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Original Article

Monitoring the Change in Water Quality in Pulicat Lake From 2012-2022

Saurish Kapoor

St. Joseph's Institution International School, W.P. Kuala Lumpur, Malaysia.

Corresponding Author : saurishk0508@gmail.com

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Abstract - *Pulicat Lake is the second-largest brackish water ecosystem on the Coromandel Coast of southern India, with over 30,000 fishermen, 20,000 agricultural workers, and 100,000 people whose livelihoods depend on it. Recently, the region has experienced rapid urbanization and industrialization. However, this has negatively impacted the fragile ecosystem and threatened the livelihoods of these individuals. This study examines the changes in water quality parameters in the lake over a decade, between 2012 and 2022, by extracting data from an online open-source water quality repository by the Government of India. Mean values were computed, and the results were graphically represented to aid in identifying visual trends and patterns. The parameters analyzed include temperature, dissolved oxygen, pH, conductivity, biochemical oxygen demand, nitrate + nitrite, fecal coliform, and total coliform levels. The findings show that the water quality of the lake has fluctuated significantly over the past decade. In its current state, the water is unfit for consumption or agricultural purposes. This is heavily influenced by anthropogenic activities taking place near the lake, which harm the ecological integrity of the lake.*

Keywords - *Pulicat Lake, Aquatic ecosystem, Environment, Pollution, Water quality*.

1. Introduction

Pulicat Lake is India's second-largest brackish water habitat, located north of Madras in the Nellore district of Andhra Pradesh. It is home to 168 fish species, as well as over 110 terrestrial and aquatic birds, small animals, and reptiles [1]. This essential ecosystem is facing increasing anthropogenic pressures, including siltation, reduced freshwater inflow, urban growth, fisheries, prawn farms, industrialization (such as port construction and expansion), tourism, and hunting. The livelihoods of over 50,000 fishermen, agricultural workers, and hundreds of thousands of people who rely on the lake are threatened due to these environmental impacts [2]. Inadequate management and industrial wastewater contamination have seriously harmed the once-thriving fishing grounds and ecologically vital mangrove forests in the lagoon north of Chennai. Pathogenic bacteria, phosphate, nitrogen, hydrocarbons, heavy metals, endocrine disruptors, and organic waste in the lake are primarily caused by pollutants emitted by neighboring industrial and residential activities [3, 4, 5]. These pollutants endanger the water quality of the lake, leading to eutrophication, algal blooms, and fish mortality. Additional risks come from the discharge of human sewage, irrigation of pesticides, agricultural chemicals, and industrial effluents. Moreover, these pollutants compromise aquaculture development and waste from fish-processing facilities, further degrading water quality and damaging surrounding areas [6]. A recent study conducted by K. Nirmala et al. [7] has shown a considerable increase in saline levels in Pulicat Lake, which is mostly due to reduced freshwater inputs and seawater intrusion. Anthropogenic activities such as dam construction and river diversion that feed the lake have aggravated the situation. Furthermore, nutrient concentrations have increased, particularly nitrates and phosphates, as a result of agricultural runoff and untreated sewage flow from nearby settlements. This nutrient loading has led to the lake's eutrophication, causing frequent algal blooms and a drop in dissolved oxygen levels, further worsening water quality and killing aquatic life. Further studies by S. Kamala-Kannan et al. [4, 5] found heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg), in Pulicat Lake's sediments and water. These toxins have been linked to industrial effluents, specifically from neighboring petrochemical facilities and small-scale enterprises. These metals have been found to bioaccumulate in fish species, which may have long-term ecological repercussions and damage the health of communities that rely on the lake for fishing. This study looks at main water quality metrics from 2012 to 2022. It assesses them against the best-use water quality classifications C (Drinking Water Source after Conventional Treatment and Disinfection) and D (Propagation of Wildlife and Fisheries). The primary goals of this research are to (i) analyze trends in water quality in Pulicat Lake from 2012 to 2022, (ii) assess the impact of urbanization and industrialization on lake water quality, and (iii) compare water quality data to the standards established for the designated best-use classifications C and D, identifying potential impacts on human health and the environment.

2. Methodology

This study used open-source secondary data on the water quality of Pulicat Lake from 2012 to 2022 provided by the Central Pollution Control Board (CPCB) of India's Ministry of Environment, Forest, and Climate Change [18]. Temperature, dissolved oxygen (D.O.), pH, conductivity, biochemical oxygen demand (B.O.D), nitrate + nitrite, fecal coliform, and total coliform were among the characteristics tested. The data presented in Table 1 was first extracted and then compiled. Mean values were then calculated, which were graphically represented using Microsoft Excel to help visually identify trends and patterns and compare them to the standards for best-use classifications C and D, essential for assessing the lake's ecosystem health. The reasoning for selecting these specific parameters is as follows:

- Temperature: Influences metabolic rates of aquatic organisms and the solubility and reaction rates of pollutants.
- D.O: Essential for aquatic organisms' survival and an indicator of the biological health of water bodies.
- pH: Affects the solubility and toxicity of chemicals in the water, impacting aquatic life.
- Conductivity: Estimates the amount of dissolved salts or inorganic materials in the water.
- B.O.D: Measures the oxygen required by bacteria to decompose organic material; high levels can deplete oxygen, affecting aquatic life.
- Nitrate + nitrite: are nutrients that can promote harmful algal blooms and lead to eutrophication.
- Fecal coliform and total coliform: are indicators of fecal contamination, posing risks to human health and aquatic life.

3. Study Area

Pulicat Lake is a saltwater lagoon located on the Coromandel Coast of southern India, 96% of which spans across the southeastern part of Andhra Pradesh and the remaining portion in Tamil Nadu. The lake, approximately 50 kilometers (km) long and varying between 5 and 16 km wide, is situated on the sandy Andhra plains. The surrounding area, home to towns such as Dugarajupatnam and Pulicat, is sparsely populated [8]. The lake, known for its salt and prawn yield, is separated by Sriharikota Island from the Bay of Bengal.

It also hosts a satellite-launching facility, the Satish Dhawan Space Centre. The lake's only sea entrance is located at the island's southern end. Pulicat Lake, with coordinates between 13.33° to 13.66° N and 80.23° to 80.25°E, is a dynamic ecosystem influenced by tidal fluctuations and freshwater inflows from the Arani and Kalangi Rivers.

The lagoon, enclosed by Sriharikota, features extensive mudflats and sandflats typical of shallow coastal environments. Its connection to the Bay of Bengal via northern and southern channels enables seawater and nutrient exchange, influencing the region's ecological dynamics. The lagoon's area fluctuates with the tide, spanning 450 km^2 at high tide and 250 km^2 at low tide. Tropical monsoons dominate the region's climate.

Fig. 1 Map of Pulicat Lake, the focal point of the study area

4. Results and Discussion

Table 1. The mean values of key water quality parameters, including temperature, dissolved oxygen (D.O.), pH, conductivity, biochemical oxygen demand (B.O.D.), nitrate + nitrite, fecal coliform, and total coliform, recorded between 2012 and 2022 in the Pulicat Lake

Year	Temperature (°C)	D.O. (mg/l)	pH	Conductivity (μS/cm)	B.O.D. (mg/l)	Nitrate + Nitrite (mg/l)	Fecal Coliform (MPN/100ml)	Total Coliform (MPN/100ml)
2022	20.00	6.25	7.75	36,650.00	2.75	1.45	32.50	382.00
2021	21.00	5.10	7.70	42,450.00	2.60	1.42	3.00	98.50
2020	23.50	4.30	7.70	37,960.00	2.50	1.10	3.00	142.50
2019	23.00	5.20	7.45	34,865.00	2.50	1.63	3.50	905.00
2018	28.00	6.30	7.55	27,935.00	4.35	2.10	3.00	1350.00
2017	27.50	6.00	7.80	79,935.00	1.65	3.78	2.00	1200.00
2016	28.00	5.25	7.50	33,380.00	1.65	1.40	2.00	1850.00
2015	28.00	5.40	8.05	35,706.00	1.60	0.65	701.00	651.00
2014	25.00	5.85	7.90	40,550.00	0.75	1.35	2.00	400.00
2013	23.00	4.80	8.15	48,100.00	1.00	0.95	2.00	550.00
2012	27.00	4.70	7.75	46,400.00	1.15	0.54	4.00	1250.00

Table 2. Criteria set by the CPCB for water classifications C (Drinking Water Source after Conventional Treatment and Disinfection) and D (Propagation of Wildlife and Fisheries)

Parameter	Class C	Class D
Total Coliforms Organism (MPN/100ml)	≤ 5000	-
pH	6 - 9	6.5 - 8.5
Dissolved Oxygen (mg/L)	≥ 4	≥ 4
Biochemical Oxygen Demand (5 days, 20 °C) (mg/L)	≤ 3	-
Free Ammonia (as N) (mg/L)	-	≤ 1.2

The temperature in Pulicat Lake has shown a decrease, following a linear downward trend, as shown in Figure 2, ranging from the lowest at 20.0 °C in 2022 to the highest at 28.0 °C which was seen in 2015, 2016, and again in 2018. The temperature decrease in Pulicat Lake may be linked to local climate fluctuations, land use changes, and human activities. These activities, such as runoff from nearby mining operations and emissions from vehicles, fishing boats, and rocket launches at the Satish Dhawan Space Centre, contribute to atmospheric metal pollution and the release of industrial effluents containing metals. The biochemical processes in the aquatic environment are regulated by temperature, which alters the rates of metabolism, the cycles of reproduction, and the distribution patterns of aquatic species. Changes in temperature regimes could influence the D.O. concentrations, nutrient cycling, and ecosystem productivity overall, which may impact the diversity and health of the lake's aquatic life. As a result, these variables changes in temperature regimes can alter fish and other aquatic creatures' metabolism rates, reproductive cycles, and distribution patterns. This eventually impacts the diversity and health of the aquatic life in the lake [9]. The optimum temperature for aquatic ecosystems varies widely depending on the specific organisms within the ecosystem. For instance, freshwater crayfish have been found to have different temperature preferences and optimal growth temperatures [10]. Similarly, seagrasses and macroalgae in marine environments have their upper lethal limits found between 28.9 and >34 °C [11]. However, it is important to remember that temperature is a master abiotic factor that controls many aspects of the biology, physiology, distribution, and behavior of aquatic ectothermic organisms [10]. Therefore, any significant alterations in temperature regimes can disrupt these biological processes and lead to adverse effects, which could fundamentally transform current ecosystems and food webs, the overall health, and the diversity of aquatic life. D.O. levels in Pulicat Lake, as illustrated in Figure 3, showcased an upward trend that has increased over the past decade. This increase in D.O. levels can be considered an improvement in the lake's water quality, which can be attributed to mitigating pollution inputs, enhanced water circulation dynamics, or favorable environmental shifts. D.O. is crucial in supporting marine life, with 4–9 mg/L considered the optimal range for a diverse fish population [12]. The observed D.O. levels ranged between 4.30 mg/L in 2020 and 6.25 mg/L in 2022, indicating a generally favorable environment for marine life. However, excessively high D.O. levels can lead to a condition known as hyperoxia, which can cause oxidative stress in aquatic organisms [13]. Reactive oxygen species, or free radicals, are produced in excess of what an organism can use to either detoxify them or repair the harm they have caused. This imbalance is known as oxidative stress. This imbalance may have negative repercussions such as lipid, protein, and DNA damage or even cell death [13]. High levels of D.O. can destabilize aquatic ecosystems by causing plants to over-reproduce, potentially leading to anoxic conditions that kill aquatic life, release excess nutrients, and make the water unsuitable for human consumption [14].

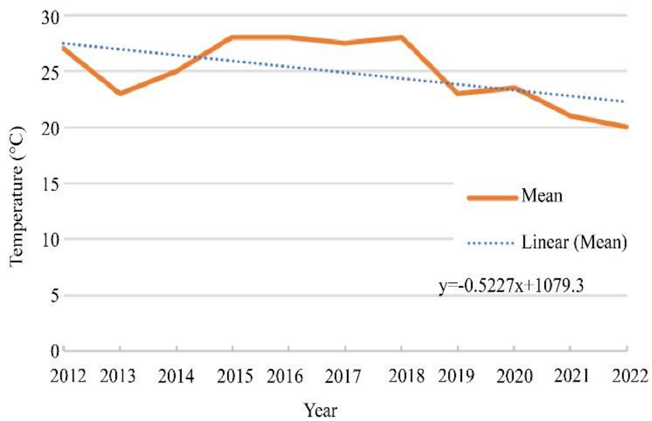

Fig. 2 Temperature variations in Pulicat Lake between 2012 - 2022

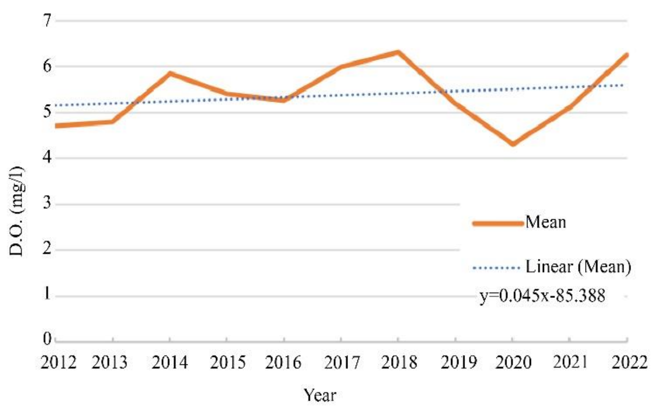

Fig. 3 D.O. levels in Pulicat Lake between 2012 - 2022

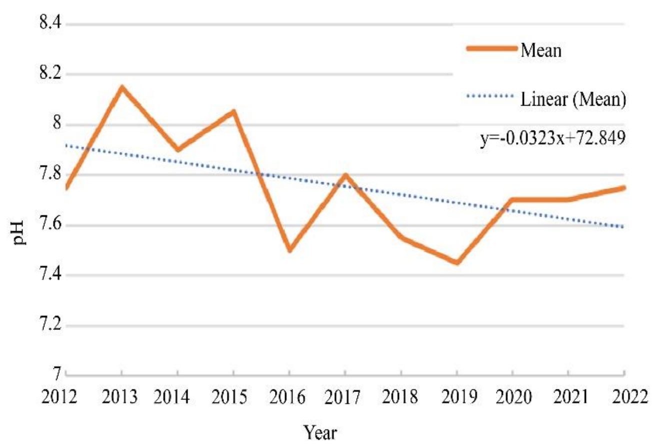

Fig. 4 pH fluctuations in Pulicat Lake between 2012 - 2022.

The declining pH levels, as illustrated in Figure 4, may stem from multiple anthropogenic sources, notably agricultural runoff and industrial discharge. The lake experienced its highest pH level in 2013, measured at 8.15, and its lowest in 2019, recorded at 7.5. These values fall within the permissible pH range for a saltwater lake, typically between 6.5 and 8.5. Pulicat Lake's water pH is influenced by various industrial contaminants, including heavy metals, pesticides, and chemical effluents, which pose a hazard to aquatic organisms and ecosystem health. Acidic substances, such as synthetic fertilizers like ammonium nitrate and urea from agricultural activities, can contribute to these fluctuations. Decreased pH can adversely affect aquatic plants and phytoplankton, leading to decreased growth and reproduction. Consequently, this may have a cascading effect on higher trophic levels, influencing the distribution and abundance of fish and other aquatic species.

In addition, decreasing pH levels can alter the toxicity and solubility of chemicals and heavy metals, increasing the bioavailability of hazardous substances that are detrimental to aquatic life [15]. The presence of inorganic dissolved particles, such as cations (sodium, magnesium, calcium, iron, and aluminum) and anions (chloride, nitrate, sulfate, and phosphate), affects the conductivity of bodies of water like Pulicat Lake. Over the past decade, a decreasing trend in conductivity levels has been observed, as illustrated in Figure 5.

However, an anomaly was noted in 2017 with a sudden spike to 79935 µS/cm, followed by a decrease to 27935 µS/cm in 2018. The permissible limit of conductivity for drinking water is 469.2 -1173 µS/cm. Irrigation, livestock, and drinking water typically require conductivity ranges of 800-2,500 µS/cm, with lower levels recommended. Drinking water should not exceed 2,500-10,000 µS/cm, but a maximum of 3,000 µS/cm is deemed safe. This range is utilized to irrigate salt-tolerant crops and cattle. Conductivity above 10,000 µS/cm is not acceptable for drinking water or irrigation but is commonly used for toilet flushing (up to 50,000 µS/cm) and concrete manufacturing. The spike in 2017 may be attributed to heavy rainfall events or anthropogenic activities such as industrial discharge or agricultural runoff. A concurrent increase in nitrate + nitrite levels to 3.78 mg/L, as seen in Figure 6, suggests a potential link between these parameters. Changes could influence the subsequent decline in conductivity in water flow patterns, precipitation, land use practices in the lake's watershed, and agricultural practices.

However, the lowest recorded conductivity level in 2018, at 27935 µS/cm, is still excessively high, indicating unsuitability for drinking purposes and potential risks to human health and agricultural productivity. The B.O.D. is a frequently used water quality evaluation criterion that provides information about the rapidly biodegradable fraction of organic load in water [16]. High B.O.D. can limit the presence of aquatic organisms and lead to oxygen depletion, causing stress and potentially death among aquatic life. The analysis of B.O.D. levels in Pulicat Lake, depicted in Figure 7, shows an upward trend over the past decade. This rise points to an increase in organic pollution, most likely caused by human activities like industrial emissions and runoff from farms. As a reference baseline, the B.O.D. standards typically mandate levels below 3 mg/L. The highest recorded B.O.D. level in 2018, reaching 4.35 mg/L, signals heightened pollution pressures, whereas the lowest in 2014 was 0.75 mg/L. Referencing the data presented in Figure 7 and the study [17], Pulicat Lake would be classified as “moderately polluted,” a classification typically corresponding to a B.O.D. level ranging between 2–8 mg/L.

Figure 8 depicts the inconclusive trend and anomalous levels of fecal coliform levels in Pulicat Lake. Fecal coliforms, bacteria associated with human and animal feces, serve as critical indicators of water quality and the potential presence of pathogenic bacteria, viruses, and protozoans [18]. High levels are indicative of the presence of pathogens causing diseases like typhoid and cholera, making the water unsafe for direct consumption and risky for irrigation and aquaculture. Elevated fecal coliform levels in aquatic ecosystems pose significant health risks to both humans and aquatic life. The peak observed in 2015, with a mean of 701 MPN/100ml, significantly exceeds the standard permissible limit of ≤ 5000 MPN/100ml for fecal coliform in designated best-use class C [19, 20], indicating severe fecal contamination. This surge could be attributed to direct waste discharge from mammals and birds [21], agricultural and storm runoff, and human sewage. The high fecal coliform concentrations in 2015 may also be due to a significant discharge of human waste into Pulicat Lake. Possible explanations for the elevated fecal coliform levels include a temporary failure of the sewage system leading to leakage and contaminated surface water entering the lake after heavy rain due to blocked drainage systems in nearby towns. Other potential contamination sources include sewers, septic systems, feedlots, and animal yards. Additionally, plant material and effluent from pulp or paper mills may contribute to the presence of fecal coliforms. The subsequent decrease in fecal coliform levels may reflect improvements in wastewater treatment and management practices in the vicinity of the lake. However, the fecal coliform levels remain inconsistent and above the safe limit, suggesting that Pulicat Lake continues to experience significant ecological stress. Environment-related factors, such as temperature, rainfall, and humidity, can also significantly influence the fecal coliform levels in a water body [22].

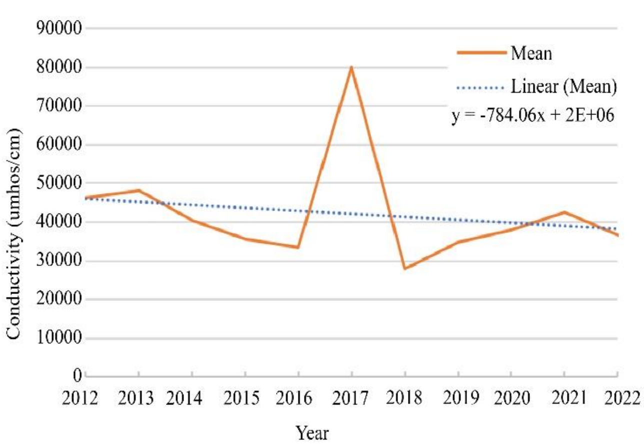

Fig. 5 Conductivity changes in pulicat lake between 2012 - 2022.

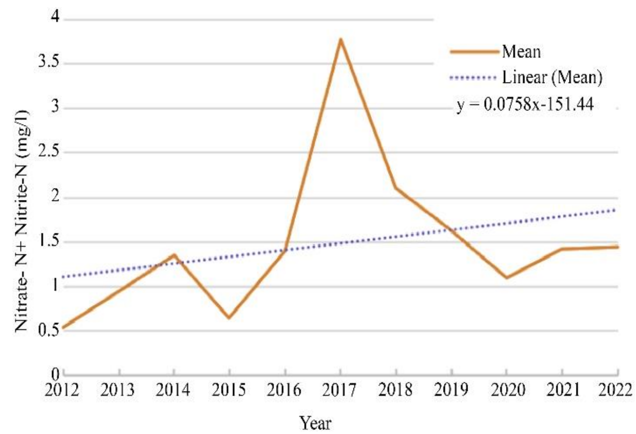

Fig. 6 Nitrate + nitrite concentrations in pulicat lake between 2012- 2022

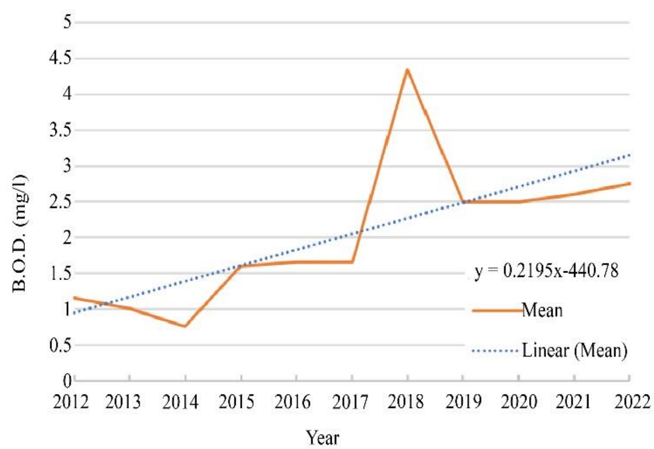

Fig. 7 B.O.D. levels in pulicat lake between 2012 - 2022

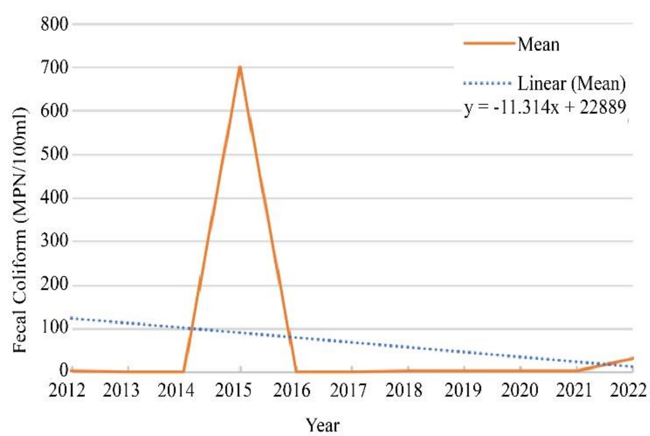

Fig. 8 Fecal coliform levels in Pulicat Lake between 2012 – 2022

Total coliform bacteria are frequently found in nature and the waste products of humans and other creatures with warm blood [23]. They act as markers for the presence of potentially pathogenic microorganisms and fecal contamination. High levels of total coliform in water can be harmful to human health, especially if the water is meant for use as classed as C or D; consuming water contaminated with coliform bacteria can result in gastrointestinal problems and other infections [24].

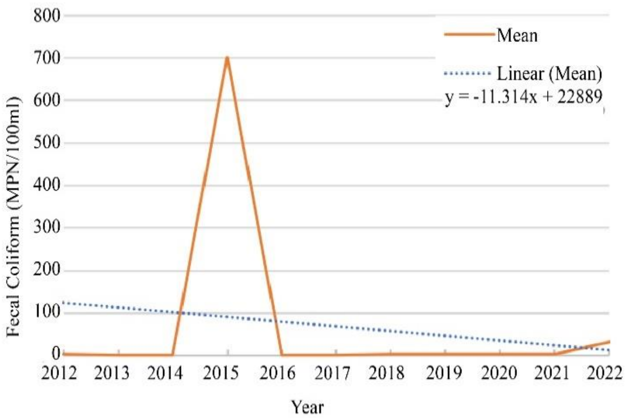

Fig. 9 Total coliform concentrations in pulicat lake between 2012 - 2022

Figure 9 shows a fluctuating and inconsistent trend in total coliform levels in Pulicat Lake over the past decade, with a peak in 2016 at 1850.0 MPN/100ml and a trough in 2021 at 98.5 MPN/100ml. Most notably, 2015 and 2022 show significant increases in total coliform levels compared to the previous year. The increase in coliform levels in 2022 suggests that the lake's water quality may be deteriorating due to increased pollution. For instance, periods of heavy rainfall or heightened industrial activity might coincide with spikes in coliform levels. In an agricultural context, crops irrigated with such water can become vectors for pathogen transmission, posing a risk to consumers. Additionally, high levels of coliform bacteria in water can indicate the presence of other contaminants, such as heavy metals and pesticides, leading to bioaccumulation and biomagnification in crops, affecting various species and the people who rely on the lake as a source of nutrition. Variations in total coliform levels in Pulicat Lake could be attributed to factors such as changes in land use, wastewater discharges, and climatic conditions.

5. Conclusion

This study analyzed the water quality trends in Pulicat Lake between 2012 and 2022 by examining the temperature, D.O., pH, conductivity, nitrate + nitrite levels, B.O.D., fecal coliform, and total coliform levels in the lake. The findings show that the water quality of the lake has fluctuated over the decade and, at its current state, is unfit for use under classifications C and D, as shown in Table 1. Anthropogenic activities and environmental causes near the lake heavily influence this. These alterations in parameter levels of the lake have had a significant impact on the overall water quality of the lake. Temperature levels in the lake showed a consistent decrease, which, despite potentially reducing heat stress, may disrupt the metabolic and reproductive cycles of aquatic life. An increase in D.O. was observed, hinting at an improvement in water quality; however, excessive D.O. in the lake can cause oxidative stress in aquatic organisms.

The falling pH levels and variable conductivity show the impact of industrial discharges and agricultural runoff on the lake, which could act as dangers to aquatic life and human health. The rising B.O.D. suggests increased organic pollution. However, the changing coliform levels show fecal contamination, leading to associated health risks to both aquatic organisms and people living in the surrounding area near the lake.The limitations of this study are that the data is secondary, which lacks seasonal granularity and may not account for potential anomalies. This provides a holistic overview and conclusion about the current water quality of Pulicat Lake. Future research should collect primary data across different seasons and include a wider range of parameters to make a more reliable and complete assessment of the lake's water quality.

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