Impact Of Industrial Effluent On Hindon River And Groundwater In Ghaziabad City: A Comparative Study

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Abstract
Ever since the dawn of industrialisation, irresponsible disposal of untreated industrial effluent has been a threat to the health of surface water bodies and groundwater quality. As a developing nation, India's socio-economic growth is driven by its industries, most of which release huge quantities of wastewater into rivers. Facing ever-increasing water scarcity, the population has become heavily reliant on groundwater resources, which are already under stress and contaminated. This study focuses on Ghaziabad city; for surface water assessment, five samples were collected from Hindon River, and for groundwater assessment, five samples each were collected from Industrial areas and Residential areas in Ghaziabad city. The samples were analysed for pH, colour, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total hardness (TH), chemical oxygen (COD) demand, biochemical oxygen demand (BOD) and Dissolved Oxygen (DO). The heavy metals analysed were Lead, Arsenic, Nickel, Zinc, Cadmium, Chromium, Copper And Iron. Several water quality parameters were found to be exceeding permissible limits prescribed by the Bureau of Indian Standards. The Water Quality Index was also calculated, and the water quality of the Hindon River and groundwater in Ghaziabad city was found to be very poor and, in some cases, unfit for drinking purposes.

Keywords: Groundwater Contamination; Heavy Metal; Industrial effluent; River pollution; Water quality

Introduction

In this day and age industrialisation is integral to the socio-economic growth of any country or region. Rapid and uncontrolled industrialization has given rise to the release of numerous pollutants which adversely affect the environment and human health. The quality of industrial wastewater effluents is responsible for the degradation of the receiving water bodies (Ilyas et al. 2019, Ahmed et al 2010,). Particularly in developing countries, industrial effluent is often discharged with minimal or no treatment, with nearby rivers often being at the receiving end.

The ecological status of many rivers is strongly affected by human activities and different types of pollution might cause environmental risk for an aquatic environment (Madhav et al 2024, Nbe˘kov et al. 2004). Among the numerous sources of pollution are domestic discharges, agricultural waste, institutional and industrial effluent. These wastewaters and the pollutants they carry alter the river water quality, rendering it unsuitable for use. Such alterations have several adverse consequences concerning human beings and aquatic life (Ahmed et al. 2014, Al-Rawi 2005). Among these industrial wastewater is a significant contributor to the degradation of water quality, in both surface as well as groundwater resources.

Untreated waste from industries has a number of reasons for not being safely treated; One of the reasons is mainly due to the lack of highly efficient and economic treatment technology (Y.C. Ho et al 2012, Ahmed et al 2010). Research by Singh and Yadav (2014) has found that various parameters such as EC, TDS, COD and heavy metal content have been found in an amount that exceeds their standard limits, near industrial effluent discharge locations.

Yet another important factor is the poor understanding about the link between water and ecological health, ecosystem services and human well-being (Gleick 2000). According to Hossain et al. (1970), the presence of a tiny part (4%) of untreated industrial effluent decreases the quality of ground water. Groundwater is the primary source of drinking water in India, with a major chunk of the population relying on hand pumps and tubewells for their domestic water needs. Thus the contamination of groundwater resources due to irresponsible discharge of untreated industrial wastewater is a cause for concern, and regular monitoring of water quality parameters is necessary.

Ghaziabad is an industrial town at the forefront of driving the economic development of western Uttar Pradesh. There is a wide variety among the established industries, from textiles, pharmaceuticals, sugar to machinery parts. Some of the oldest industrial establishments include: Bharat Electronics Limited, International Tobacco Company Limited-Manufacturing Unit-Ghaziabad, Modi Sugar Mills, Mohan Meakin Limited, Hindon River Mills Limited, Dabur India

Limited, Shriram Pistons and Rings Ltd, and Tata Steel BSL Limited. The city's industrial landscape is dominated by textile industry and industrial units manufacturing various engineering goods.
The pollutants present in the effluent are directly related to the nature of the industry. For example, in the textile industry, the discharge is usually high chemical oxygen demand (COD), biochemical oxygen demand (BOD) and colour point (Y.C. Ho et al 2012). Textile Industry, with its use of numerous chemical dyes and other agents and materials, is one of the most significant polluters of the environment.
Textile wastewater effluent contains high amounts of substances that cause damage to both the environment and human health. Suspended and dissolved solids, biological oxygen demand (BOD), chemical oxygen demand (COD), chemicals, odour and colour are some examples of undesirable characteristics which exceed permissible limits (R Ananthashankar 2013, Ahmed et al 2012). The textile effluents contain heavy metals like Cr, As, Cu and Zn, which are capable of harming the environment (Eswaramoorthi et al 2008). Dyes in water can even block sunlight from penetrating the surface of water, thus disrupting photosynthesis. Dyes in water give out a bad colour and can cause diseases like haemorrhage, ulceration of skin, nausea, severe irritation of skin and dermatitis (Tufekci et al, 2007).
Electroplating industry involves the deposition of a protective layer on top of a material. It is one of the most dangerous environmental polluters owing to a high concentration of heavy metals present in the wastewater among other pollutants. According to research by Belova et al. (2020) wastewater that formed at electroplating manufacturers has high concentrations of the heavy metals, organic compounds, low pH (1-5) and it is characterised by high degree of irregularity. Electroplating industry effluent has highly toxic constituents such as heavy metal ions, oils and greases, organic solvents, along with a possibility of high biological oxygen demand (BOD), chemical oxygen demand (COD), Suspended Solids, Dissolved Solids, and turbidity (Rajoria, Vashishtha, and Sangal 2022).
For this study water samples were collected from Hindon River and handpumps in Industrial and Residential areas within Ghaziabad city, and evaluated for water quality parameters with the aim of assessing the impact of industrial activities on the local water resources.

Materials and Methods

Study Area

The city of Ghaziabad is an industrial town situated in the middle of Ganga-Yamuna doab, with an area of roughly 210 sq.km, geographical coordinates of the city are 28.66° N latitude, and 77.45° E longitude. According to the 2011 Census, the city had a population of 16,48,643, however the Ghaziabad Municipal Corporation estimates the current population to be around 30,86,991. A large portion of Ghaziabad's population depends upon groundwater to meet its daily water needs, not only do these industries require vast amounts of water for processing but they also discharge numerous pollutants which contaminate groundwater of the region (Khan et al. 2022). Such wastewater from the industries, urban households and agricultural activities are a major pollutant of the groundwater quality (Ahmad et al 2019).
Hindon River, the main tributary of Yamuna River, one of the major rivers of India, is facing serious challenges for its existence, mainly because of various anthropogenic activities including disposal of untreated and partially treated industrial effluents and sewage containing toxic metals (Khan et al 2022, Reza and Singh 2010).
Samples of Hindon water were taken from five different sites in Ghaziabad city, whereas groundwater samples, five each, were collected from handpumps in three different industrial sites and three different residential sites. A brief description of sampling stations is as follows:

Table 1 Hindon River Sample Locations

Sampling location code	Location	Latitude	Longitude
HR1	Bhanera Bridge, Farukh Nagar	28.733826	77.385391
HR2	Asalatpur Farakh Nagar	28.717873	77.392246
HR3	Nandgram	28.692314	77.399325
HR4	Hindon Railway Bridge	28.666259	77.399114
HR5	Indirapuram	28.6525879	77.3688277

Table 2 Locations of Groundwater Samples from Industrial Areas

Sampling location code	Location	Latitude	Longitude
I1	Sector 2, Raj Nagar Industrial Area	28.679225	77.437733
I2	Meerut Road Industrial Area	28.686538	77.438422
I3	Loni Road Industrial Area	28.686223	77.385298
I4	Loni Road Industrial Area	28.685779	77.386981
I5	Meerut Road Industrial Area	28.685914	77.439183

Table 3 Locations of Groundwater Samples from Residential Areas

Sampling location code	Location	Latitude	Longitude
R1	Madhuban Bapudham, Sadarpur	28.702752	77.484176
R2	Madhuban Bapudham, Sadarpur	28.705626	77.481586
R3	Rafiqabad, Mayur Vihar, Dasna	28.685175	77.511849
R4	Rafiqabad, Mayur Vihar, Dasna	28.68456	77.51841
R5	Mishal Garhi, Govindpuram	28.68079	77.497432

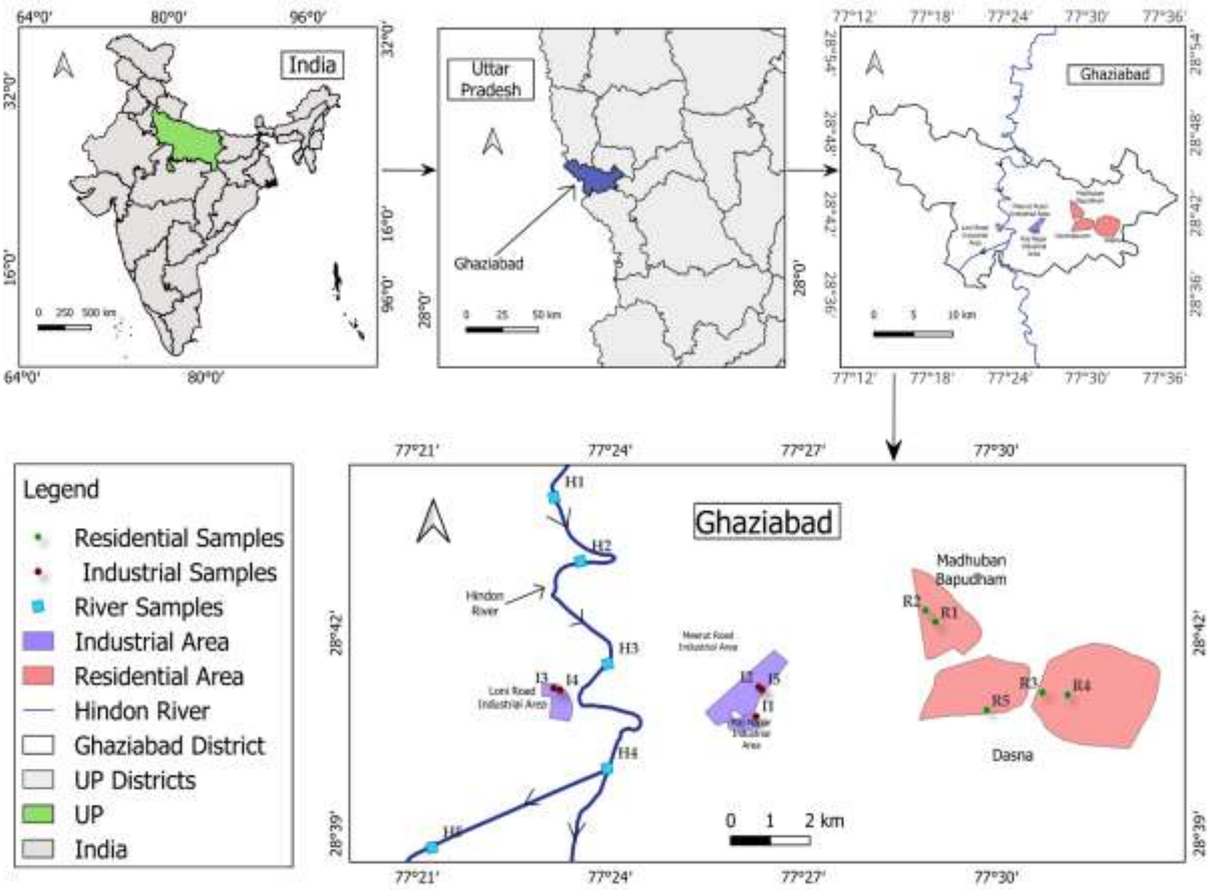

Figure 1 Location map of sampling sites in Ghaziabad city.

Water sampling and preservation

The sample collection was done in April, 2024 along the course of Hindon within Ghaziabad city limits. The groundwater samples were collected from handpumps with an expected depth of 50-80m, in May, 2024. Samples were stored in clean wide mouth polyethylene bottles with screw caps. The bottles were washed twice by water to be sampled before collection at each site. Samples were kept in sampling kits maintained at 4°C, brought to the laboratory and within 2 hours of collection.

Analysis

Water samples were analysed for the following parameters: pH, Colour, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Hardness (TH), Electrical Conductivity (EC), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), as well as heavy metals. The heavy metals analysed include Lead, Arsenic, Nickel, Zinc, Cadmium, Chromium, Copper, and Iron. all the parameters were analysed in accordance to the standard methods prescribed by the Bureau of Indian Standards for Methods Of Sampling And Test (Physical And Chemical) For Water And Wastewater.

Table 4 Summary of Analytical Methods

Parameter	**Analytical Method**	**BIS**
pH	Electrometric Method	IS 3025 (Part 11)
Colour	Spectrophotometer	IS 3025 (Part 4)
Total dissolved solids	Gravimetric Method	IS 3025 (Part 16)
Total suspended solids	Gravimetric Method	IS 3025 (Part 17)
Hardness	EDTA Method	IS 3025 (Part 21)
Electrical Conductivity	Conductivity Meter	IS 3025 (Part 14)
Dissolved Oxygen	Winkler Method	IS 3025 (Part 38)
Biochemical oxygen demand	3-day incubation	IS 3025 (Part 44)
Chemical oxygen demand	Potassium dichromate oxidation (close reflux, titrimetric)	IS 3025 (Part 58)
Heavy Metals	Inductively Coupled Plasma Method	IS 3025 (Part 2)

Water Quality Index

Water Quality Index is a tool which is used to express water quality in simple, understandable terms. For the current study, WQI was calculated by using the weighted arithmetic water quality index method. Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables (Tyagi et al. 2013). The following equations were used for the WAWQI calculation,

$$WQI = \Sigma QiWi/\Sigma Wi$$

The quality rating scale (Qi) for each parameter was calculated by using this expression:

$$Qi = 100[(Vi - Vo)/(Si - VO)]$$

Where,

V_i is the actual amount of ith parameter present,

V_o is the ideal value of the parameter, V_o was taken to be 0, except in the case of pH (V_o=7) and DO (V_o=14.6).

S_i is the standard value for the ith parameter.

Unit weight (W_i) was calculated using the formula:

$$Wi = K/Si$$

Where, K is the constant of proportionality and it was calculated using the equation:

$$K = 1/\Sigma(1/Si)$$

The rating of water quality according to WAWQI are given below in Table 5.

Table 5. Water Quality Ratings, as per Weight Arithmetic Water Quality Index.

WQI	Value Rating of Water	Quality Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Results and Discussion

Hindon River Water Analysis

The analytical results for physicochemical parameters and heavy metals for Hindon river are given in Table 6, and a statistical summary in Table 7. The correlation matrix for Physicochemical parameters is stated in Table 8, and for Heavy metals in Table 9.

In the study it was found that the pH of most samples was within the permissible range, i.e., (6.5-8.5) as per the IS 2296:1992 specifications. The exception being the sample collected from Indirapuram, which had the lowest pH of 6.1 (Table 7). The values for colour were found to be considerably higher than the permissible limit (i.e.10 CU) for all samples (Table 6). The maximum value of Colour was found in the sample collected at Bhanera Bridge (40 CU), and the minimum value was found at sample collected from Indirapuram (15 CU). The Total Dissolved Solids of all samples were found to be much higher than the maximum allowed limit of 500 mg/l, with a mean value of 697.36mg/l. The minimum value of TDS was found to be from the sample collected from Indirapuram (568.8 mg/l), while the maximum value was found at Asalatpur Farakh Nagar (747.2 mg/l). Locals washing laundry and dumping garbage are common practices along the river bank are causes of such high TDS, which drive up the chemical and biological oxygen demand, furthering the depletion of dissolved oxygen in the water body (Suther et al. 2009) On analysis, the mean value of Total Suspended Solids was found to be 46.92 mg/l. The maximum value was found at Bhanera Bridge (69.4 mg/l), and the minimum value was found at Nandgram, (32.6 mg/l). According to Singh et al. (2005), careless disposal of wastes, including industrial effluents, can degrade the quality of the receiving waters.

The total hardness of all the samples was found to be higher than the maximum limit of 200 mg/l, there was only slight variation among different sites. The maximum value was found at Asalatpur Farakh Nagar (240 mg/l), while the minimum value was found to be from the sample collected from Indirapuram (204 mg/l). A strong positive relationship was observed between TH and TDS (Table 8). The mean value of EC on analysis was found to be 1066.6 µS/cm. The maximum EC was found at Hindon Railway Bridge (1111 µS/cm), while the minimum EC was found at Bhanera Bridge (1021 µS/cm). There was a negative relationship observed between EC and Colour (Table 8).

DO is the chief indicator of the health of a water body. The dissolved oxygen of all the samples was found to be considerably lower than the minimum limit of 6 mg/l, with the mean value being 1.48 mg/l. The dissolved oxygen content was found to be the lowest near Hindon Railway Bridge (0.8 mg/l), and highest in Indirapuram (2 mg/l). During the BOD analysis it was found that the BOD values of all the samples were several times higher than the maximum limit of 2 mg/l, with a mean of 21.2 mg/l, with little variation. After analysis, the mean value of COD was determined to be 178.4 mg/l. The maximum value of 202 mg/l was found at Asalatpur Farakh Nagar and Hindon Railway Bridge. Minimum COD was found at Indirapuram (120 mg/l). There was a strong positive relationship observed between COD and TDS (Table 8).

Most of the Heavy Metals analysed were found to be below the limit of detection. Zinc content in all the samples was found to be well below the maximum permissible limit of 15 mg/l, with a mean value of 0.104 mg/l. Cadmium was found to be well above the maximum limit of 0.01 mg/l, with a mean value of 0.27 mg/l. Cadmium content was higher in the areas of Bhanera Bridge and Asalatpur, Farakh Nagar. The minimum value was found in Indirapuram (0.196 mh/l). The Copper content was found to be much lower than the maximum limit of 1.5 mg/l, the mean value was found to be 0.2 mg/l, with no variation. Iron content was found to be much higher than the maximum limit of 0.3 mg/l, with a mean value of 0.74 mg/l. The maximum Iron was found at Hindon Railway Bridge (1.37 mg/l), and the minimum value was found at Indirapuram (0.46mg/l). A significant positive correlation was observed between Iron and Zinc (Table 9).

Table 6 Physicochemical characteristics and Heavy metal content of Hindon River.

Sample	HR1	HR2	HR3	HR4	HR5
pH	7.5	7.4	7.4	7.3	6.1
Colour	40	36	30	20	15
TDS	664.6	747.2	691.8	724.4	568.8
TSS	69.4	57	32.6	42.8	32.8
TH	216	240	222	232	204
EC	1021	1059	1038	1111	1104
DO	1.6	1.8	1.2	0.8	2
BOD	21	20	23	20	22
COD	190	202	178	202	120
Pb	BDL	BDL	BDL	BDL	BDL
As	BDL	BDL	BDL	BDL	BDL
Ni	BDL	BDL	BDL	BDL	BDL
Zn	0.1	0.12	0.07	0.14	0.09
Cd	0.343	0.342	0.216	0.249	0.196
Cr	BDL	BDL	BDL	BDL	BDL
Cu	0.02	0.02	0.02	0.02	BDL
Fe	0.678	0.721	0.495	1.37	0.46

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm).

Table 7 Summary of water quality status of Hindon in Ghaziabad city.

	Minimum	Maximum	Mean	Median	Standard Deviation
pH	6.1	7.5	7.14	7.4	±0.59
Colour	15	40	28.2	30	±10.54
TDS	568.8	747.2	697.36	691.8	± 69.33
TSS	32.6	69.4	46.92	42.8	± 16.03
TH	204	240	222.8	222	± 13.97
EC	1021	1111	1066.6	1059	± 39.77
DO	0.8	2	1.48	1.6	± 0.48
BOD	2	22	21.2	21	± 1.30
COD	119	135	178.4	190	± 34.13
Zn	0.07	0.14	0.104	0.1	± 0.03
Cd	0.196	0.343	0.27	0.249	± 0.07
Cu	0.02	0.02	0.02	0.02	0
Fe	0.46	1.37	0.74	0.678	± 0.37

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm).

Table 8. Correlation Matrix for different water quality parameters for Hindon River.

	pH	Colour	TDS	TSS	TH	EC	DO	BOD	COD
pH	1								
Colour	.84	1							
TDS	.49	.5	1						
TSS	.81	.8	.36	1					
TH	.3	.38	.97**	.3	1				
EC	-.74	-.90*	-.22	-.55	-.04	1			
DO	.	.28	-.38	.52	-.27	-.18	1		
BOD	-.27	-.17	-.55	-.58	-.64	-.27	-.21	1	
COD	.73	.62	.95*	.57	.86	-.34	-.31	-.6	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 9. Correlation Matrix for Heavy Metals for Hindon River samples.

	Zn	Cd	Cu	Fe
Zn	1			
Cd	.4	1		
Cu	.29	.59	1	
Fe	.879*	.15	.43	1

* Correlation is significant at the 0.05 level (2-tailed).

Industrial Area Groundwater Analysis

The analytical results for physicochemical parameters and heavy metals for Industrial Area water samples are given in Table 10, and a statistical summary in Table 11. Table 12 presents the correlation matrix for physicochemical parameters. In the study it was found that the pH of all the samples was within the permissible range, i.e., (6.5-8.5) as per the IS 10500 : 2012 specifications. The mean value was found to be 7.46. The values for colour were found to be in accordance with the acceptable limit (i.e. 5 CU) for most samples, the mean value was estimated to be 4.6 CU. The maximum value was found at I2, Raj Nagar Industrial Area (7 CU), and the minimum value was found at I3, Loni Road Industrial Area (3 CU). A significant relationship was observed between Colour and TSS (Table 12). The Total Dissolved Solids of all samples were found to be well over the maximum allowed limit of 500 mg/l (Table10), with a mean value of 835.48 mg/l. TDS values ranged from 591.8 mg/l to 1149.4 mg/l. A strong positive relationship was observed between TDS and EC (Table 12). The mean value of TSS was found to be 2 mg/l, with the maximum TSS being observed at I2, Meerut Road Industrial Area (4.8 mg/l) and the minimum being at I1, Raj Nagar Industrial Area (0.4 mg/l). Total Hardness must be taken into consideration when assessing water quality with respect to industrial consumption as hard water is known to cause problems where boilers are involved. The total hardness of all but one sample was found to be higher than the maximum limit of 200 mg/l, with the mean value being 401 mg/l. The maximum TH was found at I5, Meerut Road Industrial Area (565 mg/l), while the minimum TH was found to be from the sample collected from I3, Loni Road Industrial Area (120 mg/l). On analysis, the mean value of EC was found to be 1326.6 µS/cm (Table 11). The maximum value was found at I3, Loni Road Industrial Area (1837 µS/cm) and the minimum value was found at I4, Loni Road Industrial Area (908 µS/cm). Most of the Heavy Metals analysed, such as Lead, Arsenic, Nickel, Zinc, Cadmium, Chromium, Copper, were found to be below the limit of detection. Iron values were detected to be higher than the maximum acceptable limit of 0.3 mg/l, in all the samples, with the mean value being 0.576 mg/l. The maximum amount of Iron was found at I4, Loni Road Industrial Area (1.02 mg/l), while the minimum value was found at Raj Nagar Industrial Area (0.39 mg/l).

Table 10 Physicochemical characteristics and Heavy Metal content of Groundwater from Industrial Areas in Ghaziabad city.

Samples	I1	I2	I3	I4	I5
pH	7.5	7.3	7.9	7.4	7.2
Colour	4	7	3	5	4
TDS	772.4	801.6	591.8	1149.4	862.2
TSS	0.4	4.8	1.2	2	1.6
TH	360	505	120	455	565
EC	1253	1305	908	1837	1330
Pb	BDL	BDL	BDL	BDL	BDL
As	BDL	BDL	BDL	BDL	BDL
Ni	BDL	BDL	BDL	BDL	BDL
Zn	BDL	BDL	BDL	BDL	BDL
Cd	BDL	BDL	BDL	BDL	BDL
Cr	BDL	BDL	BDL	BDL	BDL
Cu	BDL	BDL	BDL	BDL	BDL
Fe	0.39	0.46	0.52	1.02	0.49

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm)

Table 11 Statistical summary of water quality parameters in Groundwater from Industrial Areas in Ghaziabad city.

	Minimum	Maximum	Mean	Median	Standard Deviation
pH	7.2	7.9	7.46	7.4	±0.27
Colour	3	7	4.6	4	±1.51
TDS	591.8	1149.4	835.48	801.6	±202.34
TSS	0.4	4.8	2	1.6	±1.67
TH	120	565	401	455	±174.12
EC	908	1837	1326.6	1305	±332.27
Fe	0.39	1.02	0.576	0.49	±0.25

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm)

Table 12. Correlation Matrix for different water quality parameters for Industrial Area samples.

	pH	Colour	TDS	TSS	TH	EC
pH	1					
Colour	-.66	1				
TDS	-.69	.37	1			
TSS	-.73	.881*	.18	1		
TH	-.84	.61	.63	.52	1	
EC	-.68	.43	.995**	.2	.63	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Residential Area Groundwater Analysis

The analytical results for physicochemical parameters and heavy metals for Residential Area water samples are given in Table 13, and a statistical summary in Table 14. Table 15 presents the correlation matrix for physicochemical parameters. In the study it was found that the pH of all the samples was within the permissible range, i.e., (6.5-8.5) as per the IS 10500 : 2012 specifications. The mean value was found to be 7.5. The values for colour were found to be varying substantially. All the samples exceed the acceptable limit of 5 CU, except at Mishal Garhi, Govindpuram which has the minimum value of 5 CU (Table 13). The maximum value was found to be at R2, Madhuban Bapudham, Sadarpur, (27 CU). Colour has a strong negative correlation with TDS, TH and EC (Table 15). The Total Dissolved Solids of most samples were found to be well above the maximum allowed limit of 500 mg/l, with a mean value of 701.48 mg/l (Table 14). The minimum TDS value, the only one under the acceptable limit, was found at R2, Madhuban Bapudham, Sadarpur, (496.2 mg/l). Maximum TDS was found at R3, Rafiqabad, Mayur Vihar, Dasna (847.2 mg/l). TDS shows a strong positive relationship with TH and EC (Table 15). The mean value of TSS was found to be 12.04mg/l, with the maximum value being at R1, Madhuban Bapudham, Sadarpur (25.6 mg/l) and the minimum being at R4, Rafiqabad, Mayur Vihar, Dasna (6.2 mg/l). Total Hardness is a significant indicator of water quality, with respect to domestic usage. The total hardness of all samples was found to be higher than the maximum limit of 200 mg/l, with the mean value being 333.6 mg/l. The maximum value was found at R3, Rafiqabad, Mayur Vihar, Dasna (404 mg/l), while the minimum value was found to be from the sample collected from R2, Madhuban Bapudham, Sadarpur, (236 mg/l). On analysis, the mean value of Electrical Conductivity was found to be 1099.4 µS/cm (Table 14). The maximum value was found at R3, Rafiqabad, Mayur Vihar, Dasna (1259 µS/cm) and the minimum value was found at R2, Madhuban Bapudham, Sadarpur, (800 µS/cm). A strong positive relationship was observed between EC and TH (Table 15). Most of the Heavy Metals analysed, such as Lead, Arsenic, Nickel, Zinc, Cadmium, Chromium, Copper, were found to be below the limit of detection. Iron values were detected to be lower than the maximum acceptable limit of 0.3 mg/l, in most of the samples, with the mean value being 0.314 mg/l. The maximum amount of Iron was found at R3, Rafiqabad, Mayur Vihar, Dasna (0.59 mg/l), while the minimum value was found at R2, Madhuban Bapudham, Sadarpur, (0.18 mg/l).

Table 13 Physicochemical characteristics and Heavy Metal content of Groundwater from Residential Areas in Ghaziabad city.

Samples	R1	R2	R3	R4	R5
pH	7.5	7.7	7.4	7.6	7.3
Colour	20	27	8	9	5
TDS	650.4	496.2	847.2	723.8	789.8
TSS	25.6	10.4	10.6	6.2	7.4
TH	308	236	404	344	376
EC	1058	800	1259	1162	1218
Pb	BDL	BDL	BDL	BDL	BDL
As	BDL	BDL	BDL	BDL	BDL
Ni	BDL	BDL	BDL	BDL	BDL
Zn	BDL	BDL	BDL	BDL	BDL
Cd	BDL	BDL	BDL	BDL	BDL
Cr	BDL	BDL	BDL	BDL	BDL
Cu	BDL	BDL	BDL	BDL	BDL
Fe	0.21	0.18	0.59	0.36	0.23

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm)

Table 14 Statistical summary of water quality parameters in Groundwater from Residential Areas in Ghaziabad city.

	Minimum	Maximum	Mean	Median	Standard Deviation
pH	7.3	7.7	7.5	7.5	±0.16
Colour	5	27	13.8	9	±9.31
TDS	496.2	847.2	701.48	723.8	±136.27
TSS	6.2	25.6	12.04	10.4	±7.81
TH	236	404	333.6	344	±65.27
EC	800	1259	1099.4	1162	±183.58
Fe	0.18	0.59	0.314	0.23	±0.17

All units in mg/l, except Colour (in CU) and Electrical Conductivity (in µS/cm)

Table 15. Correlation Matrix for different water quality parameters for Residential Area samples.

	pH	Colour	TDS	TSS	TH	EC
pH	1					
Colour	.72	1				
TDS	-.78	-.938*	1			
TSS	.34	.46	-.23	1		
TH	-.79	-.937*	1.000**	-.24	1	
EC	-.69	-.947*	.986**	-.19	.985**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Figures 2-7 present a comparison of physicochemical parameter analysis of Hindon River, Industrial Area and Residential Area water samples as box plots. Figure 8 shows the comparison of Iron content of Hindon River, Industrial Area and Residential Area water samples. Figures 9, 10 and 11 present box plots for DO, BOD and COD, respectively of Hindon River samples.

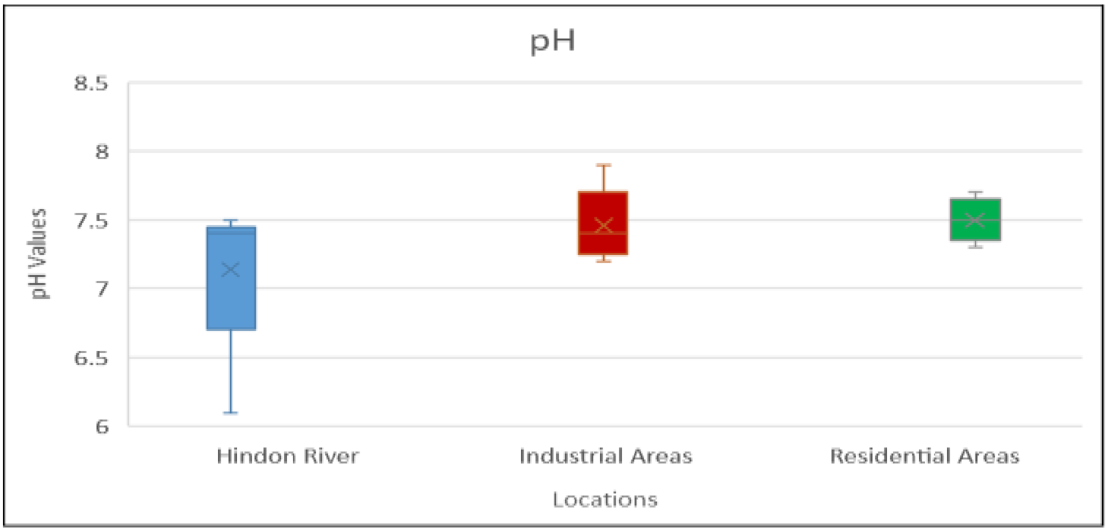

Figure 2. Comparative Box Plots for pH of Hindon River, Industrial Area samples and Residential Area samples.

Figure 3. Comparative Box plots of Colour of Hindon River samples, Industrial Area samples and Residential Area samples.

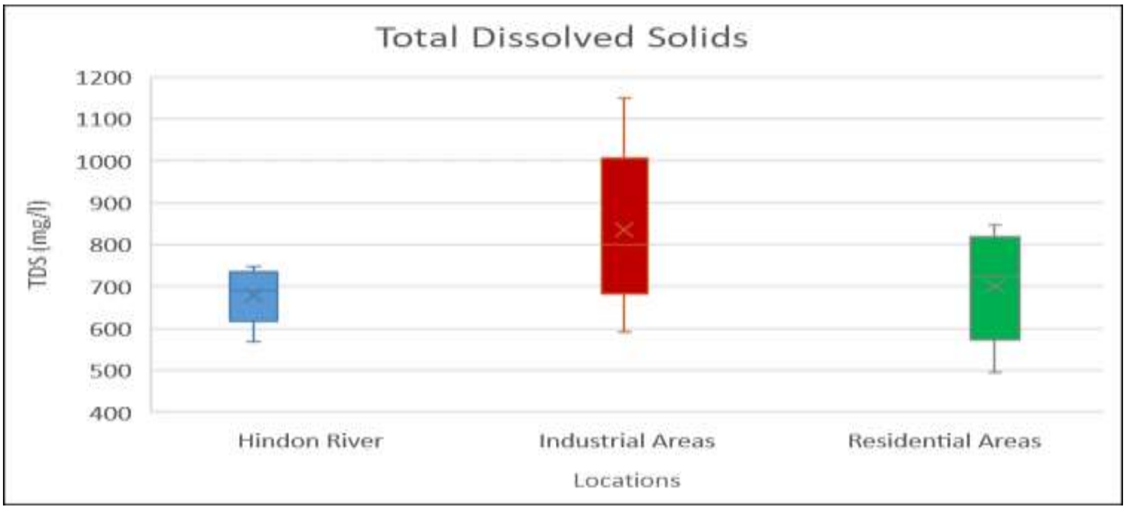

Figure 4. Comparative Box Plots for TDS of Hindon River samples, Industrial Area samples and Residential Area samples.

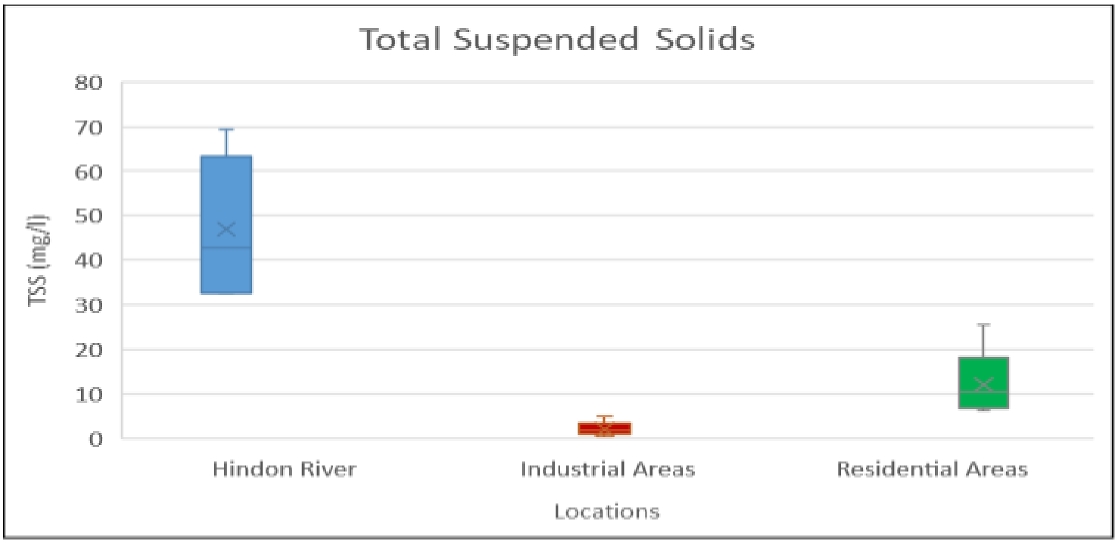

Figure 5. Comparative Box Plots for TSS of Hindon River samples, Industrial Area samples and Residential Area samples.

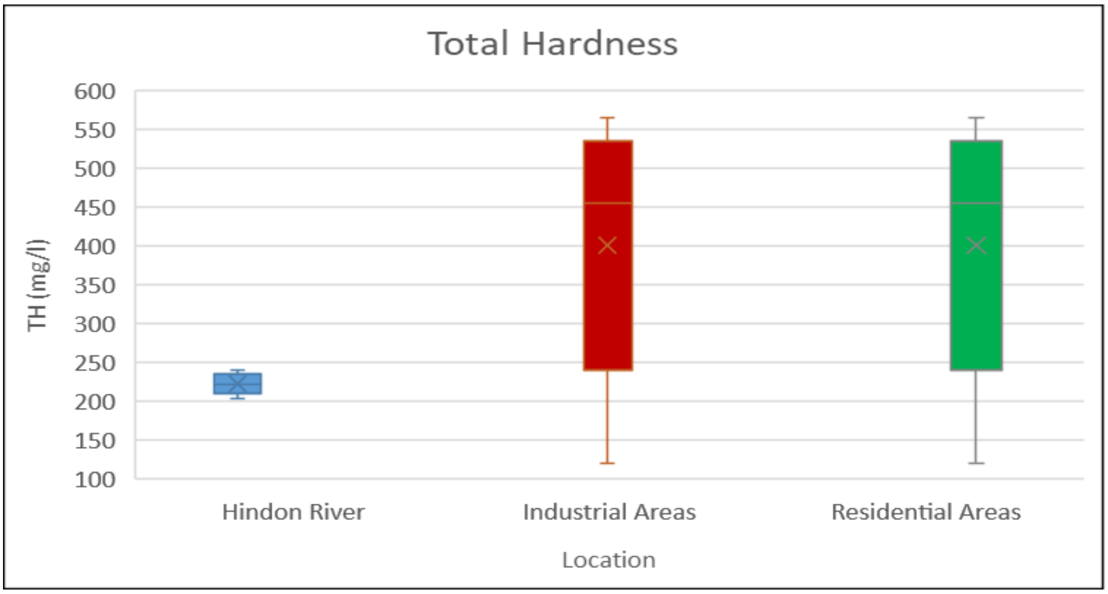

Figure 6. Comparative Box Plots for TH of Hindon River samples, Industrial Area samples and Residential Area samples.

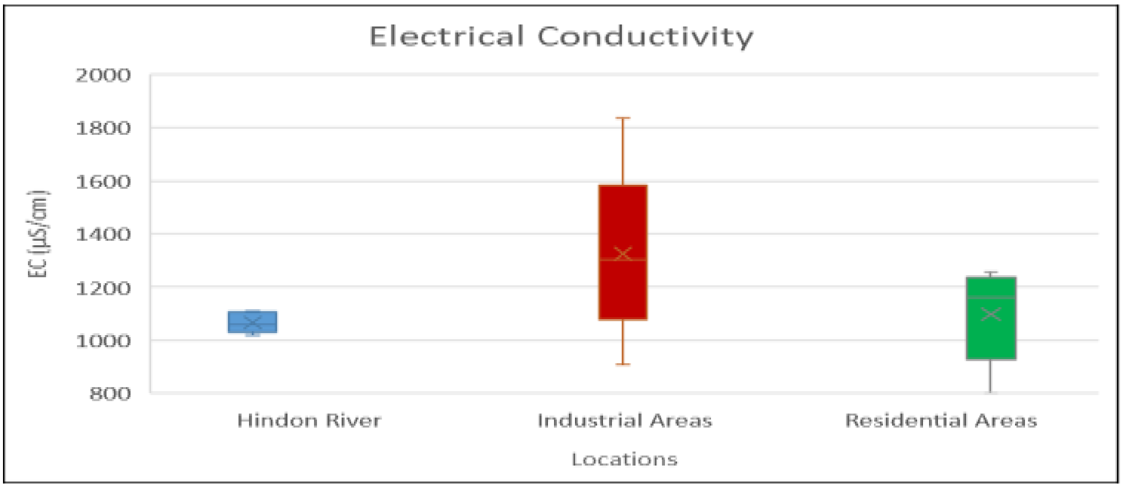

Figure 7. Comparative Box Plots for EC of Hindon River samples, Industrial Area samples and Residential Area samples.

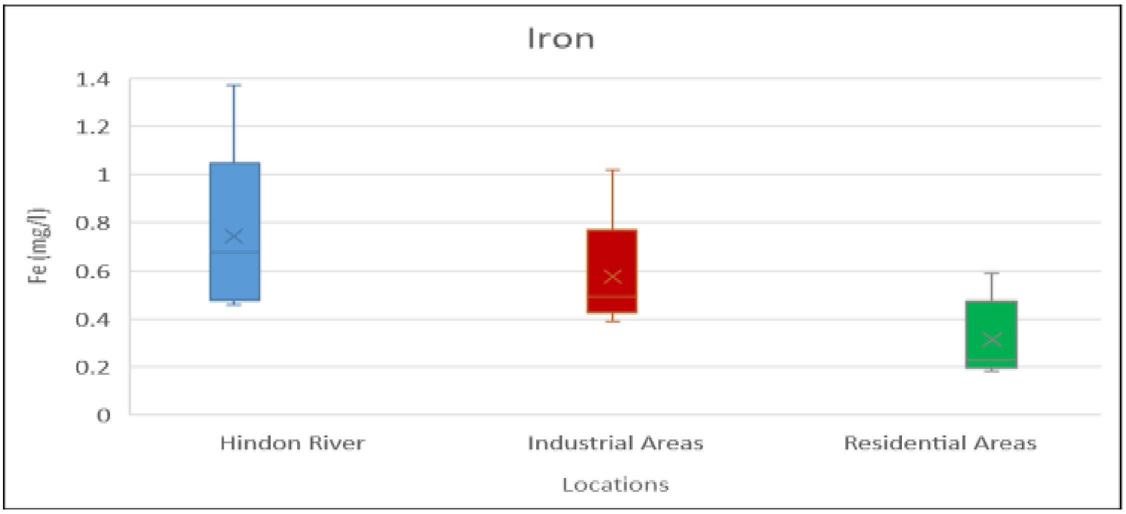

Figure 8. Comparative Box Plots for Iron of Hindon River samples, Industrial Area samples and Residential Area samples.

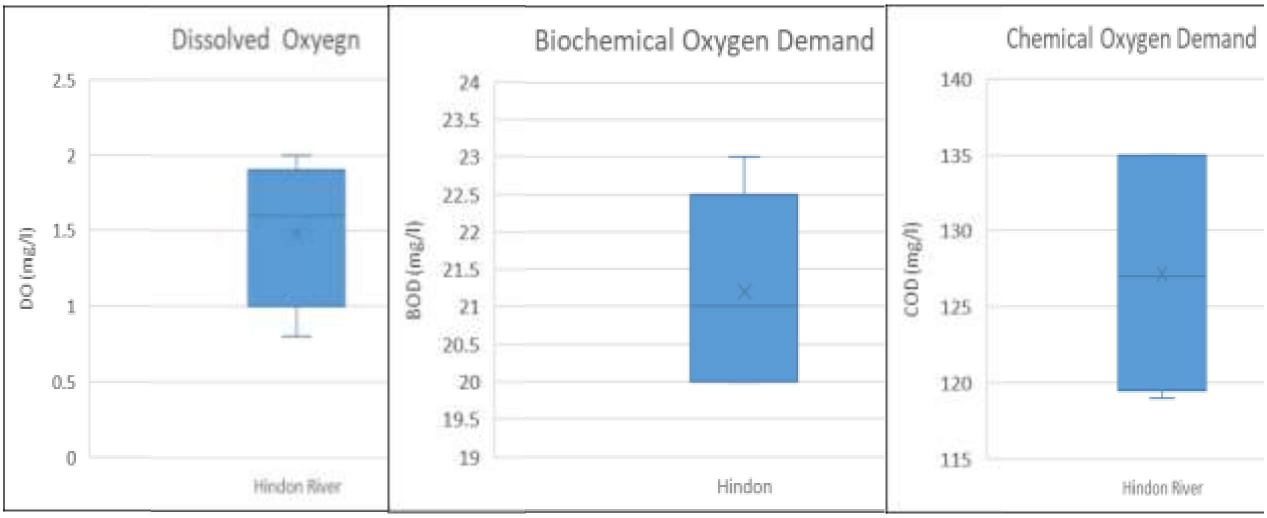

Figure 9. Box Plots for DO, BOD, and COD of Hindon River samples.

Water Quality Index

For the current study, WQI was calculated using the weighted arithmetic water quality index method. According to the findings of the current study, the entire stretch of Hindon River in Ghaziabad is highly polluted and unfit for human consumption. WQI values at most of the sampling sites were found to be above 150 (Table 16), only at HR5 is the WQI below 100. A progressive decrease in the WQI values is observed as we move downstream (Figure 12). This gradual decrease in pollution can be attributed to subsequent dilution of municipal and industrial wastewater.

Table 16. WQI rating of Hindon River samples.

Sample ID	WQI	Value Rating
HR1	178.68	Unsuitable for drinking purpose
HR2	165.7	Unsuitable for drinking purpose
HR3	153.17	Unsuitable for drinking purpose
HR4	127.69	Unsuitable for drinking purpose
HR5	84.58	Very Poor water quality

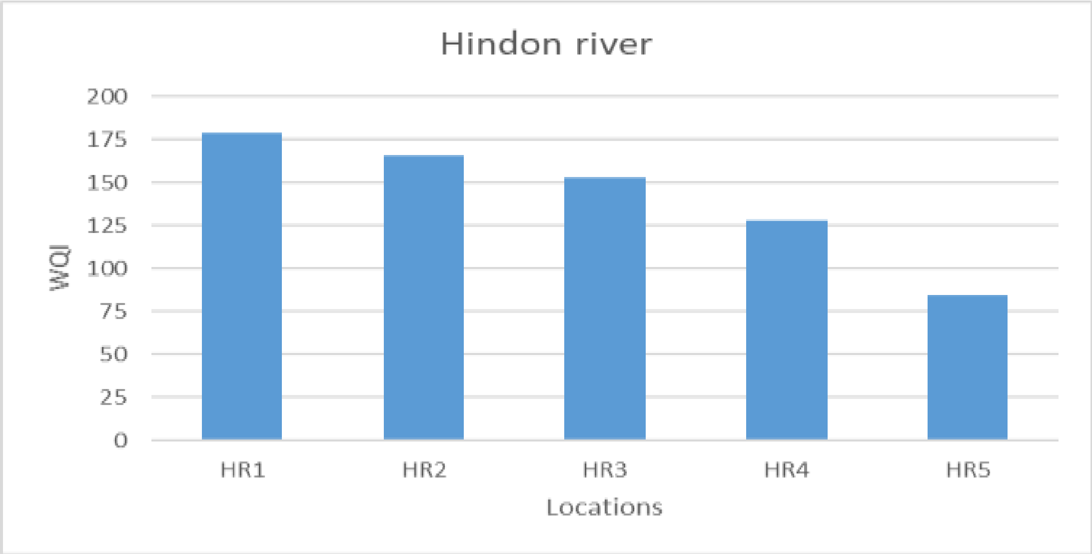

Figure 12. WQI for sampling locations of Hindon River.

In the case of Industrial Area Groundwater samples, 2 out of 5 samples were determined to be of very poor quality, while the rest were found to have poor water quality (Table 17). Even so, a stark difference can be observed between groundwater sample from I2, Meerut Road Industrial Area and the rest of the samples (Figure 13). The WQI for I2 is close to 100, while the WQI values for the rest range from 59.52-76.18.

Table 17. WQI rating of Industrial Area samples.

Sample ID	WQI	Value Rating
I1	65.08	Poor water quality
I2	98.37	Very Poor water quality
I3	60.35	Poor water quality
I4	76.18	Very Poor water quality
I5	59.52	Poor water quality

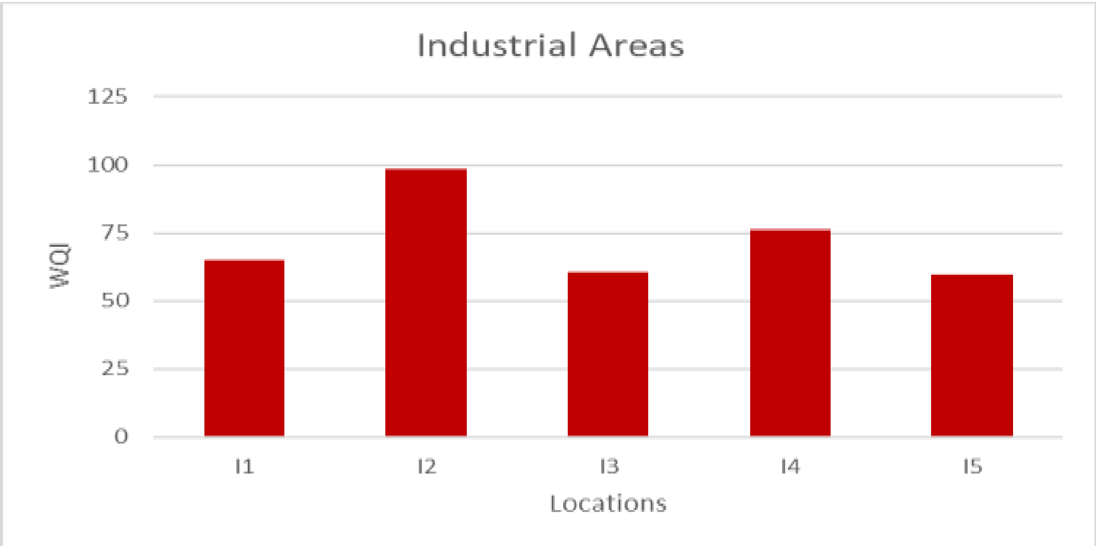

Figure 13. WQI for sampling locations of Industrial Areas.

As stated earlier in Table 5, water with a WQI value over 100 is unfit for drinking. Out of 5 Residential Area groundwater samples, 4 had WQI values above 100, i.e. were found to be unsuitable for drinking purposes. It is easily discernible that water samples R1 and R2, both from Madhuban Bapudham, Sadarpur - are the most polluted (Figure 14). The highest WQI among Residential area samples was determined to be 352.01 at R2, Madhuban Bapudham, Sadarpur while the lowest WQI value was 72.72 at R5, Mishal Garhi, Govindpuram (Table 18).

Table 18. WQI rating of Residential Area samples.

Sample ID	WQI	Value Rating
R1	261.67	Unsuitable for drinking purpose
R2	352.01	Unsuitable for drinking purpose
R3	112.38	Unsuitable for drinking purpose
R4	128.92	Unsuitable for drinking purpose
R5	72.72	Poor water quality

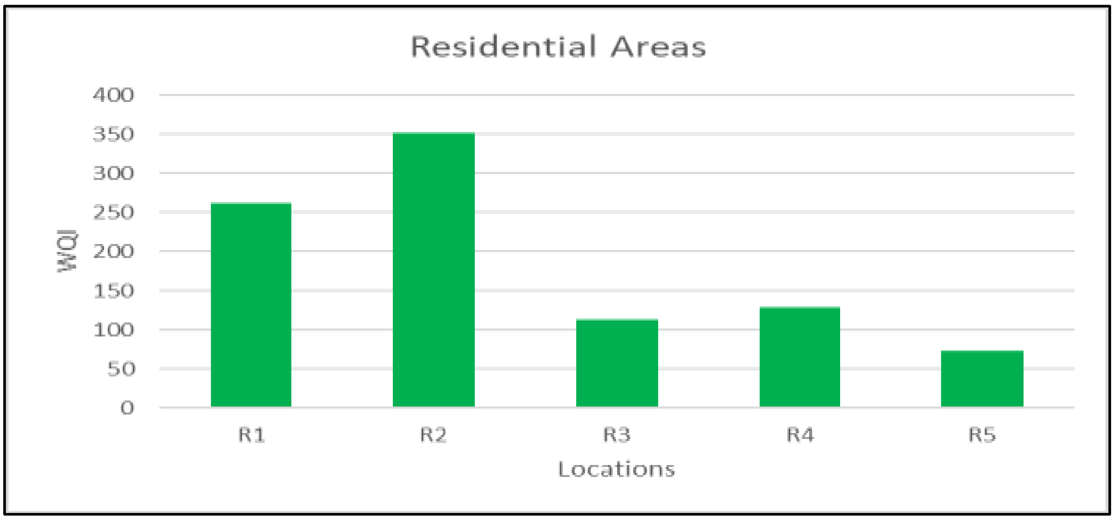

Figure 14. WQI for sampling locations of Residential Areas.

Conclusion

In the current study, the effect of industrial activities on the Hindon River and further contamination of the underlying groundwater, within Ghaziabad city was analysed. The city's population is growing increasingly dependent on its groundwater resources for everyday domestic needs in addition to agricultural and industrial consumption. Hindon River has a history of being used for the disposal of industrial effluent, even before it enters Ghaziabad, it bears a heavy pollution load. It is therefore necessary that the water quality of the river and groundwater is analysed with respect to the guidelines prescribed by the Bureau of Indian Standards.

The amount of dissolved oxygen is a chief indicator of the health of any surface water body. In the case of Hindon River, the dissolved oxygen at all sampling stations was found to be substantially lower than the minimum requirement of 6 mg/l as designated by IS 2296:1992 specifications. The amount of dissolved oxygen being below 2 mg/l at all sampling sites indicates that the river is not capable of supporting aquatic life. Another major indicator is Biochemical Oxygen Demand, the BOD of all sampling sites was calculated to be as much as ten times higher than the minimum acceptable limit of 2 mg/l, as per the IS 2296:1992 specifications for Class A surface water bodies. The values of BOD represent the high organic content that polluted the river. The presence of Cadmium, in amounts much higher than the minimum acceptable limit, expresses the contamination of the river water due to industries of the city, which are dominated by electroplating facilities.

A heavily polluted Hindon River further drives the pollution of groundwater in its vicinity. This is corroborated by the WQI values for groundwater as stated in Tables 16, 17 and 18. The groundwater in the Industrial area was found to be either of Grade C (Poor water quality) or Grade D (Very poor water quality). As for the groundwater in Residential areas, most of the samples were found to be of Grade E (Unsuitable for drinking purpose), and one of Grade C (Poor water quality). These results reflect the high pollution and extremely poor water quality of Hindon River, as most samples from the river were found to be of Grade E (Unsuitable for drinking purpose), with the exception of the last sample downstream which was found to be of Grade D (Very poor water quality). Overall the water quality of Hindon River was found to be very poor, and so was the groundwater quality in Ghaziabad city.

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