# COMPREHENSIVE ASSESSMENT OF THE WATER QUALITY AND PATHOGENIC RISK OF WEST KOCHI CANALS, KERALA, INDIA

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## ABSTRACT

This study focused on quality and pathogenic risk assessment of water samples collected from highly polluted Rameshwaram, Eraveli and Calvathy canals in West Kochi. Organoleptic, physical, chemical and microbiological analysis of water samples, such as odour, colour, temperature, pH, alkalinity, salinity, turbidity, conductivity, total solids (TS), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), oil and grease, chloride, calcium and sulphate was carried out and compared with the permissible limits of the Central Pollution Control Board (CPCB). The study shows that some of the analysed parameters were higher than the permissible limits of the CPCB, and the presence of potential pathogens was confirmed. Calvathy canal was found to have a high level of pollution, followed by Eraveli and Rameshwaram canal.

***Keywords***: *water pollution, Fort Kochi, canals, physicochemical, microbiology, pathogens*

## INTRODUCTION

The environment plays a significant role in sustaining life on Earth [1]. Anthropogenic activities have destroyed the environment over the years, resulting in various forms of pollution [2]. One of the most critical consequences of environmental pollution is the contamination of water sources, which has far-reaching effects on the ecosystem and human health. Contamination of water sources with chemicals and pollutants is a direct consequence of environmental pollution [3]. Plastic pollution in canals, as well as in other water bodies, is caused by the accumulation of plastic waste and improper disposal. Canals often carry garbage, especially plastic, which originates from runoff from urban areas, industrial circumstances, or even directly discarded by individuals [4]. Industrial sewerage, agricultural runoff, and untreated wastewaters are other significant sources of water pollution. These pollutants can have a strong impact on ecosystems and aquatic life. As pollution affects the balance of ecosystems, certain species can become dominant, disrupting natural food chains and causing the loss of biodiversity. It affects the overall health and resilience of water bodies, making them more vulnerable to pollution and other stressors [5]. The influence of environmental pollution on water quality also extends to human health [6]. Contaminated water sources can harbour disease-causing microorganisms, such as bacteria, viruses, and parasites, leading to waterborne diseases [7]. Consumption or use of contaminated water for daily activities can cause diseases, such as cholera, dysentery, and typhoid fever [8].

Fort Kochi is a historical place in the Ernakulam District in Kerala [9]. It has a rich history, cultural diversity, and scenic beauty [10]. Since ancient times, the region has been of great historical importance as a centre of trade and commerce [11]. Kochi is one of the fastest growing cities in the country and has a population of 3,507,053, with 74 wards [12]. The Cochin Corporation faces many challenges: inadequate water distribution networks, reduction in water quantity and quality, water pollution, population growth, and changing land patterns, resulting in loss or depletion of water resources in the area [13]. Saltwater intrusion in West Kochi also significantly threatens freshwater sources [14]. The corporation mainly depends on the Kerala Water Authority and groundwater for distribution of drinking water.

West Kochi, the commercial metropolis of Kerala, is densely urbanised and located in a high-risk zone in terms of sea level rise [15]. Variations in climate and changes in rainfall patterns are becoming a significant threat to Fort Kochi. The canals of West Kochi are remnants of old trade routes used for transportation and were initially built for trade, allowing spices, tea, and other goods to move quickly between the land areas and the Arabian Sea. The appearance of roads and modern shipping lanes reduced the importance of these waters for commercial purposes [16].

Canals connect larger water bodies such as rivers, lakes, or seas. Changes in water quality within canals can also affect the overall health of the adjoining water bodies. Pollutants carried by the tide can be deposited in the adjacent ecosystems, affecting the aquatic life and the biodiversity of nearby ecosystems [17]. With climate change, there may be changes in tidal patterns, precipitation, and temperature, which may also affect water quality in canals [18].

As they lose importance for water transport, canals are neglected and become points of deposition of liquid and solid wastes, causing oxygen depletion in canals and adversely affecting marine flora and fauna. Canals were completely silted up and blocked. A thick concrete slab was cast over the canals to form a roadway, resulting in a complete blockage of the canals. The stagnant water will provide a breeding ground for infectious insects such as mosquitoes [19]. During the monsoon season, the water from overflowing canals enters the households, spreading infectious diseases. Moreover, if the drinking water pipes passing through the canals burst, the drinking water will mix with the contaminated water and become unusable for human consumption [20]. Studying water quality in low- and high-tidal regions provides valuable data for understanding the impacts of climate change on these environments and enables the development of adaptation strategies [21]. Variations in water quality are continuous, and updated water quality data are necessary for water quality assessment. Water quality reflects the relationship of all hydrological properties, including physical, chemical, and biological properties of water bodies.

Monitoring the physicochemical water quality parameters is essential for the assessment of the condition of the environment, the ecosystem and ecology and for the restoration of water quality [22]. The water quality guidelines of CPCB provide a limit value for each parameter. This study focused on the assessment of physical, chemical, and microbiological parameters of heavily polluted canals of West Kochi in Kerala. The obtained values of the analysed parameters are compared with the CPCB.

## EXPERIMENTAL

### Study area

Fort Kochi (Geo URI: geo: 9.961, 76.243) lays between 9° 57′ 39.6″ N and 76° 14′ 34.8″ E; it is located at the northern end of a small land peninsula that is around 19 km long and less than 1.6 km wide and is separated from the mainland by inlets from the Arabian Sea and river estuaries channelling from the Western Ghats [23]. Fort Kochi thus becomes a natural harbour, which lies at sea level, and has a rich network of backwaters [24]. The eastern part of Kochi is usually called Ernakulam, and the western part of the city, beyond the Venduruthy Bridge, is known as Western Kochi [25]. Canals of West Kochi were studied to assess the water quality and pathogenic risk (Figure 1). The sampling sites were the highly polluted Rameshwaram, Eraveli, and Calvathy canals (Table 1). The Rameshwaram canal (3711 m) starts from Cochin Fisheries Harbour and ends at the Manthra Bridge with fourteen road crossings. The Eraveli canal (1406 m) starts from the Manthra Bridge and ends at the Calvathy Bridge with five road crossings. The Calvathy canal (733 m) extends from the Calvathy Bridge to Kayal near Fort Kochi Boat Jetty with two road crossings. The canals banks are highly urbanised and are prominent receivers of surface runoff and untreated sewage in West Kochi [26]. The canals flow into the Arabian Sea. The canals are influenced by tides [27].

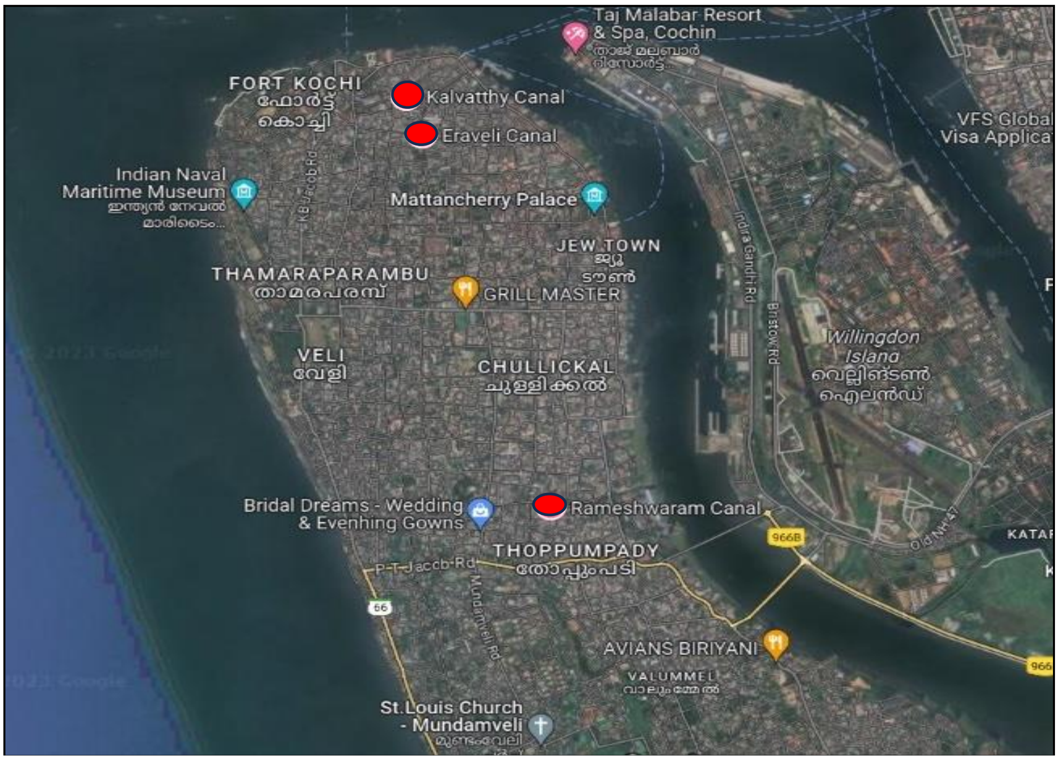



Figure 1. Satellite view of study area (West Kochi)

Table 1. Sampling sites

| Canal No | Canal name | Canal code | Sampling points | Location | |
|---|---|---|---|---|---|
| | | | | Latitude ($^0$N) | Longitude ($^0$E) |
| Canal 1 | Rameshwaram canal | RC | Karuvelipady Junction | 9°57'58.6"N | 76°14'54.9"E |
| Canal 2 | Eraveli canal | EC | Mattanchery | 9°57'50.0"N | 76°14'58.0"E |
| Canal 3 | Calvathy canal | CC | Fort Kochi | 9°56'21.6"N | 76°15'24.2"E |

## Methodology

Sampling points were selected based on the intensity of pollution and anthropogenic activities. Water samples collected from three canals in the West Kochi region were used in this study. Water samples were collected about 30 cm below the surface in clean sterilised glass bottles and BOD bottles in April (pre-monsoon) and September (post-monsoon) 2023 and preserved for chemical and microbiological analysis according to the American Public Health Association (APHA) [21]. All water samples were stored in a refrigerator for further study. Organoleptic parameters, odour, colour and physicochemical parameters, such as temperature, pH, salinity, turbidity, conductivity, TDS, and DO were analysed immediately on site after collection. The analysis of the remaining parameters was performed in the laboratory within 48 hours after taking the samples, according to the Table 2.

Microbiological analysis of water samples was performed to determine the presence of water-borne pathogens. The microbial analysis of water samples was done by isolating bacteria using serial dilution, spread plate, streak plate, and agar slant preparation methods. The agar plates and agar slant media were prepared by mixing 1.3 g of nutrient broth (Himedia) and 2 g of agar agar (Himedia) in 100 ml of distilled water. The serial dilution method involves diluting water samples in series from $10^{-1}$ to $10^{-6}$ and spreading them on agar plates using the L-rod by the spread plate method and holding them for incubation for 24 hours. The bacterial colonies were taken using a sterilised inoculation loop from spread plates inoculated on agar plates by streak plate method and kept for incubation for 24 hours. Bacterial colonies from the streak plates were taken using a sterilised inoculation loop, inoculated into agar slants, and kept for incubation for 24 hours. A MacConkey agar test was performed for all isolated bacterial strains from the collected water samples of the three sampling areas using Himedia MacConkey agar.

Table 2. Methods and instruments used for testing water quality

| Water quality test | Method used for estimation / instruments / electrodes used |
|---|---|
| Colour | Visual verification |
| Odour | Physiological sense verification |
| Temperature | PT 100 sensor (Systronics water analyser kit) |
| pH | GE & RE/ Combined electrodes (Systronics water analyser kit) |
| Alkalinity | Titrimetric method |
| Salinity | Glass conductivity cell - 1.0 cell constant (Systronics water analyser kit) |
| Turbidity | Silicon photodiode (Systronics water analyser kit) |
| Conductivity | Glass conductivity cell - 1.0 cell constant (Systronics water analyser kit) |
| TS | Filtration method |
| TDS | Glass conductivity cell - 1.0 cell constant (Systronics water analyser kit) |
| DO | Au & Ag probe (Systronics water analyser kit) |
| BOD | Winkler's Method, IS: 3025 (P-44): 1993; Reaff. 2019 |
| Oil and grease | Gravimetric method |
| Chloride | Titrimetric method |
| Calcium | Titrimetric method |
| Sulphate | Spectrophotometric method |
| Free $CO_2$ | Titrimetric method |
| Nitrate | Spectrophotometric method |

## RESULTS AND DISCUSSION

The water samples collected from the canals were labelled as follows: RC (Rameshwaram canal), EC (Eraveli canal), and CC (Calvathy canal). The results of physicochemical and biological analysis of water samples were compared with the standards prescribed by the CPCB (Table 3).

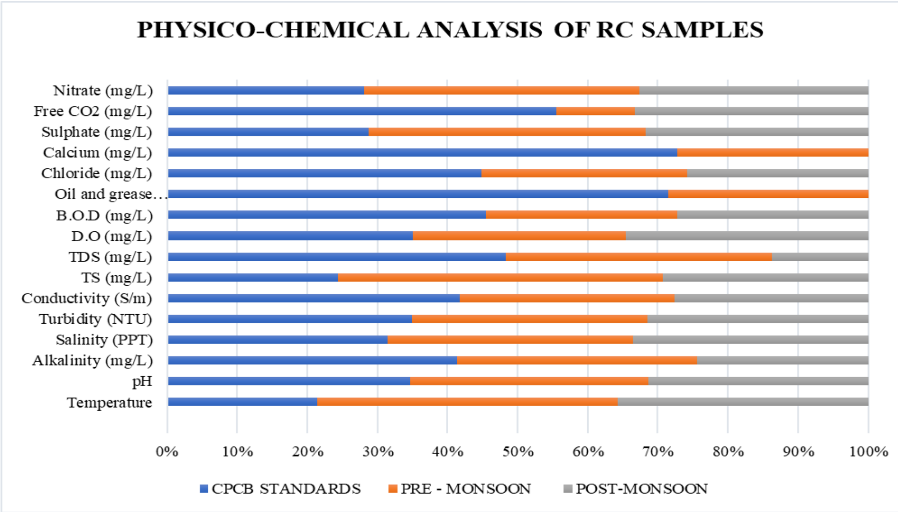
The colour of the water samples showed variations and was not in an acceptable condition in pre-monsoon season as compared to CPCB standards (Table 3). A water sample taken in the pre-monsoon season from RC showed a slightly ashy colour, the sample from EC had a dark ashy colour, and the one from CC had a black colour. The substances suspended and dissolved in water affect its colouration [28]. Highly coloured water may have less light penetration, limiting the growth of aquatic flora and fauna [29]. Increasing colouration of water can affect thermal stratification of the body [30]. Similar colour variations were found in the studies of the Canoli canal [31].

Odours are light and small molecules that can cause anatomical responses when they interact with different human sensory systems, even at insufficient concentrations in the air that people use. This sensation is known as the odour [32]. The odour of RC, EC, and CC samples collected in pre-monsoon season was unpleasant, which is not in accordance with CPCB (Table 3). Similar odour observations were found in studies of the Buckingham canal [33].

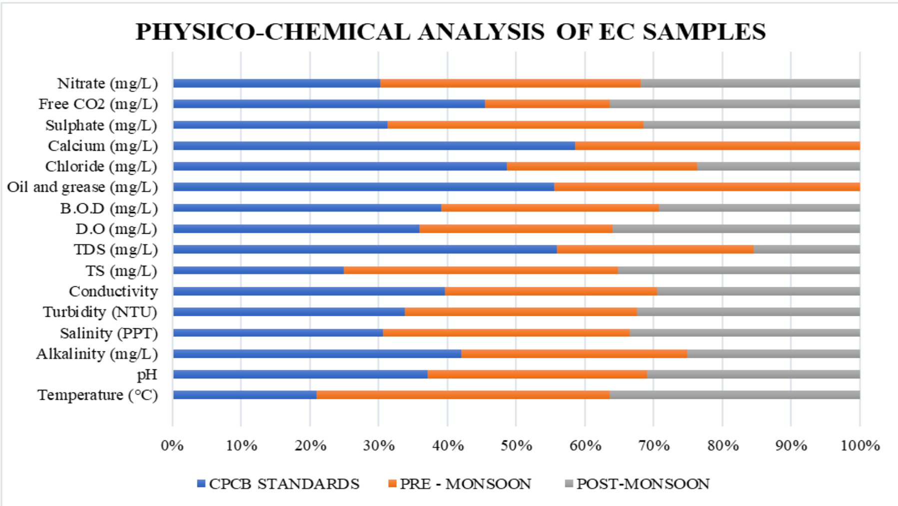
Temperature is an important factor that affects the metabolic activities of living organisms [34]. All the water samples collected in pre- and post-monsoon season had temperature higher than the permissible 15 °C, according to CPCB (ranged from 25 °C to 30.4 °C, Table 3). The highest temperature was recorded in EC, followed by CC and RC (Figure 2 a-c). Water temperature may depend on the season, geographic location, and the time of sampling. This makes it difficult for aquatic life to get enough oxygen [35]. Similar observations were found in studies of the Ganga canal [36].

Table 3. Physicochemical and biological analysis of water samples in the pre-monsoon and post-monsoon season

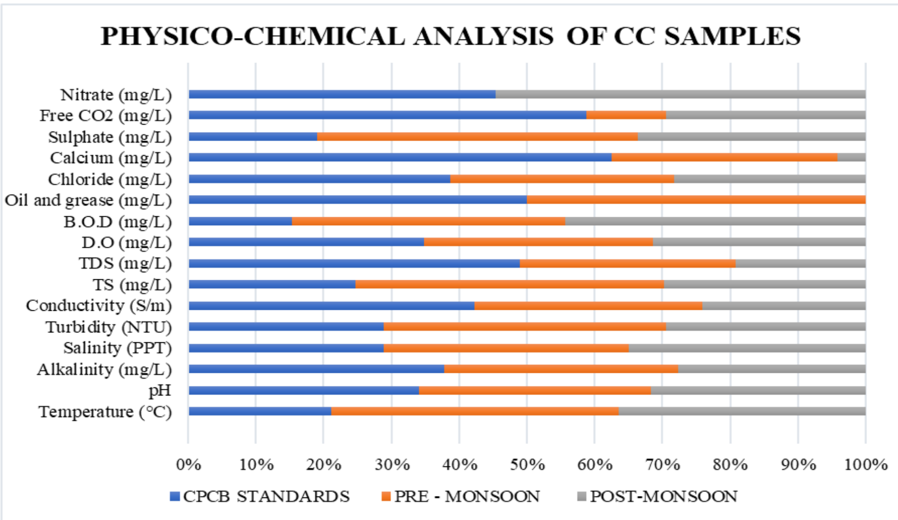
| Parameters | Permissible limits according to the CPCB | RC | | EC | | CC | |
|---|---|---|---|---|---|---|---|
| | | Pre-monsoon | Post-monsoon | Pre-monsoon | Post-monsoon | Pre-monsoon | Post-monsoon |
| Colour | No visible colour | Slightly ashy | Colourless | Dark ashy | Colourless | Black | Colourless |
| Odour | No offensive odour | Foul odour | No odour | Foul odour | No odour | Foul odour | No odour |
| Temperature (°C) | 15 | 30 | 25 | 30.4 | 26 | 30.2 | 26 |
| pH | 6.5 - 8.5 | 8.35 | 7.7 | 7.32 | 7.1 | 8.51 | 7.9 |
| Alkalinity (mg/L) | 200 | 165 | 118 | 156 | 120 | 183 | 147 |
| Salinity (PPT) | 2 | 2.22 | 2.13 | 2.34 | 2.18 | 2.50 | 2.42 |
| Turbidity (NTU) | 5 | 4.8 | 4.5 | 5 | 4.8 | 7.2 | 5.1 |
| Conductivity (S/m) | 250 | 183 | 165 | 195 | 186 | 199 | 142 |
| TS (mg/L) | 1.0 | 1.9 | 1.2 | 1.6 | 1.41 | 1.85 | 1.21 |
| TDS (mg/L) | 500 | 394 | 142 | 256 | 138 | 326 | 196 |
| DO (mg/L) | 6 | 5.2 | 5.9 | 4.7 | 6.02 | 5.8 | 5.4 |
| BOD (mg/L) | 2.0 | 1.2 | 1.2 | 1.62 | 1.5 | 5.3 | 5.8 |
| Oil and grease (mg/L) | 0.5 | 0.2 | 0 | 0.4 | 0 | 0.5 | 0 |
| Chloride (mg/L) | 250 | 163 | 144 | 142 | 122 | 213 | 183 |
| Calcium (mg/L) | 75 | 28 | 0 | 53 | 0 | 40 | 5 |
| Sulphate (mg/L) | 200 | 275 | 221 | 238 | 201 | 500 | 354 |
| Free $CO_2$ (mg/L) | 1.0 | 0.2 | 0.6 | 0.4 | 0.8 | 0.2 | 0.5 |
| Nitrate (mg/L) | 20 | 28 | 23.2 | 25 | 21.1 | 30 | 24 |




a)




b)




c)

Figure 2. Physicochemical analysis of RC, EC, and CC samples

pH is an important parameter that determines the water quality and extent of pollution by measuring the concentration of hydrogen ions [37]. The pH of the water samples varied from 7.1 to 8.51 and is within the permissible limits of the CPCB (Table 3). Also, pH is inversely proportional to temperature (Figure 2 a-c). The highest pH was recorded in CC in the pre-monsoon season and the lowest pH was in EC in the post-monsoon season. Similar observations were found in studies of the Kharicut canal [38].

The alkalinity of water is its capacity to neutralise a strong acid, generally due to the presence of carbonates, bicarbonates, and hydroxide compounds of Ca, Na, and K [39]. The alkalinity of all the water samples ranged from 120 mg/L to 183 mg/L and was within the permissible limits of CPCB (Table 3). The highest alkalinity was recorded in the CC in the pre-monsoon season and the lowest in RC in the post-monsoon season (Figure 2 a-c). Similar findings were found in the studies of canals in the Allahabad region [40].

The salinity of all the water samples ranged from 2.13 PPT to 2.5 PTT and was not within the permissible limits of CPCB (Table 3). The highest salinity was found in the CC in the pre-monsoon season and the lowest in RC in the post-monsoon season (Figure 2 a-c). Similar observations are found in studies of cochin backwaters [41]. The clay soil layer of the Kochi area is the primary factor preventing saltwater intrusion, even in the coastal areas of the city [14]. Fresh groundwater from inland sources naturally mixes with freshwater, resulting in saltwater intrusion. In the summer, the degree of saltwater intrusion increases with a decrease in groundwater recharge and an increase in freshwater demand [42].

Turbidity is the reduction of water transparency due to the presence of suspended matters and measures the quality and clarity of water (it indicates the amount of light scattered by particles in the water column) [43]. In this study, turbidity varied from 4.5 NTU to 7.2 NTU. The highest value was recorded in CC in the pre-monsoon season, and the lowest in RC in the post-monsoon season (Figure 2 a-c). Except for the water sample from CC (pre-monsoon), all other samples were within the permissible limits of CPCB (Table 3).

Conductivity indicates the presence of a large amount of ions in water [44]. The conductivity of all water samples ranged from 142 S/m to 199 S/m and was within the permissible limits of CPCB (Table 3). The highest and lowest conductivity were recorded in the pre- and post-monsoon season in CC (Figure 2 a-c). Similar observations were found in the studies of canals in the Allahabad region [40].

Total solids are the total suspended and total dissolved solids in a given sample [45]. TS is a consequence of silt and organic matter [46]. The TS of all the water samples was not within the permissible limits prescribed by CPCB and ranged from 1.2 mg/L to 1.9 mg/L (Table 3). The highest and lowest TS were recorded in the pre-monsoon and post-monsoon season in RC (Figure 2 a-c). Similar findings were observed in studies of the Ganga canal [45].

Total dissolved solids (TDS) of all the water samples ranged from 138 mg/L to 394 mg/L and were within the permissible limits of CPCB (Table 3). The highest TDS was recorded in RC in the pre-monsoon season, and the lowest was found in EC in the post-monsoon season (Figure 2 a-c). A high value of suspended solids can reduce the primary productivity of algae and macrophytes, leading to their complete removal. Similar observations are found in the studies of canals in the Allahabad region [40].

Dissolved oxygen (DO) levels ranged from 5.2 mg/L to 6 mg/L. Except for the DO level in EC in the post-monsoon season, the other samples were within the permissible limits of CPCB (Table 3). The lowest DO was recorded in EC in the pre-monsoon season (Figure 2 a-c). The low level of oxygen in water is a consequence of the removal of free oxygen by the respiration of bacteria and other animals and the need for oxygen to decompose organic matter [47]. The concentration of DO regulates the distribution of flora and fauna in water bodies [48]. Similar observations are found in the studies of the Ganga canal in Uttarakhand [45].

Biological oxygen demand (BOD) of the water samples ranged from 1.2 mg/L to 5.8 mg/L. It was within the permissible limits of CPCB in RC and EC in the pre- and post-monsoon season (Table 3). The highest BOD was observed in CC in the pre- and post-monsoon season (Figure 2 a-c). A high BOD value indicates a significant level of pollution [49]. Low BOD was mainly due to higher algal productivity and increased oxygen solubility at higher temperatures [50].

A higher concentration of oil and grease usually forms a layer on the water surface that prevents the penetration of sunlight into water, which hinders photosynthesis [51]. The presence of oil and grease was confirmed only in water samples from the pre-monsoon season, and it ranged from 0.2 mg/L to 0.5 mg/L, which is within the permissible limits of CPCB (Table 3). Similar observations were found in studies of the Lahore canal [52]. Oil and grease were not present in water samples from the post-monsoon season (Figure 2 a-c).

Excessive amounts of chloride in the water are not desirable. Chloride content ranged from 122 mg/L to 213 mg/L (Table 3). The highest chloride content was recorded in CC in the pre-monsoon season and the lowest in EC in the post-monsoon season (Figure 2 a-c). Similar observations were found in the Lahore canal [53].

Calcium concentration is directly related to hardness [54]. The calcium concentration in water samples ranged from 0 mg/L to 53 mg/L and was within permissible limits of CPCB (Table 3). The highest concentration was recorded in EC in the pre-monsoon season. Calcium was not found in RC and CC in the post-monsoon season (Figure 2 a-c). Similar observations were found in the studies of the South Bank canal in Tamil Nadu [55].

The sulphate concentration in all the water samples ranged from 201 mg/L to 500 mg/L and was not within the permissible limits (Table 3). The highest sulphate concentration was found in CC in the pre-monsoon season and the lowest in EC in the post-monsoon season (Figure 2 a-c). Similar observations were found in the studies of the Buckingham canal [33].

Carbon dioxide is a vital element for the life of plants and microorganisms. Free carbon dioxide in all water samples ranged from 0.2 mg/L to 0.8 mg/L and was within the permissible limits of CPCB (Table 3). The highest free carbon dioxide was recorded in EC in the post-monsoon season (Figure 2 a-c). Similar observations were found in the studies of the Ganga canal. The increase in carbon dioxide in water bodies is caused by the decay and decomposition of organic matter [45].

Nitrate concentration was not within the permissible limits and ranged from 21.1 mg/L to 30 mg/L (Table 3). The highest nitrate concentration was observed in CC in the pre-monsoon season, and the lowest concentration was observed in EC in the post-monsoon season (Figure 2 a-c).

Microbiological analysis. Nine bacterial strains were isolated from water samples from RC, eight strains from water samples from EC, and five strains from water samples from CC. Six bacterial strains (two from RC [RC 1, RC 3], one from EC [EC 2] and three from CC [CC 1, CC 2, CC 3]) from all isolated bacterial strains from the collected water samples showed a positive result for the MacConkey agar test (Figure 3).

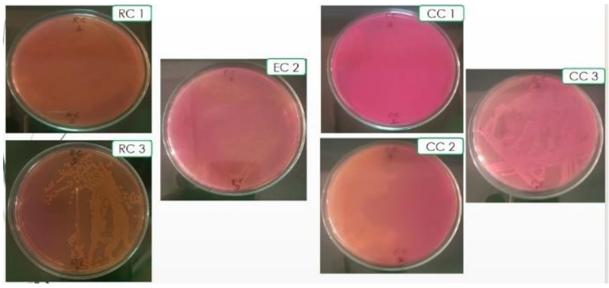



Figure 3. MacConkey agar test for water samples

The presence of *Coliform* sp. and *Staphylococcus* sp. in the RC, *Coliform* sp. in the EC, *Coliform* sp., *Staphylococcus* sp., and

*Klebsiella* sp. in CC was confirmed by comparing the results with the previous studies (Table 4) [56]. Pathogenic bacteria in canals may originate from faecal matter in canals due to water runoff during the rainy season [46].

Table 4. Diseases caused by bacterial strains isolated from water samples

| | | |
|---|---|---|
| RC 1 | *Coliform* sp. | Diarrhoea, Urinary tract infections, Respiratory illness, Pneumonia |
| RC 3 | *Staphylococcus* sp. | Skin infections, Pneumonia, Endocarditis, Osteomyelitis |
| EC 1 | *Coliform* sp. | Diarrhoea, Urinary tract infections, Respiratory illness, Pneumonia |
| CC 1 | *Coliform* sp. | Diarrhoea, Urinary tract infections, Respiratory illness, Pneumonia |
| CC 2 | *Staphylococcus* sp. | Skin infections, Pneumonia, Endocarditis, Osteomyelitis |
| CC 3 | *Klebsiella* sp. | Pneumonia, Meningitis, Surgical and wound infections, Bloodstream infections |

## CONCLUSION

Physicochemical and microbiological analysis of water samples collected from the three canals in West Kochi show that the values of some parameters are higher than the permissible limits according to CPCB. Microbiological analysis of samples showed the presence of heterotrophic bacterial flora, many of which can be potential pathogens. The Calvathy canal was found to have a high level of pollution, followed by the Eraveli and the Rameshwaram canal. The greater extent of pollution in the canal is a consequence of anthropogenic activities and improper management of canals. The findings revealed significant seasonal variations and deviations from the standards, highlighting potential environmental and public health concerns and the urgent need for improved water management practices and pollution control measures in the canals to protect aquatic life and public health. The findings also highlight the importance of continued monitoring and enforcement of water quality regulations to mitigate environmental and health risks.

## REFERENCES

[1] S.P. Prasood, M.V. Mukesh, K.S. Sajinkumar, K.P. Thrivikramji, COVID-19 pandemic lockdown modulation of physico-chemical parameters of surface water, Karamana river basin, Southwest India: A weighted arithmetic index and geostatistical perspective, Total Environment Research Themes 6(2023), Article ID: 100042. https://doi.org/10.1016/j.totert.2023.100042

[2] R. Radhika, S. Mathew, S. Prasad, Physico-Chemical and Biological Water Quality Analyses of Meenachil River, Kottayam, Kerala, South India, Uttar Pradesh Journal of Zoology 44(2023) 2, 79-94. https://doi.org/10.56557/upjoz/2023/v44i23408

[3] F. Talay, C. Molva, H.I. Atabay, Isolation and identification of *Arcobacter* species from environmental and drinking water samples, Folia Microbiologica 61(2016), 479-484. https://doi.org/10.1007/s12223-016-0460-0

[4] V. Glaxy Ezekel, H.R. Nair, Review on face masks - source of microplastics and its impact on ecosystem, International Research Journal of Environmental Sciences 11(2022) 2, 31-35.

[5] O.I. Omezuruike, A.O. Damilola, O.T. Adeola, E.A. Fajobi, O.B. Shittu, Microbiological and physicochemical analysis of different water samples used for domestic purposes in Abeokuta and Ojota, Lagos State, Nigeria, African Journal of Biotechnology 7(2008) 5, 617-621.

[6] A. Suresh, G. Vijayaraghavan, K.S. Saranya, K.V. Neethu, B. Aneesh, B. Nandan, Microplastics distribution and contamination from the Cochin coastal zone, India, Regional Studies in Marine Science 40(2020), Article ID: 101533.

https://doi.org/10.1016/j.rsma.2020.101533

[7] G. Matta, S. Srivastava, R.R. Pandey, K.K. Saini, Assessment of physicochemical characteristics of Ganga Canal water quality in Uttarakhand, Environment, development and sustainability 19(2017), 419-431. https://doi.org/10.1007/s10668-015-9735-x

[8] S.P. Gorde, M.V. Jadhav, Assessment of water quality parameters: a review, International Journal of Engineering Research and Applications 3(2013) 6, 2029-2035.

[9] A. K Joshy, A. Johny, A. Daison, H. Mary V L, R. Elsa Antony, Historical Insight into the Vypeen - Fort Kochi Jankar (Ferry) Service, Graduate thesis, M.G. University, Kottayam, Kerala, Ernakulam, 2023.

[10] P.N. Kuriakose, S. Philip, City profile: Kochi, city region - Planning measures to make Kochi smart and creative, Cities 118(2021), Article ID: 103307. https://doi.org/10.1016/j.cities.2021.103307

[11] J. Alias, S. Wadhwa, Kochi: provincialising postcolonial metro-cosmopolitan spatialities, Cultural geographies 31(2024) 2, 167-182. https://doi.org/10.1177/14744740221147554

[12] F. Rahman, N. abd Halim, A. Ahad, A. Alam, K. Noor, Local Economic Impact of COVID-19 on the Urban Tourism-Related Services: A Perspective of Kochi Heritage City, Kerala, Sustainability 15(2023) 24, Article ID: 16585. https://doi.org/10.3390/su152416585

[13] A. Kunjmon, B. Biju, K.R. Sreelakshmy, Comparative Study on Well Water, Tap Water, River Water in Corporation, Municipality, and Panchayat of Ernakulam District, Graduate thesis, M.G. University, Kottayam, Kerala, Ernakulam, 2023.

[14] S. Sreedharan, R. Pawels, Seasonal deviation of saltwater intrusion in the shallow aquifers of Kochi municipal corporation, Kerala, India, International Journal of Civil Engineering and Technology 9(2018) 2, 596-605.

[15] S. Joshy, J. Shukla, S. Dhyani, A Participatory Stakeholder - Based Approach to Assess the Drivers and Challenges of Mangrove Loss in Kochi, Kerala, India, in: Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region, eds.: R. Dasgupta, S. Hashimoto, O. Saito, Science for Sustainable Societies, Springer, Singapore, 2022, 77-98. https://doi.org/10.1007/978-981-19-2738-6_5

[16] T.V. Vineeth Kumar, R. James, A.K. Prema, A Pilot Study on Microbial After growths in the Municipal Water Supply from Aluva to West Kochi, Scholars Academic Journal of Biosciences 2(2014) 12B, 913-919.

[17] R.R. Baxter, The law of international waterways: with particular regard to interoceanic canals, Cambridge, Mass.: Harvard University Press, 1964.

[18] D.E. Barbé, S. Carnelos, J.A. McCorquodale, Climatic effect on water quality evaluation, Journal of Environmental Science and Health, Part A 36(2001) 10, 1919-1933. https://doi.org/10.1081/ESE-100107438

[19] R.K. Mishra, Fresh Water availability and its Global challenge, British Journal of Multidisciplinary and Advanced Studies 4(2023) 3, 1-78. http://dx.doi.org/10.37745/bjmas.2022.0208

[20] F.N. Chaudhry, M.F. Malik, Factors affecting water pollution: a review, Journal of Ecosystem and Ecography 7(2017) 1, Article ID: 1000225. http://dx.doi.org/10.4172/2157-7625.1000225

[21] Standard methods for the examination of water and wastewater, eds.: E.W. Rice, L. Bridgewater, American Public Health Association, 2012.

[22] P. Whitehead, G. Bussi, M.A. Hossain, M. Dolk, P. Das, S. Comber, R. Peters, K.J. Charles, R. Hope, M.S. Hossain, Restoring water quality in the polluted Turag-Tongi-Balu River system, Dhaka: Modelling nutrient and total coliform

intervention strategies, Science of the total environment 631-632(2018), 223-232. https://doi.org/10.1016/j.scitotenv.2018.03.038

[23] https://en.wikipedia.org/wiki/Fort_Kochi, Accessed: March 17, 2024.

[24] https://en.wikipedia.org/wiki/Kochi, Accessed: April 12, 2024.

[25] https://en.wikipedia.org/wiki/Neighbourhoods_of_Kochi, Accessed: April 15, 2024.

[26] https://www.swissrefoundation.org/dam/jcr:a42c80f5-b893-4f3d-9148-c640f7cedb25/Final%20Report_Kochi%20Smart%20Canal_Swiss%20Re%20Foundation.pdf, Accessed: April 20, 2024.

[27] M.A. Paikada, Salinity Intrusion and Seasonal Water Quality Variations in the Tidal Canals of Cochin, A Thesis, Cochin University of Science and Technology, Kochi, 2005.

[28] B.A. Anhwange, E.B. Agbaji, E.C. Gimba, Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis, International Journal of Science and Technology 2(2012) 5, 248-254.

[29] J.N. Lythgoe, Light and vision in the aquatic environment, in: Sensory biology of aquatic animals, eds.: J. Atema, R.R. Fay, A.N. Popper, W.N. Tavolga, Springer, New York, 1988, 57-82. https://doi.org/10.1007/978-1-4612-3714-3_3

[30] A Water Monitor's Guide to Water Quality, DataStream initiative, 2021.

[31] K.V. Sruthi, A. Navaneeth, P.S. Harikumar, Assessment of water quality and ecosystem health of a canal system during the lockdown period, Sustainable Water Resources Management 9(2023), Article number: 5. https://doi.org/10.1007/s40899-022-00784-0

[32] M. Brattoli, G. De Gennaro, V. De Pinto, A.D. Loiotile, S. Lovascio, M. Penza, Odour Detection Methods: Olfactometry and Chemical Sensors, Sensors 11(2011) 5, 5290-5322. https://doi.org/10.3390/s110505290

[33] S.V. Kuma, L.F. Pascal, M. Meeran, M. Byrose, V. Selvi, G. Marin, S. Arivoli, Comprehensive Analysis on The Physical, Chemical, Nutrient, Heavy Metal and Microbiological Parameters at Selected Stations of Buckingham Canal, Chennai, Tamil Nadu, India, Environmental Contaminants Reviews 3(2020) 2, 77-86.

[34] P.R. Dugan, Biochemical ecology of water pollution, Springer, New York, 2011. https://doi.org/10.1007/978-1-4613-4389-9

[35] P. Van Wyk, J. Scarpa, Water quality requirements and management, in: Farming marine shrimp in recirculating freshwater systems, eds.: P. Van Wyk, M. Davis-Hodgkins, R. Laramore, K.L. Main, J. Mountain, J. Scarpa, Florida Department of Agriculture and Consumer Services, BOB CRAWFORD, Commissioner, 1999, 141-161.

[36] A. Rahul, M. Mukherjee, A. Sood, Impact of Ganga canal on thermal comfort in the city of Roorkee, India, International Journal of Biometeorology 64(2020), 1933-1945. https://doi.org/10.1007/s00484-020-01981-2

[37] K. Saravanakumar, R.R. Kumar, Analysis of water quality parameters of groundwater near Ambattur industrial area, Tamil Nadu, India, Indian Journal of Science and Technology 4(2011) 5, 660-662. https://dx.doi.org/10.17485/ijst/2011/v4i5.28

[38] R.N. Kumar, R. Solanki, J.I.N. Kumar, An assessment of seasonal variation and water quality index of Sabarmati River and Kharicut canal at Ahmedabad, Gujarat, Electronic Journal of Environmental, Agricultural and Food Chemistry 10(2011) 5. 2248-2261.

[39] M.S. Islam, S.M.M.H. Majumder, Alkalinity and hardness of natural waters in Chittagong City of Bangladesh, International Journal of Science and Business 4(2020) 1, 137-150. https://doi.org/10.5281/zenodo.3606945

[40] O.P. Verma, B. Khanan, S. Shukla, Determination of physico-chemical

characteristics of four canals of Allahabad region and its suitability for irrigation, Advances in applied science research 3(2012) 3, 1531-1537.

[41] M.J. George, K.N. Krishna Kartha, Surface salinity of Cochin backwater with reference to tide, Journal of the Marine Biological Association of India 5(1963) 2, 178-184.

[42] P.M. Barlow, Ground water in freshwater-saltwater environments of the Atlantic coast, US Department of the Interior, US Geological Survey, 2003.

[43] A. Singh, M. Agrawal, F.M. Marshall, The role of organic vs. inorganic fertilizers in reducing phytoavailability of heavy metals in a wastewater-irrigated area, Ecological Engineering 36(2010) 12, 1733-1740. https://doi.org/10.1016/j.ecoleng.2010.07.021

[44] G.E. Adjovu, H. Stephen, D. James, S. Ahmad, Measurement of total dissolved solids and total suspended solids in water systems: A review of the issues, conventional, and remote sensing techniques, Remote Sensing 15(2023) 14, Article ID: 3534. https://doi.org/10.3390/rs15143534

[45] G. Matta, S. Srivastava, R.R. Pandey, K.K. Saini, Assessment of physicochemical characteristics of Ganga Canal water quality in Uttarakhand, Environment, development and sustainability 19(2017), 419-431. https://doi.org/10.1007/s10668-015-9735-x

[46] S.M. Goyal, C.P. Gerba, J.L. Melnick, Occurrence and distribution of bacterial indicators and pathogens in canal communities along the Texas coast, Applied and environmental microbiology 34(1977) 2, 139-149. https://doi.org/10.1128/aem.34.2.139-149.1977

[47] L.J. Tranvik, Degradation of dissolved organic matter in humic waters by bacteria, in: Aquatic humic substances. Ecology and Biogeochemistry, eds.: D.O. Hessen, L.J. Tranvik, Springer, Berlin, Heidelberg, 1998, 259-283. https://doi.org/10.1007/978-3-662-03736-2_11

[48] R.A. Wahaab, M.I. Badawy, Water quality assessment of the River Nile system: an overview, Biomedical and environmental sciences 17(2004) 1, 87-100.

[49] S. Kaur, J. Kaur, Assessment of Seasonal variations in oxygen demanding parameters (DO, BOD, COD) along Sirhind Canal passing through Moga, Punjab, India, International Journal of Innovative Science, Engineering & Technology 2(2015) 5, 697-700.

[50] S.A. Chetana, R.K. Somasekhar, Ecological study on the riverine ecosystem of Karnataka. III. Physico-chemical characterisation of River Vrishabhavathi, Journal of Environmental Pollution 4(1997) 1, 71-77.

[51] P. Nowak, K. Kucharska, M. Kamiński, Ecological and health effects of lubricant oils emitted into the environment, International journal of environmental research and public health 16(2019) 16, Article ID: 3002. https://doi.org/10.3390/ijerph16163002

[52] M.W. Mumtaz, M. Hanif, H. Mukhtar, Z. Ahmed, S. Usman, Evaluation of pollution load of Lahore Canal by quantification of various pollutants through physicochemical characterisation, Environmental monitoring and assessment 167(2010), 437-446. https://doi.org/10.1007/s10661-009-1062-y

[53] N.C. Mondal, V.P. Singh, V.S. Singh, V.K. Saxena, Determining the interaction between groundwater and saline water through groundwater major ions chemistry, Journal of Hydrology 388(2010) 1-2, 100-111. https://doi.org/10.1016/j.jhydrol.2010.04.032

[54] K.R. Tavabe, G. Rafiee, M.M. Shoeiry, S. Houshmandi, M. Frinsko, H. Daniels, Effects of water hardness and calcium : magnesium ratios on reproductive performance and offspring quality of *Macrobrachium rosenbergii*, Journal of

the World Aquaculture Society 46(2015) 5, 519-530. https://doi.org/10.1111/jwas.12217

[55] J. Sirajudeen, M.M. Mubashir, Statistical approach and assessment of physico-chemical status of ground water in near proximity of South Bank Canal, Tamil Nadu, India, Archives of Applied Science Research 5(2013) 2, 25-32.

[56] B. Jung, G.J. Hoilat, MacConkey Medium, StatPearls [Internet], StatPearls Publishing, 2024. https://www.ncbi.nlm.nih.gov/books/NBK557394/, Accessed: April 20, 2024.

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