Spatial and temporal variation of physicochemical parameters of coastal waters in the southwestern region of Sri Lanka

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Abstract Physicochemical parameters of coastal water in the southwestern area of Sri Lanka were studied from January to November 2016. Surface water samples from 15 selected locations were analysed according to standard methods. The ranges of the values recorded were; water temperature (WT) 26.5-33.9 ºC, pH 7.1-8.4, dissolved oxygen (DO) 4.4-7.4 mg L^{-1}, salinity 14-38 ppt, electrical conductivity (EC) 27.1-53.8 mS cm^{-1}, total suspended solids (TSS) 50.2-403.4 mg L^{-1}, turbidity 1.2-64.9 NTU, nitrate nitrogen (NO_3--N) 0.00-0.57mg L^{-1}, nitrite nitrogen (NO_2--N) 0.00-0.035mg L^{-1}, ammoniacal nitrogen (NH_4+-N) 0.00-1.72mg L^{-1}, dissolved inorganic phosphorous (DIP) 0.00-0.65 mg L^{-1}, biochemical oxygen demand (BOD) 0.1-11.6 mg L^{-1} and chemical oxygen demand (COD) 40-768 mg L^{-1}. Results of Two-way ANOVA showed that there was a seasonal variability in parameters such as water temperature ($p<0.001$), dissolved oxygen ($p<0.001$), BOD ($p<0.001$), COD ($p<0.001$), nitrite nitrogen ($p<0.001$), nitrate nitrogen ($p<0.001$), dissolved inorganic phosphorous ($p<0.001$), turbidity ($p<0.001$), TSS ($p<0.001$) and Chlorophyll *a* ($p<0.001$). Spatial variation was identified in parameters, pH ($p<0.001$), turbidity ($p<0.001$), dissolved oxygen ($p=0.004$) and nitrite nitrogen ($p<0.001$) whereas the interaction between time and location was significant in pH ($p=0.005$) and turbidity ($p=0.007$). However, EC, salinity and ammoniacal nitrogen were not significant by either of the factors of consideration. In conclusion, the physicochemical characteristics of water are highly variable over time and location due to both natural and human factors. Water quality near fish processing areas such as fishery harbours and fish markets relatively deteriorated in terms of pH, DO, turbidity and nitrite nitrogen compared to recreational beaches. It is recommended to regulate any discharges of sewage and industrial wastewater directly into the sea. A long-term coastal water quality monitoring programme is vitally important to comprehensively characterise the coastal segments for a long-term strategic plan for sustainable development.

Keywords: western coastal water, physicochemical parameters, spatial and temporal variations

INTRODUCTION

The relative importance of coastal areas has increased over the years with the development of commercial ports, fishery harbours, transportation, leisure facilities and tourism (BOBLME 2013). Thus, the coastal region is characterized by a higher population density and a higher degree of urbanization than in the rest of the country. Such urban coastal settlements exert intense pressure on the coastal environment and are subjected to degradation. Moreover, development has been particularly intense in coastal areas in the west and southwest of Sri Lanka locating the main commercial city and the development of Colombo and Galle harbours (BOBLME 2013). In addition, the coastal areas of Colombo, Negombo and Kalutara include several fishing villages. In 2018, total contribution to marine fish production of Negombo, Kalutara and Colombo, the major fisheries districts in southwestern region was 76,770 MT (NARA 2018).

The problem of coastal water pollution in Sri Lanka has risen over the past few decades (CZMP 2006; BOBLME 2013). With the increase in population and accelerated economic activities, the western part of the coastal waters of Sri Lanka

receives untreated or partially treated wastewater, toxic substances, discharges of raw sewage and waste oil, fertilizer and agro-chemical runoff and waste from squatter settlements and other domestic sources (Hettige *et al.* 2014; Dissanayake 2009; Bandara *et al.* 2021; Liyanage and Manage 2016; Manage *et al.* 2022). However, maintaining the quality of coastal water along the western coast within an environmentally healthy range is important because it forms the dynamic interface between land and ocean and consists of abundant natural resources. Therefore, continuous monitoring of coastal water quality is vital. In addition, monitoring of the coastal water quality in Sri Lanka has been identified as a requirement to establish suitable coastal water quality standards for designated uses (CZMP 2006).

Physico-chemical parameters of coastal water play an important role in conserving coastal resources which contribute to the sustainability of the marine ecosystems (BOBLME 2013; Sivakumar 2016). Comprehensive studies on marine water pollution are somewhat limited in Sri Lanka. However, past studies have revealed important information on water quality in the coastal and offshore areas around Sri Lanka (Hettige *et al.* 2014; Sivakumar 2016; BOBLME 2013; Manage *et al.* 2022; Bandara *et al.* 2021). According to Hettige *et al.* (2014), during the 2011-2012 period, the biochemical oxygen demand (BOD) values exceeded the maximum permissible limits of the proposed ambient water quality standards for coastal waters. One-year water quality analysis in the coastal sea at 13 locations from Norochcholai to Mirijjawila reported that organic pollution was apparent throughout the year at Beruwala and Unawatuna (Joseph 2003).

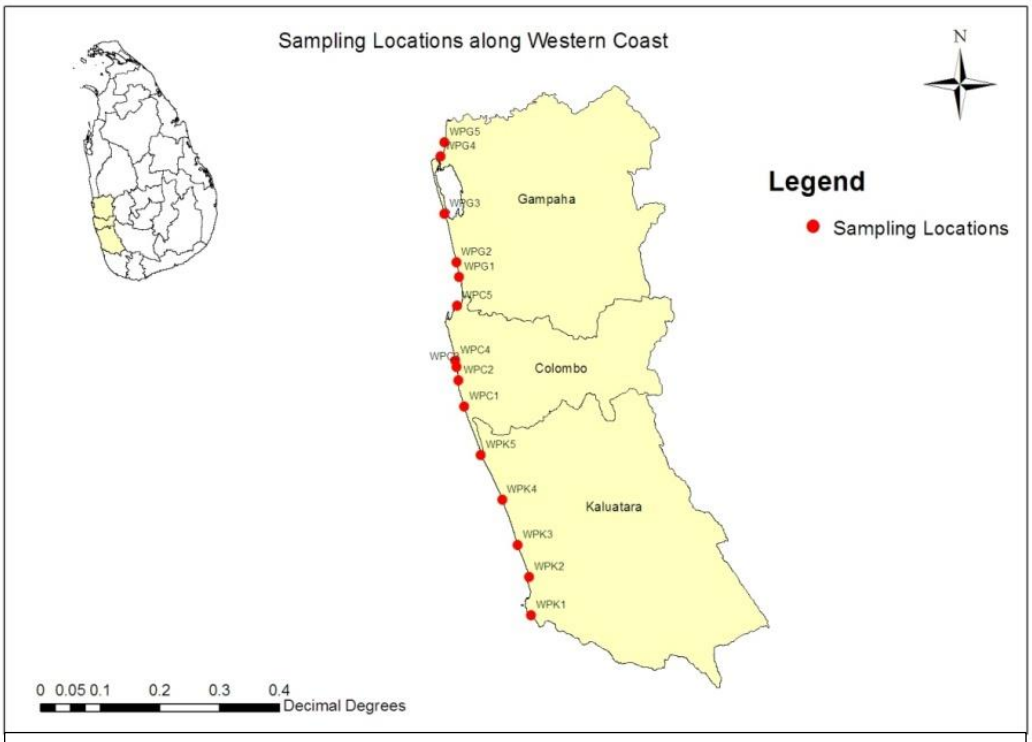
Physico-chemical parameters of lagoons and estuaries on the west coast, such as Negombo and Lunawa lagoons revealed that average COD, BOD, and Mercury (Hg) levels were higher than maximum permissible limits of industrial wastewater discharged into marine and coastal waters (Mendis *et al.* 2015; Mendis *et al.* 2021). Another study in Lunawa lagoon also discovered that BOD, COD, nitrate (NO_3^-) levels in the southern part and, phosphate concentration in the northern part exceeded above standard limits (Jayathunga *et al.* 2018). Pollution of these waters impacts on the important habitats associated with them. High oil and grease content, BOD, TSS, Chlorophyll *a*, ammoniacal-nitrogen, ortho-phosphate and COD values exceeding the standard limits were reported in Beruwala fishery harbour (Chathurani *et al.* 2019). A recent study reported high levels of Tributyl Tin (TBT), which is highly toxic, in the Dikkovita fishery harbour and selected sampling locations from Negombo to Mirissa along the southwestern coastal belt (Manage *et al.* 2022).

Considering the data deficiency of important water quality parameters in marine water, the present study was conducted to study the spatial and temporal variations of water quality in coastal waters in the southwestern region, of Sri Lanka, from January to November 2016. The result will provide baseline data for forthcoming scholarly studies and use to predict ecological responses to future environmental changes.

MATERIALS AND METHODS

Study area

The present study was carried out along a 96 km long stretch in the western coastline of Sri Lanka from Moragalla (6º 26’44.29” N, 79º 59’5.59” E) to Negombo (7º 14’17.52” N, 79º 50’25.50” E). Sampling locations were selected only within the boundary of the Western Province (Kalutara, Colombo, and Gampaha) considering the intense pressure on the coastal environment from this highly urbanized area. The locations included dense communities, industrial areas, recreational beaches, fishery harbours and fishing boat landing sites. The relative sampling locations are illustrated in Figure 1 and special characteristics are described in Table 1.



WPK1 – Moragalla	WPC1 – Lunawa	WPG1 – Dikkovita F. Harbour
WPK2 – Maggona	WPC2 – Mount Lavinia	WPG 2 – Uswetakeiyawa
WPK3 – Katukurunda	WPC3 – Dehiwala	WPG 3 – Pamunugama
WPK4 – Pothupitiya	WPC4 – Wellawatta	WPG 4 – Negombo Fish Market
WPK5 –Panadura	WPC5 –Modara Fishery Harbour	WPG 5– Brownsbeach Negombo

Fig 1 Sampling locations selected for the present study

Table 1 Description of sampling locations

No.	Sampling Locations	District	Coordinates	Site Description	Category
1.	Moragalla (WPK1)	Kalutara	6° 26'44.13" N 79° 59'4.47" E	Benthota river estuary; Moragalla beach is known as the 'Golden Mile'; famous tourist destination; Near Barberyn Reef Beruwala	Recreational
2.	Maggona (WPK2)	Kalutara	6° 30'33.52"N 79° 58'52.51"E	Sea Bathing Site; Nearby poultry farms discharges; Blackish sand; Solid waste found on the beach	Recreational
3.	Katukurunda (WPK3)	Kalutara	6° 33'46.51"N 79° 57'43.14"E	Relatively less anthropogenic activities; Sea covered by a Breakwater; near sea mouth of Kalu river	Less utilized
4.	Pothupitiya (WPK 4)	Kalutara	6° 38'17.97"N 79° 56'9.49"E	A relatively deserted beach; Fishing boat landing site is close by	Fishing boat landing site
5.	Panadura (WPK5)	Kalutara	6° 42'49.30"N 79° 54'0.94"E	Coastal Beach Park; sea bathing; Bolgoda river estuary; Panadura fishery harbour	Recreational
6.	Lunawa (WPC1)	Colombo	6° 47'40.00"N 79° 52'21.24"E	At Lunawa lagoon mouth; Polluted lagoon; Opened artificially by people;	Fishing boat landing site
7.	Mount Lavinia (WPC2)	Colombo	6° 50'16.25"N 79° 51'45.59"E	Very famous tourist destination; sea bathing	Recreational

8.	Dehiwala (WPC3)	Colombo	6° 51'37.20"N 79° 51'33.76"E	Bordered by several mini-tourist restaurants and coastal dwellings;	Recreational
9.	Wellawatta (WPC4)	Colombo	6° 52'15.86"N 79° 51'28.59"E	Recreational activities; solid waste on the beach	Recreational
10.	Modara (WPC 5)	Colombo	6° 57'47.26"N 79° 51'38.47"E	Near the fishery harbour; receives a high load of domestic sewage and other organic waste; West to the Kelani River mouth	Fishery harbour
11.	Dikkowita (WPG1)	Gampaha	7° 0'37.42"N 79° 51'52.09"E	Near Dikkovita fishery harbour; Southeast Asia's largest fishery harbour;	Fishery harbour
12	Uswetakeiyawa (WPG 2)	Gampaha	7° 2'5.17"N 79° 51'34.07"E	Famous place for sea bathing; the Shallow tank is made from a breakwater; Solid waste on the beach	Recreational
13	Pamunugama (WPG 3)	Gampaha	7° 6'58.05"N 79° 50'23.88"E	Solid waste accumulated; Fishing boat landing site;. Breakwater parallel to the beach	Fishing boat landing site
14	Negombo (WPG4)	Gampaha	7° 12'43.80"N 79° 49'59.00"E	Fish offal and wastewater discharged to sea; beach seines operate on the shore; solid waste on beach	Fish and Dry fish processing
15	Negombo Beach Park (WPG5)	Gampaha	7° 14'10.10"N 79° 50'22.70"E	Known as 'Brown's beach'. Famous tourist destination.	Recreational

Sample collection

Overall, 165 surface coastal water samples from 15 selected locations (Figure 1) were collected monthly from January to November (11 months) 2016 for physico-chemical measurements. The collected water samples were stored in a refrigerator at four degree Celsius until analysis.

Water quality analysis

Water quality analysis was performed according to Standard Methods for the Examination of Water and Wastewater (22nd Edition) published by American Public Health Association (APHA 2012). Water temperature, pH, Electrical Conductivity (EC), salinity, turbidity and dissolved oxygen (DO) were measured on-site using standard portable meters. Water temperature and pH were measured using EUTECH Cyber Scan 600 pH/mV Meter. YSI ProODO Optical Dissolved Oxygen Meter, HANNA HI-8633N Multi-range Conductivity Meter, and EUTECH digital turbidity meter were used to obtain dissolved oxygen, conductivity, salinity and turbidity values in water respectively.
Water samples were filtered through a weighed standard Whatmann grade (GF-C) filter paper with 0.45µm pores size prior to analysing nutrients. The residue retained on the filter was dried to a constant weight at 103°C to 105°C, thus calculated the Total Suspended Solids (TSS). Colorimetric methods were used to determine NH_4^+–N (4500-NH3 F Phenate method), NO_3-_N(4500 E Cd Reduction Method), NO_2^--N(4500 B Colorimetric method NED/Sulphanilamide) and DIP (4500–P E Ascorbic acid method). The Modified Winkler method was used to determine the 5-day Biochemical Oxygen Demand (BOD). Chemical Oxygen Demand (COD) was tested using the Closed Reflux Digestion Method whereas Chlorophyll *a* concentration was measured using the method 10200 H Chlorophyll (APHA 2012).

Statistical Analysis

The Two-way ANOVA test and Tukey's method for pair-wise comparisons were used in MINITAB 17 package in order to identify variations in terms of locations and monsoon seasons. Monsoon and Inter-monsoon seasons were considered for temporal variation thus; January-February (Northeast monsoon-4), March-April (First inter-monsoon-1), May-September (Southwest monsoon - 2), October-November (Second inter-monsoon-3).

RESULTS AND DISCUSSION

The summary results of the physicochemical parameters in different monsoon seasons during the entire study period (11 months) are given in Table 2.

Table 2 Mean of physico-chemical parameters of coastal water according to season

Parameter	Northeast monsoon Mean ± SD (Min.-Max.)	First inter- monsoon Mean ± SD (Min.-Max.)	Southwest monsoon Mean ± SD (Min.-Max.)	Second inter-monsoon Mean ± SD (Min.-Max.)	Standard Limit*
Water Temp. (ºC)	29.8±1.3 (26.9-32.8)	32.1±0.8 (30.6-33.9)	29.3±0.8 (26.5-31.5)	30.3±1.1 (27.9-32.8)	< 32
pH	8.0±0.1 (7.7-8.2)	8.1±0.1 (7.7-8.2)	8.0±0.2 (7.1-8.4)	8.0±0.3 (7.1-8.3)	7.0-8.5
Dis. Oxygen (mg/l)	6.7±0.4 (5.8-7.4)	6.3±0.4 (5.1-7.0)	6.4±0.5 (4.4-7.3)	6.9±0.5 (5.0-7.4)	> 80%
Elec. Cond. (µS/cm)	49.9±4.3 (33.7-52.5)	49.9±4.4 (28.6-52.7)	46.5±9.1 (7.1-53.8)	48.4±4.3 (34.0-52.6)	-
Salinity (ppt)	33.1±2.9 (33.1 – 2.9)	32.6±2.8 (20.0-36.0)	31.3±5.8 (14.0-38.0)	32.3±3.4 (24.0-36.0)	< 10% N**
Turbidity (NTU)	6.1±5.4 (1.7-28.9)	8.2±6.0 (1.7-26.7)	13.5±12.5 (2.9-64.9)	5.9±3.4 (1.2-16.8)	-
Biochemical Oxygen Demand	4.7±2.8 (0.5-11.6)	2.8±1.7 (0.2-6.5)	2.5±1.8 (0.1-10.0)	2.6±2.0 (0.2-7.2)	< 2
Chemical Oxygen Demand	188.9±61.9 (108-328)	297.4±157.2 (120-768)	309.1±133.2 (106-576)	392.5±153.7 (148-704)	-
Ammoniacal nitrogen (mg L^{-1})	0.048±0.06 (0.002–0.29)	0.085±0.16 (0.001-0.85)	0.125±0.210 (0.016-1.72)	0.088±0.106 (0.001-0.58)	< 0.4
Nitrite nitrogen (mg L^{-1})	0.003±0.003 (<0.001-0.01)	0.004±0.004 (<0.001-0.02)	0.007±0.006 (0.001-0.03)	0.004±0.004 (0.001-0.02)	-
Nitrate nitrogen (mg L^{-1})	0.015±0.041 (<0.001– 0.22)	0.029±0.05 (0.002-0.27)	0.062±0.08 (0.001-0.57)	0.009±0.007 (0.001-0.04)	-
Diss. Inorganic Phosphorous (mg L^{-1})	0.015±0.016 (<0.001-0.07)	0.035±0.118 (<0.001-0.65)	0.051±0.069 (0.001-0.38)	0.166±0.15 (0.016-0.49)	-
Total Suspended Solids (mg L^{-1})	104.3±35.4 (50.2-159.4)	174.5±47.6 (99.2-243.5)	188.8±78.4 (82.0-403.4)	107.2±26.6 (52.5-146.8)	N**
Chlorophyll-*a* (µg/l)	1.17±1.02 (0.1-4.1)	2.74±2.18 (0.41-7.33)	3.42±2.34 (1.17-8.83)	6.0±3.6 (1.3-13.9)	-

*Proposed quality standards for different use classes of coastal water in Sri Lanka. **Natural condition.

According to the summarized results in Table 2, the mean value of BOD_5 exceeds the limits of 'Proposed quality standards for different use classes of coastal water in Sri Lanka' indicating organic pollution.

Spatial and Temporal Variation in physicochemical parameters

The Two-way ANOVA results revealed a statistically significant difference in average pH by the effect of location (F=5.19, p<0.001) and the interaction between location and monsoonal season (F=1.87, p<0.005) whereas, average turbidity variation was statistically significant by all three factors thus, the effect of location (F=3.61, p =<0.001), monsoonal season (F=13.59, p =<0.001) and interaction between the two (F=1.84, p = 0.007) (Table 3). Thus, turbidity in water was identified as the only parameter with a major variability in terms of monsoonal season, sampling location, and the interaction between the two factors. None of the

other parameters were statistically significant by the interaction between the location and season (Tables 3 and 4). In addition, means of dissolved oxygen and nitrite nitrogen were significantly different by both seasonal (p =<0.001) and location (p =<0.001) effects.

Table 3 Two-way ANOVA results 1

Dependent Variable	Independent Variables	DF	F value	p value
pH	Monsoonal Season (MS)	3	1.16	0.327
	Location (L)	14	5.19	<0.001*
	MS*L	42	1.87	0.005*
Turbidity	Monsoonal Season (MS)	3	13.59	<0.001*
	Location (L)	14	3.61	<0.001*
	MS*L	42	1.84	0.007*
Dissolved Oxygen (DO)	Monsoonal Season (MS)	3	10.2	<0.001*
	Location (L)	14	2.51	0.004*
	MS*L	42	0.54	0.987
Nitrite nitrogen	Monsoonal Season (MS)	3	6.43	<0.001*
	Location (L)	14	3.47	<0.001*
	MS*L	42	0.91	0.626

Dissolved oxygen and nitrite nitrogen were significantly different in terms of monsoonal season and location. Moreover, mean values of water temperature (F=62.49, p<0.001), BOD_5 (F=7.15, p<0.001), COD (F=9.92, p = <0.001), nitrate nitrogen (F=7.64, p<0.001), dissolved inorganic phosphorous (F=14.55, p<0.001), total suspended solids (F=18.20, p<0.001) and Chlorophyll *a* (F=14.46, p<0.001) showed statistically significant difference only by the effect of the monsoonal season (Table 4). However, mean values of electrical conductivity, salinity and ammoniacal nitrogen had no variation by the factors of consideration.

Table 4 Two-way ANOVA results 2

Dependent Variables	Independent Variables	DF	F value	P value
Water Temperature (WT)	Monsoonal Season (MS)	3	62.49	<0.001*
	Location (L)	14	2.13	0.015
	MS*L	42	1.00	0.488
BOD_5	Monsoonal Season (MS)	3	7.15	<0.001*
	Location (L)	14	0.51	0.920
	MS*L	42	0.44	0.998
COD	Monsoonal Season (MS)	3	9.92	<0.001*
	Location (L)	14	0.72	0.747
	MS*L	42	0.48	0.996
Nitrate nitrogen	Monsoonal Season (MS)	3	7.64	<0.001*
	Location (L)	14	1.20	0.286
	MS*L	42	0.52	0.990
Dissolved phosphorous	Monsoonal Season (MS)	3	14.55	<0.001*
	Location (L)	14	1.38	0.178
	MS*L	42	0.59	0.974
Total Suspended Solids	Monsoonal Season (MS)	3	18.20	<0.001*
	Location (L)	14	0.25	0.997
	MS*L	42	0.42	0.999
Chlorophyll *a*	Monsoonal Season (MS)	3	14.46	<0.001*
	Location (L)	14	0.87	0.591

Temporal variation:

Seasonal variations of each parameter were revealed from the results of Tukey's post-hoc test. Accordingly, mean water temperatures in the first inter-monsoon and southwest monsoon were significantly different from each other and from the mean value of the other two seasons. Conversely, no major differences were reported in average pH between the four seasons. The average dissolved oxygen in the first inter-monsoon and southwest monsoon were different significantly from that of the other two seasons. Further, the mean turbidity of the southwest monsoon was significantly high compared to the other three seasons thus average BOD and COD in the northeast monsoon were significantly different from the respective values recorded in other seasons (Table 5).

In addition, NO_3^--N and NO_2^--N in the second inter-monsoon and northeast monsoon were significantly different from those during the southwest monsoon. Similarly, TSS in the second inter-monsoon and northeast monsoon was significantly different compared to the other two seasons. Results further revealed a significantly high average DIP and Chlorophyll *a* in the second inter-monsoon.

Table 5 Tukey's pairwise comparison results between different rainfall seasons

Parameter	First Inter-monsoon	Southwest monsoon	Second Inter-monsoon	Northeast monsoon
W. Temp.	32.12^{a}	29.31^{c}	30.30^{b}	29.80^{b}
Turbidity	8.16^{b}	13.47^{a}	5.92^{b}	6.07^{b}
DO	6.34^{b}	6.36^{b}	6.87^{a}	6.69^{a}
TSS	174.5^{a}	188.8^{a}	107.2^{b}	104.3^{b}
N-NO_3^-	0.029^{ab}	0.062^{a}	0.009^{b}	0.015^{b}
N-NO_2^-	0.004^{ab}	0.007^{a}	0.004^{b}	0.003^{b}
Dis. Inor. PO_4^{3-}	0.034^{b}	0.050^{b}	0.166^{a}	0.015^{b}
BOD	2.79^{b}	2.50^{b}	2.60^{b}	4.67^{a}
COD	297.4^{ab}	309.1^{b}	392.5^{a}	188.9^{c}
Chlorophyll *a*	2.75^{b}	3.06^{b}	6.08^{a}	1.11^{b}

Spatial Variation

There was no major difference in mean water temperature among sampling locations. Considering the Tukey's test results, sampling locations WPK3 (Katukurunda) and WPK5 (Panadura) were significantly different from WPG1 (Dikkovita harbour) and WPC5 (Modara fishery harbour) in terms of pH. Mean dissolved oxygen in 10 sampling locations was significantly different from WPG1 (Table 6). The average turbidity of WPG4 (Negombo fish market) was significantly higher than in other locations and the interaction between season and location of turbidity was significantly different during the southwest monsoon in several locations such as WPK2, WPC1, WPC4, WPG1, WPC3 and WPC2. Nitrite nitrogen in WPC5 (Modara fishery harbour) was reported significantly higher than in nine other locations along Colombo and Kalutara coastal lines.

Table 6 Tukey's pairwise comparison results among sampling locations

Location	pH	Dissolved Oxygen	Turbidity	N-NO_2^-
WPK1	8.07^{ab}	6.88^{a}	5.60^{abc}	0.004^{b}
WPK2	8.06^{ab}	6.64^{a}	15.40^{ab}	0.003^{b}
WPK3	8.12^{a}	6.61^{a}	11.11^{abc}	0.003^{b}
WPK4	8.12^{ab}	6.62^{a}	9.19^{abc}	0.003^{b}
WPK5	8.13^{a}	6.67^{a}	7.45^{abc}	0.002^{b}
WPC1	8.06^{ab}	6.52^{ab}	5.67^{abc}	0.003^{b}
WPC2	8.09^{ab}	6.63^{a}	4.61^{bc}	0.003^{b}
WPC3	7.99^{ab}	6.73^{a}	3.74^{c}	0.003^{b}
WPC4	7.97^{ab}	6.74^{a}	4.38^{bc}	0.004^{b}
WPC5	7.67^{c}	6.40^{ab}	10.50^{abc}	0.011^{a}
WPG1	7.86^{bc}	5.80^{b}	4.54^{bc}	0.008^{ab}
WPG2	8.07^{a}	6.74^{a}	6.62^{abc}	0.005^{ab}
WPG3	8.11^{a}	6.55^{ab}	6.11^{bc}	0.003^{b}
WPG4	7.97^{a}	6.34^{a}	16.43^{a}	0.007^{ab}
WPG5	8.06^{a}	6.67^{a}	14.74^{abc}	0.007^{ab}

Items with different superscripts indicate significant difference

DISCUSSION

All physico-chemical parameters except electrical conductivity, salinity and ammoniacal nitrogen were either temporally or spatially variable. Parameters that were directly affected by rainfall and stormwater runoff namely water temperature, dissolved oxygen, turbidity, and total suspended solids showed statistically significant deviations in the southwest monsoon that provided the highest rainfall for the selected area during the study period as similar to the previous results obtained by Hettige *et al*. 2014. Sewage, fertilizer, and agrochemicals are generally mixed with runoff water and finally, come into coastal water during rain. Therefore, nitrate nitrogen, nitrite nitrogen, dissolved inorganic phosphorus, BOD and COD parameters showed significant differences among seasons.

Higher BOD values recorded at Pamunugama (11.6 mg L^{-1}), Negombo fish market (11.2 mg L^{-1}) and Negombo beach park (11.1 mg L^{-1}) (Locations: WPG3, WPG4, WPG5) in January 2016 might be due to discharges into coastal waters from fishery-related activities and hotel effluents. Further, Hettige *et al.* (2014) also recorded higher BOD values (Highest average: 16.50±1.38 mg L^{-1}); in this area, and effluents from fishing activities were identified as the leading cause of organic pollution. The lowest BOD was recorded at Moragalla recreational beach in Kalutara in August 2016, having similar results obtained by Hettige *et al.* (2014).

CONCLUSIONS

In conclusion, physico-chemical characteristics of water are highly variable over space and time due to both natural and human factors. Water temperature, turbidity, dissolved oxygen, nitrite nitrogen, nitrate nitrogen, dissolved inorganic phosphorous, biochemical oxygen demand, chemical oxygen demand, total suspended solids and Chlorophyll *a* were significantly different across four monsoon seasons. Meanwhile, parameters such as pH, turbidity, dissolved oxygen and nitrite nitrogen revealed a spatial variation among sampling locations. However, a significantly different interaction between location and season was revealed in turbidity and pH. Thus, coastal water quality near fish processing areas such as fishery harbours and fish markets deteriorated relatively in terms of pH, DO, turbidity and nitrite nitrogen, compared to recreational beaches.

RECOMMENDATIONS

It is recommended to regulate any discharges of sewage and industrial wastewater directly into the sea. A comprehensive characterization of natural coastal water quality requires a large amount of data acquired over a long period. Hence, a detailed observation programme of all aspects of water quality parameters is necessary for coastal water around the country.

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REFERENCES

APHA, AWWA, WEF 2012. Standard Methods for examination of water and wastewater. 22nd ed. Washington: American Public Health Association. 1360 p. ISBN 978-087553-013-0

Bandara, K.R.V., S.D.M. Chinthaka, S.G. Yasawardene & P.M. Manage 2021. Modified, optimized method of determination of Tributyltin (TBT) contamination in coastal water, sediment and biota in Sri Lanka. Marine Pollution Bulletin 166: 112202. https://doi.org /10.1016/j.marpolbul.2021.112202

Chathurani, S.H.U., R.R.M.K.P. Ranatunga, A.A.D. Amarathunga, N.D. Hettige & K.A.W.S. Weerasekara 2019. Present status of the water quality in Beruwala fishery harbour, Sri Lanka. Proceedings of Scientific Sessions, National Aquatic Resources Research and Development Agency (NARA), Colombo. pp. 46.

Coastal Zone Management Plan 2006. 'Sri Lanka Coastal Zone Management Plan', Amendment under the Section 12(5) of the Coast Conservation Act No. 57 of 1981

Dissanayake, D.M.P.S. 2009. A comparative study of plankton composition and water quality of coastal waters in some selected coastal locations of Sri Lanka. M.Sc.Dissertation, Master of Science in Fisheries and Aquatic Resources Management, University of Sri Jayewardenepura.

Hettige, N. D., K.A.W.S. Weerasekara, S.A.M. Azmy & K.B.S.N. Jinadasa 2014. Water pollution in selected coastal areas in western province, Sri Lanka: a baseline survey. Journal of Environmental Professionals Sri Lanka 3(2): 12-24.

Jayathunga, J.N.D., R.U.K. Piyadasa & G.R.A.G. Kumari 2018. Assessment of surface water quality by evaluating the physico-chemical parameters and identify the impacts of water pollution. The International Journal of Science and Technology 6(8): 984-994.

Joseph, L. 2003. National Report of Sri Lanka on the Formulation of a Transboundary Diagnostic Analysis and Strategic Action Plan for the Bay of Bengal Large Marine Ecosystem Programme. Bay of Bengal Large Marine Ecosystem Programme. 115 p.

Liyanage, G.Y. & P.M. Manage 2016. Isolation and characterization of oil degrading bacteria from coastal waters and sediments from three locations in Sri Lanka. Journal of the National Science Foundation of Sri Lanka 44(4): 351–358. DOI: http://doi.org/10.4038/ jnsfsr. v44i4.8017

Manage P.M., G.Y. Liyanage, I. Abinaiyan, D.A.T. Madusanka & K.R.V. Bandara 2022. Pollution levels in Sri Lanka's west-south coastal waters: Making progress toward a cleaner environment. Regional Studies in Marine Science 51: 102193. https://doi.org/10.1016/j.rsma.2022.102193

Mendis, B.R.C., M.M.M. Najim, H.M.P. Kithsiri & S.A.M. Azmy 2015. Assessment of water quality and identification of pollution status of Negombo estuary in Sri Lanka. Proceedings of the Twenty-first Scientific Sessions of the Sri Lanka Association for Fisheries and Aquatic Resources, May, 2015. Sri Lanka Association for Fisheries and Aquatic Resources, Colombo, Sri Lanka. pp.39.

Mendis, B.R.C., M.M.M. Najim & H.M.P. Kithsiri 2021. Assessment of current water pollution status and accumulation of trace metals in *Mugil cephalus* from Negombo estuary. Sri Lankan Journal of Technology 2(1): 30-38.

National Aquatic Resources Research and Development Agency (NARA) 2018. Fisheries Industry Outlook, NARA, Colombo. pp 2-4.

National Environmental (Protection and Quality) Regulations 2008. Tolerance limits for industrial and domestic waste discharged into marine coastal areas in Sri Lanka, No. 1 of 2008, schedule I, List III