Assessing Contamination Levels and Ecological Impacts in Lakes: A Comprehensive Review on Worldwide Lakes

[1]Prasanna Lavhale, [2]Pranaya Diwate*, and [3]Rushikesh Golekar

Author's Affiliations:
[1]Research Scholar, Department of Geology, School of Basic and Applied Sciences, MGM University, Chhatrapati Sambhajinagar, Maharashtra- 431003, India. E -mail: prasanna.lavhale7@gmail.com
[2]Assistant Professor, Department of Geology, School of Basic and Applied Sciences, MGM University, Chhatrapati Sambhajinagar, Maharashtra-431003, India. E-mail: pdiwate@mgmu.ac.in
[3]Assistant Professor, Department of Geology, Khare Dhere Bhosale College, Guhagar District Ratnagiri, Maharashtra- 415703, India. E-mail: rbgolekar@gmail.com

*Corresponding Author: Pranaya Diwate, Department of Geology, School of Basic and Applied Sciences, MGM University, Chhatrapati Sambhajinagar, Maharashtra-431003, India
E-mail: pdiwate@mgmu.ac.in

How to cite this article: Lavhale P., Diwate P., and Golekar R. (2025). Assessing Contamination Levels and Ecological Impacts in Lakes: A Comprehensive Review on Worldwide Lakes. *Bulletin of Pure and Applied Sciences- Geology,* 44F (2), 124-153.

Abstract:
Lakes are vital in retaining global and local water balances. In past few years, the lakes have faces numerous changes. Present review paper discusses the lake sediment contamination due to presence of heavy metals. Total 53 important lakes around the globe were chosen to carry out the current research. To evaluate heavy metal contamination in lake sediments, heavy metals such as Pb, Ni, Co, Cr, Cu, Zn were analysed and discussed. It was observed that almost all African lakes had existence of Cu and Zn in their sediments. Lakes like the Manzala Lake in Egypt showed a greter percentage of Cu having concentration 110 ppm while Zn was observed in the Naivasha Lake in Kenya having concentration 231.94 ppm. American lakes showed the dominance of heavy metals like Cu, Pb and Zn in significant percentage. Maximum proportion of Zn was observed in the Michigan Lake, USA having value 317 ppm. Asian lakes showed the existence of heavy metals like Cr, Ni, Pb, Zn, and Cu in almost all lakes. The presence of Zn in Asian lakes like the Manchar Lake in Pakistan was up to 154 ppm, the Hazar Lake in Turkey showed value 210 ppm and the Nansi Lake in China showed concentration 149.96 ppm. Asian lake sediments showed existence of all kind of heavy metals except Cobalt. Cu and Zn was also detected in majority of lakes which exceeded the average crustal value. It is necessary to analyse pollution in lake as it has adverse effect on ecosystem.

Keywords: *Heavy Metal Contamination; Sustainability; Pollution; Limnology*

INTRODUCTION

The lakes are an immense source of freshwater for drinking, domestic, irrigation, and industrial purposes as well as lakes also play a vital part in replenishment of groundwater and influencing the climate (Gaury et al., 2018; Qin et al., 2022; Li et al., 2024). Peoples always relied upon aquatic sources for medicines, food and materials along with both commercial and recreational motives such as tourism as well as fishing. Lakes gives significant contribution across water cycle and

they also act as a sign for worldwide climate alteration. As per geographical location and weather conditions of lakes, they are classified either cold and arid lakes or as humid lakes (Patil et al., 2014; Adimalla, 2020; Wang et al., 2023; Nazir et al., 2024). Lakes are the habitats for various species of plant and animal, ranging from microscopic algae to large fish and migratory birds (Jumbe et al., 2009; Anthony, 2023; Potharaju et al., 2023; Wang et al., 2024). Limnology is the discipline which focuses on the study of biological, chemical, and physical features of lakes. The lakes possess complicated and sensitive ecosystem because they are lacking of self-cleaning ability and thus easily incorporate toxic materials (Haribhau, 2012; Patil et al., 2016; Guo et al., 2019; Zhu et al., 2024). Lakes are not coherent bodies of water but differ in shape, depth, volume, water temperature and other characteristics. Lakes serves as one of the most efficient ecosystems. Globally lakes covered 0.8% of the earth's surface. They are crucial and hold nearly 87% of surface freshwater (Kolli, 2020; Guo et al., 2021; Wang et al., 2024).

The majority of the freshwater lake posses tremendous ecological concern posed by pollutants due to toxic substances. This is caused because of the rise in usage of chemicals in industries, mining and urbanization and agriculture modernization (Singh et al., 2017; He et al., 2019; Olando et al., 2020; Al-Taee et al., 2024). The threat posed by water pollution from trace metal is widely recognised throughout the world and notably in a developing country like India. The lakes obtain municipal sewage that has not been treated earlier from a variety of settlements, agricultural activities and industries. Degradation of water bodies is serious in least developed nations mostly due to lack of wastewater treatment systems (Ghorade et al., 2014; Das et al., 2016; He et al., 2020; Yang et al., 2024). The proportion of heavy metals are typically greater in sediment than in water as the elements are transported by the rivers and settled in nearby lakes. Sediments serves as a archive of heavy metals, offering site for deposition. The evapotranspiration and stable water condition of lake enables them inevitably become rich as contaminant over time. Lake sediments are important markers as they function as sinks as well as carriers for heavy metals. Heavy metals

readily get consumed and stored in the lake sediments as they are least soluble (Suresh et al., 2012; Humane et al., 2018; Batapola et al., 2023). Contamination of heavy metals can be analysed by studying heavy metal concentration in lake sediments. The precise evaluation of trace metal content is essential, as several components have been recognised as probable harmful elements. The unscientific disposal of wastes and pollution in urban water bodies resulted in several issues not only to human beings but also to the aquatic biodiversity (Jones et. al., 1990; Jumbe et al., 2009; Shree et al., 2019; Zhao et al., 2021). Vulnerability to heavy metals been aligned with numerous detrimental impacts on health such as cancer, kidney damage, behavioural problems, impaired intelligence, developmental problems and miscarriage or stillbirth (Wani et al., 2006; Bhagure et al., 2011; Kalekar et al., 2022; Cui et al., 2023).

The current review article deals with the determination of contamination level of various lakes all over the globe with respect to heavy metals. In this review paper, information of more than 50 lakes are incorporated along with the findings which is one of its kind of study. It is essential to study heavy metal contamination as it poses threat to the ecosystem and the peoples depends on the lake for various purposes. Recommendations and future prospects are also discussed at the end of review article to mitigate the contamination problem.

HEAVY METALS AND THEIR SOURCES OF POLLUTION

Heavy metals are nothing but the elements occurring naturally having a high atomic weight, an atomic number higher than 20 and a density is higher than 5 g cm−3. Heavy metals are stubborn type of contaminant within the ecosystem like water, sediments, and biota as they are resilient to degradation (Szymanowska et al., 1999; Yu et al., 2001; Ayyanar et al., 2020; Zhou et al., 2020; El-Degwy et al., 2023). Heavy metals not easily ripped in ecosystem, and those heavy metals get introduced into a water body can settle there for a while (Shaikh et. al. 2013; Kamble et al., 2014; Algul et al., 2020; Rosado et al., 2024). Lake bottom sediments serves as a sink and are sensitive markers for observing pollutants as

they are transporter of contaminant in lake ecosystem. Weathering of rocks and anthropogenic activities resulted in production and transportation of sediments by waterways and dispersed to the nearby lakes (Dev et al., 2017; Ayyanar et al., 2020; Kamzati et al., 2020; Zhao et al., 2024). Interaction with geological materials is among the most crucial steps which affect dispersion of components (Suresh et al., 2012; Kumar et al., 2019; Keshavarzi et al., 2021). By various processes like agricultural runoff, wastes from factories and transportation, heavy metals can enter the soil exposing substantial health threat to living organisms. In Indian subcontinent, degradation of water bodies by heavy metals is one of the typical and fast-growing issue because of industrialisation and anthropogenic processes. Certain heavy metals like Ni, Pb, Cd, Cu, Cr, Hg, Zn and As are categorised as lethal elements as per water quality standards, which causes severe harm to the environment when they exceeds highest permissible limits. Various heavy metals and their sources is mentioned in Table 1.

Table 1: Heavy metals and their sources of pollution

Heavy Metals	Pollution Sources	References
Chromium (Cr)	Mining, Factories producing Chromium salts, Tanning of leather, Textiles, Electroplating industries, Coolants used in industries etc.	Forstner, 1976; Jumbe et al., 2009
Lead (Pb)	Batteries made up of Lead acid, Additives used in Gasoline, Operations involved in smelting processes, Ceramic industries, Bangle industry, Metal plating, Battery cells, Paints, Electrical instruments, Spinning factories, Dye and pigments, Paper mills, E-waste, Coal-based thermal power plants etc.	Jumbe et al., 2009; Gan et al., 2023
Mercury (Hg)	Clinical and scientific waste, Thermal power plants, Electrical gadgets, Fluorescent lamps, Pulp mill, Smelting process.	Forstner, 1976
Arsenic (As)	Thermal power plants, Fuel burning, Detergents, Smelting operations.	Forstner, 1976
Copper (Cu)	Copper-based fungicides and pesticides, Mining activities, Electroplating, Smelting operations, Textile industries	Ayyanar et al., 2020
Nickel (Ni)	Battery industry, Electrical industries, Oil refineries and industrial processes.	Jumbe et al., 2009
Cadmium (Cd)	Anticorrosive agents, E-waste, Cobustion of fuels, Power stations, Metal working industries, Industrial processes, Fabrication processes, Electroplating industry, Pigments.	Jumbe et al., 2009; Ayyanar et al., 2020
Cobalt (Co)	Chemical and fertilizer industries, glass manufacturing industries.	Jumbe et al., 2009
Zinc (Zn)	Zinc Plating Industries, Metallurgical and galvanic industries, Mining activities, Incineration process, Phosphates fertilizers, Ghee Manufacturing, Poultry sewage and compost, Silver plating industries, Distillation plants, Leaching of landfill materials, Fly ashes of coal powered plants.	Jumbe et al., 2009; Humane et al., 2016

HEAVY METALS AND THEIR EFFECTS

Arsenic (As): Arsenic produces a various type of inorganic and organic aggregates of varying level of toxicity indicating the physicochemical characteristic of arsenicals of variable valency. Elevated percentage of arsenic in groundwaters and soil are possibly related to diffusion of waste from factories or by percolation from sewage. Arsenic poisoning is typically acute with main effect on gastrointestinal tract and cardiovascular system (Forstner, 1976; Lokhande et al., 2011; Singare et al., 2012; Bhateria et al., 2016).

Cadmium (Cd): Cadmium mainly occurred in the crust of earth having average crustal value of 0.3 ppm. It plunges into the environment primarily through the ground. Cadmium is present in manures as well as pesticides used in agriculture. Waste of Cadmium from the production industries usually end up in soils. A catchment's geology and agricultural runoff where phosphate content manures utilized frequently contribute to accumulation of Cadmium. Cadmium enters the air through combustion of residuals and combustion of hydrocarbons. Cadmium is immensely hazardous and possesses capability to have a detrimental impact on health like renal diseases and cancer. It is deadly, and eliciting signs like nausea, cramps, respiratory difficulties, vomitting and loss of consciousness at high doses. Chronic exposure to metal resulted in anaemia, renal problems and loss of sense, hypertension and cardiovascular diseases (Khare et al., 2008; Jumbe et al., 2009; Singare et al., 2010; Ayyanar et al., 2020; Radfard et al., 2023).

Chromium (Cr): Chromium is necessary trace element which plays crucial role in lipid and protein metabolism to keep a glucose level normal. Excessive consumption of chromium results in liver and renal damage and chromate dust cause cancer. Chromium (III) found naturally in several fruits, vegetables, meats, yeasts and grains. Several methods of food cooking and storage is responsible to modify the chromium contents of food. Storing food in steel containers can resulted in increase in chromium concentrations. The salt made up of Chromium are utilized in industrial operations and get mixed in water bodies by untreated release of waters. Chromium are also added in cooling water for corrosion control. Chromium is usually more hazardous at higher temperatures (Forstner, 1976; Jumbe et al., 2009a; Singare et al., 2011b; Ayyanar et al., 2020).

Cobalt (Co): Excessive Cobalt concentrations can contribute to nutrient imbalances in water and potentially promoting the growth of harmful algal blooms. Higher exposure to cobalt can cause a nausea, depression, vomiting, anorexia and diarrhoea. Vitamin B12 which is essential to humans contains cobalt (Coen et al., 2001; Jumbe et al., 2009; Lotfinasabas et al., 2013; Singare et al., 2013).

Copper (Cu): Copper is used across several sectors like manufacturing, transportation, construction, currency, transportation of electricity and agriculture field etc. Copper in less proportion is required to keep cellular functions and metabolic enzymes. Toxic nature of Copper depend on alkalinity of water, as copper is typically more harmful to water dwelling species at lower alkalinities. Overdose of copper can cause liver and kidney disfunction, neurological complications and hypertension. Copper becomes poisonous for living things when the frequency of consumption exceeds the rate of emission (Singare et al., 2011; Agarwal et al., 2015; Showqi et al., 2018; Kumar et al., 2019; Ayyanar et al., 2020).

Lead (Pb): Lead is a toxic environmental contaminant. By many ways, humans are get contacted with Lead through air, drinking water, food, contaminated soil etc. Nutritionally Lead is not a necessary nutrient for humans or other living organisms. Lead is a prominent toxic metal and it is eliminated slowly through the materials that humans utilised in day-to-day life. Lead is a hazardous, resulted in hypertension, anaemia, tiredness, behavioural changes, irritability and impairment of intellectual functions. Longer exposure to lead or its salts might have negative impact on nervous system and kidneys (Jumbe et al., 2009; Singare et al., 2011; Kinare et al., 2019; Gan et al., 2023; Shirmohammadi et al., 2024).

Manganese (Mn): Manganese occurs in nature as solid in the soil and small particles in the water. Manganese occurs in different salts and minerals

typically associated with iron compounds. Usually these are deposited on earth in dust particles. Intake of high concentration of manganese dust lead to permanent crippling and damage of the central nervous system. Humans enhances manganese content in the atmosphere by factories and by combustion of hydrocarbons.

Mercury (Hg): Mercury is lethal, it possibly turned into organomercurials which are notably more toxic and preserved in the cells of plants and other organisms. Mercury is unstable specifically in aquatic environment under the effect of bacteria and fungi, it gets turned into the highly toxic methyl mercury form. Such compounds are quickly consumed by aquatic plants species and animals (Forstner, 1976; Alissa et al., 2011; Singare et al., 2012; Labhade, 2013).

Nickel (Ni): Nickel is primarily utilised for manufacturing of stainless steel, non-ferrous alloys and super alloys directly expelled from steel industries. Nickel is a nutritionally valuable and necessary trace heavy metals for lots of animal species, microorganisms and plants. Excess percentage of Nickel can cause chronic bronchitis and alters the structure of lungs. Nickel and its compounds possess a numerous industrial and commercial uses (Jumbe et al., 2009; Singare et al., 2012; Arnous et al., 2015; Li et al., 2017).

Zinc (Zn): Zinc found in nature and it also present in many foods which is the reason for presence of Zinc in all human wastes which are flushed down the toilets. It is the major single source of zinc from domestic waste. Zinc is a member of trace metals which is needed for the development of living things and are probably hazardous to biosphere when accumulated in higher proportion (Jumbe et al., 2009; Humane et al., 2010; Singare et al., 2011; Kumkar et al., 2023).

ROLE OF GEOLOGY

In lake ecosystem, heavy metals are observed in aqueous phase, suspended particles and sediments. The contaminated state of sediment is among the crucial factors to determine the lake water condition (Kumar et al., 2019; Zhang et al., 2021; Cai et al., 2023). Sediments play a vital part in physicochemical and ecological changes. Any

modification in amount of heavy metal content on the sediments will impact the natural aquatic life support systems (Jumbe et al., 2009; Chu et. Al 2010; Malik et al., 2013). Land use and soil profiles play a notable role in surface runoff and available moisture conditions. Soil erosion is a very complex procedure that keeps going on and noticed when the area is impacted by natural and human activities (Dixit et al., 2008; Singare et al., 2013; Kolli, 2020; Mawari et al., 2022). Quality of this environment is heavily influenced by the water and elements discharged into that system by the rivers, surrounding landmass and their geo physical and chemical characteristics. Suspended particles play a major part in managing the transport activity, reactivity and biological effect of metals and other things in aquatic ecosystem and establish crucial connection between water column, bed sediments and food chain (Pertsemli et al., 2007; Shinde et al., 2020; Diwate et al., 2021; Mawari et al., 2022). Sediment can be able to give information on present condition of aquatic ecosystem along with the details regarding transportation and fate of pollutants. The scattering of heavy metals is tightly associated with the physical and chemical characteristics of the soil, the land-use type and the agricultural irrigation type. Toxic metal content in estuarine sediments reflect the range of chemical, oceanographic and geological controls on their distribution.

NEED OF STUDY OF HEAVY METALS IN ECOSYSTEM

Harmful components in the lake ecosystem has become a concern globally in the twenty-first century. This is because of their plentifulness, higher toxicity, non-degradability and accumulation in aquatic systems (Meena et al., 2017; Rehman et al., 2018; Wagh et al., 2018; Avdan et al., 2019; El-Degwy et al., 2023). An assessment of heavy metal concentrations within the aquatic system helps us in a better knowledge of processes which are responsible for the concentration of heavy metals in these ecosystems (Fazil et al., 2012; Zhuang et al., 2014; Humane et al., 2016; Mert, 2023). The substantial industrialization and the rise in urbanization are reason behind the quick increase in pressure on water and soil ecosystem of surrounding area.

Pollution of lake by human induced sources has become a major risk to the aquatic environment because of the existence of a larger percentage of toxic heavy metals (Panda et al., 1995; Rostom et al., 2017; Ayyanar et al., 2020; Githaiga et al., 2021). Shrinking of lake, water quality declination and ecological deterioration of the watershed are all present day problems impacted by global warming and human activities (Pandey et al., 2006; Purushothaman et al., 2012; Gholizadeh et al., 2016; Wang et al., 2023). The quick industrialization and rapid urbanization that have changed India in recent years pose danger to the water ecosystem. Contamination by heavy metals is among the variable that compromise the climate and evaluating the heavy metals input is fundamental for advancing appropriate freshwater. The lake serves over 600 million people worldwide and act as a vital thing in their daily life by providing food and habitat for living beings, preserving biodiversity and by controlling flood. The Indian subcontinent's aquatic systems are overburdened because of high population density, increasing industrial growth and modernization. Heavy metals in water body can have remarkable ecological and environmental implications posing danger to living organisms. The dispersion, quantity and storage of contaminant in aquatic ecosystem have adverse effect of environmental chemistry, ecology and quality of water. To mitigate the effect of heavy metals in water bodies, monitoring and regulation are essential. Maharashtra, being one of the most industrialized and urbanized states in India may exhibit unique patterns of heavy metal contamination influenced by its specific economic activities and geographic features. The estimation of heavy metal pollution is very important to know the status for planning and management of valuable freshwater. Therefore, the assessment of anthropogenic agent impact over lakes required knowledge of the current scenario of heavy metal input in the lake. The overall study of all lakes from World, India and from Maharashtra provides the synoptic views on spatial variability and the intensity of the pollution in the lakes. After evaluation of the heavy metal analysis for lakes depending upon the pollution level in the lakes the appropriate mitigation measure will be implemented for

improving the status of the lakes those who have found above the permissible level.

STUDY AREA AND METHODOLOGY

The current study focuses on the heavy metal pollution in lake sediments and its pattern across the world. To carry out the research work, initially total 53 lakes from all over the world are selected. Further selected lakes are classified into majorly three divisions i.e., Global lakes, Indian lakes and lakes from the Maharashtra state as per their locations. Global lakes are further classified based on their geographic location like African lakes, American lakes, Asian lakes and European lakes. Out of 53 lakes selected for review, 15 lakes are from India, 5 lakes are situated in Maharashtra state and remaining are global lakes. This study has purpose to analyze the condition of the heavy metal contamination and its adverse effect in the various regions. The data on the sediment contamination by heavy metals is gathered from previously published research papers. The studies on heavy metal contamination pattern of the lake sediments by previous researcher are particularly focused on the occurrence of heavy metals like Ni, Cr, Pb etc. in the lake sediments. Obtained values of heavy metals like Co, Cu, Cr, Pb, Ni and Zn in lake bed sediments were compared to the average crustal value of that particular heavy metal. Geology of the catchment, natural factors and anthropogenic factors has been taken for consideration to achieve our goal. Obtained values of various heavy metals are shown in graphs.

Spatial and statistical analysis was done to interpret the data. Analysis of data helps to identify patterns, trends, and hotspots of heavy metal contamination. Location maps of lakes were made using ArcGIS software. Lakes from all over the world which are under study are shown as per their location in Fig. 1. Graphs of heavy metal contamination in lakes are plotted with the help of SigmaPlot software.
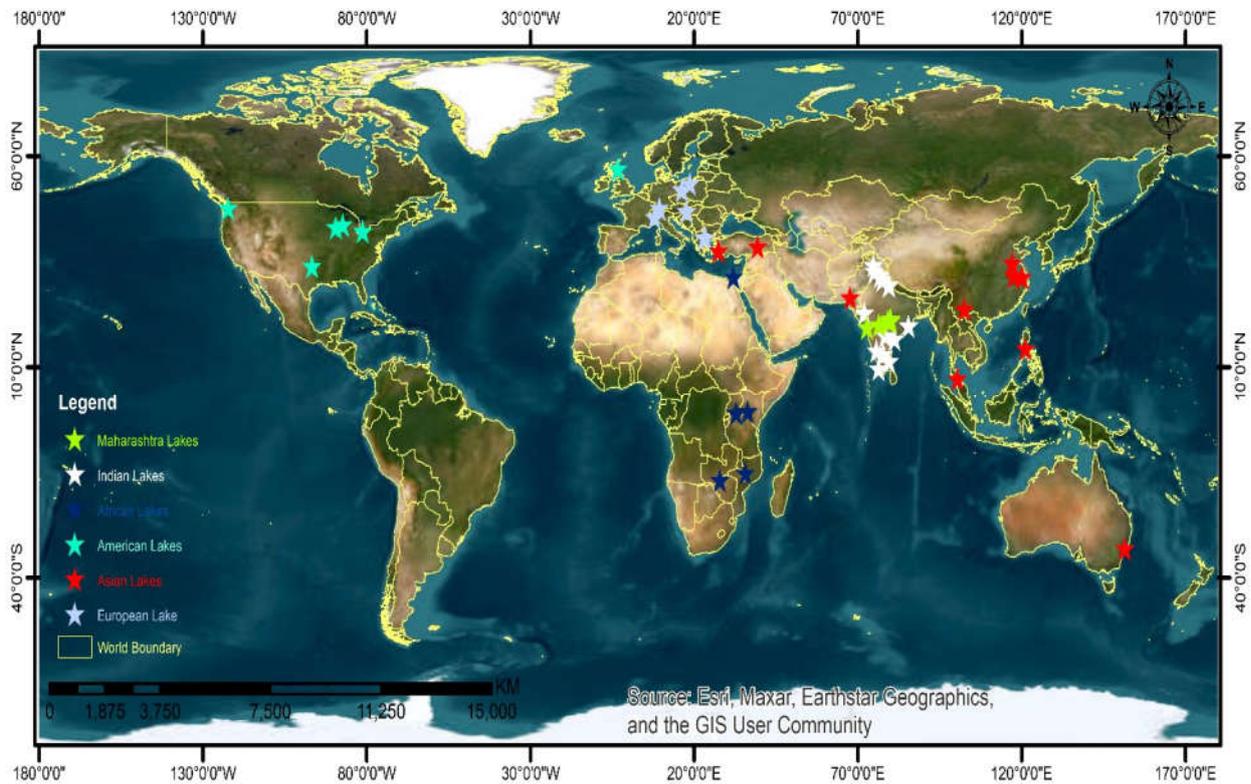
Figure 1: Location Map of Global lakes used for present study

RESULTS AND DISCUSSION

1. CONTAMINATION OF HEAVY METALS IN GLOBAL LAKES

Contamination of heavy metals can be analysed by studying heavy metal content in lake sediments. Many different types of heavy metals are present in lake water and lake sediments in different proportions. Their concentrations values help us to infer that lake is polluted or not. Though they are crucial in trace quantity for bodily function, their elevated concentrations pose serious risks to environments and humans. Few lakes are selected to study from the Africa to determine the heavy metal contamination pattern in lake sediments. Values of heavy metals observed in African lakes are shown in Table 2.

Table 2: Heavy metal contamination in African lakes

African Lakes							
Sr. No.	Name of Lakes	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
1	Manzala Lake, Egypt	-	-	-	110.014	15.083	13.557	Arnous et al., 2015
2	Naivasha Lake, Kenya	24.04	27.44	-	33.74	22.11	231.94	Olando et al., 2020
3	Bonga, SA	-	-	-	1.273 - 1.629	-	1.527 - 1.659	Kamzati et al., 2020

4	Chaone, SA	-	-	-	0 - 0.575	-	0.209 - 1.078	Kamzati et al., 2020
5	Thunde, SA	-	-	-	0 - 0.637	-	0.245 - 1.825	Kamzati et al., 2020
6	Mchenga, SA	-	-	-	0 - 0.249	-	0.153 - 1.086	Kamzati et al., 2020
7	Kachulu, SA	-	-	-	0.405 - 0.548	-	0 - 1.289	Kamzati et al., 2020
8	Victoria Lake, Tanzania	-	11	-	21.6	29.6	36.4	Suresh et al., 2012
9	Kariba Lake, Zimbabwe	-	29.3	-	16.1	9.4	42.4	Suresh et al., 2012

Presence of Cobalt was observed only in the Naivasha Lake in Kenya. The crustal average value of Cobalt is 19 ppm. The Naivasha lake showed value of Cobalt 24.04 ppm, exceeding the desired value which makes lake water harmful. Chromium was present in the Naivasha Lake, Kenya, the Victoria Lake, Tanzania and the Kariba Lake in Zimbabwe. The average of Chromium in these lakes ranging from 11 – 29.3 ppm. The crustal average value of Chromium is 90 ppm. Chromium was within limit in all three lakes. Presence of Nickel were not observed in lakes of Africa. Contamination of Copper was observed in African lakes like the Manzala Lake, Egypt, the Naivasha Lake, Kenya and the Kariba Lake in Zimbabwe. The Manzala Lake in Egypt showed heavy concentration of Copper which is up to 110.014 ppm while lowest concentration of Copper was observed in the Mchenga Lake, South Africa. Average crustal value of Copper is 45 ppm. Except than the

Manzala lake, all lakes showed values within limit. Lead showed its presence in the Manzala Lake in Egypt, the Naivasha Lake in Kenya, the Victoria Lake in Tanzania and the Karika Lake in Zimbabwe. Lead ranges from 9.4 – 29.6 ppm in these lakes. Higher values were observed in the Victoria Lake in Tanzania which was 29.6 ppm. The average crustal value of Lead is 7 ppm. The Naivasha Lake in Kenya and the Victoria Lake in Tanzania exceeds the average crustal value of Lead. Zinc was present in all African lakes. Zinc ranges from 0.153 – 231.94 ppm. Highest value of Zinc was observed in the Naivasha Lake in Kenya. The lesser value of Zinc shown by the Mchenga Lake in South Africa. The average crustal value of Zinc is 95 ppm. All lakes showed Zinc value within range except the Naivasha Lake in Kenya. African lakes under study are shown in Fig. 2. Observed proportion of heavy metals are plotted in the graphs and depicted in Fig. 3.
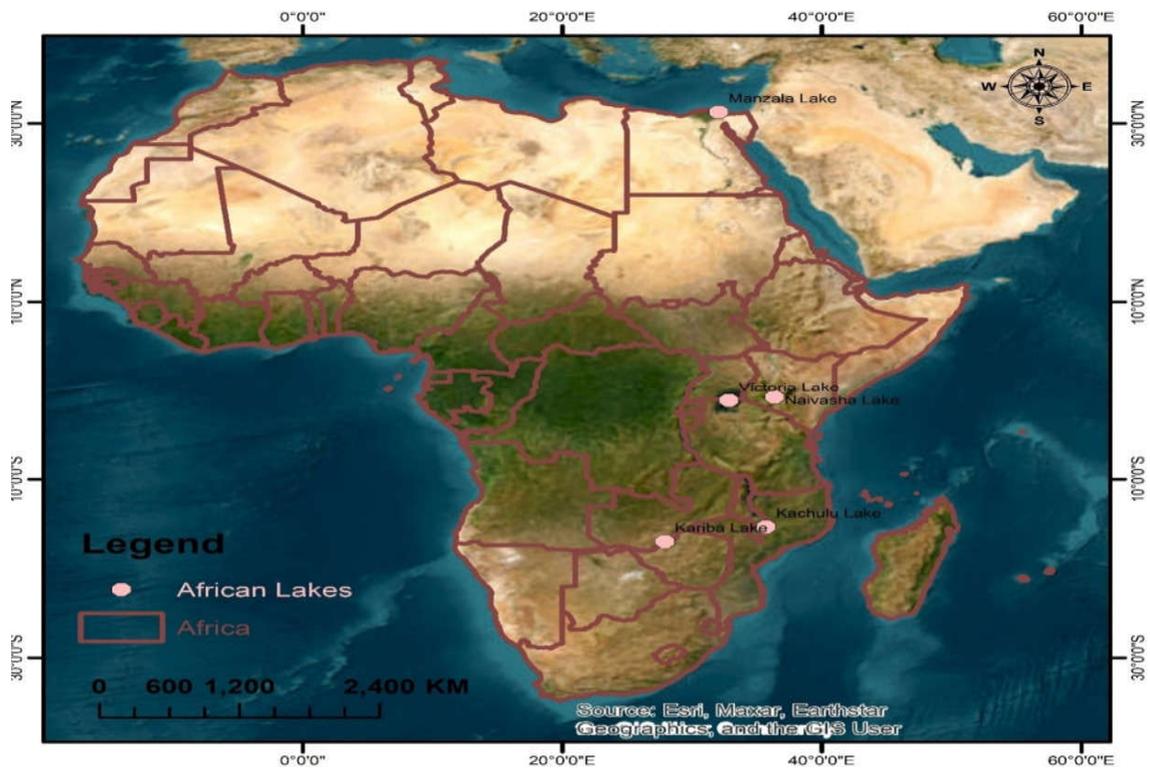
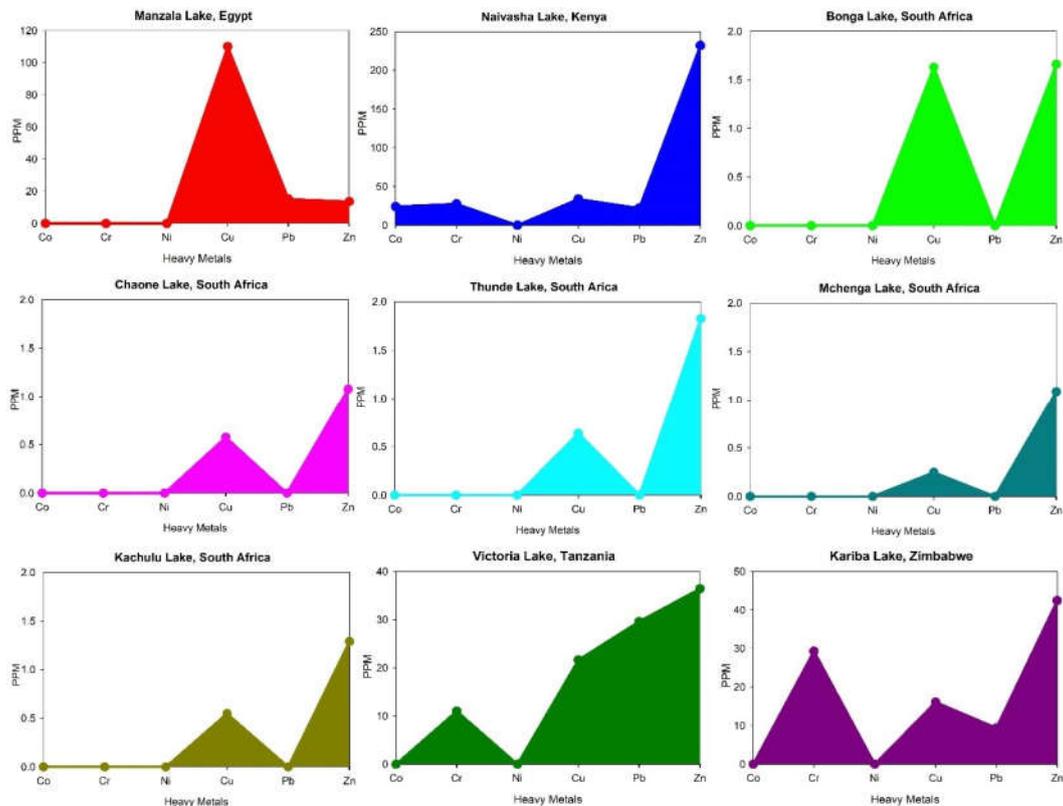**Figure 2: Location Map of African lakes used for present study**

Figure 3: Heavy metal distribution graphs of African lakes used for present study

Lakes present in various part of United State of America also showed presence of heavy metals in lake sediments. Few lakes in United State of America have been chosen to know the concentration of heavy metals in lake sediments. Lakes which are selected to carry out study can be seen in Table 3 along with level of heavy metals in their sediments. Few lakes showed higher amount of heavy metals. Such higher proportion in water ecosystem can damage environment severely.

Table 3: Heavy metal contamination in American lakes

Sr. No.	Name of Lakes	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
	American Lakes							
1	Michigan Lake, USA	-	85	44	75	145	317	Forstner, 1976
2	Monona Lake, Wisconsin	-	49	50	268	124	92	Forstner, 1976
3	Washington Lake, USA	-	-	-	50	400	230	Forstner, 1976
4	Erie Lake, Canada	-	60	95	58	-	42	Forstner, 1976
5	Lochnagar Lake, UK	-	-	-	-	30–400	50–250	Pertsemli et al., 2007
6	Texoma Lake, USA	-	12–51	6–31	9–136	5–15	33–242	Pertsemli et al., 2007

Lakes in America does not show presence of Cobalt. Chromium was present in most of lakes except the Washington Lake, USA and the Lochnagar Lake, United Kingdom. Range of Chromium was varying between 12 – 85 ppm. Highest value of Chromium was observed in the Michigan Lake, USA. The crustal average value of Chromium is 90 ppm. All the lakes showed value less than 90 ppm. It means Chromium is within range in lake water. Nickel was present in most of lakes except the Washington Lake, USA and the Lochnagar Lake, United Kingdom. Nickel ranges between 6 – 95 ppm in lake sediments. The crustal average value of Nickel is 68 ppm. The Erie Lake exceeds the average crustal value of Nickel which indicated the Erie Lake was polluted by Nickel. Copper was present in all lakes except the Lochnagar Lake in United Kingdom. The range of Copper observed in lakes are 9 – 268 ppm. Average crustal value of Copper is 45 ppm. All lakes exceed the average crustal limit of Copper. From this we can concluded that American lakes were heavily polluted by Copper. Presence of Copper in lake water prove harmful to living things in many ways. Highest value of Copper shown by the Moona Lake in Wisconsin is 268 ppm, it is much more than the average crustal average value of Copper. Lead is present in all American lakes except the Erie Lake in Canada ranging from 5 – 400 ppm. The Washington Lake in USA and the Lochnagar Lake in United Kingdom showed Lead value up to 400 ppm which was much more than average crustal value of Lead. The average crustal value of Lead is 7 ppm. Except than the Texoma Lake in USA, all lakes exceeded the Lead values. This means most of American lakes are polluted by Lead. Presence of Zinc was observed in all American lakes. Zinc values ranges from 33 – 317 ppm. Least value was observed in the Texoma Lake in USA while highest value of Zinc was observed in the Michigan Lake in USA. The average crustal value of Zn is 95 ppm which is exceeded by American lakes namely the Michigan Lake in USA, the Washington Lake, USA, the Lochnagar Lake, United Kingdom and the Texoma Lake in USA. Location of American lakes are shown in Fig. 4. Heavy metal distribution graphs of American lakes which is utilised in current study is depicted in Fig. 5.
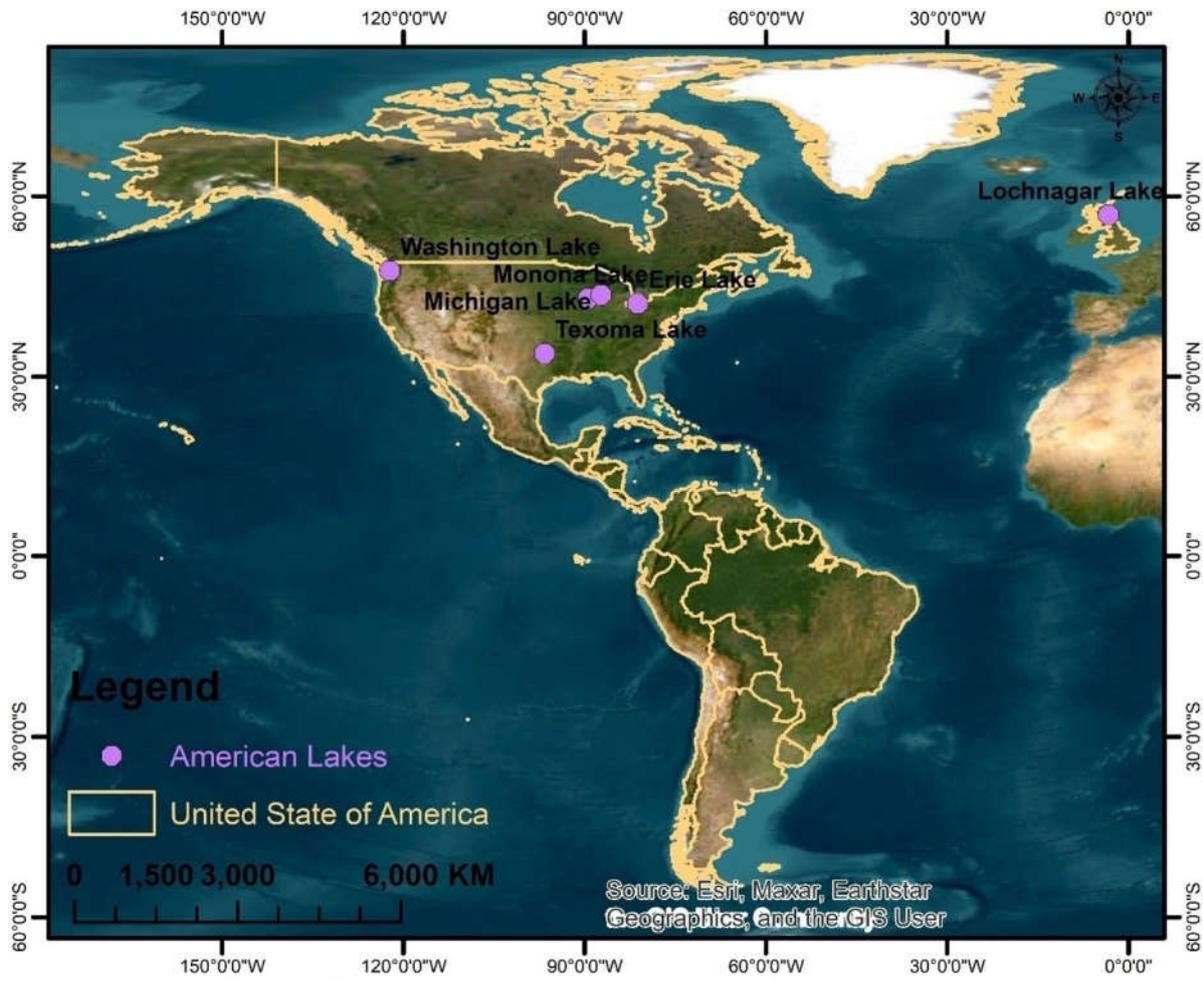
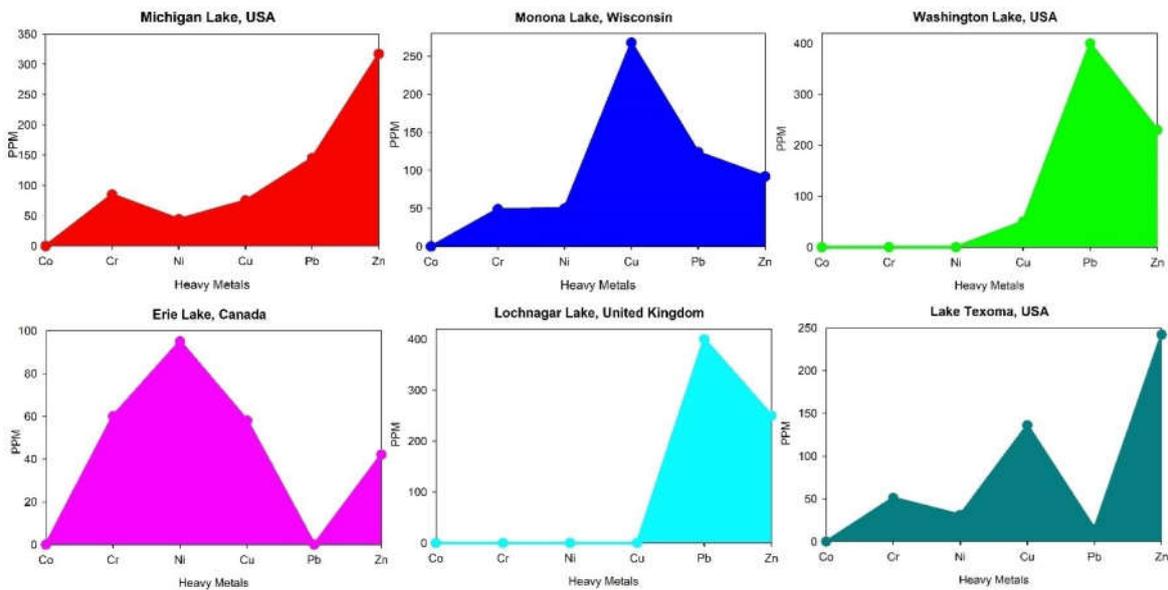**Figure 4: Location map of American lakes used for present study**

Figure 5: Heavy metal distribution graphs of American lakes used for present study

Europe have countries like Germany, Poland, Greece, Hungary etc. Lakes from these countries showed presence of heavy metals in their lake water and sediments in various proportions. Observed concentrations of heavy metals in lake sediments is depicted in Table 4. Presence of heavy metals in higher proportion is hazardous to human health.

Table 4: Heavy metal contamination in European lakes

Sr. No.	Name of Lakes	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
						European Lakes		
1	Constance Lake, Germany	-	153	50	34	52	42	Forstner, 1976
2	Wielkie Lake, Poland	2.3	1.15	1.6	2.05	9.7	571	Szymanowska et al., 1999
3	Bosz-kowo Lake, Poland	4.2	1.85	2.95	2.95	13.4	1100	Szymanowska et al., 1999
4	Dominickie Lake, Poland	2.25	1.3	2.05	2.65	12.9	475	Szymanowska et al., 1999
5	Volvi Lake, Greece	-	20–25	-	12–16	10.5–14.4	48–75	Pertsemli et al., 2007
6	Koronia Lake, Greece	-	27–37	-	15–19	16.3–24.5	72–100	Pertsemli et al., 2007
7	Palas Lake, Italy	-	22–58	-	0–51	-	10–47	Pertsemli et al., 2007
8	Balaton Lake, Hungary	-	5.7–66	4.4–55	0.7–36	2.4–160	13–150	Suresh et al., 2012

European lakes showed presence of Cobalt in three lakes in Poland namely the Wielkie Lake, the Bosz-kowo Lake and the Dominickie Lake. The observed range of Cobalt in this lake ranging from 2.25 – 4.2 ppm. The crustal average value of Cobalt is 19 ppm. All the three lakes are within range of average crustal value of Cobalt. Existence of Chromium was reported in all European lakes. Maximum concentration of Chromium was reported in the Constance Lake, Germany. The crustal average value of Chromium is 90 ppm. All European lakes have value of Chromium less than the average crustal value except the Constance Lake in Germany which indicated this lake was heavily polluted by Chromium.

Presence of Chromium in water bodies may prove harmful to living things and it will be hazardous. Nickel was present in most of lakes except the Volvi Lake, Greece, the Koronia Lake, Greece and the Palas Lake in Italy. Average range of Nickel varies between 1.6 – 50 ppm. The crustal average value of Nickel is 68 ppm. Not any European lake crossed the average crustal value of Nickel, it means there is no pollution of Nickel in lakes. Copper was present in all European lakes and their range varies between 0.7 – 51 ppm. Average crustal value of Copper is 45 ppm. Only the Palas Lake in Italy showed the excess value which is 51 ppm. The Palas Lake was contaminated by Copper. Except than the Palas Lake in Italy, all the European lakes showed

presence of Lead in their ecosystem. The value of Lead ranges from 2.4 – 160 ppm. The average crustal value of Lead is 7 ppm. Most of lakes like the Constance Lake in Germany, the Koronia Lake in Greece and the Balaton Lake in Hungary showed the elevated concentration of Lead in their sediments. The Balaton Lake in Hungary showed value of Lead up to 160 ppm which was more than ten times of the average crustal value of Lead. This clearly indicated that lake is heavily polluted by the Lead. Presence of Lead in lake water can cause various dangerous disease and it pose threat to human being. Presence of Zinc was observed in all the European lakes. The average range of Zinc in European lakes were 10 – 1100

ppm. Least value of Zinc was observed in the Palas Lake, Italy while maximum value of Zinc was reported in the Bosz-kowo Lake in Poland which was 1100 ppm. The average crustal value of Zinc is 95 ppm. Most of European lake crosses the average crustal value of Zinc. Lakes in Poland was highly polluted by Zinc which was major threat to aquatic ecosystem as well as living beings which is dependent on this water bodies. European lakes which are selected for the study are shown in Fig. 6. Observed concentration of heavy metals in all these lakes are plotted in graph and shown in Fig. 7.
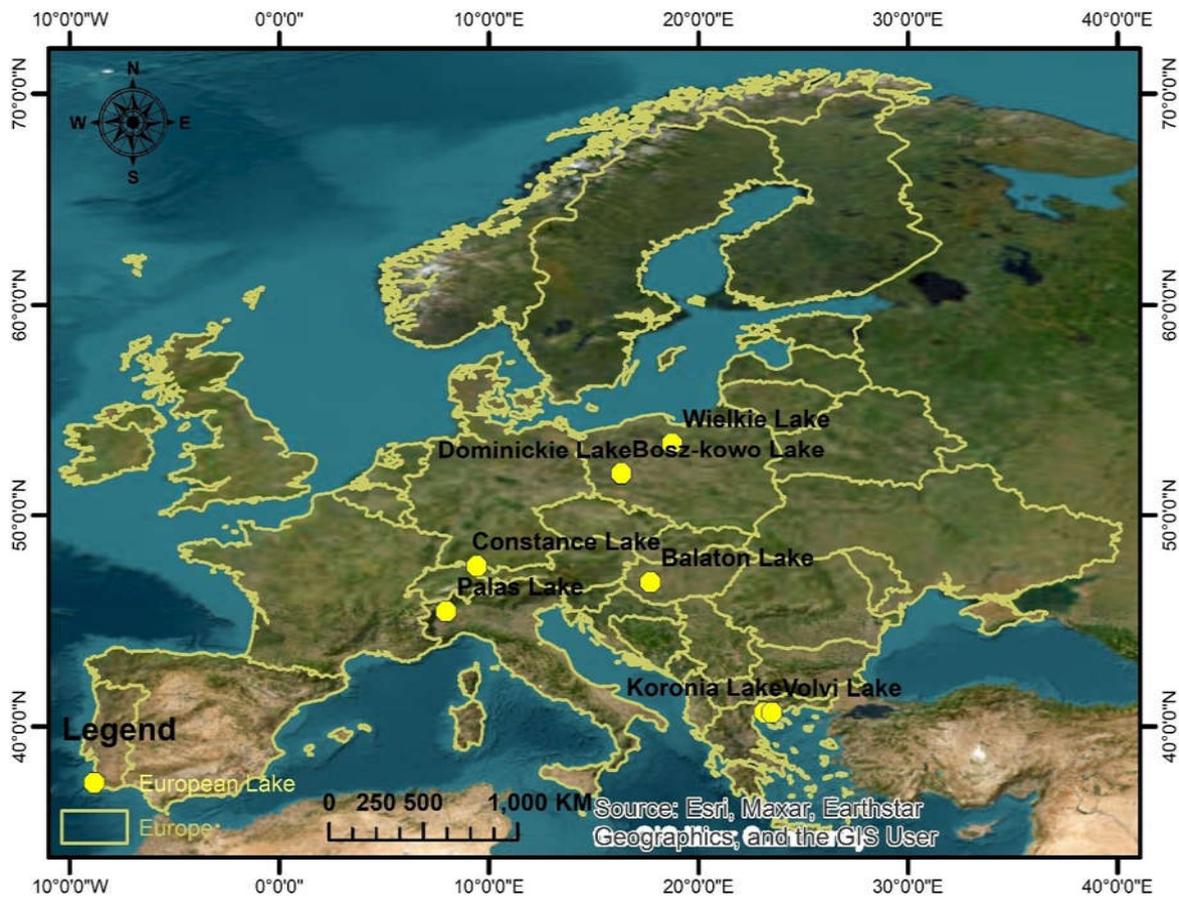

Figure 6: Location map of European lakes used for present study
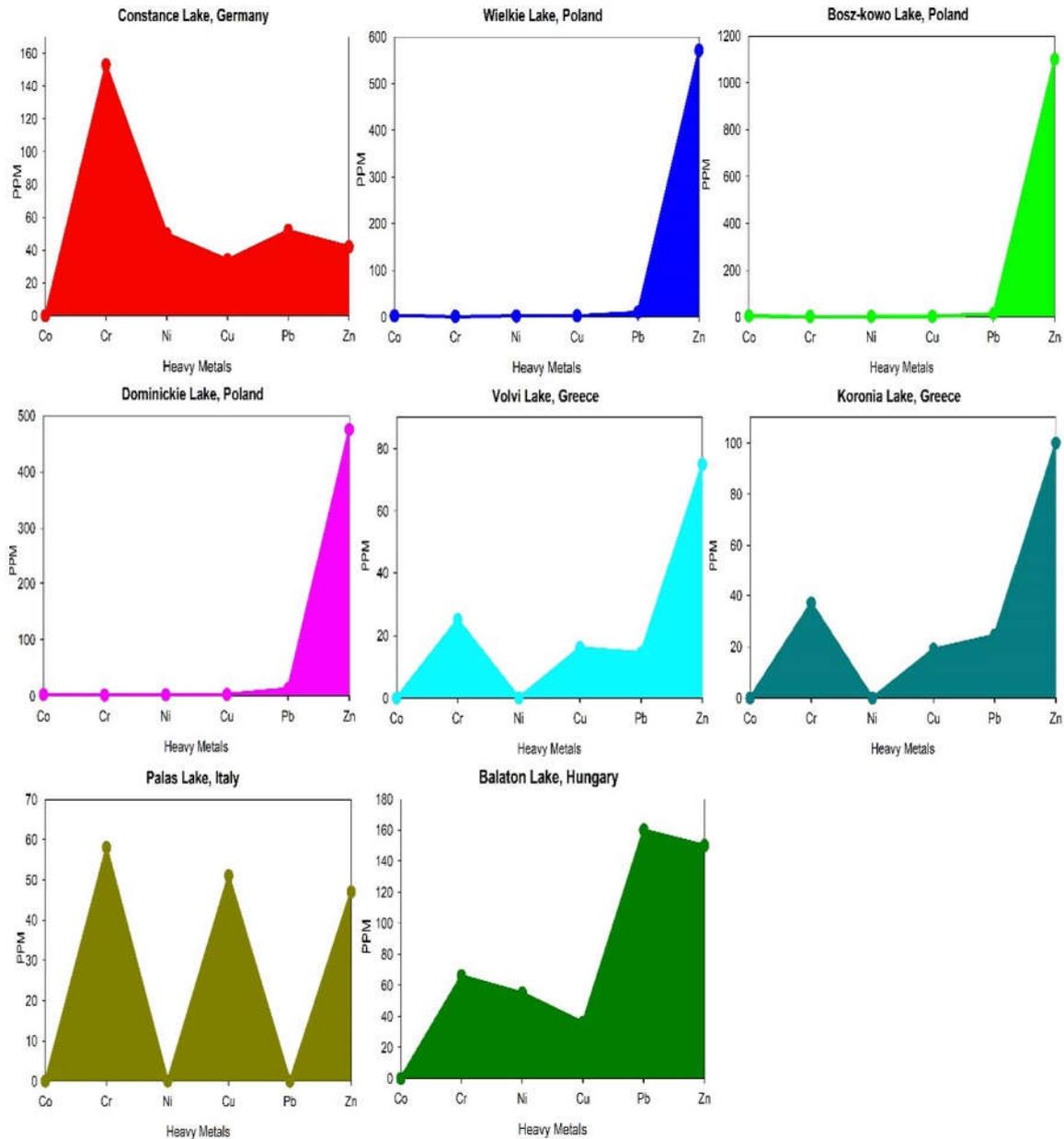
Figure 7: Heavy metal distribution graph of European lakes used for present study

Lakes from Asia continent showed existence of heavy metals in variable quantity. Few heavy metals are present in much more quantity while some are within permissible limit. Heavy metals values shown in Table 5 gives us idea of dispersion of heavy metals in lake sediments of Asia continents.

Table 5: Heavy metal contamination in Asian lakes

Sr. No.	Name of Lakes	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
				Asian Lakes				
1	Manchar Lake, Pakistan	-	14.7–26.8	16.1–26.6	15.6–29.7	14.6–20.9	53.9–154	Suresh et al., 2012
2	Hazar Lake, Turkey	-	17–79	38–130	10–64	-	46–210	Suresh et al., 2012
3	Nansi lake, China	-	136.54	46.21	41.85	50.18	149.96	Guo et al., 2021
4	Yilong lake, China	-	86.73	35.99	31.4	53.19	86.82	Suresh et al., 2012
5	Songkhla Lake, Thailand	-	-	2.5–21.9	1.8–125	8.2–131	5.4–562	Suresh et al., 2012
6	Laguna Lake, Philippines	-	-	9.7–18.7	9.7–18.7	17–23	10.3–18.3	Suresh et al., 2012
7	Chaohu Lake, China	-	80.1	44.7	38.6	94.9	-	Suresh et al., 2012
8	Lake Bafa, Turkey	-	13.22 - 80.97	29.01 - 175.97	10.23 - 25.28	2.71 - 13.75	6.26 - 36.52	Algül et al., 2020
9	Taihu Lake, China	-	56.2	-	36.7	51.8	-	Suresh et al., 2012
10	Macquarie Lake, Australia	-	7–45	11–57	6–17	5.5–17	12–68	Pertsemli et al., 2007

Lakes in Asia did not showed presence of Cobalt in their sediments, from this we can inferred that Asian lakes are free from Cobalt contamination. Chromium was present in most of lakes except the Songkhla Lake in Thailand and the Laguna Lake in Philippines. The average value of Chromium observed ranges between 7 – 136.54 ppm. Least Chromium concentration was observed in the Macquarie Lake in Australia while higher value of Chromium was noticed in the Nansi Lake in China. The crustal average value of Chromium is 90 ppm. The Nansi Lake in China showed elevated proportion of Chromium i.e., 136.54 ppm which was more than the average crustal value. It indicated the Nansi Lake in China was polluted by the Chromium. Nickel is present in all Asian lakes except the Taihu Lake in China. Average value of Nickel in these lakes varies between 2.5 – 175.97 ppm. The least value was shown by the Songkhla Lake in Thailand while highest value was observed in the Bafa Lake in Turkey. The

average crustal value of Nickel is 68 ppm. The Hazar Lake in Turkey and the Bafa Lake in Turkey exceeded the average value. The Bafa Lake showed value up to 175.97 ppm which was much more than the average crustal value. Copper can be seen in all Asian lakes ranging from 1.8 – 125 ppm. Average crustal value of Copper is 45 ppm which was exceeds by the

Hazar Lake in Turkey and the Songkhla Lake in Thailand. Appearance of Lead was seen in all lakes except the Hazar Lake in Turkey. The range of Lead in Asian lakes ranges between 2.71 – 131 ppm. The average crustal value of Lead is 7 ppm. Except than the Bafa Lake in Turkey, all the Asian lakes showed higher value of Lead. It clearly indicated that all lakes are polluted by Lead. Higher values of Lead were observed in the Songkhla Lake, Thailand which pose major threat to the people who are depends on this lake. Zinc was present in Asian lakes except the Chaohu Lake in China and the Taihu Lake in China. Value

of Zinc was ranges from 5.4 – 562 ppm. The average crustal value of Zinc is 95 ppm. The Manchar Lake in Pakistan, the Hazar Lake in Turkey, the Nansi Lake in China and the Songkhla Lake in Thailand all exceeded the average value of Zinc. The least value of Zinc was observed in the Laguna Lake in Philippines while elevated proportion of Zinc was detected in the Songkhla Lake in Thailand which was up to 562 ppm. Such high proportion of Zinc in lake ecosystem pose severe threat to the population which was depends on lake for their various purposes. Such high quantity of Zinc indicated that this lake is being polluted by some external source like industries. Location of lakes which are used for study illustrated in Fig. 8. Graphs of heavy metal distribution in lakes is illustrated in Fig. 9.
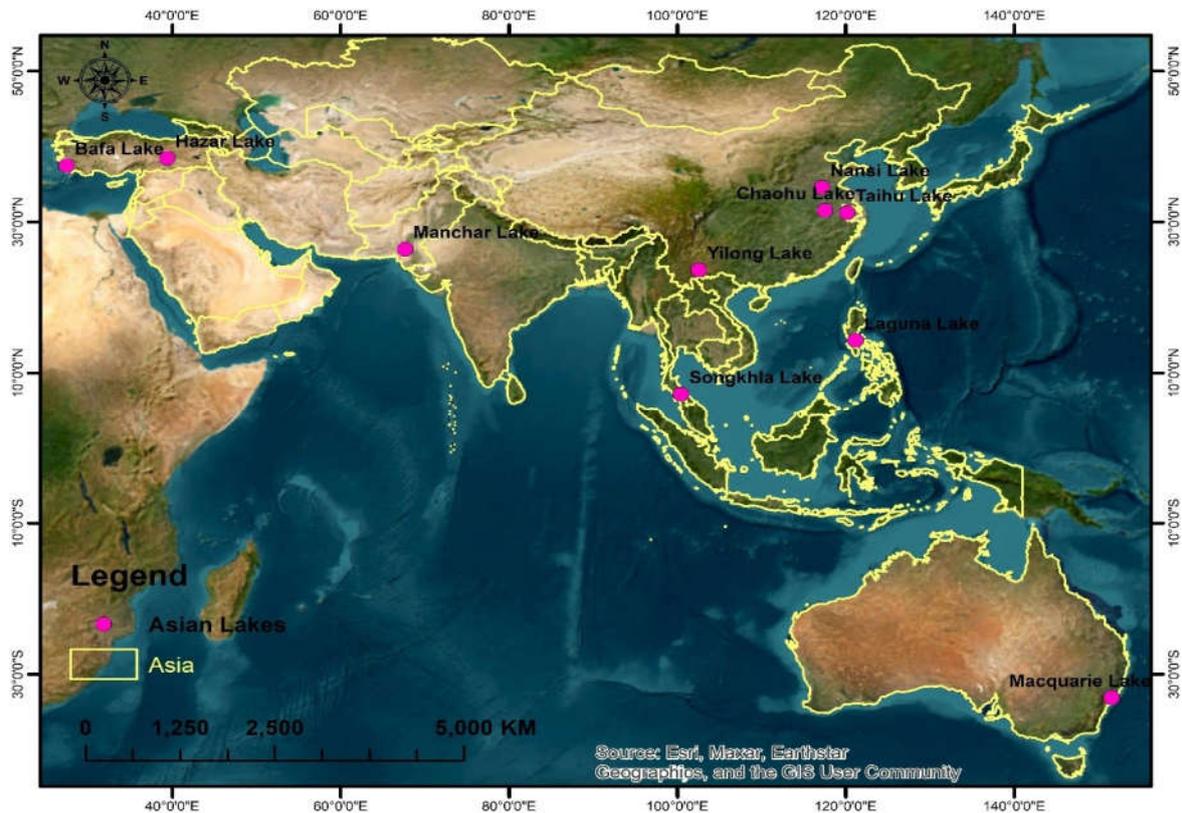

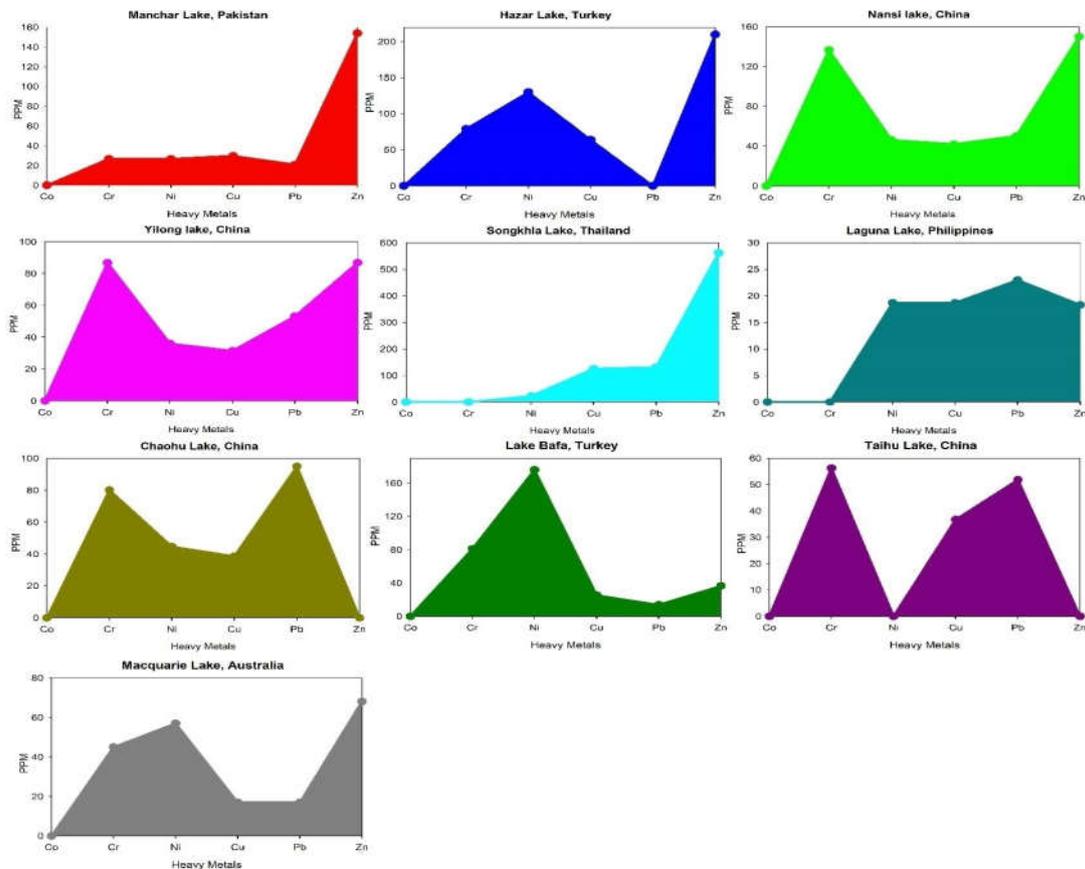**Figure 8: Location map of Asian lakes used for present study**

Figure 9: Heavy metal distribution graphs of Asian lakes used for present study

2. CONTAMINATION OF HEAVY METALS IN INDIAN LAKES

To study the distribution of heavy metals in sediments of Indian lakes, 15 lakes were selected randomly from all over India. All lakes which were selected for review showed existence of heavy metals in their sediments and their values as per shown in Table 6. Some lakes are heavily polluted while some lakes have values within its permissible limit. Presence of contaminants in lakes sediments helps us to understand the present scenario of lakes.

Nearly all lakes showed presence of heavy metals in their sediments which were selected to carry out the study. Cobalt was present in most of the lakes. The average range of Cobalt observed ranges from 7 – 87 ppm. The average crustal value of Cobalt is 19 ppm. Apart from the Rewalsar Lake in Himachal Pradesh, all lakes exceeded the average crustal value of Cobalt.

Highest value of Cobalt was observed in the Naukuchiatal Lake in Uttarakhand. Excessive Cobalt has many adverse effects on human health. Chromium was present in nearly all lakes except the Vembanad Lake in Kerala, the Jannapura Lake in Karnataka and the Nalsarovar Lake in Gujrat. Least amount of Chromium percentage was reported in the Anchar Lake in Kashmir while highest concentration was observed in the Rewalsar Lake, Himachal Pradesh. Average crustal value of Chromium is 90 ppm. The Rewalsar Lake in Himachal Pradesh, the Chilka Lake in Odisha and the Veeranam Lake in Tamilnadu exceeded the average crustal value of Chromium. The Rewalsar Lake in Himachal Pradesh showed much more concentration of Chromium which may prove very dangerous. Appearance of Nickel was reported in all the lakes. The Kolleru Lake in Andhra Pradesh have least concentration of

Nickel while the Chilka Lake in Odisha showed highest concentration of Nickel. The average crustal value of Nickel is 68 ppm. Most of lakes had Nickel concentration within range except two lakes namely the Chilka Lake in Odisha and the Veeranam Lake in Tamilnadu which exceeded the average crustal value of Nickel. Copper was observed in all the lakes. Average crustal value of Copper is 45 ppm. Unfortunately, most of lakes exceeded the average crustal value. Least value of Copper contamination was reported in the Anchar Lake in Kashmir while the Kolleru Lake in Andhra Pradesh showed very high concentration of Copper. Presence of Copper in lake may prove dangerous to lake ecosystem. Lead is present in all lakes except the Vembanad Lake in Kerala. The average crustal value of Lead is 7 ppm. Most of lakes exceeded the average crustal value of Lead except the Anchar Lake in Kashmir, the Kolleru Lake in Andhra Pradesh and the Jannapura Lake in Karnataka. The Bhimatal Lake in Uttarakhand showed highest elevated proportion of Lead which is up to 178 ppm. Least Lead was observed in the Jannapura Lake in Karnataka. Presence of Zinc were observed in all lakes. The average crustal value of Zinc is 95 ppm. Most of lakes exceeded the proportion of Zinc than the average crustal value. The Kolleru Lake in Andhra Pradesh and the Veeranam Lake in Tamilnadu showed Zinc concentration 622 ppm and 599 ppm respectively. Least Zinc concentration observed in the Jannapura Lake in Karnataka. Location of lakes selected for study is shown in Fig. 10. Observed values of heavy metal in Indian lakes is shown in graphs in Fig. 11.

Table 6: Heavy metal contamination in Indian lakes

Indian Lakes							
Sr. No.	Name of Lakes	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
1	Renuka Lake, Himachal Pradesh	7 - 51	5 - 62	11 - 25	11 - 40	21-27	43-127	Kumar et al., 2019
2	Rewalsar Lake, Himachal Pradesh	10.5-16.3	64-165	23.3-50	24.6-97	19-29	84-116	Meena et al., 2017
3	Nainital Lake, Uttarakhand	7 - 33	11 - 59	30-64	18-40	6 - 21	31-105	Purushothaman et al., 2011
4	Bhimatal Lake, Uttarakhand	13-20	47-71	26-42	36-60	45-178	42-73	Purushothaman et al., 2011
5	Naukuchiatal Lake, Uttarakhand	41-87	12 - 47	26-51	80-120	48-73	66-159	Purushothaman et al., 2011
6	Chilka Lake, Odisha	-	4 - 74	52-143	10-101	28-59	21-63	Panda et al., 1995
7	Anchar Lake, Kashmir	-	3.3 - 5.02	2.01 - 4.3	9.7 - 26.9	1.33 - 4.33	2.11 - 13.61	Showqi et al., 2018
8	Hussain Sagar lake, Hyderabad	-	90	47.042	90.108	79.885	273.14	Ayyanar et al., 2019
9	Kolleru Lake, Andhra Pradesh	-	44–66	0.2–2.2	270–572	2.5–5.1	356–622	Pertsemli et al., 2007
10	Vartur lake, Karnataka	11.68-69.37	0-21.37	16.2-68.0	130.52-134	4.43-88.5	25.71-220.2	Jumbe et al., 2009
11	Veeranam lake, Tamilnadu	-	40–150	34–95	65–125	20–41	69–599	Suresh et al., 2012

12	Vembanad lake, Kerala	-	-	64	47	-	259	Suresh et al., 2012
13	Jannapura lake, Karnataka	-	-	40.05	89.75	0.2	0.034	Suresh et al., 2012
14	Mansar lake, Jammu and Kashmir	42	51	46.3	26.4	32.67	67	Malik et al., 2013
15	Nal Sarovar Lake, Gujarat	64.83	-	50.33	32.88	5.59	553	Malik et al., 2013
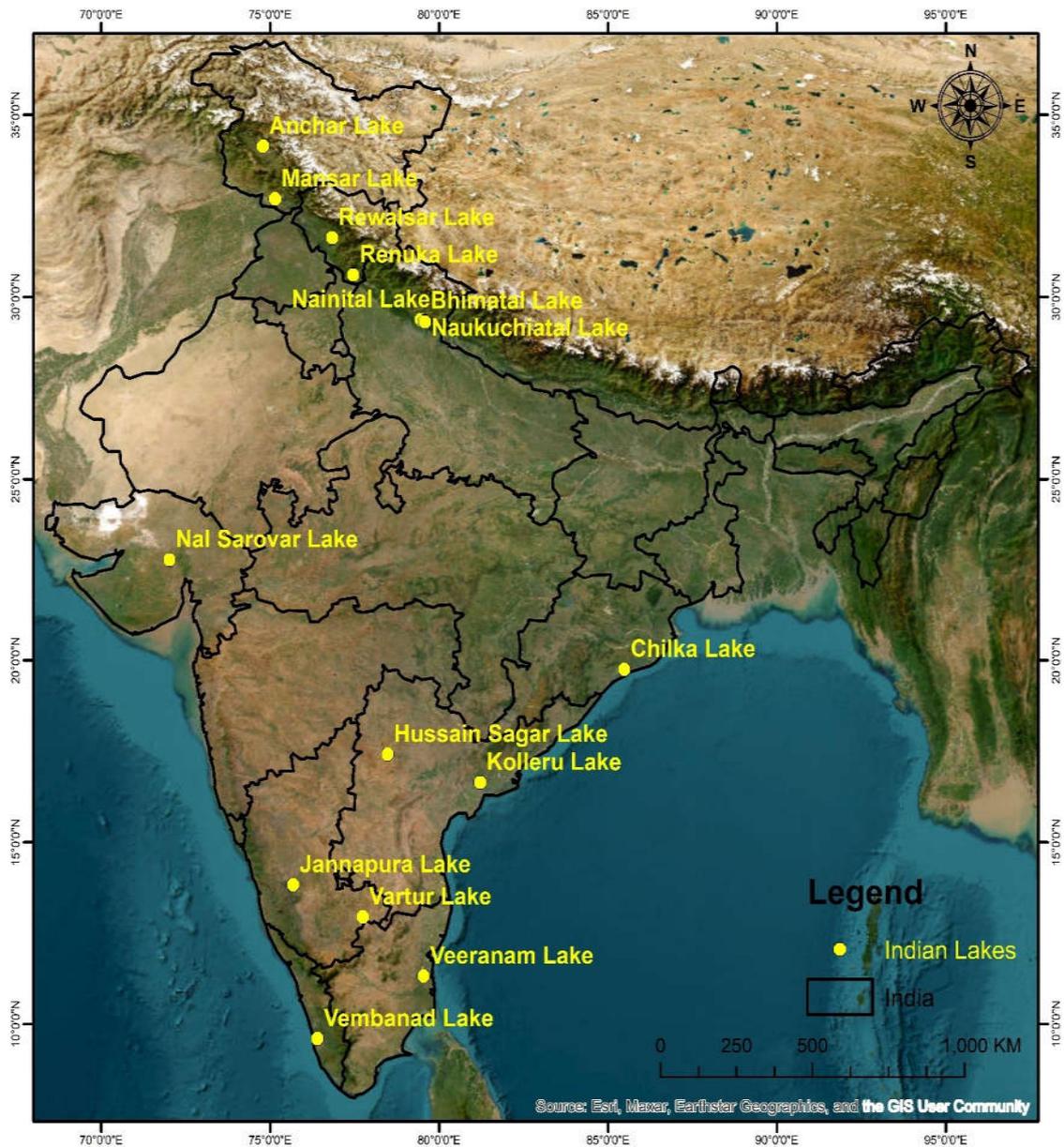
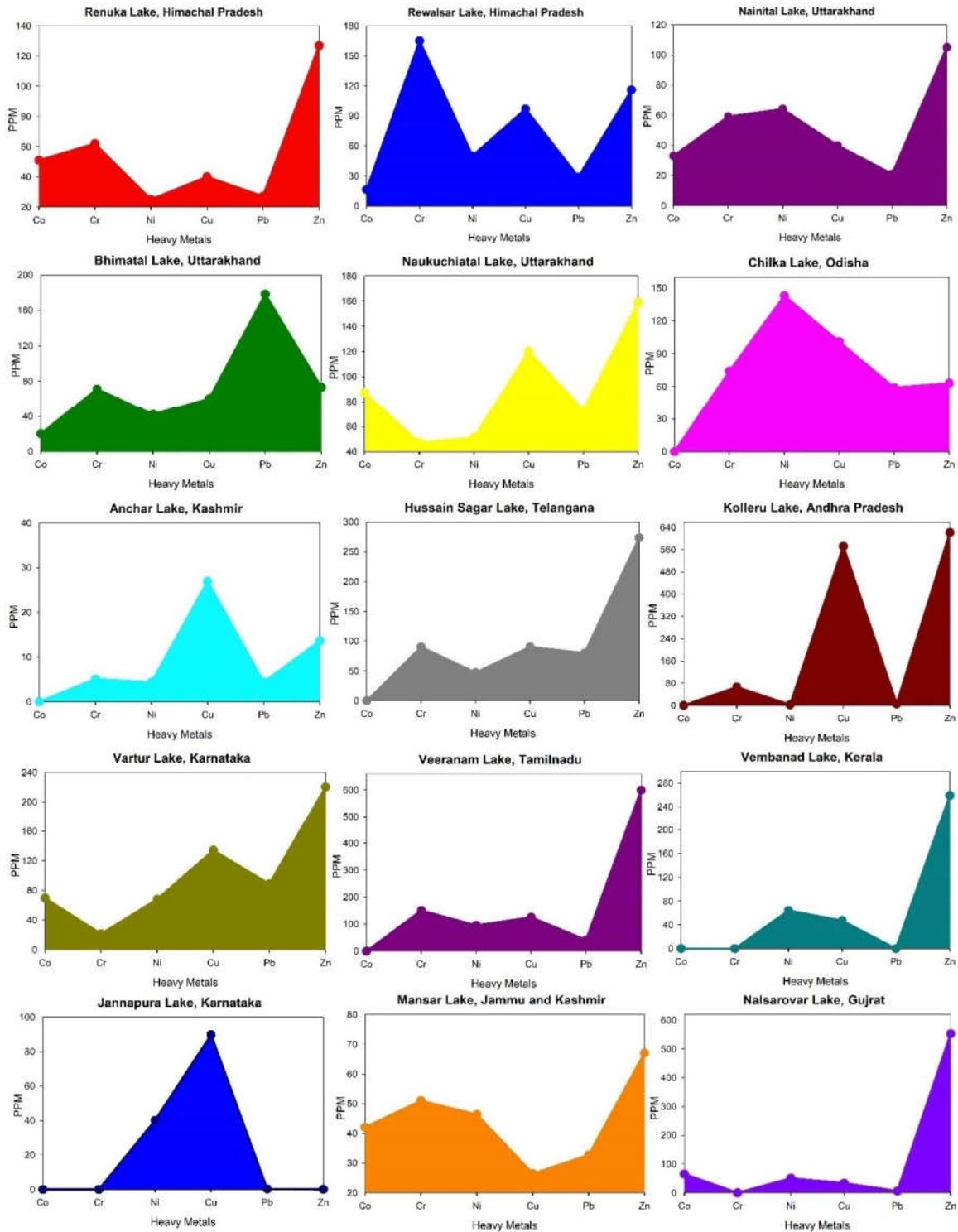**Figure 10: Location map of Indian lakes used for present study**

Figure 11: Heavy metal distribution graphs of Indian lakes used for present study

3. CONTAMINATION OF HEAVY METALS IN MAHARASHTRA LAKES

Total 5 lakes were selected from Maharashtra state to carry out the study. Most of lakes showed presence of heavy metals in their sediments. Observed values are shown is Table 7.

Table 7: Heavy metal contamination in lakes in Maharashtra

Maharashtra Lakes							
Sr. No.	Name of Lake	Co (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Reference
1	Paradgaon Lake, Nagpur	34.72-39.27	102.61-116.72	54.40-67.20	103.40-117.14	29.52-37.52	98.66-103.19	Kamble et al., 2014
2	Navegaon Bandh, Gondia	52	329	124	181	5.6	159	Humane et al., 2016
3	Bodhalkasa Lakes, Gondia	34	165	94	180	21	144	Humane et al., 2016
4	Papadi Lake, Vasai	-	623.49 - 922.28	-	-	524.54 - 775.92	-	Kinare et al., 2019
5	Lonar Lake, Buldhana	0.0037	-	0.00825	-	-	-	Wani et al., 2006

Lakes which were under investigation showed presence of heavy metals in their sediments. Cobalt was reported in all lakes except the Papadi Lake in Vasai. The highest concentration of Cobalt was observed in the Navegaon Bandh Lake which was 52 ppm. The average crustal value of Cobalt is 19 ppm. All lakes exceeded the average crustal limit which was harmful to lake ecosystem. Chromium was present in all lakes. The Papadi Lake in Vasai showed elevated concentration of Chromium which was up to 922.28 ppm. Least value of Chromium was observed in the Bodhalkasa Lake in Gondia which is 165 ppm, still it exceeded the average crustal value. The average crustal value of Chromium is 90 ppm. Presence of Chromium indicated heavy metal contamination in lake. Nickel was present in lakes except the Papadi Lake in Vasai. The average crustal value of Nickel is 68 ppm. The Paradgaon Lake showed Nickel value within range while other two lakes exceeded the

average crustal value. Presence of Copper was seen in three lakes. The average crustal value of Copper is 45 ppm. All lakes exceeded the average value of Copper. The Navegaon Bandh Lake showed highest proportion of Copper i.e., 181 ppm. Lead was present in all the lakes and showed much more elevated quantity in the Papadi Lake in Vasai. The average crustal value of Lead is 7 ppm. The Navegaon Bandh Lake showed least concentration of Lead i.e., 5.6 ppm and it was within the range. Lead value in the Papadi Lake indicated that lake was heavily contaminated. Zinc was observed in all three lakes except the Papadi Lake in Vasai. Elevated proportion of Zinc was noticed in the Navegaon Bandh Lake which was 159 ppm. The average crustal value of Zinc is 95 ppm. All three lakes exceeded Zinc concentration which indicated pollution in all three lakes. Location of lakes under study are shown in Fig. 12. The observed concentration are shown in Fig. 13.
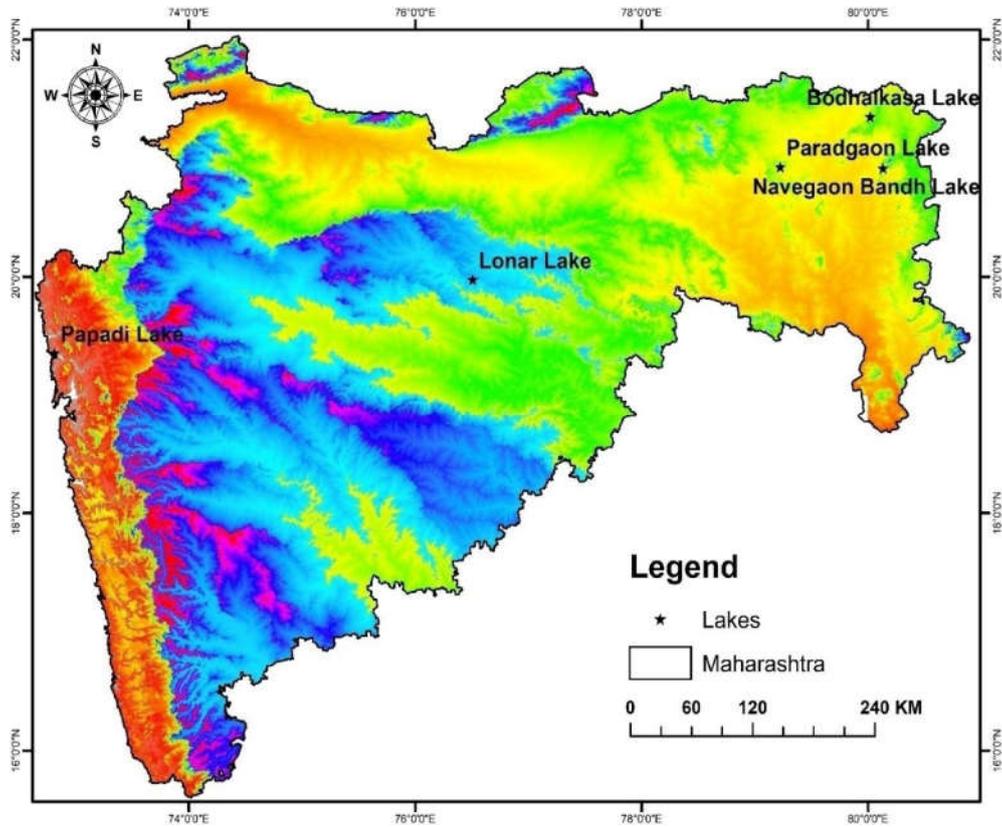
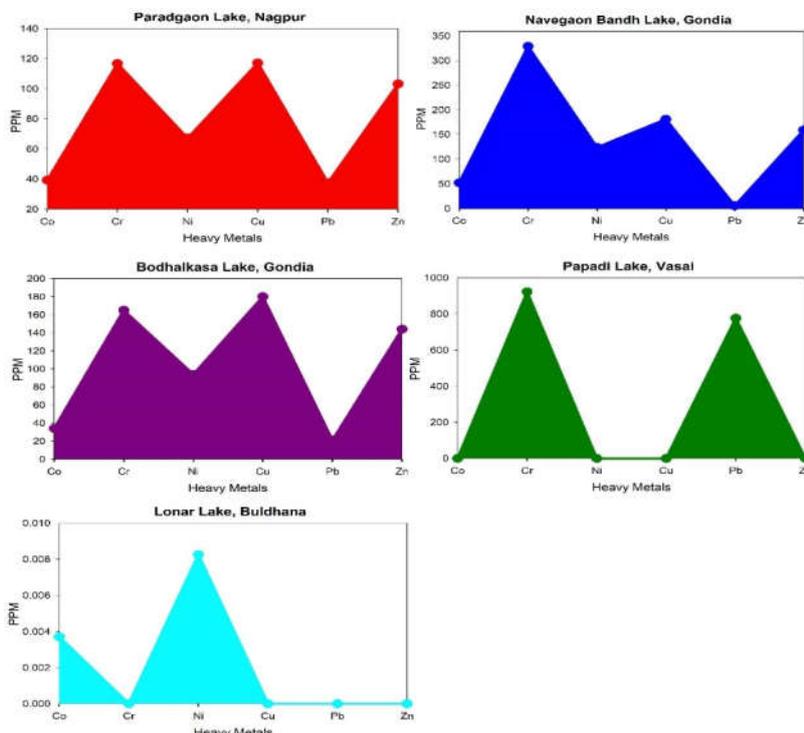**Figure 12: Location map of Maharashtra lakes used for present study**

Figure 13: Heavy metal distribution graphs of Maharashtra lakes used for present study

CONCLUSION

The results obtained by studying the heavy metal contamination in all 53 lakes, it can be inferred that the lakes all over the globe shows existence of heavy metals in their sediments which may prove hazardous to ecosystem. Heavy metal introduced in water sources mainly by various industries as well as by fertilizers and agricultural runoff. Lakes in Africa shows presence of Copper, Zinc, Lead in excess proportion. In case of American lakes, Cobalt is not detected while Chromium is within the permissible limit. The Erie Lake in Canada exceeds the average crustal value of Nickel which clearly indicates pollution. Nearly all lakes in America are heavily polluted by the Copper as it crosses average crustal value of Copper. European lakes show presence of Cobalt within permissible limit. Presence of Copper observed in all European lakes but only the Palas Lake in Italy crosses the average crustal value of Copper which may prove dangerous for lake ecosystem. Lead is present in most of lakes whereas the Constance Lake in Germany, the Koronia Lake in Greece and the Balaton Lake in Hungary shows the elevated concentration of Lead in their sediments which is major threat to the ecosystem. The Balton lake in Hungary is the most polluted lake as it shows ten times more concentration of Lead than the crustal average value. Zinc is observed in all lakes in Europe and most of them crosses the average crustal value. The Bosz-kowo Lake in Poland shows presence of Lead in much higher proportion. Asian lakes do not show presence of Cobalt in their sediments while Chromium is present in most of lakes and the Nansi Lake in China exceeds the average crustal value of Chromium. Nickel is detected in all Asian lakes except the Taihu Lake in China. Asian lake shows presence of Copper in all lakes and few of them have high proportion in their sediments. In case of Lead contamination, except than the Bafa Lake in Turkey all other lakes show Lead proportion in much higher proportion which is the major threat to the people depends on lake. Many diseases related to kidney and nervous system will be caused by Lead. Zinc is also observed in Asian lakes in elevated proportion except the Chaohu Lake in China and the Taihu Lake in China. It clearly indicates that Asian lakes are polluted by heavy metals.

Lakes in India are contaminated by nearly all types of heavy metals. Cobalt is present in most of lakes. Except the Rewalsar Lake in Himachal Pradesh, all the lakes show presence of Cobalt in elevated proportion. Presence of Chromium is observed in many lakes in India and few of them like the Rewalsar Lake in Himachal Pradesh, the Chilka Lake in Odisha and the Veeranam Lake in Tamilnadu exceeds the average crustal value. Nickel is present in all Indian lakes and the Chilka Lake in Odisha as well as the Veeranam Lake in Tamilnadu exceeds the average crustal value of Nickel. Presence of Lead is observed in all lakes except the Vembanad Lake in Kerala and most of them shows values higher than the average crustal value. The Bhimatal Lake in Uttarakhand shows highest contamination of Lead. Presence of Zinc is observed in all Indian lakes. The Kolleru Lake in Andhra Pradesh and the Veeranam Lake in Tamilnadu shows Zinc concentration in elevated proportion.

Lakes in Maharashtra also shows presence of heavy metals in their sediments. Except the Papadi Lake in Vasai, all other lakes show presence of Cobalt and crosses average crustal value. Chromium is present in all lakes and the Papadi Lake in Vasai is heavily contaminated by the Chromium. Nickel present in most of lakes in Maharashtra and the Navegaon Bandh Lake and the Bodhalkasa Lake in Gondia exceeds the average crustal value of Nickel. Copper is observed in three lakes except, the Papadi Lake in Vasai and the Lonar Lake in Buldhana. All the remaining lakes are heavily polluted by the Copper. Presence of Lead is noticed in all lakes and the Papadi Lake in Vasai shows highest contamination by the Copper. Zinc is present in all lakes in higher proportion which clearly indicates that lakes are contaminated by the heavy metals.

RECOMMENDATION AND FUTURE PROSPECT

1. It is necessary to spread awareness among people to mitigate pollution problem and

implement some conservation method to protect lake ecosystem.

2. Continuous monitoring and structures like check dams, retention wall will be established to prevent direct discharge of polluted water into water ecosystem.

3. The collaboration with government entities is needed for efficient functioning of environment monitoring program.

4. The installation of extensive monitoring system and data collection should be prioritize by government.

5. Combined efforts by governemt institutions and research focused entitites will enable to use resources in effective way.

AUTHOR CONTRIBUTIONS

Conceptualization, P.D.; methodology, P.D. and R.G.; software, P.L.; validation, P.D.; investigation, P.D. and R.G.; resources, P.D. and P.L.; data curation, P.D.; writing and original draft preparation, P.D. and P.L.; writing, review and editing, P.D., and R.G.; visualization, P.D. and P.L.; supervision, P.D.; project administration, P.D..; All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

Adimalla, N. (2020). Heavy metals pollution assessment and its associated human health risk evaluation of urban soils from Indian cities: a review. Environmental geochemistry and health, 42(1), 173-190.

Agarwal, A., Prajapati, R., Singh, O. P., Raza, S. K., and Thakur, L. K. (2015). Pesticide residue in water—a challenging task in India. Environmental monitoring and assessment, 187, 1-21.

Algül, F., and Beyhan, M. (2020). Concentrations and sources of heavy metals in shallow sediments in Lake Bafa, Turkey. Scientific reports, 10(1), 11782.

Alissa, E. M., and Ferns, G. A. (2011). Heavy metal poisoning and cardiovascular disease. Journal of toxicology, 2011(1), 870125.

Al-Taee, I. A., Al-Khafaji, A. S., and Mahmoud, A. J. (2024). Comparative assessment of some heavy metals in water and sediments from Sawa Lake, South Iraq. Caspian Journal of Environmental Sciences, 22(1), 197-210.

Anthony, T. (2023). Assessment of Heavy Metal Contamination in Wetlands Soils Around an Industrial Area Using Combined GIS-Based Pollution Indices and Remote Sensing Techniques. Air, Soil and Water Research, 16, 11786221231214062.

Arnous, M. O., and Hassan, M. A. (2015). Heavy metals risk assessment in water and bottom sediments of the eastern part of Lake Manzala, Egypt, based on remote sensing and GIS. Arabian Journal of Geosciences, 8, 7899-7918.

Ayyanar, A., andThatikonda, S. (2020). Distribution and ecological risks of heavy metals in Lake Hussain Sagar, India. Acta Geochimica, 39(2), 255-270.

Batapola, N. M., Dushyantha, N. P., Ratnayake, N. P., Premasiri, H. M. R., Panagoda, H., Jayawardena, C. L., ... and Ratnayake, R. M. P. (2023). Risk assessment of heavy metals in the freshwater lake sediments around Eppawala phosphate deposit, Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 51(4).

Bhagure, G. R., andMirgane, S. R. (2011). Heavy metal concentrations in groundwaters and soils of Thane Region of Maharashtra, India. Environmental monitoring and assessment, 173, 643-652.

Bhateria, R., and Jain, D. (2016). Water quality assessment of lake water: a review. Sustainable water resources management, 2, 161-173.

Cai, Y., Wei, J., Zhang, S., Wang, X., Zhang, Z., and Gao, J. (2023). Spatial Risk Assessment and Source Identification of Heavy Metals in Riverine Sediments of Lake Chaohu Basin, China. Ecosystem Health and Sustainability, 9, 0040.

Chandran, S. Distribution of heavy metals in Vembanad Lake with special reference to hydrology and geochemistry.

Cui, W., Mei, Y., Liu, S., and Zhang, X. (2023). Health risk assessment of heavy metal pollution and its sources in agricultural soils near Hongfeng Lake in the mining area of Guizhou Province, China. Frontiers in Public Health, 11.

Chu, X., Zhang, J., Chi, Y., and Yang, J. (2010). An improved method for watershed delineation and computation of surface depression storage. In Watershed management 2010: innovations in watershed management under land use and climate change (pp. 1113-1122).

Coen, N., Mothersill, C., Kadhim, M., and Wright, E. G. (2001). Heavy metals of relevance to human health induce genomic instability. The Journal of Pathology: A Journal of the Pathological Society of Great Britain and Ireland, 195(3), 293-299.

Das Sharma, M., Juyal, A., Mantha, K., and Das Sharma, S. (2016). A student-centric research and education programme on heavy metal pollution of water bodies from selected Indian cities. Current Science, 1393-1400.

Dev, M. K., Zodge, S. D., Puranik, U. Y., and Chandraprabha Miri, C. M. (2017). Analysis of heavy metal concentration in ground water around industrial area MIDC Lote, Maharashtra, India.

Diwate, P., Khan, F., Maurya, S., Meena, N. K., Humane, S., andGolekar, R. B. (2021).

Sedimentation Pattern and its Controlling Factors in Indian Lakes.

Dixit, S., and Tiwari, S. (2008). Impact assessment of heavy metal pollution of Shahpura Lake, Bhopal, India.

El-Degwy, A. A., Negm, N. A., El-Tabl, A. S., andGoher, M. E. (2023). Assessment of heavy metal pollution in water and its effect on Nile tilapia (Oreochromis niloticus) in Mediterranean Lakes: a case study at Mariout Lake. Applied Water Science, 13(2), 50.

Fazila, M. I., Iqbalb, M. A., and Abdullaha, S. (2012). A study on heavy metal ion contamination of groundwater reserves in Beed City, Maharashtra, India. Bull. Environ. Pharmacol. Life Sci, 1(8), 18-21.

Förstner, U. (1976). Lake sediments as indicators of heavy-metal pollution. Naturwissenschaften, 63(10), 465-470.

Gan, W., Zhang, Y., Xu, J., Yang, R., Xiao, A., and Hu, X. (2023). Spatial Distribution of Soil Heavy Metal Concentrations in Road-Neighboring Areas Using UAV-Based Hyperspectral Remote Sensing and GIS Technology. Sustainability, 15(13), 10043.

Gaury, P. K., Meena, N. K., and Mahajan, A. K. (2018). Hydrochemistry and water quality of Rewalsar Lake of Lesser Himalaya, Himachal Pradesh, India. Environmental monitoring and assessment, 190, 1-22.

Ghorade, I. B., Lamture, S. V., and Patil, S. S. (2014). Assessment of heavy metal content in Godavari river water. Int J Res Appl Nat Soc Sci, 2(6), 23-26.

Gholizadeh, M. H., Melesse, A. M., and Reddi, L. (2016). A comprehensive review on water quality parameters estimation using remote sensing techniques. Sensors, 16(8), 1298.

Githaiga, K. B., Njuguna, S. M., Gituru, R. W., and Yan, X. (2021). Water quality assessment, multivariate analysis and human health risks of heavy metals in eight major lakes in Kenya. Journal of Environmental Management, 297, 113410.

Guo, H., Yang, L., Han, X., Dai, J., Pang, X., Ren, M., and Zhang, W. (2019). Distribution characteristics of heavy metals in surface

soils from the western area of Nansi Lake, China. Environmental monitoring and assessment, 191, 1-13.

Guo, S., Zhang, Y., Xiao, J., Zhang, Q., Ling, J., Chang, B., and Zhao, G. (2021). Assessment of heavy metal content, distribution, and sources in Nansi Lake sediments, China. Environmental Science and Pollution Research, 28, 30929-30942.

Haribhau, M. G. (2012). Trace metals contamination of surface water samples in and around Akot city in Maharashtra, India. Research Journal of Recent Sciences. ISSN, 2277, 2502.

He, J., Yang, Y., Christakos, G., Liu, Y., and Yang, X. (2019). Assessment of soil heavy metal pollution using stochastic site indicators. Geoderma, 337, 359-367.

He, L., Hu, W., Wang, X., Liu, Y., Jiang, Y., Meng, Y., ... and Lu, Y. (2020). Analysis of heavy metal contamination of agricultural soils and related effect on population health—a case study for East River Basin in China. International journal of environmental research and public health, 17(6), 1996.

Humane, S. K., Bokade, P. R., Humane, S. S., and Wankhade, A. S. (2010). Trophic status and ecological studies of the Ambazari Lake, Nagpur, Maharashstra, based on sedimentary diatoms. Current Science, 816-822.

Humane, S. S., Humane, S. K., andJuare, S. (2016). 210 Pb dating and trace metal accumulation study of sediment cores from Navegaon Bandh and Bodhalkasa Lakes, Gondia District, Maharashtra, India. Environmental Earth Sciences, 75, 1-26.

Humane, S. K., Humane, S. S., and Chalakh, S. (2018). Limnological study of Gadchiroli lake, Maharashtra, India using hydrosediment chemistry and sedimentary diatoms in. International Journal of Scientific Research in Science and Technology, 4, 1659-1670.

Jones, N. L., Wright, S. G., and Maidment, D. R. (1990). Watershed delineation with triangle-based terrain models. Journal of Hydraulic Engineering, 116(10), 1232-1251.

Jumbe, A. S., and Nandini, N. (2009). Heavy metals analysis and sediment quality values in urban lakes. American Journal of Environmental Sciences, 5(6), 678.

Jumbe, A. S., and Nandini, N. (2009). Impact assessment of heavy metals pollution of Vartur lake, Bangalore. Journal of Applied and Natural Science, 1(1), 53-61.

Kalekar, P., Kamble, P., Chakraborti, S., Dev, P., Alvarez, E., and Laware, S. (2022). Heavy metal contamination in surface sediments of the Upper Bhima Basin, Maharashtra, India. Environmental Sustainability, 5(4), 507-531.

Kamble, S., Humane, S. K., and Humane, S. S. (2014). Seasonal diatom diversity with reference to hydrochemistry and geochemistry of the Paradgaon Lake, Umrer Taluka, Nagpur District Maharashtra. Gond Geol Mag Spec, 15, 41-52.

Kamzati, L. L. J., Kaonga, C. C., Mapoma, H. W. T., Thulu, F. G., Abdel-Dayem, S. M., Anifowose, A. J., ... andSakugawa, H. (2020). Heavy metals in water, sediment, fish and associated risks from an endorheic lake located in Southern Africa. International Journal of Environmental Science and Technology, 17, 253-266.

Keshavarzi, A., Kumar, V., Ertunç, G., and Brevik, E. C. (2021). Ecological risk assessment and source apportionment of heavy metals contamination: An appraisal based on the Tellus soil survey. Environmental Geochemistry and Health, 43(5), 2121-2142.

Khare, K. C., and Jadhav, M. S. (2008). Water quality assessment of Katraj lake, Pune (Maharashtra, India): A case study. In Proceedings of Taal2007: The 12th World Lake Conference (Vol. 292, p. 299).

Kinare, P. P., andShingadia, H. U. Heavy Metals Accumulation in Sediment, Water and Various Tissues of Labeo Rohita in Papadi Lake of Vasai Taluka, Maharashtra. Journal of Indian Fisheries Association, 46(2).

Kolli, M. K. (2020). Lake Catchment Interaction Analysis by Using Remote Sensing and GIS Techniques–the case study of Kolleru Lake, South India.

Kumar, P., Meena, N. K., Diwate, P., Mahajan, A. K., and Bhushan, R. (2019). The heavy metal contamination history during ca 1839–2003 AD from Renuka Lake of Lesser Himalaya, Himachal Pradesh, India. Environmental Earth Sciences, 78, 1-14.

Kumar, V., Parihar, R. D., Sharma, A., Bakshi, P., Sidhu, G. P. S., Bali, A. S., ... and Rodrigo-Comino, J. (2019). Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses. Chemosphere, 236, 124364.

Kumar, V., Sharma, A., Kaur, P., Sidhu, G. P. S., Bali, A. S., Bhardwaj, R., ... and Cerda, A. (2019). Pollution assessment of heavy metals in soils of India and ecological risk assessment: A state-of-the-art. Chemosphere, 216, 449-462.

Kumkar, P., Verma, C. R., Hýsek, Š., Pise, M., Źółtowska, S., Gosavi, S. M., ... and Kalous, L. (2023). Contaminants and their ecological risk assessment in beach sediments and water along the Maharashtra coast of India: A comprehensive approach using microplastics, heavy metal (loid) s, pharmaceuticals, personal care products and plasticisers. Science of the Total Environment, 892, 164712.

Labhade, K. R. (2013). Assessment of heavy metal contamination in vegetables grown in and around Nashik City, Maharashtra State, India. IOSR J. Appl. Chem, 5, 9-14.

Li, P., Feng, W., Xue, C., Tian, R., and Wang, S. (2017). Spatiotemporal variability of contaminants in lake water and their risks to human health: a case study of the Shahu Lake tourist area, northwest China. Exposure and health, 9, 213-225.

Li, D., Zhu, Z., Cao, X., Yang, T., and An, S. (2024). Increasing trends in heavy metal risks in the Caohai Lake sediments from 2011 to 2022. Arabian Journal of Chemistry, 17(2), 105543.

Lokhande, R. S., Singare, P. U., and Pimple, D. S. (2011). Toxicity study of heavy metals pollutants in waste water effluent samples collected from Taloja industrial estate of Mumbai, India. Resources and Environment, 1(1), 13-19.

Lotfinasabasl, Sakineh, V. R. Gunale, and N. S. Rajurkar. "metal pollution assessment in the soil and surface water of Alibaug mangrove forest, Maharashtra, India." In First International Conference on Environmental Crisis and Solutions, pp. 13-14. 2013.

Malik, N., and Biswas, A. K. (2013). Heavy metals in sediments of inland water bodies of india: a review. Nature Environment and Pollution Technology, 12(2), 233.

Mawari, G., Kumar, N., Sarkar, S., Daga, M. K., Singh, M. M., Joshi, T. K., and Khan, N. A. (2022). Heavy metal accumulation in fruits and vegetables and human health risk assessment: findings from Maharashtra, India. Environmental Health Insights, 16, 11786302221119151.

Mawari, G., Kumar, N., Sarkar, S., Frank, A. L., Daga, M. K., Singh, M. M., ... and Singh, I. (2022). Human health risk assessment due to heavy metals in ground and surface water and association of diseases with drinking water sources: A study from Maharashtra, India. Environmental health insights, 16, 11786302221146020.

Meena, N. K., Prakasam, M., Bhushan, R., Sarkar, S., Diwate, P., and Banerji, U. (2017). Last-five-decade heavy metal pollution records from the Rewalsar Lake, Himachal Pradesh, India. Environmental Earth Sciences, 76, 1-10.

Mert, B. K., andKasapoğulları, D. (2023). A Case Study of Using Artificial Neural Networks to Predict Heavy Metal Pollution in Lake Iznik.

Nazir, A., Hussain, S. M., Riyaz, M., Kere, Z., Zargar, M. A., and LK, K. D. (2024). Environmental risk assessment, spatial distribution, and abundance of heavy metals in surface sediments of Dal Lake-Kashmir, India. Environmental Advances, 17, 100562.

Olando, G., Olaka, L. A., Okinda, P. O., andAbuom, P. (2020). Heavy metals in surface sediments of Lake Naivasha, Kenya: spatial distribution, source identification and ecological risk assessment. SN Applied Sciences, 2, 1-14.

Panda, D., Subramanian, V., and Panigrahy, R. C. (1995). Geochemical fractionation of heavy metals in Chilka Lake (east coast of India)—a tropical coastal lagoon. Environmental Geology, 26, 199-210.

Pandey, V. K., Panda, S. N., Raghuwanshi, N. S., and Sudhakar, S. (2006). Delineation and parameterization of Banikdih watershed using remote sensing and AVSWAT model. Journal of the Indian Society of Remote Sensing, 34, 143-152.

Pertsemli, E., andVoutsa, D. (2007). Distribution of heavy metals in lakes doirani and kerkini, northern Greece. Journal of Hazardous Materials, 148(3), 529-537.

Patil, S. S., Thakur, V. R., andGhorade, I. B. (2014). Analysis of heavy metals in Jaikwadi dam water, Maharashtra (India). International Journal of Research in Applied, Natural and Social Sciences, 2(5), 69-74.

Patil, S. S., and Kaushik, G. (2016). Heavy metal assessment in water and sediments at Jaikwadi dam (Godavari river) Maharashtra, India. International Journal of Environment, 5(2), 75-88.

Pradeep, V., Deepika, C., Urvi, G., and Hitesh, S. (2012). Water quality analysis of an organically polluted lake by investigating different physical and chemical parameters. Int. J. Res. Chem. Environ, 2(1), 105-111.

Purushothaman, P., and Chakrapani, G. J. (2012). Trace metals biogeochemistry of Kumaun Himalayan Lakes, Uttarakhand, India. Environmental monitoring and assessment, 184, 2947-2965.

Qin, Y., and Tao, Y. (2022). Pollution status of heavy metals and metalloids in Chinese lakes: Distribution, bioaccumulation and risk assessment. Ecotoxicology and environmental safety, 248, 114293.

Raju Potharaju, M. Heavy Metal Pollution in a Lake: An Assessment of the Ecological Threat.

Radfard, M., Hashemi, H., Baghapour, M. A., Samaei, M. R., Yunesian, M., Soleimani, H., and Azhdarpoor, A. (2023). Prediction of human health risk and disability-adjusted life years induced by heavy metals exposure through drinking water in Fars Province, Iran. Scientific Reports, 13(1), 19080.

Rehman, K., Fatima, F., Waheed, I., and Akash, M. S. H. (2018). Prevalence of exposure of heavy metals and their impact on health consequences. Journal of cellular biochemistry, 119(1), 157-184.

Rosado, D., Castillo, F., Nambi, I., Sadhasivam, R., Valleru, H., and Fohrer, N. (2024). Evaluating heavy metal levels and their toxicity risks in an urban lake in Chennai, India. International Journal of Environmental Science and Technology, 21(2), 1849-1864.

Rostom, N. G., Shalaby, A. A., Issa, Y. M., and Afifi, A. A. (2017). Evaluation of Mariut Lake water quality using Hyperspectral Remote Sensing and laboratory works. The Egyptian Journal of Remote Sensing and Space Science, 20, S39-S48.

Shirmohammadi, B., Rostami, M., Varamesh, S., Jaafari, A., and Taie Semiromi, M. (2024). Future climate-driven drought events across Lake Urmia, Iran. Environmental Monitoring and Assessment, 196(1), 24.

Showqi, I., Lone, F. A., andNaikoo, M. (2018). Preliminary assessment of heavy metals in water, sediment and macrophyte (Lemna minor) collected from Anchar Lake, Kashmir, India. Applied Water Science, 8, 1-11.

Shaikh Parveen, R., and Bhosle Arjun, B. (2013). Heavy metal contamination in soils near Siddheshwar Dam Maharashtra, India. Research Journal of Chemical Sciences ISSN, 2231, 606X.

Shinde, D., Mahajan, D. M., and Chakane, S. D. (2020). Assessment of heavy metal concentration in Ujjani Reservoir water and sediment, Maharashtra, India.

Shree, B. V., K, R. K., and Nishikant, G. (2019). Examining the heavy metal contents of an estuarine ecosystem: case study from Maharashtra, India. Journal of Coastal Conservation, 23(6), 977-984.

Singare, P. U., Lokhande, R. S., and Naik, K. U. (2010). A case study of some lakes located at and around thane city of Maharashtra, India, with special reference to physico-chemical properties

and heavy metal content of lake water. Interdisciplinary Environmental Review, 11(1), 90-107.

Singare, P. U., Jagtap, A. G., and Lokhande, R. S. (2011). Water pollution by discharge effluents from Gove Industrial Area of Maharashtra, India: Dispersion of heavy metals and their Toxic effects. International Journal of Global Environmental Issues, 11(1), 28-36.

Singare, P. U., Bhanage, S. V., and Lokhande, R. S. (2011). Study on water pollution along the Kukshet Lakes of Nerul, Navi Mumbai, India with special reference to pollution due to heavy metals. International Journal of Global Environmental Issues, 11(1), 79-90.

Singare, P. U., Jagtap, A. G., and Lokhande, R. S. (2011). Water pollution by discharge effluents from Gove Industrial Area of Maharashtra, India: Dispersion of heavy metals and their Toxic effects. International Journal of Global Environmental Issues, 11(1), 28-36.

Singare, P. U., Naik, K. U., and Lokhande, R. S. (2011). Impact assessment of pollution in some lake water located at and around Thane City of Maharashtra, India: physico-chemical properties and toxic effects of heavy metal content. Interdisciplinary Environmental Review, 12(3), 215-230.

Singare, P. U., Mishra, R. M., and Trivedi, M. P. (2012). Heavy metal pollution in Mithi River of Mumbai. Frontiers in Science, 2(3), 28-36.

Singare, P. U., Mishra, R. M., and Trivedi, M. P. (2012). Sediment contamination due to toxic heavy metals in Mithi River of Mumbai. Adv Anal Chem, 2(3), 14-24.

Singare, P. U., Trivedi, M. P., and Mishra, R. M. (2012). Sediment heavy metal contaminants in Vasai Creek of Mumbai: pollution impacts. American journal of chemistry, 2(3), 171-180.

Singare, P. U., Talpade, M. S., Dagli, D. V., and Bhawe, V. G. (2013). Heavy metal content in water of Bhavan's College Lake of Andheri, Mumbai. International Letters of Chemistry, Physics and Astronomy, 8(2), 94-104.

Singare, P. U., Bhattacharjee, S. S., and Lokhande, R. S. (2013). Analysis of the heavy metal pollutants in sediment samples collected from Thane Creek of Maharashtra, India. International Journal of Sustainable Society, 5(3), 296-308.

Singh, A., Singh, D. R., and Yadav, H. K. (2017). Impact and assessment of heavy metal toxicity on water quality, edible fishes and sediments in lakes: a review. Trends. Biosci, 10(8), 1551-1560.

Suresh, G., Sutharsan, P., Ramasamy, V., andVenkatachalapathy, R. (2012). Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. Ecotoxicology and environmental safety, 84, 117-124.

Szymanowska, A., Samecka-Cymerman, A., and Kempers, A. J. (1999). Heavy metals in three lakes in West Poland. Ecotoxicology and environmental safety, 43(1), 21-29.

Wagh, V. M., Panaskar, D. B., Mukate, S. V., Gaikwad, S. K., Muley, A. A., and Varade, A. M. (2018). Health risk assessment of heavy metal contamination in groundwater of Kadava River Basin, Nashik, India. Modeling Earth Systems and Environment, 4, 969-980.

Wang, W., Li, W., Xue, M., Gu, X., Ye, C., Jiao, Y., ... and Zhang, X. (2023). Spatial-Temporal Characteristics and Influencing Factors of Lake Water and Groundwater Chemistry in Hulun Lake, Northeast China. Water, 15(5), 937.

Wang, S., Li, X., Jiang, X., Zhang, Y., Zhang, J., Liu, Y., ... and Fu, Z. (2024). The interaction between nutrients and heavy metals in lakes and rivers entering lakes. Ecological Indicators, 161, 111963.

Wang, L., Liu, D., Sun, Y., Zhang, Y., Chen, W., Yuan, Y., ... and Li, S. (2024). Machine learning-based analysis of heavy metal contamination in Chinese lake basin sediments: Assessing influencing factors and policy implications. Ecotoxicology and Environmental Safety, 283, 116815.

Wani, A. A., Surakasi, V. P., Siddharth, J., Raghavan, R. G., Patole, M. S., Ranade,

D., andShouche, Y. S. (2006). Molecular analyses of microbial diversity associated with the Lonar soda lake in India: an impact crater in a basalt area. Research in Microbiology, 157(10), 928-937.

Yang, X., Leng, M., Ge, X., Wu, X., Liu, H., Lin, G., ... and Chen, Y. (2024). Characterization and Risk Assessment of Nutrient and Heavy Metal Pollution in Surface Sediments of Representative Lakes in Yangxin County, China. Sustainability, 16(6), 2252.

Yigit Avdan, Z., Kaplan, G., Goncu, S., and Avdan, U. (2019). Monitoring the water quality of small water bodies using high-resolution remote sensing data. ISPRS International Journal of Geo-Information, 8(12), 553.

Yu, K. C., Tsai, L. J., Chen, S. H., and Ho, S. T. (2001). Chemical binding of heavy metals in anoxic river sediments. Water Research, 35(17), 4086-4094.

Zhang, Z., Wei, S., and Liu, J. (2021). Pollution characteristics and risk assessment of heavy metal elements in sediment in the west lake of Hengshui Lake. Advances in Materials Science and Engineering, 2021, 1-6.

Zhao, H., Liu, P., Qiao, B., and Wu, K. (2021). The spatial distribution and prediction of soil heavy metals based on measured samples and multi-spectral images in Tai Lake of China. Land, 10(11), 1227.

Zhao, S., Zhao, Y., Cui, Z., Zhang, H., and Zhang, J. (2024). Effect of pH, temperature, and salinity levels on heavy metal fraction in lake sediments. Toxics, 12(7), 494.

Zhu, X., Wu, Z., Han, X., Yang, Z., Dong, X., Yuan, Y., ... and Wang, C. (2024). In situ, high-resolution evidence for the release of heavy metals from lake sediments during ice-covered and free periods. Frontiers in Ecology and Evolution, 11, 1326818.

Zhou, Q., Yang, N., Li, Y., Ren, B., Ding, X., Bian, H., and Yao, X. (2020). Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. Global Ecology and Conservation, 22, e00925.

Zhuang, P., Lu, H., Li, Z., Zou, B., and McBride, M. B. (2014). Multiple exposure and effects assessment of heavy metals in the population near mining area in South China. PloS one, 9(4), e94484.

****