



# Assessment of water quality and ecosystem health of a canal system during the lockdown period

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## Abstract

The impacts of the lockdown period on water quality and ecosystem health in an artificial canal water system were investigated from the rapidly growing Kozhikode City in India. The ecosystem health is measured in terms of water quality indicators such as pH, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD) and *Escherichia coli* (*E. coli*) during the pre-lockdown and lockdown period. The study reveals the massive improvement of the ecosystem health of the canal in terms of DO, BOD, and *E. coli* during the lockdown period. DO values were improved from anoxic (0 mg/L) to oxic (> 5 mg/L), BOD reduced from 31 to 0.7 mg/L as well as *E. coli* at major urban stretches were 800 MPN/100 mL, which was observed to be absent during the lockdown period. Urban stretches of the canal implicitly proved that the lockdown period was not sufficient to recover the natural ecosystem condition of the canal system. Principal component analysis revealed that the ecosystem health of the canal majorly governs two factors, such as the weathering process and anthropogenic waste sources. The study advocates the policy makers that temporary pollution source control in a timely interval may heal the environment and is useful to the regulatory bodies for suggesting the pollution source control mechanism.

**Keywords** Ecosystem health · Water quality · Canal system · Lockdown · Anthropogenic interference

## Introduction

Water resources are highly impacted by anthropogenic interferences and climate dynamics (Dutheil et al. 2020; Han et al. 2020). Anthropogenic activities are a key source of pollution in different environmental spheres. As we know, at the end of the year 2019, the tragic COVID-19 pandemic occurred (Tian et al. 2020; Wang et al. 2020) and the first coronavirus case in India was reported in Thrissur District of Kerala State on 30th January 2020. Most of the economic activities were shut down impacting the world. During this scenario, it was reported from several parts of the world that the lockdown ensued in improving the environmental quality or reduced environmental degradation in different ways, such as improving air quality and water resource quality (Ma et al. 2020; Gautam and Hens 2020; Sharma et al. 2020a, b;

Bera et al. 2021; Beine et al. 2020; Mani 2020; Han et al. 2020; CPCB 2020).

Several studies are available on water quality issues of the natural river system during the pre-lockdown period. Water quality predictions were performed by using artificial intelligence techniques to accurately analyse the time series of water quality components and their influence on each parameter including the physico-chemical and hydrodynamic parameters, which have major contribution towards the potability of water. Water quality components such as temperature, pH, EC, DO, COD, BOD, K, Na, and Mg of Tireh River of Iran, revealed that land use changes pattern impact pollution transmission to rivers (Parsaie and Haghiabi 2015; Haghiabi et al. 2018). Later on, Parsaie (2017) portrayed the significance of mathematical models in determining pollution transmission. The study utilized the finite volume method (FVM) to solve the advection dispersion equation (ADE) related to pollution transmission in rivers and the hydrodynamic parameter estimation for river water. It showed that utilization of mathematical models for water quality estimation could give accurate results.

The environmental pollution level in 88 cities across India had drastically reduced down during lockdown.

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period (Sharma et al. 2020a, b). The National Air Quality Index had improved more than 50% in the central, eastern, southern, western and northern parts of Delhi within 4 days after the commencement of the lockdown. Not only air pollution levels, but also the water quality of the polluted rivers were improved (CPCB 2020; Dhar et al. 2020; Chakraborty et al. 2020). During this period, Ganga River had exhibited an improved water quality with increasing DO and reduced nitrate ( $\text{NO}_3^-$ ) concentration (Dhar et al. 2020; Chakraborty et al. 2020; Mukherjee et al. 2020). The real-time water monitoring data of the Central Pollution Control Board (CPCB) reveal that 75% of monitoring units at various points of Ganga River were found to be suitable for bathing and propagation of wildlife and fisheries (CPCB 2020). Multiplicative water quality index, MED-WQI, for surface water quality assessment of River Ganga indicated critical anthropogenic activities along the river course, leading to water quality deterioration (Verma et al. 2022). Kumar et al. (2021) had introduced Fuzzy River Health Index to understand the health of a river system and the study was applied to Chambal River health estimation. It indicated that the health of the Chambal River is within an excellent range ( $\text{FRHI} > 80$ ) in terms of DO, BOD, total solids (TS), total coliform (TC), nitrate ( $\text{NO}_3^-$ ), and phosphate ( $\text{PO}_4^{3-}$ ).

Remote sensing data record of Ganges River in terms of turbidity reveal the region-specific improvement of water quality (Muduli et al. 2021). Aman et al. reported the reduction in the turbidity level of Sabarmati River and associated improvement of water quality using the remote sensing technique (Aman et al. 2020). The limitations of remote sensing studies were the absence of field data, pointing out to the importance of ground truth data availability. Water quality of Yamuna River improved significantly during the

lockdown period with respect to DO, BOD, and COD (Patel et al. 2020; CPCB 2020).

Several studies have estimated the effect of the lockdown period on the environment in the short and long term, which is an important task to understand the benefit on the natural resource quality improvement, e.g. of rivers such as Ganga ( $\text{DO} = 11.6 \text{ mg/L}$ ,  $\text{BOD} = \text{BDL}$ ), Yamuna ( $\text{DO} = 3.6 \text{ mg/L}$ ,  $\text{BOD} = 30 \text{ mg/L}$ ), and Damodar in India (CPCB 2020; Mani 2020; Bera et al. 2021; Dhar et al. 2020; Chakraborty et al. 2020, 2021; Patel et al. 2020, Table 1). Studies show that groundwater quality deteriorates due to the uncontrolled dumping of urban wastes to the Canal Adi Ganga in India (Ghosh et al. 2019), but limited investigations are available in this aspect related to the improvement of lakes, canals, groundwater, etc., during the lockdown period, specifically in southern India.

This study attempts to quantify the level of ambient water pollution in the Canoli Canal system of Kozhikode, Kerala during the COVID-19 spread. Kozhikode district in Kerala State experienced lockdown from 21st March onwards, affecting urban activities near the major canal system of the city, Canoli Canal (Ray and Subramanian 2020; Narayanan et al. 2020). The Canoli Canal connects the cities between the north and south of Kozhikode City and can be developed into a transport path with tourism activity and inland navigation. But presently, Canoli Canal receives the sewage of Kozhikode City along its length of 11.3 km through 70 drains, approximately the same number of channels carrying sewages without treatment. The canal has been reduced to a nondescript drainage with contaminated water and waste from commercial land use, affecting the economic benefits and also with a high impact on drinking water wells of near areas (Ghosh et al. 2019). During the lockdown period, the

**Table 1** Water quality status of rivers in India (Central Pollution Control Board 2011)

Rivers	Total coliform (MPN/100 mL)	Fecal coliform (MPN/100 mL)	DO (mg/L)	BOD (mg/L)
Yamuna	16.0E+08	11.0E+08	3.8	41
Ganga	02.5E+06	01.1E+06	8.8	11
Damodar	08.0E+06	01.8E+06	3.4	7.8
Alakananda	11.0E+04	04.6E+04	8.6	0.8
Mahanadi	16.0E+04	16.0E+04	6.8	3.6
Brahmaputra	01.5E+04	07.3E+02	6	9.8
Krishna and Tungabhadra	01.6E+04	90.0E+02	1.7	8.2
Cauvery	62.0E+02	03.4E+02	1.7	7.2
Chambal	09.0E+04	04.0E+04	2.8	42
Satluj	09.0E+04	05.0E+04	3.8	32
Baitarani	05.4E+04	02.4E+04	7.3	1.6
Periyar	50.0E+02	35.0E+02	2.4	3
Godavari	900	90	4.2	12.9

pollution from the discharge of pollutants from municipal effluents and other small-scale industries has come down substantially, which prompted us to investigate such a study. Therefore, the study investigated the status of ecosystem health of the Canoli Canal in Kerala, India, and evaluated the effect of the lockdown on its water quality.

## Study area

Canoli Canal is a man-made canal and was constructed in 1848, connecting Korapuzha in the north with Kallai River in the south. This canal is 11.20 km length and the width varies from 6 to 20 m with a bed level  $-1.50$  m, which flows through the Kozhikode Corporation, Kerala. The water depth in the peak monsoon ranges from 0.5 to 2.0 m. The banks of the canal are highly urbanized and are the prominent receiver of surface runoff and untreated sewage of Kozhikode City. Finally, the canal discharges to the Arabian Sea through the Kallai River. The canal is affected by tidal influence with an average low and high tide level of  $-0.5$  and  $+1.00$  m, respectively. The areas along the whole stretch of the canal are heavily urbanized and comprise 35–40% of the total Kozhikode City area (Pettersson 2005; Kozhikode Corporation 2017).

The pre-lockdown condition of Canoli Canal had been very bad (Fig. 1). More than 30 watercourses, channels and streams, which are not treated properly, discharge into this canal. These discharges including urban liquid and solid wastes such as from toilets, slaughterhouses, and hospitals result in toxic and unhygienic conditions of the canal. These activities lead to the siltation of the canal, which considerably reduces the depth of the canal (Harikumar and Anitha 2003; Pettersson 2005). Certain stretches of the canal are in a dilapidated condition and the existing protection is insufficient at some other places. Groundwater in this area is polluted (Pramada and Soumya 2020). DO and BOD in most of the areas of the canal are beyond the permissible limits as per the standards of CPCB.

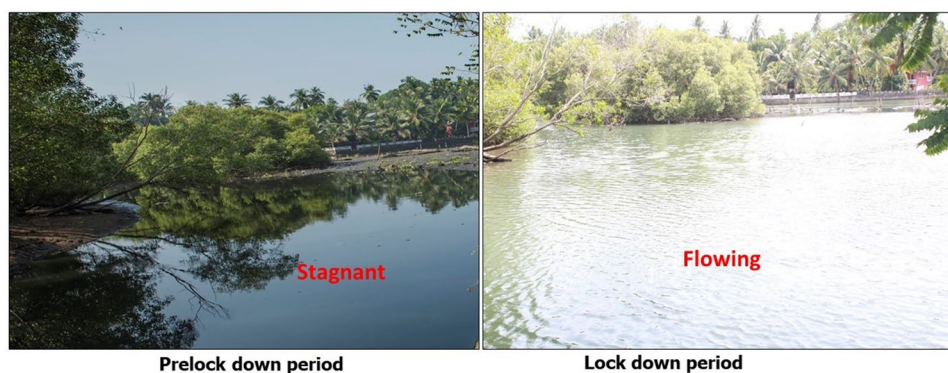
## Methodology

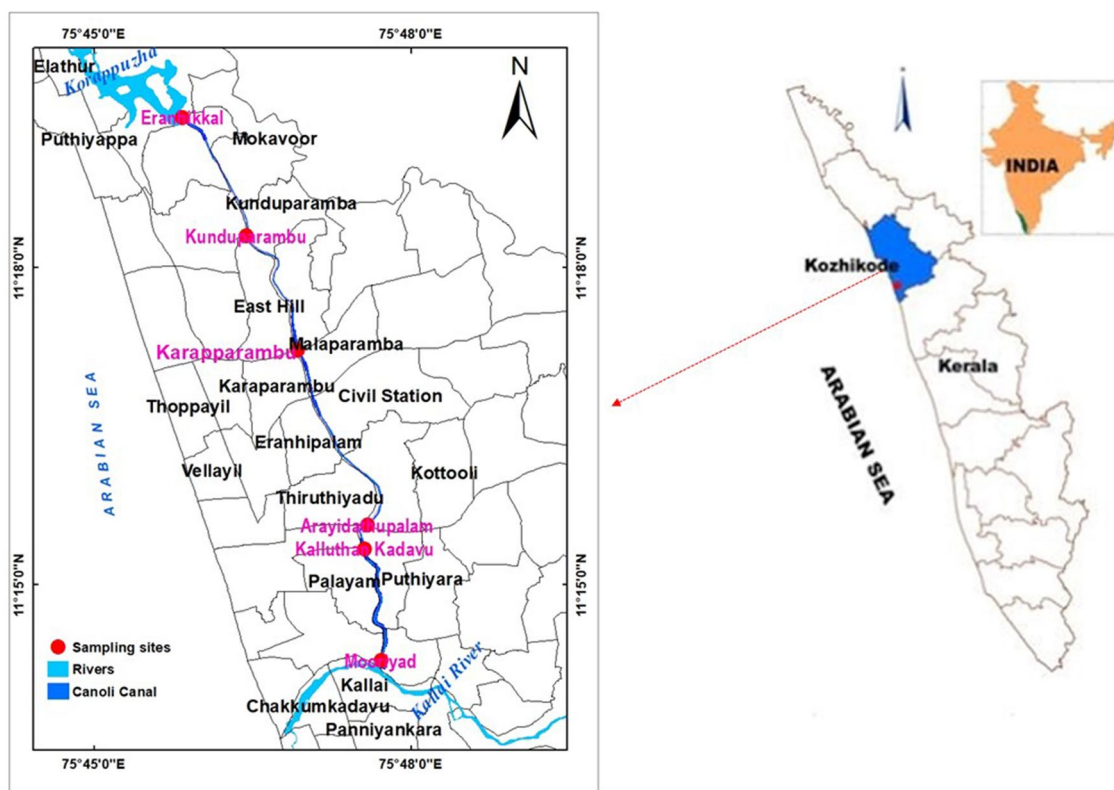
The criteria for selecting sampling points were based on the pollution intensity during the pre-lockdown period (January 2020) as well as anthropogenic activity-concentrated stretches. The present study was conducted using water samples collected from six heavily polluted stretches of the Canoli Canal system (Fig. 2). Canal water samples were collected and preserved for chemical and microbiological analyses as per the standard protocol of APHA (Rice et al. 2017). Three replicates of the water samples were taken from each station. The water sample was collected about 10 cm below water using plastic bottles (500 mL) and BOD bottles. The water samples for physico-chemical analysis were kept in ice for further analyses in the laboratory. Standard procedures were followed for water sample collection and water sample analysis.

The pH, temperature, and EC were measured on the sampling site (model Eutech – PC 2700, Eutech Instruments). In the laboratory, the electrical conductivity (EC) and turbidity of the water samples were measured using Systronics EC meter-306 and Digital turbidity meter (EIModel-33E), respectively. The total suspended solids (TSS) and total dissolved solids (TDS) were measured gravimetrically by the standard methods reported in APHA, 2017. The complexometry titrations were done using ethylenediaminetetraacetic acid (EDTA) to measure the total hardness and calcium (Ca) hardness of the water samples using Eriochrome Black T and Murexide indicators, respectively.

Iodometric method was performed for the estimation of DO and BOD (Rice et al. 2017). The quantity of DO present in the given sample was determined by using modified Winkler's (azide modification) method (APHA, 2017). Collection and preservation of DO samples were performed using Winkler's reagent, i.e. adding manganous sulphate ( $\text{MnSO}_4$ ) and alkali iodide solution and stored away from strong sunlight. DO present in the sample quickly oxidizes an equivalent amount of dispersed divalent manganous hydroxide precipitate to hydroxides of higher valence state.

**Fig. 1** Visual observation of changes in Canoli Canal during the pre-lockdown and lockdown periods





**Fig. 2** Study area with sampling site

In the presence of iodide ions and upon acidification, the oxidized manganese reverts to the divalent state, with the liberation of iodine equivalent to the original DO content in the sample. The iodine is then titrated with the standard solution of thiosulphate.

Five-day BOD ( $BOD_5$ ) determination was utilized in the study for BOD determination. The test measures the oxygen utilized during the incubation period for biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulphide and ferrous ions. The test consists in taking the given sample in suitable concentrations in dilute water in BOD bottles. Two bottles were taken for each concentration and three concentrations were used for each sample. One set of bottle was incubated in a BOD incubator for 5 days at 20°C; the dissolved oxygen (initial) content (D1) in the set of bottles was determined immediately. At the end of 5 days, the dissolved oxygen content (D2) in the incubated set of bottles was determined.

$$B.O.D. (mg/L) = D1 - D2,$$

where D1 = DO of the sample (mg/L) immediately after preparation and D2 = DO of the sample (mg/L) at 5 days incubation.

Multiple tube fermentation technique was applied for coliform bacterial count estimation. Samples were enriched in Lauryl tryptose broth for isolation of *E. coli*. From tubes showing colour change and gas production, one loopful was transferred to EC broth for confirmation. For isolation of *E. coli*, inocula from EC broth was transferred to eosin methylene blue agar and incubated at 37 °C for 24 h. Colonies with blue metallic sheen were presumptively identified as *E. coli*.

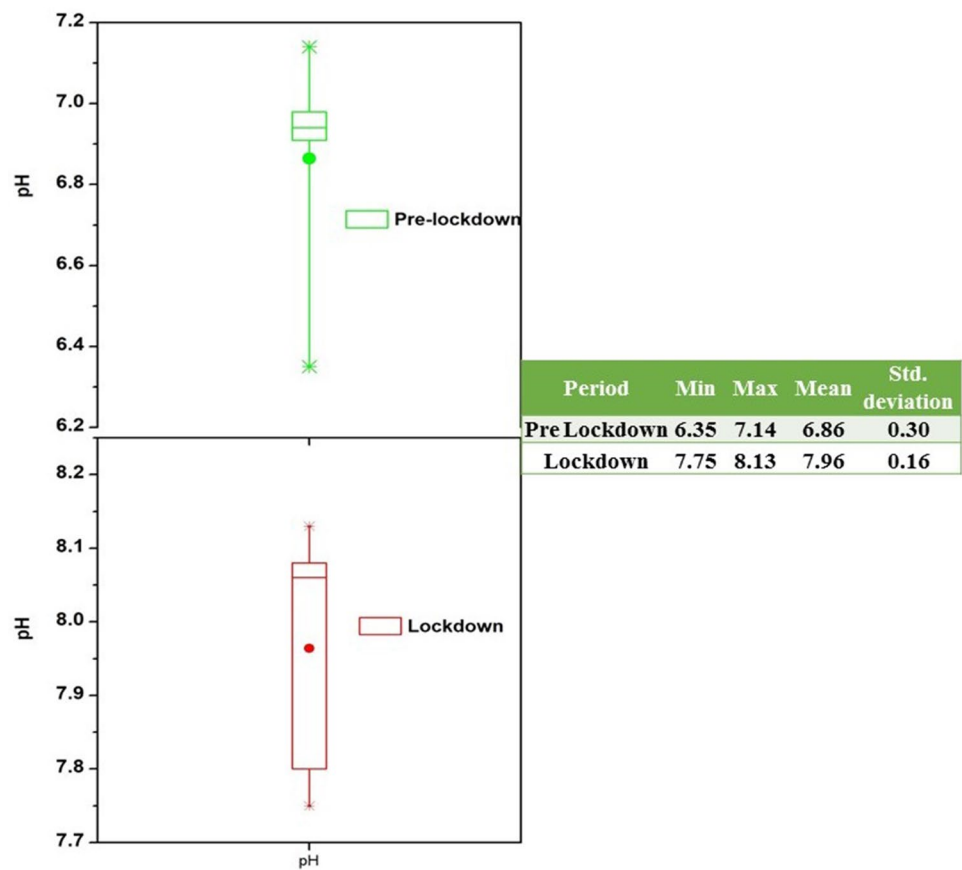
Spatial interpolation of the quality parameters was performed by spatial interpolation function of the Kriging method (Nas 2009) in Arc Map to demonstrate the spatial variation of parameters along the canal stretch. The variance analysis was performed for all chemical variables using Microsoft Office Excel 2010, a statistical tool, used to describe the degree to which one variable is linearly related to another. The correlations of the observed water quality parameters were performed using the coefficient of correlation (CV) and *t* test.

### Statistical analysis

Principal component analysis (PCA) was performed as an exploratory data analysis tool to understand the major factors influencing the water quality variables in the study



**Fig. 3** Box plot showing distribution of pH in two observation periods



region. PCA was performed on all analysed water quality parameters. Principal components (PCs) have been presented as linear combinations of the original variables. PCs with eigenvalues greater than 1 is considered for the data interpretation and PC development (Alberto et al. 2001). Contributions of each PCs for all water quality variables are expressed as factor loadings. PCA and statistical analyses were performed using statistical software XLSTAT software v5.03.

## Results and discussion

### Qualitative evidence of improvement of canal water during the lockdown period

The quantitative estimation of water quality parameters pH, EC, DO, and BOD of Canoli Canal water was performed for five stretches during the pre-lockdown and the lockdown period. The comparison of physical parameters was carried out based on data collected from four canal stretches, i.e. Eranhikkal to Kunduparamb (stretch 1), Kunduparamb to Arayidathupalam (stretch 2), Arayidathupalam to Kalluthankadavu (stretch 3), and Kalluthan Kadavu to Mooriyad (stretch 4) (Fig. 2).

pH is a significant water quality indicator. Measurement of pH is associated with the acidity or alkalinity of water. The alkaline characteristic water exhibits a pH value higher than 7.0. Acidic water causes corrosion of metal pipes and plumping system. As per CPCB, normal pH of the surface water to sustain aquatic life is 6.5–8.5 (Central Pollution Control Board). It is observed that pH distribution along the stretches of the Canoli Canal varied from 6.3 to 7.1 during pre-lockdown and varied from 7.7 to 8.1 during the lockdown period (Fig. 3). The acidic nature of the canal stretch during the pre-lockdown was shifted to alkaline nature during the lockdown period. Also, the variance in pH value was higher during the lockdown period comparatively with the pre-lockdown period (Fig. 3). The low variance in pH during the pre-lockdown denotes the very stabilized condition due to the constant input of components leading to acidic pH which is anthropogenic interference (Siddik et al. 2018). The increased variance during the lockdown period indicates the tendency of pH to a shift towards a stabilized natural condition, where it could not revive to the natural condition. This shows that the lockdown period is not sufficient to attain the natural environment pH level of the canal system, which demands a furthermore period to neutralize the anthropogenic interferences during the pre-lockdown periods.

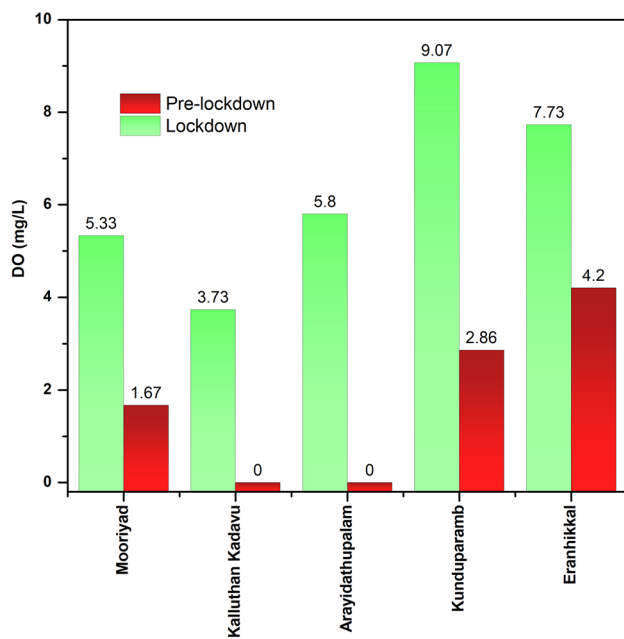


Fig. 4 DO values at different sampling sites

Figure 4 shows the variation of DO of four stretches of the canal during the lockdown and pre-lockdown period. It was observed that the DO of the water samples varied from 3.73 to 9.07 mg/L during the lockdown period, while the variation was from 0 to 4.2 mg/L during the pre-lockdown period (Fig. 4). During the pre-lockdown period, the four canal stretches exhibited lower DO value ( $< 5.0$  mg/L) and was anoxic in Arayidathupalam–Kalluthan Kadavu (stretch 3) (Fig. 5). During the lockdown period, major stretches of the canal water system exhibited a DO value of greater than 5 mg/L except at Arayidathupalam–Kalluthan Kadavu (3.73 mg/L) (Fig. 5). It is incredibly significant from the results that the DO concentration had increased threefold in the lockdown period compared to the concentration during the pre-lockdown. This is one of the highest DO value (9.07 mg/L) observed in Canoli Canal stretch during the past 10 years (CWRDM 2016). The increased DO value indicates the reduced pollution level in the canal water and points towards the reduced input of sewage (Siddik et al. 2018; Pettersson 2005).

During pre-lockdown, Arayidathupalam to Kalluthan Kadavu (stretch 3) was anoxic in nature where the aquatic organisms were not able to survive, while the lockdown period produced a very optimistic change that revived the

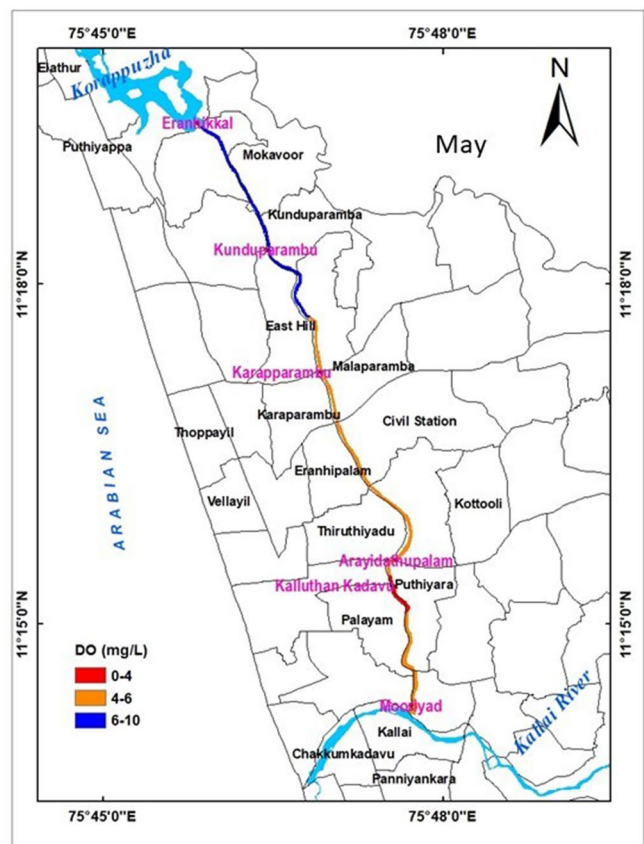
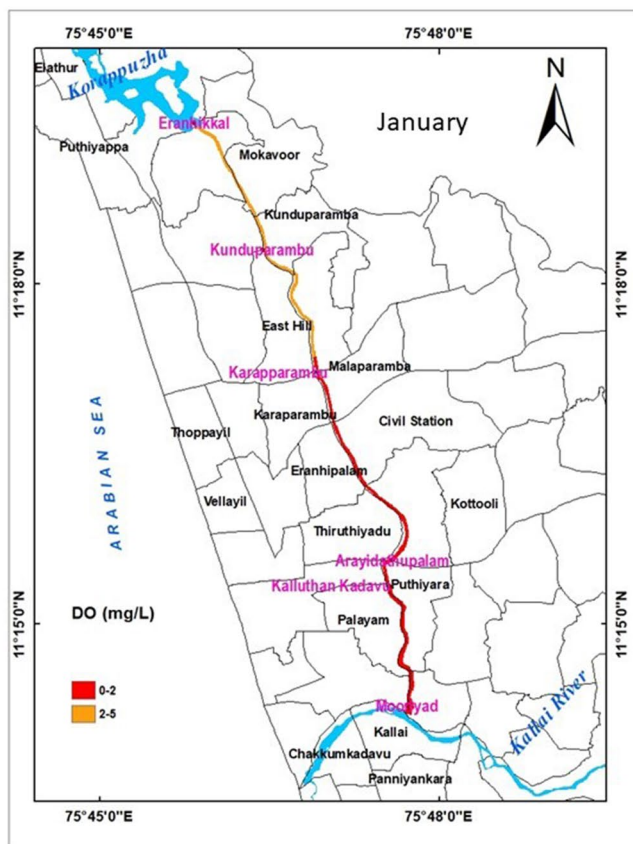


Fig. 5 Spatial distribution of DO along the Canal stretch during two periods

oxic nature of the canal system (Figs. 4, 5). The deteriorated DO levels of this stretch indicate intensive pollutant load from the nearest urban centres such as Palayam and Big Bazar during the pre-lockdown (Fig. 5; Daniel et al. 2002; Wilcock et al. 1995). This is the stretch near the biggest commercial and retail activity area, Palayam, and Big Bazar is the main agricultural market of Kozhikode Corporation (KozhikodeCorporation 2017; Siddik et al. 2018).

It is observed that hydraulic retention time for the pollutant is larger in this stretch 3 (Arayidathupalam to Kalluthankadavu), which requires more time for degradation and to attain normal DO level of the canal system. Observation suggests that the time period required to attain the normal DO level at this stretch is greater than that of the lockdown period (> 40 days), i.e. intense pollutant load magnifies the time required to degrade and attain the normal level of DO in this area. The significant correlation between DO and BOD ( $r=0.62$ ,  $P<0.01$ ) points towards the degradation of organic matter through aerobic bacterial activity where aerobic bacteria is present only in aerobic condition (USGS 2018). Moreover, this particular area has been significantly identified for the presence of deadly pathogenic bacteria compared to the remaining stretch (Megha et al. 2015). Therefore, reduced DO level in this stretch points towards a higher level of severity/toxicity of pollutant present in this stretch and it exists as a critical stretch in terms of DO level even after the lockdown period.

### Spatial distribution of *E. coli*, BOD, and its implication to organic pollution

The biological oxygen demand value varied from 8.2 to 31.82 mg/L during the pre-lockdown period, whilst it exhibited values from 0.23 to 3.47 mg/L during the lockdown (Fig. 6). The excess reduction in BOD level indicates the stabilization of waste organic matter or made unobjectionable value through its decomposition by living bacterial organisms so far and needs to be maintained for normal aquatic life further. The lower BOD level, together with low DO profile in the stretches of Kalluthan Kadavu–Mooriyad (stretch 4), reveals the source of different nature of pollutant in this stretch rather than organic pollution (Figs. 5, 7). Because BOD indicates the amount of oxygen required to decompose waste organic matter from water by aerobic bacteria (those bacteria that live only in an environment containing oxygen) only. The southern stretch 4 (Kalluthan Kadavu–Mooriyad) is dominated by a lot of industrial activities such as coir retting, log setting, and other kinds of timber industries (Bindhya Mol and Harikumar 2013; Siddik et al. 2018). However, in Arayidathupalam, BOD is comparatively higher than that in Kalluthan Kadavu and Mooriyad (Fig. 6), which indicates organic pollution to be the dominant type in Arayidathupalam region. This indicates the input of waste

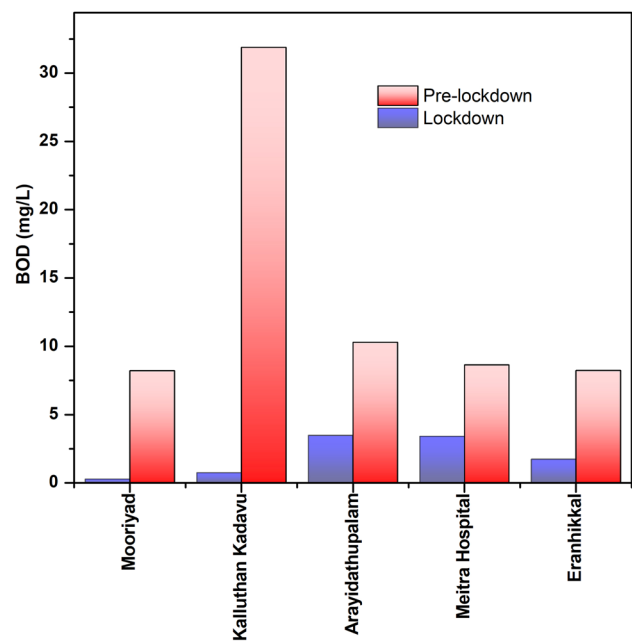


Fig. 6 Distribution of BOD in the sampling site during two periods

from domestic activities, hospitals, hotels, garages, slaughterhouses, etc. to this location (Megha et al. 2015).

It was found that the studied canal stretch 3 was contaminated with a high proportion of *E. coli* bacterial community during the pre-lockdown period (Fig. 8). The number of *E. coli* bacteria had reduced in massive quantity during the lockdown period (Fig. 8). The number of *E. coli* during the pre-lockdown varied from 0 to 1500 MPN/100 mL, while in the lockdown period, the variation was from 0 to 200 MPN/100 mL. During the lockdown period, a higher number of *E. coli* were observed at the southern stretch near Arayidathupalam (200 MPN/100 mL), which is an urban activity centre and the other observed points were free of *E. coli* bacteria (Fig. 8). The southern stretch of the Canoli Canal is polluted with input of sewage from residential areas and hospitals (Siddik et al. 2018; Megha et al. 2015). This indicates that Arayidathupalam–Kalluthan Kadavu stretch is still in a critical situation even after the lockdown period, which needs more recovery period to achieve the natural environmental condition or there is an active source of pollutants to the stretch even during the lockdown period.

### Tidal influence on the distribution of physico-chemical parameters in Canoli Canal

The distribution pattern of parameters such as salinity, EC, and  $\text{Cl}^-$  in canal water samples were studied (Fig. 9). Salinity varied from 9.01 to 30 ppt in the studied canal stretch (Fig. 10). The highest value of salinity was observed at the southern point of Canoli Canal

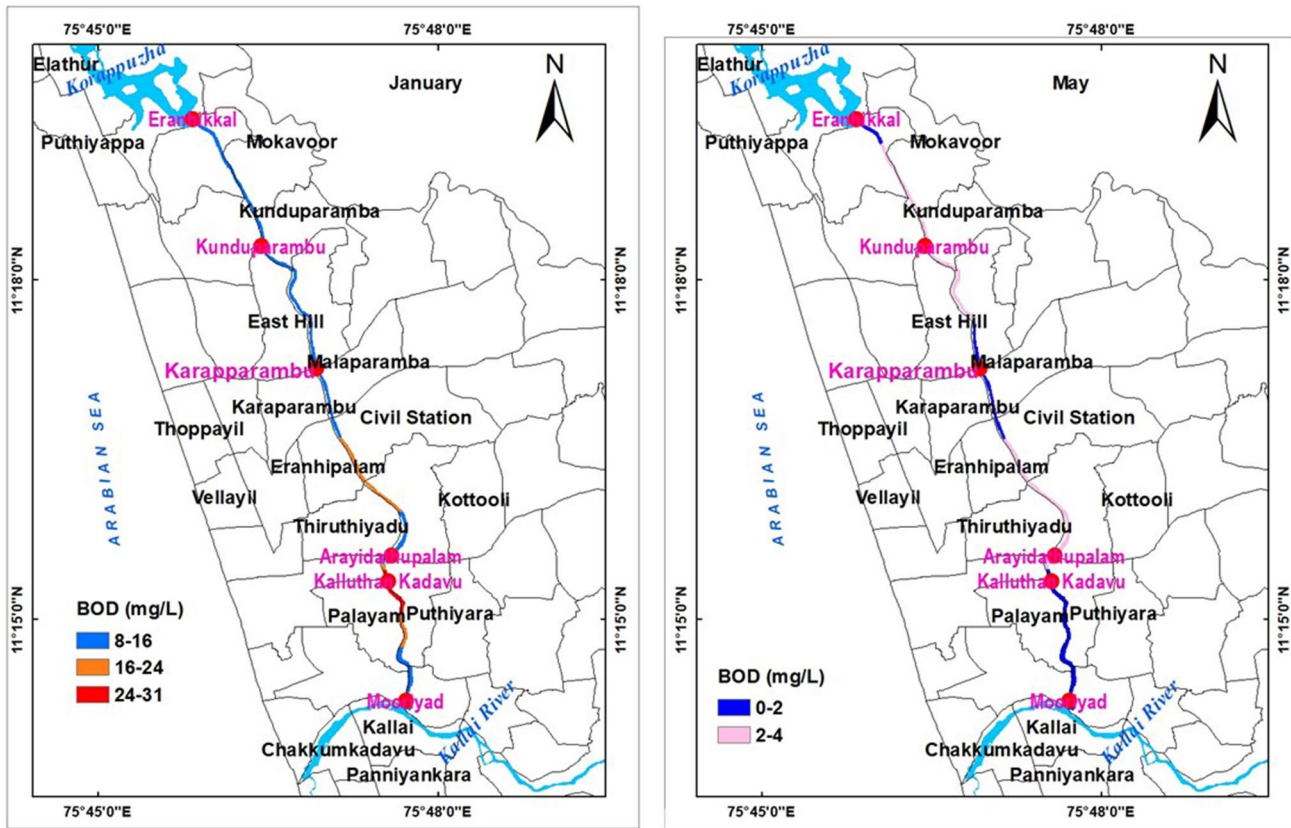


Fig. 7 Spatial variation of BOD along the canal stretch during pre-lockdown and lockdown

where it joins the Kallai River, and the area near the river mouth in the northern point (Eranhikkal) also exhibited

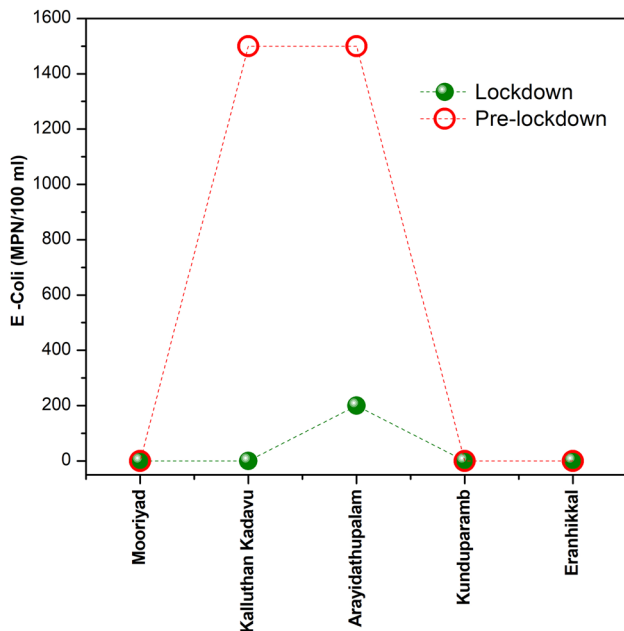


Fig. 8 Number of *E. Coli* in each sampling site during pre-lockdown and lockdown

a significantly greater value (Fig. 10). The least salinity was monitored at Arayidathupalam (9.01 ppt), which is the

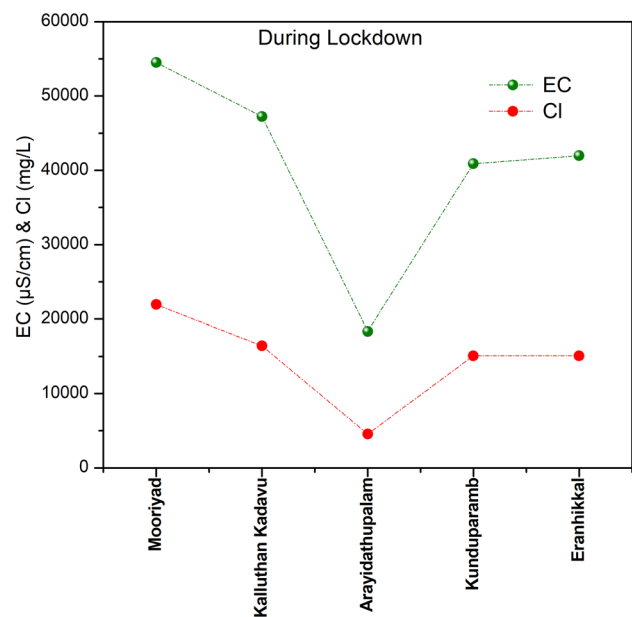
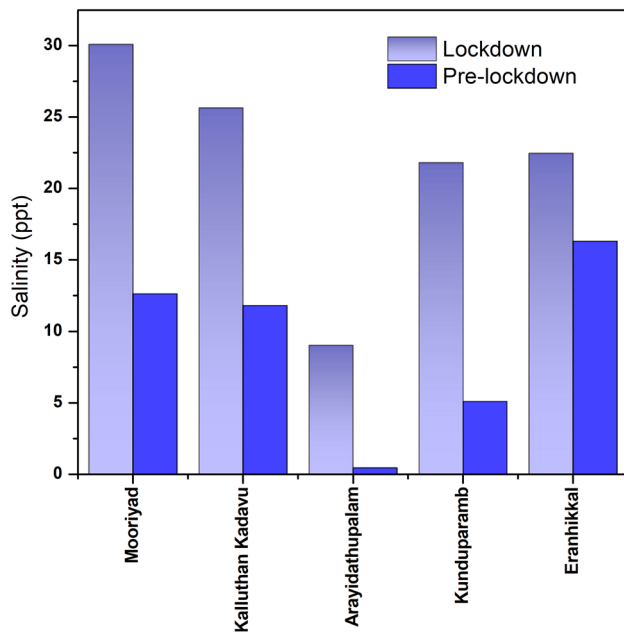


Fig. 9 Distribution of the pattern of EC and  $\text{Cl}^-$  along the canal stretch during the lockdown





**Fig. 10** Salinity values of the sampling site during the lockdown period

urban centre of Kozhikode. The observation is corroborated by EC and  $\text{Cl}^-$  measurement in the canal (Fig. 10). Similarly, a strong positive correlation between EC and  $\text{Cl}^-$  was observed ( $r=0.98$ ,  $P<0.01$ ). The increased salinity in the canal can affect the water quality of the wells near the Canoli Canal and can also lead to the intrusion of saline water to inland. Also, the overexploitation of wells near the canal will lead to lowering of the water table, resulting in accelerated saline water intrusion into this area (Barlow and Reichard 2010; Kim et al. 2018; Kruse et al. 1998). The distribution pattern of salinity, EC, and  $\text{Cl}^-$  in this study reveals the tidal effect along the canal stretches near the river mouth in the northern and southern region (Bindhya Mol and Harikumar 2013). The tidal influence on Canoli Canal can induce saline water intrusion problems to the wells near the northern and southern stretches (Pramada and Soumya 2020).

### Statistical evidences for improved water quality during the lockdown period

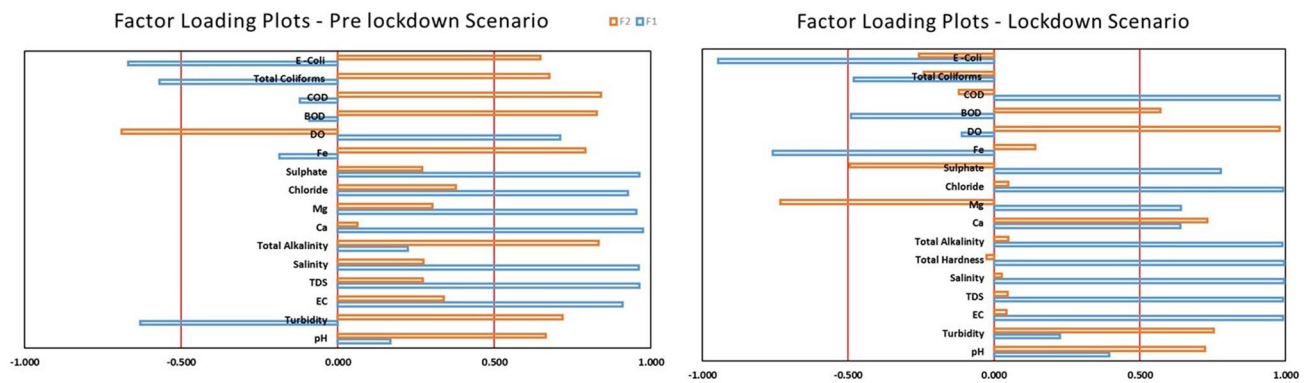
The principal component analysis (PCA) showed that the two major principal components (PC) control more than 80% of variability in the water quality variations in both the occasions. Principal component 1 explains a variability of greater than 50%. PC1 exhibited a significant positive factor loading towards TDS, total hardness, alkalinity, Ca, Mg,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ , and DO (Fig. 11). PCA reveals that PC 1 represents the weathering or mineral constituents in the pre-lockdown

and lockdown scenarios (Fig. 11). This indicates that the water is affected by dissolution of soil minerals and runoff from near landscapes majorly.

PC 2 explains 22% of the variability in the data. In this, PC 2 is significantly positively associated with the biological–organic constituent during the pre-lockdown and lockdown scenarios. During the pre-lockdown scenario, PC2 has more positive factor loadings towards *E. coli*, total coliform, BOD, and COD and negative association with DO. This illustrates that PC2 is the factor related to sewage input to the canal, because this canal is a receptor of 74 drains from different urban settlements. It has to be highlighted that PC2 has negative factor loadings with *E. coli*, total coliforms, and COD and a positive correlation with DO during the lockdown period (Fig. 11). The magnitude positive factor loadings towards BOD during the lockdown has reduced comparatively with BOD factor loading during the pre-lockdown period. This indicates the variation in the constituents of sewage input, i.e. reduced organic and inorganic pollutant input to the canal during the lockdown period. The negative factor loadings with *E. coli*, total coliform, and COD could be associated with less sewage input during the period due to the lockdown effect. The major factor loading changes in *E. coli*, total coliform, and COD reflects reduced organic pollution during this period. Therefore, the statistical analysis also supports our findings that improved water quality of the canal during the lockdown period.

### Conclusion

Comparison of water quality parameters such as pH, EC, DO, BOD, *E. coli*, and faecal coliform during the pre-lockdown and lockdown period of the Canoli Canal revealed a drastic improvement in quality during the lockdown period. This kind of observation is due to restriction measures towards the anthropogenic activities in the lockdown period. Certain critical stretches still exist near urban centres (Arayidathupalam and Kalluthan Kadavu stretch/stretch 3) that need to be revived to their natural/pristine condition and require a larger recovery period than the lockdown period. This reveals that the impact of existing contaminants is not eliminated or the point/non-point source of contaminant in urban centres is still active. Water quality maps are very illustrative of the spatial distribution of the different parameters in canal stretches, condition of the water body, and the location of the contaminations hotspots. The critical stretches are identified to be the urban centres in the southern region, viz. Arayidathupalam to Kalluthan Kadavu. The canal stretches are critical in terms of DO and *E. coli* and are not within the limit of the natural environmental system. Larger variation in pH distribution during the lockdown



**Fig. 11** Loading plot of water quality data during Pre lock down and lockdown scenario

is due to its insufficient recovery or stabilization period to natural system and is still in recovering status. Accumulating evidence from water quality parameters reveals that freshwater systems still show delays in the recovery of ecosystem health from pollution loads. The longer recovery period in this stretch vindicates intense and severe environmental stress due to urban pollution. Moreover, these canal water contaminations can result in a serious water quality deterioration near drinking water resources too. Tidal influence is another factor, which contributes to the quality of the canal water irrespective of the lockdown period. PCA illustrates that the water quality of the canal system is majorly governed by two factors such as weathering and urban sewage impact. The improvement of water quality during the lockdown is majorly associated with the restrictions on PC-2 (second factor) which indicates anthropogenic activities. Overall, the present study reveals the positive impact of the lockdown period on recovering deteriorated quality of a canal system. It is recommended to map more parameters such as heavy metals, nutrients, and organic matter to specify the improvement of quality in terms of specific economic activities and will be helpful for the policymakers to develop and establish short-term or long-term-based management and mitigation plans.

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**Availability of data and material** Not applicable.

**Code availability** Not applicable.

## Declarations

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

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