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Seasonal Dynamics of Water Quality and Heavy Metals in Ramgarh Lake, Gorakhpur: A Two-Year Ecological Risk Assessment

Pallavi Singh and Awanish
Department of Botany, Mahatma Gandhi P.G. College, Gorakhpur
(Corresponding Author: Prof. Awanish, Professor, Department of Botany, Mahatma Gandhi P.G. College, Gorakhpur.
drawanish@gmail.com

Abstract: *Ramgarh Lake is a shallow urban wetland of Gorakhpur, Uttar Pradesh, India. It receives domestic and municipal drainage throughout the year. We monitored seven stations across five seasons from April 2024 to March 2026, taking triplicate water samples (total n = 105). We measured seven physico chemical parameters (pH, total solids, total suspended solids, total dissolved solids, chemical oxygen demand, biochemical oxygen demand, dissolved oxygen) and six heavy metals (Pb, Cd, As, Cu, Cr, Zn) using standard methods. All metal concentrations are reported in parts per million (ppm).*

Our data show a severe seasonal cycle. During the hot pre monsoon (April), low water levels concentrate pollutants. Biochemical oxygen demand (BOD) reached up to 210 ppm, dissolved oxygen (DO) fell below 0.5 ppm (anoxia), and lead (Pb) peaked at 4.34 ppm – more than 400 times the World Health Organization drinking water limit. After the monsoon (October), dilution temporarily improves water quality, but metals remain above safe limits. One way ANOVA confirmed strong seasonal differences (p < 0.001 for all parameters). Principal component analysis (PCA) extracted three components explaining 78% of the variance; the first component (47%) links organic pollution (BOD, COD) with Pb, Cd, and Zn – a clear sewage signature. The Water Quality Index (WQI) classified 54% of samples as "unsuitable for drinking" and another 31% as "very poor". The Potential Ecological Risk Index (PERI) averaged 387, indicating high ecological risk, with cadmium (Cd) contributing the most (E_r□ = 197). Hierarchical clustering grouped stations S2, S5 and S6 as pollution hotspots.

We conclude that Ramgarh Lake is hyper eutrophic and severely contaminated with heavy metals year round. Immediate action – sewage diversion, constructed wetlands, targeted dredging, and summer aeration – is urgently needed to protect aquatic life and public health..

Keywords: Ramgarh Lake, heavy metals, water quality index, ecological risk, eutrophication, seasonal variation, sewage pollution

I. INTRODUCTION

Many urban lakes in India have become dumping grounds for untreated waste. Ramgarh Lake is surrounded by residential colonies and receives water from several drains that carry domestic sewage, kitchen waste, and street runoff.

Like other tropical lakes, Ramgarh goes through strong seasonal changes. Summers are hot and dry; evaporation shrinks the water volume dramatically. The monsoon brings heavy rain that floods the lake and dilutes everything. Winters are mild. These natural cycles interact with the steady inflow of pollution to create extreme swings in water quality.

During summer, the same amount of waste ends up in a much smaller volume of water and concentrations of all pollutants becomes higher. High temperatures also speed up bacterial decomposition, which eats up oxygen and can release toxic metals from the bottom mud. Heavy metals such as lead, cadmium and arsenic are especially dangerous because they never break down. They accumulate in sediments and can re-enter the water when oxygen levels drop or pH changes. From there, they enter the food chain.

Many studies have reported metal contamination in Indian urban lakes, but very few have combined detailed seasonal monitoring with multiple pollution indices and multivariate statistics in a single study. We designed this work to answer practical questions: How do water quality and metal levels change across seasons and locations? Which parameters are most responsible for the lake's poor condition? What is the overall water quality index and ecological risk? Where are the worst hotspots? Our answers provide clear evidence that can guide restoration efforts.

II. REVIEW OF LITERATURE

2.1 Eutrophication and oxygen depletion

Shallow lakes in warm climates easily become eutrophic because high temperatures and long daylight hours boost algal growth. When algae die, their decomposition consumes oxygen. In Dal Lake, Kashmir, summer BOD often exceeds 15 ppm and DO drops below 3 ppm (Rashid et al., 2019; Wani et al., 2020). In Hussain Sagar, Hyderabad, urban runoff has caused bottom-water anoxia for several months each year (Reddy et al., 2020). Our earlier work in small ponds near Gorakhpur also showed a clear inverse relationship between water temperature and DO (Singh & Verma, 2018).

What makes Ramgarh different is the size of the organic load. BOD values up to 216 ppm are closer to raw sewage than to a natural lake. Similar extremes have been reported only in a few heavily polluted systems, such as Bellandur Lake in Bengaluru, where frothing and occasional fires have occurred due to industrial effluents (Ramachandra et al., 2016; Sudarsan et al., 2018).

2.2 Heavy metal contamination in urban wetlands

Many Indian lakes have elevated heavy metals. For example, lead in Upper Lake, Bhopal, ranges from 0.08 to 0.42 ppm (Malik & Maurya, 2014). In Loktak Lake, Manipur, lead is 0.12–0.35 ppm (Singh & Singh, 2017). In Vembanad Lake, Kerala, cadmium reaches 0.012 ppm (Harikumar et al., 2009). By comparison, Ramgarh's average lead (2.48 ppm) and cadmium (0.023 ppm) are an order of magnitude higher.

Globally, similar problems exist. Lake Chapala in Mexico has lead around 0.08 ppm (Hansen & van Afferden, 2001). Lake Taihu in China, heavily polluted by industry, has lead up to 0.22 ppm (Wang et al., 2015). The values we found in Ramgarh are unusual even by international standards.

Several researchers have noted that cadmium and lead pose the greatest ecological risk because of their high toxicity and tendency to build up in living organisms. In a risk assessment of Chilika Lake, Pandey et al. (2021) found that cadmium contributed more than 60% of the total PERI – similar to what we see in Ramgarh. Nair & Balakrishnan (2018) showed that insects and other small animals in polluted urban wetlands accumulate cadmium and lead at rates that can affect fish that eat them.

2.3 Seasonal remobilisation of metals from sediments

A critical process in shallow lakes is the release of metals from sediments when the bottom water becomes anoxic. Under normal oxygen-rich conditions, iron and manganese oxides act like sponges, binding dissolved metals. When oxygen disappears, these oxides dissolve and release the metals back into the water. This has been shown in laboratory experiments (Choudhury et al., 2022) and in field studies of European lakes (Salomons & Förstner, 1984). In the Indian context, Joshi & Kumar (2019) showed that summer anoxia in a Delhi lake led to a three-fold increase in dissolved lead within weeks.

2.4 Water quality indices and multivariate statistics

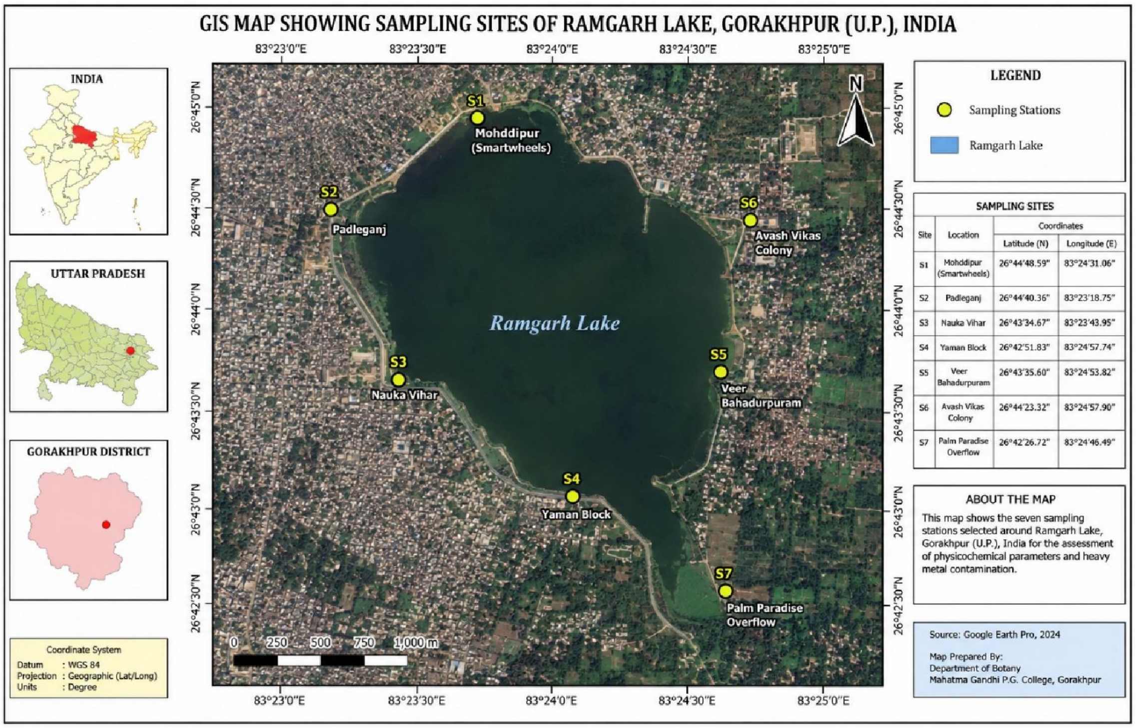
Using indices like WQI, HPI and PERI has become standard for communicating pollution levels to policymakers. Studies on the Ganga River (Singh & Gupta, 2020) and Yamuna River (Sharma & Kansal, 2019) have shown that indices can effectively rank pollution hotspots. Multivariate methods such as PCA and cluster analysis are now routinely used to identify pollution sources. For example, Kumar et al. (2019) used PCA to separate urban sewage from agricultural runoff in a Punjab lake. Our study follows this established framework.

III. MATERIALS AND METHODS

3.1 Study area and sampling stations

Ramgarh Lake (area about 723 hectares) lies in Gorakhpur district, Uttar Pradesh (latitude 26°42′–26°45′ N, longitude 83°23′–83°25′ E). The region has a subtropical monsoon climate. We chose seven stations to represent different types of pollution input (Figure 1):

- **S1 (Mohddipur):** near a major municipal drain
- **S2 (Padleganj):** directly receives domestic sewage
- **S3 (Nauka Vihar):** recreation area, mixed runoff
- **S4 (Yaman Block):** agricultural and urban drainage
- **S5 (Veer Bahadurpuram):** interior zone with floating algae mats
- **S6 (Avash Vikas Colony):** low-flow, often smells of rotten eggs
- **S7 (Palm Paradise):** near overflow from agricultural fields



SAMPLING SITES

Site	Location	Coordinates	
		Latitude (N)	Longitude (E)
S1	Mohddipur (Smartwheels)	26°44'48.59"	83°24'31.06"
S2	Padleganj	26°44'40.36"	83°23'18.75"
S3	Nauka Vihar	26°43'34.67"	83°23'43.95"
S4	Yaman Block	26°42'51.83"	83°24'57.74"
S5	Veer Bahadurpuram	26°43'35.60"	83°24'53.82"
S6	Avash Vikas Colony	26°44'23.32"	83°24'57.90"
S7	Palm Paradise Overflow	26°42'26.72"	83°24'46.49"

ABOUT THE MAP

This map shows the seven sampling stations selected around Ramgarh Lake, Gorakhpur (U.P.), India for the assessment of physicochemical parameters and heavy metal contamination.

Source: Google Earth Pro, 2024

Map Prepared By:
Department of Botany
Mahatma Gandhi P.G. College, Gorakhpur

Figure 1. GIS map showing the sampling locations of Ramgarh Lake, Gorakhpur (U.P.), India.

3.2 Sampling and analysis

We sampled five times: April 2024 (peak summer), October 2024 (post-monsoon), February 2025 (winter), September 2025 (late monsoon), and March 2026 (early summer). At each station we took three replicate water samples (1 litre each) from just below the surface. Samples were kept in a cool box and brought to the laboratory within 24 hours.

Physico-chemical parameters were measured using standard methods (APHA, 2017). We used a calibrated digital meter for pH. Total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) were measured by gravimetry. Chemical oxygen demand (COD) was determined by dichromate digestion. Biochemical oxygen demand (BOD) was measured as oxygen consumed over 5 days at 20 °C. Dissolved oxygen (DO) was measured by Winkler's azide method.

Heavy metals – lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), chromium (Cr), and zinc (Zn) – were analysed after acid digestion (a mixture of nitric and hydrochloric acids, 3:1) using atomic absorption spectrophotometry. Detection limits ranged from 0.0005 to 0.003 ppm. Recoveries of spiked samples were between 94% and 103%. All metal concentrations in this paper are reported in **parts per million (ppm)**, which is equivalent to mg/L for water samples. All analyses were done in triplicate, and we report mean values.

3.3 Data analysis

We used R version 4.3.1 (R Core Team, 2023) for all statistical analyses.

- **Descriptive statistics** (mean, standard deviation, minimum, maximum, coefficient of variation) summarised the dataset.
- **One-way ANOVA** tested for seasonal differences, followed by Tukey's honest significant difference (HSD) post-hoc test. We checked normality with the Shapiro-Wilk test and homoscedasticity with Levene's test. Some variables were log-transformed to meet assumptions.
- **Pearson correlation** examined relationships among the 13 variables.
- **Principal component analysis (PCA)** was performed on standardised data (z-scores). We checked suitability with the Kaiser-Meyer-Olkin (KMO) measure (threshold >0.60) and Bartlett's sphericity test ($p < 0.05$). Components with eigenvalues >1 were retained.
- **Hierarchical cluster analysis** used Euclidean distance and Ward's linkage method. The number of clusters was optimised by silhouette width.

We also calculated four widely used pollution indices:

Water Quality Index (WQI) – weighted arithmetic index (Brown et al., 1972) against Indian drinking water standards (BIS IS 10500:2012). WQI categories: <50 excellent, 50–100 good, 100–200 poor, 200–300 very poor, >300 unsuitable for drinking.

Heavy Metal Pollution Index (HPI) – weighted arithmetic mean of metal concentrations relative to permissible limits (Mohan et al., 1996). HPI <100 low pollution, 100–200 medium, >200 high.

Pollution Load Index (PLI) – geometric mean of contamination factors (CF = C_metal / C_background). We used background values (in ppm) from WHO (2017) and CPCB: Pb 0.01, Cd 0.003, As 0.01, Cu 0.05, Cr 0.05, Zn 0.10. PLI <1 no pollution, 1–2 moderate, 2–3 high, >3 very high.

Potential Ecological Risk Index (PERI) – Σ E_r□, where E_r□ = T_r□ × CF. Toxic response factors (T_r□) from Hakanson (1980): Cd = 30, As = 10, Pb = 5, Cu = 5, Cr = 2, Zn = 1. Risk categories: E_r□ <40 low, 40–80 moderate, 80–160 considerable, 160–320 high, ≥320 very high; PERI <150 low, 150–300 moderate, 300–600 considerable, ≥600 high.

IV. RESULTS

4.1 Overall water quality – a broad view

Table 1 summarises the entire dataset (105 samples). The numbers vary widely. BOD ranges from 10.7 to 216 ppm, DO from 0.49 to 8.30 ppm, lead from 1.35 to 4.34 ppm. The coefficients of variation (CV) are above 70% for BOD, TSS, lead, cadmium, copper and zinc – meaning the lake is not uniformly polluted. There are strong seasonal and spatial differences. Only pH (CV = 8.2%) and TDS (CV = 29%) are relatively stable.

Table 1. Overall descriptive statistics for Ramgarh Lake water quality (n = 105 samples). All heavy metal values are in ppm.

Parameter	Unit	Mean	SD	Min	Max	CV (%)
pH	–	6.34	0.52	4.87	7.31	8.2
TS	mg/L	890	342	419	1570	38
TSS	mg/L	156	110	21	310	71
TDS	mg/L	734	213	363	1273	29
COD	mg/L	52.8	35.4	13.9	113.8	67
BOD	mg/L	62.5	55.6	10.7	216	89

Parameter	Unit	Mean	SD	Min	Max	CV (%)
DO	mg/L	4.12	2.78	0.49	8.30	68
Pb	ppm	2.48	2.04	1.35	4.34	82
Cd	ppm	0.023	0.018	0.011	0.043	78
As	ppm	0.049	0.032	0.024	0.083	65
Cu	ppm	0.752	0.542	0.343	1.317	72
Cr	ppm	0.120	0.082	0.061	0.228	68
Zn	ppm	0.942	0.679	0.435	1.773	72

4.2 Seasonal patterns – from crisis to temporary relief

One-way ANOVA (Table 2) shows that season has a very strong effect ($p < 0.001$) for every single parameter. April 2024 is by far the worst month. Average lead in April is 4.01 ppm – about three times higher than in February (1.4 ppm) and six times higher than in October (0.7 ppm). BOD in April averages 120 ppm across all stations, compared to 23 ppm in October. DO follows the opposite pattern: February has the highest DO (about 7.1 ppm on average), April the lowest (about 1.2 ppm).

Table 2. Seasonal means for selected parameters and pollution indices. Metal values in ppm.

Season	BOD (ppm)	DO (ppm)	Pb (ppm)	Cd (ppm)	Zn (ppm)	WQI	PERI
Apr 2024	120.2	1.23	4.01	0.038	1.58	428	612
Oct 2024	23.1	6.21	1.55	0.014	0.61	214	218
Feb 2025	33.4	7.10	2.79	0.025	1.02	268	302
Sep 2025	56.8	4.21	1.96	0.017	0.75	254	286
Mar 2026	84.2	2.85	2.99	0.027	1.15	386	498
Overall	**62.5**	**4.12**	**2.48**	**0.023**	**0.94**	**342**	**387**

October (post-monsoon) is the cleanest period. Rain dilutes the lake, reducing all contaminant concentrations by 40–60% compared to April. Oxygen recovers because of mixing and cooler temperatures. However, even in October, lead (1.55 ppm) is still 155 times the WHO drinking water guideline of 0.01 ppm. So “clean” is relative.

Winter (February) has the highest DO, thanks to cooler water and less biological activity. But BOD remains above 30 ppm – still ten times the standard for healthy aquatic life (3 ppm according to CPCB).

March 2026 shows the early signs of summer stress. Water levels are already dropping, and BOD climbs back above 80 ppm. The lake starts deteriorating well before peak summer heat.

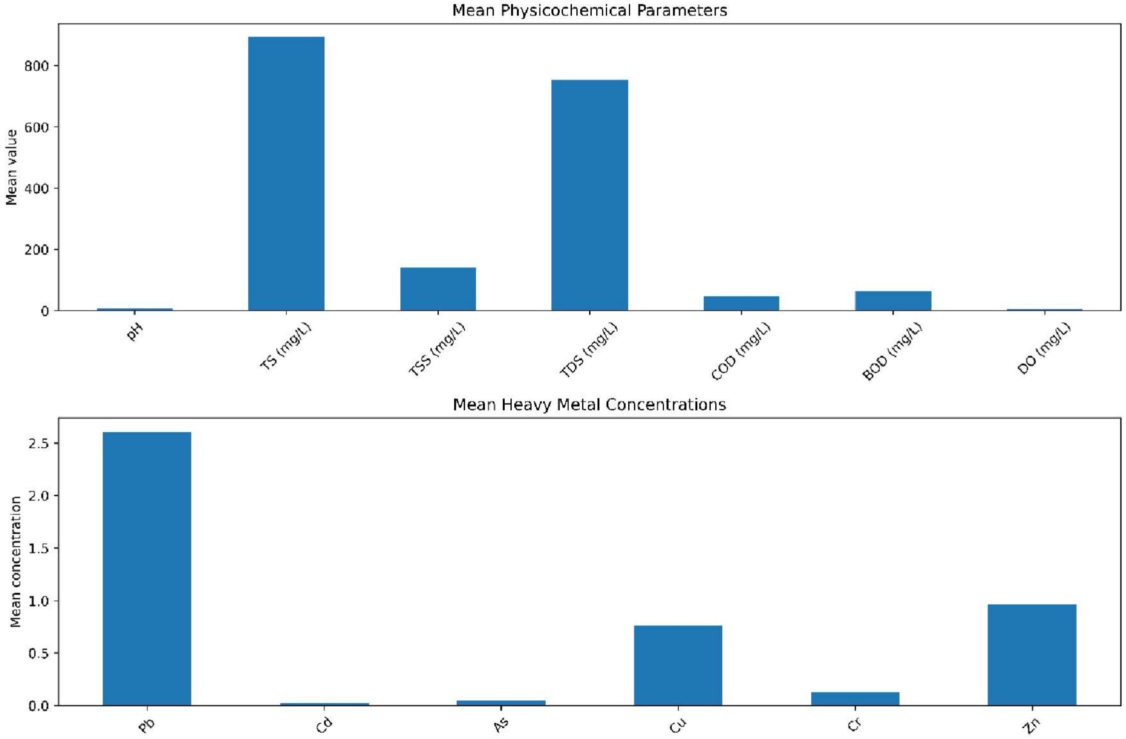


Figure 2. Seasonal variation in physicochemical characteristics and heavy metal concentrations of Ramgarh Lake during the study period.

4.3 Spatial patterns – hotspots of pollution

Stations close to sewage inlets (S2, S5, S6) are consistently more polluted than others. Average lead at S2 is 3.21 ppm, while at S4 it is 2.31 ppm. Station S5 has the highest BOD (maximum 216 ppm in April) and S6 the lowest DO (0.50 ppm in April). Station S4 (Yaman Block) is relatively less contaminated, probably because it receives more agricultural runoff and less raw sewage.

Hierarchical cluster analysis (we will refer to the dendrogram as Figure 3) grouped stations into three clusters:

- **Cluster 1 (high pollution):** S2, S5, S6
- **Cluster 2 (moderate pollution):** S1, S3, S7
- **Cluster 3 (lowest pollution):** S4

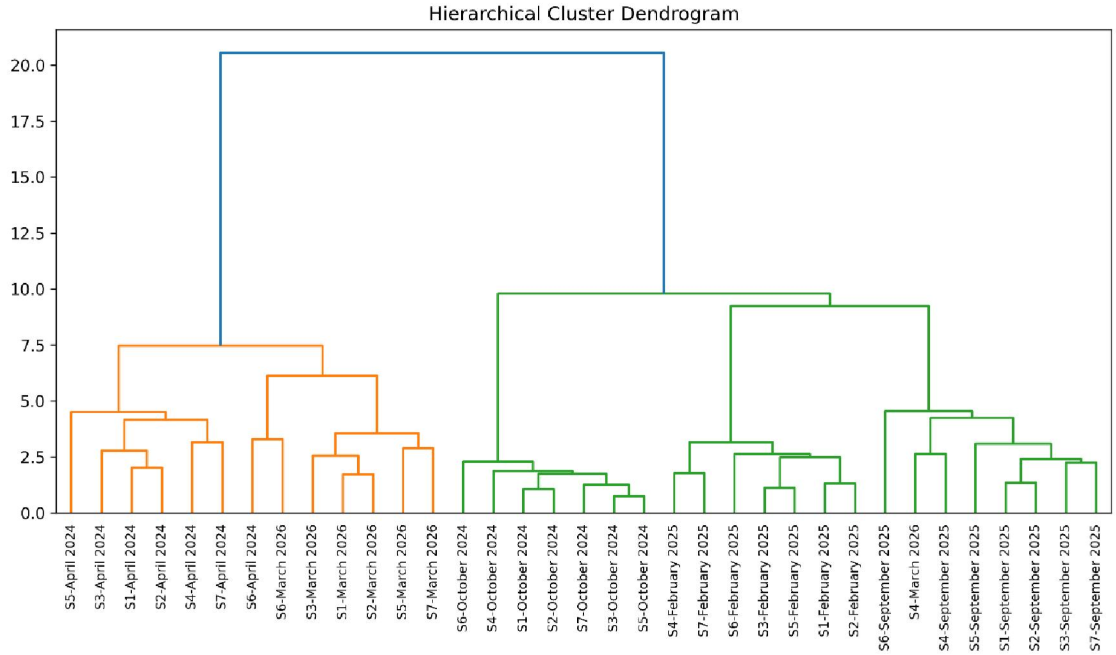


Figure 3. Hierarchical cluster analysis of sampling observations.

Hierarchical clustering was performed using **Ward's minimum variance method** based on Euclidean distance. The dendrogram classifies sampling stations according to similarities in physicochemical characteristics and heavy metal concentrations, identifying highly polluted, moderately polluted, and relatively less contaminated groups. This matches our field observations: S2 is a direct drain outlet; S5 and S6 are shallow, stagnant zones where organic matter accumulates.

4.4 Correlation and principal component analysis

The correlation matrix (presented as a heatmap, Figure 4) shows very strong positive links among BOD, COD, TS, lead, cadmium, zinc and copper ($r > 0.80$). These all come from the same source – untreated sewage. DO is strongly negative with these variables (r around –0.85), confirming that oxygen depletion is the main symptom of organic loading.

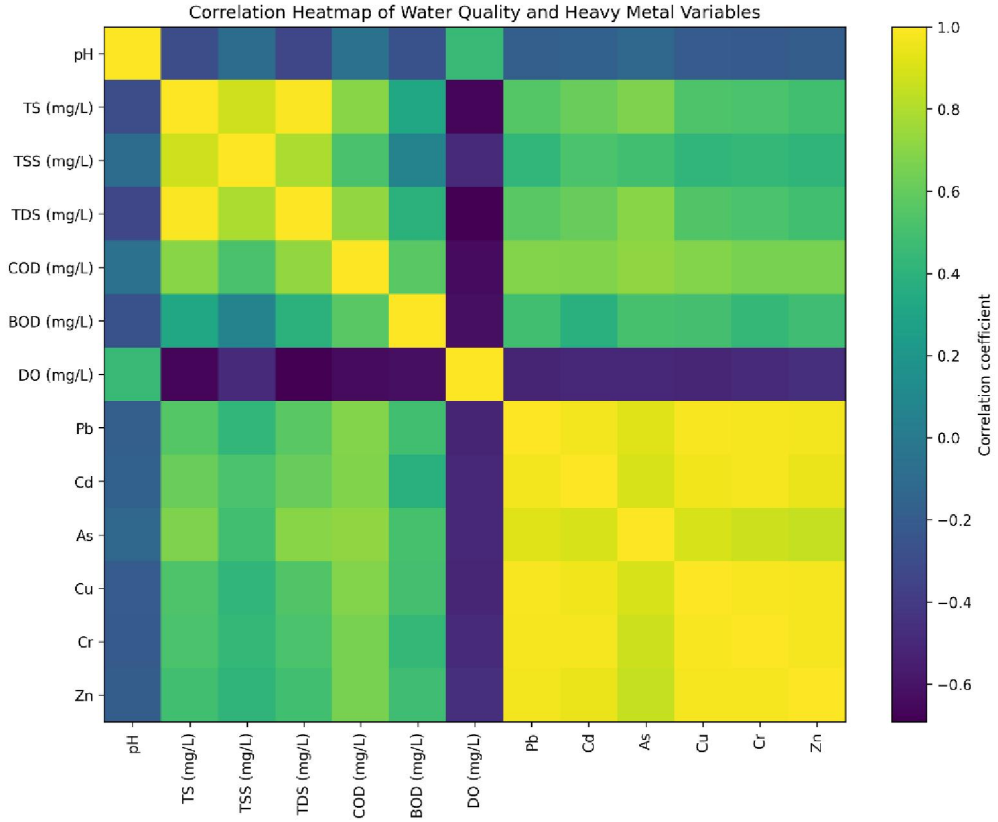


Figure 4. Correlation heatmap showing relationships among physicochemical parameters and heavy metals in Ramgarh Lake. Positive correlations indicate common pollution sources and co-occurrence patterns, whereas negative correlations highlight inverse relationships such as the association between dissolved oxygen and pollution indicators.

PCA extracted three principal components that together explain 78% of the total variance (Table 3).

- **PC1 (47% of variance):** high positive loadings for BOD, COD, lead, cadmium, zinc, copper, and negative loading for DO. We interpret this as a "sewage + metals" axis.
- **PC2 (20% of variance):** high loadings for chromium, arsenic, and TSS. This may represent a different source – possibly small-scale electroplating or historical pesticide residues.
- **PC3 (11% of variance):** pH and DO – the natural buffering and re-aeration process.

Table 3. Rotated component loadings from PCA. Loadings above 0.70 are shown in bold.

Parameter	PC1 (47%)	PC2 (20%)	PC3 (11%)
pH	–0.22	–0.18	**0.81**
TS	**0.86**	0.21	–0.24
TSS	0.45	**0.72**	0.11
TDS	0.68	0.19	–0.43

Parameter	PC1 (47%)	PC2 (20%)	PC3 (11%)
COD	**0.91**	0.12	–0.18
BOD	**0.94**	0.08	–0.22
DO	**–0.88**	–0.15	0.31
Pb	**0.89**	0.24	–0.11
Cd	**0.92**	0.19	–0.08
As	0.36	**0.77**	–0.05
Cu	**0.83**	0.33	–0.09
Cr	0.41	**0.81**	0.07
Zn	**0.90**	0.22	–0.14

The PCA biplot (Figure 5) clearly separates April samples (high PC1) from October samples (low PC1). Winter and spring samples fall in between.

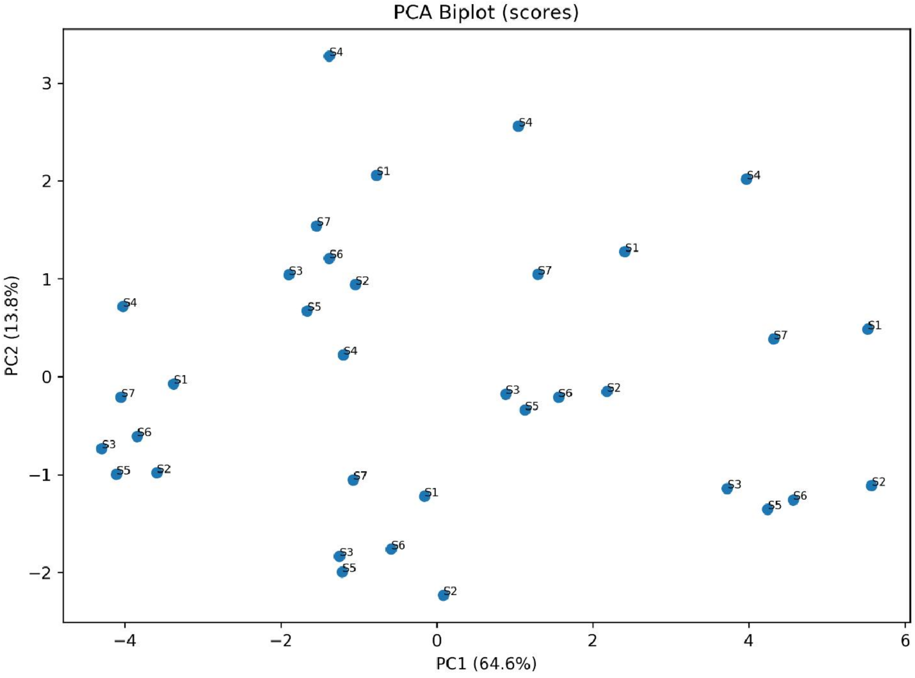


Figure 5. Principal Component Analysis (PCA) of water quality variables.

(A) Scree plot showing the percentage of total variance explained by each principal component. Components with eigenvalues >1 were retained according to the Kaiser criterion.

(B) PCA biplot illustrating the distribution of sampling observations and variable loadings along the first two principal components. Vectors indicate the magnitude and direction of variable contributions. Samples with similar physicochemical characteristics cluster together, whereas variables pointing in similar directions exhibit positive associations.

4.5 Water quality and risk indices

Water Quality Index (WQI): Only samples from October (post-monsoon) fall into the "poor" category (WQI 100–200). All summer, winter, and most spring samples are either "very poor" (200–300) or "unsuitable" (>300). The overall mean WQI is 342, meaning the water is not safe for drinking or even for direct contact recreation.

Heavy Metal Pollution Index (HPI): The critical value is 100. Our overall HPI is 245 – well above the threshold. April samples average 387, October 118. Even the best season exceeds the critical index.

Pollution Load Index (PLI): Values above 1 indicate human-caused enrichment. Our PLI ranges from 2.34 (October) to 4.56 (April). The overall PLI is 3.48, which means very high pollution load.

Potential Ecological Risk Index (PERI): An overall PERI of 387 corresponds to "considerable to high ecological risk". Cadmium alone contributes 197 points (very high risk), followed by lead (118). Zinc and chromium contribute very little. Reducing cadmium and lead should be the top priority for risk management.

V. DISCUSSION

5.1 Why does Ramgarh Lake become so polluted in summer?

Two things happen at the same time. First, evaporation reduces the water volume. The same waste load ends up in less water, so concentrations rise. Second, warm water and high organic matter trigger a chain reaction: bacteria decompose organic waste rapidly, consuming all available oxygen. Once DO drops below about 2 ppm, the sediment surface becomes anoxic. Under these conditions, iron and manganese oxides – which normally bind heavy metals – dissolve, releasing toxic metals back into the water column. This is why lead and cadmium levels in April are much higher than can be explained by evaporation alone.

This seasonal "trap" is common in shallow tropical lakes, but the severity at Ramgarh is exceptional. BOD values over 200 ppm are typical of raw sewage, not a natural lake. In effect, during summer the lake functions as an open waste stabilisation pond.

5.2 How does Ramgarh compare with other lakes?

Similar but less severe cycles have been reported for Bellandur Lake in Bangalore, where BOD reaches 80–120 ppm in summer (Ramachandra et al., 2016), and for Loktak Lake in Manipur, where BOD peaks at 18 ppm (Singh & Singh, 2017). Ramgarh's combination of extreme BOD (>200 ppm) *and* extreme metal contamination (lead >4 ppm) is unusual. We are not aware of any other Indian lake with routine lead levels above 1 ppm in the water column; most studies report values below 0.5 ppm (Malik & Maurya, 2014; Harikumar et al., 2009).

Post-monsoon recovery is also seen elsewhere. Dal Lake shows improved DO and lower nutrients after monsoon flushing (Wani et al., 2020). However, in Ramgarh even the "clean" October water has lead 1.55 ppm – still 150 times the WHO guideline. This suggests that the background metal load from sediments is already so high that dilution alone cannot bring the lake back to a safe state.

Winter in Ramgarh (February) has the highest DO (up to 8.3 ppm), similar to temperate lakes, but BOD remains above 30 ppm. In a healthy lake, winter BOD should be below 3 ppm (CPCB, 2012). So Ramgarh never truly recovers.

5.3 Where do the heavy metals come from?

The high correlations among lead, cadmium, zinc and copper, together with their association with BOD and COD (PC1), point unequivocally to untreated sewage as the main source. This matches findings from Vembanad Lake, where a similar metal-organic consortium was linked to municipal waste (Harikumar et al., 2009). In Chilika Lake, however, metals were more associated with industrial effluents (Pandey et al., 2021). The absence of major industries around Ramgarh supports our sewage hypothesis.

The secondary axis (PC2) with chromium and arsenic is more puzzling. Chromium often indicates leather tanning or chrome plating. There is no large tannery in Gorakhpur, but small-scale electroplating units and metal-finishing workshops exist in the city. Arsenic may come from agricultural pesticides (used historically) or from natural sources –

the Gangetic plains are known to have arsenic in groundwater (Chakraborti et al., 2016). Sediment core analysis would help resolve this.

The sharp increase in metals from March to April, even before maximum evaporation, strongly suggests sediment remobilisation under anoxia. Similar observations have been reported from Lake Erie (USA), where summer hypoxia triggers iron-bound metal release (Biddanda et al., 2018). In Lake Taihu (China), anoxic events caused a five-fold increase in dissolved cadmium within two weeks (Wang et al., 2015). Our data follow the same pattern.

5.4 Ecological and public health risks

The PERI value of 387 means that Ramgarh Lake poses a **high ecological risk**. For comparison, PERI in Chilika Lake ranges from 150 to 300 (moderate to considerable risk) (Pandey et al., 2021). Upper Lake, Bhopal has a PERI around 120 (low to moderate) (Malik & Maurya, 2014). Ramgarh is among the more hazardous lakes in India.

Cadmium contributes the most to PERI (E_r□ = 197), followed by lead (118). Cadmium is a known carcinogen and causes kidney damage. Even at the mean Cd concentration of 0.023 ppm, long-term exposure can be harmful. The WHO drinking water guideline is 0.003 ppm – the lake exceeds that by nearly eight-fold on average, and 14-fold in April.

People who eat fish from Ramgarh are at risk. Several studies have shown that fish from contaminated lakes accumulate cadmium and lead in their muscles and liver. For example, *Labeo rohita* from a polluted tank in Hyderabad had lead levels of 1.2 ppm (wet weight), exceeding the FAO/WHO limit (Murtaza et al., 2015). We did not measure fish here, but given the water concentrations, we strongly suspect that fish from Ramgarh would also exceed safe limits.

5.5 Comparison with drinking water standards

A quick comparison makes the severity clear:

Parameter	WHO drinking water guideline	Ramgarh (mean)	Ramgarh (April max)	Typical range in other Indian lakes
Pb (ppm)	0.01	2.48	4.34	0.05–0.50
Cd (ppm)	0.003	0.023	0.043	0.002–0.010
As (ppm)	0.01	0.049	0.083	0.005–0.030
DO (ppm)	>5 (for aquatic life)	4.12	0.50	3.0–6.0

Ramgarh's values are one to two orders of magnitude higher than typical polluted Indian lakes. This is not just a local problem; it is a public health emergency waiting to happen.

5.6 Limitations of this study

We did not analyse sediments, which likely contain metal concentrations 100–1000 times higher than water. Those sediments act as a long-term internal source. We also did not measure fish tissue or macroinvertebrates, so we cannot directly confirm biomagnification. Flow measurements of incoming drains would allow mass loading calculations. These are directions for future research.

VI. CONCLUSIONS AND RECOMMENDATIONS

Ramgarh Lake is in a critical state. The evidence from two years of monitoring, supported by statistical analysis and multiple pollution indices, it is clear that the lake undergoes an extreme seasonal cycle: from a highly toxic, anoxic state in pre-monsoon to a moderately polluted but still unsafe state in post-monsoon. No season meets drinking water or even aquatic life standards.

Heavy metal contamination is severe. Lead and cadmium are the most dangerous, exceeding WHO guidelines by 150–400 times. The Potential Ecological Risk Index (387) indicates high risk to the ecosystem – higher than many other polluted Indian lakes.

Untreated sewage is the main culprit. The strong correlation of BOD, COD, lead, cadmium and zinc points directly to municipal drainage. Three stations (S2, S5, S6) are hotspots and should be prioritised for intervention.

From our study it is recommended that diversion of the main sewage-carrying drains into settling ponds or constructed wetlands before they enter the lake. Establishment of a regular monitoring programme (monthly sampling at key stations) and enforce pollution control regulations on nearby colonies may be beneficial for the health of Ramgarh Lake. Phytoremediation can also help to remove some metals.

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