Effects of COVID-19 lockdown and unlock on the health of tropical large river with associated human health risk

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Abstract

River Damodar (India) is one of the most significant tropical large rivers and this river is carrying predominantly industrial effluents, urban sewage, and non-degradable chemical agricultural fertilizers. Several industries, cities, and townships directly depend on this important river throughout the year. It is highly essential to evaluate its surface water quality, characteristics, and improvement status during the COVID-19 lockdown and unlock phases. The major objectives of the present study are to analyse changing nature of heavy metals (Zn, Cd, Pb, Ni, Cr, and Fe) and microbial load (TVC, TC, and FC) of river water and to identify heavy metals impact on water quality and human health in pre, during, and after unlocking of COVID-19 lockdown. Here, a total of 33 water samples have been collected in the pre-lockdown, lockdown, and unlock phases. The results showed that decreasing trend of the microbial load was found in the lockdown phase. Heavy metal pollution index (HPI) illustrated that all samples are highly polluted ($HPI > 150$) during the pre-lockdown phase, while during the lockdown phase; HPI showed that around 54.54% of samples have been positively changed (low pollution level). During the unlock phase, 45.45% of samples were again amplified to the high pollution level. Pearson's correlation coefficient and hierarchical cluster analysis indicated strong relation among heavy metals with faecal coliform at a 0.05% level of significance. Noncarcinogenic hazard index (HI) shows the higher possibility of health risk ($HI > 1$) particularly for children in all the phases and during the lockdown phase, 36.36% of samples showed no possible health risk for adults ($HI < 1$). However, HI of dermal contact showed no possible health risk for children and adults in the assessment periods. This applied research can definitely assist planners and administrators in making effective solutions regarding public health.

Keywords Heavy metals impact · Microbial load · Pearson's correlation coefficient · Hierarchical cluster analysis · Pollution index

Introduction

It has now become a great environmental issue that deterioration of surface water quality is being increased day by day worldwide (John et al. 2014; Zhaoshi et al. 2017). Increasing pollution load of industrial, urban, agricultural, and transport declines the natural quality of surface water (Karunanidhi et al. 2020a, b; Zou et al. 2018). Pollution of water resources brings a negative impact on the ecological condition, aquatic bio-diversity, and also human health

(Ouyang et al. 2006). Heavy metals are considered one of the major contaminants of surface water pollution in many parts of the world (Ali and Khan 2018; Tiwari et al. 2015). For the past few decades, the aquatic environment is being faced with hazardous heavy metals pollution. Some heavy metals are naturally originated by weathering of parent rocks. But, the accelerating rate of mining, industrial waste discharge, fossil fuel burning, metallurgical waste disposal, usages of pesticides, fertilizers, etc. promotes toxic metal contamination to the aquatic environment. Mixing heavy metals with water will bring serious negative effects on utilization of household water, agro-farming, industrial, or urban purposes (Akhilesh et al. 2009). Toxicity of heavy metals could exist for a longer time period in the environment and, therefore, it leads to a hazardous impact on living organisms (Yahaya et al. 2009; Klavins et al. 2000; Tam

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and Wong 2000; Hakan 2006). Many studies have found the potential adverse impact of heavy metals on human health (Giuliano et al. 2007; Smith et al. 2000; Kabir et al. 2021a; Ahmed et al. 2021; Chen et al. 2017). Long-period intake of manganese, zinc, chromium with drinking water can cause neurosis, chlorosis type chronic diseases in the human body (Tumuklu et al. 2007). A higher intake of iron with drinking water may lead to gastrointestinal disorders (Rezaei et al. 2017). Excess concentration of nickel in drinking water damages lungs and nasal organs, and it can also reduce body weight, heart affectivity, etc. (USEPA 1995). Higher intake of lead with drinking water raises blood pressure, muscle pain, kidney problems, etc. (Sekar and Suriyakala 2016). Thus, excess consumption of heavy metals can cause non-carcinogenic or carcinogenic type health hazards in affected areas (Mohammadi et al. 2019; Kavcar et al. 2009; Sun et al. 2007). Increasing contamination of heavy metals promotes the resistance power of bacteriological activities in surface water. Municipal wastes, pathological wastes, and agricultural runoff are the major supply sources of microorganisms in surface water (Besharati et al. 2018). These microorganisms can cause bacterial contamination in the human body, and it may lead to severe infections (Rahube and Yost 2010). Therefore, control of pollutants contamination to water and supply of safe drinking water becomes a vital contemporary challenge to the world, especially for developing countries.

At the end of December 2019, a sudden outbreak of the coronavirus very rapidly transformed into a pandemic condition all over the world. As a result, more than 179 million active cases and nearly 3.8 million death cases from all over the world have been reported by WHO until the last week of June 2021. In India, this brutal pandemic took nearly 3.9 lacks lives until the above-mentioned time as reported by WHO (2021). In these circumstances, the lockdown process of all socioeconomic sectors brought a significant control on viral transmission. The temporal shutdown of all industrial, transportation, and urban activities significantly helped to reduce pollution load to the environment as well as aquatic ecosystem very effectively. With the significant strict restrictions of human activities, movement, and industrial shutdowns, the scholars, decision-makers took this little window of opportunity to assess the status of river water pollution and compare it with the lockdown and unlock periods to understand the positive impacts of the COVID-19 lockdown on the environment.

Many countries of South East Asia (Malaysia, Thailand, Indonesia, Bangladesh, and the Maldives) have been reported their improvement of water quality in various parts (Kundu 2020). In India, a nationwide lockdown of 68 days (25th March 2020 to 31st May 2020) also drastically facilitated to amelioration of environmental quality in most regions of this country. In this period, an abrupt decrease of total coliform (TC) load in the river Ganga near

Kolkata city has been noticed (Mukherjee et al. 2020). It has been also reported that dissolved oxygen (DO) was highly increased in the river Ganga near Kolkata city (Dhar et al. 2020). During the lockdown, assessment of water quality of river Ganga revealed lowering down of biological oxygen demand (BOD), chemical oxygen demand (COD), fecal coliform (FC), TC, and increasing of DO in its water (Dutta et al. 2020). In this period, about 50% of heavy metal contamination was reduced in the river Ganga (Shukla et al. 2021). The water of the Sabarmati River showed improvement in its quality by decreasing suspended particulate matter (SPM) during lockdown (Aman et al. 2020). The river Gomti also improved by its river water quality due to the reduction of BOD during the lockdown period (Khan et al. 2021). Karunanidhi et al. (2021) reported that a significant reduction of microbial load and metals contaminations has been evidenced from the river Thirumanimuthar, South India during the COVID-19 lockdown period.

Despite these significant rivers, Damodar is also a very important water source of the Chota Nagpur plateau region of India. Mineral and coal reserve of upper catchment and fertile soil-based lower catchment considerably assist to the rapid development of industrial, urban, and agricultural activities on both sides. Heavy metals are being mixed regularly in river water by numerous mining, industries, urban, and agricultural sectors. The human fecal matter and urban waste ultimately mixed with river Damodar by sewage discharge and the water is being contaminated at the discharge points such as Noonla nalla, near Perbelia coal mining field, near Burnpur IISCO, Confluence of Noonla nalla, near Durgapur Barrage, Confluence of Telenda, near ACC Cement factory, Sponge Iron (Madhukunda), etc. In the past, heavy metal contamination was assessed for some tributaries and the main river bed of Damodar by WQI (water quality index) method with considering other physiochemical parameters also in it (Singh et al. 2017). Another study of heavy metal contamination of Tamla Nala (important effluent discharge channel) of river Damodar was carried through different indexing methods such as geo-accumulation index (Igeo), pollution load index (PLI), and factor analysis (Banerjee and Gupta 2013). An additional study has been found on the water quality of river Damodar considering various physiochemical and heavy metal parameters and evaluated through factor analysis method (Chatterjee et al. 2009). A recent study on water quality changes during the lockdown period in a polluted stretch of river Damodar was conducted considering the physiochemical and heavy metal components and it was assessed by the water pollution index (WPI) method (Chakraborty et al. 2020). Before the COVID-19 lockdown period, microbial contamination of river Damodar was assessed (Halder et al. 2014; Chatterjee et al. 2009). Previous researches also indicated that various anthropogenic activities were the main cause of river water deterioration.

But there was no such relevant integrated study especially based on heavy metal pollution and microbial load with associated human health risk in any industrially developed catchment of river Damodar. Therefore, the main objectives of this study were (i) to evaluate the changes of heavy metals and microbial load of river water in three periods i.e. pre-lockdown, during the lockdown, and unlock (ii) to identify major sources of contaminants and their interrelation using correlation and multivariate analysis and (iii) to assess potential health hazard (noncarcinogenic) of children and adult residents of the catchment area.

Materials and methods

Description of the study area

River Damodar originates from the Patland region (Khamarpat hill) of Palamau district under Jharkhand state then flows to the eastern direction and finally joins with river Hooghly. The entire Damodar basin is influenced by monsoonal climate. In the summer season, the temperature rises up to 47 °C. During winter, the temperature falls up to 8.3 °C. The annual average rainfall is recorded as 1200 mm. Monsoonal rainfall is the key source of water supply in Damodar (Singh et al. 2017). The present study area is situated between the transitional zone of Chota Nagpur plateau and Rarh Bengal. The geographical extension of this study lies between 23°28′28.7″N to 23°40′52.5″N and 86°49′26.8″E to 87°18′42.4″E with 65.37 km length upper Damodar river stretch (Fig. 1). Geologically, this area is composed of granitic gneiss and mica schist rocks and inundated by Damodar fertile alluvial soil. Naturally, this region is enriched with high-quality Gondwana coal reserves and valuable minerals such as iron, copper, limestone, etc. This advantage makes this region well developed for establishing any type of mining or metal-based industries and associated urban sectors. Fertile soil and extensive plain land help to grow paddy cultivation in the downward basin of this study area. Many small channels or locally pronounced ‘nalla’ are drained up to the main riverbed on both sides of this section. Solid and liquid untreated wastes from many large- and small-scale iron industries, steel producing industries, sponge iron plants, cement factories, thermal power plants, chemical factories, municipal garbage, and agricultural runoff are directly discharged to riverbed by those nallas and it mixes with main river water.

Methods of sample collections

Confluence points of channels or nallas with the main riverbed are considered the most contaminated zones where pollutants are directly mixed with fresh water. Therefore, 11

confluence points were selected for the collection of samples from the main riverbed in this study area. A total of 33 water samples were collected in three periods i.e. pre lockdown, during the lockdown, and unlock. Samples of pre-lockdown were collected in December 2019. Water samples of lockdown were collected after restarting of public transport and experimental laboratories in the first week of June 2020, and again samples of unlocking or new normal period were collected in November 2020. Sample collection and its procedure have been followed by a previous study (Chakraborty et al. 2021a, b).

Heavy metals such as zinc (Zn), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), and iron (Fe) were measured by the anodic stripping voltammetry (VA797, Switzerland) method in a hanging mercury drop electrode (3 M-KCL) using three different pulse analysers (Chakraborty et al. 2020). The peak of the voltammetric pulse was recorded in a windows computer. The concentration of all heavy metals was expressed in µg/l. Microbial components as total viable count (TVC) were measured by the plate count number method. In this technique, bacterial colonies were counted by multiplying plate count number with dilution factor and expressed in cfu/ml (normal saline 0.85% sterile) (Leong et al. 2018). TC and FC bacteria were both estimated by the most probable number method (MPN/100 mg) and fermentation tubes were prepared for incubation of bacterial growth within 48 h. After that, Durham tubes were used to test the positive tubes by gas and acid production (Srivastava et al. 2017).

Element source identification by statistical methods

Pearson's correlation coefficient method was used for the analysis of interrelationship among heavy metals and microbial parameters. Multivariate analysis such as hierarchical cluster analysis (HCA) was applied to identify possible connections of sources of different parameters that contributed to water pollution. Hypothesis testing of significant difference among health hazard index values of ingestion and dermal contact in three periods was conducted by one-way ANOVA analysis. All statistical analysis was performed using SPSS (v. 17) and RStudio package for diagrammatic representation.

Human health hazard identification

Heavy metal pollution index (HPI)

The heavy metal pollution index is an integrated approach to studying the water quality based on heavy metal contamination and their overall effects on human health (Ahamed et al. 2015; Rezaei et al. 2017). A rating scale of 0 to 1 has been used to assess the relative significance of each metal which

Fig. 1 Location map of the study stretches of river Damodar (India)

is oppositely proportional to the standard limit (S_i) of the respective metal (Reza and Singh 2010; Prasad and Mondal 2008). HPI was popularly used by many researchers for the assessment of water quality (Abdullah 2013; Setia et al. 2020; Manoj et al. 2012; Ojekunle et al. 2016). Therefore, computation of HPI was conducted step by step as follows:

at first, the weightage (W_i) of each metal has been calculated as

$$W_i = \frac{K}{MAC} \quad (1)$$

where MAC specifies maximum allowable concentration of respective heavy metals as suggested by the Bureau of Indian Standards (BIS 2012) (Table 1). “K” indicates proportional constant value i.e. 1.

In the second step, quality rating (Q_i) value has been obtained by using formula below:

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

where M_i refers to the measured value of each metal in water samples. I_i and S_i denote the ideal value and standard value of each metal respectively. In this study, the M_i and S_i of heavy metals were taken from BIS guidelines (Table 1).

At last, calculation of HPI was conducted as follows:

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (3)$$

where W_i is weightage of heavy metals (i) and Q_i is quality rating of that particular metal, n indicates total number of heavy metals. The critical value of HPI is considered 100 and indicated an adverse impact on human health (Prasad and Kumari 2008). In this study, values of HPI have been classified into three groups as low pollution (< 90), medium pollution (90–150), and high pollution (> 150) (Kwaya et al. 2019). Spatiotemporal variation of water pollution by HPI has been performed by inverse distance weightage (IDW) interpolation method in ArcGIS 10.4 software.

Human health hazard index (HI)

Human health risks by heavy metal ingestion through drinking water and dermal adsorption were assessed for no carcinogenic type of diseases for children and adults in the study area. Health risk of heavy metal ingestion can be analysed by measuring chronic daily dose intake (CDI) using the formula which was suggested by USEPA (2011)

$$CDI_i = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \quad (4)$$

where CDI_i is chronic daily dose intake of particular heavy metal ($\mu\text{g/kg/day}$), C_w is concentration of metal in drinking water ($\mu\text{g/L}$), IR is ingestion rate of drinking water (0.70 l for children and 2 l for adults), EF is exposure frequency (365 days for both children and adults), ED is exposure duration (6 years for children and 30 years for adults), BW is body weight of persons (15 kg for children and 70 kg for adults), and AT is average time (2190 days for children and 10,950 days for adults) for noncarcinogenic health risk.

CDI of dermal adsorption was analysed by the prescribed method of USEPA as follows:

$$CDI_d = \frac{C_w \times SA \times K_p \times ET \times EF \times ED \times CF}{B_w \times AT} \quad (5)$$

where CDI_d is chronic daily dose intake by dermal contact by heavy metals ($\mu\text{g/kg/day}$). SA denotes available area of skin contact (cm^2). K_p designates permeability coefficient (cm/hour). ET denotes exposure time (h/day), CF is the conversion factor of unit (L/cm^3).

hazard quotient (HQ) of each heavy metal was estimated by the ratio of CDI and reference dose of oral intake (RfD) using the formula.

$$HQ_{(\text{ingestion/dermal})} = \frac{CDI}{RfD} \quad (6)$$

RfD ($\mu\text{g/kg/day}$) of each metal was obtained from USEPA guidelines of drinking water quality (Table 1).

Potential to health risk by all heavy metals of noncarcinogenic type was computed by using the formula.

$$HI_{(\text{ingestion/dermal})} = \sum_{i=1}^n HQ \quad (7)$$

where HI represents hazard index of overall metal ingestion by drinking water. HI value greater than 1 indicates severe possibility to health risk and below than 1 shows no obvious possibility of exposure to health risk (Karunanidhi et al. 2020c; Guerra et al. 2012).

Results

Distribution of heavy metals in pre, during lockdown, and unlock period

Heavy metals of river water in pre lockdown period showed that the mean $\pm$ Sd concentration of Zn was $39,845.45 \pm 6280.34$ and Cd was 10.20 ± 1.77 . Similarly, Pb was 26.18 ± 5.23 while Ni was 84.55 ± 33.57 . Consequently, Cr

Table 1 Statistical description of heavy metals and microbial components in river water

	Zn2 +	Cd2 +	Pb2 +	Ni2 +	Cr	Fe	TVC	TC	FC
Standard value ($\mu\text{m/L}$) (BIS, 2012)	15,000	3	10	20	50	300	Standard value (WHO, 2011)	100 cfu mL^{-1}	30 coli/ mL
Ideal value ($\mu\text{m/L}$) (BIS, 2012)	5000	0	0	0	0	0	Ideal value (WHO, 2011)	-	-
RfD (USEPA 2011)	300	0.5	1.4	20	3	700	Mean	23,545.45	9263.64
Pre lockdown (December, 2019)	39,845.45	10.20	26.18	84.55	87.67	674.82	Standard error	1253.10	345.17
	1893.60	0.54	1.58	10.12	3.11	34.06	Standard	4156.05	1144.79
	6280.34	1.77	5.23	33.57	10.32	112.96	Sample variance	17,272,727.27	790,325.45
	39,442,727.27	3.15	27.36	1127.27	106.51	12,759.56	Kurtosis	-0.56	-0.61
	-2.18	-1.08	-1.24	-1.42	-1.27	-2.27	Skewness	0.25	-0.48
	-0.10	-0.34	-0.33	-0.04	-0.48	0.10	Range	13,000.00	3600.00
	15,000.00	5.20	15.00	90.00	28.22	258.00	Mean	13,363.64	4341.82
	5300.00	3.11	3.54	6.55	33.86	132.91	Standard error	1644.73	235.94
During lockdown (June, 2020)	230.02	0.40	0.50	0.49	1.91	2.62	Standard deviation	5454.96	782.53
	762.89	1.33	1.66	1.63	6.34	8.68	Sample variance	29,756,545.45	612,356.36
	582,000.00	1.77	2.76	2.67	40.14	75.29	Kurtosis	-0.69	0.21
	-0.75	-1.53	-1.51	-0.81	-1.94	3.67	Skewness	0.59	-0.55
	-0.10	-0.45	-0.23	0.24	-0.61	-1.75	Range	16,200.00	2600.00
	2400.00	3.23	4.70	5.00	13.99	30.00	Mean	14,463.64	5856.36
	7566.36	5.01	5.36	22.36	41.15	284.36	Standard error	2454.84	305.55
Unlock phase (November, 2020)	222.88	0.39	0.47	1.27	2.41	25.16	Standard deviation	8141.78	1013.39
	739.21	1.29	1.57	4.20	7.98	83.46	Sample variance	66,288,545.45	1,026,965.45
	546,425.45	1.65	2.45	17.65	63.68	6965.65	Kurtosis	-0.46	-0.10
	-0.09	-1.56	-0.98	-0.59	-1.83	-1.77	Skewness	-0.51	-0.36
	1.08	-0.16	0.21	-0.12	-0.47	0.00	Range	25,100.00	3140.00
	2000.00	3.24	5.00	14.00	19.55	228.00			

was 87.67 ± 10.32 and Fe was 674.82 ± 112.96 (Table 1). The distribution of heavy metals in water samples showed negative skewness of Zn, Cd, Ni, Cr, Pb, and positive distribution of Fe in this period. All heavy metals of 100% samples designated higher concentrations than their standard limit recommended by BIS (2012). During the lockdown, the mean $\pm$ Sd concentration of Zn was 5300.00 ± 762.89 while Cd was 3.11 ± 1.33 . Pb was 3.54 ± 1.66 whereas Ni was 6.55 ± 1.63 . Similarly, Cr was 33.86 ± 6.34 and Fe was 132.91 ± 8.68 . In this period, the distribution of Zn, Cd, Pb, Cr, and Fe showed negative distribution and only Ni illustrated positive distribution in water samples. During the lockdown, zinc concentration of 100% water samples and Cd of 63.63% water samples showed higher concentrations than their standard limit. All other heavy metals (Pb, Ni, Cr, and Fe) highlighted no excess concentration in this period due to the very low mixing of those metals in water samples. Unlock phase, mean $\pm$ Sd concentration of Zn, Cd, Ni, Cr, and Fe was 7566.36 ± 739.21 , 5.01 ± 1.29 , 5.36 ± 1.57 , 22.36 ± 4.20 , 41.15 ± 7.98 , and 284.36 ± 83.46 , respectively. In this period, Cd, Ni, Cr showed negative skewness, and Zn, Pb, Fe stands positive skewness of their distribution. Water samples of unlock period showed Zinc and cadmium exceeded their standard limit in 100% sample water. Around 72.72 and 45.45% of water samples of Ni and Fe, respectively, revealed higher concentrations than their standard limit. No samples were found an excess concentration of Pb and Cr in this period. The average concentration of these metals was suggested their same order of accumulation as $\text{Zn} > \text{Fe} > \text{Cr} > \text{Ni} > \text{Pb} > \text{Cd}$ in three periods over river water.

Quality of microbial parameters in river water

In pre lockdown period, descriptive statistical analysis (Table 1) showed that the mean $\pm$ Sd concentration of TVC, TC, and FC was $23,545.45 \pm 4156.05$, 9263.64 ± 1144.79 , and 2623.64 ± 889.00 , respectively. During the lockdown, the mean $\pm$ Sd concentration of TVC, TC, and FC was $13,363.64 \pm 5454.96$, 4341.82 ± 728.53 , and 944.27 ± 134.24 , respectively. Unlock of COVID-19 lockdown, mean $\pm$ Sd concentration of TVC, TC, and FC was found as $15,736.36 \pm 5468.87$, 5856.36 ± 1013.39 , and 1209.09 ± 183.44 , respectively. In these three periods, the distribution of TVC and FC indicated positive skewness and TC indicated negative skewness. Statistical measurement clearly showed that the mean value of TVC, TC, and FC was in pre lockdown $>$ unlock $>$ during the lockdown period and suggested a huge reduction of microbial load during the lockdown in river water. Though, 100% of samples showed an excess concentration of microbes than their standard limit in three periods as recommended by WHO, 2011 (Table 1).

Identification of major sources of pollutants by statistical techniques

Correlation analysis

Pearson's correlation coefficient of six heavy metals and microbial parameters showed a very strong positive correlation among all heavy metals with each other ($\rho > 0.85$) at 0.05 level of significance (Fig. 2a). Before the lockdown of COVID-19, water samples showed a very high positive correlation between TVC and TC ($\rho = 0.92$). FC conveyed positive correlation with TVC and TC ($\rho = 0.83$, $\rho = 0.82$, respectively). Heavy metals like Cd, Pb, and Fe indicated a significant positive correlation with microbial parameters. During the lockdown, a very high positive correlation ($\rho > 0.80$) was found among Zn, Cd, Pb, Ni, and Cr to each other (Fig. 2b). But Fe showed a comparatively low positive correlation with other metals in this period. This indicated a common source of origin i.e. industrial discharge of Zn, Cd, Pb, Ni, and Cr in river water. But, during lockdown Fe might be supplied by the natural weathering process of basal rocks. In this period, a high positive correlation was identified among microbial. TC and FC brought low positive correlation with Zn ($\rho = 0.59$) and Cr ($\rho = 0.54$), respectively. Unlock period, correlation coefficient indicated very low positive correlation ($\rho < 0.50$) of Zn with Ni, TVC, TC, and FC in sample water (Fig. 2c). Ni indicated a high positive but not significant relationship with other parameters. In this period, microbial parameters suggested strong positive relationship with each other ($\rho > 0.80$) but not highly significant relationships with other heavy metals in river water. This suggested supply of coliform bacteria from various medical and pathogenic discharges and waste disposal to river beds by many hospitals during the COVID-19 situation.

Multivariate analysis

To find out the similarities and dissimilarities among multiple variables or data, HCA is one of the best methods and selected for water quality analysis in many previous studies (Isa et al. 2017; Muhammad et al. 2016; Panda et al. 2020). It is such a unique technique of multivariate analysis which easily defines the distance, difference, and connection among the clusters or groups of data. In this method, uniformity of clusters and diversity between groups could be easily found out (Fatoba et al. 2017).

In pre-lockdown, during the lockdown, and unlock period, the dendrogram of cluster analysis showed that there were three clusters of microbial and heavy metal parameters (Fig. 3a, b, c). In both three periods, cluster I consisting of Cd, Pb, Ni, Cr, Fe, and FC indicated high similarity among these parameters and most possibly the common source of discharge i.e. industrial wastes. In pre-lockdown, cluster II

Fig. 2 Pearson's correlation coefficient matrix (at 0.05 level of significance) for **a** pre-lockdown, **b** during lockdown, and **c** unlock phase

was contributed by TC, and cluster III was comprised of Zn and TVC indicated a high possibility of TVC enrichment by zinc supply from an agricultural or industrial source. During the lockdown and unlock period, cluster II was comprised of Zn, TC, and cluster III consisted of TVC.

Human health hazard evaluation

Assessment of heavy metal pollution index (HPI)

In the study stretch of river Damodar, HPI of pre-lockdown showed that around 100% of water samples ($n = 11$) were highly polluted by heavy metal contamination (Table 2). During the lockdown, around 54.54% of water samples had low pollution, and 45.45% of samples indicated medium pollution. In this period, no sample was detected as highly polluted and clearly showed betterment of river water quality. Unlock phase, 9.09% of samples were lowly polluted, around 45.45% indicated medium polluted, and the rest 45.45% indicated highly polluted water. This outcome exposed again an increase in contamination of heavy metals and their pollution in river water. Spatial mapping showed that the lower course of river water was more polluted by heavy metals in three periods (Fig. 4).

Analysis of human health hazard of three periods

Heavy metal can affect the human body via exposure pathways as ingestion of drinking water, food, inhalation, or dermal contact (Somoano et al. 2009). In the present study, the expected noncarcinogenic health risk of children and adult populations was assessed for ingestion and dermal adsorption of river water.

In the pre-lockdown period, the mean HQ value of six heavy metal ingestion by children was found as an order of $Zn > Cd, Cr > Pb > Ni > Fe$ by their mean value (Table 3). During the lockdown, mean HQ values of six heavy metals were arranged as $Zn > Cr > Cd > Pb > Ni > Fe$. Unlock phase, mean HQ values showed as same as lockdown period i.e. $Zn > Cr > Cd > Pb > Ni > Fe$. In these three periods, Zn posed highest possibility of health risk ($HQ > 1$) via drinking water for children by its mean value. Mean HQ of heavy metal ingestion by adults in pre-lockdown, during the lockdown, and unlock period showed their order as $Zn > Cr > Cd > Pb > Ni > Fe$ and indicated Zn as the highest possibility to health risk for adults like children. The total health risk of all six heavy metals ingestion by children showed that its cumulative HI value was ranged from 7.82 to 11.95 with a mean value

Fig. 3 Dendrogram of hierarchical cluster analysis of **a** pre-lockdown, **b** lockdown, and **c** unlock phase

of 10.04 in the pre-lockdown period (Fig. 5a). During the lockdown, HI showed that it ranges from 1.20 to 2.26 with 1.78 mean values. Unlock phase, HI value was ranged from 2.00 to 3.10 with 2.53 mean values. In all three periods, HI values of ingestion of heavy metals by children indicated that 100% water samples were higher than 1, which suggested a higher possibility of noncarcinogenic health risk for them.

Total HI of ingestion of drinking water by the adult population showed that the ranges in pre-lockdown were 4.61 to 7.00 with 5.90 mean values (Fig. 5a). During the lockdown, the total HI was ranged from 0.74 to 1.38 with a 1.09 mean score. Unlock period, HI value was ranged from 1.22 to 1.90 with 1.55 mean values. In pre lockdown and unlock period, 100% of samples showed HI value > 1. During the lockdown,

36.36% sample showed HI < 1 and indicated betterment of water quality in those sample sites.

Heavy metals intake due to dermal adsorption like bathing or recreational contact of river water by children in pre lockdown showed that their mean value was in an order of $Zn > Pb > Cr > Cd > Fe > Ni$ (Table 3). During lockdown, their mean value showed $Cr > Zn > Pb > Cd > Fe > Ni$ by their order of accumulation. Unlock period, mean HQ of heavy metals ordered as $Cr > Pb > Zn > Cd > Fe > Ni$. Dermal HQ of heavy metals for adults in pre-lockdown showed that Zn has the highest mean value for health risk during the lockdown and unlock, Cr indicated the highest mean HQ for health risk for them.

Total HI value of dermal adsorption by children in pre-lockdown was obtained its ranges $4.58E-02$ to $7.07E-02$

Table 2 Quality of sample water samples in three period by HPI method

HPI category	Pre-lockdown	During lockdown	Unlock phase
Low pollution (<90)	0%	54.54%	9.09%
Medium pollution (90–150)	0%	45.45%	45.45%
High pollution (> 150)	100%	0%	45.45%

Fig. 4 Spatial distribution of HPI in river Damodar

with $6.00\text{E} - 02$ mean value (Fig. 5b). Total HI during lockdown was ranged from $8.12\text{E} - 03$ to $1.67\text{E} - 02$ with $1.27\text{E} - 02$ mean value. Unlock period, HI showed its ranges from $1.27\text{E} - 02$ to $2.23\text{E} - 02$ with $1.75\text{E} - 02$ mean value. HI value of dermal contact of adult persons in pre-lockdown showed that its ranges from $2.68\text{E} - 02$ to $4.13\text{E} - 02$ with $3.51\text{E} - 02$ mean. During the lockdown, it ranged from $4.75\text{E} - 03$ to $9.75\text{E} - 03$ with $7.42\text{E} - 03$ mean value (Fig. 5b). Unlock period, HI was ranged from $7.39\text{E} - 03$ to $1.30\text{E} - 02$ with a $1.02\text{E} - 02$ mean value. All samples of pre-lockdown, during the lockdown, and unlock period (100%) showed a total HI value lower than 1 and indicated a very negligible health risk to children and adults by dermal contact in this region.

Analysis of variance (ANOVA)

When the difference between or within variables is compared for three or more groups, then one-way ANOVA testing is appropriate to use. In this analysis, if the “*F*” value is observed greater than the level of significance (ρ) value then the null hypothesis is rejected and significant difference among groups is considered. In this study, one-way ANOVA test was conducted for analysis of difference

among HI values of pre-lockdown, during the lockdown, and unlock period for ingestion and dermal contact by children and adults. Means of HI (ingestion, dermal) values of three periods were compared by the least square difference (LSD) method at a 0.05 significance level. Analysis showed that all *F* value was much greater than their significant level ($\rho = 0.000$) and hence completely accepted significant changes in mean HI values of three periods for adults and children (Table 4).

Discussion

The above assessment on water quality changes in three different time periods (pre-lockdown, during the lockdown, and unlock) of the COVID-19 scenario has brought some significant conversion of aforesaid heavy metals and microbes contained in the Damodar river. On the basis of our objectives the major results have been discussed as below.

1) Reduction of heavy metals and microbial load during lockdown: the assessment of heavy metals, it was clearly observed that 100% sample water was over contaminated by heavy metals than their standard value recommended by WHO (2011). Higher concentration of Zn, Fe, Pb, and Ni indicated industrial discharge of these metals by iron and steel, chemical industries, coal mining extracts, agricultural runoff in this period. During the lockdown, the concentration of Pb, Ni, Cr, and Fe was lowered down than the standard value in all samples. Other studies on heavy metals in drinking water at COVID-19 lockdown times also revealed a huge reduction of toxic metals load in water resources (Selvam et al. 2020b; Shukla et al. 2021; Chakraborty et al. 2021a, b).

A significant and sudden fall in bacterial load during the lockdown period was observed in the river water of the present study stretch. Many types of research on water quality changes during lockdown were identified, and the main cause of a decrease in microbial population i.e. temporary shutdown of industries, traffic vehicles, recreational amusements, bathing, etc. near riverbank has been recognized (Yunus et al. 2020; Khan et al. 2021; Selvam et al. 2020b; Mukherjee et al. 2020; Dutta et al. 2020). Another cause may be the usage of disinfecting sanitizers and their mixing with river water due to maintenance of COVID-19 safety measures.

2) Source identification of pollutants: very high positive correlation among those heavy metals and microbial signified that they mixed with river water from possibly common sources i.e. industrial wastes, agricultural runoff, or municipal garbage. During the lockdown, the shutdown of industrial activities and the generation of waste materials helped to reduce their load in river water. Again, amplification of toxic metals and microbes after reopening of industrial and all other economic activities indicated untreated

Table 3 Hazard quotient (HQ) values of six heavy metals for ingestion and dermal

Category	Period	Statistics	Zn2 +	Cd2 +	Pb2 +	Cr +	Ni2 +	Fe
HQ ingestion (children)	Pre lockdown	Mean	6.20	1.36	0.87	1.36	0.20	0.04
		Minimum	4.98	1.00	0.60	1.11	0.09	0.04
		Maximum	7.31	1.69	1.10	1.55	0.30	0.05
	During lockdown	Mean	0.82	0.29	0.12	0.53	0.02	0.01
		Minimum	0.62	0.11	0.04	0.40	0.01	0.01
		Maximum	1.00	0.42	0.20	0.62	0.02	0.01
	Unlock phase	Mean	1.18	0.47	0.18	0.64	0.05	0.02
		Minimum	1.07	0.31	0.10	0.47	0.04	0.01
		Maximum	1.38	0.61	0.27	0.77	0.07	0.03
HQ ingestion (adult)	Pre lockdown	Mean	3.79	0.58	0.53	0.83	0.12	0.03
		Minimum	3.05	0.43	0.37	0.68	0.06	0.02
		Maximum	4.48	0.73	0.67	0.95	0.19	0.03
	During lockdown	Mean	0.50	0.18	0.07	0.32	0.01	0.01
		Minimum	0.38	0.07	0.02	0.25	0.01	0.00
		Maximum	0.61	0.25	0.12	0.38	0.01	0.01
	Unlock phase	Mean	0.72	0.29	0.11	0.39	0.03	0.01
		Minimum	0.66	0.19	0.06	0.29	0.02	0.01
		Maximum	0.85	0.38	0.16	0.47	0.04	0.02
HQ dermal (children)	Pre lockdown	Mean	2.03E-02	5.21E-03	1.91E-02	1.49E-02	2.16E-04	2.46E-04
		Minimum	1.63E-02	3.83E-03	1.31E-02	1.22E-02	1.02E-04	1.97E-04
		Maximum	2.40E-02	6.49E-03	2.41E-02	1.70E-02	3.32E-04	2.91E-04
	During lockdown	Mean	2.71E-03	1.59E-03	2.58E-03	5.76E-03	1.67E-05	4.85E-05
		Minimum	2.04E-03	6.28E-04	8.75E-04	4.38E-03	1.02E-05	4.05E-05
		Maximum	3.27E-03	2.28E-03	4.30E-03	6.76E-03	2.30E-05	5.14E-05
	Unlock phase	Mean	3.86E-03	2.56E-03	3.91E-03	7.00E-03	5.71E-05	1.04E-04
		Minimum	3.52E-03	1.70E-03	2.19E-03	5.14E-03	3.83E-05	6.20E-05
		Maximum	4.54E-03	3.36E-03	5.83E-03	8.47E-03	7.40E-05	1.45E-04
HQ dermal (adult)	Pre lockdown	Mean	1.19E-02	3.04E-03	1.12E-02	8.72E-03	1.26E-04	1.44E-04
		Minimum	9.55E-03	2.24E-03	7.67E-03	7.12E-03	5.97E-05	1.15E-04
		Maximum	1.40E-02	3.79E-03	1.41E-02	9.93E-03	1.94E-04	1.70E-04
	During lockdown	Mean	1.58E-03	9.27E-04	1.51E-03	3.37E-03	9.76E-06	2.83E-05
		Minimum	1.19E-03	3.67E-04	5.11E-04	2.56E-03	5.97E-06	2.36E-05
		Maximum	1.91E-03	1.33E-03	2.51E-03	3.95E-03	1.34E-05	3.00E-05
	Unlock phase	Mean	2.26E-03	1.50E-03	2.29E-03	4.09E-03	3.34E-05	6.06E-05
		Minimum	2.06E-03	9.96E-04	1.28E-03	3.01E-03	2.24E-05	3.62E-05
		Maximum	2.65E-03	1.96E-03	3.41E-03	4.95E-03	4.33E-05	8.48E-05

wastewater and recreational activities are the main sources of their concentration.

3) Identification of human health impact by heavy metal pollution in three periods: it is the most important part of our analysis that significant positive changes were found in river water quality with the application of HPI. During

the lockdown, around 54.54% of water samples were transformed into low pollution, and around 45.45% of samples were transformed into medium pollution. This is a significant symptom of river water quality improvement.

Assessment of noncarcinogenic health risk by heavy metals showed that HQ (ingestion) of zinc has the higher

Fig. 5 Hazard index (HI) for children and adult population (noncarcinogenic). **a** Ingestion and **b** dermal with error bars and standard error

potentiality to health risk among all metals to children and adults both. HI value indicated that children are more potential to health risk than the adult population in the study area. Though during lockdown HI values of ingestion of drinking water by children and adults were lowered down than pre lockdown and unlock, there were higher possibilities to

health risk remain same ($HI > 1$). HI values of dermal contact suggested that there were no immediate possibilities of health risk to children and adults in this region. In the present study, the trend of increasing microbial and heavy metal pollution load after reopening of all industrial, traffic, recreational sectors in unlock period strongly recommended that

Table 4 One-way ANOVA for significance test of hazard index (HI) values

Variable		Sum of squares	df	Mean square	F	Sig
Ingestion (children)	Between groups	458.196	2	229.098	242.907	0.000
	Within groups	28.295	30	0.943		
	Total	486.490	32			
Ingestion (adult)	Between groups	154.542	2	77.271	235.978	0.000
	Within groups	9.824	30	0.327		
	Total	164.366	32			
Dermal (children)	Between groups	0.015	2	0.007	198.054	0.000
	Within groups	0.001	30	0.000		
	Total	0.016	32			
Dermal (adult)	Between groups	0.005	2	0.003	198.054	0.000
	Within groups	0.000	30	0.000		
	Total	0.005	32			

immediate scientific management practice should be adopted to sustain river water quality for its ecosystem and human health. Therefore, industrial authorities should be followed the environmental norms and regulations before the direct discharge of waste materials to the riverbed. Municipal corporations should specify the definite places to deposition of domestic wastes. In city areas, more usages of personal RO (reverse osmosis) purification machines will be encouraged by local authorities. Higher usages of chemical fertilizers and pesticides must be controlled. Most of all, a village-level public awareness program will effectively be helped to reduce pollution contamination on river water.

Conclusion

The present study of river Damodar in an industrially influenced catchment area was uniquely assessed to evaluate river water quality on the basis of heavy metals and microbial concentration along with human health risk in the pre, during, and unlock phase of COVID-19 lockdown. The sample analysis showed mean concentration of heavy metals was $Zn > Fe > Cr > Ni > Pb > Cd$ over three periods in river water. The mean value of all heavy metals crossed their standard limit of concentration in drinking water according to BIS (2012) in all samples of pre lockdown. Pb, Ni, Cr, and Fe were identified as their values below the standard limit of concentration during the lockdown. After unlock, 72.72% sample of Ni and 45.45% sample of Fe again crossed their standard limit by their mean values. There was a noticeable decrease in microbial load in river water during the lockdown. HPI indicated that 100% sample was highly polluted in pre lockdown which changed to 54.54% sample of low pollution and 45.45% sample of medium pollution during the lockdown. Again 45.45% sample water changed to high pollution after restarting of commercial activities.

HI of ingestion indicated > 1 for children in all samples of three periods and confirms possibilities to health hazard (noncarcinogenic) more than adults by their mean values. HI of dermal contact showed that there were no possibilities to the health-related hazard of children or adults in this area. Scientific techniques and cost-effective remediation are highly recommended to control water quality after a new normal period. There is an enormous possibility to do a further study on the basis of this field and GIS-based research in these changing circumstances, and simultaneously it is highly required to find out the solutions because this river contributes multidimensional ecosystem services to millions of people in India.

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Author contribution P.K. Shit conceptualized and planned the study and reviewed and edited the manuscript. B. Chakraborty conducted the survey, water sampling, analysed the data, and write-up the manuscript. S. Roy conducted the survey, water sampling, and prepared the maps. S. Saha. conducted the survey, prepared the graphs, and analysed the data. S. Bhattacharjee reviewed and edited the manuscript. P.P. Adhikary reviewed and edited the manuscript. B. Bera supervised the study and reviewed and edited the manuscript. D. Sengupta supervised the overall research and interpreted the results. All authors have read and approved the final manuscript.

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Declarations

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References

- Abdullah EJ (2013) Evaluation of surface water quality indices for heavy metals of Diyala River-Iraq. *J Nat Sci Res* 3:63–69
- Ahmed F, Fakhruddin ANM, Fardous Z, Chowdhury MAZ, Kabir MM (2021) Accumulation and translocation of chromium (Cr) and lead (Pb) in chilli plants (*Capsicum annuum* L.) grown on artificially contaminated soil. *Nat Environ Pollut Technol* 20:63–70
- Ahmed MK, Shaheen N, Islam MS, Habibullah-al-Mamun M, Islam S, Mohiduzzaman M, Bhattacharjee L (2015) Dietary intake of trace elements from highly consumed cultured fish (*Labeorohita*, *Pangasius* and *Oreochromis mossambicus*) and human health risk implications in Bangladesh. *Chemosphere* 128:284–292. <https://doi.org/10.1016/j.chemosphere.2015.02.016>
- Akhilesh J, Savita D, Suman M (2009) Some trace elements investigation in groundwater of Bhopal and Sehore District in Madhya Pradesh, India. *J Appl Sci Environ Manag* 13(4):47–50
- Ali H, Khan E (2018) What are heavy metals? long-standing controversy over the scientific use of the term ‘heavy metals’—proposal of a comprehensive definition. *Toxicol Environ Chem* 100:6e19
- Aman MA, Salman MS, Ali PY (2020) COVID-19 and its impact on environment: Improved pollution levels during the lockdown period—a case from Ahmedabad, India. *Remote Sens Appl: Soc Environ* 100382. <https://doi.org/10.1016/j.rsase.2020.100382>
- Banerjee US, Gupta S (2013) Impact of Industrial Waste Effluents On River Damodar Adjacent To Durgapur Industrial Complex, West Bengal, India. *Environ Monit Assess*. <https://doi.org/10.1007/S10661-012-2690-1>
- Besharati S, Motamedi H, Zallaghi R (2018) A survey on microbial quality and antibiotic resistance in Karoon River, Khuzestan, Iran. *Appl Water Sci* 8:146. <https://doi.org/10.1007/s13201-018-0786-7>
- BIS (Bureau of Indian Standards) (2012) Indian standard, drinking water—specification, Second Revision, IS 10500: ICS 13.060.20
- Chakraborty B, Roy S, Bera A, Adhikary PP, Bera B, Sengupta D, Bhunia GS, Shit PK (2021a) Cleaning the river Damodar (India): impact of COVID-19 lockdown on water quality and future rejuvenation strategies. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-020-01152-8>
- Chakraborty B, Roy S, Bera A, Adhikary PP, Bera B, Sengupta D, Bhunia GS, Shit PK (2021b) Eco-restoration of river water quality during COVID-19 lockdown in the industrial belt of eastern India. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-12461-4>
- Chatterjee SK, Bhattacharjee I, Chandra G (2010) Water quality assessment near an industrial site of Damodar River. *Environ Monit Assess India*. <https://doi.org/10.1007/S10661-008-0736-1>
- Chen L, Zhou S, Shi Y, Wang C, Li B, Li Y, Wu S (2018) Heavy metals in food crops, soil, and water in the Lihe River Watershed of the Taihu Region and their potential health risks when ingested. *Sci Total Environ* 615:141–149
- Dhar I, Biswas S, Mitra A, Pramanick P, Mitra A (2020) COVID-19 lockdown phase: a boon for the River Ganga water quality along the city of Kolkata. *NUJS J. Regulatory Studies*, 2456–4605(O)
- Di'az-Somoano M, Kylander ME, Lo'pez-Anto'n MA, Suárez-Ruiz I, Marti'nez-Tarazona MR, Ferrat M, Kober B, Weiss DJ (2009) Stable lead isotope compositions in selected coals from around the world and implications for present day aerosol source tracing. *Environ Sci Technol* 43:1078–1085
- Dutta V, Dubey D, Kumar S (2020) Cleaning the River Ganga: impact of lockdown on water quality and future implications on river rejuvenation strategies. *Sci Total Environ*. 140756. <https://doi.org/10.1016/j.scitotenv.2020.140756>
- Fatoba JO, Sanuade OA, Hammed OS, Igboama WW (2017) The use of multivariate statistical analysis in the assessment of groundwater hydrochemistry in some parts of southwestern Nigeria. *Arab J Geosci* 10 (15). <https://doi.org/10.1007/s12517-017-3125-7>
- Giuliano V, Pagnanelli F, Bornoroni L, Toro L (2007) Toxic elements at a disused mine district: particle size distribution and total concentration in stream sediments and mine tailings. *J Hazard Mater* 148(1–2):409
- Guerra F, Trevizamar, Muraoka T, Marcante NC, Canniatti-Brazaca SG (2012) Heavy metals in vegetables and potential risk for human health. *Sci Agric* 69:54–60
- Hakan P (2006) The distribution and sources of heavy metals in Izmit Bay surface sediment affected by a polluted stream. *Mar Pollut Bull* 52:1197–1206
- Haldar D, Halder S, Das P, Halder G (2014) Assessment of water quality of Damodar River in South Bengal region of India by Canadian Council of Ministers of Environment (CCME) WaterQuality index: a case study. *Desalination Water Treat* 1–14. <https://doi.org/10.1080/19443994.2014.987168>
- Isa NM, Aris AZ, Sheikhy Narany T, Sulaiman WNA (2017) Applying the scores of multivariate statistical analyses to characterize the relationships between the hydrochemical properties and groundwater conditions in respect of the monsoon variation in Kapas Island, Terengganu, Malaysia. *Environ Earth Sci* 76(4). <https://doi.org/10.1007/s12665-017-6487-y>
- John V, Jain P, Rahate M, Labhasetwar P (2014) Assessment of deterioration in water quality from source to household storage in semi-urban settings of developing countries *Environ Monit Assess* 186:725–734
- Leong SS, Ismail J, Denil NA, Sarbini SR, Wasli W, Debbie A (2018) Microbiological and physicochemical water quality assessments of river water in an industrial region of the Northwest Coast of Borneo. *Water* 10. <https://doi.org/10.3390/w10111648>
- Kabir MM, Mouna SSP, Akter S, Khandaker S, Didar-ul-Alam M, Bahadur NM, Mohinuzzaman M, Islam MA, Shenashen MA (2021a) Tea waste based natural adsorbent for toxic pollutant removal from waste samples. *J Mol Liq* 322:115012
- Karunanidhi D, Aravinthasamy P, Subramani T, Setia R (2021) Effects of COVID-19 pandemic lockdown on microbial and metals contaminations in a part of Thirumanimuthar River, South India: a comparative health hazard perspective. *J Hazard Mater* 416. <https://doi.org/10.1016/j.jhazmat.2021.125909>
- Karunanidhi D, Aravinthasamy P, Subramani T, Muthusankar G (2020) Revealing drinking water quality issues and possible health risks based on water quality index (WQI) method in the Shanmuganadhi River basin of South India. *Environ Geochem Hlth*. <https://doi.org/10.1007/s10653-020-00613-3>
- Karunanidhi D, Aravinthasamy P, Kumar D, Subramani T, Roy PD, (2020c) Sobol sensitivity approach for the appraisal of geomedi-cal health risks associated with oral intake and dermal pathways of groundwater fluoride in a semi-arid region of south India. *Ecotoxicol Environ Saf* 194 (110438). <https://doi.org/10.1016/j.ecoenv.2020.110438>
- Kavcar P, Sofuoğlu A, Sofuoğlu SC (2009) A health risk assessment for exposure to trace metals via drinking water ingestion pathway *Int J Hyg Environ Health* 212:216–227

- RKhan R, Saxena A, Shukla S, Selvam S, Goel P (2021) Effect of COVID-19 lockdown on the water quality index of River Gomti, India, with potential hazard of faecal-oral transmission. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-13096-1>
- Klavins M, Briede A, Rodinov V, Kokorite I, Parele E, Klavina I (2000) Heavy metals in Rivers of Latvia. *Sci Total Environ* 262:175–183
- Kundu C (2020) Has the Covid-19 lockdown returned dolphins and swans to Italian waterways? *The India Today*, 22 March 2020. <https://www.indiatoday.in/fact-check/story/has-covid19-lockdown-returned-dolphins-swans-italian-waterways1658457-2020-03-22>. (Accessed 14 April 2020)
- Kwaya MY, HamiduH, Mohammed AI, Abdulmumini YN, Adamu IH, Grema HM, Dauda M, Halilu FB, Kana AM (2019) Heavy metals pollution indices and multivariate statistical evaluation of groundwater quality of Maru Town and Environs *J Mat Environ Sci* 10 32 44
- Manoj K, Kumar Padhy P, ChaudhuryS (2012) Study of heavy metal contamination of the river water through index analysis approach and environmetrics. *Bull Environ Pharmacol Life Sci* 1:7–15
- Mohammadi AA, Zarei A, Majidi S, Ghaderpoury A, Hashempour Y, Saghi MH, Alinejad A, Yousefi M, Hosseingholizadeh N, Ghaderpoori M (2019) Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. *MethodsX* 6:1642–1651. <https://doi.org/10.1016/j.mex.2019.07.017>
- Muhammad I, Ashiru S, Ibrahim ID, Salawu K, Muhammad DT, Muhammad NA (2014) Determination of some heavy metals in wastewater and sediment of artisanal gold local mining site of Abare Area in Nigeria. *J Environ Treat Technol* 1(3):174–182
- Mukherjee P, Pramanick P, Zaman S, Mitra A (2020) Eco-restoration of river Ganga water quality during COVID-19 lockdown period using total coliform (TC) as proxy. *NUJS J. Regulatory Studies*, 2456–4605(O)
- OOjekunle OZ, Ojekunle OV, Adeyemi AA, Taiwo AG, Sangowusi OR, Taiwo AM, Adekitan AA (2016) Evaluation of surface water quality indices and ecological risk assessment for heavy metals in scrap yard neighbourhood. *SpringerPlus* 5:560. <https://doi.org/10.1186/s40064-016-2158-9>
- Panda B, Chidambaram S, Thilagavathi R, et al (2020) Source governed trace metal anomalies in groundwater of foothill aquifer and its health effect. *Appl Water Sci* 10:173. <https://doi.org/10.1007/s13201-020-01253-9>
- Prasad B, Kumari S (2008) Heavy metal pollution index of ground water of an abandoned open cast mine filled with fly ash: a case study. *Mine Water Environ*. 27(4):265–267
- Prasad B, Mondal KK (2008) The impact of filling an abandoned open cast mine with fly ash on ground water quality: a case study. *Mine Water Environ* 27(1):40–45
- Rahube TO, Yost CK (2010) Antibiotic resistance plasmids in wastewater treatment plants and their possible dissemination into the environment. *Afr J Biotech* 9:9183–9190
- Rezaei A, Hassani H, Hayati M, Jabbari N, Barzegar R (2017) Risk assessment and ranking of heavy metals concentration in Iran's Rayen groundwater basin using linear assignment method. *Stoch Environ Res Risk Assess* 32(5):1317–1336. <https://doi.org/10.1007/s00477-017-1477-x>
- Reza R, Singh G (2010) Heavy metal contamination and its indexing approach for river water. *Int J Environ Sci Tech* 7(4):785–792
- Sekar KG, Suriyakala K (2016) Seasonal variation of heavy metal contamination of groundwater in and around Udaiyarpalayam Taluk, Ariyalur district, Tamil Nadu. *World Sci News* 47–60
- Selvam S, Muthukumar P, Venkatramanan S, Roy PD, Manikanda Bharath K, Jesuraja K (2020a) SARS-CoV-2 pandemic lockdown: effects on air quality in the industrialized Gujarat state of India. *Sci. Total Environ* 140391. <https://doi.org/10.1016/j.scitotenv.2020.140391>
- Selvam S, Jesuraja K, Venkatramanan S, Chung SY, Roy PD, Muthukumar P, Kumar M (2020b) Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, south India: a revival perspective. *Sci Total Environ* 139848. <https://doi.org/10.1016/j.scitotenv.2020.139848>
- Setia R, Dhaliwal SS, Kumar V, Singh R, Kukal SS, Pateriya B (2020) Impact assessment of metal contamination in surface water of Sutlej River (India) on human health risks. *Environ Pollut* 114907. <https://doi.org/10.1016/j.envpol.2020.114907>
- Shukla T, Sen IS, Boral S, Sharma S (2021) A time-series record during COVID-19 lockdown shows the high resilience of dissolved heavy metals in the Ganga River. *ACS Publications Collection*. <https://doi.org/10.1021/acs.estlett.0c00982>
- Singh RK, Chaturvedi A, Kumari K (2017) Water-quality assessment of Damodar River and its tributaries and subtributaries in Dhanbad Coal mining areas of India based on WQI. *Sustain Water Resour Manag*. <https://doi.org/10.1007/s40899-017-0159-7>
- Smith A, Lingas E, Rahman M (2000) Contamination of drinking water by arsenic in Bangladesh: a public health emergency. *Bull World Health Org* 83:177–186. <https://doi.org/10.1590/S0042-96862000009000005>
- Srivastava S, Dash H R, Das S (2017) Assessment of the Biological Quality of Riverine Water Using Pathogenicity Islands (PAIs) of Coliform Bacteria as Pollution Indicator I. *Water Resour* 44(1):150–157. <https://doi.org/10.1134/S0097807817010146>
- Sun F, Chen J, Tong Q, Zeng S (2007) Integrated risk assessment and screening analysis of drinking water safety of a conventional water supply system. *Water Sci Technol* 56:47–56
- Tam NFY, Wong WS (2000) Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. *Environ Pollut* 110:195–205
- Tiwari AK, Maio MD, Singh PK, Mahato MK (2015) Evaluation of surface water quality by using GIS and a heavy metal pollution index (HPI) model in a coal mining area. *India Bull Environ Contam Toxicol* 95:304e310
- Tumuklu A, Yalcin MG, Sonmez M (2007) Detection of heavy metal concentrations in soil caused by Nigde City Garbage Dump. *Pol J Environ Stud* 16(4):651
- USEPA (1989) Risk assessment guideline for superfund V. 1 Human Health Evaluation Manual (Part A). U.S. Environmental Protection Agency. [EPA/540/1-89/002](https://www.epa.gov/epaosopr/risk/assessment/guidelines/superfund/vol1/human-health-evaluation-manual-part-a)
- USEPA (1995) EPA-823-B-94-005a, b Water quality standards handbook, 2nd ed., National Technical Information Service, Springfield, VA
- USEPA (2011) Exposure Factors Handbook, 2011 edn. U.S. Environmental Protection Agency. <https://www.epa.gov/600/R-090/052F>. Accessed 23 June 2021
- WHO 2011 Guidelines for drinking-water quality 4 World Health Organization Geneva
- WHO (2021) Coronavirus disease (COVID-19) situation report-197. Available online: [https://www.who.int/docs/default-source/coronavirus/situation-reports/20200804-covid-19-sitrep-197.pdf?sfvrsn=94f7a01d_2\(2021\)](https://www.who.int/docs/default-source/coronavirus/situation-reports/20200804-covid-19-sitrep-197.pdf?sfvrsn=94f7a01d_2(2021)). Accessed 28 June 2021
- Wu Z, Zhang D, Cai Y, Wang X, Zhang L, Chen Y (2017) Water quality assessment based on the water quality index method in Lake Poyang: the largest freshwater lake in China. *Sci Rep* 7:17999. <https://doi.org/10.1038/s41598-017-18285-y>
- Yahaya MI, Mohammad S, Abdullahi BK (2009) Seasonal variations of heavy metals concentration in Abba toir dumping site in Nigeria. *J Appl Sci Environ Manag* 13(4):9–13
- Yunus AP, Masago Y, Hijioka Y (2020) COVID-19 and surface water quality: improved lake water quality during the lockdown. *Sci*

Total Environ 139012. <https://doi.org/10.1016/j.scitotenv.2020.139012>.

Zou L, Xia J, She D (2018) Analysis of impacts of climate change and human activities on hydrological drought: A case study in the Wei River Basin, China. *Water Resour Manag* 32:1421–1438

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