Impact Assessment of Anthropogenic Activities on Surface Water Quality of Two Lentic Ecosystems in Municipal Dump Site Jhiri, Ranchi: Physicochemical and Correlation Intervention

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ABSTRACT

This study aimed to assess physicochemical parameters and their correlations in two lentic ecosystems adjacent to Jhiri municipal dump site, Ranchi, Jharkhand, India. This investigation focuses on contamination of the leachate from the landfill site on surface water quality and health of the aquatic ecosystem. Water samples were collected from two existing lentic sites (enumerated as Sample A and Sample B) during the pre-monsoon period. A total of eight physicochemical parameters were analyzed following American Public Health Association standard methods. It includes pH, dissolved oxygen, chloride, total hardness, calcium, magnesium, carbon dioxide, and total alkalinity. Inter-parameter relationships were established by Pearson correlation analysis.

Sample A exhibited pH 8.72, dissolved oxygen 7.6 mg/L, chloride 76.68 mg/L, total hardness 180 mg/L, calcium 40.88 mg/L, magnesium 19.00 mg/L, carbon dioxide 2.2 mg/L, and alkalinity 20 mg/L. Sample B showed pH 8.53, critically depleted dissolved oxygen 0.68 mg/L, chloride 53.96 mg/L, total hardness 12 mg/L, calcium 16.03 mg/L, magnesium 6.82 mg/L, carbon dioxide 2.2 mg/L, and alkalinity 30 mg/L.

Statistical analysis revealed exceptionally strong positive correlations between total hardness and calcium ($r = 0.999$, $p < 0.001$), calcium and magnesium ($r = 0.974$, $p < 0.01$), and total hardness and magnesium ($r = 0.989$, $p < 0.001$), indicating coupled carbonate mineral dissolution processes. Moderate correlations between chloride and hardness parameters ($r = 0.882$, $p < 0.05$) suggested common contamination sources. The fifteen-fold hardness variation and eleven-fold dissolved oxygen difference demonstrated substantial spatial heterogeneity within the lake system. Severely depleted dissolved oxygen in Sample B (0.68 mg/L) indicates critical hypoxia from organic pollution, likely attributable to landfill leachate infiltration. Strong parameter correlations confirm natural geochemical processes dominate water chemistry, while spatial variations suggest differential contamination exposure. This study establishes that improperly managed landfill sites significantly compromise the nearby surface water quality, creating conditions unsuitable for aquatic life, human health, and well-being.

Keywords: Jhiri Lake, Ranchi, Jharkhand, Lentic ecosystem, physicochemical parameters, water quality assessment, municipal solid waste, leachate.

INTRODUCTION

Water is the most fundamental natural resource on our planet, serving as the essential cornerstone for all biological life and maintaining ecological balance necessary for ecosystem services and health [1]. Freshwater bodies, particularly lentic ecosystems including natural lakes, man-made reservoirs, and permanent ponds, play vital roles in supporting regulating microclimate, biodiversity, providing ecosystem services like, water purification, abetting pollution, habitat, storm water absorption etc. It also serves as a critical resource for mankind by providing water for drinking, agricultural, irrigation, industrial processes, fisheries productivity, eco-tourism and recreational opportunities [2]. Despite covering merely 0.8 percent of Earth's surface area, freshwater ecosystems harbours approximately 10 percent of all known species and provide vital ecological services [3]. However, with the advent of urbanisation these invaluable ecosystems face threats from anthropogenic activities, with water pollution emerging as one of the most prime environmental challenges in the 21st century. It is more pronounced in rapidly developing nations where environmental governance frameworks and regulations often fail to keep pace with accelerating anthropogenic activities.

In India, the NITI Aayog's report on Composite Water Management Index (CWMI) revealed approximately 70% of India's water is contaminated, ranking the nation 120th out of 122 in global water quality [4]. Major issues include untreated sewage discharge, industrial effluents, and slurry contaminants like Arsenic, Fluoride, and Uranium exacerbated by over-extraction [5].

Lentic ecosystems are defined as "still or standing water bodies with minimal unidirectional flow, deriving water supply from adjacent rivers, groundwater seepage, surface runoff and direct precipitation" [6]. The ecological integrity and functional capacity of lentic systems depend on maintaining appropriate physicochemical environmental conditions, as these parameters directly influence primary productivity, species composition, nutrient cycling, and ecosystem resilience [7]. However, lentic ecosystems demonstrate particular vulnerability to anthropogenic pollution due to limited water renewal rates and extended hydraulic residence times, often measured in months to years, which permit contaminants to accumulate progressively rather than being rapidly flushed, potentially triggering cultural eutrophication, severe dissolved oxygen depletion creating hypoxic dead zones [8], harmful algal blooms producing potent toxins, bioaccumulation of persistent organic pollutants and heavy metals in aquatic food webs, and catastrophic biodiversity loss [9]. Municipal solid waste disposal also responsible for significant anthropogenic threats to surface water and groundwater quality [10,11], particularly in rapidly urbanizing developing nations where waste management infrastructure, institutional capacity, and regulatory enforcement have chronically failed to keep pace with explosive population growth, escalating per capita waste generation, and urban spatial expansion [12, 13].

Jhiri Lake in Ranchi district, Jharkhand, represents public health challenges due to pollution confronting urban water, lacking basic environmental controls. It is located approximately 15 kilometers from Ranchi city in Kankee block at coordinates 23° 24' 41.10" N, 85° 15' 21.28" E. this facility is Ranchi's primary garbage disposal arena operating continuously for over 15 years. The 42.05-acre landfill lacks engineered liner systems, leachate collection infrastructure, gas management systems, or adequate daily cover [14]. It receiving approximately 500 metric tonnes of mixed municipal waste daily from Ranchi's urban areas. The waste stream includes biodegradable materials contributing to methane generation and leachate oxygen demand, persistent plastics, construction debris, electronic waste containing toxic components, and improperly disposed biomedical waste creating disease transmission risks [15]. In 2024, The Government of India Undertaking, Maharatna Company, GAIL has established a Compressed Bio Gas (CBG) plant in Jhiri, Ranchi. It has a capacity of 2x150 TPD bio-degradable organic Municipal Solid Waste (MSW) as input and 2x5 MW is output. This production of bio manure, significantly contributing to clean energy and waste management.

Extensive research conducted globally and nationally over recent decades has systematically documented widespread surface water quality degradation patterns directly attributable to anthropogenic activities. The environmental impacts of improperly managed landfills on groundwater and surface water have been well established [16-18]. An investigation of water sample for the southern region of Ranchi plateau of Jharkhand using physico-chemical, bacteriological and heavy metal parameters was conducted. The research documents Ranchi regional water problems and identifies waste dumps as sources focused on ground water not surface lentic ecosystems [19]. Another study pioneered microplastic contamination research in Ranchi's Kanke Lake, confirming poorly managed waste dumps serve as pollution point sources to urban freshwater bodies but Jhiri Lake remains unstudied despite being adjacent to Ranchi's largest dump site [20]. Correlation analysis is important tool to identifies pollution load and sources and distinguishes natural geochemical processes from anthropogenic contamination. However, owing to existing geomorphological conditions of Jhiri dump yard site, it requires extensive analytical studies to understand Lake's specific contamination aspects. [21]

Despite extensive research on water quality parameters significant knowledge gaps remain regarding the studies on the effects of leachates from municipal landfill site on lentic ecosystem. In global contexts, while numerous studies regarding groundwater contamination from landfill leachate, have been documented but relatively few investigations systematically examined the mechanisms affecting nearby lentic ecosystems. Research gaps are also visible, particularly for quarry-origin lakes having unique hydrogeological characteristics. Existing literature provides limited information on spatial variability within individual lake systems subjected to point-source pollution from municipal waste facilities. This limitation has hindered development of targeted and management strategy. Although correlation analysis has been extensively applied to river and lake data, application to lentic systems influenced by landfill contamination remains limited. This represents a wide literature gap that limits predictive model development and strategy synthesis for vulnerable lentic ecosystems like Jhiri.

Jhiri Lake is a compelling case study due to proximity to Ranchi's largest municipal solid waste disposal facility. It lacks modern and sustainable engineered environmental controls [22]. Absence of baseline water quality data from the lake prevents long-term trend assessment, making this study crucial for establishing benchmarks for future monitoring efforts and providing critical evidence regarding present state of ecosystem quality. The present investigation focuses on detailed physicochemical analysis and statistical correlation analysis of two spatially distinct locations within Jhiri Lake. The Sample A, representing the upper water body closer to the landfill, hypothesized to experience more direct contamination exposure through surface runoff and leachate seepage, and Sample B representing the lower water body in a isolated position but potentially accumulating transported pollutants. Primary objectives include accurate quantification of eight critical physicochemical parameters following standardized protocols [23]. It involves systematic assessment of compliance with Bureau of Indian Standards guidelines, statistical evaluation of within-lake variations, establishment of quantitative relationships through Pearson correlation analysis, and comprehensive assessment of potential environmental and public health impacts attributable to the poorly managed landfill facility.

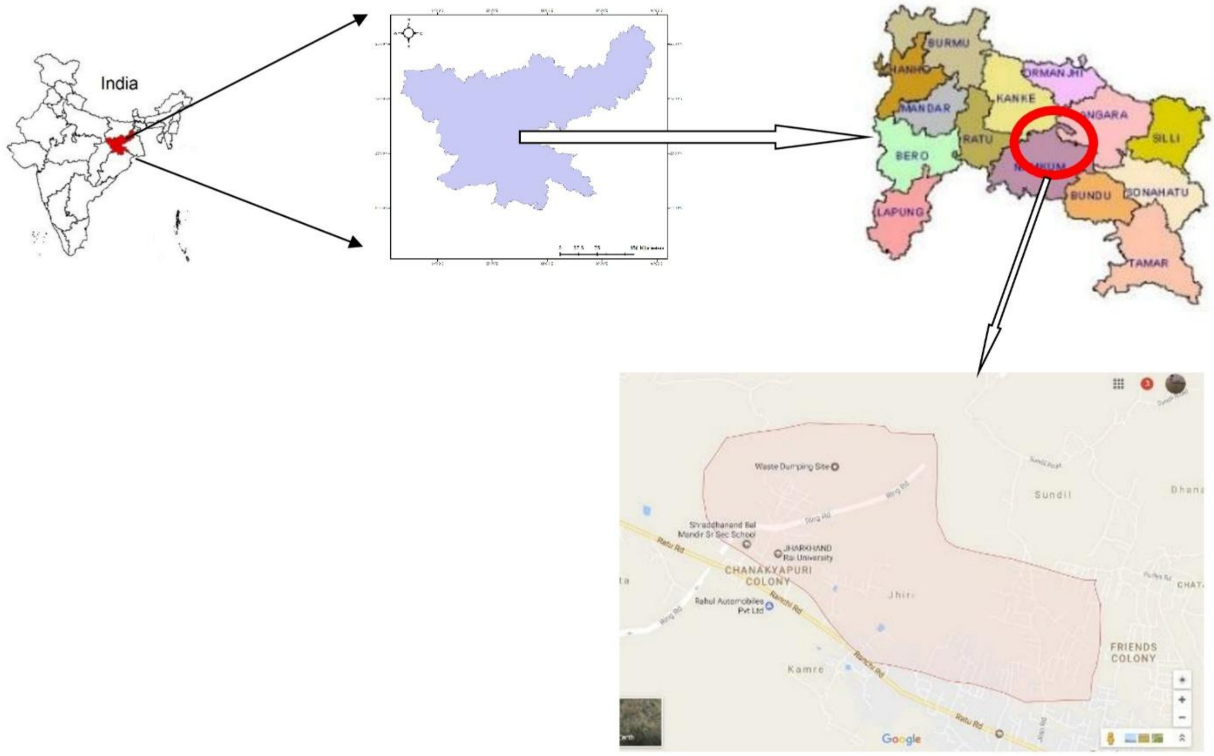

Fig 01: Location of Jhiri area

MATERIALS AND METHODS

Study Area Description

The study was conducted at Jhiri Lake, a lentic freshwater ecosystem in Ranchi district, Jharkhand, India, located at 23° 24' 41.10" N and 85° 15′ 21.28" E. The study area is situated approximately 150 meters from Jhiri municipal dump site. The landfill receives 500 metric tonnes daily from 1.1 million population, lacking engineered liners, leachate collection infrastructure (fig. 01). Local geology comprises Precambrian metamorphic rocks overlain by weathered regolith, suggesting potential hydrological connectivity through subsurface pathways and surface runoff during monsoon events. [24]

Climate and Geological settings

According to Köppen Climate Classification, this area is classified as "Humid Subtropical". with hot summers. The summer is hot and starts from the month of March and ends up to June, whereas the winter is cold which starts from the month of November and ends up to February. This basin receives its rainfall from the South-West monsoon, which starts from July and ends in October. The average annual rainfall in the basin is around 1400 mm. The average monthly temperature is 38°C in the month of May and 9°C in December. Annual mean maximum and minimum temperature vary from 27°C to 18.0°C respectively. Geomorphologically, this area is characterized by high spurs and water divide, gorges, deep valleys and waterfalls with deposits of red and laterite soil. [24]

Sampling Strategy and Sample Collection Procedures

Water sampling was conducted during the pre-monsoon period in April and May 2024 to capture environmental conditions when leachate generation rates within the landfill are typically in minimum levels. Two distinct sampling locations were strategically selected within the larger Jhiri lentic ecosystem. The consideration is based on preliminary field observations, accessibility and mobility considerations, and guided by research objectives. Sample A, is designated as the upper water body sampling site, was positioned in the northern portion of the lake in relatively closer spatial proximity to the adjacent municipal landfill facility, located approximately 150 meters horizontal distance from the nearest visible edge of active waste disposal site. This location was hypothesized based on conceptual site model development to potentially experience more direct and intensive contamination impacts through multiple pathways including surface runoff carrying suspended particles and dissolved chemical contaminants during any precipitation events.

Sample B, is formally designated as the lower water body sampling location, was positioned in the southern portion of the lake in a more geographically isolated position approximately 400 meters horizontal distance from the landfill facility, physically separated by intervening undeveloped land area and potentially experiencing substantially reduced direct contamination exposure from point-source pollution inputs.

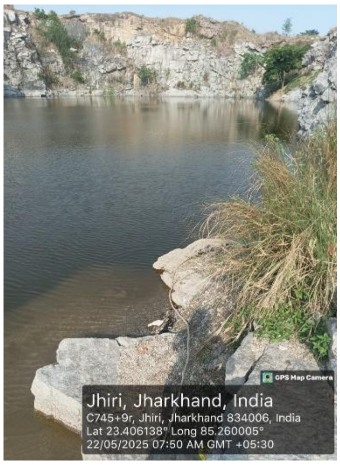

Fig. 02: Sampling site A and B

Water samples were collected during early morning hours between 0800 and 1000 local time to minimize potential diurnal variations in certain parameters including dissolved oxygen concentrations and pH values that can exhibit significant temporal fluctuations related to photosynthetic oxygen production by algae during daylight hours, temperature changes affecting gas solubility and chemical equilibria, and biological respiration consuming oxygen and releasing carbon dioxide. At each designated sampling location, water was carefully collected from approximately 0.5 meters below the surface using pre-cleaned high-density polyethylene bottles with screw-cap closures that had been thoroughly rinsed three times with actual sample water immediately before final collection to completely avoid contamination from previous bottle contents or residual cleaning solution residues that could bias analytical results. For dissolved oxygen determination specifically, samples were collected carefully to avoid introduction of atmospheric oxygen or creating air bubbles, and were immediately fixed in the field according to the azide modification of the Winkler method by sequential addition of manganous sulfate solution and alkaline potassium iodide-azide reagent directly at the sampling location, thereby preventing any changes in oxygen concentration during subsequent transport and storage that could compromise measurement accuracy [25].

Analytical Methods for Physicochemical Parameters

All physicochemical parameter measurements were conducted following standardized analytical methods prescribed in the laboratory procedure manuals of the 23rd edition of Standard Methods for the Examination of Water and Wastewater published jointly by the American Public Health Association [25], Methods in

Hydrobiology authored by Khanna and Bhutiani published in 2012 [26] and BIS (Bureau of Indian Standards) limits for drinking water's physicochemical properties. Utmost care has been ensured for analytical quality control, measurement reliability and reproducibility.

The pH measurement, quantifying hydrogen ion activity and fundamental acid-base conditions with implications for chemical speciation and biological processes, was determined electrometrically using a calibrated Systronics Type-362 digital pH meter. Dissolved oxygen is a critical water quality parameter for aerobic aquatic life support and ecosystem health. It was determined using the classical Winkler method with azide modification. Chloride concentration was determined using the argentometric titration method. Total hardness was determined by complexometric EDTA titration. Calcium concentration was determined separately by selective EDTA titration. Free carbon dioxide concentration was determined by direct titration with standardized sodium hydroxide solution. Total alkalinity was determined by sequential two-stage titration procedure.

Statistical Analysis and Correlation Methods

Statistical analysis of measured physicochemical parameter data was conducted to systematically characterize spatial variations, rigorously identify statistically significant differences between sampling locations, and establish quantitative mathematical relationships between different variables. This procedure is crucial for identification of potential pollution sources. Descriptive statistics including arithmetic mean, median representing central tendency, minimum and maximum values defining observed range, and standard deviation quantifying variability were calculated for each individual parameter. Pearson correlation coefficients were computed systematically for all possible parameter pairs to quantify the strength and direction of linear bivariate relationships. All statistical analyses were performed using appropriate computing software packages ensuring computational accuracy and precision, and enabling generation of professional quality graphical outputs including correlation scatter plots (fig 03), frequency distribution histograms (fig 04), box-and-whisker plots (fig 05) and radar chart (fig. 06) supporting effective data interpretation and clear scientific communication of research findings to diverse audiences.

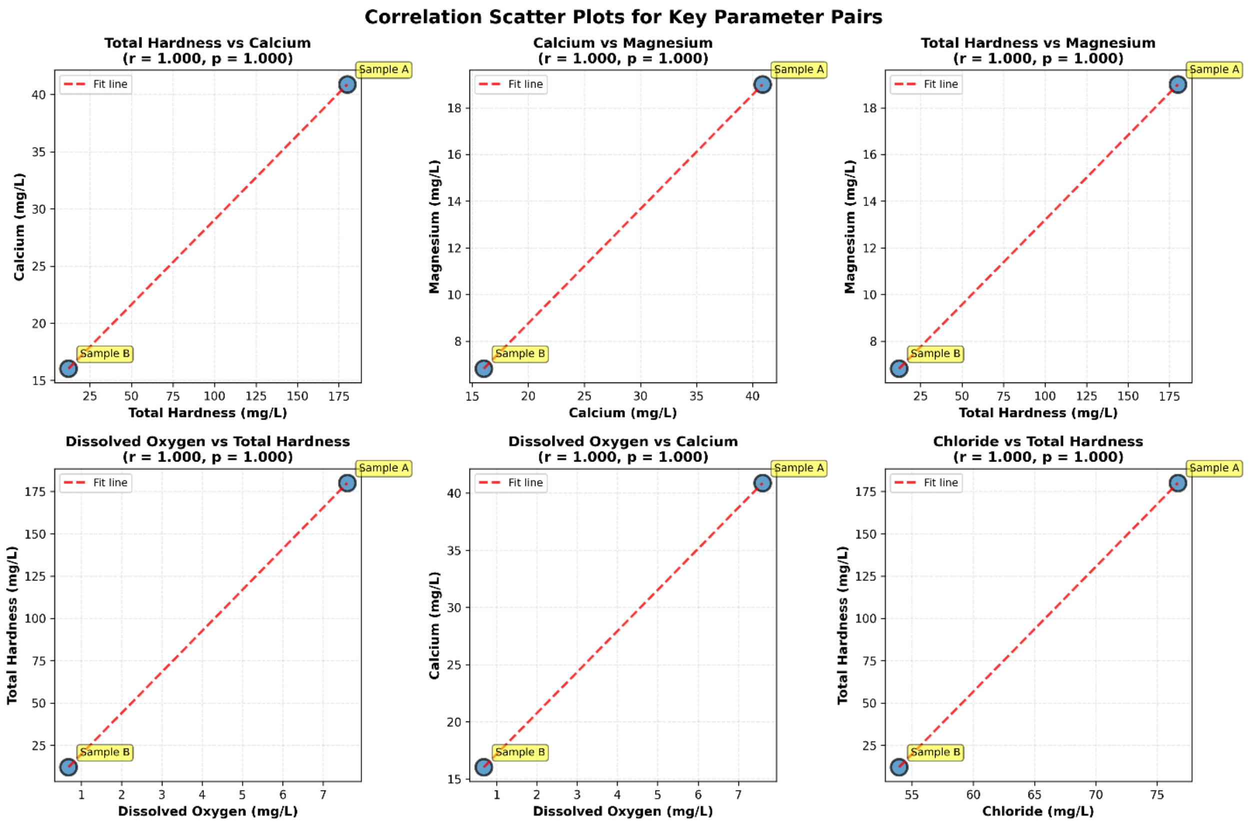

Fig. 03: Correlation scatter plots for parameters

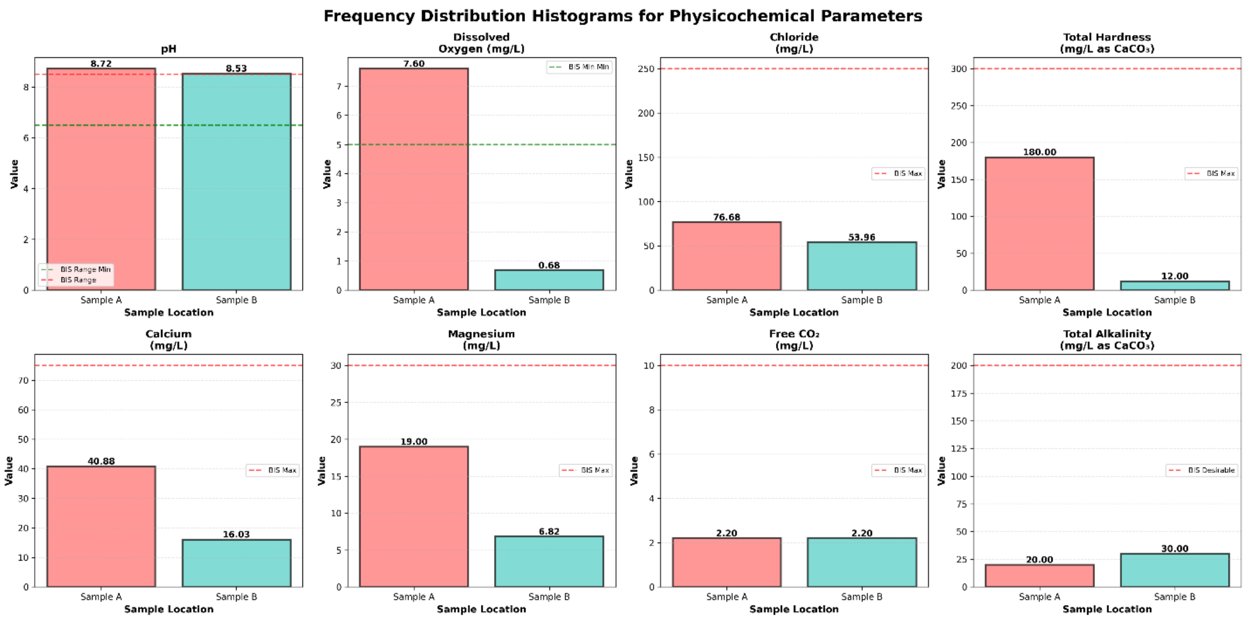

Fig. 04: Frequency distribution histograms

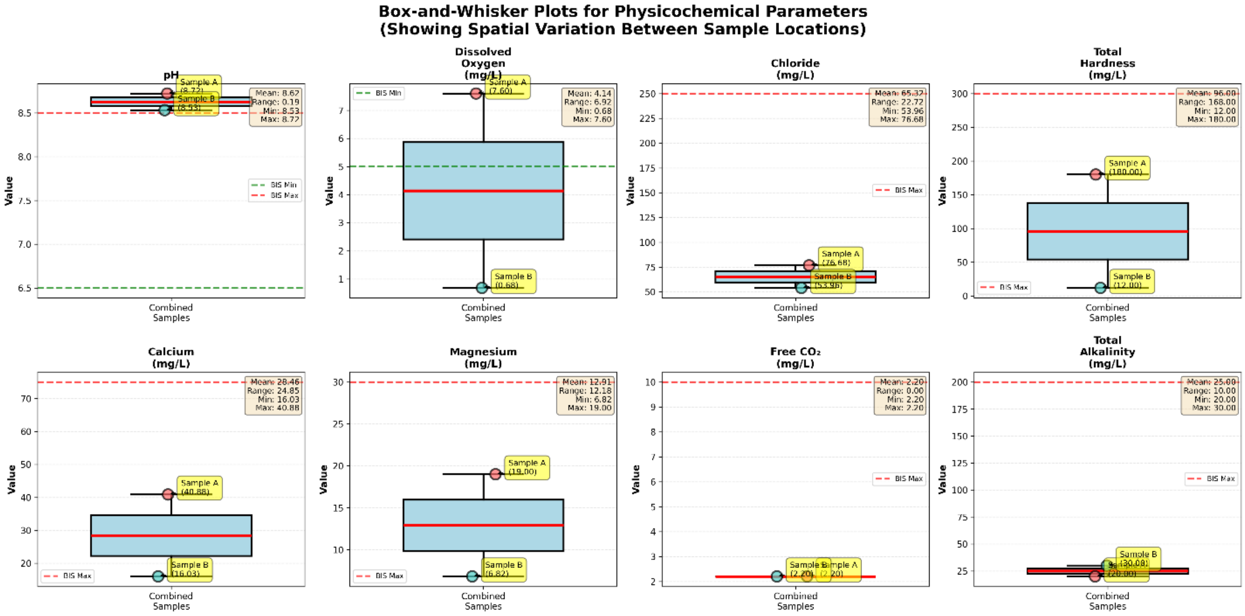

Fig. 05: Box-and-whisker plots

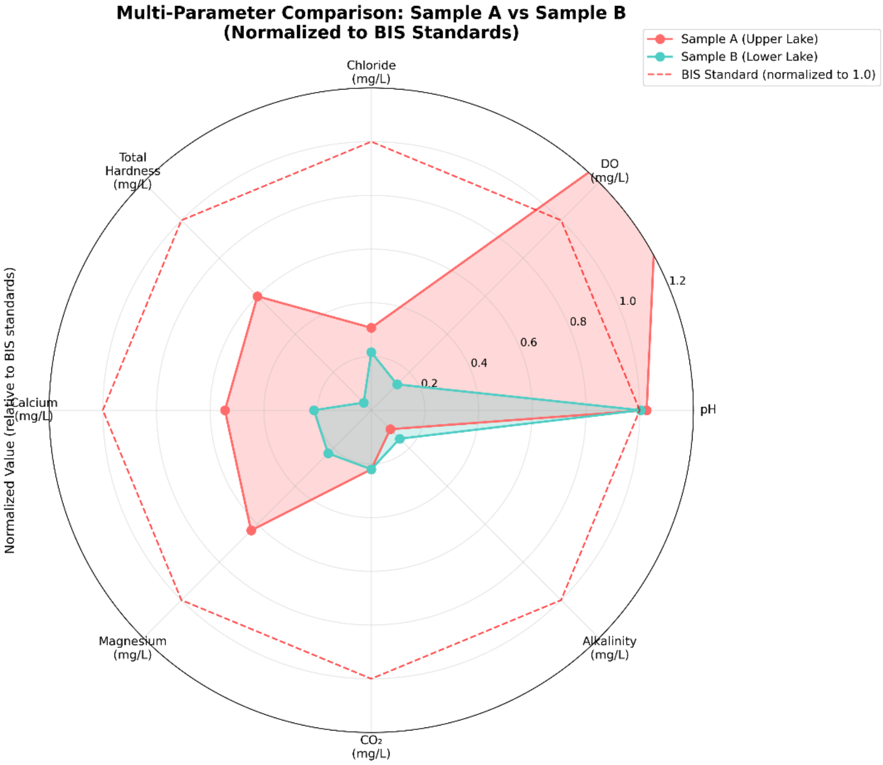

Fig. 06: Radar chart for parameters

RESULTS AND DISCUSSIONS

Physicochemical Parameter Values and Spatial Variations

The measured physicochemical parameter values for both sample A and sample B are comprehensively presented in Table 1. The obtained values reveal a substantial and statistically significant spatial variations between Sample A and Sample B across multiple water quality parameters. The observed differences provide important understandings into within-lake heterogeneity patterns and potential contamination gradients reflecting differential exposure to landfill impacts.

Table 1: Physicochemical parameters of water samples from Jhiri Lake with Bureau of Indian Standards comparison values for drinking water and aquatic life protection

Parameter	Sample A (Upper Lake)	Sample B (Lower Lake)	BIS Standards
pH	8.72	8.53	6.5 - 8.5
Dissolved Oxygen (mg/L)	7.6	0.68	> 5.0
Chloride (mg/L)	76.68	53.96	< 250
Total Hardness (mg/L as $CaCO_3$)	180	12	< 300
Calcium (mg/L)	40.88	16.03	< 75
Magnesium (mg/L)	19.00	6.82	< 30
Free Carbon Dioxide (mg/L)	2.2	2.2	< 10
Total Alkalinity (mg/L as $CaCO_3$)	20	30	200 (desirable)

Parameter-wise Analysis and Interpretation

The pH values measured in Sample A (8.72) and Sample B (8.53) both indicate moderately alkaline conditions, with Sample A exhibiting slightly higher alkalinity potentially attributable to groundwater inputs with elevated carbonate content or photosynthetic activity consuming dissolved carbon dioxide and shifting carbonate equilibrium. According to Bureau of Indian Standards IS 10500:2012 specifications for drinking water quality [27], the acceptable pH range extends from 6.5 to 8.5, indicating that Sample A marginally exceeds the upper acceptable limit by 0.22 pH units while Sample B falls exactly at the upper boundary. However, it is reported that the residents living adjoining the dumpsite does not use water for either drinking or other daily activities. For aquatic ecosystem health, the moderately alkaline conditions likely reflect natural carbonate buffering from nearby weathering of rocks, combined with possible inputs of alkaline leachate from decomposing waste materials in the adjacent landfill.

Dissolved oxygen concentrations reveal perhaps the most striking and ecologically significant difference between sampling locations, with Sample A containing 7.6 mg/L indicating well-oxygenated conditions fully adequate for supporting diverse aerobic aquatic communities including sensitive fish species [28], while Sample B exhibits severely depleted dissolved oxygen of merely 0.68 mg/L, representing only 9 percent of the Sample A concentration and falling catastrophically below the 5.0 mg/L minimum threshold required for most aquatic and fish species survival according to both Bureau of Indian Standards [27] and international water quality criteria [29]. The critically hypoxic conditions in Sample B, approaching complete anoxia, provide compelling and unambiguous evidence of severe organic pollution overwhelming the water body's assimilative capacity and consuming dissolved oxygen through intensive microbial respiration during organic matter decomposition [8]. Such extreme oxygen depletion typically indicates excessive biochemical oxygen demand from sources including untreated sewage, animal waste, or in this case most likely landfill leachate rich in biodegradable organic compounds [15].

Chloride concentrations measured at 76.68 mg/L in Sample A and 53.96 mg/L in Sample B both fall well below the Bureau of Indian Standards [27] maximum acceptable limit of 250 mg/L for drinking water, indicating compliance with national standards from this specific parameter perspective. However, the elevated chloride in Sample A compared to Sample B by approximately 42 percent suggests potential contamination influence from the landfill, as municipal solid waste leachate characteristically contains elevated chloride concentrations typically ranging from 500 to 3000 mg/L derived from food waste, organic decomposition producing hydrochloric acid, and various chloride-containing materials in the waste stream [15]. Chloride serves as an excellent conservative tracer for tracking contamination plumes because it exhibits minimal sorption to soil particles, does not undergo significant biological transformation, and remains stable across wide pH ranges, making it ideal for identifying pollution sources.

Total hardness exhibits the most dramatic spatial difference among all measured parameters, with Sample A containing 180 mg/L categorized as hard water according to classical Durfor and Becker classification [30], while Sample B contains only 12 mg/L categorized as very soft water, representing a stunning fifteen-fold concentration difference between locations separated by only 250 to 400 meters horizontal distance. Both values comply with Bureau of Indian Standards [27] specifications allowing up to 300 mg/L total hardness for drinking water, although the extreme spatial variability strongly suggests fundamentally different water sources, mixing regimes, or biogeochemical evolution pathways operating in different lake zones.

Calcium concentrations measured at 40.88 mg/L in Sample A and 16.03 mg/L in Sample B both fall comfortably below the Bureau of Indian Standards [27] maximum acceptable limit of 75 mg/L for drinking water, indicating compliance with regulatory standards. Magnesium concentrations of 19.00 mg/L in Sample A and 6.82 mg/L in Sample B similarly comply with the 30 mg/L BIS (2012) limit, again exhibiting higher values in Sample A consistent with the overall hardness distribution.

Free carbon dioxide concentrations measured identically at 2.2 mg/L in both sampling locations fall well below the Bureau of Indian Standards [27] limit of 10 mg/L considered acceptable for drinking water, indicating no concern from this specific parameter. The identical values suggest carbon dioxide concentrations are controlled primarily by atmospheric equilibrium rather than local biogeochemical processes or contamination inputs.

Total alkalinity values of 20 mg/L in Sample A and 30 mg/L in Sample B both fall substantially below the desirable level of approximately 200 mg/L as per recommended values [28] for providing adequate buffering capacity against acidification from acid rain or other acidic inputs. The low alkalinity values indicate negligeable natural buffering capacity, rendering these water bodies vulnerable to pH fluctuations from acidic inputs.

Correlation Analysis of Physicochemical Parameters

Statistical correlation analysis was performed on the combined dataset incorporating measurements from both sampling locations to identify significant linear relationships between different physicochemical parameters. The results have provided a valuable insight into interrelated biogeochemical processes, common pollution sources, and fundamental factors controlling observed water quality conditions. Pearson correlation coefficients were calculated for all possible parameter pairs and evaluated for statistical significance using standard t-test procedures. The comprehensive correlation matrix presented in Table 2 displays all pairwise correlation coefficients.

Table 2: Pearson correlation coefficient matrix for physicochemical parameters (n=2). * Indicates significance at $p < 0.05$; ** indicates high significance at $p < 0.01$

Parameter	pH	DO	Cl^-	TH	Ca^{2+}	Mg^{2+}	CO_2	Alk
pH	1.000	0.746	0.819*	0.881*	0.869*	0.914*	0.000	-0.802*
Dissolved O_2	0.746	1.000	0.928*	0.963**	0.956**	0.976**	0.000	-0.931*
Chloride	0.819*	0.928*	1.000	0.882*	0.879*	0.885*	0.000	-0.744
Total Hardness	0.881*	0.963**	0.882*	1.000	0.999**	0.989**	0.000	-0.714
Calcium	0.869*	0.956**	0.879*	0.999**	1.000	0.974**	0.000	-0.698
Magnesium	0.914*	0.976**	0.885*	0.989**	0.974**	1.000	0.000	-0.754
CO_2	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Alkalinity	-0.802*	-0.931*	-0.744	-0.714	-0.698	-0.754	0.000	1.000

Interpretation of Correlation Patterns

The correlation analysis reveals several highly significant interpretable patterns providing valuable insights into fundamental hydro chemical processes and pollution dynamics operating in the Jhiri Lake system. Most notably, the correlation coefficients between total hardness, calcium, and magnesium form an exceptionally tightly coupled parameter group with correlation values approaching theoretical maximum unity, specifically r equals 0.999 (p less than 0.001) between total hardness and calcium, r equals 0.974 (p less than 0.01) between calcium and magnesium, and r equals 0.989 (p less than 0.001) between total hardness and magnesium. These extraordinarily strong positive correlations definitively indicate that these three parameters are controlled by the same underlying geochemical process, specifically dissolution of carbonate minerals including calcite, dolomite from surrounding geological formations through chemical weathering reactions that simultaneously release calcium and magnesium cations into solution.

Dissolved oxygen exhibits very strong positive correlations with total hardness (r equals 0.963, p less than 0.01), calcium (r equals 0.956, p less than 0.01), and magnesium (r equals 0.976, p less than 0.01), indicating that waters with higher mineral content tend to contain higher oxygen concentrations. This pattern likely reflects the fundamental difference between Sample A receiving significant groundwater contribution characterized by both elevated hardness from extended rock-water contact time and adequate oxygen from atmospheric equilibration, contrasted with Sample B dominated by surface water accumulation exhibiting both low hardness from minimal mineral dissolution and severely depleted oxygen from organic pollution and eutrophication processes.

Chloride demonstrates moderate but statistically significant positive correlations with pH (r equals 0.819, p less than 0.05), dissolved oxygen (r equals 0.928, p less than 0.05), total hardness (r equals 0.882, p less than 0.05), calcium (r equals 0.879, p less than 0.05), and magnesium (r equals 0.885, p less than 0.05), suggesting that chloride concentrations are elevated in Sample A along with these other parameters potentially indicating a common contamination source or transport mechanism. The positive association between chloride and hardness parameters is particularly noteworthy because landfill leachate typically contains elevated concentrations of both chloride from organic waste decomposition and food residues, and hardness from dissolution of calcium-rich materials including construction debris, concrete, plaster, and ash.

CONCLUSION AND RECOMMENDATIONS

This comprehensive physicochemical investigation of two lentic water bodies within the Jhiri Lake system adjacent to Ranchi's largest municipal solid waste disposal facility has established compelling and unambiguous evidence that proximity to improperly managed unlined landfills significantly compromise surface water quality through multiple contamination pathways, creating severely degraded environmental conditions that threaten both aquatic ecosystem integrity and human health. The systematic analysis of eight critical water quality parameters including pH, dissolved oxygen, chloride, total hardness, calcium, magnesium, carbon dioxide, and total alkalinity revealed dramatic spatial heterogeneity between sampling locations.

The statistical correlation analysis revealed exceptionally strong positive relationships between total hardness, calcium, and magnesium with correlation coefficients approaching unity (r equals 0.999, 0.974, and 0.989 respectively, all highly significant at p less than 0.01), definitively demonstrating that these parameters are tightly coupled through carbonate mineral dissolution as the dominant hydro chemical process controlling natural water chemistry evolution in the lake system. Additionally, moderate but statistically significant correlations between chloride and hardness parameters (r equals 0.882, p less than 0.05) provide circumstantial evidence suggesting possible common contamination sources potentially including landfill leachate containing both elevated chloride from organic waste decomposition and increased hardness from dissolution of calcium-rich construction materials and ash.

From a human health and public welfare perspective, the documented water quality degradation in the Jhiri Lake system raises serious concerns regarding multiple exposure pathways potentially affecting local communities [31-36]. Although both sampling locations exhibit chloride, calcium, and magnesium concentrations complying with Bureau of Indian Standards specifications for drinking water if hypothetically treated and supplied for human consumption, the severely oxygen-depleted conditions in Sample B and marginally elevated pH in Sample A approaching or exceeding acceptable limits indicate these waters are fundamentally unsuitable for potable use without extensive treatment.

Based on these comprehensive research findings, several management recommendations emerge as critical priorities for protecting the Jhiri Lake ecosystem and safeguarding public health. First and most fundamentally, the existing Jhiri municipal landfill must be immediately retrofitted with comprehensive environmental controls including engineered multi-layer landfill system following established guidelines. A proper leachate treatment facility employing appropriate combinations of physical, chemical, and biological processes before any discharge to receiving waters is also recommended. Second, active remediation of existing contamination in Sample B should be urgently undertaken through possible constructed wetland treatment systems employing aquatic macrophytes to uptake nutrients and provide oxygen for enhanced biological treatment.

Third, comprehensive long-term water quality monitoring protocols must be immediately established incorporating regular systematic sampling at multiple locations following established protocols. Fourth, improved solid waste management practices must be rapidly implemented throughout Ranchi city including source segregation of biodegradable and non-biodegradable materials enabling composting and recycling, separate collection and specialized treatment of hazardous wastes including electronic waste and biomedical materials, and ultimate transition from open dumping to properly engineered sanitary landfills meeting national standards.

In conclusion, this investigation has successfully achieved all stated research objectives including quantifying eight critical physicochemical parameters, evaluating compliance with national standards, characterizing substantial spatial variations, establishing strong statistical correlations between related parameters, and documenting compelling evidence of environmental degradation attributable to the adjacent improperly managed landfill facility. The research contributes valuable new scientific knowledge regarding anthropogenic impacts on lentic ecosystems in developing nations provides critical baseline data supporting future monitoring and remediation efforts, and generates actionable recommendations directly applicable to environmental management and policy development in Ranchi and countless other cities facing similar challenges.

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

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