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Evaluation of Pollution Load Index: A case study from Bollaram Industrial area

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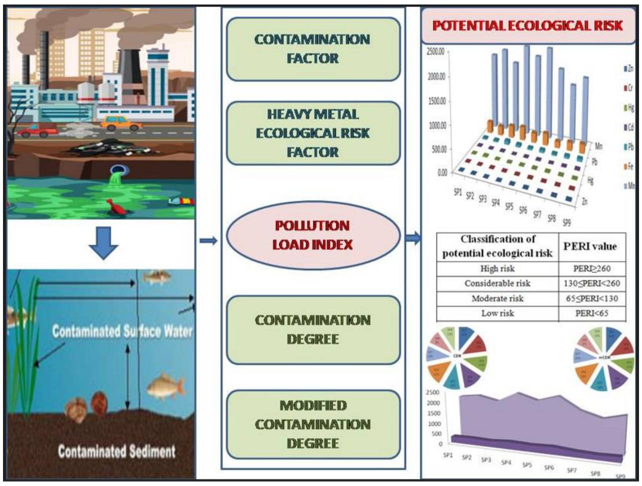
Graphical abstract



Abstract

This study has been conducted to comprehensively evaluate ecological risk through pollution indices of chemical water quality parameters in the aquatic body of the Bollaram industrial area. For the data, the water quality parameters were analyzed seasonally throughout the year and depicted the significant enrichment of heavy metals. Our results indicated a very high degree of contamination (CDR>24). Further, the Pollution load index also reflected "very high polluted" with PLIX>5 in the study area. Overall, the decreasing trend of Contamination factor (CFR) for the Bollaram lentic aquatic system through various heavy metals was observed as Mn>Fe>Pb>Hg>Zn>Cr>Cd. Overall, the potential ecological risk index (PERI) value for all sampling sites varied from 1629.41 to 2505.37, reflecting very high ecological risks. Fe and Mn predominantly contribute a significant amount to the potential ecological risk in the Bollaram pond. A pollution load index (PLIX) value equal to zero signifies perfection, 1 represents only the occurrence of the baseline level of the various contaminants, whereas a value of more than 1 reflects progressive water contamination by the trace metals. The highest PLIX value was perceived at SP6 (10.23), followed by SP2 (8.79). The lowest PLIX value was obtained at SP4 (5.22), followed by SP7 (5.91). An elevated level of PLIX in the sampling sites reported that the disposal of municipal waste and sludge from small-scale industries illegally might have caused ecological risk to the water ecosystems.

Keywords: Pollution indices, Ecological risk, Heavy Metal pollution, Contamination

1. Introduction

Industrialization and urbanization have significantly impacted the ecosystem, causing deterioration and depletion of freshwater resources. Wastewater can come from various sources, including industrial, residential, commercial, agricultural, and storm water runoff in urban areas. Pollutants of concern include organic matter, nutrients, pharmaceuticals, personal care products, polyfluoroalkyl compounds, biocides, heavy metals, dyes, radionuclides, plastics, nanoparticles, and pathogens (Venkataraman *et al.* 2024). According to Adimalla (2020), heavy metal ions are a major source of pollution and should be taken seriously. Studies suggest that live organisms accumulate these compounds gradually over time (Saha *et al*. 2021). They have long-lasting effects and can impact several organisms through biomagnification. Pollution indices (PIS) are widely recognized emphatic tools for comprehensively evaluating and assessing environmental quality, degree of contamination, and forecasting future environmental sustainability (Kowalska *et al*. 2018). Basically, pollution indices used for the evaluation of heavy metals are classified into two categories: Single (individual metal) and multi or integrated (sum of all studied metals together) pollution index (Cheng *et al*. 2022). Single metal PI includes contamination factor (CNR), ecological risk factor (ERFR), and integrated PIS involves contamination degree (CDR), modified contamination degree (mCDR), pollution load index (PLIX), and potential ecological risk index (PERI) (He *et al*. 2022, Selvanarayanan *et al*. 2024). The research location is the Bollaram industrial zone situated in Hyderabad, India. The pollution issue is exacerbated by the direct release of runoff water from numerous iron, pharmaceutical, and cement businesses into nearby water bodies (Su *et al*. 2023). Consequently, this study was conducted to evaluate pollution trends in the adjacent pond in Bollaram by ecological risk assessments.

2. Methodology

The study area Bollaram pond is also known as IDA Bollaram area, present in the Hyderabad metropolitan region of India. Many industries are located here, like small and medium-scale iron industries, cement industries, pharma companies, etc. The gathered water samples from study area were examined for their heavy metal composition, including chromium (Cr), manganese (Mn), lead (Pb), iron (Fe), zinc (Zn), cadmium (Cd), and mercury (Hg) via the ICP-MS technique (Chen *et al*. 2020). The concentrations of several heavy metal ions were quantified using the ICP-MS technique using an AGILENT ICPMS (Model - 7800) (Kumar *et al*. 2022). Heavy metal contamination levels are assessed using single metal and multiple metal pollution indices (Islam *et al*. 2015b). The single metal pollution indices (SPI) include contamination factor (CFR) and ecological risk factor (ERFR). The multi-metal pollution indices (MMPI) include contamination degree (CDR) and modified contamination degree (mCDR), pollution load index (PLIX), and potential ecological risk index (PERI).

Table 1. Classification criteria of CDR and mCDR

Degree of Contamination	CDR value	Modified degree of contamination	mCDR value
Low concentration	CDR<6	Unpollution	mCDR<1.5
Moderate concentration	6≤CDR<12	Slightly pollution	1.5≤mCDR<2
Considerable concentration	12≤CDR<24	Moderately pollution	2≤mCDR<4
Very high contamination	CDR≥24	Considerably pollution	4≤mCDR<8
		Highly pollution	8≤mCDR<16
		Strongly pollution	16≤mCDR<32
		Extremely pollution	mCDR≥32

The contamination of aquatic ecosystems can be assessed using the concentration of metal (Cm) and the degree of metal contamination (Dm). It was calculated using the formula given by Hakanson (Dipti *et al*. 2023). The CFR<1 indicates less contamination, where as CFR>6 indicates very high contamination. In this, CFR value in between 1 to 3 indicates moderate contamination and 3 to 6 indicates considerable contamination. The heavy metal ecological risk factor (HER) is the value of the contamination factor multiplied by its "toxic-response" factor (TRF). The HER<40 indicates low potential ecological risk where as HER>320 resembles very high ecological risk. HER in between 40 to 50 indicates moderate ecological risk, 80 to 160 shows considerable ecological risk, and 160 to 320 resembles high ecological risk. Contamination degree (CDR) of aquatic ecosystem can be calculated by the addition of all metal contamination factors in all the study locations. Modified contamination degree **(**mCDR) of aquatic ecosystem was calculated by dividing the contamination degree with the 'n' number of analyzed elements (Villarin and Merel, 2020). Classification criteria for multi-metal contamination degree and modified contamination degree is presented in **Table 1**.

2.1. Pollution load index (PLIX)

PLIX explicit the overall toxicity level in the water body and it can be calculated by the n^{th} root of multiplied contamination factor (CFR). The PLIX value in between 2 to 3 indicates moderate pollution, 3 to 4 indicates moderate to high, 4 to 5 indicates high pollution and >5 resembles extremely pollution. Potential ecological risk index (PERI) is extensively applied to calculate the potential ecological deficit which was caused by the heavy metals (Wan *et al*. 2020). This process integrates various interdisciplinary fields such as bio-toxicology, and ecology to reflect the impacts of different toxic elements on the various ecosystems and their comprehensive effects too. PERI is the sum of all HER which were calculated at every sampling location. PERI<65 indicates low risk, 130-260 indicates considerable risk, and >260 indicates high risk.

3. Results and Discussion

Various pollution indices were calculated with respect to Cr, Mn, Pb, Fe, Zn, Cd, and Hg[5]. The local background values and toxic factor values for the reported heavy metals are available in the study area (Monteiro *et al*. 2021). Overall, nine sampling points (SP 1, SP 2, SP3, SP 4, SP 5, SP 6, SP 7, SP 8, AND SP 9) were selected to collect the water samples from the study area, which covers the entire aquatic body. Many heavy metals in the Bollaram pond were observed at different study sites (Maruthai *et al.* 2025). The mean values of the heavy metal concentrations in the nine sampling sites are presented in **Figure 1**.

The Chromium (Cr) concentration in the study area is 4.3 ppm, which exceeds the prescribed limit of BIS (0.1 ppm) at all the sampling points (SP 1 to SP 9). The concentration of Mercury (Hg) is identified as 0.4 ppm, which exceeds the prescribed limit of BIS (0.001 ppm) at all the sampling points (SP 1 to SP 9). The Cadmium (Cd) concentration in the study area is 0.6 ppm, and Zinc (Zn) is 1.2 ppm, which are under the permissible limits of BIS, i.e., 3 ppm and 5 ppm, respectively in all the sampling points (SP 1 to SP 9). The concentration of Lead (Pb) is reported as 2.5 ppm, which exceeds the prescribed limit of BIS (0.1 ppm) at all sampling points (SP 1 to SP 9). Iron (Fe) concentration is reported as 426.2 ppm, and Manganese (Mn) is reported as 326 ppm, which exceeded the permissible limit of BIS, i.e., 5 ppm in all the sampling points (SP 1 to SP 9). These results showed that this lentic water system is highly contaminated with heavy metals. Fe, Mn, and Cr metals are present at high levels. Hg and Pb heavy metals are present at moderate contamination levels. Zn and Cd levels are reported below the BIS permissible limits in the study area. The surrounding area was surveyed manually to identify the main reasons for these heavy metal concentrations in the Bollaram lentic aquatic system. The survey identified that the runoff water from cement and iron-casting-based small-scale industries and wastewater discharge from the surrounding settlements through open drainage channels are reaching the study area. These water channels are active in the monsoon season and dry in the summer season (Xiong *et al*. 2016).

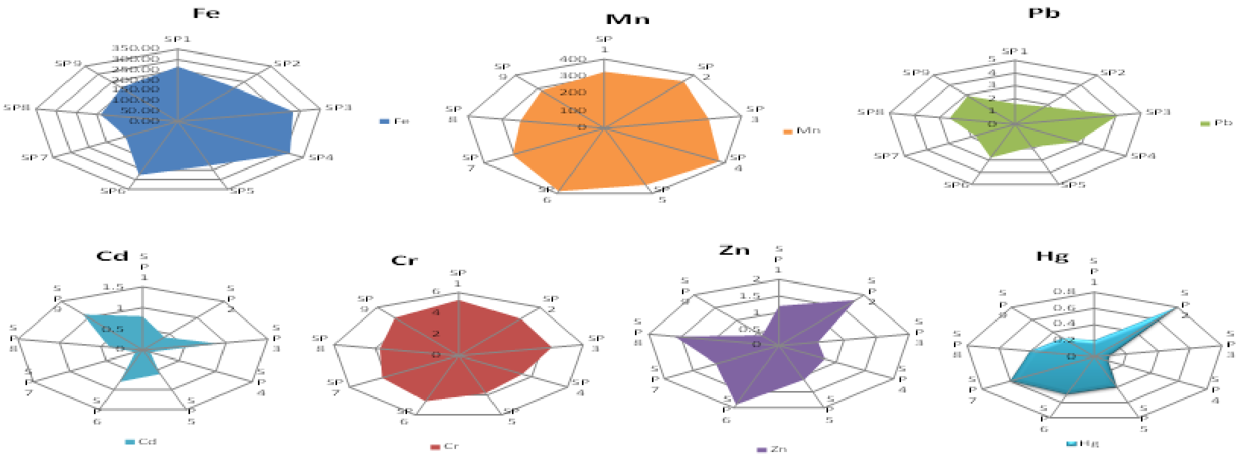


Figure 1. Concentrations of evaluated Heavy metals in the study area

The average contamination factor (CFR) of Fe, i.e., 236.79, indicates very high contamination (CFR>6). The CFR for Fe is reported in the range of 146.67 to 313.33 in the study area. The average CFR of Cr, i.e. 0.9, indicated low contamination (CFR<1), and the range of CFR reported in all the sampling points is between 0.73 to 1.10. The average CFR for Pb is 10.32, which indicates very high contamination (CFR>6). The reported Pb for CFR is in the range of 6.67 to 12.08. The average CFR for Cd is reported as 0.26, which indicates low concentration (CFR<1). Its CFR range is between 0.04 to 0.49 for all the sampling points. The average CFR for Mn is 1811.11, which indicates a very high CFR (CFR>6), and its range is between 1577.78 and 2122.22. The average CFR for Zn is 1.23, which indicates moderate contamination (1≤CFR<3), and the CFR range is between 0.42 to 2.00. The average contamination factor for Hg is 1.89, which indicates moderate contamination (1≤CFR<3), and the CFR range is reported between 0.5 to 4.00 in all sampling sites. Overall, the decreasing trend of CFR through various heavy metals was observed as: Mn>Fe>Pb>Hg>Zn>Cr>Cd (**Figure 2**). Among all heavy metals, Mn and Fe showed extreme dominance in all the sampling sites with very high CFR. These results signify the heterogeneous anthropogenic pollution sources, exhibiting that these toxic heavy metals can cause potential carcinogenic and non-carcinogenic health risks to the surrounding living organisms (Zzaman, 2015; Li *et al*. 2020)).

The heavy metal ecological risk factor (HER) in the study area was in the following descending order: Mn>Fe>Pb>Hg>Cd>Cr>Zn. Conceivable variations were noticed for HER of individual elements, signifying that the ecological risk of these heavy metals varied from one sampling point to the other (Liu *et al*. 2020 and Ma *et al*. 2020). Fe showed considerable variations in HER. It ranged from 146.67 to 313.33, which resembled considerable ecological risk to the high ecological risk. Cr, Hg, Zn, and Cd showed low potential ecological risk, which is less than 40 in all the sampling points. HER for Pb varied from 33.33 to 85.42, which signifies low potential ecological risk in four sampling points, moderate ecological risk in another four sampling points, and considerable ecological risk in one sampling point. In all the sampling points, Mn showed a very high ecological risk, which is above 320. It varies between 1360.67 to 2144.44.

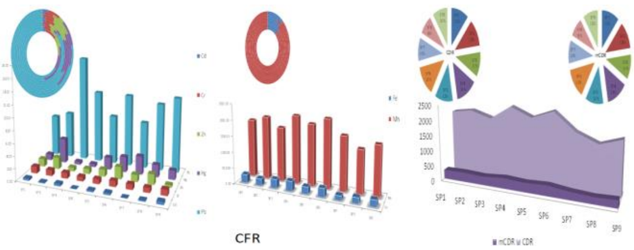


Figure 2. Contamination factor, mCDR, CDR of identified heavy metals

The contamination assessment for all the sampling sites was done based on the Contamination degree (CDR) and mCDR (**Figure 2**). The results clearly showed that the contamination degree (CDR) is very high (CDR≥24) in all the sampling sites. In this particular, the sampling sites 4 and 6 showed the highest CDR values (2449.34 and 2437.48, respectively). The minimum CDR values reported in sampling site (SP) 5 as 1572.15. The results depicted the mCDR with extreme pollution in all sampling sites (mCDR>32) (Hafizur*et al*. 2012; Yadav and Yadav, 2018). The lowest mCDR value is identified as 224.59 at sampling site 8, and the highest mCDR values are reported as 348.21 and 349.91 at sampling points 6 and 4, respectively.

3.1. Pollution Load Index (PLIX) and Potential ecological risk index (PERI)

A pollution load index (PLIX) value equal to zero signifies perfection, 1 represents only the occurrence of the baseline level of the various contaminants, whereas a value of more than 1 reflects progressive water contamination by the trace metals. As per these grades in this study, the water samples collected from various sampling points were considerably contaminated with heavy metals (**Figure 3**) as the PLIX value was more significant than 1 (13). The highest PLIX value was perceived at SP6 (10.23), followed by SP2 (8.79). The lowest PLIX value was obtained at SP4 (5.22), followed by SP7 (5.91). In the remaining sampling points, PLIX values were perceived to be around 7. All these sampling points showed very high pollution with the heavy metals respectively. An elevated level of PLIX in the sampling sites reported that the disposal of municipal waste and sludge from small-scale industries illegally might have caused ecological risk to the water ecosystems.

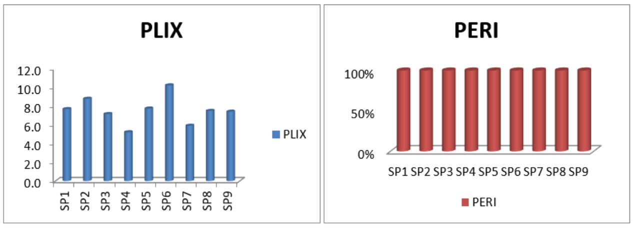


Figure 3. Pollution Load Index (PLIX) and Potential ecological risk index (PERI)

The potential ecological risk index (PERI) indicates the sensitivity of the biological communities to numerous toxic substances and demonstrates the probable ecological risks resulting from trace metals. The PRIX of the study area was in the following order: SP6> SP4> SP2> SP5> SP1> SP3> SP7> SP9> SP8. Overall, the PERI value for all sampling sites varied from 1629.41 to 2505.37, reflecting very high ecological risks.

4. Conclusion

This study confirmed that heavy metals from the Bollaram aquatic body showed a high degree of contamination based on calculated values of different pollution indices. However, the dumping of pharma sludge at the boundaries of Bollaram Pond and runoff water from the nearby iron-based small-scale industries highly contaminated this study area. The toxic situation in the nine studied sampling points showed extreme dominance by Fe and Mn. Cr and Cd showed less contamination factor. Similarly, the pollution load index also signifies "very high Polluted" in all the study sites. Seasonal variations are the main limitations for this study. A pollution load index (PLIX) value equal to zero signifies perfection, 1 represents only the occurrence of the baseline level of the various contaminants, whereas a value of more than 1 reflects progressive water contamination by the trace metals. The highest PLIX value was perceived at SP6 (10.23), followed by SP2 (8.79). The lowest PLIX value was obtained at SP4 (5.22), followed by SP7 (5.91). Hence, continuous monitoring of contaminants at a regular time interval is necessary after restricting the waste disposal at the boundaries of Bollaram pond. During the summer season, when the water quantity is less, the local authority has to take action to remove the sludge accumulated at the bottom of the water body. Also, it is necessary to provide artificial aeration to reduce the degree of contamination, which helps to restore the pond water quality.

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