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Research Article

Physico-chemical properties as a tool for monitoring marine water quality in selected coastal beaches of Northern Sri Lanka

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Abstract: Sri Lanka is an island with extending coastal shores and extra valuable resources. Anthropogenic pressures and climate change have made the coastal environment increasingly susceptible. As coastal waters are dynamic and unstable, monitoring water quality parameters is essential. Monitoring of water quality measures of coastal waters plays a vital role in identifying the pollution sources and understanding the variations in water quality. It is helpful for stakeholders in making policies and standards to ensure the current status of the aquatic environment and life in it. A long-term assessment of physical and chemical properties was conducted every month for 18 months, from August 2020 to January 2022, at the coastal shores of Mathagal, Point Pedro, and Charty Beach to understand the current status and Spatio-temporal variations of water quality parameters in the studied locations. The parameters such as air and water temperature, pH, salinity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), and Electric Conductivity (EC) were measured on-site using the smarTROLL multiparameter handheld equipment. For statistical analysis, Minitab 2019 statistical software was used. Sampling locations significantly affected the spatial variation of DO but not the other studied parameters. The sampling months significantly affected the temporal variation of all assessed water quality parameters. The overall mean values of air and water temperature, pH, salinity, DO, TDS and EC were 29.90±1.43°C, 31.61±1.60°C, 8.11±0.13, 32.57±2.90 ppt, 6.85±0.86 mg/dl, 31.84±2.66 ppt and 52969.6±5355.96 μS/cm respectively. From the current study, it can be pointed out that the water quality parameters are influenced by precipitation and seasonal trends.

Keywords: Long-term monitoring, Pollution, Precipitation, Seasonal trends

1. Introduction

Marine environments play an important role in people's day-to-day lives, providing food, recreation, employment, residence, and, more importantly, protection from various natural risks, man-made hazards, and disasters (Sivakumar, 2019). In recent years, fishing and coastal tourism have become prominent economic sectors worldwide. According to the World Bank report in 2017, these two sectors together gain 10 percent of Sri Lanka's foreign exchange.

These valuable coastal ecosystems are prominent environmental components under enormous pressure due to pollution caused by human activities (Salvi et al., 2014), affecting the ecosystem's overall health. Accessible data on water quality and a better knowledge of the effects of pollution are urgently needed to enable sustainable fishing and tourism, protect the ecosystem and preserve human health (Devlin et al., 2020). The conservation of marine resources and the stability of the marine ecosystem are both dependent on the quality of the water in the ocean (Sivakumar, 2016). The physico-chemical parameters of a marine water resource are used to determine its quality. Monitoring and evaluating the physico-chemical properties of seawater is becoming increasingly crucial in determining the quality state of the near-coastal environment (Nisha and Achyuthan, 2014). Compared to other monitoring or bio-monitors, water quality analysis provides a thorough description of environmental quality and is simple and rapid due to its comprehensive analytical procedures (Yap et al., 2011). Thus, assessment of the water quality of these coastal areas has become essential to understand the emerging problems and help policymakers to implement proper management plans. Also, most importantly, long-term monitoring of the water body will help the stakeholders to get a clear picture of the variation of physico-chemical parameters during the season (dry and wet) and with the other hydrological parameters.

Sri Lanka is a 65610 km^2 island in the northern Indian Ocean with a 1600 km long coastline belt (Ratnasooriya and Samarawickrama, 2015) rich in biological hotspots, harbors, fishing grounds and recreational beaches. In the southern region Galle, Matara, Mirissa, Weligama, and in the eastern and northern parts Pasikudah, Arugam Bay, Keerimalai, and Casuarina are some of the world-famous tourist destinations in Sri Lanka. Sri Lanka's tourism industry contributes significantly to the country's revenue (Samarasekera and Abeygunawardena, 2017). Moreover, these coastal areas are considered extra valuable for fisheries. Coastal areas are home to half of the world's population. As a result, human

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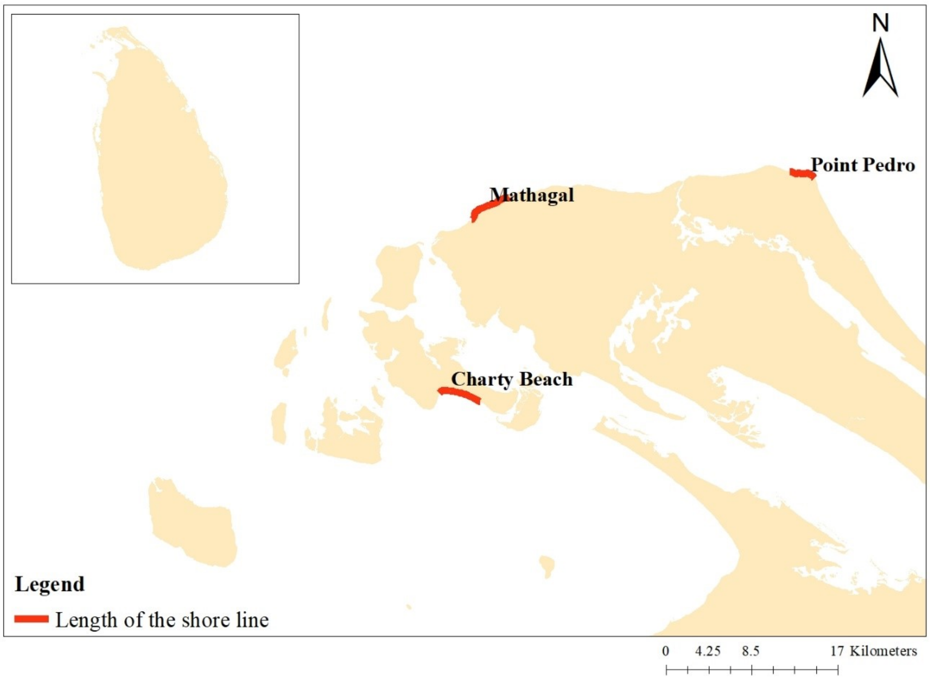

Figure 1: Location map showing the study area

activities impact the coastal waters and their resources (Gupta et al., 2005).

Jaffna is a 1,000 km^2 peninsula in the northern province with a 160 km coastline (Sivakumar, 2013). These areas were isolated for more than thirty years due to the civil war in Sri Lanka, which ended in 2009, opening the coastal line to fisheries and fishing-related activities and foreign and local tourists. Due to the thirty years of civil conflict, there is limited research on the marine water quality of the beach areas in the northern province of Sri Lanka. Research regarding water quality in these coastal areas is found to be minimal. No research has been done in Sri Lanka, including the northern region, to provide a baseline for classifying beaches according to international standards (Samarasekera and Abeygunawardena, 2017), as these areas are threatened by pressure from coastal development, erosion, pollution, and unsustainable development of tourism infrastructure (Sivakumar, 2016; Samarasekera and Abeygunawardena, 2017).

While considering the sampling locations, Mathagal, Point Pedro and Charty Beach are where both recreational and fishing activities are carried out. To date, studies on marine water quality at the sampling locations are sparse, and a knowledge gap exists regarding the current environmental status of these coastal shores. Considering the value of these sites as fishing and recreational grounds will help identify the ongoing issues in the area and impose mitigation measures that will benefit all the stakeholders in the resources. Thus, the study was conducted to understand the present water quality status at the selected study locations for 18 months and to compare the Spatio-temporal variation of the parameters.

2. Materials and methods

The research was carried out on Mathagal, Point Pedro, and Charty Beach shores in Northern Province, Sri Lanka (refer Figure 1). The study covered 11.7 km of coastal stretch, 4.6 km, 2.7 km, and 4.4 km at Mathagal, Point Pedro, and Charty Beach, respectively. The Mathagal coast is well known for its gill net and longline fishing and is a famous tourist destination due to its white sand appearance and historical importance. The Point Pedro coast is the northernmost point of Sri Lanka, consisting of a sandy coastline with coral rocks, and is a historical fishing spot with high marine biodiversity. Charty Beach is a white sand beach near the mini-island called "Vellanai". Six samples were taken from each of the three locations for the water quality assessment. The sampling locations' positions were accurately located using a Geographical Positioning System (GPS) (Garmin Oregon 750, USA), and the GPS coordinates of the sampling locations are shown in Table 1.

The study was conducted monthly at the selected locations for 18 months, from August 2020 to January 2022. The physical and chemical parameters such as air and water temperature, pH, salinity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), and Electric Conductivity (EC) were measured on-site using the smarTROLL multi-parameter (Insitu 458389, USA)

Table 1: Description and GPS coordinates of studied sampling locations

Sampling location	Coordinates	Usage of beaches
Mathagal	9°47'91.50"N, 79°57'46.60"E	Fishing, presence of fish market
Point Pedro	9°49'53.70"N, 80°15'10.00"E	Beach Park & recreational activities, fishing and related activities
Charty Beach	9°37'59.00"N, 79°55'26.00"E	Tourism and recreational activities

Table 2: The descriptive statistical values of studied parameters at the sampling location.

Location	Parameter	Max	Min	Mean	SD
Mathgal	Water temperature	33.34	26.02	29.28	1.87
	Air temperature	35.38	26.6	30.63	2.42
	Salinity	37	25.75	32.51	3.32
	pH	8.86	7.65	8.15	0.18
	DO	8.8	5.57	6.8	0.92
	TDS	35.5	26	31.78	2.83
	EC	62928.45	42078.78	52909.73	6115.96
Point Pedro	Water temperature	32.44	25.98	29.14	1.63
	Air temperature	38.1	27.2	32.44	2.89
	Salinity	35.23	25.78	32.46	2.86
	pH	8.43	7.07	8.05	0.21
	DO	9.83	5.95	9.55	1.25
	TDS	34	26	31.78	2.48
	EC	59760.8	42215.25	52724.91	5114.06
Charty Beach	Water temperature	31.79	26.73	29.42	1.4
	Air temperature	35.38	27.8	31.52	1.55
	Salinity	38	27.7	32.93	3.19
	pH	8.62	7.02	8.11	0.33
	DO	8.87	4.8	6.38	1.48
	TDS	36	27.75	32.13	2.79
	EC	62181.33	44834.68	53525.67	5062.14

hand-held equipment (Shobiya et al., 2019; Saruga et al., 2019). The multi-parameter consists of two different gadgets: (i) the probe and (ii) the battery pack. The sensors attached to the probe measure the water quality parameters such as water temperature, pH, salinity, DO, TDS and EC, while the sensors attached to the battery pack measure the air temperature. The probe was dipped in the surface water for a few seconds, and the values of the water quality parameters were displayed automatically on the iPhone connected to it. The battery pack attached to the multi-parameter held in the atmosphere to measure the air temperature displayed the locked results directly on the iPhone. Three replicates of each parameter were taken at each sampling location. Those parameters were measured in standard units such as air and water temperature in Celsius (°C), salinity in parts per thousand (ppt), DO in milligrams per deciliter (mg/dl), TDS in parts per thousand (ppt), and EC in micro Siemens per centimeter (µS/cm). In addition, the rainfall data (August 2020 to January 2022) was obtained from the meteorological department.

For statistical analysis, Minitab 2019 statistical software was used. Two-way ANOVA was used to compare the sampling locations and sampling months with the studied physical and chemical parameters. Descriptive statistics were performed to analyze the studied parameters' mean, minimum, maximum, and standard deviation (SD). Differences in means were considered as significant at $p < 0.05$. A Pearson correlation matrix and corresponding p-values were used to describe the correlations between the measured water quality parameters.

3. Results and discussions

The values for the mean, minimum, maximum, and standard deviation (SD) for each water quality parameter measured at the three sampling sites from the current study are shown in Table 2.

The correlation between the analyzed parameters in the sampling locations is shown in Table 3. Statistically significant strong correlations were obtained between salinity and TDS, salinity and EC, TDS and EC, and water temperature and air temperature. There was a moderate correlation between salinity and water and air temperature and TDS and water and air temperature. An inverse relationship was found between pH and salinity, DO with water and air temperature, DO and salinity, and TDS and pH.

Water temperature: The two-way ANOVA results revealed that sampling locations (Df (2), F = 0.34, $p > 0.05$) had no significant effect on the spatial varia-

Table 3: Pearson correlation matrix between the studied physico-chemical parameters

	WT	AT	SA	pH	DO	TDS
AT	0.845*					
SA	0.624*	0.585*				
pH	0.094	0.080	-0.507*			
DO	-0.683*	-0.556*	-0.360	0.531*		
TDS	0.612*	0.565*	0.999*	-0.516*	-0.369	
EC	0.770*	0.688*	0.976*	-0.357	-0.239	0.972*

(WT - Water temperature, AT - Air temperature, SA - Salinity, DO - Dissolved Oxygen, TDS - Total Dissolved Solids, EC - Electrical conductivity, *$p < 0.05$)

tion of water temperature. However, sampling months (Df (17), F = 6.70, $p < 0.05$) had a significant effect on the temporal variation of water temperature. The water temperature ranged from 26.02 - 33.3°C at Mathagal, 25.98 - 32.44°C at Point Pedro, and 26.73 - 31.79°C at Charty Beach (refer Figure 2 in Appendix). The lowest water temperature was recorded as 26.34±0.27°C in January 2022; the highest water temperature was recorded as 32.89±0.16°C in April 2021 at Mathagal, the lowest water temperature was 26.86±0.13°C in December 2020; the highest water temperature as 32.20±0.18°C in April 2021 at Point Pedro; the lowest water temperature as 27.04±0.28°C in December 2020; the highest water temperature as 31.67±0.09°C in August 2021 at Charty Beach. In each of the three locations, lower temperatures were recorded in November, December, and January compared to other months.

Changes in air temperature affect shallow water quickly; when the air temperature increases, the water temperature also increases (Rajkumar et al., 2011). Hence, water temperature is one of the most significant physical parameters that regulate biological, chemical, and physical water quality processes in the marine environment. The Pearson correlation (refer Table 3) in the present study between water temperature and air temperature had a strong relationship (r = 0.845, $p = 0.000$). Water temperature fluctuation was observed with the seasonal changes during the study period. There was a negative correlation (r = -0.639, $p = 0.004$) between water temperature and rainfall during the study period. This might result from high ambient temperatures during the dry season and low ambient temperatures during the rainy season. Gupta et al. (2005) reported that water temperature varied with the seasons, with higher water temperature in the summer and lower water temperature in the winter, similar to the present study's observation.

Air temperature: The air temperature values ranged from 26.60 - 35.38°C at Mathagal, 27.20 - 38.10°C at Point Pedro, and 27.80 - 35.38°C at Point Pedro. ANOVA results revealed that there was a significant difference in the monthly air temperature (Df = (17), F = 2.16, $p < 0.05$). However, there was no significant difference between the air temperature and sampling locations (Df = (2), F = 3.2, $p > 0.05$). It can be seen that the atmospheric temperature reached a maximum value in April 2021 at Mathagal (34.05±0.77°C), Point Pedro (36.26±0.37°C), and in March 2021 at Charty Beach (35.55±0.17°C) while it reached a minimum in January 2022 at Mathagal (27.35±0.22°C), December 2020 (28.50±0.89°C) at Point Pedro and November 2021 (29.80±0.36°C) at Charty Beach (refer Figure 3 in Appendix).

The study covered all the prevailing climatic seasons in the country, and the air temperature fluctuated with the seasons. The Pearson correlation (refer Table 3) resulted in a statistically negative relationship between air temperature and rainfall (r = -0.621, $p = 0.006$). Throughout the study period, the air temperature tended to be low during the rainy season and high during the dry season.

Salinity: Sampling locations had no significant impact on the variation of salinity among sampling locations (Df = (2), F = 0.48, $p > 0.05$) but there was a significant impact on salinity variation among sampling months (Df = (17), F = 13.07, $p < 0.05$). Generally, the salinity value of seawater is 35 ppt. The salinity values ranged from 25.75 - 37.00 ppt at Mathagal, 25.78 - 35.23 ppt at Point Pedro, and 27.70 - 38.00 ppt at Charty Beach. During the sampling period, maximum salinity (36.38±0.17 ppt) in September 2021 and minimum salinity (26.40±0.10 ppt) in November 2021 at Mathagal; maximum salinity (34.85±0.15 ppt) in October 2021 and minimum salinity (26.36±0.40 ppt) in November 2021 at Point Pedro and maximum salinity (37.33±0.15 ppt) in September 2021 and minimum salinity (28.20±0.28 ppt) in November 2021 at Charty Beach were recorded at the sampling locations (refer Figure 4 in Appendix).

Salinity is the amount of salt concentration in the water (Berthold et al., 2010). It is an essential ecological element that affects the organisms living in water bodies (Yap et al., 2011). Evaporation, precipitation, freshwater influx, and ocean currents can influence marine water's salinity (DEFA, 2007). The salinity of a body of water will alter depending on how it is recharged: during wet periods, salinity will decrease as salt concentrations become more dilute, whereas, during dry periods, salinity will increase (Carr and Neary, 2008). A negative correlation (r = -0.601, $p = 0.008$) was found between the salinity and precipitation during the study period. In the current study, the summer had high water temperatures and evaporation, which led to high salinity values. Due to precipitation, the wet season had a large amount of water, which diluted the salt concentration and decreased salinity. Previously published literature revealed a similar trend (Nelson et al., 2003; Gupta et al., 2005: Ladipo et al., 2011; Babalola and Agbebi, 2013; Sugirtharan et al., 2015).

pH: pH variation was not statistically significant in geography (Df = (2), F = 1.03, $p > 0.05$), but it was statistically significant in temporal (Df = (17), F = 1.03, $p < 0.05$). pH levels in Mathagal, Point Pedro, and Charty Beach ranged from 7.65 to 8.86, 7.07 to 8.43, and 7.02 to 8.62, respectively. In April 2021, Charty Beach had the highest pH, while in August 2020, it had the lowest. Although the highest pH value was recorded as 8.29$\pm$0.12 in January 2022 and the lowest value was 7.95$\pm$0.11 in September 2020 at Mathagal. In Point Pedro, the recorded highest value was 8.30$\pm$0.05 in March 2021, and the lowest value was 7.91$\pm$0.16 in September 2021. The pH values varied within a narrow range (refer Figure 5 in Appendix). The pH of water indicates the alkaline value in the three locations.

The pH is a measure of the acidity or alkalinity of water (Ma et al., 2020) and is a significant environmental element and is commonly used to evaluate the compatibility of the environment, which is connected to biochemical processes and species diversity (Rani et al., 2012). Most aquatic organisms require that pH is in a specified range. Physiological processes may be adversely affected if pH changes above or below the preferred range of an organism. The pH in the current study was within the acceptable limit for supporting the aquatic environment and aquatic life. Although aquatic life can exist in a pH range of 6.0 to 9.0, they may not withstand an immediate change within this range (Adefemi et al., 2007).

DO: DO change was statistically significant in terms of geography (Df = (2), F = 4.17, $p < 0.05$) and time (Df = (17), F = 3.18, $p < 0.05$). In Mathagal, DO levels varied from 5.57 to 8.80 mg/dl, in Point Pedro, from 5.95 to 9.83 mg/dl, and in Charty Beach, from 4.80 to 8.87 mg/dl. In February 2021, the greatest DO (9.83$\pm$0.92 mg/dl) was obtained at Point Pedro, while the lowest DO (4.80$\pm$0.47 mg/dl) was observed at Charty Beach in August 2020 (refer Figure 6 in Appendix).

DO is a direct indicator of an aquatic resource's ability to support aquatic life. The oxygen level in the water will indicate the pollution level of the water. According to scientific studies, the best DO range for supporting marine life is 4 - 9 mg/L (Gupta et al., 2005; Best et al., 2007; Ranaraja et al., 2019; Manage et al., 2022). However, DO concentrations above 5 mg/L are generally considered beneficial to marine life, while concentrations below this are potentially hazardous (Best et al., 2007). The DO level in the current study indicates good clarified water in three locations and is found to be in the ideal optimal range that supports aquatic life. Higher oxygen levels indicate good clarified water, and low oxygen levels indicate highly polluted water (Berthold et al., 2010).

TDS: The study locations' TDS ranged between 26.00 to 35.50 ppt in Mathagal, 26.00 to 34.00 ppt in Point Pedro, and 27.75 to 36.00 ppt in Charty Beach (refer Figure 7 in Appendix). The overall mean value of the TDS for the study period was 31.84$\pm$2.66 ppt. The minimum TDS was recorded in all sampling sites in November 2021, while the maximum value was recorded in September 2021 at both Mathagal and Charty, and in August 2021 at Point Pedro. At the 95% confidence level, TDS did not show significant variance among the sampling locations (Df (2), F = 0.34, $p > 0.05$) while significant variance was shown among sampling months (Df (17), F = 6.70, $p < 0.05$) with respect to the pooled sampled data.

In the present study, TDS had a statistically strong positive correlation with salinity and EC. The TDS varied with the temporal changes. According to the Pearson correlation (refer Table 3), TDS and rainfall had an inverse relationship (r = -0.582, $p = 0.011$). In the present study, the trend of salinity and conductivity showed a similar pattern. It can be explained that when the dissolved solids are increased, ion concentration in the water increases, which increases the conductivity and salinity. The TDS can be elucidated as the presence of inorganic salts and organic matter in seawater that is derived from both anthropogenic and natural sources, including anthropogenic sources such as domestic waste, agricultural runoff, soil contaminant leaching, and discharges from industrial or sewage treatment plants (Yap et al., 2011) and natural sources geological conditions and seawater (Rusydi, 2018).

EC: The EC recorded in the study areas ranged between 42078.78 to 62928.45 μS/cm at Mathagal, 42215.25 to 59760.80 μS/cm at Point Pedro, and 44834.68 to 62181.33 μS/cm at Charty Beach (refer Figure 8 in Appendix). The overall mean conductivity value was 52969.6$\pm$5355.96 μS/cm. When considering the variation of conductivity in seawater, there was no significant difference across the sampling sites (Df = (2), F = 0.42, $p > 0.05$) in the confidence level of 95%. At the same time, there was a significant difference between the mean values of the conductivity during the sampling months (Df = (17), F = 12.40, $p < 0.05$). The minimal EC values were recorded in November 2021 at Point Pedro and Charty, and in December 2020 at Mathagal. The highest EC values were recorded in Mathagal in September 2021, Point Pedro in August 2020, and Charty Beach in August 2021.

EC shows a positive correlation with water temperature, TDS, and salinity. It greatly depends on the dissolved solid content of the waterbody (Ma et al., 2020). Water temperature affects conductivity by increasing the ionic mobility of many salts and minerals. When water temperature increased, the EC also increased in the present study, which is evident through the Pearson correlation (refer Table 3) between EC and rainfall (r = - 0.651, $p = 0.003$). Lower values of EC were recorded during the rainy season and vice versa in the dry season.

4. Conclusion

The vital water quality properties such as water temperature, air temperature, salinity, pH, DO, TDS, and EC were measured for 18 months in the three coastal waters of Northern Sri Lanka. The overall mean values of air and water temperature, pH, salinity, DO, TDS and EC were 29.90$\pm$1.43°C, 31.61$\pm$1.60°C, 8.11$\pm$0.13, 32.57$\pm$2.90 ppt, 6.85$\pm$0.86 mg/dl, 31.84$\pm$2.66 ppt and 52969.6$\pm$5355.96 µS/cm respectively. The pH and DO values in the current study were within the acceptable limit for supporting the aquatic environment and aquatic life. The water quality parameters were changed potentially with the availability of precipitation and evaporation.

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Appendix

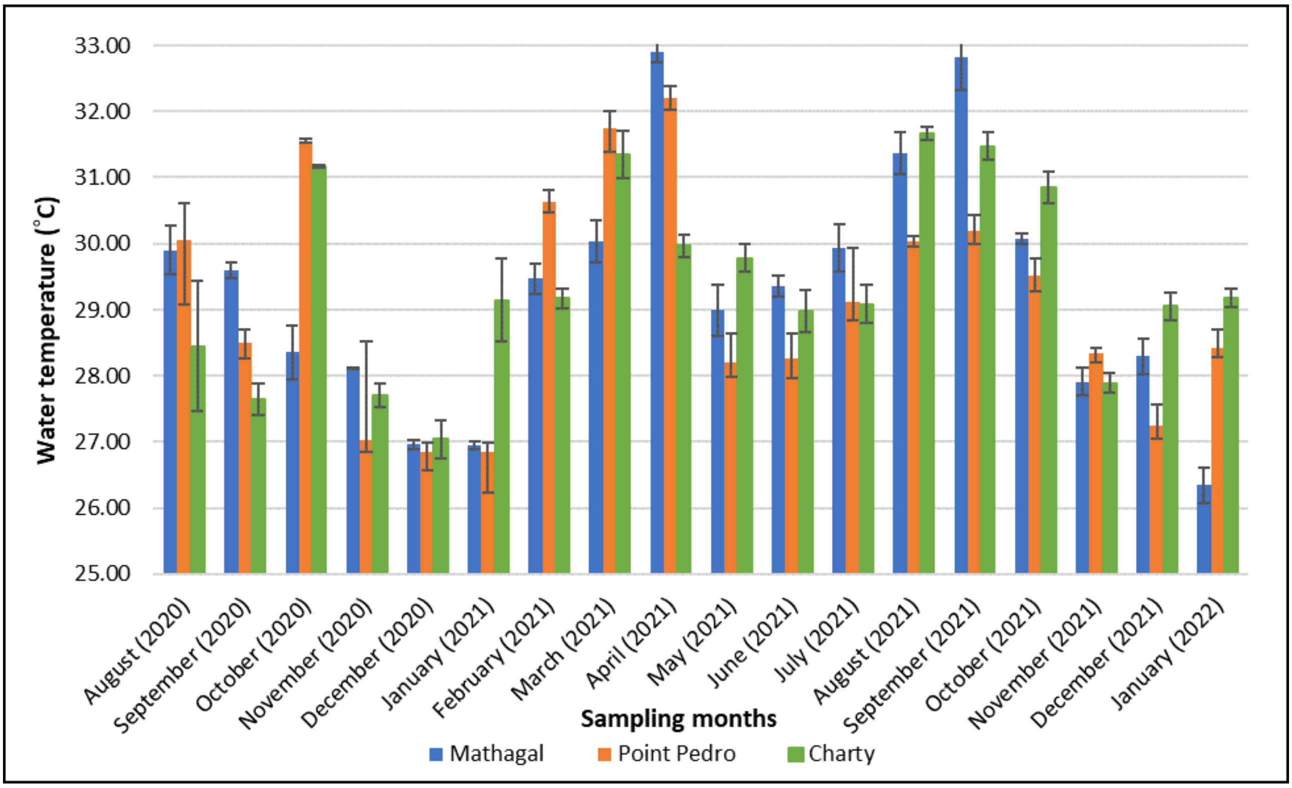

Figure 2: Temporal variation of water temperature among studied sampling sites from August 2020 to January 2022

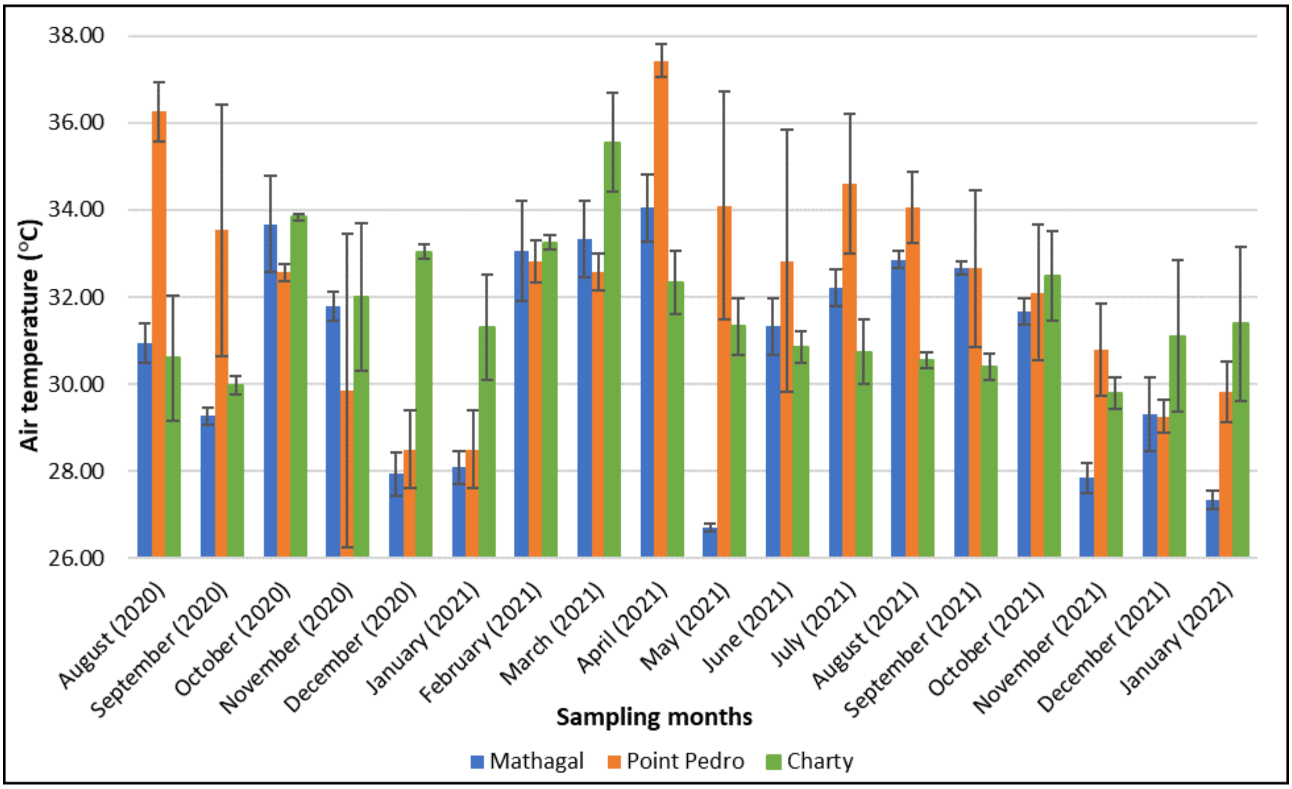

Figure 3: Temporal variation of air temperature among studied sampling sites from August 2020 to January 2022

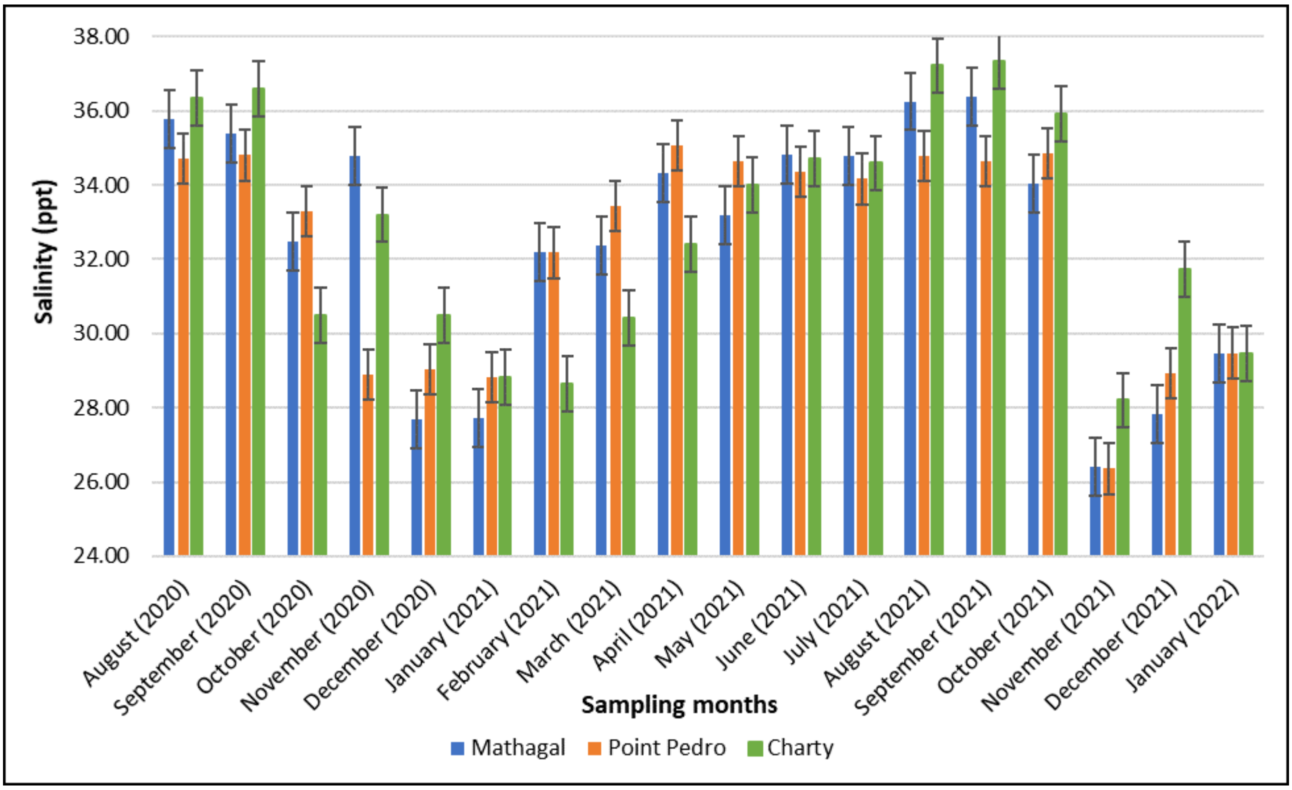

Figure 4: Temporal variation of salinity among studied sampling sites from August 2020 to January 2022

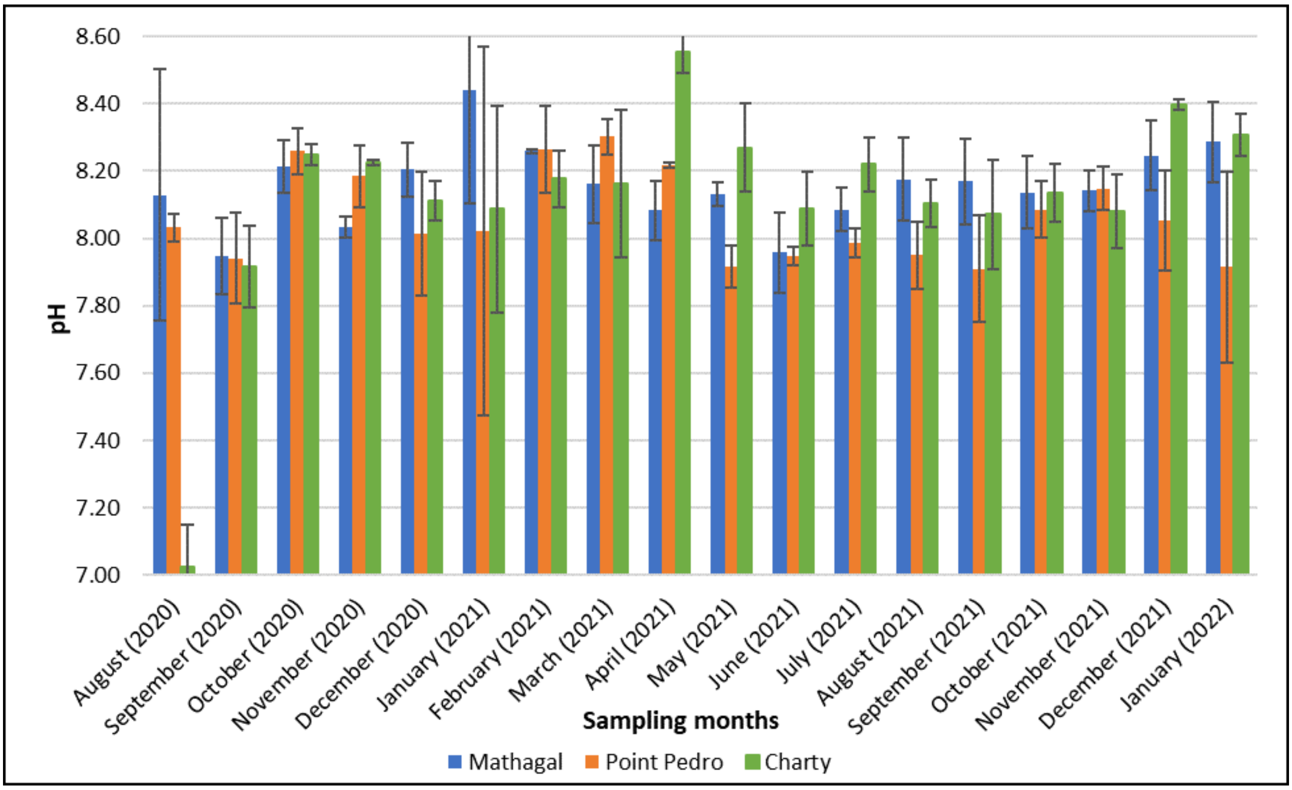

Figure 5: Temporal variation of pH among studied sampling sites from August 2020 to January 2022

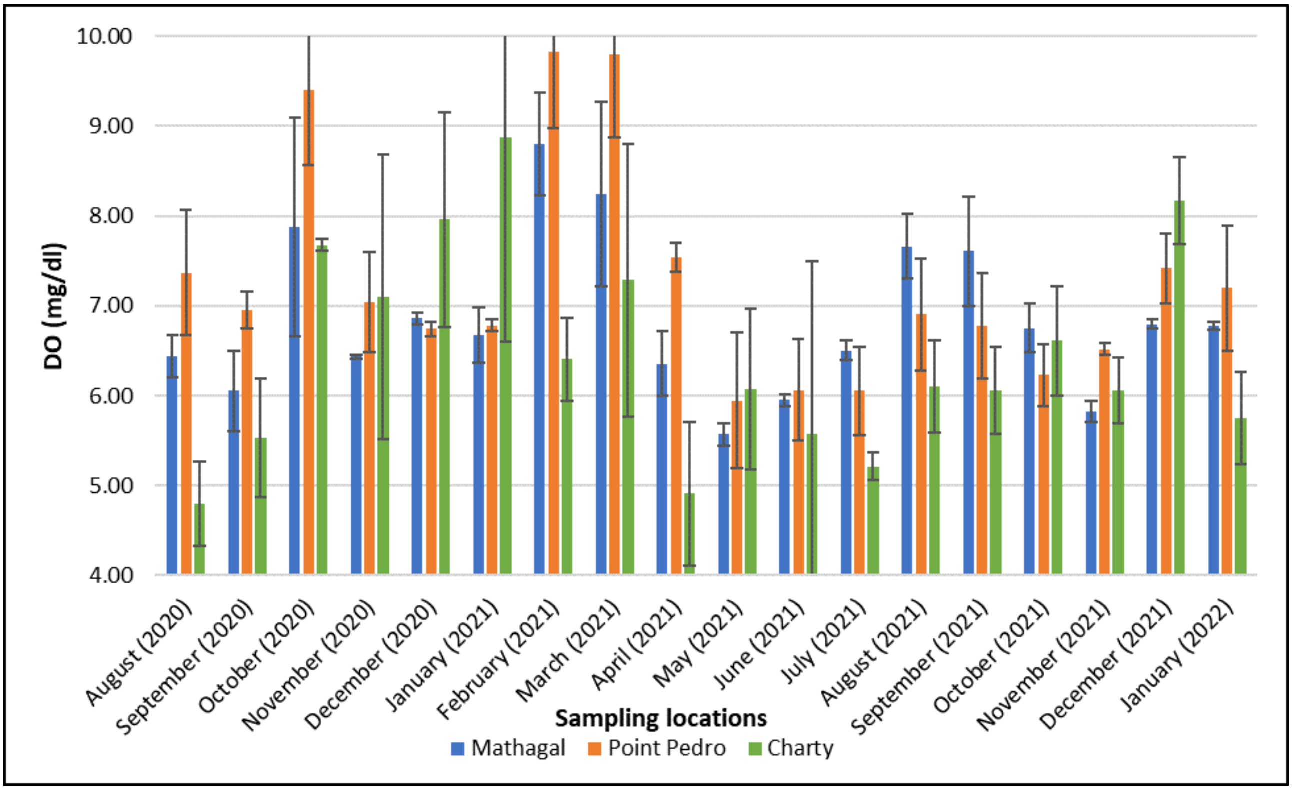

Figure 6: Temporal variation of DO among studied sampling sites from August 2020 to January 2022

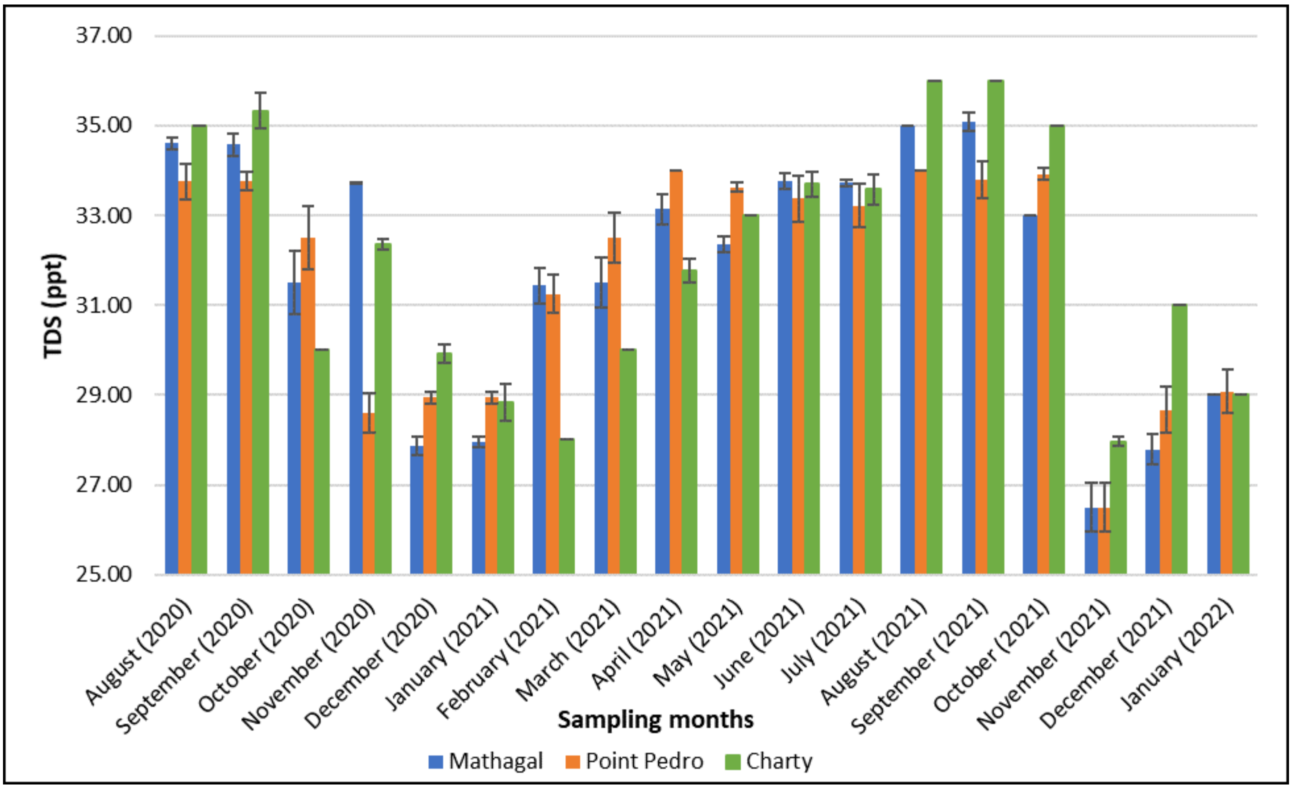

Figure 7: Temporal variation of TDS among studied sampling sites from August 2020 to January 2022

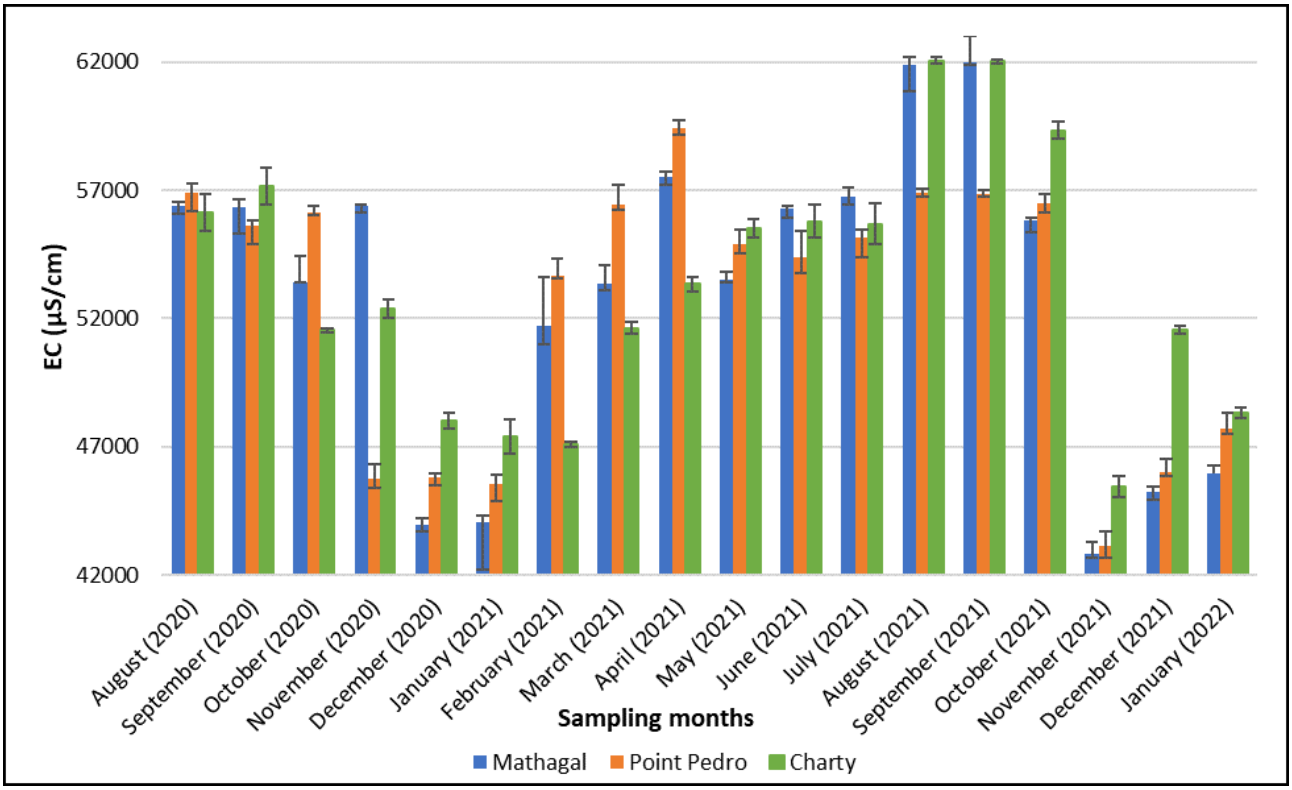

Figure 8: Temporal variation of EC among studied sampling sites from August 2020 to January 2022