ORIGINAL ARTICLE

Estimation of heavy metal contamination in the Hindon River, India: an environmetric approach

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Abstract

The Hindon River is a major freshwater resource predominantly for the rural population of the western region in Uttar Pradesh, India. The river receives industrial wastewaters having heavy metals concentration at potentially toxic levels. The focus of this study is to estimate the heavy metals (such as Fe, Cu, Zn and Cr) contamination in the Hindon River using Nemerow pollution index followed by environmetrics to identify their pollution source. The water samples are collected from 28 industrial discharge sites in the river to analyze metals concentration during pre- and post-monsoon months. The estimated Nemerow pollution index value is more than 3 indicating severely contaminated river water. Principal component analysis results confirm that Fe and Cu are the major contaminants in the river, which indicates the direct input of wastewater from electroplating industries. Therefore, it is suggested that a strategic eco-conservation plan should be formulated and implemented in advance to prevent the deterioration of the water quality and aquatic life.

Keywords Hindon River · Heavy metal · Pollution index · PCA

Introduction

The quality of water is the foremost basic necessity for flourishing aquatic diversity and sustainable eco-development of human civilization and water resources management. Rapid urbanization, industrial advancement and water shortage deteriorate the freshwater bodies in the current world and provoked serious research concerns to safeguard natural resources and to promote sustainable environmental management (Kumar et al. 2017a; Lone et al. 2020). In the developing world, rivers flowing through urban areas are facing the threat of extinction due to endpoint discharge of partially/untreated effluents from the point and/or nonpoint sources (Mishra and Kumar 2020). In India, the direct urban runoffs and sewerage disposal in the freshwater ecosystem (e.g., river, lakes, reservoirs) are the major challenging threats in deteriorating water quality and ecological health of the aquatic ecosystem (Singh et al. 2020). In recent decades, the heavy metal contamination of surface freshwater bodies, especially rivers, has been hot spots of current research (Mishra et al. 2016a; Kumar et al. 2017b). The heavy metals are added into the river system (by anthropogenic and natural sources) and are distributed either in the aqueous phase, suspended stage, or settle down in the riverbed sediments (Kumar et al. 2017c). Under certain environmental conditions, accumulated heavy metals in the river systems lead to ecological disturbances (Yang et al. 2013; Adimalla 2020). Due to bioaccumulation capacity and the environmental persistence of heavy metals, it has been given special attention to know the potential risk of hazardous heavy elements in water bodies (Alves et al. 2014; Misaghi et al. 2017; Kumar et al. 2020b,c). In this regard, multidisciplinary analytical methodologies based on physiochemical, biological and

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eco-toxicology datasets have been developed around the world through triad approaches so that a strategic catchment area treatment plan could be made in advance (Kumar et al. 2020a). However, due to the rapid growth in number of toxic chemicals compounds potentially render the complete chemical characterization of contaminants (Vink et al. 1999; Singh et al. 2019).

In India, major industrial operations which required a huge amount of freshwater are still dependent upon the rivers; hence, it is essential to study the nutrient loading and its potential sources, systemically (Kaushik et al. 2009; Barnwal et al. 2015). Considering the ecological asset, several studies have been reported in the literature related to the assessment of water quality and heavy metal contamination in benthic sediment of Hindon River (Jain and Sharma 2001; Jose et al. 2014; Nur et al. 2015; Chabukdhara and Nema 2012; Wang et al. 2015). But, a comprehensive study related to the assessment of the heavy metal contamination in the subsurface water of Hindon River along the stretches has not been reported yet. The raw datasets of metals concentration were used to evaluate Nemerow pollution index, which classifies the overall contamination level in the Hindon River in single numeric terms (Mishra et al. 2016b). During the analysis, composite data matrices of heavy metal concentration were difficult to illustrate, interpret and draw meaningful conclusions. Therefore, principal component analysis (PCA) is performed to simplify the interpretation of complex data matrices of water quality and the ecological status of any river (Mishra et al. 2018; Turunen et al. 2020; Kumar and Mishra 2020). PCA has been carried out to identify the possible input sources of heavy metal contaminants in the Hindon River. Identification of metal input sources could give reliable information for better management and conservation of water resources as well as useful to develop a rapid solution to mitigate the problems in effective ways (Simeonov et al. 2004; Dalakoti et al. 2015; Lone et al. 2020). Considering the above research gaps, the present study has been performed to estimate the heavy metals (such as Fe, Cu, Cr and Zn) concentration in the subsurface water of Hindon River along the stretches so that its medium or long-term ecological risk could be reduced.

Materials and methods

Detail of water sampling locations

The Hindon River is a major tributary of the Yamuna River, flows in the western part of Indo-Gangetic plain. It is a completely rainfed seasonal river that covers a catchment area of about 5000 km^2, for length 260 km and lies between latitude 28°04′–35°05′ N and longitude 77°04′ E–77°08′ E. The average rainfall of the river catchment is ~ 1000 mm. The Hindon River basin lies in six different districts starting from Saharanpur via Muzaffarnagar, via Meerut, via Baghpat, via Ghaziabad, via Gautam Buddh Nagar in western Uttar Pradesh and final merges in the Yamuna River at outskirt of Delhi. There are two main tributaries of Hindon River (Krishna and Kali). The Kali merges in the Hindon River near Barnava village, while Krishna River joins Hindon River near Binauli village in Meerut district. The densely populated river basin has very fertile land where agricultural practices have been actively flourishing, which also supports the growth of industries. However, the discharge of wastewater from domestic, municipal, agriculture and industrial sectors laden with heavy metals concentration has significantly affected the water quality in the river. The major sources of pollution are coming from sugar distilleries, pulp and paper, and others join the river through various drains network (Nagdev, Dhamola and Barnawa nalla). Considering the joining sites of major drains and ecological signification, the sampling locations were chosen to collect the river water samples, whose details are shown in Table 1 and depicted in Fig. 1.

Sampling, data collection and analysis

The composite water samples were collected (using an acid-washed plastic container) during day time at 10 am near the shoreline at each sampling locations (R1–R28) in the Hindon River during pre-and post-monsoon months of year 2013–14. The collected composite samples were filtered through Whatman no. 42 papers followed by preservation with 6 N HNO$_3$ in acid rinsed containers. The containers were stored at 4 °C temperature without freezing and transported to the laboratory within 24 h to avoid unpredictable changes in characteristics. The water samples were analyzed in the laboratory by following the procedure reported by APHA (2011). Atomic absorption spectrophotometer (AAS, GBC, Avanta) equipped with a specific lamp for the particular metal was used for the analysis of heavy metals concentration in water samples. The overall recovery rates (mean ± SD) of Fe, Zn, Cr and Cu, were 92 ± 5.4, 89 ± 6.9, 93 ± 5.4 and $94 \pm 3.2\%$, respectively, where limit of detection of Fe, Zn, Cr and Cu in aqueous were 0.03, 0.004, 0.002, 0.003 mg/L, respectively. Each experimental analysis was conducted in three replicates, and the mean values of the raw data for each sample were considered for further analysis in this study. The detailed procedure adopted to carry out this study has been presented in the form of a flowchart, as shown in Fig. 2. All the graphs have been constructed using MS Excel version 7 software to represent their actual mean

Table 1 Different surface water sampling locations

Location code	Sampling location	Coordinates
R1	Atali village	29° 26′ 45″–77° 29′ 43″
R2	Banganga nala	29° 65′ 04″–77° 26′ 25″
R3	Krishna River	29° 60′ 53″–77° 25′ 52″
R4	Kalina village drain	28° 58′ 30″–77° 27′ 58″
R5	Habibpur nala	28° 56′ 31″–77° 27′ 38″
R6	Siwat drain	28° 56′ 46.″–77° 27′ 40″
R7	Daula drain	28° 52′ 46″–77° 25′ 38″
R8	Tera drain	28° 47′ 49″–77° 23′ 25″
R9	Sonda drain	28° 43′ 58″–77° 23′ 06″
R10	Drain Upstream Karedha village	28° 41′ 05″–77° 23′ 36″
R11 and R12	Mohannagar area in Ghaziabad where various polluting industries are located	28° 39′ 56″–77° 23′ 57″
R13	It is a downstream site nearby railway bridge of Mohannagar	28° 39′ 59″–77° 23′ 25″
R14	Downstream site which is near Hapur bypass	28° 38′ 04″–77° 23′ 41″
R15	Downstream site and located near Haibatpur village	28° 36′ 32″–77° 24′ 15″
R16	A branch of Hindon located near Ghazipur landfill site	28° 36′ 10″–77° 25′ 26″
R17	Pratap Vihar Drain	28° 38′ 24″–77° 23′ 22″
R18	Bahlolpur Drain	28° 38′ 22″–77° 23′ 23″
R19	Gaur City Drain	28° 36′ 34″–77° 24′ 16″
R20	Bisrakh Jalalpur Drain	28° 35′ 59″–77° 25′ 26″
R21	Kulesara drain	28° 33′ 40″–77° 25′ 21″
R22	Malakpur Drain	28° 31′ 11″–77° 25′ 59″
R23	Gujarpur Drain	28° 30′ 00″–77° 27′ 00″
R24	Badauli Bangar Drain	28° 28′ 48″–77° 28′ 27″
R25	Pitarsi Sewage Drain	28° 27′ 36″–77° 28′ 36″
R26	Bhaggal Sewage Drain	28° 25′ 47″–77° 29′ 41″
R27	GN Sewage Drain	28° 25′ 14″–77° 30′ 21″
R28	Confluence of Hindon and Yamuna River	28° 24′ 47″–77° 29′ 45″

concentration at a specific sampling location, as shown in Fig. 3.

Evaluation of pollution index

The assessment of the overall contamination level and heavy metal enrichment in the Hindon River water was performed using the contamination index (CI) and Nemerow pollution index (PI) illustrated by Yang et al. (2013). The CI and PI were evaluated using the raw data of heavy metals concentration. Primarily, the individual pollution index (Pi) of heavy metals was calculated against the permissible concentration of respective heavy metal in drinking water quality (BIS 2011; WHO 2011) using Eq. 1 and further CI was evaluated using Eq. 2, mathematically expressed as:

$$CI = \frac{1}{4} \sum Pi \tag{2}$$

The CI values represent the level of contamination in the water as CI value > 5 (contaminated), $5 \leq$ CI value > 1 (slightly contaminated) and CI $\leq$ 1 (not contaminated). Furthermore, to elaborate the enormity contribution of individual toxic heavy metal in the river water, PI was evaluated as a single factor index, which can be calculated using Eq. 3, mathematically expressed as:

$$PI = \sqrt{\frac{\left(Pi_{max}^2 + CI^2\right)}{2}} \tag{3}$$

where Pi_{max} denote the maximum value of Pi among all four heavy metals evaluated at the particular sampling

$$PI = \frac{\text{estimated concentration of individual heavy metal}}{\text{standard permisible concentration of heavy metal in drinking water}} \tag{1}$$
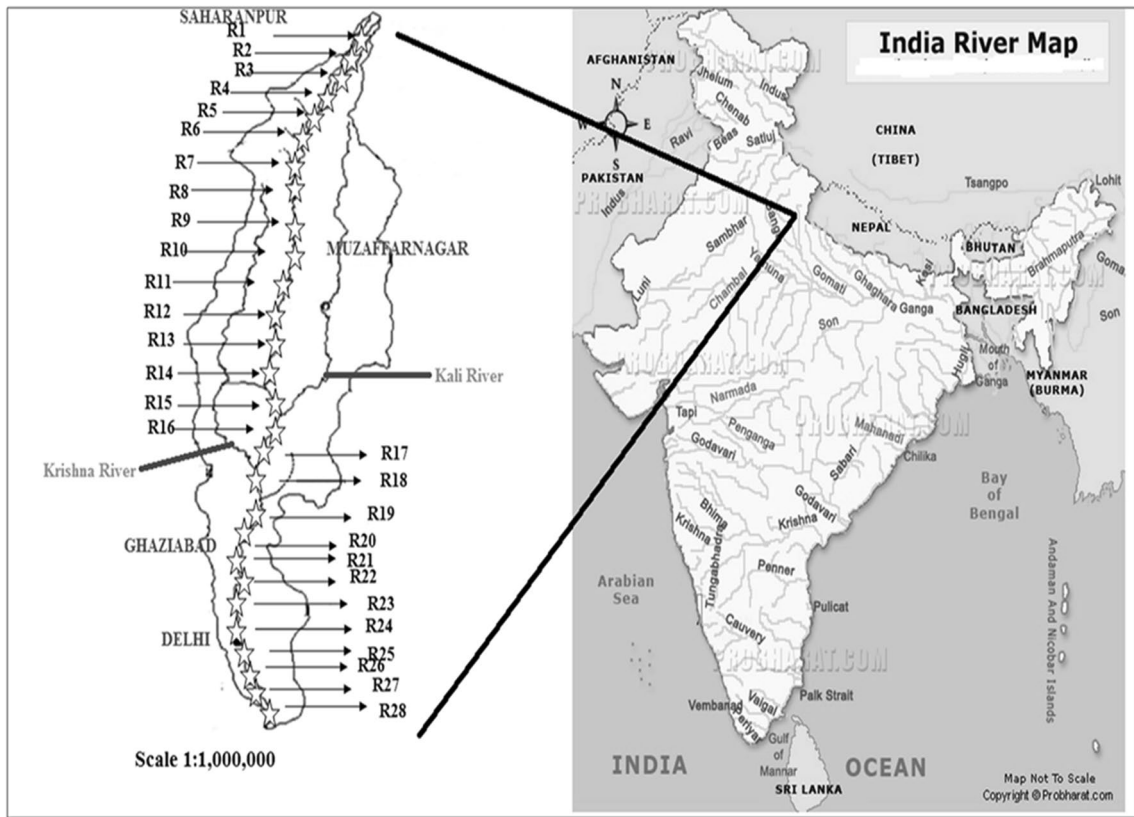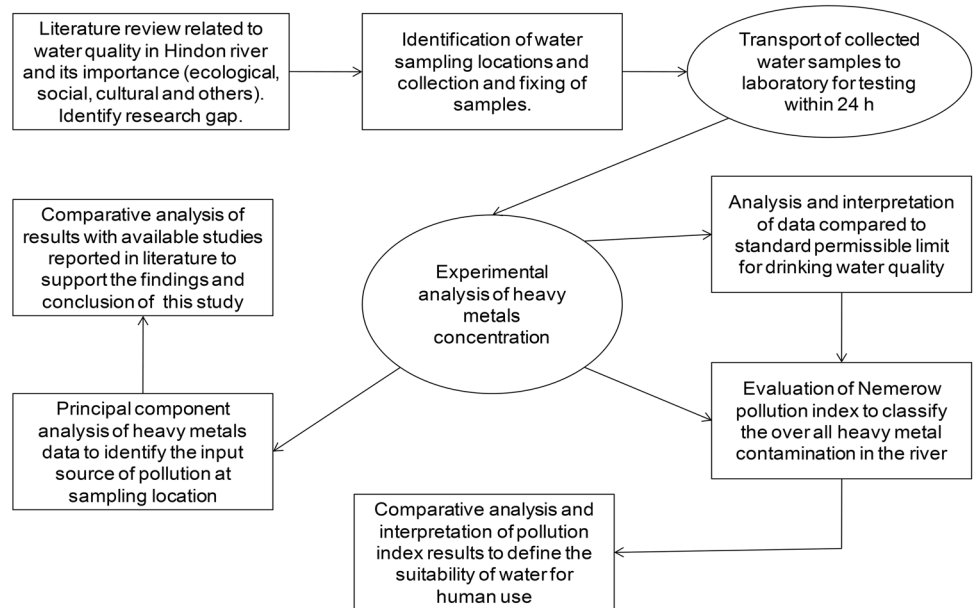
Fig. 1 Schematic diagram of sampling locations in the stretch of Hindon River

Fig. 2 Flow diagram of methodologies adopted in this study

location. PI value classifies the overall water quality as PI value ≤ 1 (not contaminated, drinkable water); 3 ≤ PI value > 1 (slightly contaminated water, unsuitable for drinking) and PI > 3 (severely contaminated water, unsuitable for drinking).

Fig. 3 Metal concentration during pre- (**a**) and post- (**b**) monsoon months at different sampling locations
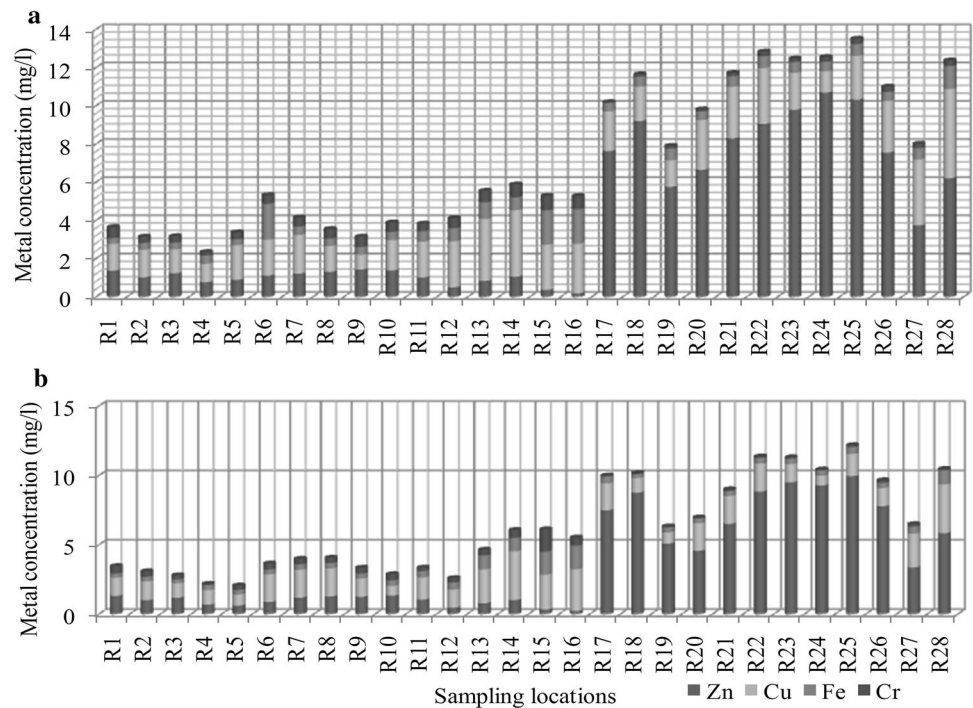
Principal component analysis

Principal component analysis (PCA) is frequently used to identify the input source of nutrients in the freshwater bodies that could provide meaningful information for eco-conservation and management. In this study, the data of heavy metals (Cu, Zn, Fe and Cr) concentration obtained during laboratory analysis were used to perform Pearson's correlation coefficients and PCA using SPSS version 17.0 software. The principal components (PCs) extracted during PCA of heavy metals datasets for all sampling locations were analyzed to assess variations in heavy metals concentration in the river water during the sampling period.

Results and discussion

Assessment of heavy metal contamination

The estimated heavy metals (Fe, Cr, Cu and Zn) concentrations were primarily compared with their respective permissible limit for drinkable water to identify the major contaminant in the Hindon River. Considerably, the estimated values of all heavy metals were found above their permissible value at each sampling location in both pre- and post-monsoon months. The results reveal that the river water is enriched with metals and unsuitable for drinking. To know the overall contamination level in the Hindon River, PI and CI were calculated using the raw datasets of four heavy metals (Fe, Cr, Cu and Zn) collected at all

locations during pre- and post-monsoon months (Table 2). The mean value of CI for all sampling locations (R1 to R28) was falling between 11.53 and 12.79 (CI > 5) during pre-and post-monsoon months, respectively, indicating contaminated water. Similarly, level of contamination was checked through PI, the estimated result is falling between 31.30 and 30.48 (PI > 3) for the respective period, indicating severe contamination of river water. The variability in the PI value at sampling locations in the studied period is graphically shown in Fig. 4.

It could be observed that there was a minor decrease in contamination level in river water during post-monsoon compared to pre-monsoon season at most of the sampling locations. This decrease in the contamination level might be due to dilution of river water that occurred during the monsoon months (Lasagna et al. 2013; Turunen et al. 2020).

Comparably, an increase in contamination level was observed at eight sampling locations (R8, R9, R14, R15, R16, R22, R27 and R28) during post-monsoon than to pre-monsoon months. It could be due to the geographical feature that supports the accumulation of water at the respective locations (Islam et al. 2015). The average PI at R1 to R16 locations during the pre- and post-monsoon months were found as 28.38 and 26.07, respectively, while PI for R17–R28 sites was found to be 35.19 and 36.35, respectively. The results indicate that the R17–R28 sites were more affected by industrialization (major industries are located in the stretch) and geographical variations, which are beyond the assimilative or carrying capacity of the river. The present results support the previous findings of the pollution status in the Hindon River reported by researchers of different

Table 2 Evaluation of CI and PI during pre- and post-monsoon months (2013–14)

Sampling location	Pi Zn		Pi Fe		Pi Fe		Pi Cr		CI		Pi Max		PI	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
R1	0.27	0.26	28.00	26.20	1.00	1.00	11.80	11.00	10.27	9.62	28.00	26.20	21.09	19.73
R2	0.20	0.20	28.80	27.00	1.20	1.13	6.80	8.20	9.25	9.13	28.80	27.00	21.39	20.15
R3	0.25	0.23	25.00	21.00	1.20	0.93	6.80	6.20	8.31	7.09	25.00	21.00	18.63	15.67
R4	0.15	0.14	19.20	21.00	1.43	1.20	3.80	2.00	6.15	6.08	19.20	21.00	14.26	15.46
R5	0.18	0.12	36.20	16.00	1.03	1.10	7.40	6.60	11.20	5.96	36.20	16.00	26.79	12.07
R6	0.22	0.17	37.60	39.80	6.27	1.17	9.20	9.00	13.32	12.54	37.60	39.80	28.21	29.51
R7	0.24	0.24	40.60	40.20	1.43	1.33	9.80	8.20	13.02	12.49	40.60	40.20	30.15	29.77
R8	0.26	0.25	27.00	40.40	1.30	1.30	10.20	7.80	9.69	12.44	27.00	40.40	20.28	29.89
R9	0.29	0.25	15.40	26.20	1.37	1.23	11.00	8.60	7.01	9.07	15.40	26.20	11.97	19.60
R10	0.28	0.27	31.80	14.00	1.43	1.30	10.00	9.40	10.88	6.24	31.80	14.00	23.77	10.84
R11	0.20	0.21	37.60	32.00	1.80	1.50	8.20	5.40	11.95	9.78	37.60	32.00	27.90	23.66
R12	0.10	0.09	48.00	26.20	2.30	1.70	10.60	6.60	15.25	8.65	48.00	26.20	35.61	19.51
R13	0.17	0.16	65.00	48.80	2.90	3.33	12.20	8.60	20.07	15.22	65.00	48.80	48.10	36.15
R14	0.21	0.20	69.60	70.20	2.23	3.27	13.60	11.40	21.41	21.27	69.60	70.20	51.49	51.87
R15	0.07	0.07	47.20	50.00	6.00	5.57	15.40	32.60	17.17	22.06	47.20	50.00	35.51	38.64
R16	0.04	0.05	52.00	60.00	6.03	5.67	14.00	12.00	18.02	19.43	52.00	60.00	38.91	44.60
R17	1.50	1.53	38.80	41.40	1.63	1.50	1.84	1.00	10.94	11.36	38.80	41.40	39.56	30.36
R18	1.75	1.84	21.00	36.00	0.93	1.73	1.92	2.80	6.40	10.59	21.00	36.00	21.48	26.54
R19	1.02	1.15	16.00	27.60	1.20	2.07	1.76	3.00	4.99	8.45	16.00	27.60	16.39	20.41
R20	0.91	1.33	39.80	52.00	1.10	1.50	2.00	2.40	10.95	14.31	39.80	52.00	40.55	38.14
R21	1.30	1.66	40.20	54.00	1.17	1.83	3.00	3.60	11.42	15.27	40.20	54.00	41.00	39.68
R22	1.76	1.81	40.40	58.40	1.33	2.07	2.64	5.00	11.53	16.82	40.40	58.40	41.22	42.97
R23	1.90	1.96	26.20	38.80	1.30	1.87	2.30	3.80	7.93	11.61	26.20	38.80	26.79	28.64
R24	1.85	2.14	14.00	22.20	1.23	1.67	1.90	5.20	4.75	7.80	14.00	22.20	14.40	16.64
R25	1.99	2.06	32.00	45.80	1.63	2.07	3.12	5.80	9.69	13.93	32.00	45.80	32.72	33.85
R26	1.56	1.51	26.20	54.00	1.20	1.60	4.20	5.60	8.29	15.68	26.20	54.00	26.85	39.76
R27	0.67	0.75	48.80	69.00	1.70	1.97	3.80	4.80	13.74	19.13	48.80	69.00	49.76	50.63
R28	1.17	1.24	70.20	93.40	3.33	4.00	2.70	6.00	19.35	26.16	70.20	93.40	71.52	68.59
							Mean CI		11.53	12.79	Mean PI		31.30	30.48

Fig. 4 Variation of PI in pre- and post-monsoon months
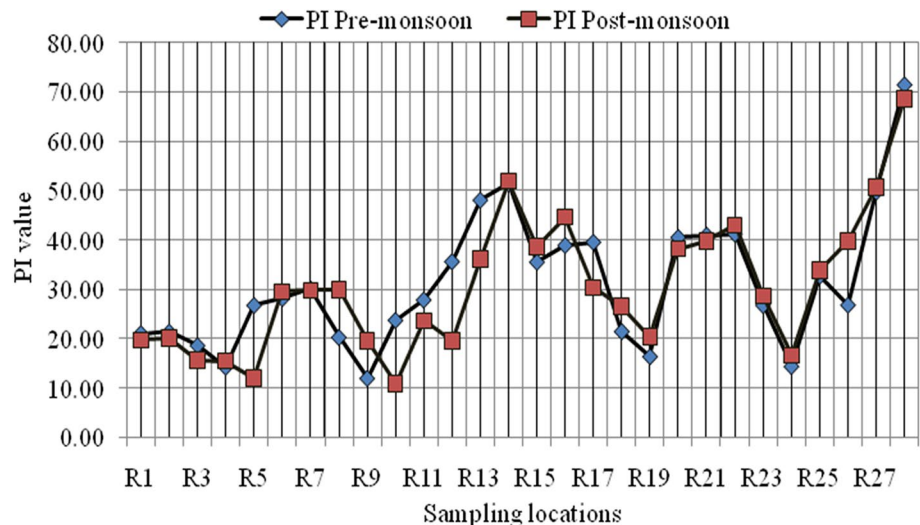
works of life (Suthar et al. 2009; Jain and Sharma 2001; Chabukdhara and Nema 2012; Mishra et al. 2015).

Inter-metal relationships

To know the inter-metal interactions, Pearson correlation coefficient was performed using the raw data of heavy metal concentration in the studied stretch of Hindon River (Table 3). This relationship could be used to demonstrate the transport pathways and further know the input sources (here heavy metals) present in the river ecosystem (Chabukdhara and Nema 2012). The correlation coefficient (R^2) values indicate a clear pattern of relationship among the heavy metals. The results reveal that in pre-monsoon months, the heavy metals like Cu–Cr, Cu–Fe and Cr–Fe gained a strong positive relationship, while Zn–Cu showed a slight positive correlation coefficient (0.15). Moreover, Zn exhibited a negative relationship with Fe (− 0.21) and Cr (− 0.72). Similarly, a strong positive relationship was observed among Fe, Cu and Cr, whereas the negative relationship with Zn during post-monsoon months. The strong correlations coefficients among the metals indicate their common input sources and similar geochemical characteristics. The variation in the correlations coefficient between Zn–Cu in

the sampling period might be due to the direct discharge of untreated wastewater in the river from electroplating industrial sources. The negative relationship between Zn–Fe and Zn–Cr might be due to their difference in origin, characteristics and input source in the river water.

Input source identifications

The PCA technique was performed to identify the source of pollution (here heavy metals) and to extract more reliable information for a better demonstration of the relationship. Primarily, Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were carried out using raw heavy metal data for both pre- and post-monsoon months. The impact of underlying factors on sampling adequacy or the proportion of common variance in estimated heavy metals data could be verified by the KMO value (Mishra et al. 2018). The high KMO value ~ 1 signifies the suitability of factor analysis for use, whereas KMO < 0.5 indicates the nonsignificant error in the estimated data. KMO was found as 0.522 and 0.518 with a significance level of 0.00 in Bartlett's tests of sphericity during pre- and post-monsoon months, respectively. The significance value close to 0.00 indicates significant factorial relationships). The PCA (with Varimax normalized rotation) of heavy metal datasets exhibited two PCs with eigenvalues > 1, indicating 81.4 and

Table 3 Pearson's correlation coefficients of heavy metals during pre- and post-monsoon months, 2013–14

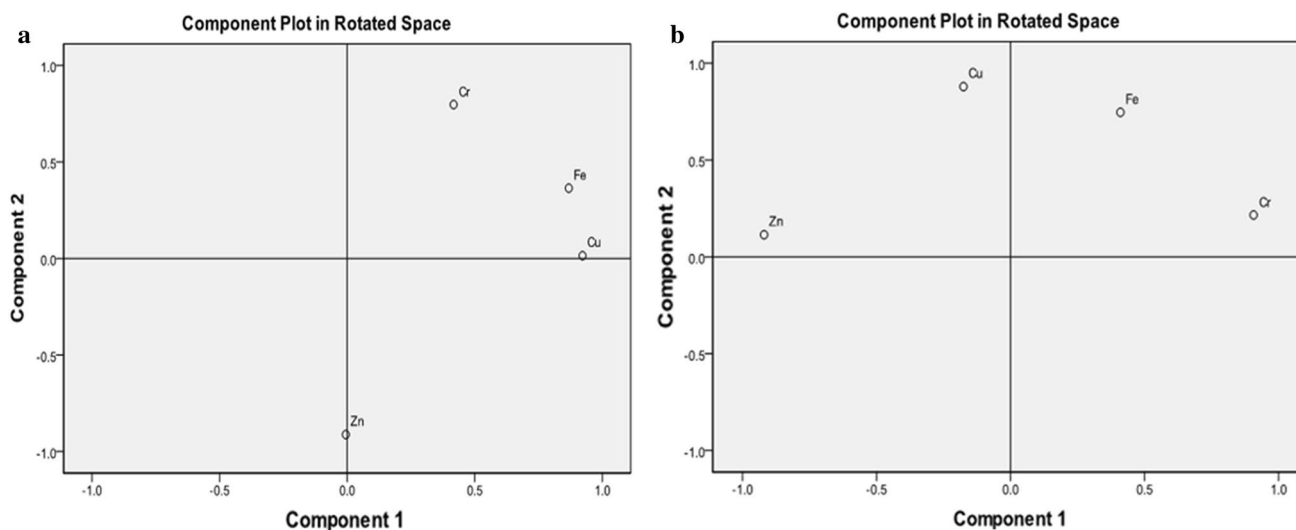| Post-monsoon		Zn	Cu	Fe	Cr	Pre-monsoon		Zn	Cu	Fe	Cr
	Zn	1.00	–	–	–	Correlation	Zn	1.00	–	–	–
	Cu	− 0.15	1.00	–	–		Cu	0.15	1.00	–	–
Correlation	Fe	− 0.28	0.69	1.00	–		Fe	− 0.21	0.36	1.00	–
	Cr	− 0.56	0.30	0.67	1.00		Cr	− 0.72	0.06	0.45	1.00

Fig. 5 PCA loadings and score plot of heavy metal during: **a** pre-monsoon months; **b** post-monsoon months

Table 4 PCA components values of heavy metals

Heavy metals	PCA components during post-monsoon		PCA components during pre-monsoon	
	1	2	1	2
Fe	0.89	0.30	0.92	−0.15
Cr	0.84	−0.33	−0.80	0.46
Cu	0.70	0.60	0.67	0.53
Zn	−0.60	0.68	0.18	0.88

84.45% of cumulative variance during pre- and post-monsoon months, respectively, as shown in Fig. 5.

The PCA results of heavy metals raw data for post-monsoon months are represented in Table 4. The PC1 explained 59.01% of the total variance and exhibited strong positive loadings of Fe, Cr and Cu, while strongly negative loading of Zn. Moreover, PC2 explained 25.41% of total variance, showed positive loading of Fe, Zn and Cu, whereas Cr showed negative loading. Similarly, for pre-monsoon months, the PC1 explained 49.21% of total variance and exhibited strong positive loadings of Fe, Cu and Zn, while strongly negative loading of Cr. Moreover, PC2 explained 32.20% of total variance, in which only Fe exhibited the negative loading and the others exhibited positive loading. The results indicate that the main input sources of these heavy metals (Fe, Cu and Zn) could be the untreated wastewater entering into the river from industrial and urban areas. The wastewater might contain enter in the Hindon River from industries such as electroplating, steel, pharmaceuticals, textile, paper and pulp. The Cu loading in PC1 and PC2 of both pre- and post-monsoon months was strongly positive, which depicts that the river water received effluents from the chemical industries.

The variation in the loading of Cr in PC1 and PC2 for both sampling months could be due to its mixed origin, which indicates the contribution of Cr in the studied stretch of Hindon River could be from industrial or urban discharges and geomorphologic aging of parental rocks. Comparably, the Fe loading in PC1 and PC2 in post-monsoon was found strongly positive than pre-monsoon months, which indicates the addition of Fe into the river from lithogenic and anthropogenic sources. The heavy metal Zn was positively loaded in PCs of pre-monsoon months, whereas negative in PC1 and positive in PC2 of post-monsoon indicate that the Zn loading could be due to the industrial source. The impact of contamination from industrial sources was more during pre-monsoon than post-monsoon months. The Cr and Fe mentioned earlier may have different sources of origin, which could cause difficulty to control the effect of PC1 and PC2 by natural factors. The PCA results were very much supportive of water quality status classified as per PI values. However, it cannot be predicted with certainty (the level of metal contamination in river water) because the concentration of many heavy metals (other than those considered in the present study) has not been analyzed yet.

From the above analysis, it is found that water quality of Hindon River is unsuitable for drinking and other life-supporting activities. The river water should be pre-treated (e.g., technologies like reverse osmosis, ultrafiltration, ion exchange, membrane separation, etc.) and others for hygiene before used for drinking. Additionally, it is also suggested that the pre-treatment of industrial wastewater should be done before discharge into the river to maintain the aesthetic value of the river and aquatic life. These measures need to be taken into consideration by industries available in the vicinity of river catchment followed by governing authorities to mitigate the further deterioration of the river water quality and to restore the ecological assimilative capacity of the river.

Conclusion

The present study was carried out to assess the heavy metals (Cu, Fe, Cr and Zn) concentration in the subsurface water of Hindon River and its stretches (at 28 sampling locations) during pre- and post-monsoon months. The raw datasets were used to evaluate the pollution index (PI) and further classify the overall metal contamination followed by PCA to know the pollution sources. The average PI value was evaluated as 31.30 and 30.48 during pre- and post-monsoon, respectively, which indicates the severe metal contamination in the river water and not fit for drinking or any other life-supporting activities. Pearson's correlation analysis of heavy metals showed a strong mutual dependency and common input source in the river water. Moreover, PCA results reveal that Cu impacts more to the water quality compared to Fe, Zn and Cr. This metal contamination is due to the inflow of partial/untreated wastewater from industrial, agricultural, domestic and saline seeps into the river. Thus, it is suggested to check each point and nonpoint source and pre-treated before discharge to the river. Moreover, catchment area treatment plans should be implemented in advance by the policy-makers and stakeholders to maintain the aesthetic value and ecological life.

Compliance with ethical standards

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