



Integrated Physico-Chemical and GIS-Based Assessment of Pollution in Lakes of Marathwada Region

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Abstract: The biological balance and the fundamental services provided by lakes are crucial to human and environmental well-being, making them valuable resources. But both natural and human caused activities are progressively endangering their quality. In this research, five lakes in the Marathwada area of Maharashtra, India, were analysed for water quality and pollution status using a mix of physico-chemical and GIS approaches. Heavy metals including cadmium, copper, manganese, and nickel, as well as important water quality indicators like hardness, pH, turbidity, chloride, and nitrate were examined. Some metrics, including turbidity and harmful amounts of cadmium, exceeded the allowed limits established by BIS and WHO regulations, indicating substantial contamination in many lakes. Land use and watershed features were analysed spatially using GIS software. This helped pinpoint pollution sources associated with urbanisation, agricultural runoff, and industrial effluents. In order to preserve ecological balance and public health in this semi-arid area that is water-stressed, the results show that targeted pollution control methods, sustainable lake management, and ongoing monitoring are necessary.

Keywords: Marathwada, GIS, Chloride, Heavy Metals, BIS, Physico-Chemical, Lakes

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INTRODUCTION

Lakes are vital freshwater resources that play a crucial role in sustaining ecological balance, supporting biodiversity, and fulfilling the socio-economic needs of human populations. In semi-arid regions like Marathwada, located in Maharashtra, India, lakes form a critical component of the hydrological system as they act as primary storage bodies for rainwater and surface runoff. These lakes are extensively utilized for domestic use, irrigation, livestock rearing, aquaculture, and in some cases, industrial purposes. However, in recent decades, rapid urbanization, population growth, agricultural intensification, and indiscriminate disposal of domestic and industrial effluents have severely affected the quality of water stored in these lakes. Pollution in freshwater ecosystems is now recognized as one of the most pressing environmental challenges in Marathwada, not only threatening the ecological health of lakes but also posing risks to human well-being, agricultural productivity, and sustainable water resource management.

Physico-chemical assessment of lake water provides critical insights into its quality status and helps in identifying the type and degree of pollution. Parameters such as pH, turbidity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total dissolved solids, hardness, and nutrient concentrations are widely used as indicators to measure the extent of contamination. Excessive levels of nutrients like nitrates and phosphates are often associated with eutrophication, leading to algal blooms, depletion of oxygen, and loss of aquatic life. Similarly, variations in hardness, alkalinity, or heavy metal content reflect the impacts

of agricultural runoff, untreated sewage, and industrial discharges. Regular monitoring and scientific evaluation of these parameters are therefore necessary to develop an accurate understanding of the pollution profile of lakes and to frame effective management strategies.

While physico-chemical studies provide detailed water quality information at selected points, they often lack spatial representation, which is essential for large-scale environmental management. In this context, Geographical Information System (GIS) has emerged as a powerful tool for analyzing, interpreting, and visualizing spatial data related to water resources. GIS-based approaches allow integration of multiple datasets such as land use/land cover patterns, watershed characteristics, drainage networks, and pollution sources with water quality results. This spatial dimension helps in mapping pollution hotspots, identifying vulnerable areas, and assessing the influence of anthropogenic activities on lake ecosystems. For example, GIS can be used to correlate agricultural land use around lakes with high nutrient levels, or to identify settlements contributing to domestic wastewater discharge. Thus, an integrated approach combining physico-chemical and GIS techniques ensures a more comprehensive and holistic assessment of lake pollution compared to conventional methods alone.

The Marathwada region is particularly vulnerable to water quality deterioration due to its unique climatic and socio-economic conditions. The region frequently experiences droughts and erratic rainfall, making lakes a lifeline for water supply during dry periods. Simultaneously, the dominance of agriculture in the local economy has increased dependency on chemical fertilizers and pesticides, leading to non-point source pollution in nearby water bodies. The growing urban centers and peri-urban settlements in Marathwada add further stress by discharging untreated sewage and solid waste into lakes. Moreover, the limited availability of surface water compels people to overexploit groundwater resources, intensifying the pressure on lakes as supplementary sources. These interlinked pressures necessitate a systematic evaluation of pollution levels and their spatial distribution across the region.

An integrated physico-chemical and GIS-based assessment not only reveals the present status of water quality but also assists in detecting long-term trends, identifying causal factors, and providing a scientific basis for policy interventions. Such studies are vital for lake conservation, restoration, and management, particularly in water-stressed regions like Marathwada, where sustainable use of freshwater resources is directly tied to livelihood security and regional development. The findings from this type of research can guide local authorities, environmental planners, and policy makers in implementing measures such as regulating effluent discharge, promoting eco-friendly agricultural practices, improving wastewater treatment facilities, and raising community awareness. Furthermore, spatially explicit water quality maps generated through GIS serve as user-friendly tools for decision-making and public communication.

Table 1: Standards set by the BIS (2012) and recommendations made by the WHO (2024)

Parameter	BIS Standard (2012) Acceptable Limit	BIS Standard (2012) Permissible Limit	WHO Guideline (2024) Value
pH	6.5–8.5	No relaxation	6.5–8.5

Turbidity	1 NTU	5 NTU	<5 NTU
Chloride	250 mg/L	1000 mg/L	250 mg/L
Total Hardness	200 mg/L	600 mg/L	100–300 mg/L
Residual Free Chlorine	0.2 mg/L	1 mg/L	0.2–0.5 mg/L
Fluoride	1 mg/L	1.5 mg/L	1.5 mg/L
Nitrate	45 mg/L	No relaxation	50 mg/L
Iron	0.3 mg/L	No relaxation	0.3 mg/L
Lead	0.01 mg/L	No relaxation	0.01 mg/L
Orthophosphate	1 mg/L	No relaxation	No guideline
Zinc	5 mg/L	15 mg/L	5 mg/L
Copper	0.05 mg/L	1.5 mg/L	2 mg/L
Arsenic	0.01 mg/L	0.05 mg/L	0.01 mg/L
Chromium	0.05 mg/L	No relaxation	0.05 mg/L
Manganese	0.1 mg/L	0.3 mg/L	0.4 mg/L
Cadmium	0.003 mg/L	No relaxation	0.003 mg/L
Nickel	0.02 mg/L	No relaxation	0.07 mg/L

The water quality standards prescribed by the Bureau of Indian Standards (BIS, 2012) and the World Health Organization (WHO, 2024) serve as benchmarks for assessing the suitability of drinking water. These guidelines specify acceptable and permissible limits for key physico-chemical parameters such as pH, turbidity, hardness, and essential ions. While BIS provides both acceptable and relaxation limits for most parameters, WHO guidelines emphasize safe thresholds to prevent health hazards. Adhering to these standards ensures that drinking water remains safe, palatable, and free from contaminants that can pose risks to human health.

In light of these considerations, the present study seeks to undertake an integrated assessment of pollution in selected lakes of the Marathwada region using a combination of physico-chemical analysis and GIS techniques. By analyzing key water quality parameters and correlating them with land use patterns and anthropogenic pressures, the study aims to provide a comprehensive understanding of the pollution dynamics affecting these freshwater bodies. This integrated approach will not only highlight the extent of degradation but also identify priority areas for intervention, thereby contributing to the sustainable management and conservation of lake ecosystems in Marathwada.

RESEARCH METHODOLOGY

Study Area

Chhatrapati Sambhajnagar and Jalna are two districts in Maharashtra that are included in the research. These districts are part of the Marathwada area.

In the heart of Chhatrapati Sambhajnagar city is Salim Ali Lake, which is around 4 meters deep on average [68], while the Harsul region is home to the city's other lake, Harsul Lake. While the mountainous landscape and agricultural area surround the Harsul Lake, human settlements surround the Salim Ali Lake, causing it to become contaminated by sources that humans create. Lake water quality declines due to runoff from adjacent farmland. Surrounded by farmland, the Somthana Lake is around 40 miles from the city of Chhatrapati Sambhajnagar. More than one million people call Chhatrapati Sambhajnagar home [69]. In the centre of the densely populated city of Jalna is the Moti Lake. The quality of the lake's water is greatly impacted by pollution that humans cause. Surrounded by farmland, the Kharpudi Lake lies around 8 km outside of the city. The quality of the lake's water could be diminished by direct runoff from farmland. More over 250,000 people call Jalna city home, as reported in the 2011 census [70]. The untreated discharge of residential wastewater into bodies of water inside cities increases the likelihood of contamination to these bodies of water. The Marathwada area is experiencing this worrying problem.

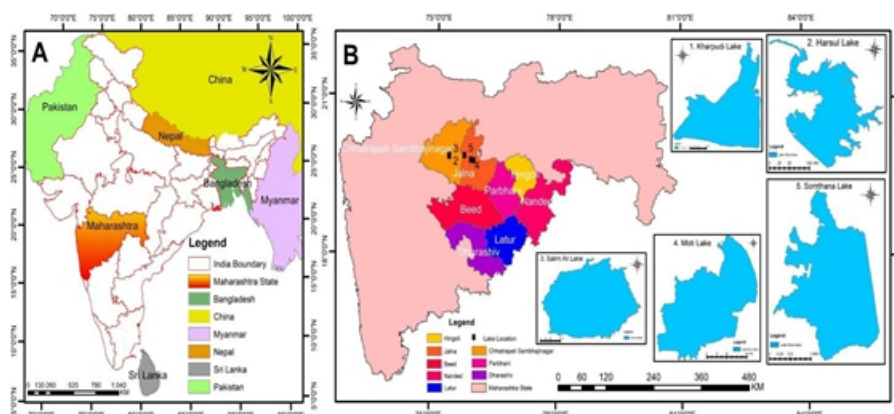


Figure 1: Area map for study. (A) the Indian subcontinent, (B) the Marathwada watershed

Marathwada is located in southern India, not far from the Deccan Volcanic Province. While laterite and bauxite rocks make up the remaining 14% of the Marathwada area, basalt rock from the Deccan Trap accounts for around 86%. There have been reports of dyke swarms in different regions of the Deccan Trap. Geological formations in the area range from gneisses and schists to intrusive rocks, sedimentary rocks from Gondwana, basalts from the Deccan trap, and both older and younger alluvium. The average monsoon rainfall in the Marathwada area is 636 mm, which indicates that the region often faces drought and water constraint. During the monsoon season, the area receives the bulk of its annual precipitation—about 903 mm.

Methods

Five lakes in the Marathwada areas were the subjects of the research. As part of our research, we used both in-situ and geospatial analysis. In order to understand the extent to which a certain aquatic

environment is polluted, it is essential to examine the physico-chemical properties of water samples.

Sample Collection

During the month of January, researchers collected water and sediment samples from each lake during the day using a random sampling approach. We took two samples from every lake. In sterile, previously cleaned bottle containers, around 1 litre of water was extracted. For safe shipment, we double-checked that the bottles were airtight. Proper labelling of samples prevented any possibility of misidentification during analysis, and geotagged images were taken at each sampling location to guarantee accurate documentation. The samples were brought to the lab for further physicochemical examination after being kept in a controlled environment at 20 °C.

Analysis based on physiochemistry

In a controlled environment, the water samples were tested for a variety of physical and chemical parameters. Acidity, turbidity, chloride, total hardness, nitrate, residual free chlorine, fluoride, orthophosphate, & heavy metals such as lead, zinc, arsenic, chromium, manganese, cadmium, copper, and nickel were among the physico-chemical parameters that were examined. For the purpose of evaluating water quality and pinpointing the origins of contamination, these metrics were chosen. To guarantee accuracy and consistency in all tests, standard procedures were followed and certified reagents and calibrated equipment were employed. All of the heavy metal and physicochemical analyses were conducted on water samples using rapid testing kits made by Himedia Laboratories Pvt. Ltd. of Mumbai, India. A growing number of laboratories are opting to adopt quick testing kits due to their portability, accuracy, and speed. In the field, these kits demonstrated their usefulness and efficacy to a large number of researchers [42–45,82–85]. Researchers looked for contaminants that may harm aquatic ecosystems and assessed the general lake water quality.

Delineating Watersheds

Using the ArcGIS 10.8 software, watershed delineation maps were created for every lake. The hydrological and geomorphological features of the studied areas could not be understood without this procedure. Within each watershed, the stream orders were determined and the flow of streams from higher to lower altitudes was mapped using SRTM-DEM. Because of this, we were able to assess the catchment regions' topography, stream flow dynamics, and slope gradients. These demarcation maps are useful for evaluating the watersheds' water supply and quality as well as for locating any pollution sources that may be impacting the lake's water quality. To make sense of the physico-chemical findings, a spatial framework that included the recognised geomorphological feature like rivers, valleys, and mountains was necessary.

Pearson Correlation Index

A Pearson correlation analysis was carried out to have a better understanding of the correlations between the different physico-chemical parameters. To find out how strong and in what direction two variables are linearly related, statisticians use the Pearson correlation coefficient. A high negative correlation is indicated by values closer to -1 and a strong positive correlation is indicated by values closer to +1 in the correlation coefficient, which may vary from -1 to +1. The resulting correlation coefficient may be used to correlate an

index; a lower value suggests a weaker connection and a larger value indicates a stronger one. In mathematics, the correlation coefficient is defined as the ratio of the covariance to the product of the standard deviations of two variables. Possible sources of pollution may also be located with the use of this correlation measure.

The Pearson correlation coefficient may be expressed mathematically as follows:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

Where

r = The Pearson correlation measure

x = Numbers in the first dataset

y = Second data set values

n = All values added together

Important relationships between water quality metrics were uncovered by this study. As an example, we looked at how turbidity correlated with the amount of suspended particles in the water samples and how pH levels correlated with metal ion concentrations. Important insights into the interplay between these characteristics and their effects on water quality were gleaned from the Pearson correlation study. In most cases, heavy metals have a detrimental effect on pH.

When the pH is lower, phosphate is more likely to dissolve. Since cadmium and nickel have similar geochemical behaviour and origins, there is a significant link between the two heavy metals. Correlations between copper and turbidity are often positive. For both short-term and long-term changes in water quality, the findings of this research allowed us to build predictive models with high accuracy, reaching prediction accuracies above 95% in several situations. Afterwards, the study's results were fine-tuned by correlating hydrological conditions with data on water resources using these models.

RESULTS

A formal analysis of the findings from the physicochemical analysis of water samples is presented in the paragraph that follows. You can see how polluted a certain lake is thanks to the visual depiction of the parameters. A small number of lakes were found to have heavy metals. All sorts of creatures rely on the lake for survival, but these heavy metals are killing them. This watershed's slope gradient may be better understood by examining the catchment's demarcation. As a result of shifts in LULC patterns within the watershed, contaminants may end up in the local aquatic environment. Researchers must therefore examine the watershed's land cover and land use trends.

Physico-Chemical Analysis

The analysis of physico-chemical parameters obtained from the selected lakes of the Marathwada region was systematically compared against the prescribed standards of the Bureau of Indian Standards (BIS,

2012) and the World Health Organization (WHO, 2024) in order to evaluate their overall water quality and suitability for use. The pH values observed across these lakes were found to lie within the range of 8 to 9, which indicates that the water is slightly alkaline in nature. According to BIS and WHO guidelines, the acceptable range for pH in drinking water is between 6.5 and 8.5. Although most lakes remain within this range, the maximum values recorded in Kharpudi Lake and Salim Ali Lake reached 9, representing a slight deviation from the recommended limits. Such alkalinity can be attributed to enhanced photosynthetic activity in aquatic plants and algal populations, as well as the decomposition of organic matter, which increases carbonate and bicarbonate ion concentrations in the water column.

Turbidity levels, which reflect the degree of suspended matter and organic load in water, showed considerable variation across the lakes. Values ranged from 5 NTU in Harsul Lake to as high as 25 NTU in Salim Ali Lake. The BIS standard specifies an acceptable turbidity of 1 NTU and a permissible upper limit of 5 NTU, whereas WHO recommends values lower than 5 NTU to ensure clarity and safety. Except for Harsul Lake, all other lakes surpassed these permissible limits, thereby indicating the presence of substantial suspended solids, silt, organic matter, and possibly microbial contamination. Elevated turbidity is most likely a consequence of surface runoff from surrounding agricultural fields, untreated sewage inflows, or the disturbance of sediments at the lake bottom.

Chloride content in the analyzed lakes was recorded within the range of 40 to 150 mg/L, which is considerably below the BIS acceptable limit of 250 mg/L and far from the relaxation limit of 1000 mg/L. The highest chloride concentration of 150 mg/L was reported in Moti Lake, and although this is well within the permissible threshold, it suggests mild anthropogenic influence, possibly from domestic sewage or agricultural return flows. At these levels, chloride does not pose any direct threat to human health, but continuous accumulation could affect the taste and palatability of water.

The hardness of water, which is primarily due to the presence of calcium and magnesium salts, was found to vary between 200 mg/L in Harsul Lake and 400 mg/L in Kharpudi Lake. As per BIS standards, an acceptable hardness value is 200 mg/L, with a permissible relaxation up to 600 mg/L. Similarly, WHO considers hardness between 100–300 mg/L as generally acceptable for drinking purposes. The findings indicate that all lakes are within safe limits, although Kharpudi Lake displayed relatively high hardness, suggesting that the lake water receives significant inputs of dissolved salts through agricultural runoff and soil leaching.

Fluoride levels across most lakes were well below the maximum acceptable limit of 1 mg/L. Specifically, Somthana, Moti, and Kharpudi Lakes showed moderate fluoride concentrations of 0.5 mg/L, which is well within the safe range. In contrast, Harsul and Salim Ali Lakes recorded negligible concentrations (<0.1 mg/L). These values indicate that none of the lakes pose any immediate risk of fluorosis, either dental or skeletal. At the same time, the moderate levels found in certain lakes may provide some beneficial effect in preventing dental caries, as small amounts of fluoride are considered essential for strengthening tooth enamel.

Nitrate was found only in Harsul Lake (10 mg/L), which is within the BIS limit but suggests fertilizer and domestic waste input. Iron, residual free chlorine, lead, arsenic, and chromium were below detection in all lakes, showing no major contamination. Orthophosphate reached 1 mg/L in Moti and Salim Ali Lakes,

touching the BIS limit and indicating nutrient enrichment that may accelerate eutrophication, especially in Salim Ali Lake with high turbidity.

Trace metals showed mixed results. Zinc (<0.5 mg/L) and copper (0.5–1 mg/L) were within safe limits, though higher copper levels suggest localized contamination. Manganese (0.1–0.4 mg/L) exceeded the BIS limit (0.3 mg/L) in some lakes, likely from runoff or leaching. Cadmium (0.1–0.4 mg/L) in Somthana and Moti Lakes far surpassed the safe limit (0.003 mg/L), posing serious health risks, while nickel remained undetected.

Overall, chloride, hardness, fluoride, and nitrate were safe, but turbidity, manganese, cadmium, and orthophosphate exceeded limits, reflecting human pressure and poor waste management. The high cadmium levels are especially concerning and call for urgent monitoring and control.

Table 2: Physicochemical parameter values obtained in parts per million (mg/L).

Name of Lakes	pH	Turbidity (NTU)	Chloride (mg/L)	Total Hardness (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Iron (mg/L)	Residual Free Chlorine (mg/L)	Lead (mg/L)	Orthophosphate (mg/L)	Zinc (mg/L)	Copper (mg/L)	Arsenic (mg/L)	Chromium (mg/L)	Manganese (mg/L)	Cadmium (mg/L)	Nickel (mg/L)
Somthana Lake	8	10	100	225	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	0.1	0.1	<0.1
Moti Lake	8	10	150	350	0.5	<0.1	<0.1	<0.1	<0.1	1	<0.1	0.5	<0.1	<0.1	<0.1	0.4	<0.1
Kharpudi Lake	9	10	100	400	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	0.3	0.4	<0.1
Salim Ali Lake	9	25	100	250	<0.1	<0.1	<0.1	<0.1	<0.1	1	<0.1	1	<0.1	<0.1	<0.1	0.4	<0.1
Harsul Lake	8	5	40	200	<0.1	10	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	<0.1	0.4	<0.1

Notes: LOD—limit of detection; LOD of pH—2; LOD of turbidity—0 NTU; LOD of chloride—10 mg/L; LOD of total hardness—25 mg/L; LOD of fluoride—0 mg/L; LOD of nitrate—0 mg/L; LOD of iron—0 mg/L; LOD of residual free chlorine—0 mg/L; LOD of lead—0 mg/L; LOD of orthophosphate—0 mg/L; LOD of zinc—0 mg/L; LOD of copper—0 mg/L; LOD of arsenic—0.05 mg/L; LOD of chromium—0 mg/L; LOD of manganese—0 mg/L; LOD of cadmium—0 mg/L; LOD of nickel—0 mg/L.

Features of the Watershed

Watershed delineation is a vital tool for understanding the physical characteristics of a drainage basin, providing detailed insights into elevation, slope gradient, stream network, and overall catchment area topology. In this study, digital elevation data with a 30 m resolution were obtained from the USGS portal and processed using ArcGIS 10.8 software to generate watershed delineation maps. Since water naturally flows from higher to lower elevations, the geomorphology of the watershed plays a decisive role in influencing hydrological processes and, consequently, the water quality of lakes and other aquatic systems. As illustrated in Figure 5, the delineated streams consistently follow the topographic gradient, draining water downslope.

Within the Marathwada region of Maharashtra, several lakes are positioned at different elevations across the watershed, as shown in Figure. Somthana Lake and Kharpudi Lake are located at relatively lower elevations, making them prime recipients of surface runoff and inflow from multiple upstream streams. In contrast, Salim Ali Lake, Harsul Lake (in Chhatrapati Sambhajnagar city), and Moti Lake (in Jalna) are positioned at medium elevations, receiving comparatively less direct runoff. Lakes at lower altitudes

generally collect inflows from a larger number of tributaries and streams, which increases their exposure to sediment loads and dissolved substances carried by surface runoff.

The quality of water in these lakes is therefore strongly linked to watershed geomorphology and land-use practices. Runoff transports not only suspended sediments but also dissolved nutrients, agrochemicals, and other pollutants, all of which contribute to the gradual deterioration of lake water quality. This emphasizes the interconnected nature of watershed characteristics and aquatic ecosystem health, underscoring the importance of integrated physico-chemical and GIS-based assessments in managing freshwater resources effectively.

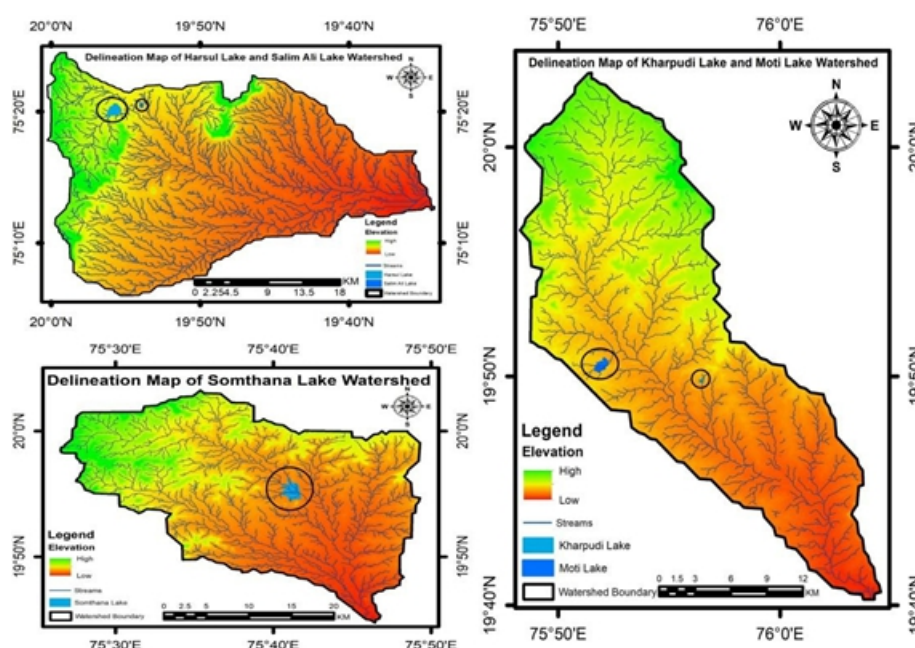


Figure 2: The Marathwada watershed

The LULC Path and How It Impacts Water Purification

The Land Use and Land Cover (LULC) pattern within a watershed is dynamic and can change over time, often contributing to increased levels of pollution in associated water bodies. In this study, Sentinel-2 satellite imagery, obtained from the Copernicus portal (<https://browser.dataspace.copernicus.eu/>, accessed on 17 May 2024), was utilized to analyze the current LULC distribution within the watershed. ArcGIS 10.8 software was employed to process the imagery and generate detailed LULC maps, allowing for the identification of various land cover types, including vegetation, agricultural fields, fallow land, urban settlements, and water bodies. Changes in LULC, such as the conversion of vegetative or fallow areas into built-up zones due to population growth and urban expansion, can significantly alter surface runoff characteristics, increase sedimentation, and elevate nutrient and chemical loads entering lakes and rivers. The quantified LULC values observed in the study area are summarized in Table, providing a basis for correlating land cover changes with potential impacts on water quality within the watershed.

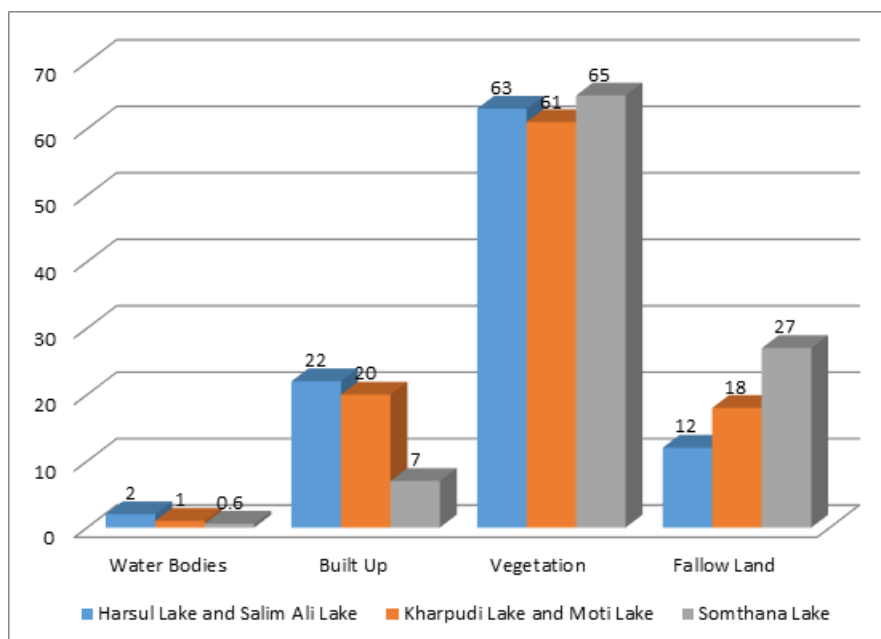


Figure 3: Ratio of LULC in the research region

As may be seen in Figure, the majority of watersheds are covered with vegetation. Figure 8 shows that in all three watersheds, vegetation was the most common kind of plant. Every one of the watersheds also had some arable land. While urban areas had a negligible amount of arable land, the Somthana Lake basin had the greatest amount. In the specified watershed, we found Somthana Lake and a number of smaller bodies of water. There was a disproportionate amount of urbanisation in the watersheds of two lakes in the Chhatrapati Sambhajnagar metro area: Salim Ali Lake and Harsul Lake. There is vegetation in these basins as well. There were other smaller bodies of water in these watersheds. Vegetation cover was higher in the watersheds of Kharpudi Lake and Moti Lake. Minimal bodies of water were found in these basins. As the population grows, more and more of it will live in urban areas, which in turn will cause pollution levels to skyrocket. Also, the neighbouring water sources are under more pressure due to the growing population.

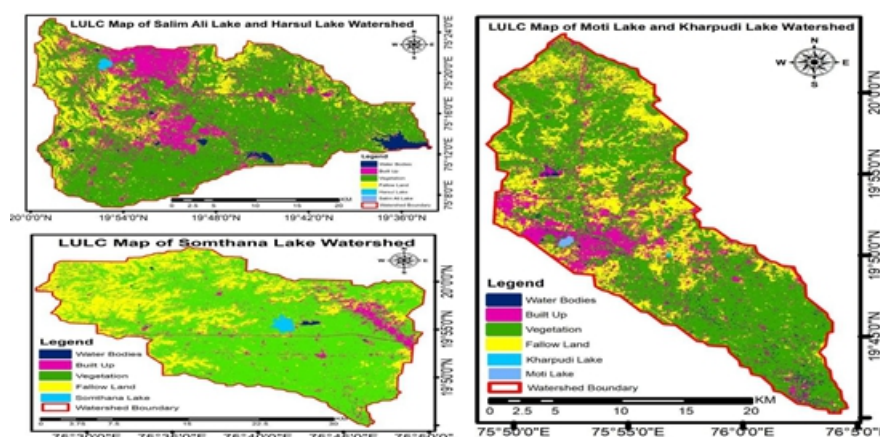


Figure 4: Watershed land cover and land use map of the Marathwada area

Statistical Analysis

If two datasets are linearly related, then the Pearson correlation coefficient will be high. There is a strong

relationship between the two variables if the correlation coefficient is positive and a weak relationship if it is negative. The connection between the several water quality metrics may be found by analysing the results in Table 4. Indicated by positive and negative Pearson correlation coefficients, certain parameters exhibit relationships. Metal ion concentrations were shown to be associated with pH, which in turn impacts solubility. Solubility of metals like iron and manganese increases when pH decreases. If water samples were turbid, it meant that particles were floating in the water. Nitrate changes how much lead is in water. It is possible to mobilise copper and lead with high concentrations of nitrate. The correlation between the parameters is essential for understanding their influence on water quality and how they interact with each other. A powerful tool for understanding the connections between parameters is the Pearson correlation approach.

While looking at the water quality metrics, it was seen that all of them showed a positive link with pH, except for manganese and nickel. The levels of nitrate were greater because of their significant association with pH, in contrast to copper's lesser affinity. The presence of both nitrate and orthophosphate in agricultural fertilisers suggests that their positive connection might be a result of fertiliser runoff. Among the metrics, turbidity was positively correlated with all save fluoride and nitrate, which showed a negative connection. There is evidence of carbonate weathering when there is a positive connection between pH and total hardness, and of geogenic sources when there is a positive correlation between pH and fluoride.

Reduction in soil erosion is indicated by a positive connection between turbidity and orthophosphate. There was a moderate association between cadmium and turbidity, but copper showed the strongest correlation. In contrast to the other metrics, chloride, nitrate, and nickel showed negative associations. If you look for a positive association among copper, cadmium, and nickel, it indicates that the pollution is coming from humans. All water quality metrics except nitrate, copper, and nickel had positive associations with total hardness.

Although nitrates showed a stronger positive link with fluoride, copper, manganese, and nickel all showed negative relationships. As turbidity rises in tandem with heavy metal concentrations, it becomes clear that these contaminants are attached to suspended particles, likely originating from wastewater treatment plants. In contrast to the stronger positive relationships shown with orthophosphate, copper, manganese, and nickel all showed negative correlations with nitrate. Iron, manganese, cadmium, and nickel were found in orthophosphate due to its positive correlational values with these heavy elements. While copper showed the most positive link, manganese was shown to be positively associated with nickel and negatively associated with cadmium. When looking at the link between manganese and nickel, the association was the greatest, but cadmium showed a negative correlation with nickel.

Table 3: Pearson correlation values of physical and chemical parameters

	pH	Turbidity (NTU)	Chloride	Total Hardness	Fluoride	Nitrate	Orthophosphate	Copper	Manganese	Cadmium	Nickel
pH	1										
Turbidity	0.22	1									
Chloride	0.14	0.28	1								
Total hardness	0.07	0/10	0/75	1							
fluoride	0.61	-0.17	0/35	0/16	1						
Nitrate	0.77	-0.04	-0.03	-0.16	0.57	1					
Orthophosphate	0.43	0.34	0.16	0.09	0.12	0.57	1				
Copper	0.03	0.93	0.12	-0.02	-0.33	-0.12	0.29	1			
Manganese	-0.04	0.60	0.02	0.12	-0.10	-0.12	0.06	0.58	1		
Cadmium	0.07	0.05	0.40	0.21	0.26	0.34	0.08	0.09	-0.05	1	
Nickel	-0.08	0.63	-0.15	-0.14	-0.23	-0.08	0.20	0.68	0.90	-0.15	1

DISCUSSION

Important insights into the effects of physico-chemical parameters, heavy metal pollution, and LULC changes on these aquatic ecosystems were derived from the water quality investigation conducted in the research area, which included five lakes in the Marathwada areas. The study's findings call attention to high levels of pollution and the need for more research into the causes of these contaminants and the wider effects they have on human and environmental health.

The degrees of pollution in aquatic ecosystems may be clearly seen by analysing the impact of several physicochemical factors on water quality, a multi-dimensional and expansive notion [96–100]. Multiple lakes have far higher levels of heavy metals than what is considered safe according to tests that measure things like total hardness, chloride, turbidity, and pH. Whether for irrigation, drinking, pleasure, or industrial purposes, water quality greatly affects its intended use, hence this is of utmost importance [99–102]. The majority of lakes showed pH values that were higher than what is considered acceptable by the BIS, according to this study's results. Because alkalinity changes the solubility and toxicity of heavy metals like iron and manganese, elevated pH levels which are especially noticeable in Lonar Lake can have negative impacts on aquatic life. Similarly, several lakes had turbidity levels that were higher than what was allowed by the BIS. Reduced light penetration, which impacts photosynthetic activity and general water quality, is known as turbidity and is produced by suspended particulate matter.

Trace levels of heavy metals including cadmium, nickel, and manganese were found in a number of lakes, with concentrations that above the acceptable BIS limits in a few instances. Because heavy metals bioaccumulate in aquatic creatures and have harmful consequences all the way up the food chain, these results provide cause for alarm. For instance, cadmium found in several lakes can enter bodies of water via industrial effluent and rock weathering. Because of its extreme toxicity, even at low concentrations, cadmium is a major threat to ecosystems and human health. Nickel and manganese, which may also be found in water due to human and industrial activity, further highlight the danger that this water poses to aquatic life and water quality. The need of ongoing monitoring is underscored by the fact that heavy metals are present, even in minute quantities. In areas where water sources are used for irrigation and drinking, heavy metal poisoning may cause long-term risks to population health and the environment. According to this analysis, the impacted lakes must immediately begin cleanup measures due to the significant metal burden.

The current research shows that LULC modifications have a major impact on water quality. Substantial changes to the terrain over time, mainly caused by the spread of cities and farms, were shown by the watershed delineation and LULC analyses. A major worry that has arisen in response to the ongoing human impact on the natural environment is the contamination of water sources by contaminants carried by surface runoff.

Lower pollution levels were often seen in watersheds with a larger proportion of vegetative cover. Minimising the introduction of contaminants into water bodies is achieved via the functions of vegetation, which act as a natural buffer by lowering runoff, filtering pollutants, and stabilising the soil. Water quality was found to be worse in locations where there was less vegetation, more urbanisation, and more fallow land. Salim Ali Lake, Kharpudi Lake, and Moti Lake are just a few examples of the many urban lakes that are located in the heart of cities and surrounded by ecosystems; these bodies of water exhibit particularly high amounts of pollution that has been caused by humans. This trend shows how land management techniques significantly affect the water quality of these ecosystems.

When compared to more conventional, costly field approaches, GIS and remote sensing technologies enable efficient and cost-effective monitoring of water quality across vast regions [103–105]. The use of remote sensing technology in this research enabled the identification of key locations experiencing an increase in urbanisation and agricultural operations, as well as a thorough evaluation of the elements that contribute to water pollution [106-109]. Targeted measures are necessary to improve water quality due to the measured levels of contamination, especially from heavy metals and human activities. In addition, Water Quality Indexes (WQI) may provide a simplified representation of the water quality situation, which can help stakeholders and policymakers understand and tackle water quality issues more easily. Given the growing urbanisation and industrialisation in the Marathwada districts, this research highlighted the critical requirement of constantly monitoring water quality. We can protect these important aquatic habitats for the future by implementing proactive water management methods and making use of contemporary technology like GIS and remote sensing to reduce negative effects on water quality.

CONCLUSION

The integrated physico-chemical and GIS-based assessment of lakes in the Marathwada region reveals pressing environmental challenges linked to both natural processes and human activities. The study highlights significant deviations in water quality parameters, with elevated turbidity, heavy metal contamination (notably cadmium), and urban runoff, especially in lakes surrounded by built-up areas and exposed to uncontrolled disposal of domestic and industrial waste. The application of GIS and remote sensing methodologies enabled the identification of pollution hotspots and provided critical insight into the influence of land use patterns, emphasizing the impact of urbanization and agricultural expansion on degradation of lake ecosystems. Vegetative cover emerged as a protective factor, buffering lakes from contamination, whereas diminished greenery and increased infrastructural development were associated with elevated pollution levels. The study underscores the urgent need for targeted water resource management, including stricter effluent control, improved wastewater treatment, restoration initiatives, and policy interventions to ensure sustainable use of these freshwater resources. Continued monitoring using advanced spatial technologies and community engagement will be crucial for safeguarding ecological

health and public safety in the Marathwada region.

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