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COVID-19 lockdown impacts on heavy metals and microbes in shallow groundwater and expected health risks in an industrial city of South India

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ABSTRACT

In this investigation, the positive impact of COVID-19 lockdown on heavy metals concentration and biological parameters in the shallow groundwater samples of Coimbatore city of South India was ascertained. The groundwater samples (n=15) were obtained from shallow open wells during before lockdown (24–25 February 2020) and after lockdown (2–3 June 2020) periods. These samples were analysed for heavy metals (Fe, Mn, Ni, Cr and Pb) and biological parameters (E. coli, Fecal coliforms, Fecal streptococci and Total coliforms). Fe concentration was within the permissible limit but, the concentrations of Mn, Ni, Cr and Pb were above the allowable limits for drinking uses as per the WHO. However, after lockdown the number of samples crossing the cutoff limit had considerably decreased (Mn: from 2 to 0 mg/L; Ni: from 13 to 10 mg/L; Cr: 7 to 5 mg/L and Pb: from 13 to 8 mg/L). The heavy metal pollution index (HPI) revealed that 176.75 km² (67.4%) and 85.35 km² (32.6%) areas fell under unsuitable and very poor categories, respectively, during the pre-lockdown period, whereas 138.23 km² (52.6%), 118.98 km² (45.3%) and 4.89 km² (2.1%) areas fell under very poor, poor and good categories, respectively, during the post-lockdown period. Similarly, Total coliform, Fecal coliform and E. coli had decreased distinctly due to the pandemic lockdown. Therefore, the shutdown of small and large-scale industries during the lockdown period had improved the groundwater quality. The health risk assessment showed that 93%, 87% and 80% of pre-lockdown samples, and 87%, 80% and 73% of post-lockdown samples possessed non-carcinogenic risks (HI > 1) for children, female and male categories, respectively.

1. Introduction

The precipitous growth of industrialization and urbanization in the last few decades has severely contaminated the natural environmental components (soil, air, water, etc.) with various pollutants throughout the globe (Prabaharan et al., 2011; Rahman et al., 2020). Among different pollutants, heavy metals are considered to be the most dangerous contaminants because of their toxic effects at higher concentrations and persistence in natural components (Elumalai et al., 2017). The main origin of the heavy metals in water is parent rock materials. The natural concentration of heavy metals in water is usually low (Mukherjee et al., 2019; Karunanidhi et al., 2020), but their concentration increases many folds due to anthropogenic activities (e.g. extensive agro-chemicals based agriculture, industrial and urban wastewater discharges in water sources etc). Water contamination with heavy metals is a primary environmental concern in both developed and developing countries (Anandakumar et al., 2007; Khan et al., 2013). A numerous investigation on contamination of heavy metals in surface water and groundwater indicate that anthropogenic factors such as municipal solid waste leachate, manufacturing industries, fertilizers, and household wastes are the important sources of contamination of groundwater (Romic and Romic, 2003; Sajil Kumar et al., 2012; Mukherjee et al., 2019). The heavy metals released from anthropogenic sources may infiltrate through leaching (Shankar, 2019). The infiltration...
of heavy metals to aquifers might lead to several health problems because of the intake of heavy metals via water used for drinking purposes (Balakrishnan and Ramu, 2016). Several studies conducted around the world have characterized the heavy metal contamination in drinking water (Prasanna et al., 2012; Wagh et al., 2018; Edet and Offiong, 2002), and some studies reported health risks and pollution index due to the heavy metals exposure (Madhav et al., 2020; Ahamad et al., 2020, 2018). In addition to health risks due to heavy metals, many bacterial diseases are transmitted through wastewaters discharged into groundwater systems (Gao et al., 2020). Therefore, assessment of the biological quality of water is also important because several bacterial illnesses (like cholera, bacillary dysentery, and typhoid fever) are transmitted through contaminated water (Cabral, 2010). However, the effect of COVID-19 lockdown on heavy metals contamination and microbiological quality of water has not been assessed simultaneously.

In India, industries were closed due to COVID-19 because the focus was on containing the spread via quarantines and national lockdowns (Hamzelou, 2020). The Indian government announced lockdown in the country from 24 March to 31 May in four phases, and industries were allowed to open in many places from 16 June 2020 onwards. However, colleges, schools, malls, public transports, markets, and hotels were closed during the lockdown period. Many studies have analysed the gaseous concentration in the atmosphere before and after the COVID-19 lockdown period (Bagyaraj et al., 2020; Ghosh et al., 2020; Das et al., 2020), but there is no comparative investigation on the evaluation of heavy metal pollution and microbiological quality of groundwater during the COVID-19 pandemic lockdown. Few researchers (e.g. Dutta et al., 2020; Singhal and Matto, 2020; Aman et al., 2020; Khan et al., 2021; Karunanidhi et al., 2021) have reported the COVID-19 impact on water pollution. It was hypothesized that heavy metal contamination in groundwater will be reduced, but the microbiological quality of groundwater will be improved during and just after the COVID-19 lockdown period. Simultaneous study on heavy metals and microbial concentrations in shallow groundwater was not conducted. Therefore, we studied the heavy metal contamination and microbiological quality of groundwater before and after the COVID-19 lockdown period in the Coimbatore (largest industrial city) region of southern India. In addition to this, human health risks were also calculated and multivariate statistics were used to identify the probable sources of metals in the groundwater of the city of Coimbatore before and after the COVID-19 lockdown periods.

2. Materials and methods

2.1. Study area

Coimbatore is the largest industrial city in the state of Tamil Nadu and is also referred to as the state of Manchester. The study area is situated between the latitudes 10°52′30″N and 11°4′30″N, and longitudes between 76°51′0″N and 77°3′0″N (Fig. 1). The total area is 262 km². The average annual rainfall ranges from 550 to 900 mm, and the temperature fluctuates from 19.8 to 35.9 °C. The land use/land cover (Lu/Lc) of the area was classified using Landsat-8 satellite data (Fig. 1). The major Lu/Lc cover is a settlement (46.4%) followed by agriculture (23.7%), industry (5.9%) and other classes like follow land (13.4%), water bodies (2.03%) and hills (8.53%). The major soil types in the region are red non-calcareous, red calcareous, black soil, and colluvial soil. The major rock types in this area are hornblende biotite gneiss, charnockite, granite, and fissile hornblende biotite gneiss (GSI, 1995). The groundwater of the area arises from weathered rocks, and the major

![Fig. 1. Land use/land cover map of the study area and sampling locations of pre- and post-COVID-19 lockdown.](image-url)
aquifer system is under unconfined nature. However, the deep aquifer (fracture aquifer) is semi-confined to confined in character. The specific yield of open wells varies from 50 to 300 liters per minute (lpm). The transmissivity (T) of this region varies from 1.49 to 164.18 m²/day. The yield of open wells varies from 50 to 300 L per minute (lpm). The aquifer system is under unconfined nature. However, the deep aquifer system is under unconfined nature. The four important steps suggested for health risk evaluation are risk identification, evaluation of dose and response, exposure assessment, and risk categorization (Arya et al., 2019; Wu et al., 2020). In this study, the drinking exposure pathway was considered for health risk assessment.

2.2. Sample collection and analytical procedure

Geo-tagged groundwater samples (n=15) were taken from shallow open wells before (February 2020) and after COVID-19 (June 2020) lockdown periods. The sampling and analysis of water followed the standard guidelines specified by APHA, 2005. Groundwater samples were taken from the field using 500 ml pre-washed Teflon bottles. One portion of the samples was acidified with concentrated nitric acid (below pH of 2.0) to reduce the absorption and precipitation on the bottle walls, and another portion of the water samples was not acidified. Besides, the collected water samples were tightly wrapped and moved to the laboratory, and placed in an ice jacket at 4°C until tested. These samples were analysed for heavy metals (Fe, Cr, Pb, Mn, and Ni) using Atomic Absorption Spectroscopy (AAS) method (PerkinElmer Analyst 700). Groundwater samples were also analysed for biological parameters (Total coliform bacteria, Escherichia coli / E.coli, Fecal streptococci and Fecal coliform bacteria) using the Most Probable Number (MPN) technique.

2.3. Statistical analyses

Pearson correlation coefficient was calculated to obtain the relationship among heavy metals using SPSS (version=20) software package. Principal Component Analysis (PCA) was used for source detection of heavy metals in groundwater of the area.

2.4. Heavy metal pollution index (HPI)

HPI was used to identify the impacts of distinct heavy metals on the quality of groundwater. The HPI was calculated using Eq. 1 (Soujanya Kamble et al., 2020).

\[
HPI = \sum_{i=1}^{n} \frac{W_i Q_i}{S_i - \bar{l}_i} 
\]

(1)

\[
Q_i = \sum_{j=1}^{i} \left( \frac{M_i}{S_i - \bar{l}_i} \right) \times 100
\]

(2)

\[
W_i = \frac{K}{S_i}
\]

(3)

Where, Qi denotes unit weight using Eq. (2): (Wj) indicate sub-index of the parameter, which is calculated by Eq. (3):

\[
Q_i = \sum_{j=1}^{i} \left( \frac{M_j}{S_i - \bar{l}_i} \right) \times 100
\]

(4)

\[
HPI = \frac{\sum_{i=1}^{n} \left( \frac{W_i Q_i}{S_i - \bar{l}_i} \right)}{n}
\]

(5)

The spatial variations in HPI were studied using the Inverse Distance Weighted (IDW) method (spatial analyst tool) in ArcGIS (version=10.4) package (e.g. Shankar and Kawo, 2019 and Soujanya Kamble et al., 2020). IDW is an effective method for spatial interpolation of groundwater quality parameters (Subramani et al., 2011; Karunanidhi et al., 2019; Kawo and Shankar, 2018; Balamurugan et al., 2020).

2.5. Health risk assessment

The contamination of water with heavy metals may create harm to human health through multi-exposure pathways like breathing, intake, and dermal contact. The USEPA has developed models for the assessment of human health risks (Wu et al., 2012). Based on USEPA (USEPA, 2014), the four important steps suggested for health risk evaluation are risk identification, evaluation of dose and response, exposure assessment, and risk categorization (Arya et al., 2019; Wu et al., 2020). In this study, the drinking exposure pathway was considered for health risk assessment.

Eq. 4 calculated the non-carcinogenic risks through the intake pathway (Karimi et al., 2020; Shams et al., 2020; Karunanidhi et al., 2020a,b,c).

\[
Intake_{oral} = C x EF x ED x IR / BW x AT
\]

(4)

Where C = concentration of heavy metals in water (mg/L); IR = daily ingestion rate of water (liter /day), and it is 0.64 L/day for children, 2 L /day for male and 1.9 L /day for female; EF = Exposure frequency and it is expressed as days/year. EF for the three age categories is 365 days or 1 year; ED = Exposure duration of the assessment (6 years for children and 40 years for male and female); BW = Bodyweight of different age groups (15 kg for children, 70 kg for male and 65 kg for female).

\[
AT = Time of exposure expressed in days. It is 2190 days for children and 14,600 days for male and female.
\]

\[
Non-carcinogenic risk quotient (HQ) through intake / oral pathway was computed using the following equation (Rezaei et al., 2019; Mohammadi et al., 2019):
\]

\[
HQ_{oral} = \frac{Intake_{oral}}{RI_{oral}}
\]

(5)

where, RI_D indicates the reference dosage for intake exposure (mg/kg/ day), which is 0.7 for Fe, 0.024 for Mn, 0.02 for Ni, 0.003 for Cr and 0.0014 for Pb.

Hazard index (HI) was eventually calculated using the equation (6) (Karimi et al., 2020; Shams et al., 2020)

\[
HI_{total} = \sum_{i=1}^{n} HI_i
\]

(6)

The HI_{total} more than 1 indicates severe non-carcinogenic risk.

3. Results and discussion

3.1. Heavy metals in groundwater

Table 1 displays the maximum, minimum, and mean values of heavy metals in groundwater samples before and after COVID-19 lockdown periods in the study area. Before COVID-19 lockdown, the Fe concentration in groundwater varied from 0.010 to 0.044 mg/L with the mean value of 0.026 mg/L, whereas after COVID-19 lockdown, it varied from 0.005 to 0.041 mg/L with a mean 0.021 mg/L. In the study area, all the groundwater samples were below the allowable limit (0.3 mg/L) of WHO guidelines. The mean concentration of Fe in groundwater decreased after the COVID-19 lockdown period compared to the pre-COVID-19 lockdown (Fig. 2a). The higher amount of Fe can cause damage of kidneys, spinal cord, heart, nervous systems and cancer (Subba Rao, 2007). Further, it enhances the iron bacterium that influences the taste of water (Brindha et al., 2020). Though iron in the groundwater is mainly caused by rock and soil chemistry (Subba Rao, 2007), industries also contribute considerable amount in the study.
Before COVID-19 (n = 15)

| Parameters | Units | Before COVID-19 Mean | Range | SD (± SE) | No. of samples above the permissible limit | % of samples above the permissible limit |
|------------|-------|----------------------|-------|-----------|------------------------------------------|-----------------------------------------|
| Fe         | mg/L  | 0.01                 | 0.01  | 0.01 (±0.01) | -                                        | -                                       |
| Mn         | mg/L  | 0.05                 | 0.12  | 0.01 (±0.01) | 13                                       | 87                                      |
| Ni         | mg/L  | 0.01                 | 0.40  | 0.01 (±0.01) | 13                                       | 87                                      |
| Cr         | mg/L  | 0.05                 | 0.30  | 0.01 (±0.01) | 7                                        | 47                                      |
| Pb         | mg/L  | 0.01                 | 0.71  | 0.01 (±0.01) | 13                                       | 87                                      |
| Total coliform | CFU/mL | 2.00 | 66.77 | 4.00 (±0.67) | 0 | <10 |
| Fecal coliform | CFU/mL | 2.00 | 66.77 | 4.00 (±0.67) | 0 | <10 |

After COVID-19 (n = 15)

| Parameters | Units | After COVID-19 Mean | Range | SD (± SE) | No. of samples above the permissible limit | % of samples above the permissible limit |
|------------|-------|----------------------|-------|-----------|------------------------------------------|-----------------------------------------|
| Fe         | mg/L  | 0.01                 | 0.01  | 0.01 (±0.01) | -                                        | -                                       |
| Mn         | mg/L  | 0.05                 | 0.12  | 0.01 (±0.01) | 13                                       | 87                                      |
| Ni         | mg/L  | 0.01                 | 0.40  | 0.01 (±0.01) | 13                                       | 87                                      |
| Cr         | mg/L  | 0.05                 | 0.30  | 0.01 (±0.01) | 7                                        | 47                                      |
| Pb         | mg/L  | 0.01                 | 0.71  | 0.01 (±0.01) | 13                                       | 87                                      |
| Total coliform | CFU/mL | 2.00 | 66.77 | 4.00 (±0.67) | 0 | <10 |
| Fecal coliform | CFU/mL | 2.00 | 66.77 | 4.00 (±0.67) | 0 | <10 |

The concentration of Mn in groundwater varied from 0.055 to 0.41 mg/L (mean = 0.123 mg/L) before lockdown, and from 0.03 to 0.40 mg/L (mean = 0.113 mg/L) after COVID-19 lockdown period. It was found that 13% of the samples before lockdown and none of the samples after lockdown exceeded the permissible limit of 0.4 mg/L recommended by WHO. Like Fe, Mn concentration in groundwater also decreased after COVID-19 lockdown (Fig. 2b). Brindha et al. (2020) showed that Mn affects the taste of water, and precipitates in food when used for food preparation and also promotes the growth of algae in reservoirs.

Before and after COVID-19 lockdown, the Ni concentration in groundwater was 0.01 to 0.39 mg/L and 0.01 to 0.32 mg/L, respectively. It was found that 87% of the samples surpassed the permissible limit (0.07 mg/L) of Ni for drinking purposes before lockdown but after the lockdown period, only 67% of the samples surpassed. There were no significant changes in Ni concentration in groundwater samples of all the sites except site no. 13 (Fig. 2c). It is well known that industries tend to increase Ni emissions to natural ecosystems, where several nickel compounds are used for industrial and commercial purposes (Patel et al., 2017).

The concentration of Cr in groundwater ranged from 0.003 to 0.3 mg/L before lockdown and from 0.010 to 0.15 mg/L after COVID-19 lockdown. The average concentration of Cr in groundwater was decreased by 0.02 mg/L from before to after COVID-19 lockdown, which was mainly due to the closure of industries during the lockdown period (Fig. 2d). As per the allowable limit of Cr (0.05 mg/L) in drinking water defined by WHO, 47% and 33% of the samples crossed the acceptable limit before and after lockdown, respectively. However, the possible sources of Cr include dyes, paints, ceramics and pottery (Patel et al., 2017).

The concentration of Pb in groundwater ranged from 0.011 to 0.188 mg/L before COVID-19 lockdown and from 0.00 to 0.12 mg/L after COVID-19 lockdown. The mean concentration of Pb in groundwater was decreased by 0.11 mg/L from before to after COVID-19 lockdown (Fig. 2e). As per the acceptable limit (0.01 mg/L) of Pb in drinking water suggested by WHO, 87% of the samples exceeded the acceptable limit before lockdown, but only 53% of the samples crossed the limit after lockdown. The possible sources of lead in water are old plumbing, animal and human excretion and disposal of materials containing lead batteries, pipes and paints at landfill sites (Rajasekaran and Abinaya, 2014; Boateng et al., 2019). The Pb concentration in drinking water > 0.01 mg/L may induce nervous problems in newborn kids, and in the fetus (WHO, 2017).

In our study pre-lockdown samples belong to post-monsoon/winter season, and post-lockdown samples belong to pre-monsoon/summer season. Generally, concentration of heavy metals in groundwater will decrease during winter season when compare with summer season due to rain fall recharge. In spite of this natural phenomenon, the lockdown has suddenly stopped the discharge of wastewater from the industries. This is the main reason for the reduced concentration of metals in the shallow groundwater of Coimbatore region. The average values of the heavy metals in this region are shown in Fig. 2f.

3.2. Heavy metal pollution index (HPI)

The HPI of groundwater samples ranged from 85.5 to 153 with an average of 101 before COVID-19 lockdown period, whereas it ranged from 42.4 to 98.5 with an average of 79.7 after COVID-19 lockdown. Based on HPI, the groundwater samples were categorized into 5 types: ‘excellent’ means less than 25, ‘good’ indicates 26 to 50, ‘poor’ indicates 51 to 75, ‘very poor’ ranges from 76 to 100 and ‘unsuitable’ means > 100. The HPI value was more than 100 in 27% of groundwater samples before COVID-19 lockdown, but it was less than 100 in all the samples after the lockdown period. Similarly, 73% of the samples were classified as very poor before lockdown, but 47%, 40% and 13% of the samples were classified as very poor, poor and good after lockdown, respectively.
Table 2

| Sampling No. | Before COVID-19 lockdown | After COVID-19 lockdown | Sampling No. | Before COVID-19 lockdown | After COVID-19 lockdown |
|--------------|--------------------------|-------------------------|--------------|--------------------------|-------------------------|
| HPI          | Water suitability class  | HPI                     | Water suitability class  |
| 1            | 110.03                   | Unsuitable              | 110.03       | Unsuitable              |
| 2            | 153.49                   | Unsuitable              | 153.49       | Unsuitable              |
| 3            | 97.29                    | Very Poor               | 97.29        | Very Poor               |
| 4            | 88.67                    | Very Poor               | 88.67        | Very Poor               |
| 5            | 99.93                    | Very Poor               | 99.93        | Very Poor               |
| 6            | 85.53                    | Very Poor               | 85.53        | Very Poor               |
| 7            | 112.29                   | Unsuitable              | 112.29       | Unsuitable              |
| 8            | 86.28                    | Very Poor               | 86.28        | Very Poor               |
| 9            | 85.93                    | Very Poor               | 85.93        | Very Poor               |
| 10           | 90.15                    | Very Poor               | 90.15        | Very Poor               |
| 11           | 91.83                    | Very Poor               | 91.83        | Very Poor               |
| 12           | 136.22                   | Unsuitable              | 136.22       | Unsuitable              |
| 13           | 95.55                    | Very Poor               | 95.55        | Very Poor               |
| 14           | 88.39                    | Very Poor               | 88.39        | Very Poor               |
| 15           | 88.49                    | Very Poor               | 88.49        | Very Poor               |
| Minimum      | 85.53                    | –                       | Minimum      | 98.53                   | –                       |
| Maximum      | 153.49                   | –                       | Maximum      | 98.53                   | –                       |
| Average      | 100.67                   | –                       | Average      | 79.69                   | –                       |

*All the 15 samples are within the most desirable limit of 0.3 mg/L based on Fe concentration.

Fig. 2. Heavy metal concentration in groundwater samples of pre- and post-COVID-19 lockdown.

(Table 2). Spatial distribution of HPI showed that groundwater quality was very poor over 176.75 km² area (67.4%) and unsuitable over 85.35 km² area (32.6%) before COVID-19 lockdown (Fig. 3a). The HPI spatial distribution map of post-COVID-19 lockdown (Fig. 3b) showed that there is a significant improvement in the groundwater quality. About 138.23 km² (52.6%), 118.98 km² (45.3%) and 4.89 km² (2.1%) areas, respectively, had very poor, poor and good types of groundwater as per HPI of post-lockdown.

3.3. Biological parameters in groundwater

The concentration of Fecal coliform bacteria varied from 6.8 to 110 MPN mL/l before lockdown and, from 4.6 to 74 MPN mL/l after the COVID-19 lockdown period. The Total coliform ranged from 2 to 118 MPN mL/l before COVID-19 lockdown, and from 1.1 to 84 MPN mL/l after the COVID-19 lockdown period. The average E. coli was 27.9 MPN mL/l before COVID-19 lockdown and 19.5 MPN mL/l after the lockdown (Fig. 4). The occurrence of E. coli is mainly associated with contamination sources like sewage and waste dumps (Kesari et al., 2015). The elevated temperature during the lockdown time, which happens during the summer, might have decreased the microbial concentration in the shallow groundwater (Ferreira and Chauvet, 2011). Furthermore, as directed by the government to regulate COVID-19 spread, residents have
used more alcoholic sanitizers, soaps and disinfectants. This might have also decreased the microbes in the wastewater, which reaches the shallow groundwater through infiltration.

3.4. Principal Component Analysis (PCA)

The PCA analysis showed that 67% and 76.2% of the total variances were extracted from three and four principal components before and after lockdown periods, respectively. The loadings of the component matrix showed that PC1 explained 2.09% of the variance and is dominated by Mn, Fecal streptococci, Ni and Total coliform bacteria before lockdown. After the COVID-19 lockdown period, the PC1 explained 24.3% of the total variance, and the contributions of Ni and Fecal coliform bacteria were positive, but the contribution of Mn was negative. The contributions of Ni, Mn and bacteria in PC1 were mainly from anthropogenic activities such as local waste disposal, industrial waste, sewage intrusion and synthetic chemical fertilizers. The PC2 explained 23.3% and 18.9% of the variances before and after lockdown periods, respectively (Fig. 5a, b). The main contributions in PC2 were from Fe and Cr. The PC3 showed the positive loading of Pb and total coliform bacteria before lockdown (50.9% of the total variance), and Fecal coli-form and Escherichia coli after the lockdown period (17.0% of the total variance). After the COVID-19 lockdown period, PC4 showed 16.1% of the variance with positive loadings for Pb and negative loadings for Fecal coliform bacteria (Table 3). These results show that industrial waste and sewage had a significant impact on metal contamination in groundwater.

3.5. Health risk assessment

The HQ values were above one for Ni, Cr and Pb, and were in the order: Pb > Cr > Ni > Mn > Fe. Before lockdown, the mean HQ among children was 0.0015 for Fe, 0.0.2095 for Mn, 0.4363 for Ni, 1.0138 for Cr and 0.0.1971 for Pb. The mean value of HQ among female category was 0.00105 for Fe, 0.1331 for Mn, 0.2776 for Ni, 0.6450 for Cr and 1.0924 for Pb. The mean value of HQ among male was 0.0010 for Fe, 0.1401 for Mn, 0.2922 for Ni, 0.6789 for Cr and 1.1499 for Pb. The non-carcinogenic risk based on HIfinal was calculated for five heavy metals. The range of HIfinal for pre—COVID-19 groundwater samples was 1.2518 to 7.1634, 0.7964 to 4.5571 and 0.8383 to 4.7970 for children, female
and male, respectively. In this, 93%, 87%, 80% of the samples exceeded the permissible limit (HI > 1).

Similarly, the mean value of HQ among children was 0.0001 for Fe, 0.1925 for Mn, 0.3896 for Ni, 0.7306 for Cr and 1.3905 for Pb in the post-COVID-19 samples. The mean value of HQ among female category was 0.0008 for Fe, 0.1291 for Mn, 0.2609 for Ni, 0.4893 for Cr and 0.9311 for Pb. The mean value of HQ among male was 0.0008 for Fe, 0.1291 for Mn, 0.2609 for Ni, 0.4893 for Cr and 0.9311 for Pb. As per the results, HI_total in the post-COVID-19 samples varied from 1.16272 to 5.02000, 0.7397 to 3.1935 and 0.7786 to 3.3616 for children, female and male groups, respectively (Table 4).

Among the category of children, the average HQ was above one for Cr and Pb in the pre-lockdown samples, whereas HQ was greater than one for Pb alone in the post-lockdown samples. For female and male categories, the average HQ was above one for Pb in the pre-lockdown samples. However, HI was more than one in 87%, 80%, 73% of the groundwater samples collected after lockdown for children, female and male, respectively.

Table 3
Principal component analysis (PCA) for the quality parameters of pre- and post-COVID-19 lockdown groundwater samples.

| Groundwater quality parameters /PCA | BeforeCOVID-19 lockdown | AfterCOVID-19 lockdown |
|-----------------------------------|-------------------------|------------------------|
|                                   | 1  | 2  | 3  | 1  | 2  | 3  | 4  |
| Fe                                | -0.014 | 0.822 | 0.329 | 0.069 | 0.849 | 0.09 | 0.053 |
| Cr                                | 0.299 | 0.727 | -0.135 | -0.365 | 0.835 | 0.065 | -0.15 |
| Pb                                | -0.03 | -0.013 | 0.821 | -0.016 | -0.006 | 0.07 | 0.847 |
| Mn                                | 0.891 | -0.182 | -0.021 | -0.646 | -0.072 | -0.11 | 0.385 |
| Ni                                | -0.698 | -0.128 | 0.126 | 0.927 | -0.053 | 0.132 | -0.106 |
| Total coliform bacteria           | -0.488 | -0.06 | 0.995 | 0.351 | 0.486 | 0.372 | 0.335 |
| Fecal coliform bacteria           | -0.441 | -0.47 | -0.332 | 0.471 | -0.146 | 0.645 | -0.565 |
| Escherichia coli                  | 0.078 | -0.726 | 0.347 | 0.05 | 0.026 | 0.962 | 0.098 |
| Fecal streptococci               | 0.822 | 0.303 | -0.085 | 0.652 | -0.126 | 0.035 | 0.326 |
| Eigen value                       | 2.485 | 27.615 | 27.615 | 2.186 | 1.698 | 1.527 | 1.45 |
| % of Variance                     | 2.099 | 23.318 | 50.933 | 24.287 | 18.872 | 16.966 | 16.109 |
| Cumulative %                      | 1.409 | 15.658 | 66.591 | 24.287 | 43.159 | 60.124 | 76.233 |

Table 4
Hazard index (HI) computed for children, female and male from the pre- and post-COVID-19 lockdown samples based on the consumption of heavy metals in groundwater.

| Hazard Index | Before COVID-19 lockdown | Female | Male |
|--------------|--------------------------|--------|------|
|              | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average |
| Fe           | 0.0006 | 0.0026 | 0.0015 | 0.0004 | 0.0016 | 0.0010 | 0.0004 | 0.0017 | 0.0010 |
| Mn           | 0.0934 | 0.7286 | 0.2092 | 0.0594 | 0.4635 | 0.1331 | 0.0626 | 0.4879 | 0.1401 |
| Ni           | 0.1021 | 0.7892 | 0.4363 | 0.0649 | 0.5021 | 0.2776 | 0.0684 | 0.5285 | 0.2922 |
| Cr           | 0.0395 | 4.0913 | 1.0138 | 0.0252 | 2.6027 | 0.6450 | 0.0265 | 2.7397 | 0.6789 |
| Pb           | 0.3098 | 5.4941 | 1.7172 | 0.1971 | 3.4951 | 1.0924 | 0.2074 | 3.6791 | 1.1499 |
| HI_total     | 1.2518 | 7.1634 | 3.3780 | 0.7964 | 4.5571 | 2.1490 | 0.8383 | 4.7970 | 2.2621 |

| After COVID-19 lockdown | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average |
|-------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Fe                      | 0.00030 | 0.00241 | 0.00124 | 0.0002 | 0.0015 | 0.0008 | 0.0002 | 0.0016 | 0.0008 |
| Mn                      | 0.09137 | 0.67541 | 0.19285 | 0.0581 | 0.4297 | 0.1227 | 0.0612 | 0.4523 | 0.1291 |
| Ni                      | 0.08469 | 0.65809 | 0.38960 | 0.0539 | 0.4187 | 0.2479 | 0.0567 | 0.4407 | 0.2609 |
| Cr                      | 0.13274 | 2.04566 | 0.73062 | 0.0876 | 1.3014 | 0.4648 | 0.0922 | 1.3699 | 0.4893 |
| Pb                      | 0.26886 | 3.50685 | 1.39050 | 0.1710 | 2.2309 | 0.8846 | 0.1800 | 2.3483 | 0.9311 |
| HI_total                | 1.16272 | 5.02000 | 2.70482 | 0.7397 | 3.1935 | 1.7207 | 0.7786 | 3.3616 | 1.8113 |
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4. Conclusions and recommendations

In the Coimbatore city of South India, heavy metal concentration in groundwater (n = 15) is in the order of Mn > Ni > Cr > Pb > Fe. Fe and Mn concentrations were below the acceptable values proposed for drinking by WHO except for concentrations of Mn in 2 samples of post–COVID-19 lockdown. The lockdown has brought down the concentrations of heavy metals in groundwater of this region and has significantly reduced the number of post-lockdown samples crossing the allowable limit for consumption. The spatial plot of the heavy metal pollution index (HPI) indicated that unsuitable and very poor groundwater quality areas were changed to the poor (118.98 km² / 45.3%) to good (4.89 km² / 2.1%) categories in the post-lockdown period. This was concluded in the closure of small and large-scale industries during the lockdown period. Similarly, the mean population of Fecal coliform, Total coliform and Escherichia coli (E. coli) has decreased from 74.29 to 45.31 MPN/mL, from 66.77 to 45.21 MPN/mL, and from 27.93 to 19.53 MPN/mL respectively, due to the COVID-19 lockdown. Principle component analysis (PCA) showed that 67% and 76.2% of the total variances were extracted from three and four principal components, respectively, in pre-and post-lockdown periods. The hazard index indicated that the number of samples possessing non-carcinogenic risk (HI > 1) has reduced from 93% to 87%, from 87% to 80% and from 80% to 73%, respectively, for children, female and male categories due to the lockdown effect. This shows children are more prone to non-carcinogenic risk than female and male. Though the COVID-19 pandemic has improved the groundwater quality, this is not the solution to improve the quality of groundwater as it has impacted millions across the world and has brought the economy to a grinding halt. However, the results will be useful for devising the remediation strategies to reduce the multi-metal contaminations in groundwater, and also the epidemiological methods to prevent the human health risks. Further, the outcome of this study insists the responsibilities of industrial, municipal and agricultural sectors to keep the environment pollution-free and to ensure the supply of potable water to the people.

Author contributions statement

P. Aravinthasamy: Writing-original draft, data curation, methodology, resources, writing-original draft and software. D. Karunanidhi: Writing-original draft, conceptualization, investigation, writing-review and editing, and supervision. K. Shankar: Software, Data curation, formal analysis. T. Subramani: writing-review and editing, methodology, and formal analysis. Raj Setia: Software, Writing-review and editing. Prosun Bhattacharya: Writing-review and editing. Sayani Das: Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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