Received: 18 January 2021 | Revised: 4 March 2021 | Accepted: 9 April 2021

DOI: 10.1002/tqem.21746

WILEY

RESEARCH ARTICLE

Assessment of the impact of COVID-19 lockdown on the heavy metal pollution in the River Gomti, Lucknow city, Uttar Pradesh, India

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Abstract

In the current study, attempts were made to analyze the effect of COVID-19 lockdown on the heavy metal concentrations in River Gomti through comparison with pre-COVID-19 lockdown status. The concentration of all the six heavy metals (As, Cd, Cr, Fe, Mn, and Pb) clearly shows a significant reduction, highlighting the impact of closure of agricultural, industrial, and commercial activities. The values of heavy metal pollution index (HPI) at all sites have also decreased with the maximum improvement at Site S1 (Chandrika Devi), signifying the impact of reduced agricultural runoff into the river from nearby fields. The correlation analysis stated a strong correlation between HPI and Cd, signifying the relatively high weightage of Cd in pollution levels. Findings from the Caboi diagram suggest classification of all water samples under the "near neutral-low metal" category.

KEYWORDS
COVID-19, heavy metal pollution index, Lockdown, Lucknow, River Gomti

1 | INTRODUCTION

Human existence on earth is dependent on various natural resources including water as one of the primary needs. The degrading impact of rapid urbanization and industrialization on the quality of water resources has emerged as a matter of concern across the globe (Adimalla et al., 2020; Shukla & Saxena, 2020a, 2020b). The history of settlements and constant encroachment in the vicinity of rivers has resultantly created extreme pressure on surface water sources, both quantitatively and quantitatively (Kumar et al., 2021). The demand of potable water for providing to the needs of human population specially in developing nations is constantly increasing (Mishra et al., 2018; Shukla & Saxena, 2020d; Shukla et al., 2020). The discharge of wastewater consequent to the pace of commercial activities, industrial activities into freshwater bodies, makes implementation of regular monitoring and prevention activities all the more important (Shukla et al., 2020; Tripathi & Shukla, 2018). The rapid increase in the levels of heavy metals has created a hazard risk of biomagnification of these heavy metals through the entrance of noxious elements in the food chain (Kumar et al., 2020; Shukla et al., 2020). Moreover, the persistent, non-biodegradable, and toxic nature of heavy metals makes them an issue for both aquatic and human population (Mishra et al., 2018).

The breakout of coronavirus disease (COVID-19) emerged as a huge challenge for all the nations across the world. During a time when the world was striving with various issues associated to human survival and growth including climate change, depleting quality of natural resources, scarcity of fresh water, etc., the novel COVID-19 outbreak affected ~30 million people while claiming more than 1 million lives (Khan et al., 2021; Selvam et al., 2020). The fatality associated with the virus led to various steps and precautionary measures by governments, including lockdowns and other advisories. India, being the second most populous nation in the world (~1.3 billion), was at a great risk of community transmission of the virus. Hence, to safeguard the population, a nationwide lockdown was declared on March 24, 2020, which was extended in phases to May 31, 2020. Reports associated with the positive impact of lockdown on water quality gained momentum and researchers across the world collaborated for further assessment. The improved water quality of the River Ganga at Haridwar during lockdown was highlighted in a study by Dutta et al. (2020). On the other hand, some reports and studies stated depletion in water quality of rivers (Ganga, Beas, Chambal, Sutlej, Svarnarekha) during the lockdown (DTE, 2020), 2021). Khan et al. (2021) also reported on depleted water quality of the River Gomti at various sites within Lucknow city during the lockdown period. However, the status of heavy metal pollution to quantify the impact of COVID-19 lockdown has not been assessed in any of the previous studies. Thus, the current study has been taken up by the authors in continuation with their pre-COVID-19 lockdown study in October 2019 (Khan et al., 2020), to comparatively evaluate the status of heavy metal pollution in the River Gomti, Lucknow city, post COVID-19 lockdown (June 2020).

> *the status of heavy metal pollution to quantify the impact of COVID-19 lockdown has not been assessed in any of the previous studies*

River Gomti, a groundwater-fed river, traverses ~960 km, providing for various needs of many rural and urban habitations along its path. Its water is utilized for drinking and other domestic purposes at many locations, including Lucknow city, where the abstraction rate is the highest. The depleting water quality has been mentioned in several previous studies (Dutta et al., 2018; Goel et al., 2018; Khan et al., 2020, 2021), highlighting the variation in its water quality index (WQI) along the upstream and downstream locations. Along with the issue of domestic sewage discharge without or with partial treatment from various drains, industrial effluent discharge has emerged as a matter of concern that needs urgent attention and remedial actions, considering the use of river water for drinking and other domestic purposes.

The positive impact of COVID-19 lockdown on the natural resources has gathered the attention of researchers and academicians across the globe. There have been various studies highlighting the improved quality of various water resources in the lockdown period (Arif et al., 2020; Dutta et al., 2020; Selvam et al., 2020; Yunus et al., 2020). Hence, this study was taken up with an aim to evaluate the impact of COVID-19 lockdown on the heavy metal pollution status in the River Gomti at Lucknow city. A comparative assessment of the concentration of heavy metals recorded) in the pre-COVID-19 lockdown phase, with the values estimated in the current study is also done. This comparative assessment will help in quantifying the effects of the closure of anthropogenic activities and other enterprises.

2 | MATERIALS AND METHODS

2.1 | Study area

The Gomti River Basin, with an approximate area of 30,437 km^2, receives mean annual rainfall ranging between 850 and 1,100 mm (Dutta et al., 2015). The city of Lucknow is the capital of Uttar Pradesh and is one of the major metro cities of North India with a population of ~3 million. It is located between 26.30°–27.10° N latitude and 80.30°–81.13° E longitude on the banks of the River Gomti. The state receives precipitation in the months of June to September from Indian Summer Monsoon. It experiences a wide gap in its maximum (46°C) and minimum temperatures (~2°C). Gomti is a groundwater-fed river originating from Fulhar Jheel, Madhotanda, and traverses ~960 km to meet the River Ganga in Varanasi. River Gomti divides the city of Lucknow into cis and trans parts along its journey. The development of riverfront in the city included construction of a diaphragm wall modifying the river channel width, shape, etc. The straightening and shortening of the river along the ~8.1 km stretch of the river has affected river water quality and flow.

2.2 | Sample collection and analysis

In the present study, 30 samples (three at each sampling station) were collected from the River Gomti, across a total stretch of ~ 61 km, in June 2020, just after the initiation of COVID-19 unlocking. The sampling locations included 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), and S10 (Bharwara STP discharge point–Gomti Confluence). The sampling stations have been presented in **Exhibit 1**. The sample collection, storage, and water sample analysis has been done according to the Standard Methods for the Examination of Water and Wastewaters (APHA, 2012). The samples were collected from well-mixed segments of the river in high-density polyethylene (HDPE) bottles, after proper rinsing with sample water at respective sites, using a cylindrical bailer. Analytical data quality was assured and maintained through duplicate, blank, and procedural spiked samples. The precipitation of metals was prevented through addition of ~2 mL of 65% nitric acid (HNO_3) into individual water samples at all the stations. The collected samples were kept in an incubator at 4°C and sent to the laboratory for analysis. The heavy metal levels in the water samples after digestion were analyzed through Atomic Absorption Spectrophotometer, Electronic Corporation of India, Models 1441 and 4341, at Bareilly College, Bareilly, Uttar Pradesh. The methodology has been illustrated in **Exhibit 2**.

2.3 | Heavy metal pollution index (HPI)

The use of HPI for the evaluation of water quality with respect to heavy metal pollution has gained wide acceptance across the globe. It can be

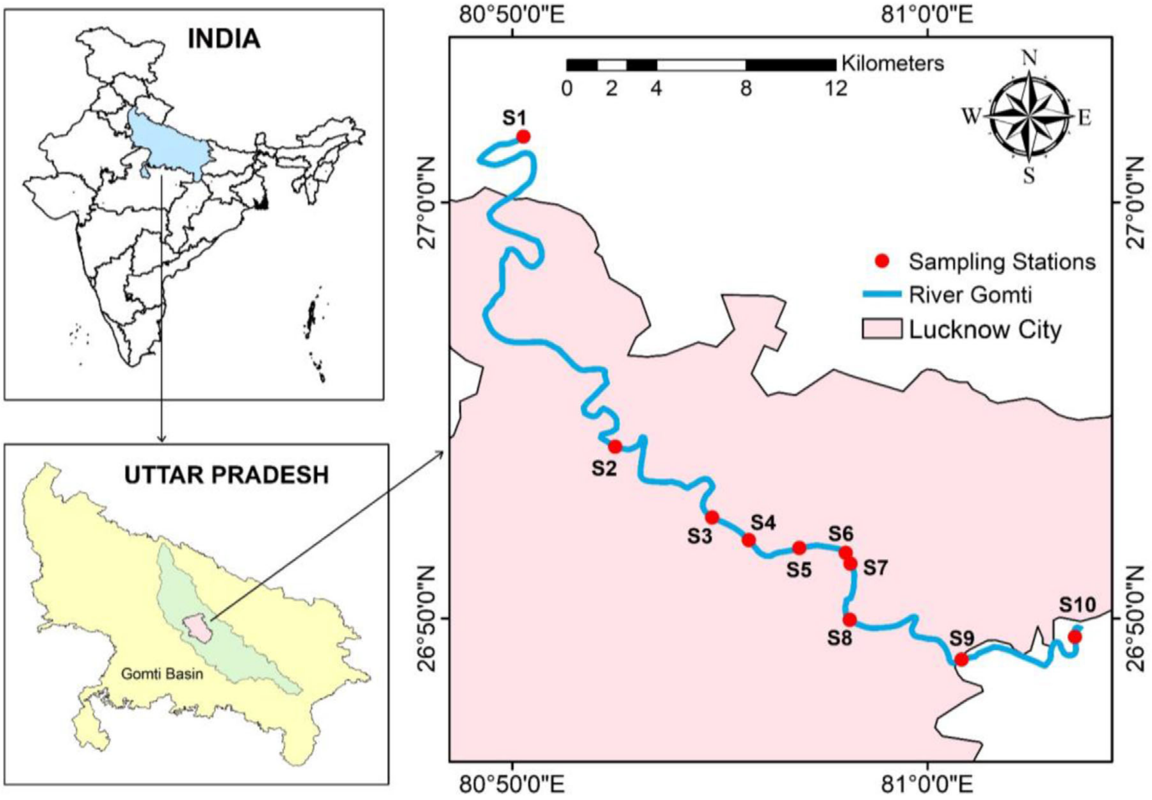

EXHIBIT 1 Map representing the stretch of River Gomti (~61 km) in the study area and sampling stations at Lucknow city [Color figure can be viewed at wileyonlinelibrary.com]

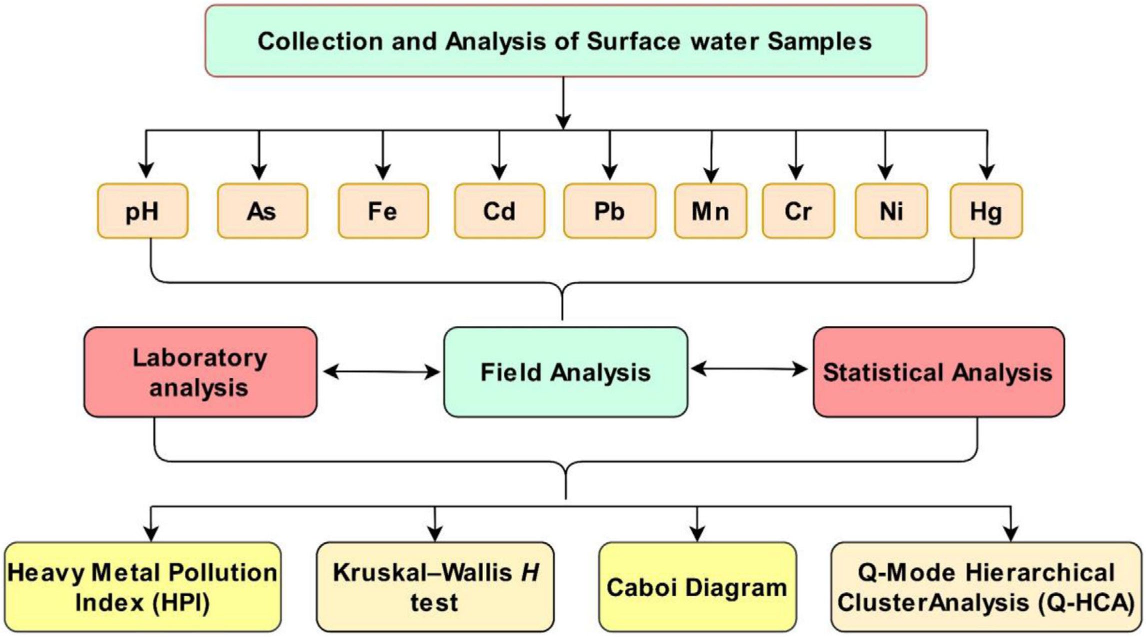

EXHIBIT 2 Work methodology adopted for the current study [Color figure can be viewed at wileyonlinelibrary.com]

explained as an average-weighted arithmetic tool for assessing heavy metal pollution levels such as WQI. HPI is an index for the classification of pollution levels and degree of toxicity due to heavy metals in water bodies. Pollution parameters are selected and assigned weightage through development of a rating scale with values between 0 and 1. The rating scale is developed through standard values of all parameters in inverse proportion (Mishra & Kumar, 2020).

The unit weightage, W_i, is calculated using Equation (1):

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}, \tag{1}$$

where W_i is the unit weight of the ith heavy metal; n is the number of heavy metals in the present study; the subindex (Q_i) is evaluated through Equation (2):

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

where M_i is the monitored value of ith heavy metal; S_i is the standard value of a particular contaminant; I_i is the ideal value of heavy metals (μg/L) in drinking water. This study incorporates a classification system of water samples based on the obtained HPI values, i.e., "low pollution" ($\mathrm{HPI} < 15$); "medium pollution" ($15 < \mathrm{HPI} < 30$), "high pollution" ($\mathrm{HPI} > 30$), and "critically polluted" when $\mathrm{HPI} \geq 100$ (Edet & Offiong, 2002; Prasad & Bose, 2001).

2.4 | Caboi diagram

The classification of water samples using the method given by Ficklin et al. (1992) and modified by Caboi et al. (1999) has also been attempted. The designation of water samples depends upon the pH value of river water and the metal load (expressed in μg/L) at a particular sampling location. The Caboi diagram represents the degree of mobility of heavy metals, which is in direct proportion with any variation in pH (Singh et al., 2017).

2.5 | Statistical analysis

Initially, the spatial variation of the heavy metals among the sampling sites across the studies stretch of the River Gomti was evaluated through the Kruskal–Wallis *H* test (Fatema et al., 2014). The Kruskal–Wallis *H* test is a nonparametric test, which is used to determine whether the difference of the parameters among the sampling sites is significant or not. The Pearson correlation matrix has been generated using Origin Pro 2019b software. The matrix incorporates the value of correlation coefficient *r*, signifying the degree of correlation, to establish any linear relationship between two or more parameters. The extent of any positive or negative correlation is assessed based upon the values of *r*, which ranges between ±1. The increase in the metal loading of one metal causing increase in the other metal concentration presents a positive correlation and vice versa is applicable for negative correlation. The range of Pearson correlation coefficient *r* lies between ±1, with no correlation when *r* is zero; "strong" correlation when *r* is in the range between ± 0.9 and ± 1 and "good" correlation for values between 0.51 and ± 0.89. A poor correlation for values between 0 and ± 0.50 (Adimalla & Qian, 2019; Batabyal, 2018; Shukla & Saxena, 2020b).

Furthermore, the data set was also subjected to cluster analysis, which was done through "Q-mode Hierarchical Cluster Analysis" (Q-HCA). The similarities or dissimilarities among the data set are the primary criteria for characterization/grouping of the sampling sites into various clusters in Q-HCA. These clusters are based upon the similarity in their chemical composition and geochemistry (Selvakumar et al., 2017; Shukla & Saxena, 2020d). The results of Q-HCA are presented through dendrograms. Squared Euclidean distance and Ward's linkage method were incorporated for the assessment of Q-HCA, which are reported to produce the best results (Shukla & Saxena, 2020c; Subba Rao & Chaudhary, 2019).

3 | RESULTS AND DISCUSSION

3.1 | Distribution of heavy metals

Analytical summary of the monitored heavy metals for all the sampling sites is presented in **Exhibit 3**. A total of eight heavy metals were analyzed, out of which six heavy metals were detected in the water samples, viz., arsenic (As), iron (Fe), cadmium (Cd), lead (Pb), manganese (Mn), and chromium (Cr) in the water samples. However, nickel (Ni) and mercury (Hg) were not reported in any of the collected water samples. The average concentration of all heavy metals considerably reduced in June 2020 in comparison with its values in October 2019 (pre-COVID-19 lockdown) thereby signifying the impact of COVID-19 lockdown on the river water as shown in **Exhibits 4** and **5**. The standard values of all parameters are in accordance with BIS (2012). The average concentration of As at all sites showed a reduction of ~29%, signifying the influence of the closure of industrial enterprises. The concentration of Fe at site S1, which was above the permissible limit in October 2019 (pre-COVID-19 lockdown phase), shifted to within the permissible limit in June 2020. The average concentration of Cd, Pb, Mn, and Cr at all sites showed a reduction of 15.13%, 11.21%, 9.62%, and 16.37%, respectively. The release of industrial effluents from small-scale manufacturing units, electroplating operations, battery manufacturing or disposal waste emerge as possible sources of heavy metal in river water (Paul, 2017).

The significant impact of COVID-19 lockdown on the heavy metal concentration is well evident in the current study and signifies the effectiveness of control measures. The discharge of untreated domestic sewage, release from local battery manufacturing enterprises, automobile garages, emissions, paints, chemicals, etc., are some probable sources of heavy metal pollution in the River Gomti (Gupta et al., 2014; Singh et al., 2005). The Kukrail drain and G.H. canal are also probable sources of heavy metal contamination carrying ~150 and ~158 MLD wastewater across the Lucknow city, out of which 60 and

EXHIBIT 3 Statistical summary of the analytical results of heavy metals at all the sampling sites

Sites	pH	As	Fe	Cd	Pb	Mn	Cr	HPI
S1	8.2	0.0	270.0	0.2	45.0	12.0	0.9	15.3
S2	8.0	8.5	93.0	5.0	47.0	13.0	3.0	40.9
S3	7.3	7.2	130.0	30.0	88.0	85.0	3.4	152.1
S4	7.5	0.0	110.0	29.0	79.0	79.0	2.9	145.5
S5	7.6	8.1	180.0	50.0	95.0	80.0	2.1	229.5
S6	7.5	7.6	170.0	33.0	82.0	85.0	21.0	234.6
S7	7.4	0.0	150.0	28.0	95.0	10.0	19.0	210.7
S8	7.5	2.1	92.0	3.0	82.0	10.2	8.5	63.5
S9	7.6	13.0	158.0	4.0	86.0	65.0	7.9	64.9
S10	7.7	14.0	170.0	13.0	140.0	85.0	7.4	110.4
Minimum	7.3	0.0	−92.0	−0.2	−45.0	−10.0	−0.9	−15.3
Maximum	8.2	14.0	270.0	50.0	140.0	85.0	21.0	234.6
Mean	7.6	6.1	152.3	19.5	83.9	52.4	7.6	126.7
SD	0.3	5.3	52.4	16.7	26.5	35.9	7.0	80.4

All concentrations are expressed in (μg/L); SD: standard deviation.

71 MLD, respectively, overflows directly into the river without any treatment (Khan et al., 2020). The riverfront development project in Lucknow city was supposedly a very beneficial step toward management of domestic sewage and creation of recreation spots. However, the lack of balance between ecological and construction activities along with complete execution and operational management emerges as a cause of reduced and sluggish flow, further affecting the self cleansing/healing capacity of the river. The use of fertilizers in agricultural activities is a potential cause of heavy metal pollution in the river specifically along sampling stations S1 and S2. The contribution of stabilizing pigments used in paint industries in heavy metal contamination also needs to be considered (Singh et al., 2005).

3.2 | Heavy metal pollution index

The HPI values at none of the sampling sites were in the low pollution category as illustrated in **Exhibit** 6. Although the value of HPI at sampling station S1 was 15.32 marginally above the low pollution level status (HPI < 15), 40% of the stations fell in the “highly polluted” category and 60% were in “critically polluted” category. The HPI values at all sites were in the order of S1 > S9 > S2 > S8 > S10 > S4 > S3 > S7 > S6 > S5, with least pollution at station S1 and maximum at station S5. The release of wastewater from various sources, including untreated or partially treated sewage, domestic waste, and agrochemical activities, has been previously reported to be a cause of heavy metal pollution in river Gomti by Singh et al. (2005). The possible entrance of heavy metals from sediments in June 2020 (monsoon season) at sites S1, S2, S3, S8, S9, and S10, which are unlined (riverfront has not been developed), cannot be ignored. Many previous studies have confirmed

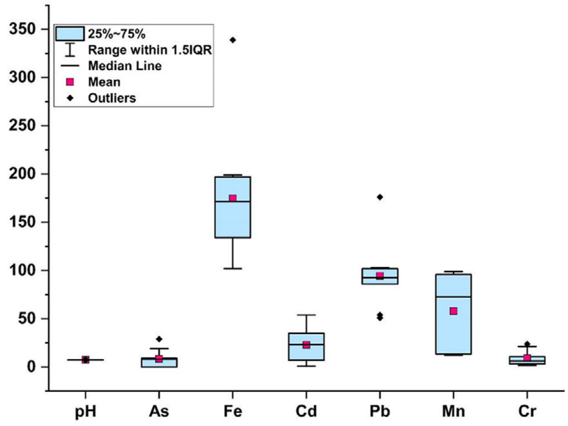

EXHIBIT 4 Variation in pH and heavy metals (μg/L) across all sites in pre COVID-19 lockdown phase (October 2019) (Khan et al., 2020). [Color figure can be viewed at wileyonlinelibrary.com]

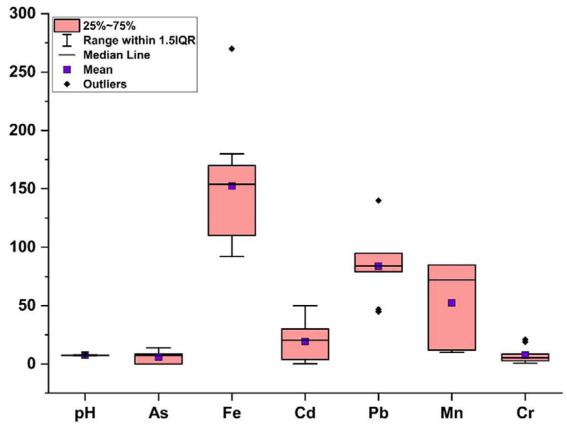

EXHIBIT 5 Variation in pH and heavy metals (μg/L) across all sites in June 2020 [Color figure can be viewed at wileyonlinelibrary.com]

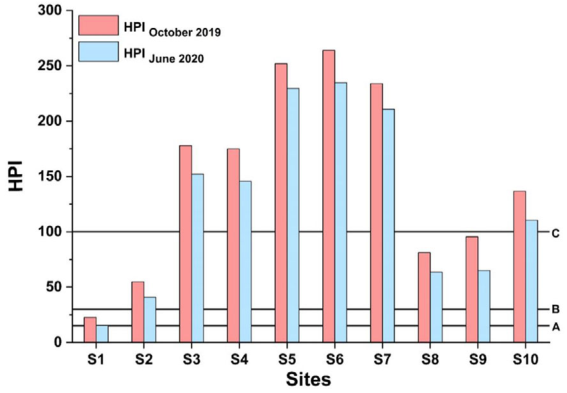

EXHIBIT 6 Site-wise variation of HPI in October 2019 and June 2020 indicating the various classes of HPI: (A) low pollution; (B) HPI: medium pollution; (C) high pollution; values above C: critical pollution [Color figure can be viewed at wileyonlinelibrary.com]

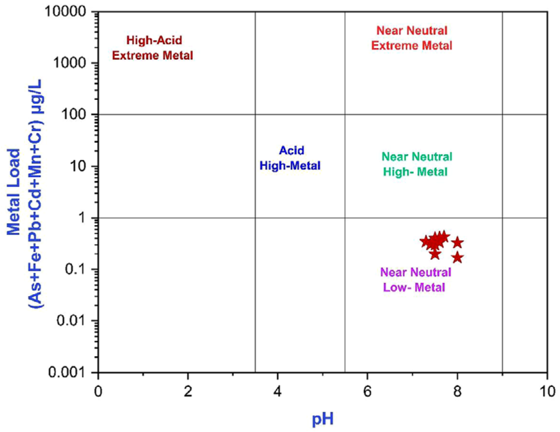

EXHIBIT 7 Caboi diagram representing the metal load and their rate of precipitation [Color figure can be viewed at wileyonlinelibrary.com]

the presence of heavy metals in sediments of river Gomti (Gaur et al., 2005; Singh et al., 2005).

The HPI values at all stations showed considerable reduction in comparison with their values in October 2019 (pre-COVID-19 lockdown), signifying the impact of the COVID-19 lockdown. A considerable improvement in HPI was witnessed at all sites, with an overall average improvement of 19.15% in June 2020. The maximum improvement in the values of HPI was observed at site S1 with a drastic reduction of 32.2%. The agro-chemical runoff from agricultural activities in the nearby vicinity of the site was stopped in the lockdown phase and, hence, emerges as a potential cause of reduction in the HPI value. A decrease of 25.28%, 14.46, and 16.78% in the HPI values was observed at sites S2, S3, and S4, respectively. The closure of anthropogenic activities in the vicinity of site S3 (washing activities, boat rides, religious ceremonies) and wastewater from textile units seems to have a prominent influence on the water quality of the river. Stations S4 and S5 are in the vicinity of a crematorium, Baikund Dham, which could have potentially affect the water quality of the river. An improvement of ~11% was observed at sites S6 and S7, signifying the reduced wastewater discharge from industries. The Kukrail drain and G.H. canal are potential source of heavy metal pollution carrying the wastewater from areas across Lucknow city at these sites. Some previous studies also highlighted the rising heavy metal pollution resultant to the release of urban effluents, municipal wastes by various drains (New Hyderabad Nala, Khadra Nala, and Daliganj Nala, etc.), into the river within an approximate stretch of 12 km across the city (Gaur et al., 2005; Singh et al., 2005). Stations S8, S9, and S10 are downstream locations, which showed ~21.2%, ~32%, and ~19.2% improvement in individual HPI values, confirming the positive impact of the COVID-19 lockdown. The development of riverfront along the river channel and consequent public gatherings in fates, exhibitions, and littering solid waste (plastics, metal cans, etc.) increased vehicular movement, is also a probable cause of heavy metal entry into the river water. The COVID-19 lockdown prevented such public gatherings, and activities along the river channel, thereby significantly affecting the heavy metal levels.

3.3 | Caboi diagram

The pH of water samples across all sampling locations in the current study ranged between 7.3 and 8.2, complying with the allowable range given by the World Health Organization (WHO 2011). The water samples presented nearly neutral to alkaline nature. Water samples across all sites were categorized with respect to their individual pH values and total metal load and are represented through the Caboi diagram (Caboi et al., 1999; Ficklin et al., 1992). The Caboi diagram for the current study illustrates the variation in relationship between pH and metal load. The various metal load categories expressed in the Caboi diagram are "near neutral-low metal," "acid-high metal," "near neutral-high metal," "near neutral-extreme metal," and "high acid-extreme metal" (**Exhibit 7**). The metal load (As + Fe + Pb + Cd + Mn + Cr) was plotted against pH for categorization of water samples at all sampling sites. Water samples from the current study were found to be falling in "near neutral-low metal" category. Because the rate and degree of precipitation of metals are primarily dependent upon pH, the near neutral to alkaline range of the river water in the current study suggests that the most of the heavy metals must have precipitated as carbonates, oxides in the sediment channel (Singh et al., 2005). Hence, the metal load in the Caboi diagram is seen under "low metal" category.

3.4 | Correlation analysis

The extent of spatial variation among the sampling sites and significance of difference among the sample size were estimated through the Kruskal–Wallis *H* tests. The results suggested that heavy metals assessed in this study were significantly different over the studied stretch of the River Gomti, at $P < 0.05$. Further, the Pearson correlation matrix was also generated, which is illustrated in **Exhibit 8**. A strong positive correlation (0.93) between HPI and Cd was observed. It clearly states the high impact of the concentration of Cd in increasing the pollution levels highlighted through HPI. The good correlation

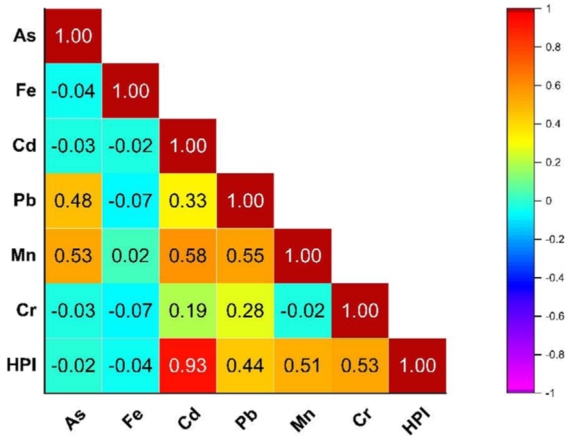

EXHIBIT 8 Interrelationship between heavy metals (including HPI) through Pearson correlation matrix [Color figure can be viewed at wileyonlinelibrary.com]

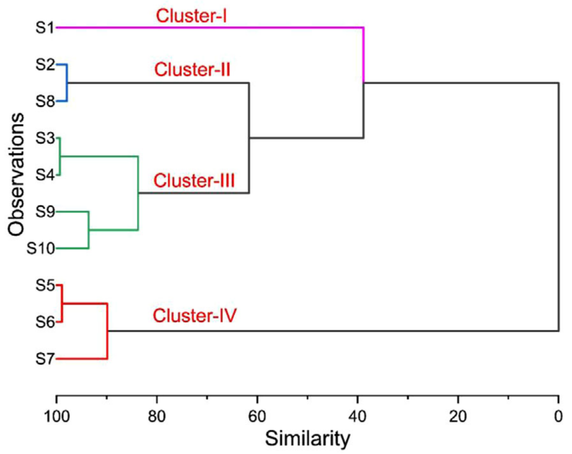

EXHIBIT 9 Dendrogram for Q-HCA indicating the four clusters of the sampling sites from the study area [Color figure can be viewed at wileyonlinelibrary.com]

of HPI with Mn and Cr ($0.51 < r < 0.89$) is in coherence with the overall findings of this study. A good correlation of Mn with As, Cd, and Pb is also observed, which is in coherence with high concentration of these heavy metals at various sites. A good correlation of HPI with Mn and Cr was also seen.

3.5 | Q-Mode Hierarchical Cluster Analysis (Q-HCA)

The categorization of the data set into different groups primarily depends upon the homogeneity or nonhomogeneity among the data sets. Sampling sites were grouped into four clusters based on the similarity of heavy metals and HPI at various locations of the River Gomti, which are presented through the dendrogram (**Exhibit 9**).

Cluster I: This cluster represents the least-polluted site S1 with respect to its HPI value 15.3, marginally above the "low pollution" range (HPI < 15). The upstream location of the site and impact of the closure of the release of agricultural runoff and visits of pilgrims emerge as the potential reason for the least HPI value.

Cluster II: This cluster contains sites S2 and S8. This cluster represents "high pollution," with similar values for Fe, Mn, Cd, and HPI. This cluster is also in coherence with the findings of a study by Khan et al. (2020), in which there is similarity of pollution status between sites S2 and S8.

Cluster III: This cluster represents three sites S3, S4, and S10 signifying "critical pollution" levels and one site S4 representing "high pollution." The reduced flow in Lucknow is prominently affected due to the development of riverfront in the city.

Cluster IV: This cluster represents sites S5, S6, and S7 highlighting "critical pollution," which have "severely high" levels of heavy metal pollution (HPI > 200). The midstream location and sluggish flow of the river considering the riverfront development in the city merge as possible cause of such high HPI values.

4 | CONCLUSION

The findings from the study have clearly stated the positive impact of COVID-19 lockdown on the heavy metal pollution of the River Gomti. A notable reduction in the concentration of heavy metals clearly validated the impact of the closure of various agricultural, industrial, and other commercial activities. The shutting down of small manufacturing enterprises at local scale, textile houses, battery production units, etc., in the lockdown visibly affected the heavy metal levels in the river. The reduction in the HPI levels of water samples just after the initiaion of unlocking of COVID-19 lockdown, in comparison with their values in pre-COVID-19 lockdown phase is a major finding depicting the prominence of anthropogenic intrusion at all sampling locations. The findings from this study provide relevant insights to authorities toward the necessity of stringent regulations to prevent the release of untreated municipal and industrial wastewater into the river. The efficacy and advantages associated with implementation of temporary, and partial lockdowns through development of policies can also be suggested through this study.

ACKNOWLEDGMENT

The authors are thankful to Dr. A. K. Singh, Vice-Chancellor, Shri Ramswaroop Memorial University for providing lab facilities for conducting this study. They would also like to acknowledge the guidance in sample testing from Dr. D. K. Saxena, Bareilly College. The support of our families during compilation of this manuscript needs to be recognized.

AVAILABILITY OF DATA

Data are available on request due to privacy/ethical restrictions.

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How to cite this article: Khan, R., Saxena, A., & Shukla, S. (2022). Assessment of the impact of COVID-19 lockdown on the heavy metal pollution in the River Gomti, Lucknow city, Uttar Pradesh, India. *Environ Qual Manage*, *31*(4), 41–49. https://doi.org/10.1002/tqem.21746