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ORIGINAL PAPER

Spatio-temporal variability of water quality of coastal waters off Mumbai, northwest coast of India

Rinkesh Nemichand Wanjari[1] · **Karankumar Kishorkumar Ramteke**[2] · **Dhanalakshmi Mathialagan**[1]

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Abstract

The purpose of this study was to evaluate the spatiotemporal distribution of physicochemical parameters along Mumbai coastal water. Water samples were taken using an experimental fishing cum research vessel in order to monitor and evaluate ecosystem stress. Sea surface temperature, sea surface salinity, pH, chlorophyll-a, DO, BOD, alkalinity, and primary productivity are all measured on a monthly basis. The range of the sea surface temperature was 26.5–29.5 °C. Sea surface salinity ranged from 32 to 36, and pH was in the 7.9 to 8.3 range. The ranged of the dissolved oxygen concentration was 2–2.9 mg/l. The alkalinity levels were 118–125 mg/l. BOD was between 3.8 and 5.4 mg/l. Primary productivity concentrations ranged from 0.77 to 0.85 mg C/m^3/day. To estimate the accuracy with in situ field measured parameters with remotely sensed parameter comparison of sea surface temperature, sea surface salinity, Chlorophyll-a, and primary productivity was carried out. All of the parameters had acceptable levels of accuracy (SST: $r^2 \geq 0.79$, ≤ 0.713 [°C], SSS: $r^2 \geq 0.90$, ≤ 0.517 [‰], Chl-a: $r^2 \geq 0.83$, ≤ 1.925 [mg/m^3]) and further adjustments could be made for satellite-based primary productivity ($r^2 \geq 0.64$, ≤ 241.30 [mg. C/m^2/day]) for use in the future.

Keywords Experimental fishing · Mumbai coastal water · Physico-chemical parameters · Primary productivity · Remote sensing

Introduction

Water quality is an indicator of the environmental health and well-being of human society. Changes in the spatial and temporal characteristics of the water quality of coastal waters are dependent on river discharge. Rivers are the main contributors of sediment to the oceans and have a substantial impact on biogeochemical cycles. The river runs across the land before reaching the ocean (Manahan 1993). The quality of surface water in a region is largely determined by natural processes such as soil erosion, weathering, and anthropogenic influences such as local waste runoff, agricultural, and industries (Carpenter et al. 1998; Jarvie et al. 1998). Crop waste, kitchen wastes, and other biodegradable solid waste contribute to the organic content of water (Finnveden et al. 2009), but the majority is attributed to fecal contamination (Stoate et al. 2009). Researchers have conducted numerous studies to identify the point and non-point sources of contamination to the river (Mathur et al. 1987; Bhardwaj et al. 2010; Singh 2010; Tyagi et al. 2013). To reduce industrial pollution, precise understanding of the quality and quantity characteristics of pollution sources is required (Valipour et al. 2012, 2013a, b). In addition to direct discharge and dumping of solid and liquid pollution into the river, the river's tributaries have been identified as significant contributors. Assessing the water quality of the river's tributaries is crucial for the effective and strategic conservation of the river. In ecosystem, water plays a crucial function in sustaining life. Coastal waters are the most dynamic and intricate aquatic ecosystems (Morris et al. 1995). Studies of water quality evaluation are identified as one of the priorities of the water resources sector (Jiang et al. 2020). Complex manmade factors, including as urban growth and development, agronomic and industrial operations, chemical spill

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✉ Rinkesh Nemichand Wanjari
rinkeshwanjari0712@gmail.com

[1] Department of Fisheries Resource Management, ICAR Central Institute of Fisheries Education, Mumbai, Maharashtra 400061, India

[2] Fisheries Resource Management Division, ICAR Central Institute of Fisheries Education, Mumbai 400061, India

situations and dam projects, and natural activities, such as climatic conditions, and weathering processes, influence the natural condition of the river (Gao et al. 2017; Mainali and Chang 2018; Matta et al. 2020). Massive amounts of untreated industrial and urban garbage have been discharged into the river as a result of fast industrialization and population growth, producing pollution issues in the coastal areas. To satisfy the growing demand and to design a plan for the sustainable management of water resources, it is essential to have a thorough grasp of seasonal and spatial water quality variation (Haji et al. 2021; Poudel et al. 2013; Spencer et al. 2008). Burgan et al. (2013) examined the water quality trend of the Akarcay River in Turkey from 2006 to 2011. The authors analysed various water quality parameters such as pH, dissolved oxygen, and turbidity to assess the river's water quality. Their findings showed that water quality deteriorated significantly in the river during the study period, indicating potential environmental and human health risks.

The Arabian Sea is known as one of the most fertile oceanic regions (De Sousa 1996; Qasim 1977). The Arabian Sea is an ocean basin with physical forcing and biological reaction vary with the weather. Because the Arabian Sea is surrounded by Eurasian landmasses and has a semiannual reversal wind pattern, subtropical convergence cannot happen (Morrison et al. 1998). Diverse researchers examined seasonal differences in physical and chemical properties, as well as nutrient dynamics throughout the nation's network of coastal and offshore waters (Singh et al. 1990; Mathew and Pillai 1990; Sulochana and Muniyandi 2005). However, there is little to no information about the qualities of the northeastern Arabian Sea (Vase et al. 2018). The majority of the world's most productive ecosystems are located in coastal marine areas, which are thought to be more diverse than open ocean regions. In order to ensure the sustainable development, improvement, and management of the coastal systems and their resources, it is crucially critical to study water quality through the use of appropriate control measures and the monitoring of a wide range of measures (Shridhar et al. 2006; Mishra 2007). Therefore, marine water quality is important to the sustainability of marine resources, which contributes to the stability of the marine environment. The expansion of industry along the river basin and coasts has significantly degraded the quality of coastal water. Physical, chemical, and biological water quality indicators have traditionally been established by taking field samples and analysing them in the laboratory. Although this in situ field-based evaluation delivers better accuracy, it is labor-intensive and time-consuming, so it is impractical on a broad scale to provide a regional water quality database at the same time (APHA 1998; Asha and Diwakar 2007). Due to the presence of allochthonous constituents, river water with a high load of contaminants in the form of waste, sediment, and fine soil material makes it difficult to assess satellite-based remote sensing results effectively (Khan et al. 2016). Consequently, difficulties with successive and integrated sampling are a major obstacle to water quality monitoring and management. Checking the appropriateness of satellite-derived physicochemical parameters is crucial. Predicting the structure and function of marine ecosystems necessitates a detailed understanding of the physical and biological processes that influence species population, allocation, and productivity across a variety of temporal and spatial dimensions (Saitoh et al. 2011; Solanki et al. 2015). Lack of prior attempts to show the spatial and temporal dynamics of physico-chemical parameters off the coast of the northern Arabian Sea makes the study more valuable and reinforces its significance. Therefore, it is essential to know physico-chemical parameters in in order to understand the coastal environment's dynamics.

Material and method

Study area

Being one of the most populated cities in the world and the commercial capital of India, Mumbai is located at 18° 55′ N 72° 54′ E. As of the year 2022, the metropolitan region of Mumbai is home to over 23 million people, representing a 1.42 % rise from the previous year. The city of Mumbai is located on India's western coast, where it was originally an archipelago consisting of seven islands. Its current location is on land that was reclaimed from the ocean. A valley is formed in the western side by the Mithi River, as well as by three big streams named Manori, Malad, and Mahim. Both the Mahim Creek and the Malad Creek have dangerous levels of pollution (Sardar et al. 2010). At the moment, drains are responsible for discharging untreated sewage into the coastal waterways, whereas primary (Worli and Bandra) and secondary (Versova) treatment facilities are responsible for discharging treated effluent (Vijay et al. 2015). Because of its location on the coast, Mumbai has two distinctly different seasons: the rainy season and the dry season.

Sampling

The present study was conducted between 19°06'866" N and 19°12'15.09" N latitude and from 72°41'23.20" E to 72°48'502" E longitude from September 2019 to March 2020 using experimental fishing on M.F.V NARMADA (IV) (Marine Fishing Vessel Narmada-Central Institute of Fisheries Education) in the traditional trawling grounds of Mumbai coastal waters (Fig. 1). Physical parameters of seawater like SST, pH, and salinity were measured directly in the feld using a calibrated mercury thermometer, OAKTON pH EcoTestr, and ATAGO S/Mill-E refractometer respectively.

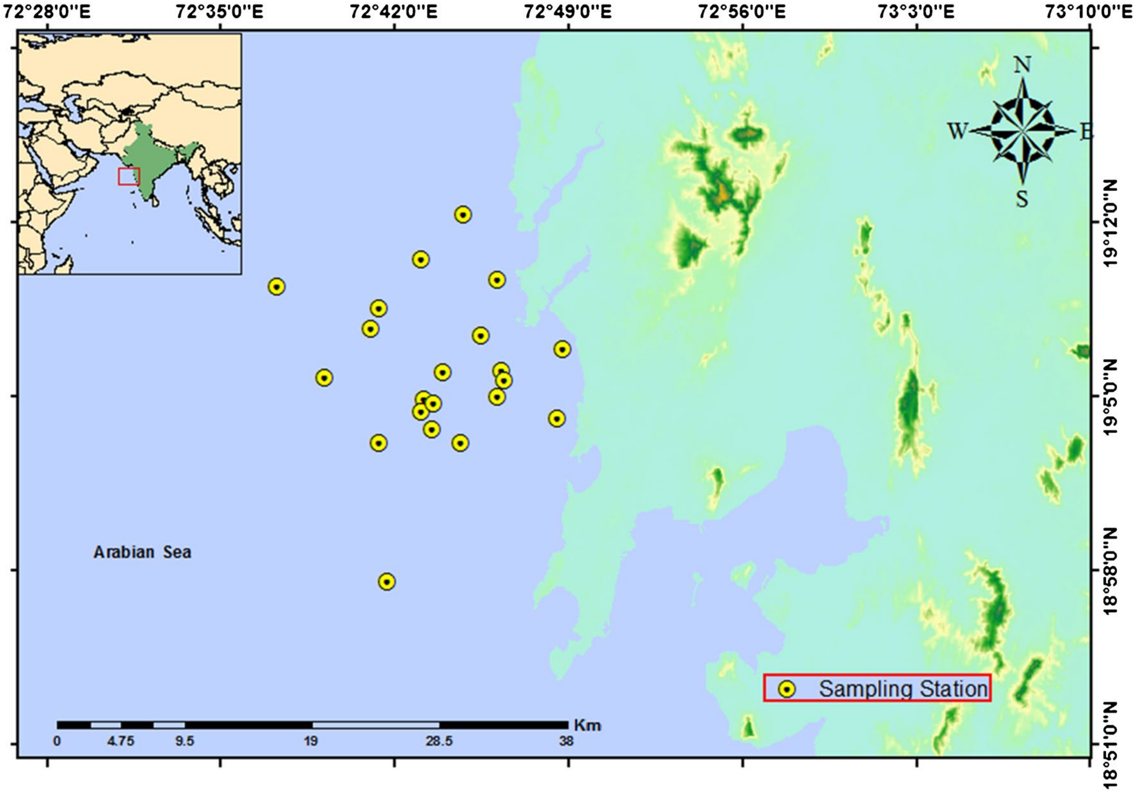

Fig. 1 GIS map showing the sampling site and study area

Water sampling and preservation were carried out as per guidelines in APHA (2005) with the help of standard techniques and procedures. All the analyses were done in triplicate, and data quality was assured through standardization. Sea surface temperature was measured using a Celsius mercury thermometer calibrated up to 0.1 °C. Water pH was measured on-site by OAKTON eco tester pH 1 (0.0 to 14.0). Sea surface salinity of water for different stations was measured with the help of a handheld refractometer ATAGO S/Mill-E (0-100%).

Statistical analyses

The water samples were collected without air bubbles in BOD bottles capacity 250 ml for DO estimation. Reagents Winkler–A (manganese sulphate) and Winkler B (alkaline iodide azide) every 2 ml were added for oxygen fixation after collection of the water sample. Water samples were collected in 250 ml BOD bottles were kept in a complete airtight bottle for incubation at 27 °C for three days. Estimation of chlorophyll-a, water samples were taken from the sea surface in 500-ml HDPE bottles, placed in iceboxes, and brought to the laboratory. Chlorophyll ‘a’ calculation involved water filtration by pore-size filter paper 0.45 µm, with a glass filter diameter of 47 mm GF 52 numbers using a suction pump. To prevent the degradation of microalgal cells that contain chlorophyll pigment, the filter paper was coated with 0.2 ml of saturated magnesium carbonate suspension (1 g powdered $MgCO_3$ in 100 ml of distilled water). The pigments were removed by placing the sample in a caped centrifugal tube in 90% v/v acetone and kept in the refrigerator for 24 h at 4 °C. Extract was cleared by centrifuging it for 15 min at 2500 rpm and supernatant used to take the spectrophotometer reading in a 10-mm optical path cuvette. The observation was done at 750 nm and 665 nm. Then 0.33 ml 0.1 N HCl was added for acidification and the sample was again measured spectrophotometrically at 750 nm and 665 nm. Primary productivity estimated by filtered water samples used (0.4 mm mesh) to minimize zooplankton interference and suspended particulate matter which helped to get a proper estimate of primary productivity. Water samples in HDPE tanks are gathered and kept untouched for a few minutes in order to disperse the phytoplankton uniformly. Samples obtained in glass bottles of ‘Light’ ‘Dark’ and ‘Initial’ were labeled without air bubbles being interwoven into them. In order to maintain the microorganisms inside the bottles, they gathered and set the incubation time for 60 min. As incubated, Winkler bottles A and B Light, and Dark bottles after incubation time b Winkler’s incubation period ‘A’ and ‘B’ used, and the dissolved oxygen values determined for the samples of 'I,' 'D' and 'L,' up to three decimal points.

Primary productivity was estimated by the Vertically Generalized Production Model

Where, *PPeu* Daily carbon fixation integrated from the surface to Zeu (mg. C/m^2), $P^B opt$ Optimal rate of daily carbon fixation within a water column [mg. C (mgChl)$^{-1}$ h^1], E_0 Sea surface daily PAR (mol quanta/m^2 /d), C_{SAT} Satellite surface Chl-a concentration (mg. Chl/m^3), *T* Sea Surface Temperature (°C), Z_{eu} Physical depth (m) of the euphotic zone defined as the penetration depth of 1 % surface irradiance. Z_{eu} is calculated from CTOT. C_{TOT} Total pigment and total Chl-a content within the euphotic layer (mg Chl/m^2), D_{irr} Daily photoperiod (in decimal hours), $P^B opt$ Observed relationship between median P^{B}opt and temperature (T): P^{B}opt 1.13 if T< -1.0 4.00 if T>28.

Interpolation of physico-chemical parameters was also carried out using IDW (Inverse Distance Weighted) spatial analyst tool under the Arc toolbox of Arc Map. Arc GIS is a powerful software used for computerized mapping and spatial analysis. For this study, the latest version of Arc GIS 10.8 by ESRI was used.

Results and discussion

A narrow range of variation (26.5–29.5 °C) in sea surface temperature recorded throughout the study (SST). SST was highest in March and its lowest in September. SST as a one of the key elements in coastal ecosystems affects the physicochemical properties of coastal water (Sundaramanickam et al. 2008). The magnitude of the coastal processes is directly proportional to the intensity of SST. SST is controlled by the amount of solar radiation, evaporation, groundwater movement, and cooling and mixing of the water (Saravankumar et al. 2008). Recorded variations are within the ideal ranged (18.3–37.8 °C) in relation to tropical plankton despite the ability of temperature to alter reproduction, growth particularly photosynthesis rates (Hossain et al. 2007; Shah et al. 2008). The current study's findings are consistent with earlier research (Dhage et al. 2006; Selvan et al. 2016), which corroborates those temperatures along the Mumbai coast ranged from 26 to 34 °C. As a result of altering biological, physical, and chemical processes within an organism due to spatiotemporal variation impacted community structure (Dupuis and Hann 2009). Analysis of in situ data and SST data from remote sensing satellites showed a coefficient of approximately $r^2 = 0.79$. The current SST findings concur with those presented by various authors (Arnone et al. 1987; Castillo et al. 1996; Rupa kumar et al. 2002 and Choudhury et al. 2007).

Sea surface salinity (SSS) measured in the 32–36 ranged. Salinity values were highest in March and their lowest in October. Low rainfall and heavy evaporation lead to an increase in salinity (Govindasamy et al. 2000). Salinity variation is crucial for determining the global water balance, the amount of evaporation, and the crucial role of ocean circulation. The main factor influencing the distribution of aquatic organisms is salinity. Increased evaporation brought on by a higher atmospheric temperature is what's responsible for the salinity increase (Gibson 1982; Singh et al. 2010; Lakwal et al. 2017). Lakwal et al. (2017) noted a similar trend in salinity along the Ratnagiri coast. A narrow range of salinities, above which osmotic and ionic balances cannot be maintained, is to which many marine species have adapted. The main physical parameter that the plankton diversity can be linked to, acting as a limiting factor and affecting the distribution of the planktonic community, is salinity (Kouwenberg 1994; Ramaiah and Nair, 1997; Mohan and Sreenivas, 1998; Balasubramanian and Kannan 2005; Sridhar et al. 2006). Sea Surface Salinity (SSS) data from remote sensing satellites were compared with in situ observation. Based on a comparative analysis, the coefficients of determination (r^2) were 0.90. The study found a significant correlation between in situ estimates of sea surface salinity and sea surface salinity derived from satellite data. In a related observation, Daqamseh et al. (2019) compared in situ salinity measurements with satellite-based salinity measurements along the western Red Sea coast and reported strong coefficients of determination (r^2) of 0.96. The current findings are consistent with earlier findings (Qing et al. 2013; Geiger et al. 2013; Salleh et al. 2013).

Water samples pH ranged from 7.9 to 8.3. The pH value was highest in January and its lowest in March. During the duration of the study, the water's pH was alkaline. The high temperature, which decreases the solubility of carbon dioxide, as well as the activity of photosynthesis hay have influenced alkaline range of water. Acidity or alkalinity is determined by the pH scale based on the concentration of hydrogen ions in seawater. Free carbonate, bicarbonate, and CO_2 all have an impact on how acidic or basic the water is. Aquatic life harmed if a water becomes overly basic or acidic. The pH for water sampled over the course of the study was always alkaline. As per to current observation, pH ranged from 7.9 to 8.3. Due to the daily photosynthetic activity of phytoplankton, which removes dissolved carbon dioxide from the water column and raises pH, the highest pH value was in January and the lowest in March (Das et al. 1997). According to Upadhyay (1998), Rajasegar (2003), Paramasivam and Kannan (2005) variations in pH values during different seasons of the year can generally be attributed to factors like removal of CO_2 by photosynthesis

Table 1 Descriptive statistics of monthly physico-chemical water parameters

Parameters	Range	SD	SE	CV	Variance	Mean
Temperature (°C)	26.5-29.5	1.148	0.434	0.042	1.319	27.57
Salinity $(^0/_{00})$	32-36	1.34	0.50	0.04	1.80	33.86
pH	7.9-8.3	0.13	0.05	0.017	0.02	8.11
Chlorophyll-a (mg/m^3)	0.95-1.39	0.17	0.06	0.14	0.01	1.21
DO (mg/l)	2-2.9	0.33	0.12	0.138	0.01	2.42
BOD (mg/l)	3.8-5.4	0.57	0.21	0.13	0.11	4.41
Alkalinity (mg/l)	118-125	2.41	0.91	0.02	0.32	121.9
Primary productivity (mg. C/m^2/d)	0.77-0.85	0.027	0.01	0.034	0.0007	0.8

through bicarbonate degradation, dilution of seawater by freshwater influx, reduction of salinity and temperature, and decomposition of organic matter. The high density of phytoplankton and the influence of seawater inundation may have affected pH values (Das et al. 1997; Subramanian and Mahadevan 1999). Aquatic life requires a pH that is best between 6.09 and 8.45 (Boyd and Lichtkoppler 1979). According to Dhage et al. (2006), the pH along the Mumbai coast ranged from 7.0 to 8.2. pH values between (6.5 and 8.5) were reported by Kamble et al. (2010) from coastal water off Mumbai.

Chlorophyll-a levels were found to be highest in January (1.39 mg/m^3) and their lowest in September (0.954 mg/m^3). It is believed that the most accurate indicator of phytoplankton is chlorophyll-a (Sahu et al. 2012). Less turbidity is advantageous for high chlorophyll-a concentrations because phytoplankton growth depends on light penetration. Changes in nutrient availability are frequently linked to variations in chlorophyll-a concentration. From Karwar to Mumbai waters chlorophyll-a concentrations, ranging from 2.0 to 21.36 mg/m^3 (Gopinathan et al. 2001). The low monsoonal values may have been caused by freshwater river discharges (dilution), which increased turbidity and reduced light availability (Kawabata et al. 1993; Godhantaraman 2002; Thillai Rajasekar et al. 2005). By using remote satellite sensing, the Chl-a data was compared to the in situ data. r^2=0.87 was recorded for the comparative Chl-a assessment coefficients of determination. The satellite's current observation of Chl-a was higher than the in situ measurement. The results of the current analysis demonstrate that the remote sensing satellite's prediction of Chl-a and found to be strongly correlated. A strong correlation (r^2=0.93) was reported for a similar observation made by Daqamseh et al. (2019) along the western Red Sea coastal areas. According to Baji et al. (2003a, b), Mumbai's Thane Creek had chlorophyll-a concentrations ranging from 3.20 to 35.24 mg/m^3. Using remote sensing and an artificial neural network, Chebud et al. (2012) reported a chlorophyll-a concentration of 0.17 mg/m^3 on a point scale with good accuracy. Different chl-a values were reported by Khalil et al. (2009), ranging from 1.00 to 56.00 mg/m^3 in near-shore waters and from 1.00 to 4.00 mg/m^3 in open sea. The same observational pattern was also noted by other authors (Chauhan et al. 2002; Hubert et al. 2010; Solanki et al. 2015).

The range of DO variations is small, and drastic changes were not seen. Low DO values were recorded in November, and higher DO values were recorded in February. An important factor in determining the quality of the water is dissolved oxygen. In particular, the relationship between physical flow and biological oxygen uptake results in DO variability in the water column. DO levels between 2.0 and 2.9 mg/l recorded. The DO variations in the current study have a narrow range, and drastic changes were not seen. In November, the DO value was low, and in February, it was high. Similar circumstances have recently been reported across the globe in estuaries and coastal groundwater (Lin

Table 2 Descriptive statistics of satellite derived physico-chemical water parameters

Parameters	Range	Max	Min	SD	SE	CV	Variance	RMSE	R^2	Mean
SST (°C)	25.9-28.8	28.8	25.9	0.991	0.374	0.036	0.981	0.713	0.79	27.51
SSS $(^0/_{00})$	32.5-35	35	32.5	1.027	0.388	0.03	1.055	0.517	0.90	33.74
Chlorophyll-a (mg/m^3)	0.14-4.43	4.43	0.14	1.636	0.618	0.643	2.675	1.925	0.83	2.54
Primary productivity (mg. C/m^2/d)	231.5-255	255	231.5	7.93	3.00	0.03	62.82	241.30	0.64	241.99

SD, standard deviation; *SE*, standard error; *CV*, coefficient of variation; *RMSE*, root mean square error

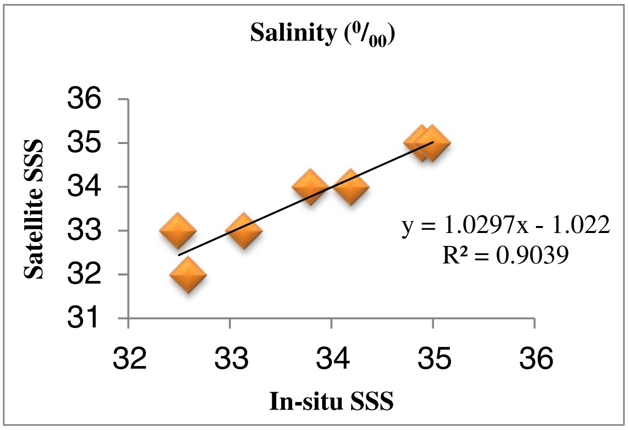

Fig. 2 In situ vs. satellite-derived reading SSS estimates

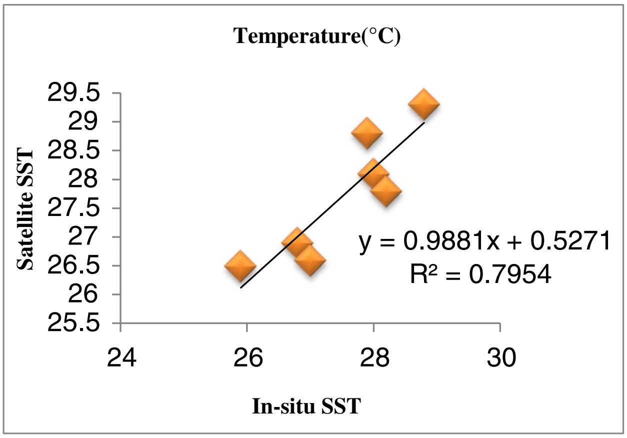

Fig. 4 In situ vs. satellite-derived reading SST estimates

et al. 2006). From India's south-east coast, Sreenivasulu et al. (2015) reported a DO ranged of 3.2–4.7 mg/l. From the Mumbai coast, DO was measured to be between 3.2 and 4 mg/l by Dhage et al. (2006). DO in coastal water off Mumbai was also reported by Kamble et al. (2010) to be in the ranged of 3–4.0 mg/l. The effects of temperature and salinity on the dissolution of oxygen in seawater are well known (Vijayakumar et al. 2000). During monsoon season, higher dissolved oxygen values were noted. Reduced agitation and turbulence of the coastal and estuarine waters may be the cause of relatively lower values. Higher wind speeds combined with heavy rain and the resulting freshwater mixing may have a cumulative effect that results in higher dissolved oxygen concentrations. Freshwater inflow and the ferruginous impact of sediments were the main cause of seasonal variation in dissolved oxygen (Das et al. 1997; Saravanakumar et al. 2008).

BOD levels were between 3.8 and 5.4 mg/l. Highest BOD values were recorded in March and lowest BOD levels in September. High BOD values indicate biological waste, and higher microbial oxygen consumption is required to break down organic compounds. The amount of temperature, metabolic activity, and organic matter in the atmosphere all affect how much biological oxygen is needed. BOD was found in the study to be between 3.8 and 5.4 mg/l. BOD values were highest in March and lowest in September. BOD levels were higher than the permitted standard for the coastal waters (3.0 mg/l). According to Selvan et al. (2016), BOD was lowest in September (2.87 mg/l) and highest in March (3.46 mg/l), while BOD was highest in the monsoon season (3.23 mg/l). According to Singh et al. (2010), BOD values along the Goa coast ranged from 1.05 to 3.0 mg/l. According to Dhage et al. (2006), BOD levels were 45 mg/l at Dadar and Mahim beaches and 13 mg/l at Bandra. The BOD value was observed to be up to 3 mg/l when Kamble et al. (2010) analysed the water quality parameters of various stations along the Mumbai coast.

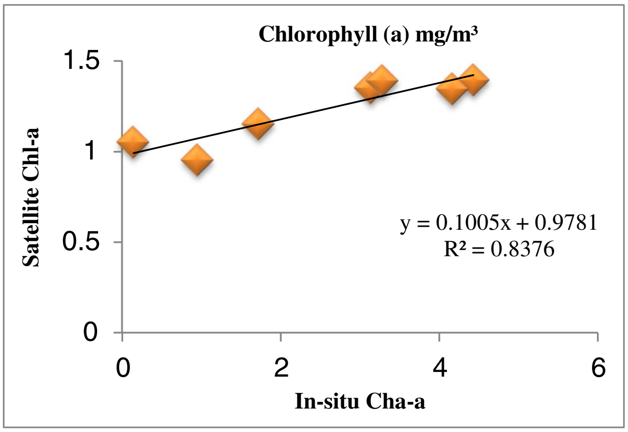

Fig. 3 In situ vs. satellite-derived reading Chl-a estimates

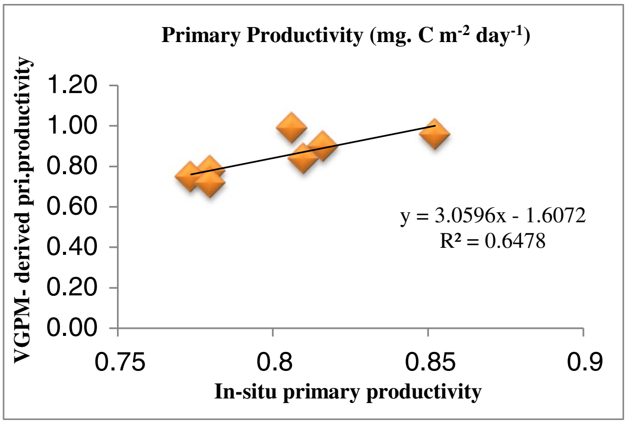

Fig. 5 In situ vs. satellite-derived reading primary productivity estimates

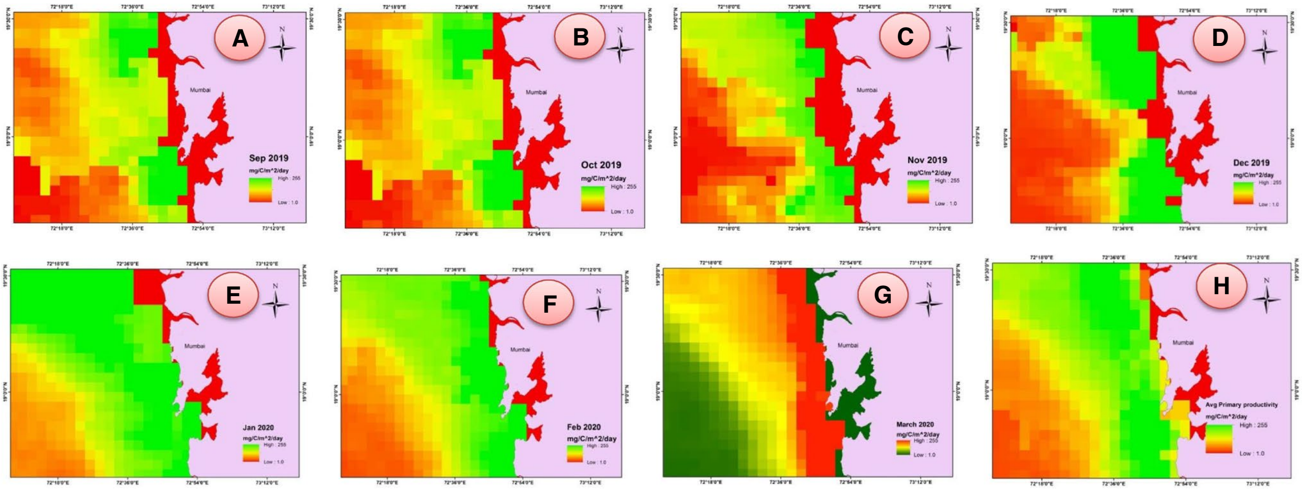

Fig. 6 Monthly primary productivity distributions along Mumbai coastal during September 2019 to March 2020. **A** September, **B** October, **C** November, **D** December, **E** January, **F** February, **G** March, and **H** average primary productivity during study period

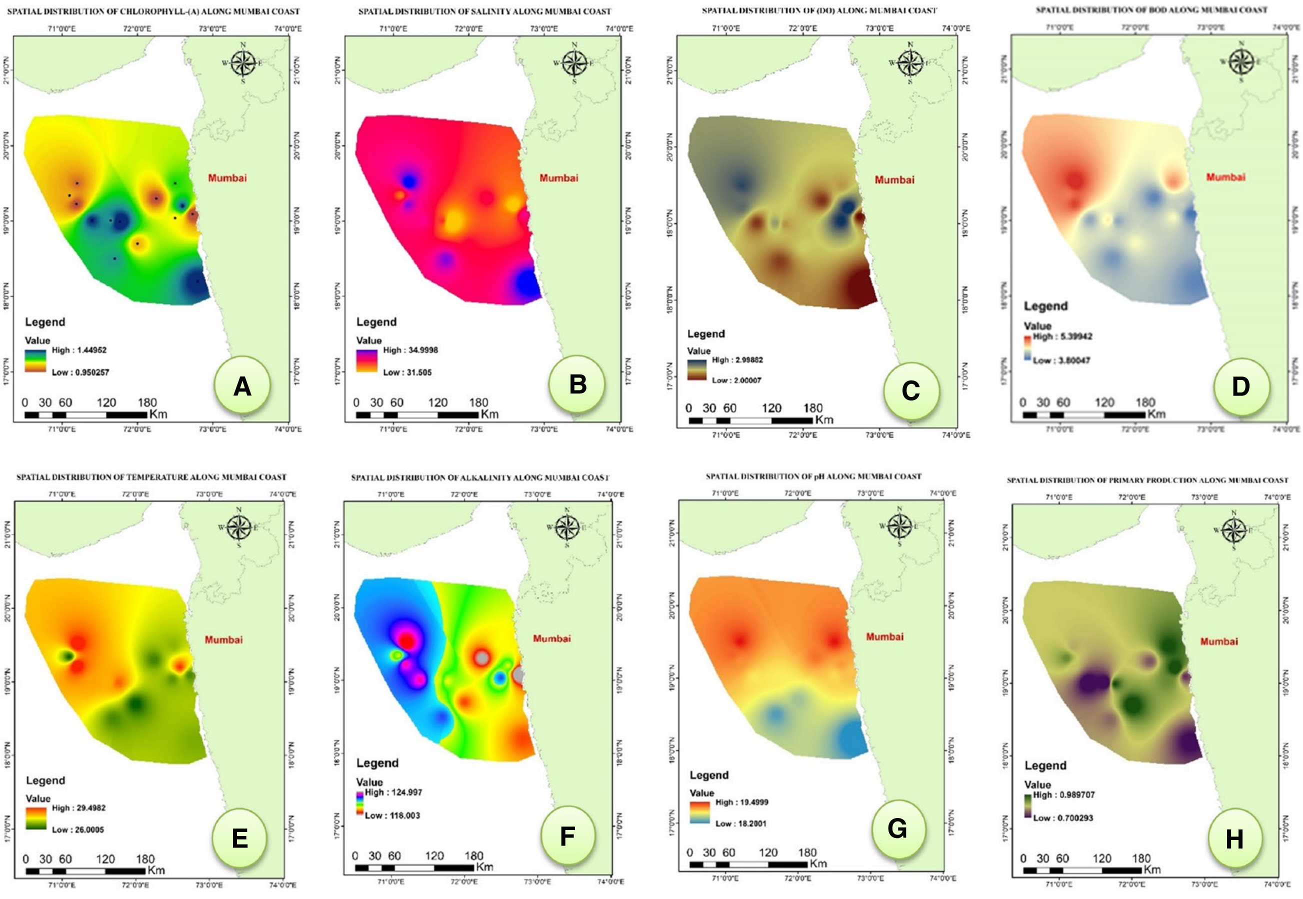

Fig. 7 Spatial distribution of physico-chemical water parameters analysis using IDW interpolation along the Mumbai coastal water. **A** Chlorophyll-a (mg/m^3), **B** salinity ($^0/_{00}$), **C** dissolved oxygen (mg/l), **D** BOD (mg/l), **E** temperature (°C), **F** alkalinity, **G** pH, **H** primary production (mg. C/m^2/day)

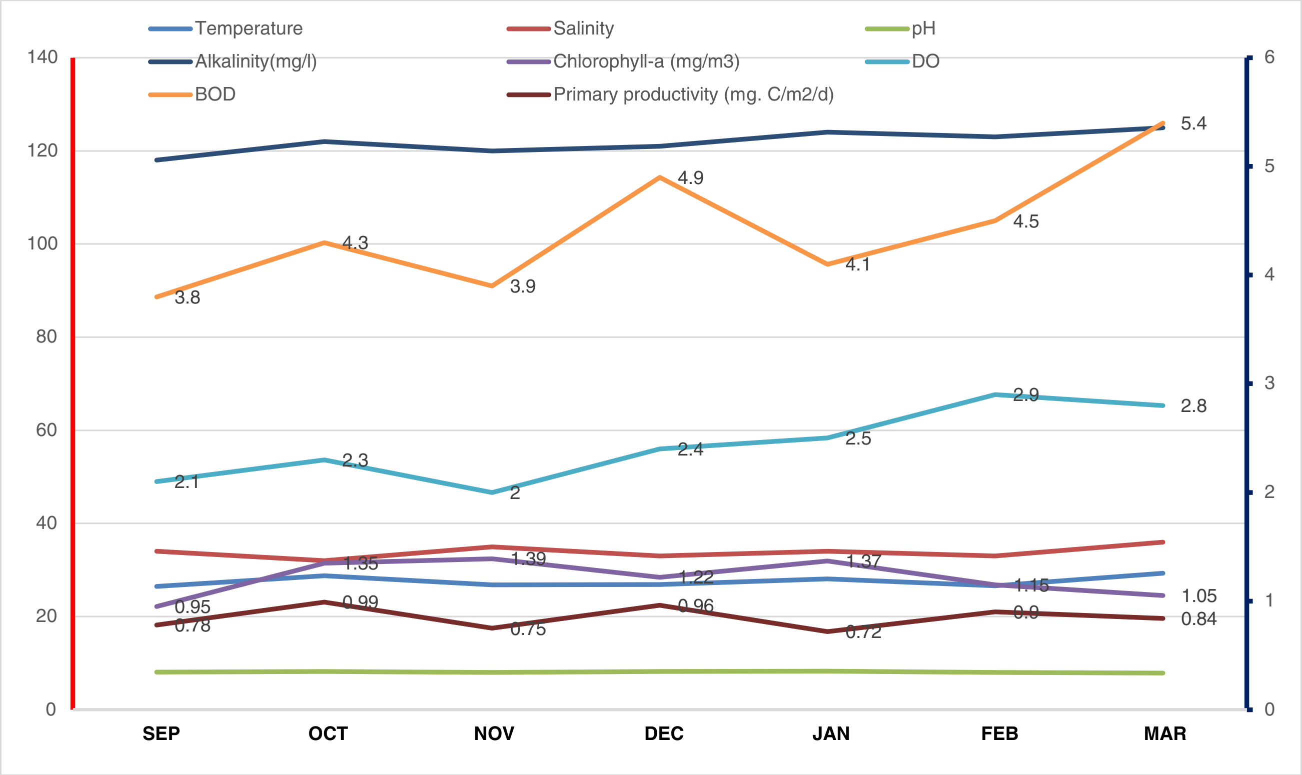

Fig. 8 In situ physico-chemical water parameters along the Mumbai coastal waters

The total alkalinity value in the current study ranged between 118 and 125 mg/l, with the highest value occurring in March and the lowest in September. The presence of a substance in the water that would change the pH has an impact on how much total alkalinity is present. The volume of bases (bicarbonates and carbonates) present in water at a specific concentration is used to calculate total alkaline (Ouyang et al. 2006). According to Selvan et al. (2016), the total alkalinity varied with the seasons, reaching its highest level in March (119.02 mg/l) and lowest level in September (117.04 mg/l).

In describing ecosystem function and its connections to environmental variability, elemental cycling, and community structure, primary productivity continues to be a crucially important quantity. The primary production rate was measured as 0.90 to 0.99 (mg. C/m^2/day). In October, primary productivity was highest, and in January, it was lowest. In addition to the reduction in salinity, which may have had an impact on the phytoplankton population, the observed low primary productivity during the monsoon may be related to the phytoplankton being washed into the neritic region by the monsoonal flood (Rajasegar et al. 2000). In marine environments, primary production is a crucial part of the biogeochemical carbon cycle. Primary production is a key element of how ecosystems function and plays a significant role in environmental change. Primary productivity levels along the Indian coast ranged from 3.0 to 8.7 g C m^{-2} day^{-1}, according to Nair et al. (1973). According to the current study, primary production varied between 0.90 and 0.99 mg C/m^3/day. October had the highest recorded primary production, and January had the lowest. The current primary productivity results are consistent with those that have already been published by various researchers (Barber et al. 2001; Radhakrishna et al. 1978; Knox et al. 1973). Primary production was discovered by the Arabian Sea Expedition to range from 1.06 to 1.64 g C/m^2/day (Barber et al. 2001). Primary production from the northern Arabian Sea was reported to be between 0.084 and 1.67 mg m^{-3} by Radhakrishna et al. (1978). The results of the current study are consistent with (Radhakrishna et al. 1978). In the estuary of Avon Heathcote in New Zealand, where an average of 2.38 g. O_2/m^3 day, primary production was observed (Knox et al. 1973).

The accuracy and suitability of the current analysis of in situ primary productivity against satellite-derived Vertically Generalized Production Model (VGPM)-based primary productivity for regional application were evaluated. Good correlations between in situ and satellite-derived observations were found (r^2=0.64). In the current study, the primary productivity observation ranges from 0.99 to 0.99 (mg. C/m^2/day) for in situ measurement and from 231.5 to 255 (mg. C/m^2/day) for VGPM-based derived values (Fig. 6). Zoppini et al. (1995) and Inamdar et al. (2011) found a similar trend in primary productivity. Comparative analysis of VGPM-based primary productivity has been conducted in conjunction with a number of global ecosystems (Campbell et al. 2002; Tilstone et al. 2005, 2009; Carr et al. 2006; Joo et al. 2015). VGPM-based primary productivity has been validated by a number of independent studies (Campbell et al. 2002; Tilstone et al. 2005, 2009; Carr et al. 2006; Friedrichs et al. 2009; Saba et al. 2010, 2011; Barnes et al. 2014; Joo et al. 2015). The current study shows higher values of VGPM-based primary productivity, indicating that it overestimated in situ values; other researchers have also noticed similar trends (Kameda et al. 2001; Campbell et al. 2002; Tilstone et al. 2005, 2009; Carr et al. 2006; Ye et al. 2015; Joo et al. 2015). The overestimation of primary production productivity based on satellite data may be caused by contamination of the Chl-a concentration caused by high concentrations of (CDOM) coloured dissolved organic matter and (NAP) non-algal particles absorption (Campbell et al. 2002; Carr et al. 2006; Tilstone et al. 2009; Joo et al. 2015). Light intensity and nutrient availability are the two main factors that affect variations in primary production. However, secondary factors such as temperature, phytoplankton cell sizes, and species composition can also influence primary production rates (Sathyendranath 2001; Boyd et al. 2014). Seasonal variations in phytoplankton pigment concentrations reveal the variability of biophysical processes that respond to environmental changes in the ocean's surface layer, such as primary production, grazing, and system changes that impact phytoplankton diversity (Barber et al. 2001; Kumar et al. 2001; Shevyrnogov and Visotskaya 2006; Harding et al. 2020). Details of the all satellite-derived and in situ water parameters are depicted in Tables 1 and 2 and Figs. 2, 3, 4, 5, 6, 7, 8, and 9. Interpolation of physico-chemical parameters by using IDW (Inverse Distance Weighted) depicted in Fig. 7.

Conclusions

Assessment of spatiotemporal variation of physicochemical parameters constitutes a preliminary contribution to the knowledge of on the Mumbai coastal water. Present study revealed that the study does not exhibit a large-scale spatial variability. All the parameters showed clear seasonal patterns and are typical to the tropical marine environment. Increased amount of BOD values illustrated that the major sources of variation were anthropogenic discharges. This study suggests that increasing anthropogenic activities

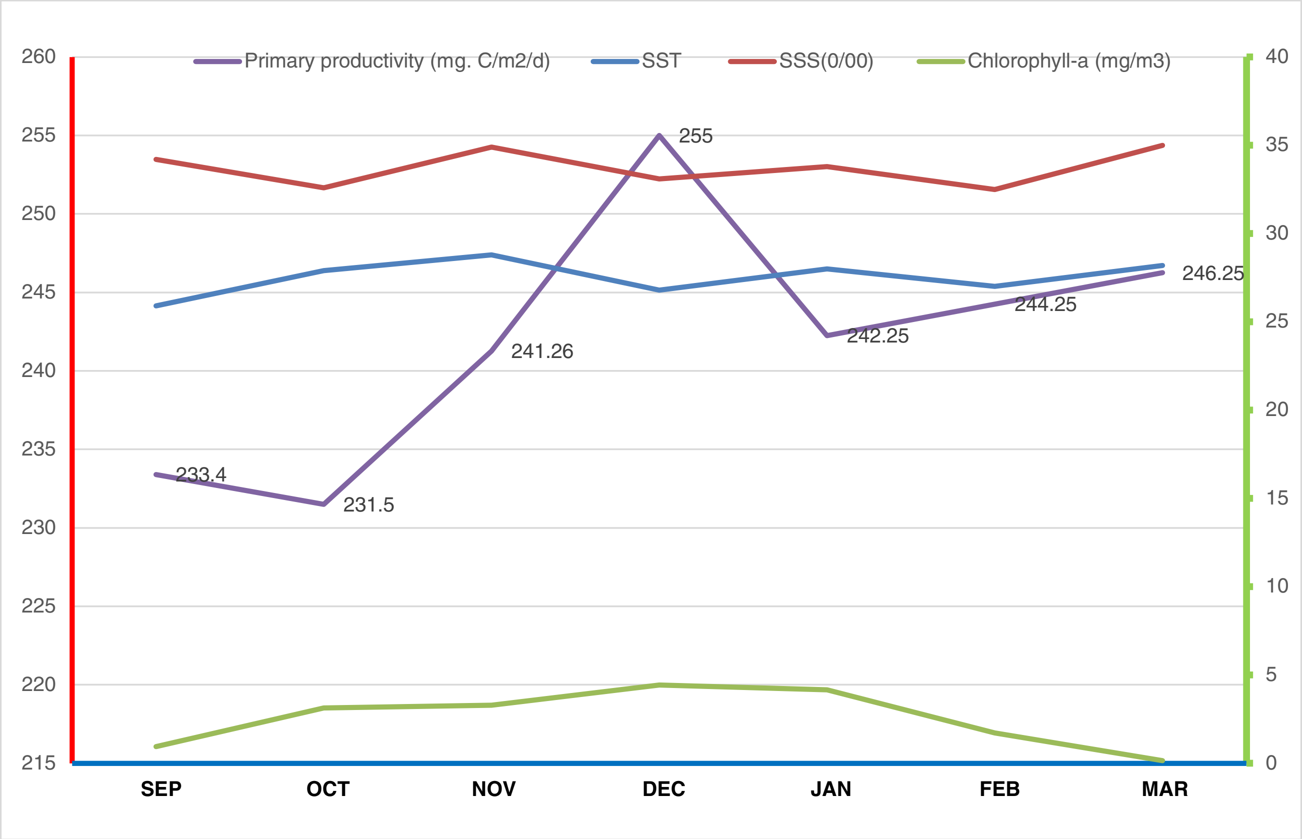

Fig. 9 Satellite derived physico-chemical water parameters along the Mumbai coastal waters

draw the need for creating a comprehensive database and monitoring strategy to better plan, conserve, and manage the tropical coastal environment. Accuracy assessment of remotely-sensed SST, SSS, Chl-a with in situ measurements showed slight mismatch which led to suggested its applicability for monitoring strategy to plan, conserve, and manage the tropical coastal environment. VGPM model derived PP require further adjustment for its application in coastal water. Increased load of organic matter and effluents discharge led to overestimation of the primary productivity. Higher PP values attributed to an overestimation of Chl a concentration by contamination from a high concentration of Coloured Dissolved Organic Matter (CDOM). The near real-time availability of these data with the adjustment would allow their use in forecast models for coastal water monitoring.

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Karankumar Kishorkumar Ramteke: Conception and design of study, Interpretation of data, Supervision, Analysis and interpretation of data, Critical revision, Writing—review & editing.

Dhanalakshmi Mathialagan: Interpretation of data, Data analysis, Drafting the manuscript.

Declarations

Conflict of interest The authors declare no competing interests.

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