Evaluation of heavy metal pollution for River Gomti, in parts of Ganga Alluvial Plain, India

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Abstract

The aim of the current study was to evaluate the status of heavy metal contamination in River Gomti for Lucknow district. The quantification of the pollution levels in River Gomti over a stretch of ~61 km, has been attempted through heavy metal pollution index (HPI). The results suggested that 30% of the total sites fall under the category of 'highly polluted' ($HPI > 30$), and 60% of the sites are designated under 'critically polluted' category ($HPI > 100$). Further, it was found that the mean HPI value across the stretch of the study area was 149.29 signifying towards the category of 'critical pollution' ($HPI > 100$). The principal component analysis results suggest strong positive loadings on arsenic (As) and lead (Pb) similar to the hierarchical cluster analysis (HCA) results which signified towards close association between As and Pb. A 'good' correlation ($0.51 < r < 0.89$) has been found for As with Pb and Mn. The possibility of anthropogenic intrusion as a cause for heavy metal contamination at all sites is also signified through the results from HCA. Thus, the untreated discharge from the agricultural runoff, sewage system including domestic and industrial wastewater has emerged as a potential cause of heavy metal contamination in the river water.

Keywords Surface water · Heavy metals · Pollution indices · River Gomti · Ganga Alluvial Plain · Multivariate statistics

1 Introduction

Rivers are the most suitable indicators of any deviation occurring in the natural state of a landscape [1]. The integration of natural and anthropogenic inputs and processes form the influence factors for river water quality [2, 3]. The development of civilizations across the globe has been witnessed in the vicinity of rivers causing deterioration in water and sediment quality through anthropogenic activities [4]. The increased settlements due to population growth in the river vicinity has led to overexploitation and excessive water quality depletion. Thus, the resultant modifications in the aquatic ecology and riverine processes have affected the aquatic flora and fauna structure and decreased biodiversity [5]. The surface water sources have undergone various quantitative

and qualitative changes while sustaining the pressure of increasing human activities. The discharge of untreated or partially treated industrial waste and domestic sewage into the rivers has led to a consistent rise in the levels of heavy metal (HM) pollution and depleting the river water quality [6–8]. The toxic and nonbiodegradable nature makes HMs a potential hazard for humans and other biotic components [9]. Karbassi et al. [10] and Akoto et al. [11] in their studies for developing countries concluded that the heavy metal pollution in rivers is in direct proportion to the population growth with consequent rapid urbanization and lack of efficient sanitation facilities with wastewater treatment system. Consequently, in developing countries the lack of potable water and depleting quality has emerged as one of the most critical challenges for the sustenance of human society and the aquatic systems

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since the last century [12]. In a developing nation like India the discharge of municipal waste, urban runoffs, etc., into the river catchments has emerged as a major challenge in maintenance of river water quality [13]. The risk of bioaccumulation and biomagnification of HMs in food chain poses serious health issues in humans and animals [14]. The critical health hazards associated with Pb ingestion via food chain have also been mentioned in a recent study by Kumar et al. [15]. Therefore, regular monitoring and effective management systems for water quality of surface sources are very important for the sustenance of biotic elements. The suitability of river water for usage can be decided through constant monitoring of metal deposition in river water and sediments [16, 17]. The source and movement of HMs in aquatic ecosystems is detected through their concentration in water and sediments [18, 19]. Accurate management of the water quality in rivers is very important, as they comprise the primary inland water resources for drinking, commercial and irrigation purposes [20, 21]. Thus, the monitoring of river water quality where it serves as a source of drinking water and is exposed to anthropogenic intrusion along its course is very vital [22]. Abeyasingha et al. [23] also suggested the need for drafting a long-term plan for adaptation with considerate weightage to environmental flows and ecosystems services to maintain the sustainability of riverine ecosystems.

Many researchers have developed water quality indices through various water quality parameters for monitoring of river water quality [24, 25]. A number of water quality indices based on National Sanitation Foundation Water Quality Index (NSF-WQI) have been developed previously to comparatively analyse the water quality of surface water bodies [26]. The assessment of water quality through a "single value" for a specific area based on various water quality parameters has been carried out through water quality indices including Oregon Water Quality Index (OWQI), British Columbia Water Quality Index (BCWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) and NSF-WQI [27]. The use of Ecological Quality Index (EQI) for river water quality assessment through WQI, Simpson's Diversity Index and Carlson's Trophic State Index (C.TSI) was stated by Joshi [28]. The water quality of rivers has also been determined through "Fuzzy River Health Index" (FRHI) which manages the potential conditions pertaining to river health [29]. The use of Comprehensive Pollution Index (CPI) for evaluation of the pollution status in River Hindon has previously provided insightful results [14]. The water quality indices vary depending upon the number of parameters used for computation and produce varying results [30–32]. With advancements in evaluation technologies of various contaminants in surface and subsurface water sources, heavy metal pollution index (HPI) has become popular. Relative

weightage is assigned to all the evaluated HMs (inversely proportionate to their permissible standard value) to assess the integrated effect of these HMs on surface water quality [33, 34].

The use of multivariate statistical techniques such as correlation analysis, principal component analysis (PCA), and hierarchical cluster analysis (HCA) have proven to be efficient while managing the water quality studies. PCA reduces the dataset while retaining the relevant information on vital parameters as an effective pattern recognition methodology [35, 36]. It is a quantitative tool that develops modified set of variables while maintaining the correlation between the parameters from original dataset [36, 37]. Moreover, application of Ward's linkage method while performing HCA is considered as an efficient tool which groups the quality parameters based on similarities within a class and dissimilarities between various classes [38]. Hence, environmetrics including cluster analysis and PCA for recognizing the potential sources of HM contamination in rivers has been widely used [14].

River Gomti, an alluvial river of Ganga Alluvial Plain (GAP), is a vital source of water for many urban and rural agglomerations of eastern Uttar Pradesh, India [38–40]. The pristine state of River Gomti has been critically deteriorated which is evident through its listing as one of most polluted rivers in India [19]. The increasing population and expanding agricultural activities have raised the pressure on Gomti river basin (GRB) with noteworthy alterations in its natural state. River Gomti is the primary source of water supply in Lucknow city and receives back ~450 million litres per day (MLD) of domestic sewage while traversing through the city. The direct inflow of sewage into River Gomti instead of trunk sewers through 25 open drains due to gradient issues causes contamination of river water [41]. Other towns, along its course, also discharge effluents from industries including distilleries, chemical, sugar mills etc. [42]. The release of wastewater from domestic and industrial sources has depleted the water quality of River Gomti [43]. The presence of HMs in River Gomti has been reported with domestic and industrial wastewater a possible source of heavy metal pollution in the river [19, 44, 45].

The study by Goel et al. [41] on water quality of River Gomti using Water Quality Index (WQI) marked high pollution levels but did not include heavy metal concentration in the study. Some more studies on the heavy metal contamination River Gomti signified the levels and sources of heavy metal pollution in the river [38, 46]. However, a detailed analysis based on the extent of heavy metal pollution using pollution indices like heavy metal pollution index (HPI) has not been done till date. The correlation between HPI and metals useful in estimating the input sources of pollution has not been done previously for River

Gomti. Thus, considering the lack of detailed information on the current status of HM pollution in River Gomti this study has been done to analyse the water quality using HPI and other environmetrics.

Hence, this study has been taken with the objectives of:

- Assessing the present heavy metal pollution status in River Gomti, Lucknow city, through HPI,
- Evaluating the possible sources of HM contamination in River Gomti using PCA, HCA, and
- Analysing the potential correlation among the metals, sources of contamination, and sampling sites.

2 Materials and methods

2.1 Study area

The capital city of Lucknow is located on the banks of River Gomti, an alluvial tributary of River Ganga in the central parts of Indo-Gangetic Alluvial Plain (GAP), formed by lithospheric flexure. The central part of Indo-Gangetic basin includes Ganga plain which is composed of sandy-silty sediments [47]. A bas-relief and gentle gradient exist in the Ganga plain with its topographic and bathymetric features resulting from typical interaction between climatic variations linked with base-level variations due to tectonic activities in the Quaternary Period including Pleistocene–Holocene epochs [48]. Lucknow city is located between 26.30°–27.10° N latitude and 80.30°–81.13° E longitude at an elevation of approximately 123 m above sea level. A distinct variation in the pre- and postmonsoon temperature is witnessed fluctuating to as high as 46 °C to a minimum of ~ 2 °C. Uttar Pradesh being a land-locked state receives ~ 75% precipitation from moisture laden Indian Summer Monsoon (ISM) in the months of June till September [49]. River Gomti initiates from a lake ‘Fulhar Jheel’ in Madhotanda, near the town of Pilibhit, and confluences with River Ganga at Varanasi after a journey of 960 km. It is a groundwater and rainwater-fed river with no glacial source of water. Gomti River Basin has an approximate area of 30,437 km² and experiences semi-arid to sub-humid tropical climate with mean yearly rainfall varying between 850 and 1100 mm [43, 50]; Rai et al. [51]. River Gomti with an average flow of 1500 MLD witnesses a fluctuation from 500 MLD in summer season to 45,000 MLD in peak monsoon season in the city of Lucknow [46]. The river is a vital source of water supply to many habitats in the downstream including Lucknow, Jaunpur. It divides the city of Lucknow while traversing through the city with Gomti Barrage for maintenance of water levels with settlements along cis and trans sides. Riverfront development project in the Lucknow city included straightening and

shortening of River Gomti through alterations in shape, width, and riverbed by construction of a diaphragm wall in an 8.1-km stretch. The floodplain width has been reduced to 240 m from 450 m and clear waterway to 100–125 m from 250 m while reclaiming approximately 200 ha of land prior and post Gomti barrage in Lucknow city.

2.2 Sample collection and analysis

In the current study, ten samples have been collected from River Gomti from the study area. The sampling has been done in the month of October 2019 at sites, S1 (Chandrika Devi), S2 (IIM Road), S3 (Harding Bridge), S4 (Arti Sthal), S5 (UP RERA), S6 (Kukrail Drain-Gomti Confluence), S7 (Gomti Barrage), S8 (Dilkusha Bridge), S9 (Shahid Path), S10 (Bharwara STP discharge point-Gomti Confluence). The sampling locations are illustrated in Fig. 1 and Table 1. Approximately, 61-km stretch of River Gomti was covered to evaluate the HM pollution status at upstream, midstream, and downstream sampling locations with reference to Lucknow city. The upstream reference site S1 and S2 are located ~ 30 km and ~ 8 km, respectively, from Lucknow city. Sites S3, S4, S5, S6, S7, and S8 are within the city, while sites S9 and S10 are on the outskirts of the city and are chosen as downstream sampling locations. The sampling points were decided based on previous research and observations made during reconnaissance survey with emphasis on the possible anthropogenic influence. An approximate 12-km stretch of the study area is within the city (midstream sites) and was selected to assess the effect of anthropogenic activities on river water quality. Site S1 was selected taking into account its distance from the city. Site S2 which is located on the outskirts of the city, was selected considering huge piles of solid waste which could be a potential source of pollution in River Gomti. Site S3 was selected to quantify the effects of nearby washing activities, Chikan textile industries and Daliganj drain. The riverbank along site S4 was also laden with solid waste piles. Site S5 is in the vicinity of Baikunth Dham (cremation ground) which might have considerable impact on river water quality. Site S6 is the confluence point of Kukrail drain and River Gomti; the drain carries domestic sewage and industrial effluents. Site S7 was selected to account the role of varying water flow on the pollution index. A drain was spotted near the site S8, along with dead remains of animals, which clearly stated potential anthropogenic effect on the water quality of River Gomti. Site S9 is along the downstream for Lucknow city, and a definite comparison for the variation in upstream and downstream water quality would be obtained. The last sampling location site S10 is a downstream location and is the confluence of River Gomti with Bharwara STP and was selected to analyse the quality of water being released from the STP

Fig. 1 Location map of sampling sites and River Gomti

Table 1 Summary of heavy metal distribution across the sampling sites

Sampling sites	As	Fe	Cd	Pb	Mn	Cr	HPI
S1	0	339	0.8	51	13.6	1.67	22.6
S2	9.1	102	7	54	16.7	4.11	54.7
S3	7.8	145	35	99	96	4.21	177.8
S4	0	134	35	94	86	3.35	174.9
S5	8.6	197	54	102	78.1	3.26	251.9
S6	8.3	199	37	89	98	23.9	263.9
S7	0	165	31	103	12.1	21.3	233.9
S8	2.7	106	5	86	13.1	10.7	81.2
S9	19	178	9	91	67.1	9.84	95.4
S10	29	181	16	176	99	8.31	136.6
Minimum	0.0	102.0	0.8	51.0	12.1	1.7	22.6
Maximum	29.0	339.0	54.0	176.0	99.0	23.9	263.9
Mean	8.5	174.6	23.0	94.5	58.0	9.1	149.3
SD	9.3	67.3	17.7	34.1	39.2	7.8	85.0

All concentrations are expressed in ($\mu\text{g/l}$)

after treatment. The sampling, storage, and transportation of the water samples have been done in strict accordance with standard methods [52]. The analytical data quality was established through procedural spiked, repeated, and blank sample measurements. Grab water sampling has been done in high-density polyethylene (HDPE) bottles. The HDPE sample bottles prior to use were preconditioned and acid washed in accordance with APHA [52]. Three replicate samples were collected and mixed at each site, respectively. The preservation of unfiltered water samples was done using ultra-pure nitric acid (HNO_3) to reduce the

pH to < 2 for the analysis of total metal concentration. The water samples were stored in an incubator at 4°C and sent to the laboratory for the analysis. The digestion of water samples was done on hot plate while using acid mixture (10 ml of HNO_3 and 5 ml of HClO_4). The final volume was brought to 100 ml with de-ionized water after the filtration of digested samples. The concentration of heavy metals in river water samples after digestion was analysed through Atomic Absorption Spectrophotometer, Electronic corporation of India, Model 1441 and 4341 in the Bareilly College, Bareilly, Uttar Pradesh (UP).

The analysis of heavy metals, viz. arsenic (As), iron (Fe), cadmium (Cd), lead (Pb), manganese (Mn), and chromium (Cr), nickel (Ni), mercury (Hg) has been selected for analysis based on the results of previous studies on surface water contamination and availability of laboratory resources.

2.3 Heavy metal pollution index (HPI)

The heavy metal pollution index has emerged as a very useful tool for the assessment of the overall water quality of with reference to HMs [34]. The HPI can be defined as a mean weighted arithmetic tool similar to water quality index. Two steps are employed which include development of a rating scale through assignment of weightage and selection of pollution parameters. The selection of parameters depends on the relevance of individual quality parameters, and the rating scale value ranges between 0 and 1. The rating scale values can also be assessed through developing inverse proportionality with standard values for respective parameters [25]. The unit weightage (W_i) is a value inversely proportional to standard value of each parameter (S_i) [53], which can be calculated using Eq. (1):

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (1)$$

where n is the number of heavy metals in the current study; W_i is unit weight of i th HM. The subindex (Q_i) is calculated from Eq. (2):

$$Q_i = \sum_{i=1}^n \frac{|M_i - I_i|}{S_i - I_i} \times 100 \quad (2)$$

where M_i ($\mu\text{g/l}$) is the analysed value of i th heavy metal. S_i is the standard value, and I_i is the ideal value of HMs ($\mu\text{g/l}$) for drinking water [54–56]. A new scale of three demarcations with low (< 15), medium ($15\text{--}30$), and high (> 30) categories based on HPI values [55] has been employed in the current study. Previously, only one demarcation with HPI value 100 falling in “Critically Polluted” category was used [56].

2.4 Pearson’s correlation coefficient

The linear relationship between two or multiple variables has been established through Pearson’s correlation coefficient analysis. An increase in one metal leading to an increase in the other metal represents a positive correlation between the metals, and for negative correlation, the vice versa is valid. The range of values for Pearson’s correlation coefficient, ‘ r ’, is ± 1 . If the value of ‘ r ’ is zero, no correlation is said to exist between the parameters. The values which range between ± 0.9 and ± 1 signify towards

a ‘strong’ correlation, while the values between ± 0.51 and ± 0.89 signify a ‘good’ correlation between the assessed parameters. Lastly, the values between 0 and ± 0.50 represent a ‘poor’ degree of correlation [20].

2.5 Cluster analysis

The cluster analysis in this study was done through HCA. It is an efficient classification and segregation tool for water quality parameters [57]. This tool organizes the samples into clusters or groups signifying hierarchy through dendrogram. The clustering or organizing is done through two methods (agglomerative or divisive), and the results are presented through plots (dendrogram) of organized samples and their respective relations [58]. The hierarchical clusters are developed systematically initiating with highly alike objects [21]. For the present study, the parameters were subjected to both Q-mode HCA (Q-HCA) and R-mode HCA (R-HCA). The classification of HMs was done through R-HCA based on the similarity/dissimilarity of their origin. The squared Euclidean distance and Ward’s linkage method were used in Q-HCA which is considered to provide best results [59]. The classification of sampling sites in accordance with Q-HCA depends on the similarity of chemical composition and geochemistry [60]. To define the similarity among the sampling locations HCA based on Ward’s linkage method has been performed in the current study.

2.6 Factor analysis

In the present study, factor analysis was carried out through PCA method to recognize the input source of HMs into River Gomti along with analysing the correlation among them. PCA was used to obtain relevant PCs from datasets of water quality to identify the potential sources of heavy metal contamination in the river [37]. PCA is a very efficient statistical tool based on pattern recognition which simplifies the variance of large datasets through reduction to smaller and easier interpretable forms based on their inter-relationships [61]. PCA is useful in management of widely spread spatial data through extraction of eigenvalues by maintaining correlation with original variables [62]. The principal components mention the important parameters providing information without reducing the original information [63]. In the current study, PCA was performed with varimax rotation for all the parameters. Varifactors (principal components) are developed through factor analysis minimizing less significant variables and rotation of axis performed through PCA [64]. The eigenvalues quantify the associated variance, while the role of original parameters is represented through loadings [65]. The use of PCA has increased for obtaining wider information

about the concentration of contaminants, sampling locations, and correlation trends associated with datasets for studies related to field of environment [66, 67]. In order to validate the relationship among heavy HMs and to obtain accurate information about the sources of contamination, PCA has been used in other studies also [37].

The multivariate statistical analysis including Pearson's correlation matrix, factor analysis using PCA, and cluster analysis using HCA have been done using IBM SPSS Statistics 25 and OriginPro 2019b.

3 Results and discussion

3.1 Distribution of heavy metals

The statistical summary of the analysed heavy metals at all sites is presented in Table 1. Six out of the eight analysed heavy metals, namely (As), (Fe), (Cd), (Pb), (Mn), and (Cr), were detected in the water samples, while (Ni) and (Hg) were not reported in any of the samples. The concentration of all heavy metals except for Mn (12.1–99 µg/l) and Cr (1.671–23.91 µg/l) does not comply with acceptable limits as per the drinking standards proposed by BIS [54]. The discharge of agro-chemical runoff, untreated domestic sewage, battery manufacturing or disposal waste, welding, and electroplating operations with other industrial effluents from the nearby habitations emerge as a possible source of contamination of river water with HMs [68, 69]. The concentration of As ranged between (0 and 29 µg/l) across the sites, with 20% of the sites along the downstream of the river, evidently showed higher levels of As concentration. The range for Fe concentration varied between (102–339 µg/l) and exceeded the acceptable limits as per BIS [54] at site S1. The possibility of anthropogenic influence on such high levels of Fe cannot be ignored as the site attracts large number of devotees around the year according to the observations made during site visits and sampling. The concentration of (Cd) ranged between (0.8 and 54 µg/l) with 90% of the sites exceeding the permissible levels according to [54]. All the sites witnessed very high levels of Pb varying between (51 and 176 µg/l), suggesting towards possibility of effluent discharge from local battery manufacturing units, automobile shops, domestic sewage, and industrial wastewater discharge without proper treatment. The probable sources of Pb contamination could be automobile emissions, pesticides (agricultural runoff), chemicals, and paints [68]. The findings of the study were in coherence with some previous studies, which have also reported anthropogenic intrusion as the primary source of heavy metal contamination in River Gomti [19, 38, 46].

3.2 Heavy metal pollution index (HPI)

The site-wise variation of HPI and various statistical measures are summarized in Table 1. Moreover, the classification of various sites as per the HPI according to the rating scale by Edet and Offiong [55] is presented in Fig. 2. Various parameters used in calculation of HPI are summarized in Table 2. The least level of heavy metal contamination has been observed in site S1 with HPI value of 22.6 falling under the 'moderate pollution' category. The presence of agricultural activities in the vicinity of the site directs towards the possibility of agricultural runoff contaminating the river water. Site S1, according to the observations made during site visits, attracts devotees from across the globe throughout the year; thereby, anthropogenic intrusion can also be a possible cause of moderate pollution in the area, while site S2 witnessed higher level of metal contamination in comparison with S1, with HPI value 54.7 depicting 'high pollution' with possible contamination of domestic and industrial wastewater discharge. The value of HPI was as high as 177.8 for site S3 and is designated under the 'critically polluted' category. The site S3 witnesses high values of Cd, Fe, and Pb exceeding the maximum desirable values. This may be due to the effluents from local textile industries and discharge from Daulatganj Sewage Treatment Plant (STP). Site S4 is also in the category of critically polluted with an HPI value of 174.9. The possible causes of contamination are sewage, domestic, and industrial wastewater discharge. The sites S5, S6, S7, and S10 are categorized under the critically polluted category owing to very high HPI values 251.9, 263.9, 233.9, and 136.6, respectively. The Kukrail drain, a possible source of heavy metal contamination in the vicinity of site (S6), transports the domestic wastewater from many areas of Lucknow city along with effluents from industries. The total discharge being 150 MLD out of which only 90 MLD is

Fig. 2 Site-wise variation of HPI with various categorization

Table 2 HPI of various HMs in River Gomti

Heavy metals	Mean ($\mu\text{g/l}$)	Highest permitted value for drinking water (S_i) ($\mu\text{g/l}$)	Maximum desirable value (I_i) ($\mu\text{g/l}$)	Unit weight $W_i = (K/S_i)$	Subindex (Q_i)	$W_i \times Q_i$
As	8.45	50	10	0.02	3.875	0.0775
Fe	174.6	300	100	0.00333	37.3	0.124
Cd	22.98	10	–	0.1	229.8	22.980
Pb	94.5	10	–	0.02	211.3	4.225
Mn	57.97	300	100	0.0033	21.015	0.070
Cr	9.065	10	–	0.1	90.65	9

$$\sum W_i = 0.247, \sum W_i \times Q_i = 36.477, \text{HPI} = 147.68$$

Table 3 Pearson's correlation between various HMs

	As	Fe	Cd	Pb	Mn	Cr	HPI
As	1						
Fe	−0.080	1					
Cd	−0.122	−0.112	1				
Pb	0.690	−0.159	0.278	1			
Mn	0.507	−0.054	0.582	0.581	1		
Cr	−0.019	−0.102	0.167	0.170	0.002	1	
HPI	−0.053	−0.139	0.923	0.386	0.539	0.525	1

Bold values indicates good correlation ($r > 0.5$)

transported to the Bharwara Sewage Treatment Plant (STP) for treatment, while 60 MLD from the drain overflows into the river. While the G.H. Canal with a total discharge 158 MLD, only 87 MLD is transported to the treatment facility at Bharwara, while 71 MLD of untreated wastewater (including industrial discharge) is discharged into the River Gomti [70]. Thus, the possible causes of such critical pollution levels in the River Gomti could be inefficient STPs in the city.

3.3 Pearson's correlation coefficient

The correlation analysis is mentioned in Table 3. The value of Pearson's correlation coefficient, ' r ', varies between ± 1 . A strong positive correlation between HPI and Cd with a value of '0.923' has been witnessed, suggesting towards the weightage of Cd in increasing the pollution levels on presentation through HPI. A 'good' correlation ($0.51 < r < 0.89$) has been found for As with Pb and Mn. The good correlation between As with Pb and Mn confirms the high and critical levels of heavy metal pollution at downstream sites S9 and S10, respectively. The highest concentration of As, Pb, and Mn has been observed at S10 which, thereby, confirms a positive good correlation and the possibility of anthropogenic intrusion. Moreover, a 'good' correlation for Mn with Pb and Cd can also be observed. No other significant correlation was observed between any

Fig. 3 Q-HCA indicating clusters of sampling sites

other HMs. This clearly indicates multiple point source apportionment for the heavy metals [20].

3.4 Hierarchical cluster analysis (HCA)

The classification of datasets into clusters depends on the homogeneity/nonhomogeneity among the datasets [71]. It can be observed through Q-HCA (Fig. 3) that the sites are divided into two major clusters with Cluster 1 including

site S1. Cluster 2 has two subclusters with sites S2, S7, and S8 in one subcluster and sites S3, S4, S5, S6, S9, and S10 in the other subcluster (Fig. 3). The clusters evidently classify site S1 as the least exposed to metal pollution with the lowest value of HPI as well. The homogeneity in HPI values of sites S2 and S8 is evident from their close linkage in the subcluster accounting to similar concentration of metals (Fe, Cd, Pb, and Mn) at these sites. Site S7 shows similarity in levels of Pb and Mn contamination with S2 and S8. The concentration of Cr is very similar at S2 and S8. A close relationship can be observed between S3 and S4 with similar HPI values and evidently very high metal contamination. The metal concentrations at S3 and S4 (Fe, Cd, Pb, Mn, and Cr) are similar which is evident in the respective subcluster. Sites S5 and S6 show similar HPI values signifying towards similar sources of contamination possibly including sewage discharge and domestic wastewater, while the concentration of Cr is within the permissible limit except for three sites, viz. S6, S7, and S8. The linkage of S9 and S10 within the subcluster signifies the varying concentrations of all metals except Fe.

Fig. 4 R-HCA indicating clusters of analysed heavy metals

The heavy metals have been grouped into two major clusters as evident in the R-HCA (Fig. 4). The two major clusters consist of (1) As, Pb, Cd, Mn; and (2) Fe and Cr. The huge difference in the concentrations of Fe and Cr is evident at all sites considering their mean values. A close linkage between As and Pb can be seen owing to possibility of agricultural runoff laden with pesticides [38]. A close linkage between Cd and Mn, Fe and Cr can also be observed owing to possible similar sources including welding operations.

3.5 Principal Component Analysis (PCA)

The principal components (PCs) with eigenvalues greater than one are significant [72]. The heavy metals have been brought down to three PCs with eigenvalues greater than unity with accountable variance of approximately 78% (Table 4 and Fig. 5). The scree plot (Fig. 5) has been prepared to determine the number of components during PCA. The scree plot presented major breaks after the first and second components, signifying relevant inputs from the respective

Fig. 5 Scree plot depicting eigenvalues for heavy metals

Table 4 Total variance and loading for HMs

Components	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	2.372	39.533	39.533	2.372	39.533	39.533	2.015	33.578	33.578
2	1.250	20.826	60.359	1.250	20.826	60.359	1.522	25.368	58.946
3	1.046	17.442	77.801	1.046	17.442	77.801	1.131	18.855	77.801
4	0.903	15.046	92.847						
5	0.300	5.002	97.850						
6	0.129	2.150	100.000						

Extraction method: Principal Component Analysis

Table 5 Rotated component loadings

Variables	PC1	PC2	PC3
As	0.954	−0.114	−0.026
Fe	−0.153	0.037	−0.704
Cd	−0.028	0.962	0.128
Pb	0.838	0.277	0.198
Mn	0.611	0.700	−0.088
Cr	−0.073	0.126	0.756

Bold values signify strong loadings (value > 0.75)

Rotation converged in 5 iterations

Fig. 6 Component plot in rotated space for heavy metals

datasets [37]. However, an approximate variance of 93% can be explained through four PCs, with the fourth PC having an eigenvalue of 0.903 being very close to unity. The rotation sum of squared loading, representing the degree of closeness and the PCs, is presented in Table 5 and Fig. 6. PC1 holds ~33% of the total cumulative variance and depicts strong positive loadings on As and Pb. The strong loadings on As indicate the excessive use of pesticides, fungicides, metal smelters sources, while strong loading of Pb can be owed to automobile emissions, paints industry, pesticide use in agricultural activities, and burning of coal activities. The close linkage between As and Pb is also evident in Q-HCA. A moderate positive loading of PC1 on Mn can be observed, suggesting welding operations and ferromanganese production activities [68]. A weak negative loading of PC1 on Fe, Cd, and Cr is also evident. PC2 explains approximately 26% of the cumulative variance and holds a strong positive loading on Cd, signifying towards possible use of fertilizers and pesticides, while dumping of waste including batteries, and release of wastewater from electroplating and welding

activities. A moderate loading of Mn can be seen on PC2, similar to PC1. A weak positive loading of PC2 on Fe, Pb, and Cr while weak negative loading on As is evident, while PC3 holds a ~19% of the total cumulative variance with a positive moderate loading on Cr and negative moderate loading on Fe. A weak positive loading of PC3 on Cd and Pb while a negative weak loading on As and Mn is observed. The high concentration of heavy metals could be a possible result of runoff from areas including polluted sites, open waste dumping sites, agricultural lands, domestic and industrial effluents [44].

4 Conclusion

The alarming levels of heavy metal concentration analysed in the study emerge as a matter of huge concern. The toxic state of the river is evident from the HPI values with 60% of the sites falling in the 'critically polluted' category, 30% of the sites in the 'highly polluted' category, and only 10% of the sites in the 'moderately polluted' category. The cluster analysis results presented least heavy metal pollution at the upstream site S1 evidently signifying the role of anthropogenic intrusion in the deteriorating the water quality at midstream and downstream sites. The PCA findings emphasize towards the potential risk posed by As, Pb, and Cd on humans and aquatic biota. The correlation analysis signifies towards various sources of contamination for HMs including domestic, industrial wastewater release with partial, or no treatment. The findings of the study provide an insight for water resources across the globe, through determining the potential causes of contamination with correlation among metal concentrations. River Gomti plays an important role as a tributary of River Ganga; hence, monitoring of the status of heavy metal contamination is very vital at regional and national level for reinstatement to its natural state.

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Compliance with ethical standards

Conflict of interest No conflict of interest to declare.

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