	76.59	Good water	138.14	Poor water
44	Bamnauli	HP	66	122.47	Poor water	171.88	Poor water
45	Barnawa	HP	66	70.42	Good water	159.30	Poor water
46	Sardhana	HP	15	109.18	Poor water	247.57	Very poor water
47	Sardhana	HP	27	84.31	Good water	126.70	Poor water
48	Kankarkhera	HP	40	99.16	Good water	165.39	Poor water
49	Surana	HP	10	163.20	Poor water	239.63	Very poor water
50	Surana	HP	40	48.08	Excellent water	139.00	Poor water
51	Muradnagar	HP	40	245.36	Very poor water	349.85	Unsuitable for drinking purposes
52	Daluhera	HP	40	58.00	Good water	100.95	Poor water
53	Daluhera	HP	10	46.49	Poor water	158.00	Poor water
54	Muradnagar	HP	23	56.54	Good water	118.19	Poor water
55	Basantpur Sainthali	HP	40	100.59	Good water	126.73	Poor water
56	Harbansnagar	HP	40	60.93	Poor water	217.25	Very poor water
57	Mohannagar	HP	40	58.81	Poor water	318.63	unsuitable for drinking purposes
58	Bisrakh	HP	26	54.10	Good water	192.01	Poor water
59	Bisrakh	HP	12	45.86	Poor water	288.76	Very poor water
60	Kulesra	HP	40	152.29	Good water	210.56	Very poor water
61	Kulesra	HP	13	261.58	Poor water	238.59	Very poor water
62	Surajpur	HP	17	57.07	Poor water	246.81	Very poor water
63	Surajpur	HP	33	55.03	Good water	166.56	Poor water
64	Jaitpur Vaishpur	HP	40	54.03	Good water	189.05	Poor water
65	Dadha	HP	36	154.60	Good water	225.97	Very poor water
66	Dadri	HP	15	75.13	Good water	231.02	Very poor water
67	Badalpur	HP	13	80.27	Good water	139.64	Poor water
68	Badalpur	HP	40	70.69	Excellent water	105.39	Poor water



Water type = 0-2: Excellent; 2-3: Good; 3-4: Poor; 4-5: Very Poor; >5: Unsuitable for drinking purpose

Fig. 49 Classification of ground water on the basis of Water Quality Index

5.0 Conclusion and Recommendations

The river Hindon is highly influenced by direct discharges of municipal and industrial effluents and surface runoff from the surrounding area. The toxic pollutants from these effluents are ultimately reaching the ground water due to surface water and ground water interaction and will enter in the food chain posing a threat to human health because of their carcinogenic nature. The outcomes of the study can be summarized as under:

i) Very high values of BOD and COD in the point sources indicates high organic pollution in drains, tributaries and river Hindon.

ii) The values of re-aeration coefficients and de-oxygenation coefficients for different stretches of river Hindon were computed and the results of estimated BOD at different sampling sites are well in agreement with observed values.

iii) The DO Sag analysis can be successfully used to predict the DO level at different location of the river.

iv) Objectionable taste, colour and odour in few of groundwater samples in the vicinity of river Hindon and Star Paper Mill Drain were noticed. .

v) Physico-chemical parameters viz; TDS, hardness, alkalinity, Ca and Mg are not conforming to Drinking Water Specifications and exceeding the maximum permissible limit prescribed for drinking purpose as recommended by BIS (2012) in the ground water of few locations.

vi) Nitrate concentration in few of the groundwater samples mostly shallow aquifer exceeded the maximum permissible limit, which may be attributed to contamination by domestic waste disposal.

vii) Bacteriological contamination was observed in few groundwater samples in the vicinity of river Hindon, which may be attributed to unorganized and improper sewerage system in the study area. .

viii) The presence of trace elements has also been recorded at many location and the water quality standards have been violated for various metals. The Concentrations of Fe, Mn, Ni, Cr, Pb and Cd in few groundwater samples exceeded the permissible limit prescribed for drinking purpose (BIS, 2012), which may be attributed to the leaching of effluent containing wastes from different industries operating in the basin.

ix) The concentration of α-BHC, γ-BHC and Methoxychlor were detected in few ground water samples of the study area, which may be attributed to extensive use of these pesticides in agricultural practice in the study area, which might have leached to ground water system.

x) Almost all collected groundwater samples from Hindon river basin falls in rock dominance zone suggesting evolution of water chemistry influenced by water-rock interaction.

xi) The scatter plot of (Ca+Mg) vs TZ^+ and high (Ca+Mg)/(Na+K) ratio indicate that carbonate weathering is a major source of dissolved ions in the groundwater of the study area.

xii) Assessment of suitability of the groundwater of the study area for irrigation purpose on the basis of total soluble salts, SAR, RSC and heavy metals revealed that these waters are of medium to good quality for irrigation purpose.

xiii) The water quality of river Hindon at all sites in both season was found to be bad and most of the ground waters were found in the good to excellent category type on the basis of Water Quality Index.

It is recommended that the affected area should be given priority for supply of safe drinking water and this should be extended to other areas in a phased manner. Safe water can be provided to the affected villages by opting following schemes:

i) **Provision of alternate source of water -** It may be possible to get a safe water source in the vicinity by drawing the water from deeper aquifers.

ii) **Transporting water from a distant source through piped water supply -** This may lead to lasting benefits, but initial cost will be high.

iii) In the absence of alternate safe source of water, the water with excessive undesirable constituents must be treated with specific treatment process before its use for human consumption. The following treatment options may be attempted:

   a) Hardness (temporary/bicarbonate) in excess of permissible limits can be removed by lime softening process. This will result in reduction of TDS also and will provide most economically viable solution. Membrane based (RO) technology based on split flow can also be used to achieve desired TDS values.

   b) Nitrate in excess of permissible limits can be removed by ion exchange resins in chloride form or by continuous backwash filters utilizing natural (biological) process of converting nitrate to nitrogen.

   c) The heavy metals, viz., Fe, Mn, Cr, Ni, Pb and Cd can be removed by opting sulfex process which is based on precipitating these metals with sodium sulfide or iron sulfide along with hardness removal.

The industries should not discharge their untreated/partially treated effluent into the river Hindon or its tributaries. The effluents should be treated at the source by installing the efficient Treatment Plant by the industries operating in the area.

The untreated sewage and sewerage flowing in various open drains are one of the causes of ground water quality deterioration. Proper underground sewage system must be laid in all inhabited areas and the untreated sewage and industrial wastes should not be allowed to flow in open drains to avoid any further contamination of ground water because once ground water contaminated, it is very difficult to purify it.

The ground water abstraction sources and their surroundings should be properly maintained to ensure hygienic conditions. Proper cement platforms should be constructed surrounding the ground water abstraction sources to avoid direct well head pollution. The surrounding surface area of the ground water abstraction structures should be frequently chlorinated by use of bleaching power. The ground water drawn from hand pumps should be properly chlorinated to eradicate the presence of bacterial contamination. The mass awareness should be generated about quality of water, its effect on human health and responsibilities of public to safeguard water resources.

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