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RESEARCH ARTICLE

SEASONAL AND SPATIAL VARIATION IN THE WATER QUALITY OF RIVER HINDON AT NCR, INDIA

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ABSTRACT

River Hindon is an important river catering the demand of highly populated and industrial cluster of western Uttar Pradesh, India. Water quality of river Hindon is constantly deteriorating at an alarming rate due to various industrial, municipal and agricultural activities taking place along the course of the river. The present study investigates the seasonal and spatial variation in the water quality parameters at eight different sites for two consecutive years (2013-2015) along the selected stretch of the river. The physicochemical parameters such as pH, temperature, turbidity, total hardness (TH), total dissolved solids (TDS), total solids (TS), dissolved oxygen (DO), biological oxygen demand (BOD), chloride, nitrate, phosphate and fecal Coliform were analyzed for the river water quality. One way analysis of variance (ANOVA) was used to investigate the statistically considerable spatial and seasonal difference. Results of ANOVA suggest that there exist a statistically significant seasonal variation in the water quality of river with respect to pH, temperature, nitrate, sulphate, phosphate and DO. Whereas, the significant spatial variation was shown by TDS, TS, TH and chloride. Water quality index (WQI) was calculated for each site using the National sanitation foundation water quality index (NSFWQI) method. WQI results in the present study reveals that the water quality varies "bad" to "very bad" category at all sites in pre monsoon season. In post monsoon water quality comes under "bad" category at all sampling locations. The significant seasonal variation ($p < 0.05$) was recorded between the WQI of pre monsoon and post monsoon.

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INTRODUCTION

Rivers plays a considerable role in the assimilation and transportation of domestic and industrial waste waters from constant pollution sources and agricultural runoff, which is temporal and commonly affected by climate (Zhau *et al.* 2007). Rivers are highly prone to pollution, therefore it becomes necessary to keep check on surface water quality and interpret the temporal and spatial variations (Yerel and Ankara, 2012). Water chemistry describes the seasonal changes in the behavior of the major ions and catchment characteristics. The constant discharges of domestic and industrial wastewater and seasonal surface runoff due to the climate all have a strong effect on the river discharge and water quality. Pollutants entering a river system normally result from many transport pathways; including storm water runoff, discharge from ditches and creeks, vadose zone leaching, groundwater seepage and atmospheric deposition.

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These pathways are also dependent on the seasons. Therefore, seasonal changes in surface water quality must be considered when establishing a water quality management program (Ouyang *et al*., 2006). A variation in the Water quality, which is influenced by various natural processes and anthropogenic activities, is worldwide current environmental issue in research (Jaiswal *et al*. 2003; Ouyang, 2005; Mukherjee *et al*, 2007; Shrestha and Kazama, 2007; Singh *et al*. 2004). Verma *et al*. (2011), showed the impact of industrial effluent on the seasonal variation of river water quality. Some researchers illustrate the impact of anthropogenic activities on the water quality of aquatic systems (Xu *et al*. 2005; Suthar *et al*. 2010). The anthropogenic discharges constitute a constant polluting source, whereas surface runoff is a seasonal phenomenon, largely affected by climate within the basin (Karbassi *et al*., 2007; Najafpour *et al*., 2008; Singh *et al*., 2004). Water quality is usually illustrated according to biological, chemical and physical properties. Based on these properties, the quality of water can be expressed via a numerical index (i.e. Water Quality Index, WQI) by combining measurements of selected water quality variables. The index is important in evaluating the water quality of different sources and in observing the changes in the water quality as a function of time and other influencing factors (Sarkar and Abbasi 2006). The objective of the index is to turn the different water quality parameters into information, which is comprehensible and usable by the layman (Brown *et al*. 1970 and Boyacioglu H. 2007). WQI value makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters. Additionally, WQI's also make possible comparison between different sampling sites and/or events. In 1970, the National Sanitation Foundation of USA developed the water quality index. This index has been widely field tested and applied to data from a number of different geographical areas all over the world in order to calculate Water Quality Index (WQI) of various water bodies.

However, studies have been reported, which utilizes a variety of chemometric methods in categorization of Spatio-temporal dissimilarity in fresh water (Shrestha and Kazama 2007; Astel *et al*. 2006; Kowalkowski *et al*. 2006). A very limited literature is available on the Integration of WQI with joint utilization of statistical techniques in case of river Hindon. River Hindon originates from the lower Himalayas in Saharanpur district, Uttar Pradesh and flows 260 km through six districts, including Muzaffarnagar, Meerut, Baghpat, Ghaziabad and Gautambudh Nagar until its confluence with the Yamuna (Suthar *et al*. 2010). It is an important river catering the demand of highly populated rural and industrial cluster of western Uttar Pradesh, India. At present Ghaziabad and Noida belt of Uttar Pradesh is undergoing rapid industrialization and urbanization and there are various reports on the constant and alarming decline in the water quality of river Hindon due to various industrial, municipal and agricultural activities (Rizvi *et al*. 2015).

Hence, the characterization of recurring changes in the surface water quality is a significant aspect of evaluating temporal variations of river pollution due to natural or anthropogenic inputs of point and non-point sources like urban, agricultural, industrial, and domestic wastewaters, industrial wastewaters and sewage of metropolitan centers, small electroplating workshops, repair shops, hospitals and medical and scientific laboratories (Vaishali and Punita, 2013). The present study aims at (1) Finding physico chemical parameters which are responsible for seasonal variation during the study period and (2) Evaluating spatial and seasonal variation in the water quality index of the river.

Study Area

Hindon River, an important river of western Uttar Pradesh (India) has its origin from Upper Siwalik (Lower Himalayas). It has an estimated basin area of about 7000 km^2. The catchment area is a part of the Indogangetic Plain, composed of Pleistocene and sub recent alluvium and it lies between latitude 28 30' to 30 15' N and longitude 77 20' to 77 50'E. The selected stretch for the present study lies in the Ghaziabad and Noida districts of Uttar Pradesh, wherein hasty industrialization and urbanization is going on. These industries manufacture a variety of products which includes diesel engines; electroplating, bicycles, picture tubes, tapestries, glassware, pottery, vegetable oil, paint and varnish, heavy chains, automobile pistons and rings, steel, pharmaceuticals, liquor, etc. Total eight study sites, (Figure 1) were selected for the collection of water samples. Some study sites were located adjacent to the areas where various illegal stone crusher units are operational. Table 1 represents the geographical location of study sites along with their codes.

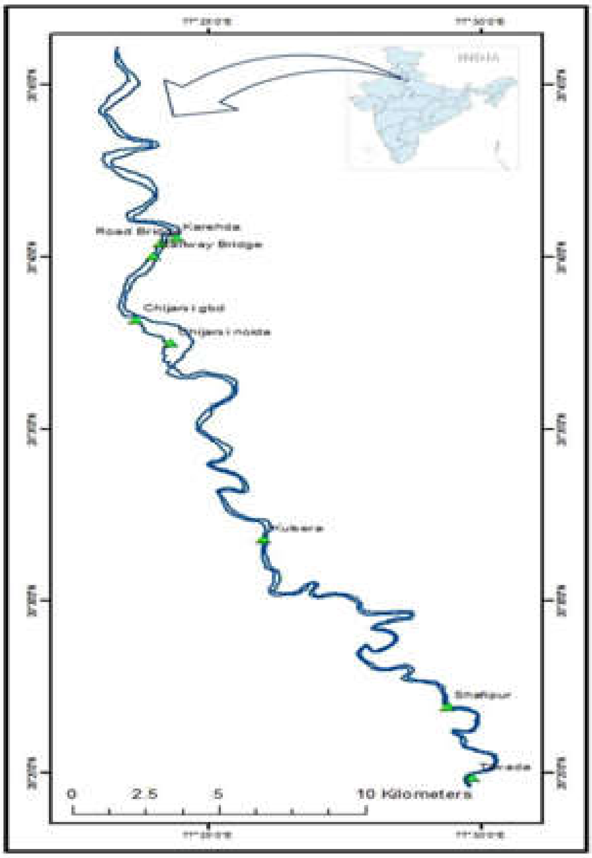

Figure 1. Map showing geographical location of study sites

Table 1. Location of the study sites and their codes

Site code	Site name	Latitude	Longitude
1	Karehda	28^{0}40'32.7" N	77^{0}24'23.2"E
2	Road bridge	28^{0}40'24.3"N	77^{0}24'05.8"E
3	Railway Bridge	28^{0}40'01.7"N	77^{0}23'58.6"E
4	Chijarsi Ghaziabad	28^{0}38'11.0"N	77^{0}23'39.4"E
5	Chijarsi Noida	28^{0}38'08.0"N	77^{0}23'39.2"E
6	Kulsera	28^{0}31'47.9"N	77^{0}26'00.4"E
7	Shafipur	28^{0}24'52.5"N	77^{0}29'20.65"E
8	Tilwada	28^{0}24'52.52"N	77^{0}29'50.98"E

MATERIALS AND METHODS

Sampling and analysis

Total 32 water samples were collected during the study period from eight sampling stations located on the selected stretch of river. Samples were collected seasonally for the two years (2013-15), during pre monsoon and post monsoon seasons. Samples were collected in sterile capped containers, following the methods prescribed in APHA (1998). Sampling bottles were kept in ice box at 4°C and transported to the laboratory within 6 hours for analysis. Global reference was recorded for each site location through Global positioning system (GPS).

Samples were analyzed for twelve water quality parameters which include pH, DO, TH, TDS, chloride, FC, BOD, nitrate, phosphate, turbidity and TS. Table 2 represents the methods used for the analysis of these parameters.

Table 2. Water quality parameters, units and analytical methods for analysis of water quality

Parameter	Units	Instrument/Method
pH	-	pH meter
Temperature	C	Thermometer
TH	Mg/l	EDTA titration
TDS	Mg/l	Gravimetric method
Chloride	Mg/l	Argentometric titration
DO	Mg/l	Winkler's method
Fecal Coliform	MPN	Multiple tube fermentation
BOD	Mg/l	3 days incubation at 28 C
Nitrate	Mg/l	Spectrophotometer
Phosphate	Mg/l	Spectrophotometer
Turbidity	NTU	Turbidity meter
TS	Mg/l	Oven/Gravimetric

Calculation of water quality index

National sanitation foundation water quality index method was used to determine the water quality of river. It is based on 9 parameters such as: BOD, DO, nitrate, total phosphate, temperature change, turbidity, total solids, pH, and Fecal Coliform. The parameters are given weights as indicated in the Table 3 according to their importance in water quality.

Table 3. NSFWQI parameters and their relative weights

Parameters	Weights
pH	0.11
DO (% saturation)	0.17
BOD	0.11
Temperature change	0.10
Turbidity	0.08
Total Solids	0.07
Fecal Coliform	0.16
Nitrate	0.10
Total phosphate	0.10

In this study, eight parameters were considered to determine the WQI excluding temperature change. If less than 9 tests are performed, the overall WQI can be estimated by adding the results and then adjusting for the number of tests. In case concentrations of some parameters are not available, first we can calculate the q- values of those parameters, the concentration of which is available and then those q- values are multiplied with their respective weighting factors. The summation of these values, divided by the summation of weighting factors of available parameters can give WQI (BASIN, 2001).

The weight score (Wi) was multiplied by the Sub index value of each parameter. Sub index value for each parameter was obtained by NSF-WQI Online calculator (www.water-research.net).Finally the WQI was calculated by using following equation:

$$\mathrm{WQI} = \sum_{i=1}^{N} \mathrm{WiQi}$$

Where W_i is the weight of i^{th} water quality parameter.
Qi is the sub index value for i^{th} water quality parameter
N is the number of water quality parameters.

NSF-WQI score was identified by the classification criteria (Table 4)

Table 4. NSFWQI water quality classification

NSFWQI Score	Water quality criteria
0-25	Very Bad
26-50	Bad
51-70	Medium
71-90	Good
91-100	Excellent

Statistical analysis

One way analysis of variance (ANOVA) was used to examine the difference between the two seasons for various physico chemical parameters and water quality index. A probability level of $p < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Hydrochemistry of river water

Descriptive statistical summary of the post monsoon and pre monsoon seasons are given in Table 5. Box and whisker plots for the parameters showing seasonal and spatial statistical significant difference as per ANOVA have been represented in Figure 2a and 2b respectively.

pH: pH is an important parameter of water quality as it affects the water dwelling organisms in a number of ways. Not only the aquatic organism, humans are also affected by extreme values of pH. Apart from its biological effects, extreme values of pH elevate the solubility of various compounds making toxic elements more mobile. It increases the risk of absorption by aquatic life. Toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). Ammonia, however, becomes more toxic with only a slight increase in pH (Vaishali and Punita, 2013).

Table 5. Descriptive statistics of physicochemical parameters in pre monsoon and post monsoon

Parameters	Pre Monsoon			Post Monsoon		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	7.1	8	7.4	7.4	8.3	7.8
Temperature	26.5	33.8	29.9	12.4	17.8	15.3
Total hardness	116	280	188.9	140	340	209.9
Total dissolved solids	243	962	538.6	325	1023	579.2
Chloride	21.3	238	148.3	39.8	309.7	155.9
Nitrate	1.5	51	11.7	1.50	10.70	6.35
Sulphate	4.9	104.5	24.5	49.9	236.5	89.1
Phosphate	3.14	26.26	10.9	0.04	0.8	0.27
Fecal Coliform	9000	210000000	18793438	150000	93000000	10949375
Biological oxygen demand	11.4	76.9	40.7	16.70	65.40	32.9
Dissolved oxygen	0.0	2.6	0.8	0.97	3.20	1.9
Total Solids	326	1494	685.8	348	1718	824.2

Table 6. ANOVA values showing seasonal variation of physicochemical parameters

Parameters	Sum of Squares	df	Mean Square	F	Sig.
pH	1.186	1	1.186	16.646	.000
Temperature	1695.075	1	1695.075	436.278	.000
TH	3549.031	1	3549.031	1.026	.319
TDS	13203.125	1	13203.125	.230	.635
Chloride	458.136	1	458.136	.055	.815
Nitrate	231.663	1	231.663	3.026	.092
Sulphate	33401.432	1	33401.432	22.434	.000
Phosphate	905.985	1	905.985	36.026	.000
FC	4.922E14	1	4.922E14	.293	.592
BOD	492.980	1	492.980	1.573	.219
DO	9.256	1	9.256	15.475	.000
TS	153181.125	1	153181.125	1.143	.294

Table 7. ANOVA values representing site wise variation of the physico chemical parameters

Parameters	Sum of Squares	df	Mean Square	F	Sig.
pH	.501	7	.072	.609	.743
Temperature	49.917	7	7.131	.097	.998
TH	50681.969	7	7240.281	3.069	.019
TDS	1612816.500	7	230402.357	45.254	.000
Chloride	193610.060	7	27658.580	12.139	.000
Nitrate	269.560	7	38.509	.409	.887
Sulphate	15103.646	7	2157.664	.822	.578
Phosphate	376.619	7	53.803	1.006	.452
FC	1.292E16	7	1.845E15	1.164	.359
BOD	2072.790	7	296.113	.908	.517
DO	3.159	7	.451	.451	.860
TS	3297553.500	7	471079.071	12.884	.000

The mean value of pH in this study varies from 7.4 to 7.8 in pre monsoon and post monsoon respectively, showing the slight alkaline nature of river water. The slight increase in the pH at some sites may be due to inputs from industrial and domestic wastewater of the city. It has been found that pH varies significantly between two seasons, p=.000 (Table 6). However, pH does not vary significantly among sites.

Temperature: Apart from its own effects, temperature can influence other physico chemical properties of water. Temperature affects the metabolic rate and biological activity of aquatic organism. It can not only lift up the solubility of toxic elements but also influence the tolerance limit of organisms (Bhadja and Vaghela, 2013). Mean Temperature of the river varied from 29.9 C to 15.3 C in pre monsoon and post monsoon season respectively, showing a statistically significant difference, p=0.00 (Table 6). Seasonal Variation in the temperature can be attributed to the climatic changes of environment. There found to be no statistically significant spatial variation.

Total hardness: Total hardness in water is due to the presence of cations such as calcium and magnesium and anion such as carbonate, bicarbonate, chloride and sulphate. Water hardness has unfavorable effects; hardness above 500 mg/l is objectionable for domestic use or irrigation, as it causes obnoxious taste to water, decreases the ability of soap to produce lather, and forms scaling inside the irrigation pipes. Mean total hardness concentration in pre monsoon and post monsoon seasons varies from 188.9 to 209.9 mg/l respectively. Variation between two seasons was not statistically significant (p=.452), however, there exist statistically significant variation among various sites, p=.019 (Table 7). Higher concentration of total hardness at sites 4, 5, 6, 7 and 8 can be attributed to the mixing of domestic wastewater in river water.

Total dissolved solids: TDS is the measure of the total amount of dissolved solids in the water. TDS includes solutes such as sodium, calcium, magnesium, bicarbonate, chloride, etc. The extent of TDS is proportional to the degree of pollution. The average value of TDS is 538.6 mg/l for the pre monsoon season is and 579.2 mg/l for post monsoon. The seasonal variation of TDS is found to be statistically insignificant (Table 6). However, slightly higher value of TDS in post monsoon is contributed by dissolution of salts and surface runoff by rain water. Spatial variation was found out to be statistically significant (Table 7). TDS values are higher at downstream sites which may be attributed to the mixing of sewerage and nalas into the river stream.

Chloride: Chloride is considered as pollutant for many reasons. High concentration of chloride in river water adversely affects the ecosystem. Chloride may impact freshwater organisms and plants by changing reproduction rates, increasing species mortality, and changing the characteristics of the entire local ecosystem. The average concentration of Chloride in the river water ranges from 148.3 mg/l and 155.9 mg/l in pre monsoon and post monsoon season respectively. Chloride is found to be not vary significantly between studied seasons (p=0.865) however, statistically significant spatial variation was recorded (p=0.00). High values of chloride at stations 5, 6 and 7 may be due to mixing of industrial effluent and urban wastewater.

Nitrate: Nitrate is known to have many adverse effects on the water quality. Excess nitrate levels in the stream can induce eutrophication and ultimately leads to anoxia. Higher nitrate and sulphate values show the anthropogenic stress on the river. Possible sources of nitrate contamination include fertilizers, animal wastes, septic tanks, sewage treatment systems and decaying plant debris (Rizvi et al. 2015). Seasonal and spatial variation of nitrate was found to be statistically insignificant. In present study mean nitrate value is 11.7 mg/l for pre monsoon and 6.35mg/l for post monsoon season. Higher nitrate values during the pre monsoon may be due to increase in the degradation of organic matter by microbial activities. A similar pattern was observed by Naseema et al. (2013) for river Ganga.

Sulphate: Natural source of sulphate in water is leaching from gypsum and other common minerals (Shrinivasa and Venkateswaralu, 2000). Discharge of industrial wastes and domestic sewage tends to increase its concentration (Murhekar, G.H., 2011). Sulphate is found to be varying significantly between pre monsoon and post monsoon (p=.002) with a mean concentration of 24.5mg/l to 89.1mg/l respectively. Urban runoff and sewage flow contribute to the higher concentration of sulphate in the river.

Phosphate: In natural waters, phosphate generally occurs in low to moderate concentration. Major sources of phosphate are Agriculture runoff containing phosphate fertilizers as well as the wastewater containing the detergents (Naseema et al. 2013).

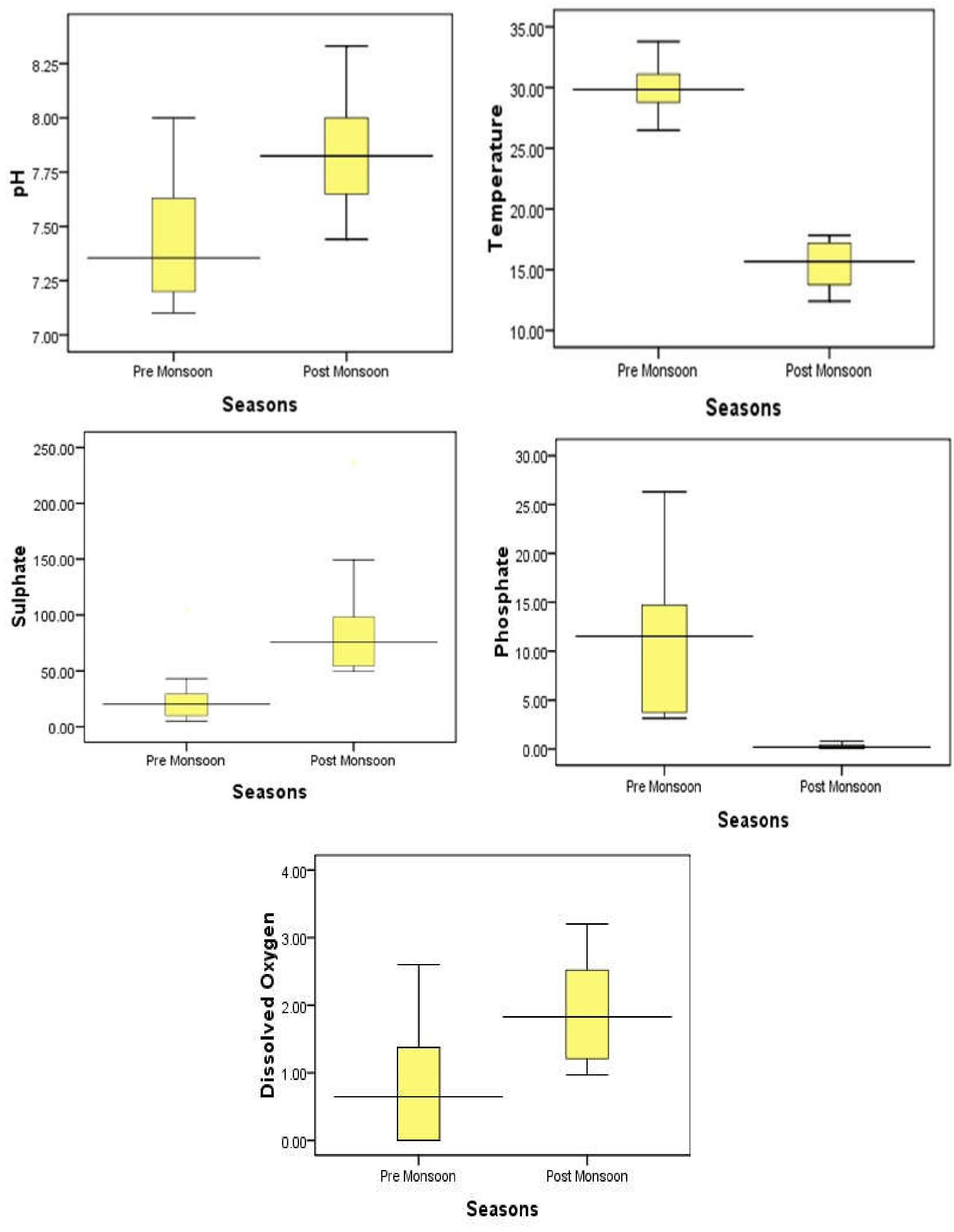

Figure 2(a). Box plots for the parameters showing seasonal statistical significant variation

The seasonal average values of phosphate in river water vary from 10.9mg/l in pre monsoon to 0.27 mg/l in post monsoon and the seasonal difference is found to be significant (p=.001).

Fecal Coliform: Fecal Coliform in water is indicative of the presence of fecal material of humans or other animals. Coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste (Shivayogimath et al. 2012). In present study, fecal Coliform values range from 9000 to 210000000 MPN in pre monsoon and 150000 to 93000000 in post monsoon season. These very high values of fecal Coliform indicate that river is under high pressure of sewage influx. All sites in both seasons are found to be severely contaminated with sewage, which can be attributed to the additional inputs of human wastes through surface runoff from the surroundings. Through ANOVA it has been reported that there is no considerable seasonal as well as spatial variation exist with respect to FC (Table 6 and Table 7).

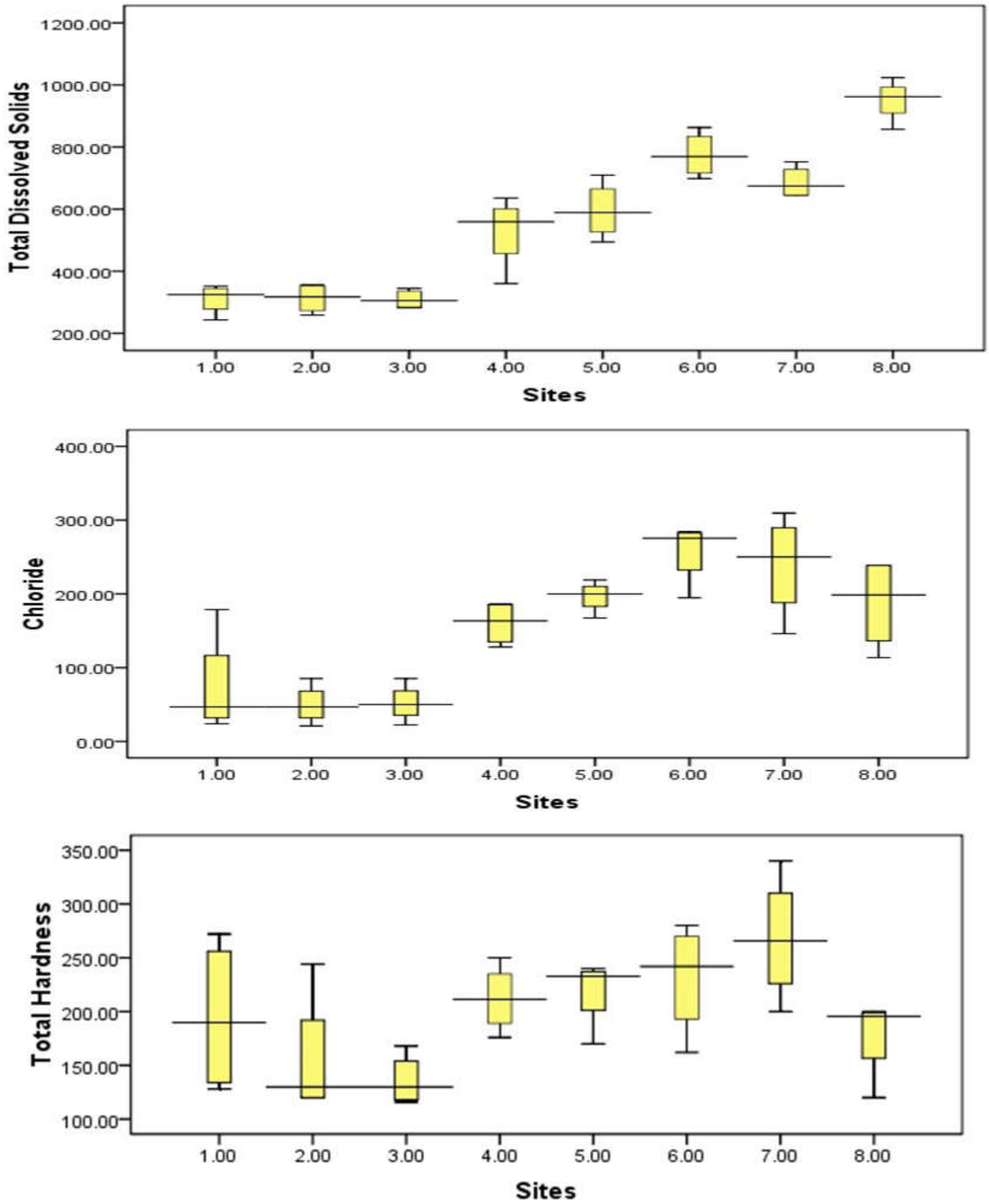

Figure 2(b). Box plots for the parameters showing statistically significant spatial variation

Table 8. Anova value showing seasonal statistical significant difference in WQI

ANOVA					
WQI					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	815.070	1	815.070	27.785	.000
Within Groups	880.059	30	29.335		
Total	1695.130	31			

Biological oxygen demand: BOD is the measure of the amount of oxygen required by the micro organisms to degrade organic matter. The biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Abida, 2008).

In present study, Seasonal variation in BOD does not exist (p=.203). The average concentration of BOD in the study ranges from 40.7 mg/l to 32.9 mg/l in pre monsoon and post monsoon season respectively. The highest value of BOD in both seasons is due to large amount of municipal sewage waste and industrial run off.

Dissolved oxygen: Dissolved oxygen is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in the water (Trivedi and Goel, 1986). A stream must have a minimum of about 2 mg/l of dissolved oxygen to maintain higher life forms (Shivayogimath et al. 2012). In present study, average DO values vary from 0.8 to 1.91 mg/l in pre monsoon and post monsoon respectively. This variation is found to be statistically significant (p=.001). DO value decreases in pre monsoon due to the high temperature and high rate of decomposition of organic matter. However, DO values in both the seasons are found to be much below the permissible limit, indicating that the river is deprived in supporting any life forms.

Total solids: Total solid is the measure of dissolved and suspended solids. In present study, Seasonal difference in the total solids is found to be insignificant (0.462) but there exists significant spatial variation (p=0.00). The mean concentration of total solids in present study varies from 685.8 mg/l to 824.2 mg/l in pre monsoon and post monsoon season respectively. High value in post monsoon season can be attributed to the siltation, heavy precipitation, and mixing runoff, which brings mud, sand, etc., into the stream. Similar such finding was reported by Salve and Hiware (2006). Downstream sites are found to consist comparatively higher values of TS which may be due to dumping of garbage, washing clothes, etc., which are the common activities observed on these sites.

Water quality index

It is clear from figure 4 that the water quality index value for all the sites in post monsoon season is higher than the pre monsoon season. A comparatively high value of wqi in post monsoon season is due to the dilution of contaminants after rainfall. Water quality at all the stations comes under "bad" category. However, in pre monsoon water quality index shifts from "bad" category to "very bad" at Chijarsi Noida, Kulsera and Shafipur. WQI results show that the river is severely polluted. Water quality data was subjected to one way analysis of variance (ANOVA). The result of ANOVA is presented in Table 8, which shows that there exists a significant difference in the mean value of both the seasons at < 0.05% level of significance.

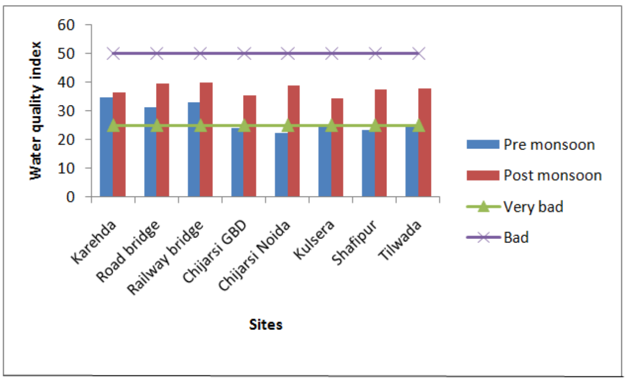

Figure 3. Water quality index at eight study sites in both seasons

Conclusion

It has been found in the present study that the river Hindon is a highly polluted river of western Uttar Pradesh. Analytical results of the physicochemical analysis indicated that most of the parameters deviate from their guideline value. Results of one way analysis of variance show that there exists statistically significant difference in the water quality of river with respect to seasons. pH, temperature, nitrate, sulphate, phosphate and DO are the parameters responsible for the seasonal variation in the water quality. TDS, TS, TH and chloride are the parameters showing statistically significant spatial variation. These parameters are showing higher concentration at downstream sites which may be due to increased domestic and industrial waste influx at these sites. WQI calculated in this study reveals that water quality varies from bad to very bad category in pre monsoon. However, in post monsoon, water quality shifts from very bad to bad at downstream sites. This slight improvement in the water quality can be attributed to the dilution of contaminants in the post monsoon season due to post effect of rainfall. Based on the above results it can be concluded the river Hindon, which is an important tributary of river Yamuna is under immense pressure of pollution load due to anthropogenic activities. Increased urbanization and industrialization in NCR region add on to the pollution level of this river. Therefore, proper maintenance, treatment and disposal of sewage water are vital steps in this regard.

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