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# Effects of COVID-19 pandemic lockdown on microbial and metals contaminations in a part of Thirumanimuthar River, South India: A comparative health hazard perspective

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ABSTRACT

Twenty-two water samples from the Thirumanimuthar River course in southern India were collected before COVID-19 lockdown and during COVID-19 lockdown periods and were analyzed for microbiological parameters (*fecal coliform bacteria, total coliform bacteria, Escherichia coli, and fecal streptococci)* and heavy metals (Fe, Mn, Zn, Cu, Cd, Ni, Pb and Cr). The lockdown has decreased microbial populations and heavy metals. Fe, Cu, Cd, Ni, Pb and Cr exceeded the drinking water limits, respectively, in 77%, 45%, 27%, 18%, 9% and 91% of the pre-lockdown samples. During the lockdown period, Fe, Cu and Cd concentrations in 23% and Cr in 50% of the samples exceeded the limits. Heavy Metal Pollution Index (PI) expressed that 27%, 64% and 9% of the pre-lockdown samples represented 'low', 'medium' and 'high' pollution categories, respectively, but 68% and 32% of the lockdown period samples represented 'low' and 'medium' categories, respectively. The Metal Index (MI) exposed that all samples of pre-lockdown were under the seriously affected category, whereas 54% and 46% of lockdown samples were under strongly and seriously affected categories, respectively. Health risk evaluation predicted that 95%, 91% and 86% of pre-lockdown samples and 45%, 36% and 33% of lockdown period samples were at risk among children, teenagers and adults, respectively. As there is no integrated study on river water quality of COVID-19 lockdown this work is uniquely carried out by combining heavy metal pollution, microbial contamination and human health risk evaluation.

## 1. Introduction

The rivers are the foremost sources of water for domestic and irrigation purposes but the misuse of rivers and their susceptibility to contamination has affected the loss of their natural environments throughout the globe (Kumar et al., 2019). The loss of natural conditions of a river is mainly due to intricate anthropogenic aspects such as urban growth and development, agronomic and industrial actions (Karunanidhi et al., 2020; Ogwueleka, 2015), constructions of the dams (Wang et al., 2014), and natural activities like climatic circumstances, weathering processes, etc. (Arya et al., 2019; Yegemova et al., 2018; Subramani et al., 2013). Metal contamination in river water is a worldwide environmental issue (Tiwari et al., 2015; Ali and Khan, 2018). Few earlier studies have shown heavy metal contamination in surface water bodies in various parts of the world (Rahman et al., 2020; Cengiz et al., 2017; Saha and Paul, 2018; Liao et al., 2017; Jahan and Strezov, 2017; Sridhar et al., 2017). Aquatic contamination by heavy metals is a vital challenge because of their hazardous effects and accretion in aquatic environments (Tscheikner-Gratl et al., 2019). The toxicity of heavy metals in water is associated with human health (Li et al., 2014). Many studies have characterized the heavy metals contamination in drinking water (Wagh et al., 2018; Prasanna et al., 2012; Edet and Offiong, 2002).

The unusual and sudden lockdown due to the spread of COVID-19 has created huge impact on water quality in different parts of the world. Kundu (2020) has reported that water pollution was minimized in the many countries such as Malaysia, Indonesia, Thailand, Bangladesh and Maldives due to COVID-19 lockdown. Cripps (2020) has stated that prohibition for public gatherings and restriction for tourism have played vital roles in reduction of pollution levels. In India,

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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 throughout the country in four phases from 24th March to 31st May 2020, and industries were allowed to open from 1st June 2020. In addition to this, colleges, schools, malls, public transports, markets, and hotels were closed during the lockdown period. Many researchers have analyzed the gaseous pollutants in the atmosphere before and after the COVID-19 lockdown periods (Manikanda Bharath et al., 2020; Mahato et al., 2020; Selvam et al., 2020a,b). Our literature review shows a very few studies have been done on the assessment of contamination of heavy metals and microbiological population in rivers of India during the COVID-19 pandemic lockdown.

Chakraborty et al. (2021) have assessed the impact of COVID-19

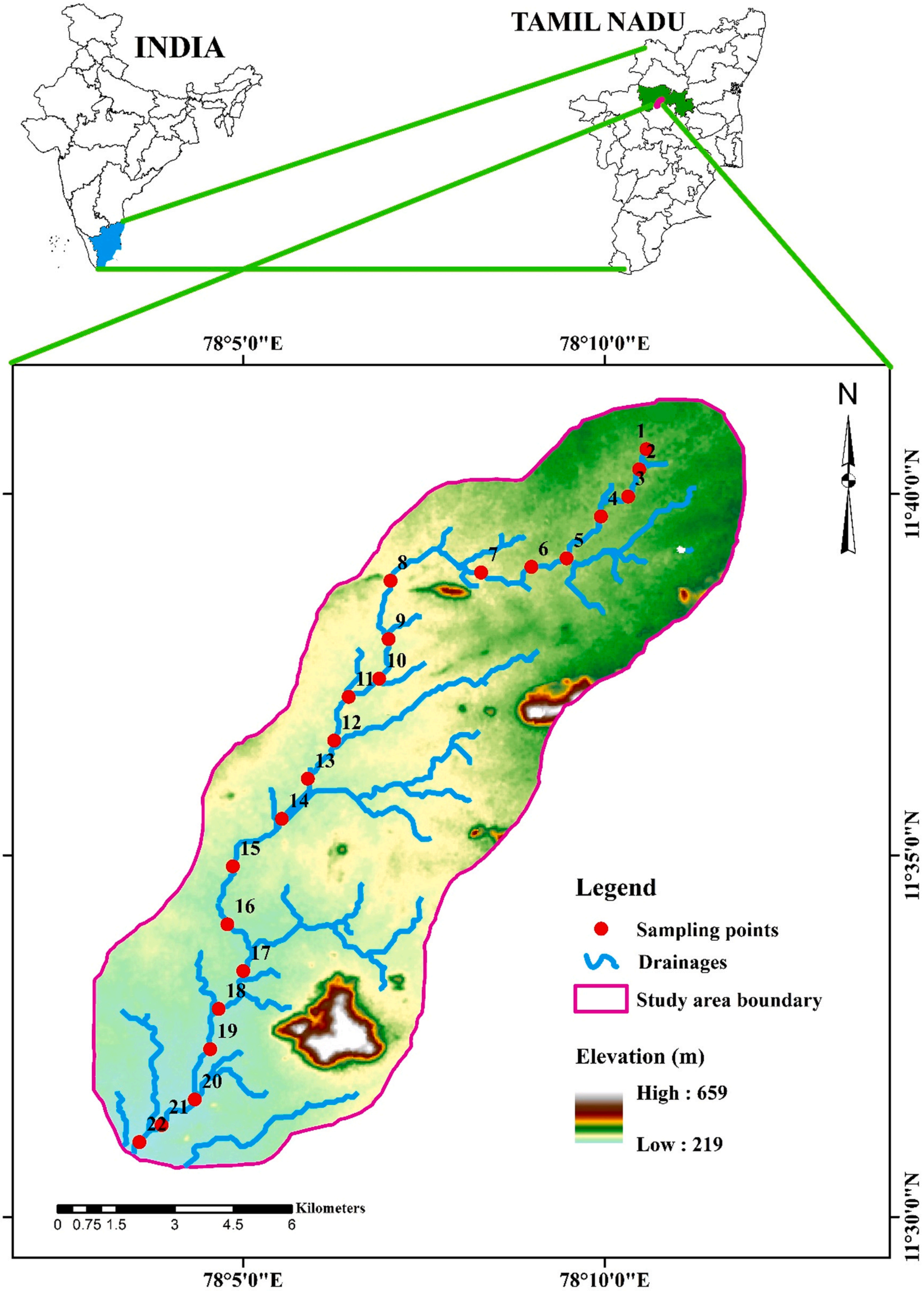

**Fig. 1.** Study area and sampling locations in the Thirumanimuthar River course.

lockdown on water quality in the Damodar River, India by computing Water Pollution Index (WPI) and reported that WPI of the pre-lockdown period was high, and WPI was moderate to good during lockdown. Dutta et al. (2020) have studied the quality of Ganga River water by assessing dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, *faecal coliform* and *total coliform*. They have observed increasing trend of DO and decreasing trend of BOD, nitrate, *faecal coliform* and *total coliform* during the lockdown period. Based on this assessment they concluded that significant improvement of water quality had occurred due to the lockdown leading the water fit for drinking (Class A) in the upper segments and for outdoor bathing (Class B) in the middle and lower segments. Mukherjee et al. (2020) have also observed the sudden dropdown in the coliform bacterial load in the river Ganges due to lockdown. Shukla et al. (2021) have also pointed out that around 50% of dissolved heavy metal concentrations were decreased in the River Ganga in a few months of lockdown due to reduction in industrial waste water discharge. Similar results were got in the other rivers such as Beas, Svarnarekha, Chambal, and Sutlej (DTE, 2020). Aman et al. (2020) have identified the decreased turbidity levels based on suspended particulate matter (SPM) in the Sabarmati River using remote sensing techniques. Arif et al. (2020) have observed the reduction of BOD and COD in the Yamuna River during the lockdown period. However, Khan et al. (2021) have reported that there is no significant improvement in the water quality of Gomti River based on DO and BOD levels due to the stoppage of sewage treatment plants and disposal of untreated sewage during the lockdown.

Though there are some recent studies in which the effect of COVID-19 lockdown on water quality and heavy metals have been reported (Chakraborty et al., 2021, Bar, 2020; Patel et al., 2020; Yunus et al., 2020; Selvam et al., 2020b), no study with simultaneous microbiological and inorganic pollutant load (heavy metals) coupled with human health risk evaluation was attempted. Comparative study of COVID-19 lockdown effects on water quality in various parts of the India are summarized in Table S1. Particularly in the state of Tamil Nadu, no such integrated studies to assess the overall river water quality and the associated health risks were conducted. Therefore, we studied the microbiological and heavy metals contamination levels in a part of Thirumanimuthar River (South India) by analyzing the samples collected before and during the lockdown periods. Heavy Metal Pollution Index (HPI) and Metal Index (MI) were computed for eight metals to assess the status of contamination. Further, human health risks were also evaluated based on the heavy metals concentration in water for three age categories such as children, teenagers and adults, and multivariate statistical techniques were used to identify the probable sources of heavy metals in the study region.

## 2. Material and methods

### 2.1. Study area

The study region is situated in between 11° 31′ 0″ N to 11° 41′ 0″ E latitudes and 78° 03′ 0″ E to 78° 12′0″ E longitudes (Fig. 1). The Thirumanimuthar River origins from Manjavadi Kanuvai in the shevaroy hills and runs through Salem city before reaching the Cauvery River. Geologically the study region is covered by charnockite and hornblende biotite gneiss rocks. The study area has tropical climatic conditions with temperature varies from 19.2 to 30.2 °C, and the annual rainfall varies from 800 to 1600 mm. The major soil types are red, black and brown soils. The major crops are sugarcane, paddy, maize, banana, cotton, coconut and vegetables. The aquifer transmissivity(T) varies from 1 to 265 $m^2$/day, storativity (S) varies from $9.6 \times 10^{-5}$ to $4.3 \times 10^{-2}$, and the specific yield (sy) is in the range of 0.05. Geomorphologically, the area is comprised of several hillocks, valleys, flood plains, alluvial fans, bajadas and pediments. The land use and land cover categories include fallow land (30.1% of the total area), settlement (25.6%), agricultural land (20.4%), industrial area (11.8%), hills (11%), and water bodies (1.1%). As per the land use pattern agricultural area has occupied more than 20% of the total area. Hence agricultural runoff is an important nonpoint source in the study region. The major industries of the study region are Sago units, bleaching units, textile and dyeing units. Eight sewage treatment plants with 98 minimal liquid discharge (MLD) capacity resituated in the Thirumanimuthar River course (Tamil Nadu Pollution Control Board (TNPCB, 2019)). These plants discharge the treated wastes into the river. Therefore, leachate from municipal solid wastes, domestic wastewater, industrial effluents and agricultural runoff enter into Thirumanimuthar River.

### 2.2. Sample collection

River water samples ($N = 22$) were collected from the Thirumanimuthar River coarse before the COVID-19 lockdown (15th and16th February 2020) and during the COVID-19 lockdown (28th and 29th May 2020). The pre-lockdown samples represent post-monsoon (winter) season, and the lockdown period samples represent pre-monsoon (summer) season. In a regular interval river water samples were collected from geotagged sampling locations (Fig. 1) at middle of the major flow from a depth of 0–5 cm. There was no rain during the collection of samples because the study area receives majority of rainfall during monsoon season, which is from June to December. The collected water samples were stored in 1000 ml pre-cleaned Teflon bottles. One portion of the sample was acidified with concentrated nitric acid below pH 2.0 to minimize absorption and precipitation of metals. Another portion of the water sample was not acidified. The water samples were examined for Cr, Pb, Mn, Fe and Ni using Atomic Absorption Spectrophotometer (AAS) (PerkinElmer Analyst 700). The AAS is one of the significant technique for measuring amounts of chemical elements in water samples by the calculation of absorbed radiation through the presence of chemical of interest. The standards used for all the metals were 0.01, 0.02, 0.05, 0.1, 0.2 and 0.5 mg $L^{-1}$. The standards were run after every three samples for precision and accuracy.

In addition to it, the water samples were also analyzed for *fecal coliform bacteria, fecal streptococci, Escherichia coli (E. coli*), and *total coliform bacteria* using Most Probable Number (MPN) method. The MPN technique was used to evaluate the presence among the most relevant number of coliforms of the lactose fermenter with gas-producing in a pipette of 100 ml water.

### 2.3. Statistical analysis

Relationships among the metals were evaluated based on Pearson correlation matrix using SPSS package (v. 20). Cluster analysis was performed using the PAST (v.3.21) package. The spatial variations of HPI was studied using the Inverse Distance Weightage (IDW) technique in ArcGIS (v.10.2.1) (Karunanidhi et al., 2020a; Shankar and Kawo, 2019).

### 2.4. Computation of Heavy Metal Pollution Index (HPI)

The assessment of heavy metal contamination is important for evaluating their impact on human health (Ahmed et al., 2015). Heavy Metal Pollution Index (HPI) is used to study the combined effect of the heavy metals for complete water quality evaluation (Rezaei et al., 2017), and is calculated using the following steps:

(1) Weightage calculation ($W_i$) of every parameter is done using Eq. (1).

$$W_i \propto \; = \frac{1}{MAC} \quad \rightarrow W_i = \quad \frac{k}{MAC} \tag{1}$$

where $k$ indicates proportionality constant and MAC is Maximum Admissible Concentration according to the Bureau of Indian

Standards (Bureau of Indian Standards, 2012).

(2) Computation of quality rating of every parameter is done using Eq. (2)

$$Q_i = \sum_{i=1}^{n} \frac{M_i - \quad l_i}{S_i - \quad l_i} x100 \tag{2}$$

where '$M_i$' indicates an observed concentration of the metal $i_{th}$ in the surface water sample, '$l_i$' indicates the ideal value of the $i_{th}$ parameter and '$S_i$' is stated as the standard value. Both '$l_i$' and '$S_i$' were obtained from BIS Bureau of Indian Standards (2012).

(3) Calculation of HPI is done using the following equation:

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{3}$$

where, '$W_i$' indicates the weight of the unit for the $i_{th}$ parameter, and '$n$' is the number of parameters. The critical value of HPI is100. If it is more than 100 it affects human health (Prasad and Kumari, 2008).

### 2.5. Computation of Metal Index (MI)

Metal Index (MI) is used for assessing the effect of the metals on drinking water quality (Bakan et al., 2010). Caerio et al. (2005) proposed the term MI, and it is computed using the following equation:

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i} \tag{4}$$

where, $C$ = concentration of metals in mg $L^{-1}$, MAC = metals maximum allowable limit in water and $i = i_{th}$ sample.

### 2.6. Computation of health hazards from heavy metals

Human exposure to heavy metals occurs through various pathways like ingestion, dermal, and inhalation. Ingestion risks occur through direct intake of water, dermal risks occur through skin absorption and inhalation through the nose and mouth (Karunanidhi et al., 2020b; Mukherjee et al., 2019). Ingestion is an important pathway for the intake of water. According to USEPA (2011), pollutant dose ingested in humans is computed using chronic daily intake (CDI), which means the dose of pollutants per kilogram per day absorbed through the ingestion pathway (USEPA, 2011). The (CDI) is computed based on Eq. (5).

$$\mathrm{CDI} = [C_i \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}]/[\mathrm{BW} \times \mathrm{AT}] \tag{5}$$

where $C_i$ = heavy metal concentration in surface water (mg $L^{-1}$), IR= Ingestion rate (0.70 L/day for Children, and 2 L for teens and adults), EF = Exposure frequency expressed in days/year (365 days for children, teens, and adults), ED = Exposure duration (6, 19 and 30 years, respectively, for children, teens and adults), BW = Bodyweight (15, 50 and 70 kg for children, teens, and adults, respectively), AT = exposure time (2190 days for children, 6935 for teens, and 10,950 days for adults).

Hazard quotient (HQ) was calculated from CDI and RfD as per equation (6).

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}} \tag{6}$$

where, RfD is reference dose (0.7, 0.024, 0.02, 0.003 and 0.0014 for Fe, Mn, Ni, Cr and Pb, respectively).

Finally, the hazard quotient (HQ) of each heavy metal was summed up to calculate the Hazard Index (HI) using the following equation:

$$\mathrm{HI}_{\mathrm{total}} = \sum_{j=1}^{n} \mathrm{HI}_i \tag{7}$$

where, $\mathrm{HI}_i$ is the hazard index for non-carcinogenic contaminants, and $\mathrm{HI}_{\mathrm{total}}$ is the overall non-carcinogenic hazard. HQ value > 1 indicates severe risk for human health, whereas HQ value < 1 indicates less risk for humans (Karunanidhi et al., 2020c).

## 3. Results and discussion

### 3.1. Microbiological parameters

The descriptive statistics of microbiological parameters and heavy metals concentration in river water before and during the COVID-19 lockdown periods is given in Table 1. The *E. coli* population varied from 10 to 110 MPN mL/L and 0–58 MPN mL/L in the pre-lockdown and lockdown period samples, respectively. The average population of *fecal coliform* was 120 and 39 MPN mL/L in the pre-lockdown and lockdown period samples, respectively. The major sources for these bacterial populations in surface water are human and animal wastes. *The total coliform* bacterial population varied from 35 to 310 MPN mL/L in the pre-lockdown samples, and 12–225 MPN mL/L in the lockdown period samples. *Fecal streptococci* were less (Est < 10) in all the samples of pre-lockdown and lockdown period samples.

The abrupt fall in microbial load (*E. coli* and *fecal Streptococci*) may be due to non-functioning of various small scale and large scale industrial units, closure of hotels, restaurants, community halls, malls, food stalls, schools and colleges, stoppage of tourism/floating population, traffic movements and business activities together with reduced waste disposal, and absence of bathing activities in the river (Mukherjee et al., 2020, Yunus et al., 2020, Selvam et al., 2020b; Khan et al., 2021). After the announcement of lockdown, the migrant workers and the students stayed in hostels left the Salem city immediately. Since the lockdown period falls in the summer season the increased temperature might have reduced the microbial concentration in the river water (Ferreira and Chauvet, 2011). Further, usage of more alcoholic disinfectants and sanitizers for hand washing, dish washing, cloth washing and bathing by the inhabitants as per the direction the government to control COVID-19 spread might have reduced the microbes in the waste water.

Dutta et al. (2020) and Mukherjee et al. (2020) have reported that shutdown of industries and commercial activities, non-appearance of bathing, and banning of religious activities during COVID-19 lockdown have drastically decreased BOD, *faecal coliform* and *total coliform* population in the Ganga River (India). In the Godavari and Krishna Rivers (India) decreased biological parameters were reported by the Maharashtra Pollution Control Board (2021) during the COVID-19 lockdown period. Particularly in the Krishna River, about 40% decrease in *fecal coliforms* was reported by MPCB. The enhancement of the river water quality in Rishikesh and Haridwar was observed by Singhal and Matto (2020) due to immediate drop of the visitors and 50% decrease of industrial and sewage waste disposal.

### 3.2. Comparison of heavy metals in pre-COVID-19 lockdown and COVID-19 lockdown samples

To know the effects of COVID-19 lockdown on river water quality, it is essential to compare the status of heavy metal pollution in pre-lockdown and lockdown period samples. Our literature studies indicate that heavy and trace metals in water system have been decreased due to COVID-19 pandemic lockdown. Selvam et al. (2020b) have reported that heavy metal pollution is reduced in the groundwater of coastal industrial city of Tuticorin, South India due to the lockdown. Chakraborty et al. (2021) and Shukla et al. (2021) have observed the decreased heavy metal contaminations in Damodar and Ganga Rivers, respectively. The important reason for the reduction of heavy metals

**Table 1**

Descriptive statistics of microbiological parameters and heavy metals in the Thirumanimuthar River water before and after COVID-19 lockdown.

| Parameters | Before COVID-19 lockdown | | | | | | | During COVID-19 lockdown | | | | | | BIS 2012 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Units | Min | Max | Mean | SE | TNES | % of TNES | Min | Max | Mean | SE | TNES | % of TNES | Desirable limit | Not permissible |
| Fe | Mg $L^{-1}$ | 0.048 | 1.329 | 0.480 | 1–5, 7–9, 11–14, 17–20, 22 | 17 | 77% | 0.048 | 0.900 | 0.282 | 3, 9, 11, 12, 17, | 5 | 23% | <0.3 | >0.3 |
| Mn | | 0.039 | 0.121 | 0.072 | all safe | – | – | 0.030 | 0.089 | 0.059 | all safe | – | – | <0.1 | >0.3 |
| Zn | | 0.039 | 0.161 | 0.082 | all safe | – | – | 0.018 | 0.110 | 0.057 | all safe | – | – | <5 | >5 |
| Cu | | 0.010 | 0.128 | 0.049 | 6, 8, 10, 12, 14, 17–20, 22 | 10 | 45% | 0.007 | 0.080 | 0.039 | (5, 6, 13, 20, 22) | 5 | 23% | <0.05 | >0.05 |
| Cd | | 0.001 | 0.004 | 0.002 | 1, 4, 6, 12, 17, 21 | 6 | 27% | 0.001 | 0.003 | 0.002 | 4, 12, 14, 17, 19 | 5 | 23% | <0.003 | >0.003 |
| Ni | | 0.002 | 0.027 | 0.013 | 3, 6, 14, 19 | 4 | 18% | 0.001 | 0.018 | 0.012 | all safe | – | – | <0.02 | >0.02 |
| Pb | | 0.001 | 0.014 | 0.006 | 8, 17 | 2 | 9% | 0.001 | 0.009 | 0.005 | all safe | – | – | <0.01 | >0.01 |
| Cr | | 0.032 | 0.951 | 0.327 | 1–12, 14–17, 19–22 | 20 | 91% | 0.022 | 0.501 | 0.108 | 1, 5–8, 10, 11, 12, 16, 19, 22 | 11 | 50% | <0.05 | >0.05 |
| *Total coliform bacteria* | MPN/ L/L | 35 | 310 | 207 | – | – | – | 12 | 225 | 124 | – | – | – | – | – |
| *Faecal coliform bacteria* | | 23 | 161 | 120 | – | – | – | 10 | 99 | 39 | – | – | – | – | – |
| *Escherichia coli* | | 10 | 110 | 58 | – | – | – | 0 | 58 | 29 | – | – | – | – | – |
| *Faecal streptococci* | CFU/ mL/ L | 0 | Est < 10 | Est < 10 | – | – | – | 0 | Est < 10 | Est < 10 | – | – | – | – | – |

SE-samples exceed the limit, TNES-total number of samples exceed the limit

contamination in surface water system is due to the non-functioning of various small- and large-scale industries.

Iron (Fe) is one of the most predominant elements in the earth's crust (Rahman et al., 2020). The Fe concentration in river water varied from 0.048 to 1.33 mg $L^{-1}$ before lockdown and 0.039–0.161 mg $L^{-1}$ during the lockdown. It was found that 77% ($n = 17$) of the samples of pre-lockdown surpassed the permissible limit of Fe for drinking needs (0.3 mg $L^{-1}$), whereas 23% ($n = 5$) of the lockdown period samples surpassed the permissible limit. A significant decrease in Fe concentration in water samples of COVID-19 lockdown period may be due to the closure of metal industries from which the effluents are discharged into the river (Shukla et al., 2021). A higher concentration of Fe causes gastrointestinal irritation and also affects the taste of water due to the development of iron bacteria (Rezaei et al., 2017).

The manganese (Mn) rich water is mainly attributed to anthropogenic actions close to water sources. Typically, Mn occurs with Fe, and it is used as bleaching, oxidant for cleaning, fumigation process and steel alloys and iron production (Bureau of Indian Standards, 2012). Industrial pollution and human activities are the important reasons for the high amount of Mn in water (Tadiboyina and Ptsrk, 2016). In the study area, the concentration of Mn varied from 0.039 to 0.121 mg $L^{-1}$ before lockdown and 0.03–0.089 mg $L^{-1}$ during the COVID-19 lockdown. According to the permissible limit of Mn in drinking water (0.3 mg $L^{-1}$), all the surface water samples were safe for drinking purposes. A decrease in Mn concentration during COVID-19 lockdown may be due to the stoppage of discharge of wastes from industries.

The concentration of Zn in the Thirumanimuthar River water varied from 0.039 to 0.161 mg $L^{-1}$ before COVID-19, but it varied from 0.018 to 0.11 mg $L^{-1}$ during the lockdown. The concentration of Zn in the river water must not surpass the permissible limit for drinking applications (5 mg $L^{-1}$) as per the Bureau of Indian Standards (2012). Zn is mainly released from fuel and coal combustion, iron and steel production, and electroplating industries. Moreover, Zn is the significant component of rubbers, paints, brass, die-casting metals, bronze, and other alloys (USEPA, 1980).

Copper (Cu) concentration in the river water ranged from 0.01 to 0.128 mg $L^{-1}$ before lockdown and 0.007–0.08 mg $L^{-1}$ during the lockdown. Before lockdown, 45% of the samples surpassed the permissible limit of Cu (0.05 mg $L^{-1}$) for drinking uses. The lockdown resulted in a 22% decrease in the number of samples exceeding the permissible limit. Copper is an important substance to human well-being (Muhammad et al., 2014). In this study, ten samples (6, 8, 10, 12, 14, 17–20 and 22) of pre-COVID-19 lockdown exceeded the permissible limit of Cu. However, during the lockdown period, only five samples (5, 6, 13, 20 and 22) were greater than the limits (23%).

Before the COVID-19 lockdown, the concentration of cadmium (Cd) in river water ranged from 0.001 to 0.004 mg $L^{-1}$, and during the lockdown, it ranged from 0.0009 to 0.0032 mg $L^{-1}$. The Cd concentration in water samples exceeded the recommended limit (0.003 mg $L^{-1}$) in 27% of the pre-lockdown samples ($n = 6$), and in 23% of the lockdown period samples ($n = 5$) (Table 1). Cadmium is mainly released in the environment from pesticide use (Muhammad et al., 2014) but other sources like fuel combustion, tyre wear, and batteries also contribute Cd to water (David et al., 2013). Naturally, due to the industrial activities, cadmium arrives at the soil and easily pollutes the surface water and groundwater via runoff and infiltration after precipitation.

The nickel (Ni) concentration varied from 0.002 to 0.029 mg $L^{-1}$ before lockdown and 0.001–0.018 mg $L^{-1}$ during the lockdown. Before COVID-19 lockdown, only four surface water samples (18%) exceeded the recommended limit (0.02 mg $L^{-1}$), but all the samples were within the permissible limit during the lockdown. The major sources of Ni in water are agricultural forms, and discharge of domestic water from urban areas. The Ni concentration in water higher than the permissible limit causes nasal and lung cancers. It can also cause bodyweight loss, liver damage, and heart issues (USEPA, 1995).

The lead (Pb) concentration was between 0.001 and 0.014 mg $L^{-1}$

before lockdown, and between 0.007 and 0.08 mg $L^{-1}$ during the lockdown period. In this study, only two samples of pre-lockdown were above the permissible limit (0.01 mg $L^{-1}$), but all the samples were within the permissible limit during the COVID-19 period. A higher concentration of Pb in surface water was due to the discharge of wastes from industries and sewage disposal. Boateng et al. (2019) suggested that the source of Pb mainly originates from house sewers, paints, old plumbing, animal and human excretion, disposal of lead batteries, and agricultural runoff including phosphate fertilizers. Raised Pb levels in the human body will cause central nerve death and brain damage (Punitha and Selvarajan, 2018). Other health issues such as hearing loss, high blood pressure, kidney problems and muscle and joint pains will also happen (Sekar and Suriyakala, 2016).

Before lockdown, the average chromium (Cr) concentration in the Thirumanimuthar River samples was 0.327 mg $L^{-1}$, but it is reduced to 0.108 mg $L^{-1}$ during the lockdown. Before lockdown, 91% of the samples ($n = 20$) exceeded the permissible limit (0.05 mg $L^{-1}$), but about 50% of the samples ($n = 11$) crossed the permissible limit during the lockdown. The major sources of Cr in water are effluents discharged from tanning, refractory, pigment production, and electroplating industries (Danil de Namor et al., 2012). The intake of water with a higher amount of Cr affects the skin, kidneys, lungs and liver (Patel et al., 2017).

### 3.3. Relationships among heavy metals

A negative correlation was observed among Mn, Cd, Pb and Cr in the water samples collected before COVID-19 lockdown, but Pb had a significant positive correlation with Mn, Zn, Cd, Ni and Cr in the lockdown period samples. A significant positive correlation between Zn and Ni and Pb and Cd indicate that major sources of heavy metals in water are due to industrial activities (Fig. 2a, b). In the water samples collected during COVID-19 lockdown, Cu, Ni, and Pb had positive correlation with each other, and Ni strongly correlated with Cu and Fe. A significant positive correlation among these metals indicates that sources are from the same origin (Cengiz et al., 2017). Anthropogenic influences such as agricultural practices and the discharge of wastes from industries into the river are the major reasons for metal pollution in this river.

### 3.4. Heavy Metal Pollution Index (HPI)

HPI is categorized into three types (Kwaya et al., 2019) such as low (<90), medium (90−150), and high (>150). Many studies have assessed the quality of river water using HPI index such as Manoj et al. (2012) for Subarnarekha River in India, Abdullah (2013) for Diyala River in Iraq, Sheykhi and Moore (2012) for Kor River in Iran, and Setia et al. (2020) for Sutlej River in India. In the Thirumanimuthar River, HPI values varied from 54 to188 before lockdown and 47–137 during the COVID-19 lockdown period. Before lockdown, six samples were classified under the low category, 14 under the medium category, and 2 under the high category. During COVID-19 lockdown, 15 samples were under the low (safe) category and 7 were under the medium category. This improvement in water quality was mainly due to the closure of all the industries during the lockdown. The spatial distribution of various HPI categories in the Thirumanimuthar River course is displayed in Fig. 3a and 3b, respectively, for pre- and lockdown periods.

### 3.5. Metal Index (MI)

The MI values in the Thirumanimuthar River samples varied from 6 to 25 before lockdown and 4–16 during lockdown (Table 2). Rezaei et al., (2017) classified the water based on MI values into six categories: very pure (<0.3), pure (0.3–1.0), slightly affected (1.0–2.0), moderately affected (2.0–4.0), strongly affected (4.0–6.0) and seriously affected (>6.0). According to this classification, all the samples of pre-lockdown were categorized under ’seriously affected’. During the lockdown, 54% of the samples were classified under ’strongly affected’ and 46% of the samples were under ’seriously affected’.

### 3.6. Hierarchical cluster analysis (HCA)

Cluster analysis is broadly used to group and categorize the water quality parameters (Kazakis et al., 2017). In this analysis, Euclidean distance is chosen to combine the parameters with respect to the degree of similarity. It will be delivered by tree diagram showing distance, connection and differences among the groups. This diagram shows an extreme uniformity among the clusters and great diversity between the groups (Fatoba et al., 2017). Various researchers have conducted cluster analysis in different regions for water quality studies (Panda et al., 2020; Aravinthasamy et al., 2019; Isa et al., 2017; Muhammad et al., 2016).

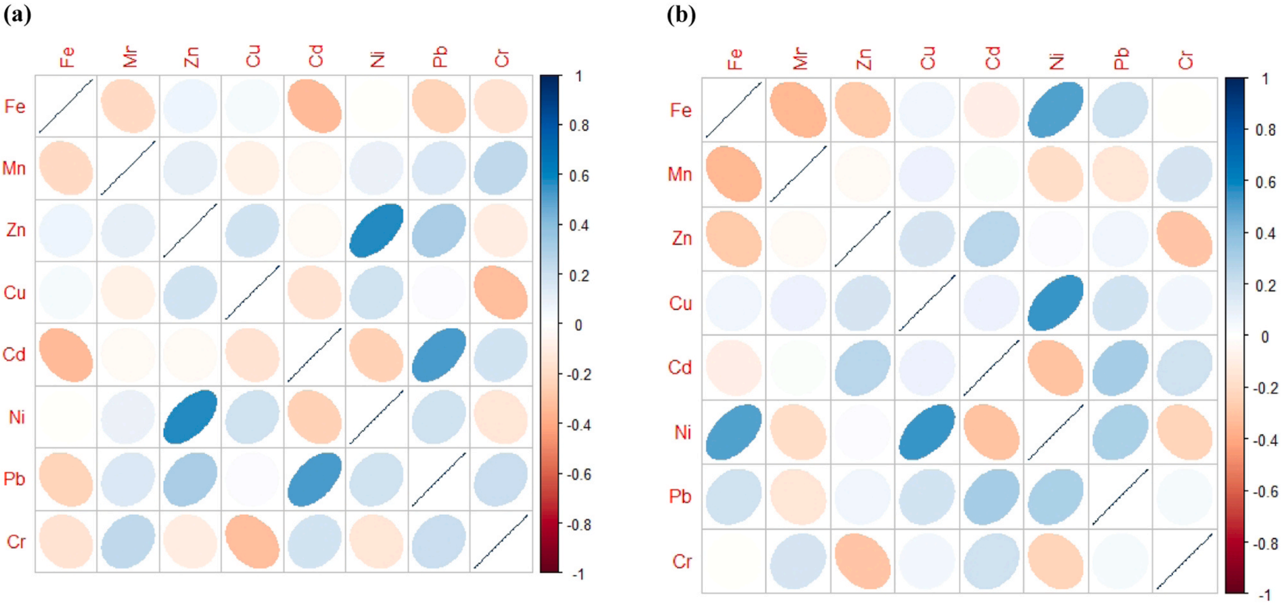

Fig. 2. Pearson correlation analysis among heavy metals in the Thirumanimuthar River water (a) before COVID-19 lockdown, (b) during COVID-19 lockdown.

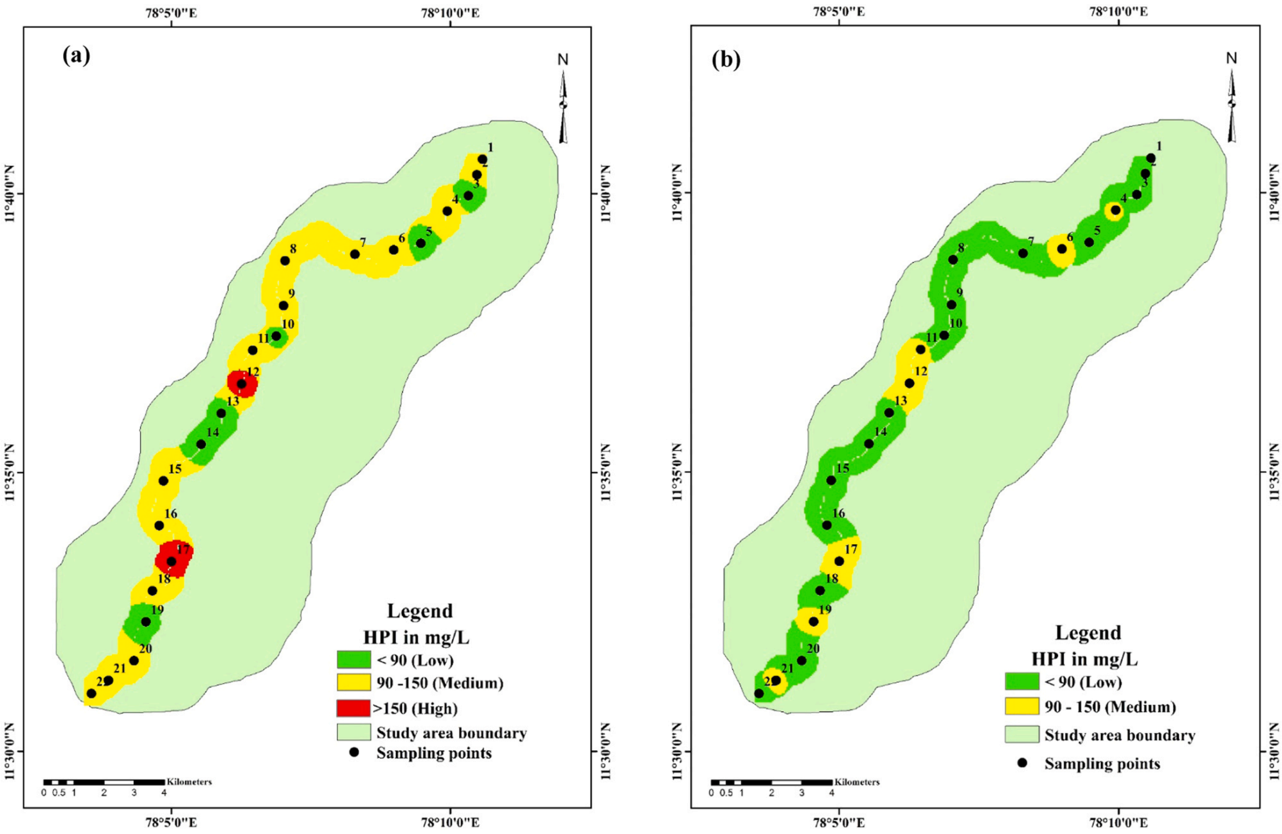

**Fig. 3.** Spatial distribution of Heavy metal Pollution Index (HPI) in the Thirumanimuthar River course (a) before COVID-19 lockdown, (b) During COVID-19 lockdown.

**Table 2**
Heavy metal Pollution Index (HPI) and Metal Index (MI) of water samples collected from the Thirumanimuthar River before and during COVID-19 lockdown.

| Sample stations | Before COVID-19 | During COVID-19 | Before COVID-19 | During COVID-19 |
|---|---|---|---|---|
| | HPI | | MI | |
| TM1 | 109 | 80 | 8 | 5 |
| TM2 | 98 | 68 | 10 | 5 |
| TM3 | 63 | 57 | 8 | 5 |
| TM4 | 128 | 96 | 8 | 6 |
| TM5 | 63 | 79 | 10 | 6 |
| TM6 | 127 | 100 | 7 | 11 |
| TM7 | 131 | 71 | 21 | 8 |
| TM8 | 148 | 65 | 19 | 7 |
| TM9 | 135 | 66 | 22 | 5 |
| TM10 | 78 | 47 | 8 | 5 |
| TM11 | 99 | 97 | 15 | 9 |
| TM12 | 186 | 137 | 25 | 16 |
| TM13 | 54 | 79 | 7 | 7 |
| TM14 | 78 | 83 | 12 | 6 |
| TM15 | 101 | 85 | 13 | 5 |
| TM16 | 141 | 75 | 21 | 9 |
| TM17 | 188 | 109 | 21 | 7 |
| TM18 | 90 | 76 | 6 | 4 |
| TM19 | 71 | 100 | 8 | 7 |
| TM20 | 90 | 53 | 12 | 6 |
| TM21 | 130 | 98 | 9 | 5 |
| TM22 | 90 | 83 | 10 | 8 |
| **Min** | **54** | **47** | **6** | **4** |
| **Max** | **188** | **137** | **25** | **16** |
| **Mean** | **109** | **82** | **13** | **7** |

Before the COVID-19 lockdown, there were four clusters of heavy metals. Zn, Ni, Cu, and Pb contributed towards Cluster 1, whereas Cluster 2 was formed by Cr and Cd. Cluster 3 and Cluster 4 were contributed by Mn and Fe (Fig. 4a, b). The major cluster was contributed by Fe, Cu before COVID-19 lockdown. The major four clusters of pre-lockdown samples suggest that the heavy metal contamination was from the industries. During COVID-19 lockdown, all the samples fall in the sub-clusters indicating the contamination of surface water with heavy metals was decreased in this river. The cluster analysis of microbial parameters indicated one major cluster and two sub clusters in the pre-lockdown samples. *E. coli* and *fecal Streptococci* have clustered in cluster-3 and *total coliform* and *fecal coliform* fall in cluster-1 and cluster-2 (Fig. 5a). During the COVID-19 lockdown period (Fig. 5b) three clusters have decreased. This is due to shutdown of different small and large industrial sectors, closure of hotels, and restricted traffic movements and business activities. Seasonal variation also played role for the declination of microbial parameters in the river.

### 3.7. *Expected health hazards in human beings*

River water is directly used by the inhabitants for drinking and domestic purposes without any pretreatment at many places in the study region. People are directly bathing in the river and domestic animals such as cow, bull, buffalo, goat and sheep are allowed to drink the water in river directly. The irrigation of crop with river water may affect water–soil–plant continuum and the heavy metals may enter into human body via food chain also.

Although some recent studies were conducted to assess the impact of COVID-19 lockdown on water quality by examining the concentrations of major ions, heavy metals, DO, BOD, COD and microbes (Yunus et al., 2020; Mukhrrjee el al., 2020; Dutta et al., 2020; Aman et al., 2020; Selvam et al., 2020b; Chakraborty et al., 2021; Khan et al., 2021; Shukla

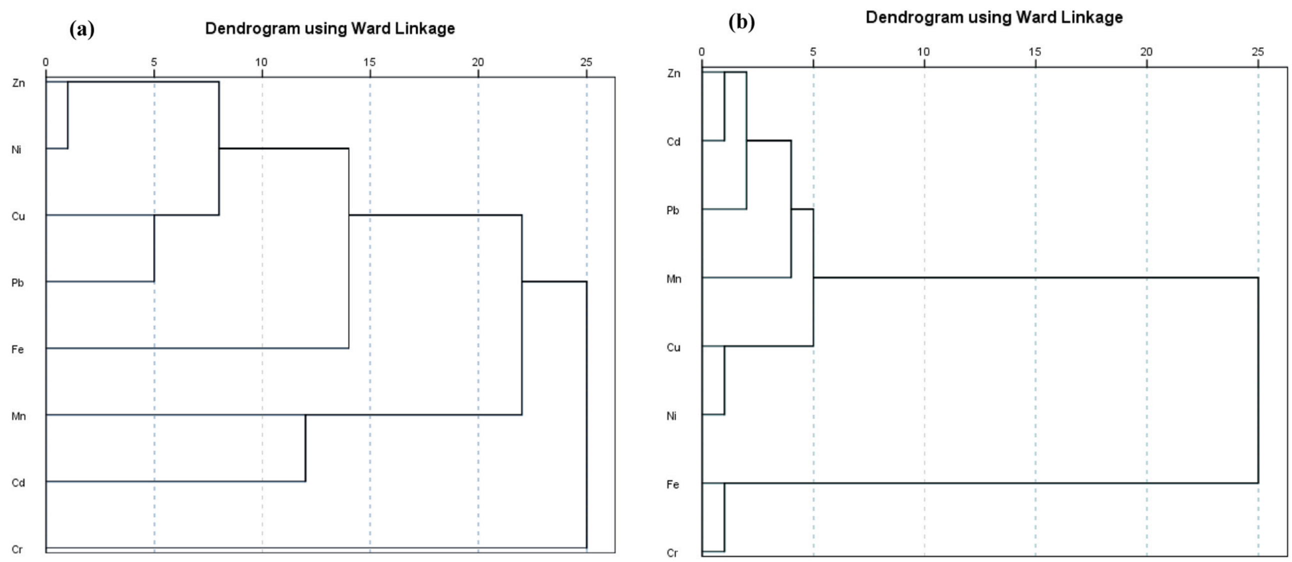

**Fig. 4.** Cluster analysis for the heavy metals in the Thirumanimuthar River water (a) before COVID-19 lockdown, (b) during COVID-19 lockdown.

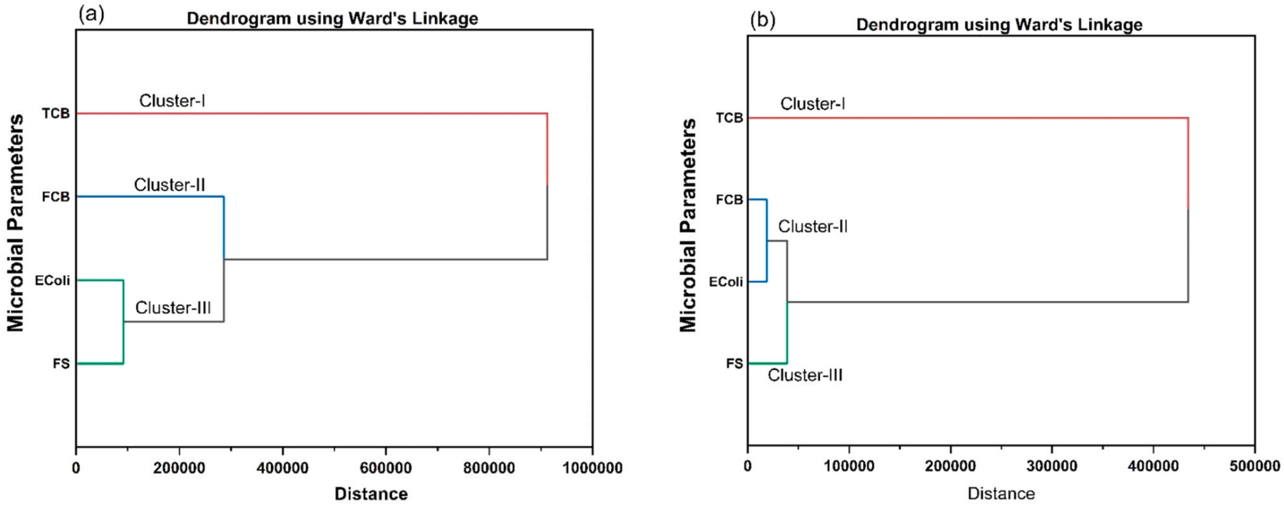

**Fig. 5.** Cluster analysis for the microbial parameters in the Thirumanimuthar River water (a) before COVID-19 lockdown, (b) during COVID-19 lockdown.

**Table 3**
Expected non-carcinogenic risks among children, teenagers and adults due to ingestion of metals in the Thirumanimuthar River water before and during COVID-19 lockdown.

| Parameters | Before COVID-19 lockdown | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Children | | | Teens | | | Adults | | |
| | Min | Max | Mean | Min | Max | Mean | Min | Max | Mean |
| **Fe** | 0.003 | 0.089 | 0.032 | 0.003 | 0.073 | 0.026 | 0.002 | 0.062 | 0.023 |
| **Mn** | 0.076 | 0.235 | 0.141 | 0.062 | 0.193 | 0.116 | 0.053 | 0.166 | 0.099 |
| **Ni** | 0.005 | 0.063 | 0.030 | 0.004 | 0.056 | 0.027 | 0.003 | 0.044 | 0.021 |
| **Cr** | 0.498 | 14.793 | 5.087 | 0.409 | 12.159 | 4.181 | 0.350 | 10.416 | 3.582 |
| **Pb** | 0.000 | 0.433 | 0.130 | 0.000 | 0.384 | 0.142 | 0.023 | 0.329 | 0.145 |
| **HI** | 0.661 | 15.250 | 5.421 | 0.680 | 12.534 | 4.492 | 0.582 | 10.737 | 3.870 |
| **Samples under risk** | **95%** | | | **91%** | | | **86%** | | |
| **During COVID-19 lockdown** | | | | | | | | | |
| | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| **Fe** | 0.003 | 0.053 | 0.016 | 0.003 | 0.049 | 0.015 | 0.002 | 0.041 | 0.013 |
| **Mn** | 0.051 | 0.152 | 0.101 | 0.048 | 0.142 | 0.095 | 0.039 | 0.117 | 0.078 |
| **Ni** | 0.002 | 0.037 | 0.024 | 0.002 | 0.035 | 0.023 | 0.002 | 0.028 | 0.019 |
| **Cr** | 0.300 | 6.833 | 1.467 | 0.281 | 6.405 | 1.375 | 0.231 | 5.262 | 1.129 |
| **Pb** | 0.023 | 0.292 | 0.156 | 0.022 | 0.274 | 0.147 | 0.018 | 0.225 | 0.121 |
| **HI** | 0.666 | 7.156 | 1.765 | 0.624 | 6.708 | 1.654 | 0.513 | 5.510 | 1.359 |
| **Samples under risk** | **45%** | | | **36%** | | | **33%** | | |

et al., 2021), no study on human health risk evaluation due to heavy metals in river water was attempted. Karunanidhi et al., (2021) have reported the effect of monsoon and COVID-19 lockdown on shallow groundwater quality by determining major ions and fluoride. They have computed health risk for human beings due to fluoride contamination in groundwater and not for heavy metals. Therefore, in this study, we used the hazard index (HI) to show the total potential human health risks from various heavy metals, which is based on hazard quotients (HQ) from oral pathways. The non-carcinogenic risk was evaluated for five important hazardous heavy metals such as Mn, Ni, Cr, Fe and Pb. The results obtained for children, teenagers and adults were depicted in Table 3.

The HQ among children for pre-lockdown period ranged from 0.003 to 0.0089, 0.076–0.235, 0.005–0.063, 0.498–14.793 and 0.000–0.433 for Fe, Mn, Ni, Cr and Pb, respectively. However, the mean HQ for these metals were 00.032, 0.141, 0.030, 5.087, and 0.130, respectively. In the pre-lockdown samples, the HQ values among teenagers for Fe, Mn, Ni, Cr and Pb ranged from 0.003 to 0.073, 0.062–0.193, 0.004–0.056, 0.409–12.159 and 0.000–0.384, respectively. In the pre-lockdown samples, the HQ for adults varied from 0.002 to 0.062, 0.053–0.166, 0.003–0.044, 0.350–10.416, and 0.023–0.329 for Fe, Mn, Ni, Cr and Pb, respectively. The non-carcinogenic risks based on $HI_{total}$ were calculated for these metals using RfD values. The $HI_{total}$ computed from the pre-lockdown samples varied from 0.661 to 15.250, 0.680–12.534, 0.582–10.737 among children, teens and adults, respectively.

Similarly, HQ values for the COVID-19 lockdown period samples ranged from 0.003 to 0.053, 0.051–0.152, 0.002–0.037, 0.300–6.833 and 0.023–0.292 for Fe, Mn, Ni, Cr and Pb, respectively, among children. The mean values of HQ for these metals were 0.016, 0.101, 0.024, 1.467 and 0.156, respectively. The HQ for teens and adults varied from 0.003 to 0.049, 0.048–0.142, 0.002–0.035, 0.281–6.405 and 0.022–0.274, and 0.00–0.041, 0.039–0.117, 0.002–0.028, 0.231–5.262 and 0.018–0.225 for above mentioned heavy metals, respectively. The mean values for these metals were 0.015, 0.095, 0.023, 1.375and 0.147, and 0.013, 0.078, 0.019, 1.129 and 0.121among teens and adults, respectively. $HI_{total}$ in the lockdown samples varied from 0.666 to 7.156, 0.624–6.708 and 0.513–5.510 for children, teens and adults, respectively. The results of $HI_{total}$ shows that children are at higher risk than teens and adults. The average HI before the lockdown was 5.42 for children, 4.49 for teenagers, and 3.87 for adults, whereas it was 1.77 for children, 1.65 for teenagers and1.35 for adults during lockdown (Table 3). About 95%, 91% and 86% of samples had higher HI (>1) in the pre-COVID-19 lockdown period, whereas, 45%, 36% and 33% of lockdown period samples possessed health risks among these age groups, respectively.

### 3.8. *Remediation for human welfare*

The knowledge and understanding of the risks to human health due to metal contamination in drinking water among local inhabitants are very less. The outcome of this work revealed that heavy metals concentration was drastically reduced in the Thirumanimuthar River water within a short period due to the closure of industries. Hence, the administrators should strictly implement the pollution control policies to avoid surface water contamination by hazardous metals. Among the eight metals examined, Cr pollution is alarming in the study region. Therefore, zero liquid discharge (ZLD) must be implemented in all the leather tanning and dye industries to minimize heavy metals pollution.

The study area is not well developed city to provide treated water to the society. The area comprises of city, towns and villages. There is no common treatment plant available in the study region to provide drinking water supply. Part of Salem city alone is getting drinking water supply from Cauvery River but the other parts are not receiving the pre-treated water. Most of the inhabitants in towns and villages are using river water and groundwater for their drinking and domestic needs. Very few people have fixed reverse osmosis (RO) units in their houses to filter the water. In villages and towns where planned waste handling and disposal and waste treatment such as incineration plants, wastewater treatment plants, etc., are not available, the innovative solutions will not be helpful. Therefore, in such scenarios public awareness will play a significant role than well developed technology. In addition, we recommend to use appropriate portable Reverse Osmosis Water Purification Unit (ROWPU) in houses for getting potable drinking water.

## 4. Conclusions

Even though many research studies have been conducted to examine the river/surface water quality by separately studying heavy metals contamination or DO, BOD and COD or microbial populations, no integrated study based on physico-chemical parameters, heavy metals and microbial levels was attempted for the COVID-19 pandemic lockdown. This research work is unique since integrated approach is used to evaluate the overall river water quality by assessing microbiological parameters along with Heavy Metal Pollution Index (HPI), Metal Index (MI), and Hierarchical Cluster Analysis (HCA). In addition, human health risk evaluation was performed for various age group of inhabitants such as children, teenagers and adults based on the oral intake of heavy metals in the Thirumanimuthar River water. The results of this study suggest that the river is contaminated from industrial, agricultural, and municipal wastes. These results are supported with a decrease in the microbiological population and heavy metals concentration during the COVID-19 lockdown period. The rainfall occurrence may naturally dilute the concentration of heavy metals in river water. Since the study period falls in summer season, and there is no dilution effect due to rain the reduction in pollution level is mainly due to closure of industries during lockdown. Among all the heavy metals analyzed in this study, the maximum decrease was for Cr concentration due to lockdown. The concentration of heavy metals in the pre-COVID-19 lockdown samples was in the order: Cd>Pb>Ni>Cu>Mn>Zn >Cr>Fe, and during COVID-19 lockdown period, it was Cd>Ni>Cu>Pb>Mn>Zn>Cr>Fe. In the pre-lockdown period, 77%, 45%, 27%, 18%, 9% and 91% of the samples exceeded the permissible limits for drinking for Fe, Cu, Cd, Ni, Pb and Cr, respectively, whereas, in the lockdown period, 23% of samples exceeded the permissible limits for Fe, Cu and Cd, and 50% of samples exceeded for Cr. The Heavy Metal Pollution Index (HPI) showed that 27%, 64% and 9% of the samples were classified under 'low/safe', 'medium' and 'high' pollution categories in the pre-lockdown period, respectively, but 68% and 32% of the samples of lockdown period were classified under 'low/safe' and 'medium' pollution categories, respectively. The Metal Index (MI) results revealed that all the samples (100%) of pre-lockdown were under seriously affected category (MI>6), whereas 54% and 46% of lockdown period samples represented strongly affected (MI = 4–6) and seriously affected categories, respectively. Health risk appraisal indicated that 95%, 91% and 86% of pre-lockdown samples, and 45%, 36% and 33% of lockdown period samples were under risk among children, teenagers and adults, respectively. If contamination of river water is regulated and sewage treatment plants (STPs) are used effectively, the river water can be used for agriculture and domestic purposes.

## CRediT authorship contribution statement

**D. Karunanidhi:** Conceptualization, methodology, Supervision, Writing - original draft, Writing - review & editing. **P. Aravinthasamy:** Data curation, Writing - original draft. **T. Subramani:** Visualization, Investigation, Writing - review & editing. **Raj Setia*:*** Writing - review & editing.

## 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.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jhazmat.2021.125909.

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