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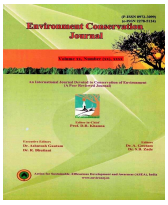

Investigation of the impacts of industrial towns on urban rivers through physicochemical analysis of water quality and the water quality index (WQI)

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ABSTRACT

The present study was undertaken to assess the pollution status of Erai and Zarpat rivers flowing through industrial Chandrapur City, Maharashtra, India. The obtained data of physicochemical parameters were processed to calculate Water Quality Index (WQI). The obtained data revealed that the physicochemical parameters such as turbidity (20.2-28.7 NTU), hardness (236-276 mg/l), total dissolved solids (1586-1730 mg/l), nitrates (49-53 mg/l), phosphate (0.7-0.9 mg/l), chemical oxygen demand (53.2-69.2 mg/l) and biochemical oxygen demand (19-22 mg/l) were beyond the permissible limits of Bureau of Indian Standard (BIS).The concentrations of toxic metals viz. cadmium (0.006-0.008 mg/l), lead (0.03-0.05 mg/l), arsenic (0.0-0.03 mg/l) and molybdenum (0.05-0.07 mg/l) in river water were also recorded higher than permissible limits of BIS. The WQI values of both the rivers at different sampling stations ranged from 144 to 220 indicating poor to very poor water quality. The sources of pollution in both the rivers were disposal of fly ash, mining, disposal of treated and untreated domestic and industrial effluent due to lack of sewage treatment plants (STPs), effluent treatment plant (ETP), and common effluent treatment plant (CETP). Therefore, there is a need of construction of STP, ETP, CETP, proper disposal of fly ash, and desludging of rivers at regular intervals.

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Introduction

Chandrapur is a major industrial and commercial city with rich reserves of coal (a city of black gold), limestone and other minerals and is responsible for the economic development of Maharashtra State. Chandrapur has a large number of industries, including the Chandrapur Super Thermal Power Station (CSTPS) and mines of coal and minerals located on the side of the city. The number of communication facilities and the population of the city also increased significantly. The Erai and Zarpat Rivers pass through the city and are important for providing an aesthetic environment, facilitating recreation and replenishing groundwater. Apart from these benefits, the Erai River is the source of water for cities and industries, including the CSTPS. However, these water bodies have been under serious threat for two decades due to pollution from domestic, industrial and mining wastewater and encroachment. The result is serious public health problems in Chandrapur, as indicated in a survey by medical practitioners (Times of India, Dec 23, 2021). Therefore, the Central Pollution Control Board (CPCB) has kept the city of Chandrapur on the list of Critically Polluted Areas in India. Studying the recent status of the quality of these rivers with special reference to their suitability for various uses is highly desirable. Considering the importance of these rivers for Chandrapur city, the present investigation was undertaken to assess the pollution status of these rivers through physicochemical monitoring and water quality index (WQI) data. Thereafter, the suitability of river water for drinking, domestic use, and irrigation purposes was also assessed. Field studies were carried out to

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identify the sources and causes of pollution in these rivers. Based on these observations, municipal authorities recommended improving sanitary infrastructure facilities to control sources of pollution in rivers and implementing river restoration measures.

Materials and Methods

Study Area

Chandrapur city is situated at the confluence of the Erai River and Zarpat River at 19.9615° N, 79.2961° E. The area of the city is approximately 162.41 km^2 (15.90 km N–S × 10.90 km E–W) and slopes from north to south. The Erai River passes from northwest to southeast diagonally through the city. The Zarpat River is a tributary of the Erai River and is a small stream that flows from the northeast to the southwest and then meets the Erai River near Mana village (Fig. 1). The Erai River supplies water to Chandrapur city and to the Chandrapur Super Thermal Power Station (CSTPS) through its Erai dam (approx. 55 km north of the city), and 30% of Chandrapur city's water supply is drawn from the Erai River intake well near Datala Road. In peak summer, the water level at the Erai Dam sometimes reaches the dead level, and water intake for industrial consumption must be restricted by the district authority to ensure that the water is supplied for drinking purposes. The Zarpat River flows between dense populations of the slum area near M/s Maharashtra Electrosmelt Ltd., Mul Road, Chandrapur, Sanjay Nagar, Krishna Nagar, Indira Nagar, and then enters the Anchleswar ward, Pathanpura, to meet the Erai River near Mana village. It receives untreated sewage from slum areas and urban residential areas and is densely covered with water hyacinth (*Eichhornia crassipes*) floating weed.

Four sampling stations were selected for the study (Fig. 1): viz. SW-1 (Erai River before CSTPS effluent disposal), SW-2 (Erai River near Bimba Gate), SW-3 (Erai River 1 km downstream of the confluence of the Erai River and Zarpat River) and SW-4 (Zarpat River near Mana Village) were used.

Sampling and analysis

Water samples from the selected sites were collected, preserved and analyzed for the selected physicochemical parameters following the standard methodology prescribed in APHA (2012). Then, to determine the suitability of the plants for drinking purposes, the obtained values of physicochemical parameters were compared with those of the BIS (2012), and the suitability for irrigation purposes was determined with the irrigation water standard of the Central Pollution Control Board (CPCB, 2001).

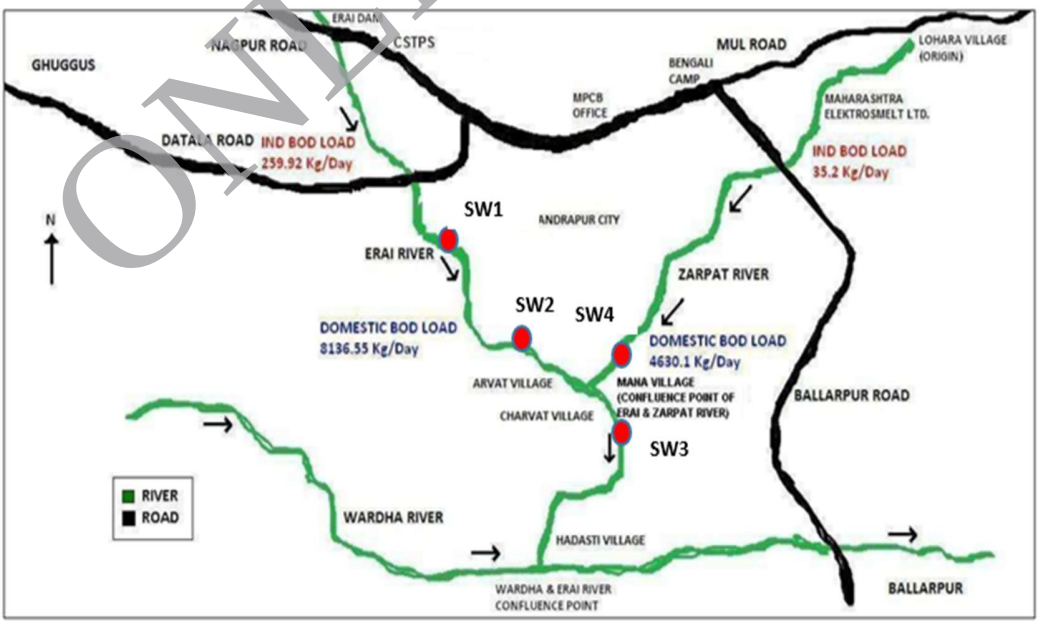

Figure 1: Diagrammatic view of the Erai River and Zarpat River showing the sampling stations

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Determination of the Water Quality Index (WQI)
The WQI was calculated following the procedure described by Ravikumar *et al.* (2013) and Hameed *et al.* (2010). The following steps were followed:
The water quality parameters were given weights (wi) based on their importance through expert evaluation. Then, the relative weights (Wi) of all the parameters were calculated by the formulaMention table number:

$$\text{Relative Weight (Wi)} = \frac{wi}{\sum wi}$$

The quality rating scale (qi) for all the parameters was calculated by dividing the observed concentration (ci) of the parameter by its respective standard (BIS, 2012) (Si), and the result was multiplied by 100:

$$qi = \left(\frac{Ci}{Si}\right) 100$$

The subindices (SIs) for each parameter were calculated by multiplying the relative weight (Wi) by the quality rating scale (qi): SI = Wiqi.
The water quality index (WQI) was calculated by taking the sum of all the subindexes (SIs): WQI = ΣSI

Results and Discussion

Physicochemical quality of river water

The pH of river water is an important indicator of water quality and a comprehensive reflection of hydrochemical characteristics (Feng *et al.,* 2017). The results of the present study are given in Table 1-4. The pH varied from 7.4 to 7.91, indicating that the

Table 1: Compliance of river water quality with Standards for Irrigation/Industrial Cooling Water (CPCB, 2001, BIS 1986)

Parameter	Irrigation water standard	Erai River			Zarpat River (SW-4)
		SW-1	SW-2	SW-3	
TDS (mg/l)	2100	1422	1730	1855	2355
Chlorides as Cl (mg/l)	500	163.8	274	342.6	374.6
SAR	26	0.80	0.28	0.32	0.29
Boron (mg/l)	2	0.7	1.4	1.2	1.3
Sulphates (mg/l)	1000	175	279	282	369
pH	6.0 – 8.0	7.9	7.8	7.6	7.4
Suitability for irrigation	–	Suitable after Boron fertilizer fortification	Suitable after Boron fertilizer fortification	Suitable after Boron fertilizer fortification	Not suitable due to high TDS

Table 2: Weights (wi) and relative weights (Wi) of the water parameters

Parameter	(IS 10500: 2012) Acceptable Limit (mg/l except pH & EC)	Weight (wi)	Relative Weight (Wi) $=\frac{\Sigma wi}{wi}$
Dissolved oxygen (DO)#	3.0#	4.09	0.1642
pH	8.5	2.54	0.102
Total dissolved solids (TDS)	500	2.75	0.1104
Electrical conductivity, EC, µS/cm	2000	3.22	0.1293
Total Hardness	200	1.46	0.0586
Total Alkalinity	200	1.36	0.0546
Calcium (Ca^{++})	75	1.25	0.0502
Sodium (Na^{+})*	200*	1.67	0.0670
Nitrate (NO_3^-)	45	2.57	0.1032
BOD_5**	5**	3.00	0.1204
Boron (B^{+++})	0.5	1.00	0.0402
		Σwi = 24.91	**ΣWi = 1.0001**

***WHO guidelines; **level in moderately clean water; #CPCB**

Impact of human activity on water quality. Feng *et al.* (2017) analyzed river water quality and observed that the pH in the acidic range where human activities were lower and in the alkaline range where human activities were more common. The value of color (7 to 9 Hazen) and turbidity (7.2 to 8.64 NTU)

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of river water were also found to be beyond the standard limit of the BIS. The total dissolved solids (TDS) values of the Zarpat River (ranging from 1422 to 2355 mg/l) were greater than the acceptable limit (500 mg/l) and permissible limit (2000 mg/l). The electrical conductivity (EC) values ranged from 2340 to 3922 µS/cm. The temperature ranged from 30°C to 31°C. The total hardness (TH) in water is due to the presence of carbonate, bicarbonate, chloride, and sulfate from calcium and magnesium (Bhutiani *et al.,* 2021). The total hardness (TH) values in both river water samples (ranging from 246 to 325 mg/l) were found to be higher than the acceptable limit of the BIS (200 mg/l). Water with low hardness adversely affects fish growth, so an optimum hardness needs to be maintained in water bodies. The total alkalinity (TA) ranged from 238 to 319 mg/l, which is above the acceptable limit of BIS (200 mg/l). TAlk is good for fish culture. Cavalcante *et al.* (2014) reported that TAlk >20 mg/l in freshwater results in optimum fish growth. A lower TAlk indicates that the water body is more susceptible to acidification. In such cases, TAlk increases with the addition of limestone (calcium carbonate). Acidity and alkalinity are important independent parameters that directly or indirectly regulate the pH of water (Singh *et al.,* 2009; Ruhela *et al.,* 2019; Bojago *et al.,* 2023). Chlorides and sulfate (SO_4) salts contribute to the total mineral content of water and add to the EC of water (Tyagi *et al.,* 2020). All the water bodies in Chandrapur contained chlorides (163.8 to 374.6 mg/l) and SO_4 (175 to 369 mg/l) above acceptable limits of 250 mg/l and 200 mg/l, respectively, but below permissible limits of 1000 mg/l and 400 mg/l, respectively, except for station SW-1, where both parameters were below the acceptable limits of 250 mg/l and 200 mg/l, respectively (Figure 2). The presence of chlorides and sulfates indicates river water pollution due to sewage and industrial waste discharge (Bhutiani *et al.,* 2018).

Ammonia was not detected; however, nitrate and phosphate were highly present, viz. 18 to 48 mg/l and 0.22 to 0.5 mg/l, respectively, indicating good self-purification capacity of the rivers due to good mixing of the water column at shallow depths in the Erai River (3 to 8 m depth), which has a good flow rate, and in the shallow Zarpat River. The sodium adsorption ratios (SARs) of all the river waters ranged from 0.28 to 0.80, indicating that there was no sodium hazard or suitability for irrigation. The water bodies also contained mineral nutrients (Figure 2) like magnesium ranging from 79 to 169 mg/l which is more than permissible limit of BIS (100 mg/l) except SW-1 station with magnesium within permissible limit, calcium from 142 to 296 mg/l which is more than acceptable limit of BIS (75 mg/l), iron from 0.50 to 0.59 mg/l which is more than acceptable limit of BIS (0.3 mg/l), zinc 6 to 8 mg/l which is more than acceptable limit of BIS (5 mg/l), copper 0.30 to 0.8 mg/l which is more than acceptable limit of BIS (0.05 mg/l), however within permissible limit of BIS (1.5 mg/l) and boron 0.7 to 1.3 mg/l is which more than permissible limit of BIS (1 mg/l) except SW-1 having 0.7 mg/l. Husain *et al.* (2017) also recorded the presence of eight heavy metals in the Godavari River. Some of them were under the limit, and some of them were above the acceptable (nickel, copper) limit.

CODs ranging from 26.8 to 49.3 mg/l and BOD ranging from 9.9 to 17.8 mg/l had very high organic pollution in all the water bodies. The COD/BOD ratio was observed to vary from 2.71 to 2.81 (within values between 2 and 4), which indicated the presence of moderately biodegradable organic matter coming from sewage mixed with industrial wastewater. All the water bodies were polluted by sewage from the city and industrial effluent and mining effluent, which contained toxic metals. Due to the rapid responses of urban rivers to intensive land use and/or diverse pollution sources, water quality deterioration may accelerate, immediately leading to direct or indirect threats to human health and aquatic ecosystems (Su *et al.*, 2011; Mouri *et al.*, 2011; Bhutiani and Ahamad, 2018; Bhutiani *et al.*, 2021).

Grading of pollution:

On the basis of the spatial distribution of the water quality indicator parameters (Figure 2), the gradation of the pollution level appeared to be as follows. Zarpat River (SW-4) > Erai R. (SW-3) > Erai R. (SW-2) > Erai R. (SW-1). Gudadhe and Manik (2022) studied the self-purification capacity of the Erai River and reported that the river quality is good before the CSTPS; however, downstream rivers are polluted due to the disposal of CSTPS effluent, industrial effluent, domestic sewage and

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agricultural runoff. Gaidhane *et al.* (2020) studied the primary productivity of the Erai River and observed deterioration of the Erai River due to rural and urban wastewater discharge. Shende and Rathoure (2020) reported very high turbidity and almost negligible dissolved oxygen, indicating high pollution during monsoons, which is also a serious threat to aquatic life. The underground M/s MEL and WCL mines contributed to the industrial pollution load in the Zarpat River. Approximately 730 m^3 of industrial effluent is discharged by M/s MEL after primary treatment.

Table 3: Determination of quality rating scale for all water quality parameters

Parameter	As per IS 10500: 2012	Concentration in water				Quality Rating (qi)			
	Accept-able Limit	Erai River			Zarpat River	Erai River			Zarpat River
		SW-1	SW-2	SW-3	(SW-4)	SW-1	SW-2	SW-3	SW-4
Dissolved oxygen (DO)#	3.0	6.3	4.8	4.2	3.5	210	160	140	117
pH	8.5	7.9	7.8	7.6	7.4	92.9	91.8	89.4	87
Total dissolved solids (TDS)	500	1422	1730	1855	2355	284.4	346	371	471
Electrical conductivity, EC, µS/cm	2000	2240	2868	3065	3922	112	143.4	153.3	196.1
Total Hardness	200	246	276	290	325	123	138	145	162.5
Total Alkalinity	200	238	268	285	319	119	134	142.5	59.5
Calcium (Ca^{++})	75	142	215	254	296	189.3	286.7	338.7	394.7
Sodium (Na^{+})*	200	125	133	175	188	62.5	66.5	87.5	94
Nitrate (NO_3^-)	45	48	29	21	18	106.7	64.4	46.7	40
BOD_5**	5	9.9	16.7	15.4	17.8	198	334	308	356
Boron (B^{+++})	0.5	0.7	1.3	1.2	1.3	140	260	240	260

*WHO guidelines; **level in moderately clean water; #CPCB

Table 4: Calculation of subindices (SI) for each parameter and water quality index

Parameter	Wi	qi				SI = Wiqi			
		SW-1	SW-2	SW-3	SW-4	SW-1	SW-2	SW-3	SW-4
DO#	0.1642	210	160	140	117	34.5	26.3	23	19.2
pH	0.102	92.9	91.8	89.4	87	9.5	9.4	9.1	8.9
TDS	0.1104	284.4	346	371	471	31.4	38.2	41	52
EC	0.1293	112	143.4	153.3	196.1	14.5	18.5	19.8	25.4
T. Hardness	0.0586	123	138	145	162.5	7.2	8.1	8.5	9.5
Total Alkalinity	0.0546	119	134	142.5	59.5	6.5	7.3	7.8	3.3
Calcium	0.0502	189.3	286.7	338.7	394.7	9.5	14.4	17	19.8
Sodium*	0.0670	62.5	66.5	87.5	94	4.2	4.5	5.9	6.3
Nitrate	0.1032	106.7	64.4	46.7	40	11	6.7	4.8	4.1
BOD**	0.1204	198	334	308	356	23.8	40.2	37.1	42.9
Boron	0.0402	140	260	240	260	5.6	10.5	9.7	10.5
	WQI = ΣSI					157.7	184.1	183.7	201.9

Boron is an essential trace element required for the human body, animals and physiological functioning of higher plants (Shireen *et al.*, 2018). The concentrations of Boron in both rivers ranged from 0.7 to 1.3 mg/l, which are higher than the acceptable limit of the BIS (0.5 mg/l). Silica in water is beneficial for the human body, plants and animals. The water soluble form of silica (orthosilicic acid) is the main source of absorbed silica in humans and is associated with several health benefits related to the structure and function of blood vessels, bones, kidneys, liver, skin, tendons, etc. (Nielsen, 2014; Jugdaohsingh, 2007). Silicon is known to treat osteoporosis problems in the human body (Jugdaohsingh, 2007). In plant, silica helps to develop immunity against pathogens through the production of antibacterial and antifungal compounds that confer resistance to powdery

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mildew in wheat and to blast in rice through the formation of antifungal compounds called phytoalexins (Remus-Borel *et al*., 2005). In the present study, the concentration of silica in both river water samples ranged from 6.5 to 7.1 mg/l. Among the toxic metals, nickel, total chromium, cyanide and mercury were not detected. Cadmium concentrations ranged from 0.006 to 0.008 mg/l (higher than the acceptable limit of BIS (0.003 mg/l)); molybdenum, from 0.05 to 0.07 mg/l (higher than the acceptable limit of BIS (0.07), except in SW-1 and SW-2, which had 0.05 mg/l and 0.06 mg/l, respectively; and lead, from 0.03 to 0.05 mg/l (higher than the acceptable limit of BIS (0.01 mg/l)). The cause of metal contamination of river water is through industrial waste, plating, cadmium pigment manufacturing plants, textile operations, nickel-cadmium batteries, or effluents from STPs (Rani *et al.,* 2014). Total arsenic was not detected in SW-1 or SW-3 but was detected in SW-2 (0.02 mg/l) and SW-4 (0.03 mg/l). The highest concentrations of toxic metals were recorded in SW-4 of the Zarpat River, followed by SW-3, SW-2 and SW-1 of the Erai River. Warhate and Patel (2016) reported that coal mine effluent discharge in the Erai River decreased the quality of river water, leading to a decrease in the fish population over time.

Basic causes of pollution

An underground sewerage scheme was not available in Chandrapur until 2017, and it still does not cover the whole city. There are three sewage treatment plants in Chandrapur with a capacity of 70.5 MLD. However, due to an inadequate sewerage network, only 30 MLDs of sewage are treated. The remaining sewage and industrial wastewater pollute all the water bodies in Chandrapur city. Domestic effluent contributed approximately 97.7%, while industrial effluent contributed approximately 2.3% of the pollution load in the Erai River and Zarpat River. Wastewater from mines also finds way to rivers. A similar observation was given in the report by the Comptroller and Auditor General of India (CAG) (2012): sewage and industrial waste discharge constitute the main polluting sources of aquatic systems in India, and only approximately 10% of all waste water generated is treated before being discharged into the water.

The shrinking and shallowness of the Erai River bed have been due to the dumping of overburden soil by the WCL (5 to 10 feet deep soil on the riverbed) and fly ash by CSPTS. These activities resulted in flooding of the surrounding villages during the rainy season.

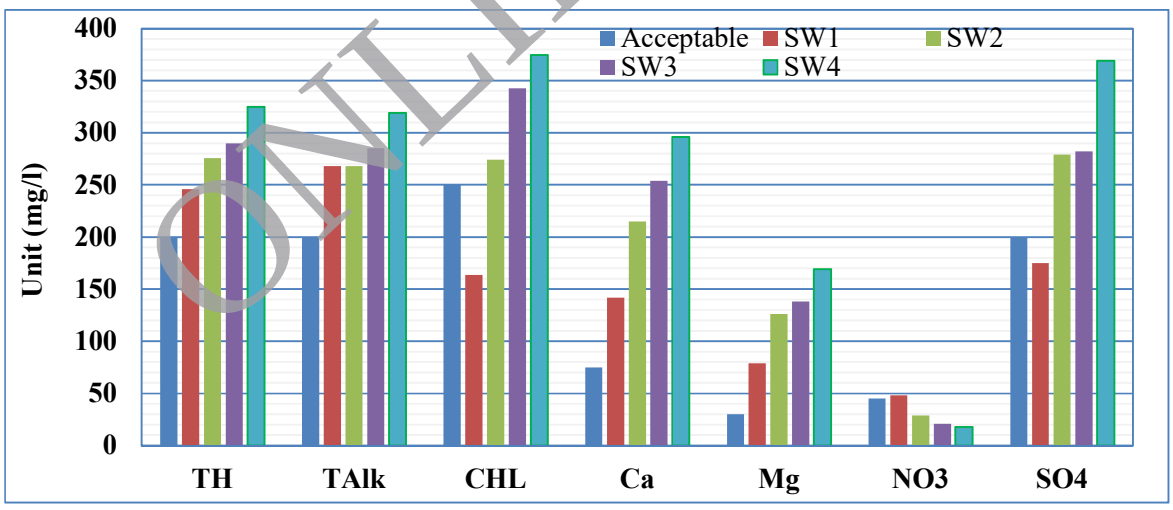

Figure 2: Chemical water quality parameters and their acceptable limits

The Erai River floods every year, affecting 150-200 families. Now, only 35 to 40% of the original water flow remains. Many wells and borehole wells in the surrounding area have gone dry. In the summer season, a shortage of water resulted in the closing of some units of power plants and domestic water supplies to the city.

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Comparison of river water quality with irrigation water standards

The physicochemical qualities of the river water samples from the Erai and Zarpat Rivers were compared with irrigation water standards (CPCB, 2001, BIS 1986) (Table 1). Erai River water samples (SW-1, SW-2, SW-3) were suitable for irrigation/industrial cooling after boron fertilizer fortification because the concentration of boron was lower than the standard, while Zarpat River water (SW-4) was not suitable because the TDS concentration was higher than the standard.

Water quality index (WQI) of the rivers

The water quality was classified into five categories based on WQI values, such as excellent (WQI = <50), good (WQI = 50-100), poor (WQI = 100-200), very poor (WQI = 200-300) and unsuitable (>300), as described by Ramkrishnaiah *et al.* (2009). The WQI of the Erai River (from sampling stations SW-1 to SW-3) varied from 157.7 to 184.1, indicating that *poor* water quality is not suitable for drinking or domestic use. The WQI at the downstream station (SW-3) of the Erai River was greater than that at the SW-1 station, revealing further deterioration of the river water quality due to sewage disposal and confluence of the Erai River with the polluted Zarpat River. The WQI of the Zarpat River at sampling station SW-4 was 201.9, indicating *very poor* water quality. When the values were compared, the order of pollution was found to be Zarpat R. (SW-4) > Erai R. (SW-3) > Erai R. (SW-2) > Erai R. (SW-1).

Suggestions for the restoration of the Erai River and Zarpat River quality

Recommendations are given considering the various causes of river pollution observed in this study. Bai *et al.* (2020) also stated that different methods that can be applied for the remediation of polluted river water can be categorized into physical, chemical, biological, ecological and engineering methods, but a single method is sometimes not effective for the purification of heavily contaminated river water. Therefore, hybrid techniques that involve the combination of two or more single methods are more widely recommended for efficient treatment. There is a need to construct a sewerage system covering the whole area of Chandrapur city to divert sewage to STPs and utilize treated sewage for irrigating agricultural fields around the city. Apart from this, removing all encroachments on riverbeds and restoring riverbeds can be performed by broadening and deepening riverbeds and by regularly cleaning riverbeds before the rainy season for the removal of water hyacinth (*Eichhornia crassipes*) and other weeds. Make the city open and defecation free by constructing public toilets in slum areas and important public places such as markets, bus stations, and railway stations. There should be bans on dumping soil, fly ash, solid waste, wastewater and industrial effluent in the river and constructing boundary walls along the banks of rivers in populated areas to avoid dumping solid waste into the river. Restrictions were placed on bathing/washing activities in river water all along the river course in the city. Treatment of wastewater from the Zarpat River and nalas was performed via an artificial wetland system to comply with the CPCB guidelines before entry of treated effluent into rivers.

Conclusion

The present study investigated the physicochemical and heavy metal characteristics of the rivers at Erai and Zarpat in Chandrapur city, Maharashtra, India. The data were also compared with the drinking water standards of the BIS to determine the suitability for drinking purposes and with those of the CPCB standards for irrigation to determine the suitability for irrigation purposes. Most of the physicochemical and heavy metal characteristics of the rivers in Erai and Zarpat were above the standard limits of BIS at all the selected sites. The quality of the river water was not suitable for drinking or irrigation purposes. Both rivers were classified as poor to very poor at all the sites based on WQI values. The rivers were found to be sluggish due to dumping of soil and fly ash. The rivers were also covered with water hyacinth (*Eichhornia crassipes*) at all the sites. Therefore, strict regulations, including penalties, are needed to save the lives of these rivers. In addition, the construction of STPs, ETP, and CETP is also needed, as is the use of a strong sewerage system to collect and treat domestic and industrial effluent.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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