Statistical Elucidations of The Seasonal Ambience of Physicochemical Characteristics of Coastal Waters Around South Andaman, India

Venkatesan Shiva Shankar (shivashankarvj@gmail.com)
Department of Coastal Disaster Management Pondicherry University https://orcid.org/0000-0002-0126-3756
Neelam Purti
Department of Environment and forest, Manglutan Range, South Andaman Forest Division
Dharanirajan Kesavan
Department of Coastal Disaster Management, Pondicherry University
Pm Mohan
Department of Ocean Studies and Marine Biology, Pondicherry University
Narayani Subramanian
Department of Ocean Studies and Marine Biology, Pondicherry University
Thanamegam Kaviarasan
Department of Marine Sciences, Bharathidasan University
Murugaiah Santhosh Gokul
Department of Marine Sciences, Bharathidasan University
Padmavati Gadi
Department of Ocean Studies and Marine Biology, Pondicherry University
Satyakeerthy Thonduparambil Ravindaran
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Abstract

The coastal areas of Port Blair in Andaman are threatened by severe water pollution due to the human settlements in these regions. The objective of this study was to determine the level of pollution in ten different anthropogenically dynamic coastal regions by assessing the seasonal variations of various physicochemical characteristics. The regions selected for this study were Burmanallah (BA), Carbyn's Cove (CC), Chattam (CH), Flat Bay (FB), HADDO Harbour (HH), Junglighat Bay (JB), Minne Bay (MB), Phoenix Bay (PB), Sisostris Bay (SB) and Wandur (WA) in South Andaman. The study was carried out from January 2018 to December 2018 to investigate seasonal variations in the physicochemical parameters such as pH, temperature, salinity, dissolved oxygen, nitrite, nitrate, ammonia, silicate, phosphate, and chlorophyll-α using multivariate statistical analysis. Statistical analyses suggest that the regions of JB and MB were highly polluted while, BA, CC, FB, and WA were the least polluted. Landuse and land cover analysis of the study area further facilitated and supported the multivariate statistical results.

Introduction

Coastal frontiers have been encroached on by human settlements since times immemorial due to the availability of rich resources and for logistical reasons as well. They are also the most vulnerable part of marine ecosystems (Jickells, 1998; Coskun et al. 2008; Jha et al. 2015a). Currently, 40% of the global population lives within 100 km of the coasts with an average population density of 80 persons/km^2, which is twice the world's average population density. This has been estimated to almost double by the year 2025 (Zhenghua et al. 2010; Joseph et al. 2012). The contamination of coastal waters by anthropogenic activities is a global concern (Beatley, 1991; Vitousek et al. 1997; Snelgrove, 1999; Sahu et al. 2013; Jha et al. 2015a). Population growth and urbanization together with related human activities are responsible for the deterioration of diversity of the world's ecosystem (Lovejoy, 1997; Crossland, et al. 2005, Patterson and Hardy, 2008; Dsikowitzky et al. 2016).

India, being a country in Asia with the second largest population enjoys high rainfall and tropical climate leading to excessive discharge of pollutants, such as domestic wastes compared to other regions of the world. This has a deleterious impact on the health of the coastal waters (Shahidul and Tanaka, 2004; Dunn, et al. 2012; Gokul et al. 2018). Thus, physicochemical parameters such as temperature, salinity, pH dissolved oxygen, nitrite (NO_2-N), nitrate (NO_3-N), ammonia (NH_3-N), silicate (SiO_3), phosphate (PO_4-P), and biological (chlorophyll-*a*) parameters are the indicators of the quality and health of the coastal waters (Conley, 2000; Sargaonkar and Deshpande, 2003; Jha et al. 2015b). The increased concentration of nutrients results in the decline of water quality (Shahidul and Tanaka, 2004) consequently resulting in the reduction of dissolved oxygen (Sanchez et al. 2007).

The coastal waters of Andaman and Nicobar Islands (ANI's) are experiencing higher rates of pollution owing to anthropogenically influenced activities and surface land runoff contaminating the pristine marine flora and fauna (Dheenan et al. 2014; Renjith et al. 2015). Nutrients from the domestic and urban sources are being drained into the coastal waters of South Andaman (Renjith et al. 2015). There are no sewage treatment plants in ANI's, so the contaminants are directly discharged into the adjacent sea through the nallahs. Nallahs are conduits of both rain runoff and sewage. South Andaman is the most populated and polluted maritime district of ANI's (Union Territory of India) as it houses the capital "Port Blair" and is the center for ANI's activities. This region being the capital is home to more than half of the island's population i.e. 1,44,418 with an urban population density of 4,402 individuals/sqkm (Census of India, 2011). Previous studies on the water quality parameters in ANI's are enumerated in Table 1.

Materials And Methods

2.1. Study Area

The study area between 11°27'00" and 11°45'00" N and 92°30'00" and 92°46'47" E, (Fig. 1), enjoys a tropical climate with an average annual rainfall of 3074.3 mm during 143 rainy days. The majority of rainfall (76.35%) is received during the Southwest Monsoon-SWM (May to September) followed by 22%, during a short spell of the Northeast Monsoon-NEM (October- December) and a dry spell during Pre-monsoon-PM, from January to April (1.64%). However, scanty rainfall is received by the study area during the dry spells of pre-monsoon (Fig. 2). The area chosen for this present study is around the capital of ANI's, is lined with sensitive and fragile wetland ecosystems such as seagrasses, mudflats, sandy beaches, and mangrove forests. It also has a tropical evergreen, semi-evergreen, and moist-deciduous forest with exuberant biodiversity and productivity.

2.2 Study design and sampling site description

The land use land cover (LULC) and sampling locations of the study are portrayed in the map (Fig. 1). The selected ten sampling sites were Chatham (CH), HADDO Harbour (HH), Phoenix Bay (PB), Sistoris Bay (SB), Junglighat Bay (JB), Minne Bay (MB), Flat Bay (FB), Wandur (WA), Carbyn's Cove (CC) and Burmanallah (BA). Out of the ten sites, WA, FB, and BA sites were less stressed by external factors. The remaining seven sampling locations are covered under densely populated Port Blair Municipal Council (PBMC) which releases sewage and other contaminants into the adjacent sea through various discharge outlets and drainage channels (Sarma et al. 2013). As per the Census of India (2011) urban and rural populations of south Andaman were estimated as 4,402 persons/sq.km and 37 persons/sq.km, respectively.

Contaminants like domestic sewage, apart from the wastes of the sawmill in Chatham (CH) drain into the adjacent sea. Haddo Harbour (HH) is the major harbor in ANI's and it shares space with the Indian Naval wharf. It is the busiest harbor as the mainland bound passenger vessels, cargo vessels, and oil tankers berth here. Apart from this, the surrounding area is densely populated. Huge quantities of pollutants are fed into the coastal waters due to the frequent movement of vessels and wastes from the dense human population. Phoenix Bay (PB) hosts inter-island transportation services and the surrounding hinterland is densely populated thus emptying its domestic sewage into the Bay. Sistoris Bay (SB) receives large amounts of anthropogenic wastes and sewage discharges. Junglighat Bay (JB) is a major fish landing center housing a dense fishing community thus discharging domestic sewage, fish trash in the coastal waters of the Bay. Minne Bay (MB) has the waste dump yard of Indian Naval residential quarters. Natural rivulets like Dhanikhari nallah, Mittakhari nallah and Ograbranj nallah drain into station Flat Bay (FB). Carbyn's Cove (CC) a pocket sandy beach is the most visited destination by both regional and international tourists. Another similar tourist destination is Wandur (WA) whose coastal waters are not as much stressed by anthropogenic activity unlike Carby's cove and also Wandur nallah drains station WA. The coastal waters of Burmanallah (BA) are polluted by the rural population in its local proximity.

2.3. Sample collection, preparation and analysis

Mid-day surface seawater samples were collected from the ten sites every month for a span of a year (January 2018 to December 2018). In each site, triplicate samples were collected for 12 months in a sterile polyethylene bottle. Parameters like pH, temperature, and salinity were recorded as *in-situ* measurements. The pH meter (OAKTON) with 0.000 accuracy was used, it had been calibrated with pH buffers (4 or 10). Standard Celsius Thermometer with 0.1°C accuracy was used for measuring temperature and a hand-held Refractometer (ATAGO) was used for measuring salinity.

In total three liters of water samples were collected for nutrient analysis, dissolved oxygen, and chlorophyll-*a*. Samples were collected separately, fixed by Winkler's reagent and acetone 90% for DO assessment Winkler (1888) and the standard protocol was adhered for measuring chlorophyll-*a* (Parsons et al. 1992). The labeled water samples were refrigerated for further analysis. Millipore filtering system was used to filter the water samples which were later analyzed for nitrite (NO_2-N), nitrate (NO_3-N), phosphate (PO_4-P), silicate (SiO_3), and ammonia (NH_3-N) by adhering to standard analytical procedures as illustrated by (APHA, 1992; Clesceri et al. 1998; Grasshoff et al. 1999). The titrimetric method (Winkler method) was adopted for measuring the dissolved oxygen as modified by Strickland and Parsons (1972) and 90% acetone method, for measuring chlorophyll-*a* spectrophotometrically (Strickland and Parsons, 1972). The results of nitrite, nitrate, silicate, phosphate, and ammonia were expressed in μ mol/l. whereas DO and chlorophyll-*a*, were expressed in mg/l and mg/ m^3 respectively.

2.4 Land Use and land Cover Analysis

The co-registration of the IRS-P6, LISS-IV, Path (114), and Row (65) satellite imagery (2014) was carried out using ERDAS image processing software (2011) with respect to the already geo-rectified Survey of India (SOI) toposheet 87A/10. Five indices techniques viz., NDWI (McFeeters, 1996), NDVI (Townshend and Justice, 1986), NDTI (Lacaux et al. 2007), SAVI (Huete, 1988), and NDBI (Zha et al. 2003) were employed for analyzing the land use and land cover. These five indices models were developed in the model maker option of the ERDAS (2011) software. The outputs thus obtained were displayed in different combinations of red, blue, and green planes for differentiating and extracting LULC features through the generation of FCC's. Visually the FCC of NDWI, NDVI, and NDBI on red, green, and blue planes allows the discrimination of forest, built-up area, and wetlands. An FCC of NDWI, NDVI, and SAVI on red, green, and blue planes allows the decoding of inundated areas (tsunami-created wetland) and mangrove from the not-wetland areas. NDWI, NDTI, and NDVI on red, green, and blue planes allow finding wetland categories such as mangrove and creek easily. LULC features deciphered from these techniques were also vectorized using Arcmap (10.5) software (Fig. 1).

2.5 Statistical analyses

Descriptive statistics such as one-way Analysis of Variance (ANOVA), Pearson's correlation matrix, Principal Component Analysis (PCA), and cluster analysis were used to assess the seasonal quality of physicochemical parameters in the ten sites using IBM SPSS-23 software. In general, One-way ANOVA is used to test interaction effects on multivariate data, using (approximate) permutation tests to avoid grossly unrealistic normality assumptions (Clarke et al. 2006). Statistical approaches like ANOVA were used by many researchers to ascertain significant differences between months and stations for physicochemical parameters (Jha et al. 2014, 2015a and b; Rajendran et al. 2018). PCA is a common but one of the most powerful techniques applied for minimizing the dimensionality of large data sets without redundancy of information. Also, the reduction of large datasets were accomplished by transforming the data set into a new set of variables called the principal components (PCs), which are orthogonal (non-correlated) and are arranged in decreasing order of importance. Mathematically, the PCs were computed from covariance or other cross-product matrices, which describes the dispersion of the multiple measured parameters to obtain eigenvalues and eigenvectors. The cluster analysis (Ward, 1963; Herion and Herion, 1995; Keenan and James, 2016) was used to detect the seasonal multivariate similarities/dissimilarities for physicochemical parameters (Farmaki et al. 2012). To assess the correlations between the levels of variables, correlation analyses were performed. Pearson correlation coefficients were calculated for a better understanding of the relationship between studied variables.

Results And Discussion

3.1 Descriptive Statistics

3.1.1 Physicochemical parameters

The minimum, maximum, mean, and standard deviation values of the measured physicochemical parameters from the chosen ten sampling locations are presented in Table 2. Low mean pH values were recorded in all the sampling stations during SWM (Southwest Monsoon) when compared to PM (Pre-Monsoon) and NEM (Northeast Monsoon). CC (7.94 ± 0.27) and FB (7.86 ± 0.26) showed high values of pH during SWM. The least pH values were recorded from JB and MB, 7.68 ± 0.08 and 7.74 ± 0.11 respectively in SWM. The highest pH value (8.18 ± 0.19) was observed in HH and SB stations in the PM season. Moreover, Low values of pH during SWM season clearly suggest the influx of freshwater in the marine environment (Rajendran et al. 2018). The pH value is a critical factor for thermodynamically maintaining the carbonate and bicarbonate levels in the seawater (Borges and Gypens 2010; Gokul et al. 2018). While a decrease of pH in stations JB and MB might indicate a localized acidification process (Abbassi et al. 2017) due to the influx of heavy rainwater and poor oceanic circulation during SWM season (Jha et al. 2014).

Salinity during the SWM season was observed to be low when compared to PM season in all the stations except in CC and FB stations. Least salinity values (29.00 ± 2.45 PSU and 29.60 ± 2.41PSU) were measured from JB and MB respectively during the SWM season. On the contrary highest salinity was recorded from the same stations viz., JB (32.00 ± 0.82 PSU) and MB (32.25 ± 0.87 PSU) during PM season. The salinity gradually increased in all the stations in NEM and SWM seasons except in station BA. The distribution of life forms in any coastal ecosystem is vitally determined by the salinity (O'Conner and Lawler, 2004; Dasgupta et al. 2017).

Water temperature recorded during SWM season shows a low profile when compared to the PM season in almost all the stations except CH (26.90 ± 1.24°C) and FB (26.80 ± 0.91°C) station. The least water temperature was documented from MB (25.90 ± 0.99°C) station during SWM season and the highest was observed in HH station during PM season. Temperature plays a vital role in the efficient functioning of an ecosystem as it regulates the survival, growth, reproduction, and distribution of type of flora and fauna (Kinne 1970; Langford 1990; Roessig et al. 2004; Nordlie, 2006; Keller et al. 2009; Putnam and Edmunds, 2011; Muduli et al. 2011; Brothers and McClintock, 2015; Rajendran et al. 2018).

Generally the observed DO levels in all the stations were high during SWM season in comparison with PM and NEM seasons. The least value was recorded from MB (3.78 ± 0.67 mg/l) followed by JB (4.00 ± 0.06 mg/l) stations during SWM and the same trend continued in these stations during NEM seasons also. The increased level of DO during SWM season suggests the increased production of oxygen due to the photosynthetic activity of phytoplankton (Muduli et al. 2011; Begum et al. 2015). Also, it is noteworthy to mention that the DO level in the present investigation is deficient (< 6.0 mg/l) during all the seasons (Okbah et al.

2013; Boyle et al. 2013; Rajendran et al. 2018). Table 2 shows the inverse relationship between temperature and DO since seawater with warm temperature (PM season) becomes easily saturated thus can hold less DO (Wu et al. 2009, 2010; Jha et al. 2015b). Low concentration of DO is linked to effects such as juvenile and adult survival, growth, and larval recruitment (Osterman et al. 2009; Fuksi et al. 2018). Also, low values of DO in coastal ecosystems can be caused by two main processes, biological and physical. Biological processes include bacterial decomposition of organic matter in bottom waters, which could either be natural or induced by eutrophication (Kramer and Stein, 2003). The physical process that decreases the oxygen in coastal waters is vertical stratification, which could be due to multiple reasons, including low tidal energy, large freshwater inputs, deep channels, and the presence of structures impeding circulation (Nixon, 1988). In general low values of Salinity, pH, DO and temperature were observed during SWM season. On the contrary, variations were observed in the aforementioned parameters during NEM and PM at all the ten stations. The low values in Salinity, pH, DO and temperature can be attributed to copious rainfall during SWM and the variation in values articulate that the rains are sporadic during NEM and PM seasons. However lowest values of the physical parameters like salinity, pH, DO and temperature were recorded from JB and MB stations during SWM followed by NEM season when compared to other stations. On the other hand, high values were recorded from these two stations in the PM season.

Low values of DO in stations JB and MB can be attributed to induction of iron in these waters either by land runoff or harbor related activities (DiTullio et al. 1993; Klaas et al. 2001; Rose et al. 2009; Franklin et al. 2018), domestic wastewater rich in organic fillers (Abbassi et al. 2017), heavy rainwater influx into this sheltered Bay (JB and MB), and poor mixing and circulation of oceanic water (Jha et al. 2014). On the contrary, other stations like CH, HH, PB, SB, WA, CC, and BA are at the closest vicinity of the open sea for mixing and circulation (Fig. 1). Field investigation of these two stations (JB and MB) also confirms that copious amount of monsoonal runoff and domestic wastewater is flushed out at these bay through 'nallahs' (92° 43' 9.08" E, 11° 39' 9.82" N; 92° 43' 43.02" E, 11° 39' 23.97" N and 92° 43' 34.16" E, 11° 39' 43.23" N). Furthermore, Station JB is a major fish landing center and harbor.

Relatively high values of Nitrite was recorded during SWM followed by NEM and PM seasons (Nallathambi et al. 2002; Jha et al. 2015b) at stations MB (0.30 ± 0.14 μ mol/l) and JB (0.35 ± 0.18 μ mol/l). Consumption of nitrite by the phytoplankton could be the reason for its low concentration in these two stations during all seasons. The constant influx of domestic sewage through the nallahs could be another reason for the high concentration of nitrite in JB and MB stations during PM and NEM seasons. The nitrite concentration of coastal waters is usually elevated when there is the oxidation of organic matter and residues from fertilizers (Montaño and Robadue, 1995).

The concentration of nitrate was recorded high during SWM season and least during PM season (SWM > NEM > PM). It is very clear that the concentration of nitrates in the coastal waters of the study area follows the rainfall pattern. Whereas, the average nitrite + nitrate concentration is more than 1 μ mol/l in all the stations and in all the seasons thus, favoring the proliferation of phytoplankton in the presence of sunlight. Also, it is indicative that uninterrupted replenishment of nitrite + nitrate (> 1 μ mol/l) concentration may be due to oceanic circulation, rainfall, erosion, or natural deterioration of minerals, despite frequent uptake by phytoplankton (Begum et al. 2012; Jha et al. 2014).

JB and MB stations recorded a null concentration of ammonia during the PM season. Low concentration (0.01 ± 0.01 μ mol/l) was observed in BA and WA stations during SWM season. Also, WA (0.03 ± 0.06 μ mol/l) station showed the least concentration of ammonia during NEM. Increased values of ammonia concentration show the reciprocation to vertical salinity stratification and low dissolved oxygen that promote regeneration of ammonia from the bottom sediments (Jha et al. 2014). JB station recorded the highest concentration of silicate 6.38 ± 1.09 μ mol/l, 8.29 ± 3.76 μmol/l and 7.73 ± 5.79 μ mol/l during PM, SWM, and NEM seasons respectively. It is quite interesting to note that silicate concentration is high during NEM season when compared to SWM season. This high concentration of silicate during NEM could owe the fact that the water holding capacity of the upstream soil would have reached the saturation level due to SWM. Henceforth, high levels of silicate-rich sediments would have been supplemented to the coastal waters as runoff. Prevailing conditions like antecedent soil moisture, soil, and rolling topography warrants 50–90% rain runoff (Ganeshamurthy et al. 2000; Shiva Shankar et al. 2018). Furthermore, silicate originates due to the weathering of silicate rocks and not through anthropogenic influence (Jha et al. 2014). Also, the residence time of silicate is longer when compared to other nutrients like nitrite, nitrate, ammonia, and phosphate this is further corroborated by the high and frequent blooms of the diatom population when compared to dinoflagellate in the study area (Dharani et al. 2004; Begum et al. 2012; Karthik and Padmavathi 2014; Begum et al. 2015).

The concentration of phosphate was recorded high during NEM season and the least PM season (NEM > SWM > PM). JB station recorded the highest concentration of phosphate 0.14 ± 0.16 μ mol/l, 0.27 ± 0.19 μmol/l and 0.52 ± 0.07 μ mol/l when compared to other stations during PM, SWM, and NEM seasons respectively. The phosphate concentration of coastal waters is said to be linked to fertilizers and domestic wastewaters (Montaño and Robadue, 1995). Nutrients like nitrates and phosphates are brought into the coastal waters through river flow, agricultural and aquaculture runoff, industrial and household waste (Casali et al, 2007).

3.1.2 Biological parameters

The chlorophyll-*a* content was estimated to be high in JB station during SWM (0.11 ± 0.04 mg/m3) and NEM (0.10 ± 0.04 mg/m3) season followed by MB station. However, during PM season JB (0.10 ± 0.03 mg/m3) and CH (0.10 ± 0.01 mg/m3) stations shows high content of chlorophyll-*a*. Similar results were documented from JB and MB stations by Eshwar et al. 2001; Muduli et al. 2011; Karthik and Padmavati 2014; Karthik et al. 2014a; Begum et al. 2015.

3.2 Statistical analysis

Cluster analysis, Pearson correlation, one-way ANOVA, and Principal Component Analysis were the four statistical analyses employed to address the seasonal ambiance of the physicochemical parameters in the focus area.

3.2.1 Principal Component Analysis

PCA was performed on the homogeneous data set of water quality parameters from all sampling stations in all seasons. The PCA results are illustrated in Fig. 3 as 3a, 3b, and 3c for SWM, NEM, and PM seasons respectively. As in the case of cluster analysis, three distinct principal components (PC) loadings were also observed in SWM, NEM, and PM seasons among the stations. Stations CH, SB, HH, and PB formed a sector. Stations such as JB and MB formed the second sector while other stations formed the third sector. The PC loading in Fig. 3 suggests that the station's JB and MB are the most polluted with the influx of nutrients owing to the proximity of human residence during all the seasons (Muduli et al. 2011; Sahu et al. 2013). Poor mixing and oceanic circulation may also be a cause for the high concentration of nutrients in these stations (Jha et al. 2014) resulting in the frequent proliferation of blooms (Eshwar et al. 2001; Muduli et al. 2011; Arun Kumar et al. 2012; Karthik and Padmavati 2014; Karthik et al. 2014a; Begum et al. 2015). While similar nutrient influxes were observed in CH, SB, HH, and PB during all the seasons, the contents were dissipated due to the thorough mixing and interaction with the open sea. Stations viz., WA, BA, FB, and CC are least polluted owing to the high freshwater influx, open sea interaction, and least anthropogenic influence due to their low population density when compared to other stations.

3.2.2 Cluster Analysis

Ward's cluster analysis was implemented to decipher the similarity and dissimilarity between stations and seasons (Fig. 4a, b, and c). Three major clusters were encountered in PM, SWM and NEM seasons shows similarity among stations. Cluster 1 comprised of WA, BA, CC, and FB; cluster 2 - CH, SB, HH, and PB; cluster 3- JB and MB stations. WA and BA stations were separated by a lesser distance when compared to CC and FB stations of cluster 1. This suggests that CC and FB are more disturbed when compared to WA and BA during all the seasons. The pollution gradation is CC > FB > WA > BA. The least polluted stations have an influx of freshwater during hydrometeorological events hence these stations form a separate cluster (Sahu et al. 2013). Although, CH and SB stations formed a separate group from HH and PB stations of cluster 2, equal distances between the stations indicate that these stations are equally polluted during all the seasons and have almost similar values of physicochemical parameters. The JB and MB cluster with a wider distance when compared to other stations clearly suggests that these stations are highly contaminated during all the seasons due to the influence of anthropogenic activity (Muduli et al. 2011; Sahu et al. 2013). The results of the present investigation are in complete accord with that of the results of Muduli et al. (2011). From the cluster analysis, it is inferred that stations of cluster 3 are the most contaminated due to anthropogenic activities while the least contaminated are the stations of cluster 1. The contamination levels of the cluster can be inferred as JB and MB > CH, SB, HH, and PB > CC and FB > WA and BA.

Cluster analysis of physicochemical parameters and their seasonal ambiance was applied to understand the similarity and dissimilarity among them (Fig. 5a, b, and c). Similar to the cluster analysis of stations and seasons, physicochemical parameters and seasons (PM, SWM, and NEM) also exhibit three distinct clusters among the parameters. Cluster 1 comprised of salinity and temperature in all three seasons suggesting that they are directly proportional to each other, i.e. if the temperature increases salinity increases and vice versa. Cluster 2 encompasses pH, silicate, and dissolved oxygen during NEM and PM season, while SWM season has only two parameters pH and silicate. The presence of silicate indicates that the focus area is devoid of landlocked watershed, meaning all the eroded materials are emptied into the adjacent sea as surface runoff (Ganeshamurthy et al. 2000; Shiva Shankar et al. 2018). 2) The frequent diatom blooms encountered in the study area are due to the presence of silicate (Dharani et al. 2004; Arun Kumar et al. 2012; Begum et al. 2012; Karthik and Padmavathi 2014b; Begum et al. 2015). 3) Influx of silicate in the coastal water is due to tropical rains naturally (Jha et al. 2014). The parameters of cluster 1 viz., temperature and salinity have a direct bearing on pH, and these three parameters together influence the dissolved oxygen. Cluster 3 comprises nutrients like nitrate, nitrite, ammonia, and phosphate.

A comparison of both the cluster analysis viz., stations and seasons, physicochemical parameters, and seasons clearly emphasize the objective of the present study.

3.2.3 Pearson correlation

Correlations between ten water quality parameters were deliberated using Pearson's correlation, and the correlation analysis was used to describe the degree of relative correlation between the parameters. The correlation matrix describing the interrelationship between variables is presented in Tables 3a, 3b, and 3c for NEM, SWM, and PM seasons respectively. A high correlation coefficient (near + 1 or -1) means a good relationship, and there exists no relationship between two variables if the value is near zero at a significance level of < 0.05. To be precise, the parameters showing r > 0.75, 0.5 < r < 0.7 and r < 0.5 are considered as strongly, moderately and weakly correlated respectively (Gokul et al. 2018). The results for 10 water quality parameters in NEM (Table 3a) showed that a strong positive correlation existed between pH-nitrite (r = 0.772), nitrite-nitrate (r = 0.974), nitrite-phosphate (r = 0.882), chlorophyll-α (0.847), nitrate-phosphate (0.905), nitrate-chlorophyll-α (0.740), phosphate-chlorophyll-α (0.733) and chlorophyll-α - ammonia (0.770). All the other parameters showed moderate correlations except temperature and DO.

During SWM season, high correlation is exhibited between the parameters viz., pH-temperature (r = 0.784), pH-nitrite (r = 0.702), salinity-nitrite (r = 0.825), temperature-nitrite (r = 0.938), silicate-nitrate (r = 0.967), silicate-phosphate (r = 0.777), silicate-chlorophyll (r = 0.839), and silicate-ammonia (r = 0.839). Nitrate-chlorophyll-α (r = 0.741), nitrate-ammonia (0.929), and phosphate-chlorophyll-α (r = 0.897). Moderate correlation was shown between the parameters viz., salinity and pH(r = 0.52571), temperature and salinity (r = 0.68388), DO and salinity (r = 0.67975), phosphate and silicate (r = 0.6743), ammonia and chlorophyll-α (r = 0.52568). During the pre-monsoon a strong positive correlation was found between temperature and pH (r = 0.94269), DO showed a weak correlation with physical parameters. Nitrite showed strong correlation with pH (r = 0.72176), salinity (r = 0.85696), and temperature (r = 0.75438). Silicate showed strong correlation with nitrite(r = 0.78072), nitrate exhibited strong correlation with nitrite (r = 0.88165), and silicate (r = 0.91962). The results of correlation express the close proximity of dependency among the various parameters irrespective of the sampling stations (Jha et al. 2013). However, there was a discrepancy in correlation among parameters was observed seasonally. A high degree of strong correlation among the various parameter was observed during the PM season. Similarly, a high degree of moderate correlation was found among various parameters during NEM season.

3.2.4 One way ANOVA

The results of one-way ANOVA (Table 4) suggest significant seasonal variation among the parameters viz., pH, Nitrite, Ammonia, Nitrate, Silicate Phosphate, and Chlorophyll *a* ($p < 0.01$). The seasonal variation in pH indicates the fluctuation in the seasonal influx of freshwater in the coastal environments (Rajendran et al. 2018). Seasonal variation in the chlorophyll-*a* content is marked by the presence of the nutrients such as nitrite, nitrate, ammonia, and phosphate (Dharani et al. 2004; Arun Kumar et al. 2012; Begum et al. 2012; Karthik et al. 2014a; Begum et al. 2015). The silicates in the coastal waters are produced because of the weathering of the silicate rocks by the seasonal rains and humans have no role in the direct introduction of this nutrient in the coastal water (Jha et al. 2014). Consistency in the physical parameters such as salinity and temperature ($p > 0.01$) was observed seasonally. Station-wise variation in DO ($p < 0.013$) suggests a differential influx of nutrients, and freshwater due to anthropogenic intervention.

3.3. Land use land cover classification

Land use and land cover map (Fig. 1) of the area under investigation classifies the surrounding areas of the sampling stations. Dense human settlements (urban) were around the stations via., HH, PB, SB, CH, JB, MB. The monsoonal stormwater and sewage are discharged into the adjacent marine environments through nallahs. An increase in population and related activities are the major source of pollution in the Bay regions. On the contrary, the pollution around rural areas surrounding the sampling stations FB, CC, WA, and BA are from the sources like small-scale farming and agriculture. It is also inferred from the land use and cover classification that the study area has a rolling topography and the domestic contaminants are directed to the nearby seas as run-off. Thus the LULC map indicates the various sources of pollution of this region (Fig. 1).

Conclusion

The present investigation focused on the seasonal variation of physio-chemical parameters in ten stations of South Andaman Island for a year during 2018. The multivariate statistical analyses such as Cluster analysis, Principal component analysis, Pearson correlation, and one-way ANOVA suggest that the coastal waters of the stations Junglighat Bay (JB) and Minne Bay (MB) are polluted due to anthropogenic activities. Hence it is strongly recommended that these stations have to be monitored regularly and necessary initiatives should be taken by the Andaman administration to create awareness among the public regarding the importance of the health of these coastal waters. The present research also, strongly recommends proper waste treatment practices in Port Blair Municipal Council (PBMC), South Andaman. Further studies need to be carried out focusing on the fecal coliform content and heavy metal concentration of the discharge waters and the sites where the magnitude of the anthropogenic interference is high especially in JB and MB stations. This would provide a comprehensive view of the overall pollution levels of these waters.

Declarations

Ethics approval and consent to participate

Neither human/tissue/body parts nor animal were used for the study: Not Applicable.

Consent for publication

Not Applicable.

Availability of data and materials

The data collected from the field and analysed are presented in tables and figures.

Competing interests

The corresonding author and the co-authors do not have any conflict of interest.

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Authors' contributions

Shiva Shankar, Mohan, Dharanirajan, and Padmavathi carried out the design and documentation of the research.

Shiva Shankar, Neelam Purti, Satyakeerthy, and Narayani carried out the field sampling and analysis.

Thanamegam Kaviarasan and Murugaiah Santhosh Gokul carried out the statistical analysis.

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Tables

Due to technical limitations, table 1 & 2 is only available as a download in the Supplemental Files section.

Table 3. Nonparametric Pearson rank correlation coefficient (rs) among the studied parameters in a) NEM, b) SWM, c) PM

NEM

	pH	Salinity	Temp	DO	Nitrite	Silicate	Nitrate	Phosphate	Chlorophyll	Ammonia
pH	1	0.63037	0.05163	-0.56278	0.77238	0.55137	0.7787	0.62702	0.48022	0.35079
Salinity		1	-0.26899	0.00463	0.61686	0.60123	0.60571	0.26722	0.39697	0.44694
TEM			1	-0.44206	0.13163	-0.12513	-2.66667	0.20341	0.49281	0.49998
DO				1	-0.64298	-0.1692	-0.67421	-0.81016	-0.52417	-0.24089
Nitrite					1	0.65438	0.97427	0.88217	0.84711	0.55319
Silicate						1	0.67585	0.55255	0.42946	0.05886
Nitrate							1	0.90582	0.74059	0.38092
Phosphate								1	0.73389	0.24498
Chlorophyll									1	0.77018
Ammonia										1
SWM										
pH	1	0.52571	0.78431	0.11932	0.7023	0.21159	0.36274	-0.11884	-0.01121	0.49572
Salinity		1	0.68388	0.67975	0.82514	-0.33278	-0.14306	-0.78866	-0.64431	0.19824
TEM			1	0.49732	0.93851	0.08147	0.20153	-0.37311	-0.21547	0.43095
DO				1	0.6592	-0.5171	-0.48236	-0.82082	-0.59498	-0.18232
Nitrite					1	0.02766	0.16608	-0.52582	-0.30023	0.47143
Silicate						1	0.96739	0.77737	0.83902	0.84951
Nitrate							1	0.6743	0.74141	0.92974
Phosphate								1	0.89737	0.36546
Chlorophyll									1	0.52568
Ammonia										1
PM										
pH	1	0.68126	0.94269	0.32648	0.72176	0.24082	0.46638	0.60007	0.65665	-0.24494
Salinity		1	0.76	0.41028	0.85696	0.44653	0.61507	0.63092	0.9091	-0.83549
TEM			1	0.45912	0.75438	0.32376	0.48441	0.61742	0.75984	-0.38077
DO				1	0.40023	0.22478	0.19643	0.33574	0.47891	-0.30154
Nitrite					1	0.78072	0.88165	0.9255	0.94288	-0.64748
Silicate						1	0.91962	0.8927	0.6918	-0.43236
Nitrate							1	0.94063	0.77967	-0.4863
Phosphate								1	0.83902	-0.38498
Chlorophyll									1	-0.7186
Ammonia										1

Table 4. Oneway ANOVA

Parameter	Seasonal	Station
pH	0.001*	0.465
Salinity	0.050	0.563
Temperature	0.146	0.541
DO	0.970	0.013*
Nitrite	0.011*	0.302
Silicate	0.005	0.105
Nitrate	0.000*	0.919
Phosphate	0.000*	0.998
Chlorophyll	0.000*	1.000
Ammonia	0.015*	0.803

One way analysis of variance showed significant seasonal variation was found in pH, Nitrite, Ammonia, Nitrate,Silicate Phosphate and Chlorophyll ($p < 0.01$). However, no statistically significant variations was observed among station and seasonal for following parameters Salinity, Temperature ($P>0.01$).DO found station wise variation ($p < 0.013$)

Figures

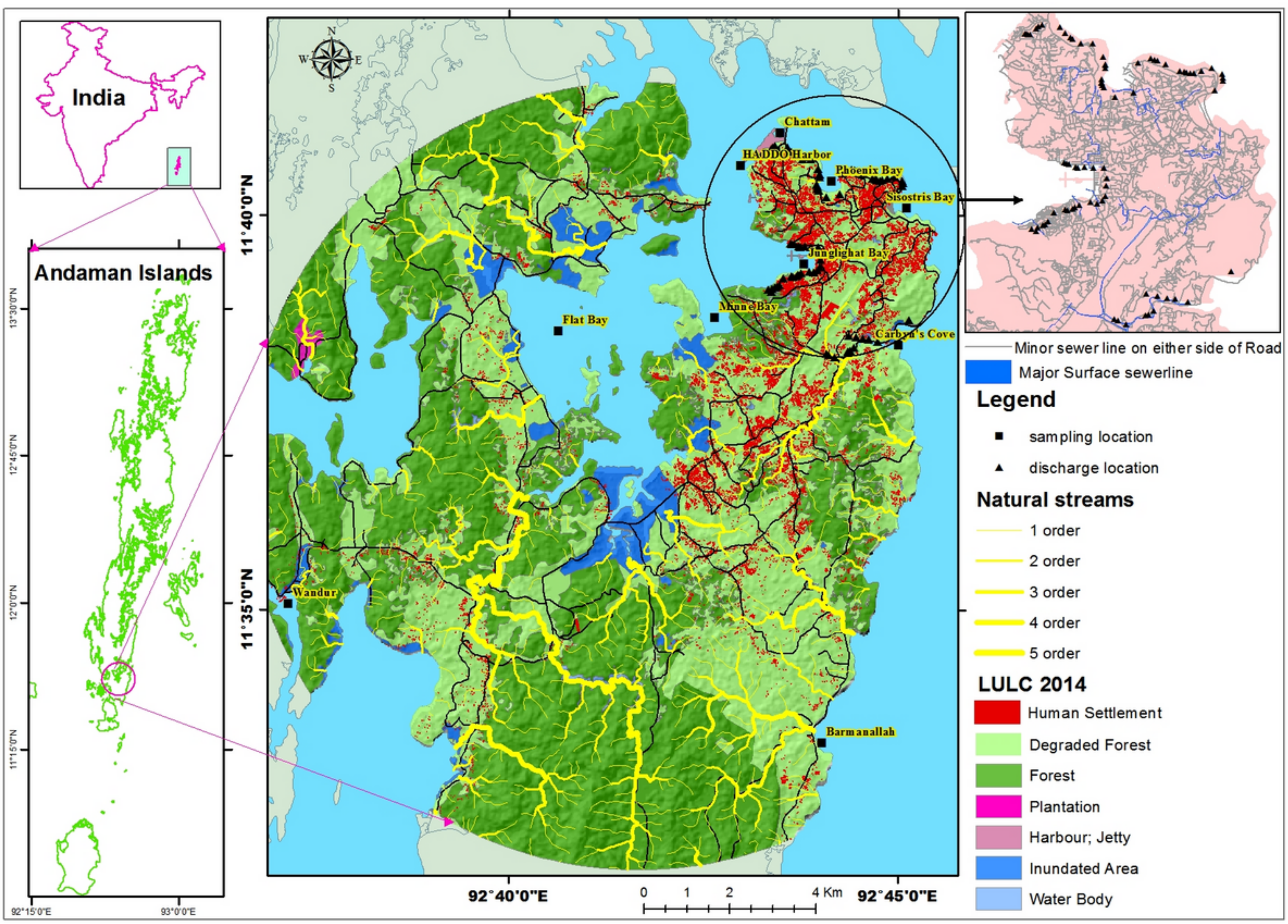

Figure 1

The sampling locations and land use land cover of the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

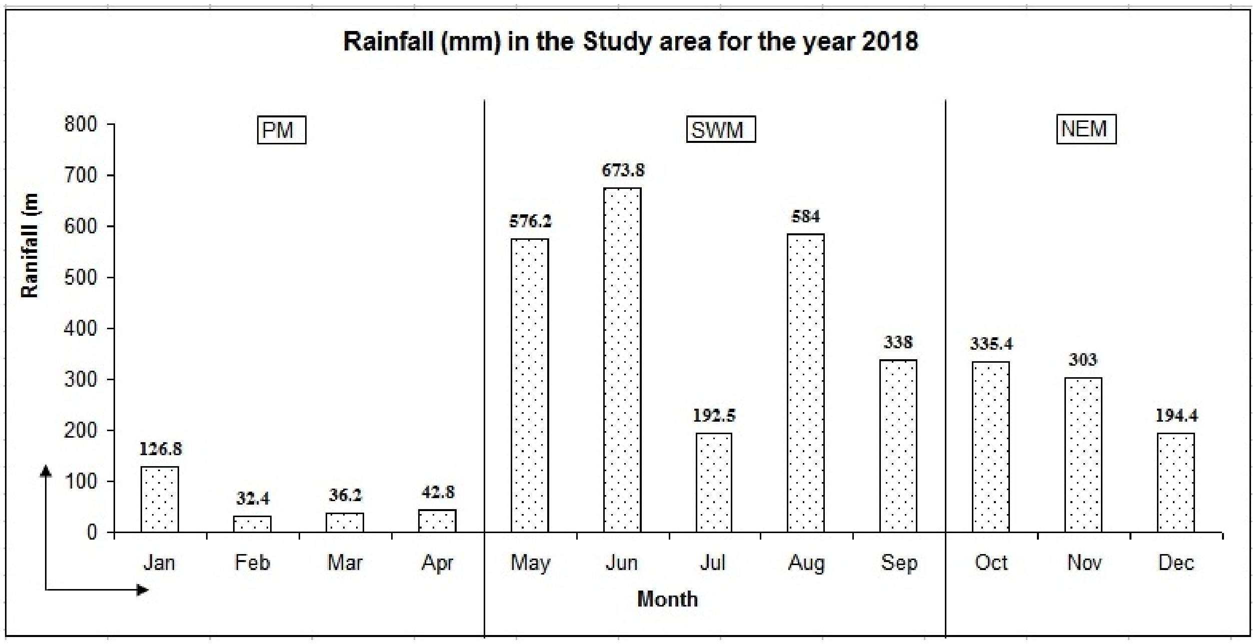

Figure 2

Seasonal Rainfall in the study area for the year 2018

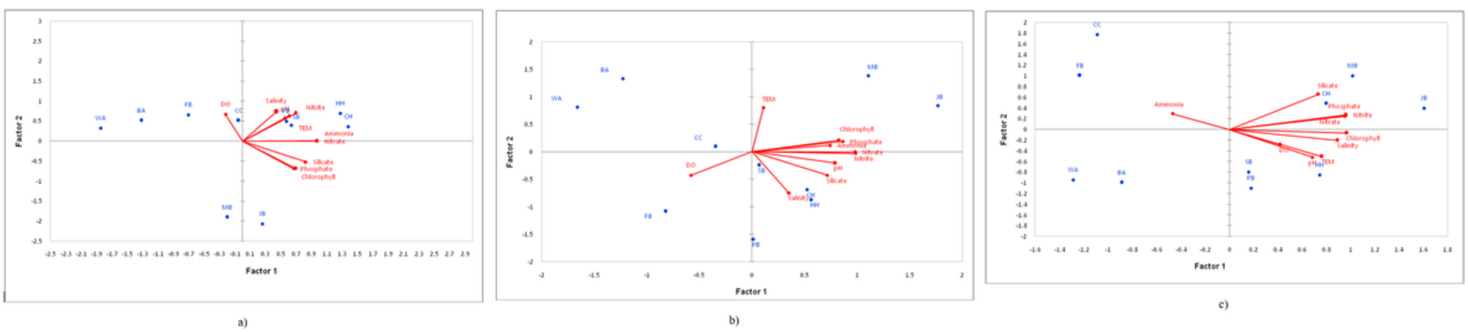

Figure 3

Principal component analysis for all parameters a) SWM season b) NEM season c) PM season

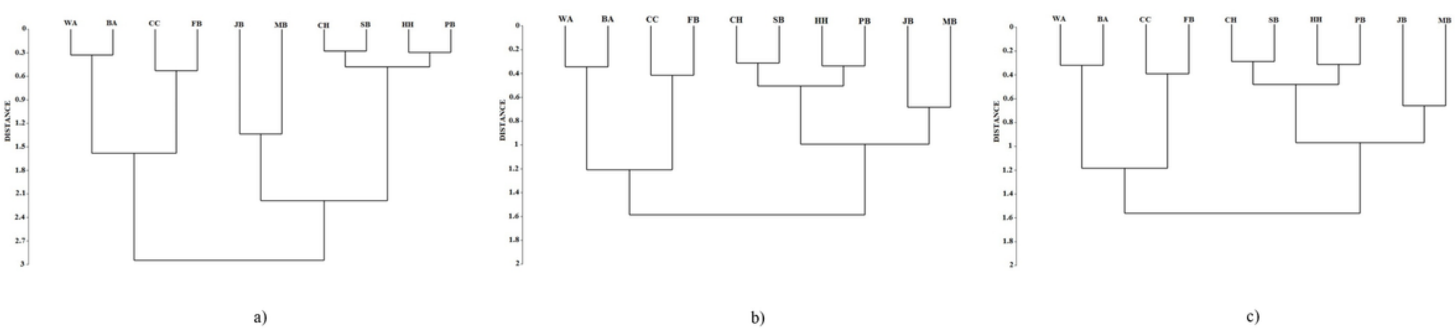

Figure 4

Station-wise dendrogram using Average Linkage (Between Groups) for all parameters a) SWM season b) NEM season c) PM season

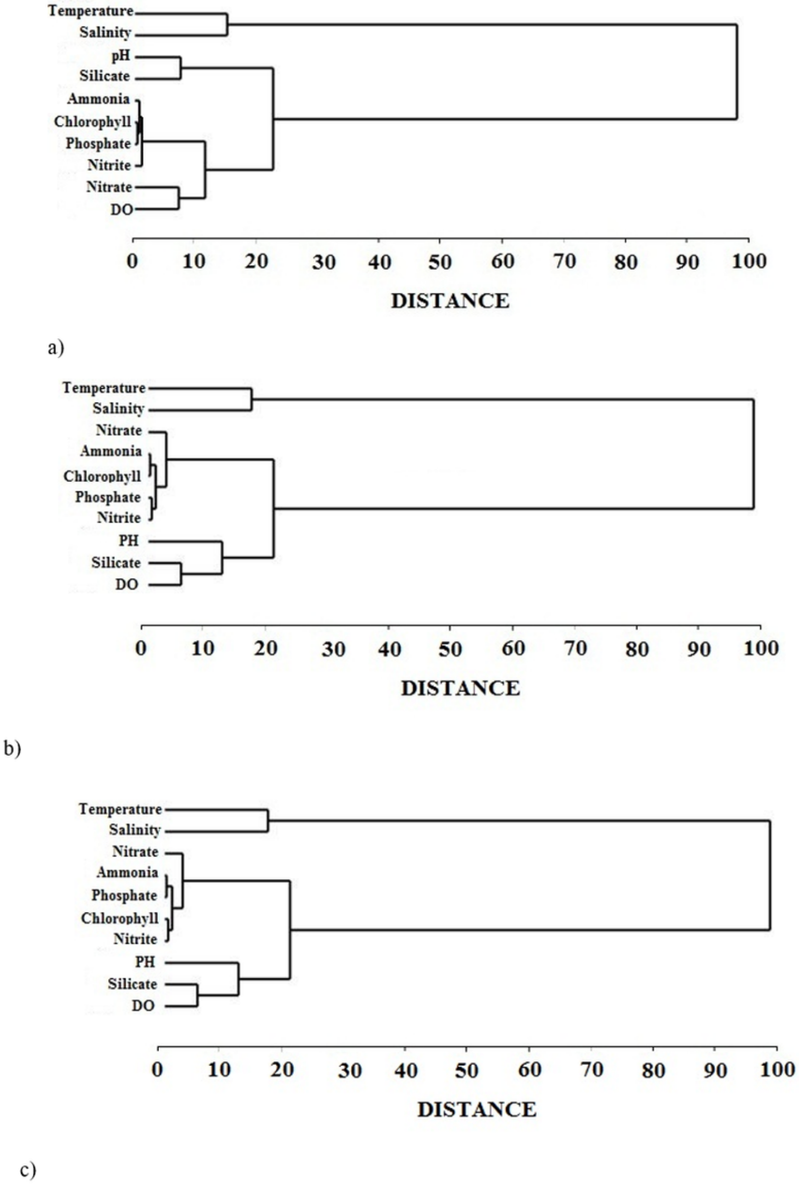

Figure 5

Parameter-wise dendrogram using Average Linkage (Between Groups) for all stations a) SWM season b) NEM season c) PM season

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1waterqualityresearch.xls
- Table2AREASEASONWISENUTRIENTDATA.xls