

Southwest monsoon influences the water quality and waste assimilative capacity in the Mandovi estuary (Goa State, India)

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Abstract

The monsoon dominated Mandovi estuary is located in Goa state - a global tourist destination along the central west coast of India. In addition to factor analyses of water quality data, the water quality index (WQI), trophic state index (TSI) and percentage of freshwater volume in the estuary are calculated in order to infer the general waste assimilative capacity and prevailing water quality conditions. Factor analysis showed a dominance of PO₄-P, NO₂-N, NH₃-N, TSS and turbidity during southwest (SW) monsoon relative to other seasons. WQI suggested that increase in nutrients, turbidity and TSS during SW monsoon increase the WQI values beyond 2, rendering the water at some locations slightly polluted. During pre-monsoon, considerable increase in WQI is observed at all the upstream stations rendering slightly polluted water at these stations. TSI showed an average value of 46.95 during SW monsoon, 42.43 during post-monsoon and 48.42 during the pre-monsoon seasons, suggesting better productivity level during pre-monsoon, followed by SW monsoon, but the least during the post-monsoon. All the seasons, however, indicated a mesotrophic condition in the estuary and the assimilative capacity of the estuary is found to be in good to fairly good state (pre-monsoon < SW monsoon < post-monsoon).

Keywords: assimilative capacity; factor analysis; water quality; monitoring; trophic state index.

1. Introduction

Environmental changes are frequently caused by human activity, particularly on coastal zones where majority of the population live [1]. Coastal water bodies around India are diverse environments, viz. creeks, estuaries, bays, wetlands, etc. Since the recent past, the adjacent coastal regions have become the hubs of anthropogenic activities due to industrialization, urbanization, boat traffic, fishing, recreation and tourism related activities [2,3] which depend upon coastal water in one way or the other. The waste material from urbanization and industrialization are treated to a considerable extent, but most of the treated and untreated anthropogenic contaminants ultimately enter the coastal water for their transportation into the sea. These contaminants cause a serious threat to the delicate balance between various physico-chemical and biological characteristics of the environments [4,5]. Among the coastal water bodies, the estuaries act as filters or exporters of both organic and inorganic material [6] that transport large quantities of natural and anthropogenic materials to the coastal water. The estuaries are peculiar ecosystems exhibiting both freshwater and marine characteristics and are the most productive ecosystems around the globe [7]. A large number of estuaries located along the coast of the Indian subcontinent are influenced by the Indian Summer Monsoon (ISM) and are referred to as “monsoonal estuaries” [8,9]. In these monsoonal estuaries, the physical and chemical properties swing between pre-monsoon, monsoon and the post-monsoon seasons as per the runoff and river discharge. The ecosystem and natural habitats associated with these estuaries routinely adjust to these seasonal changes [10]. Furthermore, the influence of anthropogenic waste, land runoff and the riverine discharge in these estuaries affects the water quality parameters bringing about significant changes in water quality, productivity and the discharge quantity of water during different seasons. In water quality management, the determination of each water quality variable is important to obtain collective information on water quality, as it can provide concise information on overall environmental conditions [11]. Practically, it is difficult to assess water quality based on each parameter/variable. Water quality indices of significantly influential parameters, aim at giving a single value to the water quality of a source on the basis of a system which translates their existing concentrations in a sample into a single value. These values are used as communication tools by regulatory agencies to describe the quality or health of a specific environmental system [12]. In recent times, eutrophication (over-enrichment of water by nutrients) has emerged as one of the main threats to water quality in estuarine and coastal waters, which can cause undesirable environmental effects [13]. Trophic State Index (TSI) assesses the eutrophication rate in an aquatic ecosystem and is useful to gain insights into its health. These indices will also help to determine

the assimilative capacity in an environmental management perspective. The natural ability of a water body to withstand or assimilate certain amount of pollutants is termed as the Waste Assimilative Capacity (WAC)/assimilative capacity/carrying capacity/ Self purification capacity [14-17].

The dissolved oxygen (DO) is a crucial water quality parameter essential for the survival of aquatic organisms and health of the ecosystem [18]. The oxygen saturation in the estuarine water is affected by temperature, salinity and tidal action. Warm, Saline water is less capable of holding oxygen than fresh, cooler water [19-20]. DO solubility is also affected by the altitude. In addition to this, the rate of metabolism of organisms and chemical processes consume and release oxygen. The organic matter in water resulting from metabolism and external sources contributes to the decrease in DO. This demand for oxygen in degrading the organic waste material is the biochemical oxygen demand (BOD), which is widely used to determine the extent of organic pollution in a water body [21]. Moreover, DO, BOD and nutrients, which help in assessing the quality of a water body, also assist in understanding the WAC of water bodies [22].

In the present study, an attempt has been made to decipher the general assimilative capacity and water quality conditions over different seasons in the Mandovi - a tropical monsoon dominated estuary located along the west coast of India.

2. Material and methods

2.1 Study Area

The Mandovi estuary is located in Goa state along the west coast of India. The region is a global tourist destination famous for its pristine beaches and historical monuments. The region also has mining, fishing and port related activities. The Mandovi River, draining into the eastern Arabian Sea, is one of the major rivers of Goa (Figure 1) along the west coast of India. The river is about 50 km long and 5 m deep (average). It is connected to another major river, the Zuari River through a canal, forming the major estuarine system called the Mandovi - Zuari estuarine system, which acts as a life line of Goa [23]. The Mandovi estuary is a tide dominated, coastal plain estuary and the tidal range is about 2.0 m [24]. Tidal reversal and seasonal changes bring about large variations in the physico-chemical and biological properties of the estuary. The estuary is provided with a large number of tributaries, which bring in freshwater from its catchment areas. The physical, chemical and biological features of this estuary are determined by the annual cycle of the ISM. The rainfall during SW monsoon results in heavy runoff into the Arabian Sea. The volume of the Mandovi (excluding the Aguada Bay) is about 70Mcum

and in an average year, the volume of freshwater flowing through the Mandovi exceeds the volume of the estuary by a factor of about 20 if using the Ganjem (gauging station located 50 km from the mouth of the Mandovi) runoff and 40 if using the Panaji (the Mandovi drains into the Arabian Sea in the vicinity of Panaji) runoff [25]. Heavy precipitation during the SW monsoon season (July–September) reduces the salinity, with more or less freshwater conditions prevailing in the estuary due to the drainage from its catchment areas. Consequently, the estuary remains stratified during the monsoon season with a salt wedge formed up to 10 km upstream [26]. The SW monsoon is followed by a recovery period during the post-monsoon season (October–January) and thereafter a stable pre-monsoon (February–May), a hot and dry season. During pre-monsoon, the estuary remains well mixed, with an intrusion of salt water felt far upstream, making it marine dominated.

Land use in the catchment area is mixed. The settlements along the estuaries discharge raw waste (a common practice), including septic waste, directly into the estuaries. Apart from such daily discharges of untreated sewage effluents, deliberately or incidentally at various locations, the seaward flows during low tide-times increase the amount of effluents [27]. Though the treated sewage from Panaji city is discharged at a location 3.93 km upstream from the estuarine mouth, both the channel and the bay region receive untreated sewage as well [28]. The sewage treatment in the region was initialized in 1976, facing great difficulties in smooth running hence mostly sulfidic conditions remained throughout the sewage channel due to periodic stagnancy. A new technologically improvised system was installed in 2005 with a sewage treatment capacity of 12.5 million litres/day though it normally handles 7 – 8 million litres/day only, in a region where intense monsoon activity can cause floods [29]. The raw sewage effluents (data from Public Works Department, Govt. of Goa) from Panaji city indicated strong effluent type as per the conventional classification of sewage types (strong [400mg O₂/L], medium [250mg O₂/L] and weak [110mg O₂/L] classes of sewage). The water quality parameters in raw and treated sewage averaged (2011-2013) for three seasons (pre-monsoon, SW monsoon and post-monsoon) are represented in Table 1.

2.2 Sampling Methodology and Laboratory analyses

The hydrographic data were collected using a CTD profiler (SBE 19+) at six stations (Table 2) in the Mandovi estuary during three different seasons: pre-monsoon, SW monsoon and the post-monsoon of 2010 to 2011. Surface and bottom water samples were collected from each of these 6 stations during low and high tide by operating a 5 L Niskin water sampler on board a hired fishing trawler. Soon after

collection, the DO was fixed onboard by Winkler's reagents; BOD was analysed after 5 days of incubation at the shore laboratory. The water samples collected for nutrients, chlorophyll a, Petroleum Hydrocarbons (PHc) and phenolic compounds were analysed as per standard methods [30,31]. Nephelometry was used for turbidity measurements and total suspended solids (TSS) were measured by the filtration method [30]. The microbiological analyses for total viable coliforms (TVC), total coliforms (TC) and total vibrios (TV) [32] were carried out for each of the surface and bottom water samples. Urea was determined by the modified diacetyl monoxide method [31]. Dissolved reactive phosphate was measured by the method in which the samples were made to react with acidified molybdate reagent and reduced using ascorbic acid. The absorbance of the resultant blue complex was measured at 880 nm using Shimadzu UV 1200 spectrophotometer. Nitrite was measured by diazotising with sulfanilamide and then coupling with N (1-Naphthyl)-ethylene diamine-dihydrochloride. The absorbance of the resultant azo-dye was measured at 543 nm using Shimadzu UV 1200 spectrophotometer. Nitrate in the sample was first reduced quantitatively to nitrite by heterogeneous reduction by passing the buffered samples through an amalgamated cadmium column, and the resultant nitrite was analyzed by diazotisation. The difference between the initial nitrite in the sample and the nitrite obtained after the reduction of nitrate, gives the quantity of nitrate. Ammonia was determined by the indophenol blue method by reacting it with hypochlorite in an alkaline medium in the presence of a catalytic amount of nitroprusside to form indophenol blue. The formation of monochloramine requires a pH between 8 and 11.5, which was measured spectrophotometrically. The determination of silicates in water is based on the formation of yellow silicomolybdic acid when a nearly acidic sample is treated with a molybdate reagent. The yellow silicomolybdic acid was reduced to an intensely blue colored complex using ascorbic acid and the reductant colour was measured spectrophotometrically at 810 nm. Dissolved / dispersed petroleum hydrocarbons were extracted from seawater with double distilled hexane and quantified using Shimadzu RF1501 fluorescence spectrophotometer. Reference material used for quantifying hydrocarbons was the Bombay High Crude Oil. Phenols in 500 ml of water were converted to organic coloured antipyrine complex by adding 4-amino-antipyrine. The complex was extracted in 25 ml chloroform and its absorbance was measured at 460 nm using phenol as a standard. For Total Phosphorous, a known quantity of the seawater sample is autoclaved at 115 °C (in an autoclave under pressure) with alkaline potassium persulphate in a closed bottle. The solution is neutralized and then estimated using inorganic / dissolved phosphorous method. Total nitrogen was estimated by the persulphate oxidation technique in which the nitrogen compounds were converted to nitrates by alkaline

persulphate at 115 °C and the resultant NO₃-N was reduced to NO₂-N by passing through cadmium reduction column. Finally the NO₂-N was estimated by diazotization, then coupled with aromatic amines and measured at 543 nm by a spectrophotometer. Fluoride, hardness and sulphate were analyzed as per the standard methods [32]. The DO, temperature and salinity data generated were processed for calculating oxygen saturation and freshwater volume using the method given by American Public Health Association (APHA) applying Fortran program; whereas the factor analyses, water quality index and trophic state index were used to understand the dominant contaminants for evaluating water quality changes affecting the assimilative capacity of Mandovi estuary over different seasons. The apparent oxygen utilization (AOU) value was obtained by subtracting the measured DO value from the saturation value. SI 01 indicates the water quality parameters, equipment used and data sources.

2.3 Oxygen saturation equation and freshwater volume

In estuaries, the most important factors affecting the oxygen saturation are temperature, salinity and partial pressure variations due to elevation [33]. The Mandovi meanders over the coastal plain and the elevation from the mouth to 50 Km upstream is small [10], so the pressure effect on saturation can be neglected for this study. A FORTRAN program (SI 02) was employed in computing the dissolved oxygen saturation and percentage of freshwater volume in the estuary over three seasons as given by Chapra [33].

a. Temperature effect

The following equation was used to establish the dependency of oxygen saturation on temperature

$$\ln O_{sf} = -139.34411 + \frac{(1.575701 \times 10^5)}{T_a} - \frac{(6.642308 \times 10^7)}{T_a^2} + \frac{(1.243800 \times 10^{10})}{T_a^3} - \frac{(8.621949 \times 10^{11})}{T_a^4} \quad (1)$$

Where ,

O_{sf} = saturation concentration of DO in freshwater at 1atm (mg l⁻¹)

$T_a = T + 273.5$

T_a = absolute temperature (K)

T = water temperature in °C

b. Salinity effect

The following equation was used to establish the dependency of oxygen saturation on salinity

$$\ln O_{ss} = \ln O_{sf} - S \left\{ 1.7674 \times 10^{-2} - \frac{(1.0754 \times 10^1)}{T_a} + \frac{(2.1407 \times 10^3)}{T_a^2} \right\} \quad (2)$$

Where,

O_{ss} = saturation concentration of DO in seawater at 1 atm (mg l^{-1})

S = salinity (g l^{-1} = practical salinity unit)

c. Salt water saturation value

$$SS = e^{(O_{ss})} \quad (3)$$

Where,

SS = salt water saturation value

d. Percentage of freshwater

$$PF_w = \left\{ \frac{SS}{e^{(O_{sf})}} \right\} \times 100$$

(4)

Where,

PF_w = Percentage of freshwater

2.4 Factor analysis

Factor analysis is one of the multivariate statistical approaches widely used for deriving the significance of specific parameters among the data. In this study, factor analysis is used for evaluating the water quality status of the Mandovi estuary during different seasons in order to identify the dominant variables using the software program STATISTICA. To generate the principal components (PCs), the R-mode (sorted) factor analysis was used, which resulted in eigen values, percentage of variance and cumulative percentage of the data set, allowing for inter-parameter relation and variation in water quality [34,35]. In the study area, major variation is shown by the first 2 or 3 factors, whereas the remaining factors show less than 10% variation. These factors exhibit inter-relationship of parameters useful in evaluating the environmental status. Hence, 5 factors were generated but the major explanation is largely based on the first 3 factors only.

A varimax rotation of different varifactors with factor loadings calculated the eigen value greater than 1, which were sorted by the results having values greater than 0.4, based on significant influence [36-38]. Rotation of the axis as defined by factor analyses produced a new set of factors, each one primarily involving a sub set of the original variables with as little overlap as possible so that original variables could be divided into groups. The factor loadings were classified based on absolute loading values and were categorized as strong (> 0.75), moderate (0.75-0.5) and weak (0.50-0.40) corresponding to absolute loading values [39].

2.5 Water Quality Index (WQI)

Water quality is a multi-parameter attribute, influenced by a large number of physical, chemical, biological and bacteriological factors. This can be used to infer the assimilative capacity by utilizing the observational data as high WQI values normally indicate polluted waters because the polluted waters have low assimilative capacity. The WQI is frequently utilized around the globe as a mathematical tool for evaluating water quality status [40-43], transforming the bulk water quality data into a single digit, cumulatively derived numerical expression indicating the level of water quality [44]. In calculating water quality, a total of nine parameters are primarily used to develop the index (WQI). These nine parameters are DO, BOD, pH, temperature change, total phosphates, nitrates, turbidity, total solids and fecal coliform. All these parameters are selected as per the classification scheme of Inland Surface Water in India for classification of the types of water, a scheme which is accepted by the Central Pollution Control Board (CPCB) [45], for recommending the suitability of water for specific use. Thus, for each water quality parameter, the WQI is first measured individually by using the equation obtained from the value function curve in which, the concentration of the parameter is taken on Y-axis and the index value on X-axis and plotted [46]. These measured values are then transformed into a single number called the Overall Index of Pollution (OIP), representing the overall quality of water at that particular location. The OIP values are estimated as the average of all the pollution indices (P_i) for individual water quality parameters considered in this study as per the equation (5)

$$OIP = \Sigma_i P_i / n \quad (5)$$

where, P_i = pollution index for i^{th} parameter

$i = 1, 2, \dots, n$

n = number of parameters.

The riverine/estuarine water is then categorized as Excellent, Acceptable, Slightly Polluted, Polluted and Heavily Polluted based on these OIP values as indicated in SI 03. From this categorization, the general assimilative capacity of the estuary can be identified.

2.6 Trophic State Index (TSI)

Recently, there has been a resurgence of interest directed at the development of criteria for assessing the ecological state of estuarine and coastal environments, primarily to assess eutrophication [47]. This is done by using Trophic State Index (TSI) and it can be applied to any surface water body. TSI is a classification system designed to "rate" individual water bodies based on the amount of biological productivity/ eutrophication rate occurring in water [6,48]. The quantities of nitrogen, phosphorus and other biologically useful nutrients are the primary determinants of the water body's TSI. Nutrients such as nitrogen and phosphorus tend to be limiting resources in standing water bodies and increased concentrations tend to result in increased plant growth, followed by analogous increase in subsequent levels. Carlson's index is one of the most commonly used trophic indices [49], which is also used by the United States Environmental Protection Agency. This index can give a quick idea about the productivity of a water body by its assigned TSI number. TSI classification ranges from 1 to 100. A water body is usually classified as one of the three possible classes: oligotrophic, mesotrophic or eutrophic. Water bodies with extreme trophic indices may also be considered hyperoligotrophic or hypereutrophic as shown in the SI 04. Oligotrophic water bodies host very little or no aquatic vegetation and are relatively clear compared to eutrophic water bodies. In mesotrophic water bodies, the water is moderately clear. Each trophic class also supports different type of fauna. When the productivity is high or very high (high trophic state), it reduces the available DO in the water column. Thus, the high trophic state indicate low assimilative capacity and low trophic state indicates high assimilative capacity of a water body.

3. Results and Discussion

The assimilative capacity of a water body primarily depends on the DO concentration. As the DO is utilized for the oxidization of the organic matter in water, it is an indicator of the health of a water body. Thus, High DO concentration in the water column indicates higher assimilative capacity of the water body. The observed surface DO values at various stations in the estuary were compared with the calculated oxygen saturation values to get a general idea about the oxygen utilization in the estuary. The patterns for the observed DO and calculated oxygen saturation values during the high tide period, irrespective of seasons, have been worked out and are shown in figure 2. It can be noted that, during the

pre-monsoon season, the observed DO values in the mid estuary are lower compared to the calculated oxygen saturation values during low tide (Figure 2 a). This is due to high BOD content as compared to other regions of the estuary. Similarly, the observed DO and calculated DO saturation values show much difference in the upstream stations during the low tide of monsoon season (Figure 2 c). This is also attributed to high BOD values encountered at these stations (around 3 mg/L) as compared to very low values (as low as 0.35 mg/L) at the remaining stations. During the post monsoon period (Figures 2e & f), the observed and calculated DO values do not show much difference. The BOD values (Figure 3) are typically low as compared to the pre-monsoon period. The AOU in the estuary during the three seasons indicates that the assimilative capacity is comparatively good throughout the estuary.

The freshwater runoff is high in the estuary during the monsoon season, providing an additional advantage in diluting and flushing the contaminants out of the estuary and largely helping to maintain a good and acceptable quality of water in the estuary during the monsoon season and thus maintaining good assimilative capacity. The percentage of freshwater influx to the estuary was calculated at each station, which indicated that the percentages of freshwater (Figures 4a and 4b) in the estuary follow the river discharge pattern. Figure 5 indicates the typical discharge pattern in the Mandovi estuary, which shows the highest discharge during the SW monsoon season. The highest volume of freshwater (SI 05 & 06) in the estuary is found during the SW monsoon season and is slightly more during the low tide (av.96%) as compared to that during the high tide (av.94.7%). Following the SW monsoon, the next higher volume is observed during the post-monsoon season and it is nearly similar during low tide and high tide (av. 93%). The lowest volume, however, is observed in the pre-monsoon season, which is 87.7% during high tide and 86.2% during low tide. The highest volume during the monsoon season is due to the monsoonal fall and land drainage which brings in large amounts of freshwater from its catchment areas through a number of tributaries during which the estuary becomes freshwater dominated. Similarly, the lowest volume during the pre-monsoon season is due to reduced freshwater flow to the estuary when the estuary becomes nearly marine dominated. The high seasonal run off flushes the estuary regularly, thereby getting rid of land generated pollutants. This also increases the general assimilative capacity of the estuarine environment.

The dominant parameters affecting the water quality over different seasons is deciphered using factor analyses. This will help in understanding the contaminants which influence the water quality and assimilative capacity of the estuary, as the external loading of contaminants reduces the assimilative capacity. The factor analyses showed that during SW monsoon season (SI 07), fluoride (0.94) and

nutrients such as $\text{NO}_2\text{-N}$ (0.93), $\text{PO}_4\text{-P}$ (0.82) and $\text{NH}_3\text{-N}$ (0.78) along with TSS (0.82) and TVC (0.81) are strongly loaded in factor 1, indicating their dominance in the estuary. This is followed by moderate loadings of turbidity (0.68), TP (0.61) and SO_4 - (0.57). To understand the effect of these dominant parameters on the quality of water in the estuary during the SW monsoon season, the WQI was used, which showed variations in WQI values depending upon the extent of parameter loadings. The calculated WQI values were then converted to OIP which showed a variation from 2.04 to 3.32 in the bottom water layers of the first 3 stations from mouth to near mouth stations in the estuary (M1 to M3) relative to surface. The average OIP values of surface and bottom water layers at these 3 stations (M1 to M3) show range of values from 1.91 to 2.46, suggesting that water at M2 remains slightly polluted while that at stations M1 and M3 tends to be closer to slightly polluted water. The OIP values of the other 3 stations, range from 1.33 to 1.96 irrespective of depth, and these values are less than the OIP value of 2 (Table 3). This suggested acceptable quality of water at the remaining stations in the estuary during high tide. During low tide of the SW monsoon season, the OIP values at the surface layer range from 1.36 to 2.25 whereas at the bottom water layer it ranges from 1.69 to 2.48. The higher value of 2.25 is observed at the surface layer at M3, and a value of 2.09 at the bottom water layer at M5. Both these values are above the OIP value of 2 and therefore suggested slightly polluted condition of water at these two stations. All the other stations show acceptable quality of water with OIP values remaining below 2. The effect of the changes in water quality on productivity potential of the estuary was evaluated using TSI. The TSI values calculated for each of the water depth samples at these 6 stations in Mandovi estuary during the monsoon season indicated a variation from 32.94 to 56.57, with higher values at stations M1 to M3 (mouth to near mouth). However, the average TSI value calculated for all the 6 stations gave a value of 46.95 (Table 4) which suggested a mesotrophic condition of the estuary during the SW monsoon season. Thus, during SW monsoon, external loadings of fluoride, $\text{NO}_2\text{-N}$, $\text{PO}_4\text{-P}$, $\text{NH}_3\text{-N}$, TSS or TVC can affect the assimilative capacity of the estuary. The WQI and TSI indicate considerably good assimilative capacity of the estuary during SW monsoon.

During the post-monsoon, factor analyses (SI 08) showed strong positive loadings of fluoride (0.84) and SO_4 - (0.76) and moderate loading of TVC (0.57) in factor 1, indicating their dominance in the water. This is followed by strong positive loadings of urea (0.82) and TN (0.78) in factor 2. The impact of these dominant parameters on water quality evaluated by calculating the WQI values showed the OIP values ranging from 1.02 to 1.46 in surface water layer and from 1.16 to 1.87 in the bottom water layer (Table 5) during the low tide. All these values are found to be much below the OIP value of 2, and thereby

indicate good and acceptable quality of water during the post-monsoon season. Similarly during the high tide, the OIP values vary from 1.01 to 1.83 at the surface water layer and from 1.17 to 2.33 at the bottom water layer. This showed that except for one high OIP value of 2.33 observed at the bottom water layer at station M3, all the other OIP values are much below the OIP value of 2. This indicated acceptable quality of water at all the other stations in the estuary during the post-monsoon season. The TSI values calculated for each of the water depth samples at 6 stations in the estuary during the post-monsoon season indicated a variation in TSI values from 29.47 to 44.47, with no fixed trend of higher values. The overall TSI value calculated for all the stations shows a value of 42.43 (Table 6), which is much lower than the one observed during the monsoon season suggesting a mesotrophic condition of the estuary during the post-monsoon season. This also suggested the input of low nutrients to the estuary during the post-monsoon season relative to the monsoon season. Thus, during post-monsoon, the assimilative capacity of the estuary can be affected by fluoride, SO_4^- , urea, TVC and TN. The WQI and TSI indicate a fairly good assimilative capacity of the estuary.

During the pre-monsoon season, the factor analyses (SI 09) showed strong positive loadings of salinity (0.94), total hardness (0.90), Ca-hardness (0.96), Mg-hardness (0.88) and SO_4^- (0.92), with negative loadings of nutrients and moderate positive loading of fluoride (0.69) in factor 1, indicating their impact on water quality. This is followed by moderate positive loading of phenol (0.52) in factor 2 and of $\text{PO}_4\text{-P}$ (0.51), $\text{NO}_2\text{-N}$ (0.53) and silicate (0.58) in factor 3, respectively. The impact of these dominant parameters on the water quality of the estuary, evaluated by calculating the WQI values, showed OIP values ranging from 2.01 to 2.69 at the surface water layer and from 2.04 to 2.48 at the bottom water layer (Table 7) during the low tide. All these values are found to be higher and remain above the OIP value of 2, and thereby indicated slightly polluted water all over the estuary during the low tide of pre-monsoon season. Similarly during the high tide, the OIP values varied from 1.82 to 2.63 in the surface water layer and from 1.91 to 2.82 in the bottom water layer. This showed that except for one last station M6 towards upstream showing low OIP values of 1.82 to 1.91, all the other stations showed higher OIP values above the OIP value of 2. This indicated a slightly polluted water condition at the other stations (M1-M5) during the pre-monsoon season and is due to high BOD, total phosphates, nitrates, fecal coliform and negligible river run off. The TSI values calculated for each of the water depth samples at these 6 stations during the pre-monsoon season indicated a variation in TSI values from 43.47 to 54.66. The overall TSI value calculated for the stations gave a value of 48.42 (Table 8), which is slightly higher than the values observed during the SW monsoon and post-monsoon seasons. Though, the observed TSI

value of 48.42 was found to be relatively higher, it falls in the range of mesotrophy, which therefore suggested a mesotrophic condition of the Mandovi estuary during the pre-monsoon season. The assimilative capacity during this season can be affected by SO_4 , fluoride, $\text{PO}_4\text{-P}$ and $\text{NO}_2\text{-N}$. Though there are some high values at some stations, the general trend of WQI and TSI throughout the estuary indicates good to fairly good assimilative capacity. The assimilative capacity of the estuary is found to be in good to fairly good state (pre-monsoon < SW monsoon < post-monsoon) considering the dominant contaminants, WQI and TSI. We have also compared the water quality conditions of other estuaries/coastal water bodies (Table 9) situated on the west coast of India with that of the Mandovi estuary [4,40,44, 50-61]. The prevailing estuarine water quality of the Mandovi estuary is found to be good and acceptable as compared to most of the other regions along the west coast of India.

4. Conclusion

Though there are a number of tourism related activities in the region, the overall water quality condition in the Mandovi estuary remains considerably good. During post-monsoon, the influence of dominant parameters is less and the water in the estuary is of acceptable quality. During pre-monsoon, though the influencing dominant parameters are less in the estuary, the prevailing marine conditions and other influencing environmental factors change the water quality making it slightly polluted. The estuary receives more contaminants of nutrients, considerable BOD at its mid region and at the upstream, with increasing TSS and turbidity from land drainage and monsoonal flow. The high land runoff during the SW monsoon contributes to large quantities of suspended matter; transports land derived and riverine organic material from the upstream region to the estuarine region. This changes the water quality of the estuarine water making it slightly polluted at the mouth and near mouth stations during the SW monsoon season. The TSI values suggest a mesotrophic condition during all the seasons. The overall assimilative capacity of the estuary is good and the estuarine water appears to be healthy. However, the slightly polluted water condition observed at selected stations in the Mandovi estuary could be a signal of gradually increasing anthropogenic pressure from various ongoing developmental and tourism activities on the aquatic ecosystem. The seasonal variability in the Mandovi estuary coupled with the input of large contaminants from various anthropogenic sources can change the quality of the estuarine water due to the dominance of influencing contaminants, which can affect its productivity. Stringent regulations should be implemented to preserve and regulate the water quality for sustainable development in future.

Acknowledgements

The authors are grateful to Director, CSIR-NIO, Goa for providing facilities to carry out the work and to the participants of field programs for their assistance in sample collection and analyses. Renjith VishnuRadhan acknowledges a research fellowship from Council of Scientific and Industrial Research (CSIR), India. We are thankful to Er. Tulshidas L. Shirodkar, Assistant Engineer, Public Works Department, Govt. of Goa for his assistance in this study. We thank Mr. Praveen Kumar, Research Fellow, CSIR-NIO for meticulously going through the manuscript. This is CSIR-NIO contribution No. xxxx.

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Figure captions

Figure 1: Map showing sampling locations in the Mandovi estuary.

Figure 2: Calculated oxygen saturation and observed DO values: a) pre-monsoon-low tide, b) pre-monsoon-high tide, c) SW monsoon-low tide, d) SW monsoon-high tide, e) post-monsoon-low tide, f) post-monsoon- high tide.

Figure 3: BOD during three seasons: a) pre-monsoon low tide, b) pre-monsoon high tide, c) SW monsoon low tide d) SW monsoon high tide e) post-monsoon low tide and f) post-monsoon high tide.

Figure 4: Percentage of freshwater volume during different seasons.

Figure 5: Typical discharge pattern over different seasons.

Table captions

Table 1: Water quality of untreated and treated sewage during different seasons.

Table 2: Geographical positions of sampling stations.

Table 3: Water Quality Index during the SW monsoon season.

Table 4: Trophic State Index during the SW monsoon season.

Table 5: Water Quality Index during the post -monsoon season.

Table 6: Trophic State Index during the post-monsoon season.

Table 7: Water Quality Index during the pre-monsoon season.

Table 8: Trophic state index during the pre-monsoon season.

Table 9: Water quality conditions of coastal water bodies along the west coast of India.

Supporting Information

SI 01: Water quality parameters, equipments used and data sources.

SI 02: Codes for oxygen saturation and amount of freshwater calculation.

SI 03: Classification of water bodies based on OIP.

SI 04: Classification of water bodies based on TSI.

SI 05: Seasonal % freshwater volume at stations in the Mandovi estuary during high tide.

SI 06: Seasonal % freshwater volume at stations in the Mandovi estuary during low tide.

SI 07: Factor analysis of the data during the SW monsoon season.

SI 08: Factor analysis of the data during the post-monsoon season.

SI 09: Factor loadings of the data during the pre-monsoon season.

Table 1: Water quality of untreated and treated sewage averaged during different seasons.

	Parameter	Raw Sewage			Treated Sewage		
		pre-monsoon	SW monsoon	post-monsoon	pre-monsoon	SW monsoon	post-monsoon
1	pH	6.8	6.8	6.9	7.1	7	7
2	Temperature (°C)	30	29	28.8	30	29	28.4
3	Total solids (mg/L)	1099.90	494.69	1118.35	951.93	326.88	716.49
4	Total dissolved solids(mg/L)	640.30	307.88	849.29	941.12	307.60	695.93
5	Suspended solids (mg/L)	876.65	186.94	269.16	21.04	17.25	20.45
6	Volatile solids (mg/L)	349.65	214.05	293.76	61.64	57.49	61.80
7	Chloride (mg/L)	265.54	60.18	305.90	383.70	67.90	263.04
8	BOD (mg/L)	384.76	197.38	279.93	5.13	2.65	4.09
9	COD (mg/L)	761.17	402.80	601.55	26.72	18.51	25.32
10	E.Coli count (MPN/100 ml)	33.17×10 ⁶	568×10 ⁶	149×10 ⁶	49.13	19.29	43.65

Table 2. Geographical positions of sampling stations.

Station No.	Latitude (°N)	Longitude (°E)	Distance from the mouth (km)
1	15.46465	73.75004	0
2	15.48714	73.80672	7
3	15.50397	73.82392	10
4	15.50813	73.86615	15
5	15.53647	73.92854	22
6	15.54224	73.95971	25

Table 3: Water Quality Index during the SW monsoon season

High Tide			
Station	Surface	Bottom	Average WQI
M1	1.77	2.19	1.98
M2	1.61	3.32	2.46
M3	1.78	2.04	1.91
M4	1.47	1.96	1.71
M5	1.48	1.33	1.40
M6	1.33	1.40	1.36
Average			1.80
Low Tide			
M2	1.66	1.85	1.75
M3	2.25	1.94	2.09
M4	1.36	1.77	1.56
M5	1.40	2.48	1.94
M6	1.68	1.69	1.68
Average			1.80

Table 4: Trophic State Index during the SW monsoon season

Station no.	Secchi depth	TSI	Chl a	TSI	TP (µg/L)	TP TSI	TN (mg/L)	TN TSI	Avg. TSI
LT									
M1	1	60.00	0.79	28.49	16.82	44.85	0.30	57.29	47.66
			0.65	26.70	71.88	65.80	0.46	58.22	50.24
M2	0.5	69.77	3.68	42.57	18.35	46.11	0.38	67.83	56.57
			0.75	27.93	32.12	54.18	0.31	68.58	50.23
M3	1	60.00	0.40	22.11	52.00	61.13	1.49	48.45	47.92
			0.61	26.01	24.47	50.26	0.42	48.61	41.63
M4	0.7	65.03	1.65	35.18	12.23	40.26	0.19	57.02	49.37
			0.51	24.47	9.18	36.11	0.64	53.22	37.94
M5	1	60.00	0.73	27.77	6.12	30.27	0.59	56.69	43.68
			0.97	30.29	6.12	30.27	0.44	56.69	39.09
M6	0.5	69.77	0.83	28.89	16.82	44.85	0.51	59.07	50.65
HT			0.60	25.83	12.23	40.26	0.41	56.09	40.73
M6	1	60.00	0.60	25.84	32.12	54.18	0.47	56.69	49.18
			1.02	30.76	19.88	47.26	0.52	57.82	45.28
M5	1	60.00	1.62	35.01	13.76	41.96	0.77	54.86	47.96
			0.32	20.02	6.12	30.27	0.70	55.51	35.27
M4	1	60.00	0.75	27.93	1.53	10.28	0.92	55.56	38.44
			0.72	27.64	6.12	30.27	0.47	42.81	33.57
M3	1.5	54.28	1.87	36.36	10.71	38.34	0.28	64.04	48.26
			0.55	25.08	24.47	50.26	0.46	49.36	41.57
M2	1	60.00	2.37	38.50	18.35	46.11	0.65	43.80	47.10
			0.69	27.18	4.59	26.12	0.48	45.51	32.94
Average		61.71		29.12		41.79		55.17	46.95

Table 5: Water Quality Index during the post-monsoon season.

Low Tide			
Station	Surface	Bottom	Average WQI
M1	1.08	1.70	1.39
M2	1.36	1.87	1.61
M3	1.46	1.66	1.56
M4	1.05	1.68	1.36
M5	1.25	1.53	1.39
M6	1.02	1.16	1.09
Average			1.40
High Tide			
M2	1.83	1.52	1.67
M3	1.36	2.33	1.84
M4	1.18	1.61	1.4
M5	1.14	1.17	1.15
M6	1.01	1.47	1.24
Average			1.46

Table 6: Trophic State Index during the post-monsoon season.

Station no.	Secchi depth	Secchi TSI	TN (mg/L)	TN TSI	TP (µg/L)	TP TSI	Chl a (µg/L)	Chl a TSI	Avg. TSI
LT			0.37	40.03	13.52	41.7	0.07	6.67	29.47
M6	0.5	69.77	0.44	42.62	11.95	39.92	0.54	25.03	44.33
			0.43	42.2	22.95	49.33	0.05	2.41	31.31
M5	0.3	76.98	0.36	39.9	7.23	32.68	0.08	7.64	39.30
			0.47	43.61	41.82	57.98	0.10	9.30	36.96
M4	0.5	69.77	0.50	44.54	24.52	50.29	0.15	13.28	44.47
			0.44	42.72	19.81	47.21	0.11	10.39	33.44
M3	0.7	65.03	0.47	43.42	27.67	52.03	0.14	12.78	43.31
			0.42	41.77	35.53	55.63	0.15	13.28	36.89
M2	0.7	65.03	0.39	40.87	29.24	52.83	0.23	17.08	43.95
			0.42	41.99	29.24	52.83	0.17	14.59	36.47
M1	0.5	69.77	0.38	40.51	24.52	50.29	0.11	10.62	42.80
HT			0.43	42.41	29.24	52.83	0.15	13.28	36.17
M1	1	60.00	0.37	40.15	24.52	50.29	0.13	12.13	40.64
			0.39	40.87	16.66	44.72	0.48	23.82	36.47
M2	1	60.00	0.45	42.92	27.67	52.03	0.22	16.52	42.87
			0.45	43.02	21.38	48.31	0.12	11.16	34.16
M3	1	60.00	0.50	44.45	24.52	50.29	0.27	18.73	43.37
			0.40	41.21	15.09	43.29	0.15	13.11	32.54
M4	1	60.00	0.51	44.81	22.95	49.33	0.11	10.28	41.10
			0.49	44.18	15.09	43.29	0.07	6.51	31.33
M5	0.5	69.77	0.45	42.82	21.38	48.31	0.13	11.75	43.16
			0.44	42.51	29.24	52.83	0.08	7.34	34.23
M6			0.37	40.15	21.38	48.31	0.07	5.89	31.45
Average		66.01		42.33		48.91		12.47	42.43

Table 7: Water Quality Index during the pre-monsoon season.

Low Tide			
Stns.	Surface	Bottom	Average WQI
M1	2.69	2.36	2.52
M2	2.1	2.33	2.21
M3	2.01	2.18	2.09
M4	2.07	2.04	2.05
M5	2.52	2.32	2.42
M6	2.42	2.48	2.45
Average			2.29
High Tide			
M2	2.63	2.82	2.72
M3	2.15	2.21	2.18
M4	2.19	2.12	2.15
M5	2.04	2.06	2.05
M6	1.82	1.91	1.86
Average			2.19

Table 8: Trophic state index during the pre-monsoon season.

Station no.	Secchi depth	Secchi	TN	TN	TP	TP	Chl a	Chl a	Avg. TSI
LT		TSI	(mg/L)	TSI	(µg/L)	TSI	(µg/L)	TSI	
M6	1.1	58.66	0.59	46.79	27.12	51.74	0.43	22.80	45.00
		58.66	0.45	42.82	94.19	69.69	0.38	21.78	48.24
M5	1	60.00	0.57	46.33	44.24	58.80	0.45	23.20	47.08
		60.00	0.54	45.65	138.44	75.25	0.44	23.09	51.00
M4	1	60.00	0.60	47.07	169.84	78.19	0.68	27.10	53.09
		60.00	0.49	44.09	45.67	59.26	0.70	27.32	47.67
M3	1	60.00	0.63	47.68	95.62	69.91	0.74	27.89	51.37
		60.00	0.52	45.15	61.37	63.52	0.42	22.65	47.83
M2	1.2	57.43	0.51	44.74	165.55	77.83	0.37	21.41	50.35
		57.43	0.55	45.75	97.05	70.12	0.45	23.23	49.13
M1	2.3	48.26	0.32	37.85	122.74	73.51	0.34	20.81	45.11
HT		48.26	0.39	40.76	15.70	43.86	0.20	15.92	37.20
M2	1.2	57.43	0.44	42.58	117.03	72.82	0.51	24.36	49.30
		57.43	0.50	44.42	124.17	73.68	0.57	25.45	50.24
M3	1.1	58.66	0.58	46.70	127.02	74.01	0.57	25.37	51.18
		58.66	0.64	47.94	37.11	56.26	SL	SL	54.28
M4	0.5	69.77	0.62	47.51	104.18	71.15	0.96	30.21	54.66
		69.77	0.57	46.24	49.95	60.55	0.70	27.35	50.98
M5	0.5	69.77	0.58	46.70	45.67	59.26	0.48	23.88	49.90
		69.77	0.60	46.98	7.14	32.49	0.52	24.63	43.47
M6	0.7	65.03	0.44	42.58	39.96	57.33	0.50	24.26	47.30
		65.03	0.47	43.41	65.65	64.49	0.34	20.58	48.38
Average		60.45		44.99		64.26		23.97	48.42

Table 9: Water quality conditions of coastal water bodies along the west coast of India.

Coastal water bodies on the west coast of India			
Region/Water body	Major sources of pollution	Water quality conditions	References
South Saurashtra (South western part of Gujarat state)	Industry, Seasonal tourism, Fish landing.	Ideal conditions at South, Deteriorating at North	Badja et al., 2012
Estuaries of Gulf of Khambhat (The Narmada, Mahi and Sabarmati)	Chemical industry, Agriculture	Sabarmati, Mahi (north); High pollutant load Narmada (south); less pollution load	Deshkar et al., 2012
Kandla Creek, Gulf of Kutch	Port activities	Slightly polluted to polluted	Shirodkar et al., 2010
Mumbai, Maharashtra state	Industry, Urbanisation, Population pressure, Port activities	highly polluted, Hypoxic	Kamble et al., 2011 Shirodkar et al., 2012 Sawant et al., 2007
Mangalore, Karnataka state	Industry, Port activities	Acceptable to Slightly polluted	Shirodkar et al., 2009 Andrade et al., 2011
Zuari estuary, Goa state	Port activities, industry, tourism	Acceptable (monsoon) Polluted (post-monsoon) Slightly polluted (pre-monsoon)	Shirodkar et al., 2012
Cochin estuary, Kerala state	Industry, Port activities, Population pressure	Moderately polluted to eutrophic	Balachandran et al., 2008 Abhilash et al., 2012 Martin et al., 2011
Ashtamudi estuarine system, Kerala state	Solid waste dumping in banks, coconut husk retting, fish processing units	Moderately polluted	Karim 2012 Sujatha et al., 2009
Akkulam–Veli coastal lake system, Kerala state	Population pressure , tourism	Organic pollution (pre-monsoon)	Sheela et al., 2012

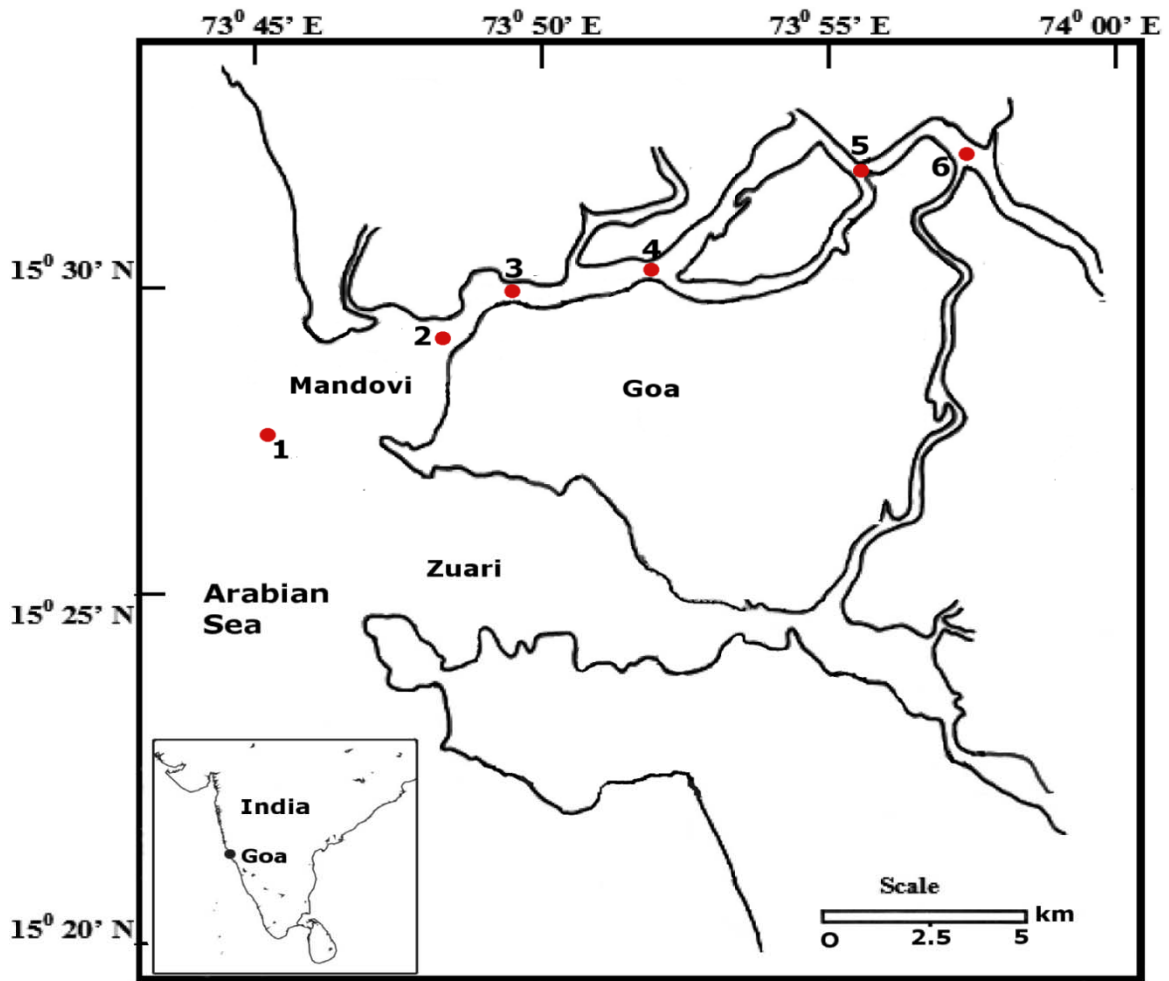


Figure 1: Map showing sampling locations in the Mandovi estuary.

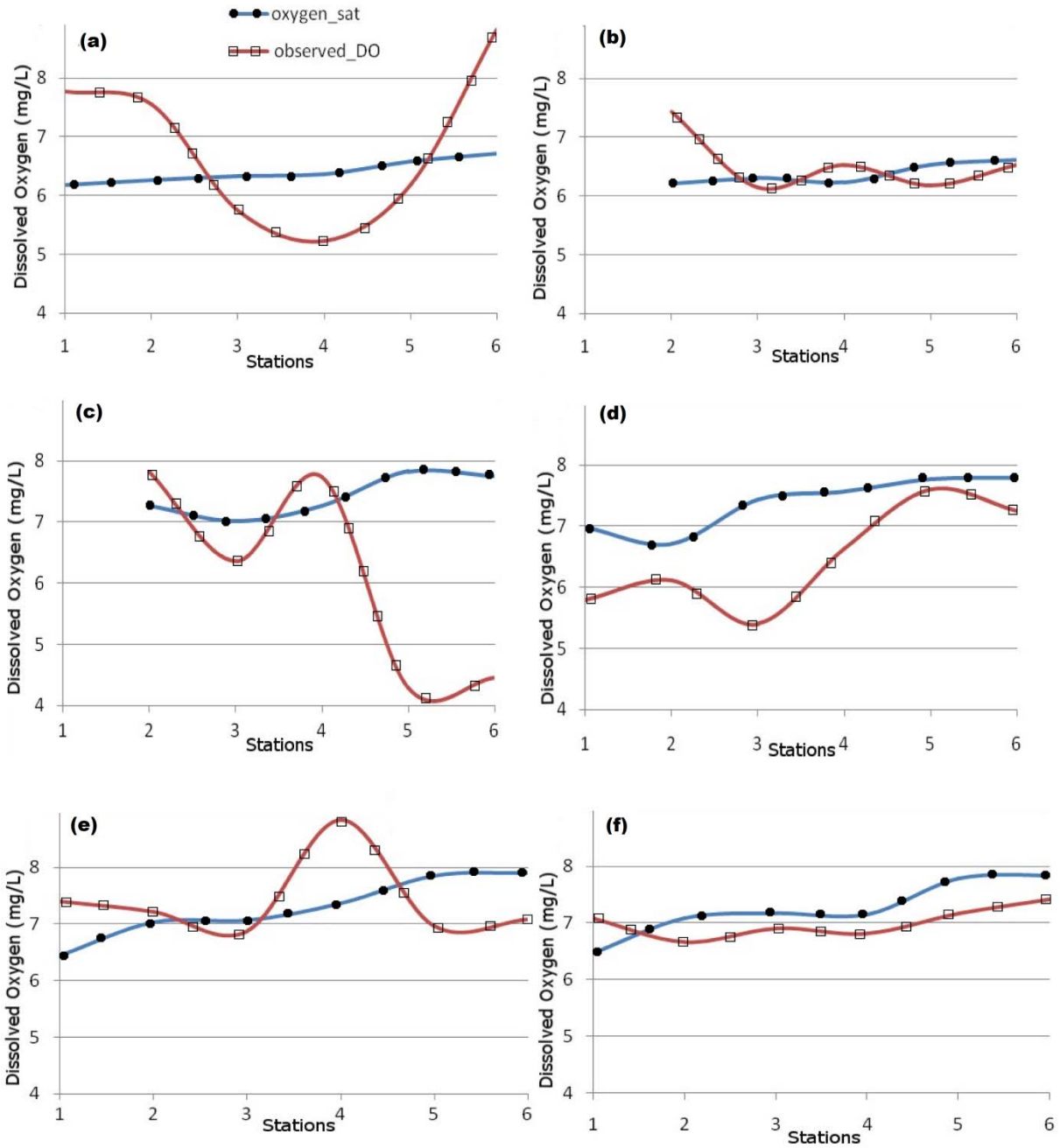


Figure 2: Calculated oxygen saturation and observed DO values: a) pre-monsoon-low tide, b) pre-monsoon-high tide, c) SW monsoon-low tide, d) SW monsoon-high tide, e) post-monsoon-low tide, f) post-monsoon- high tide.

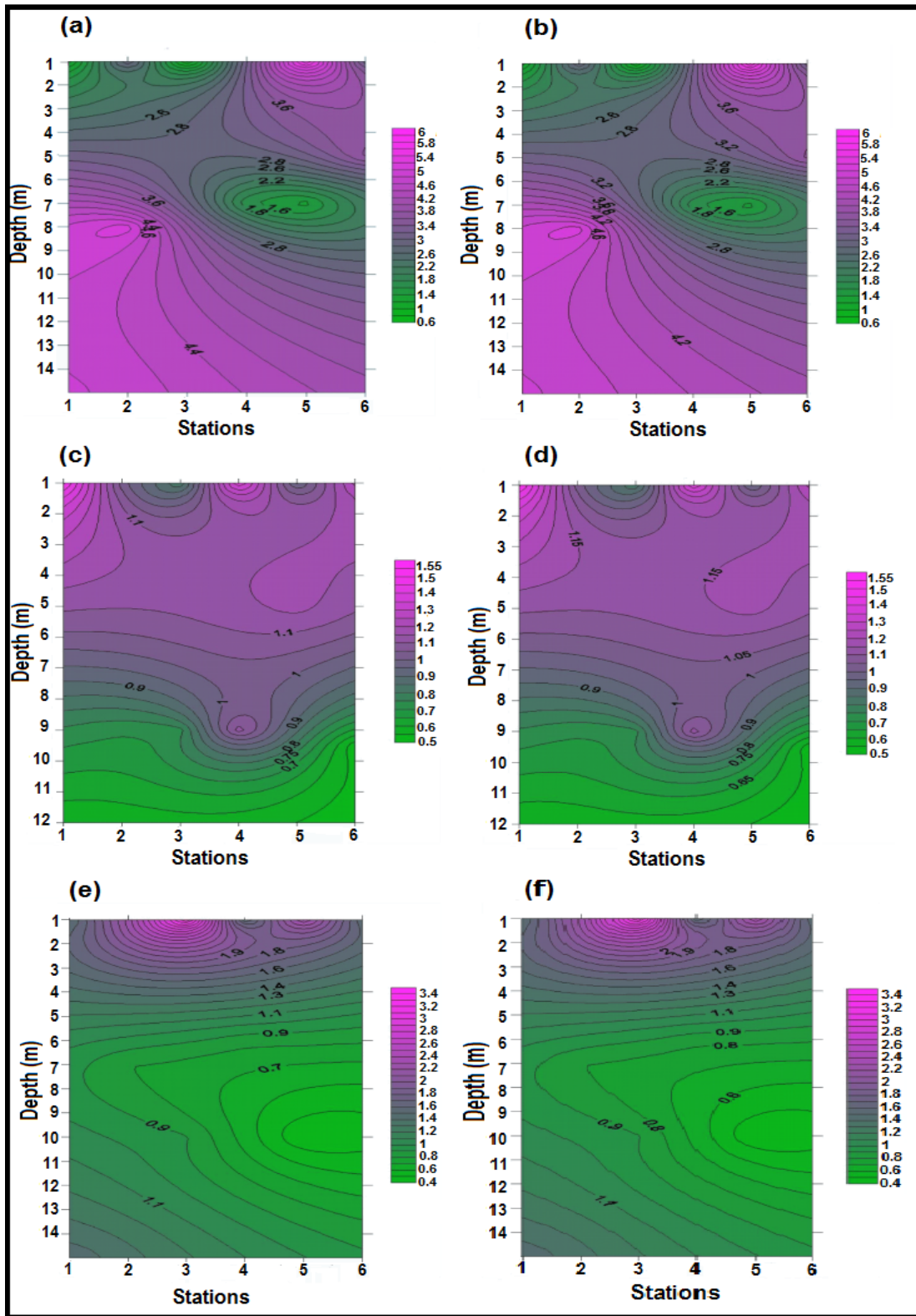


Figure 3: BOD during three seasons: a) pre-monsoon low tide, b) pre-monsoon high tide, c) SW monsoon low tide d) SW monsoon high tide e) post-monsoon low tide and f) post-monsoon high tide.

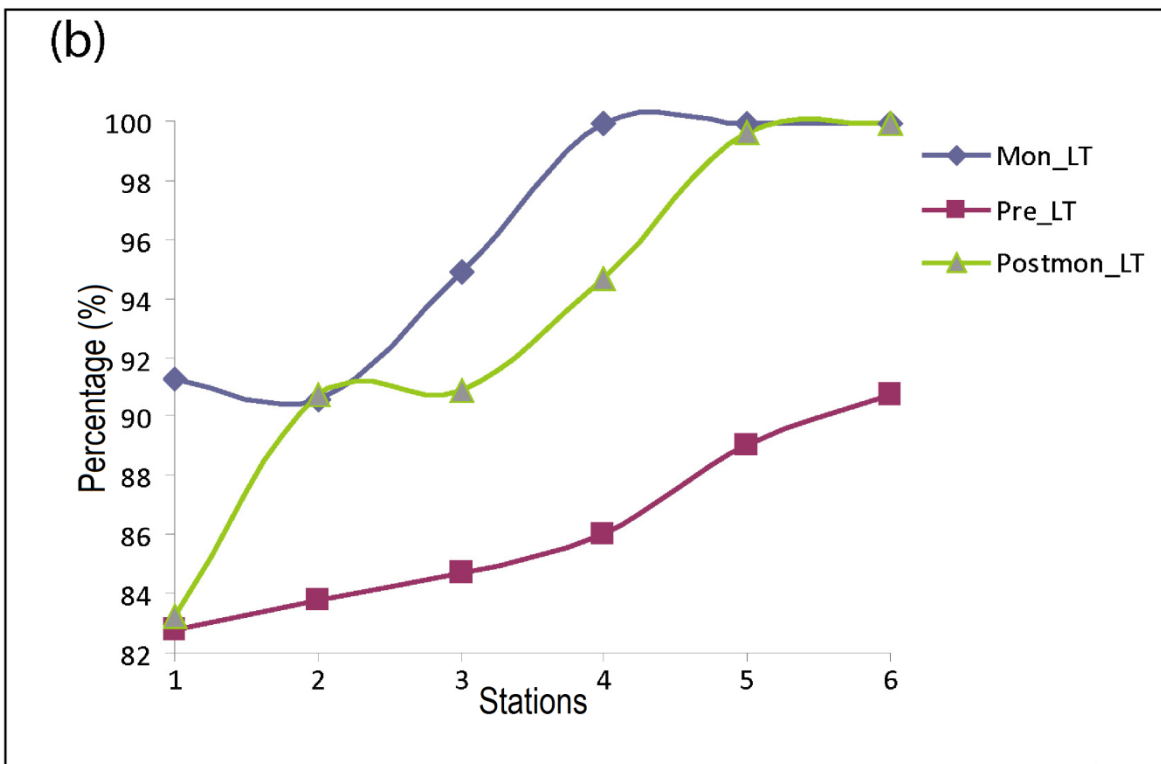
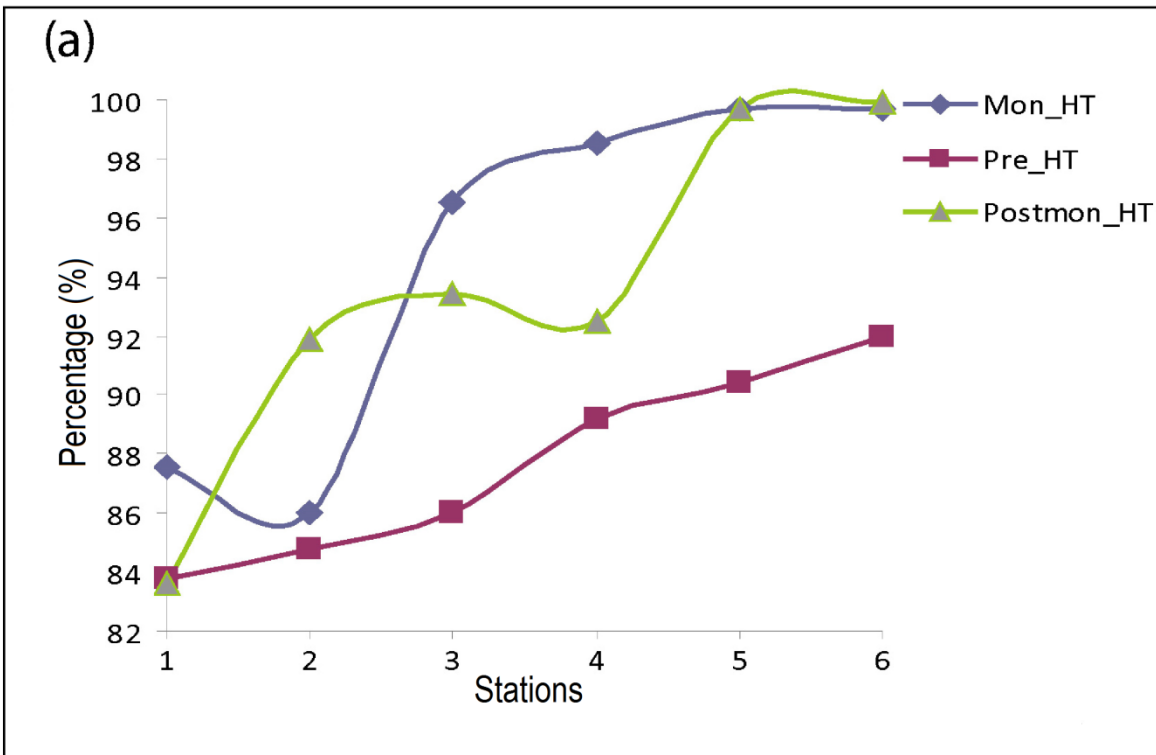


Figure 4: Percentage of freshwater volume during different seasons.

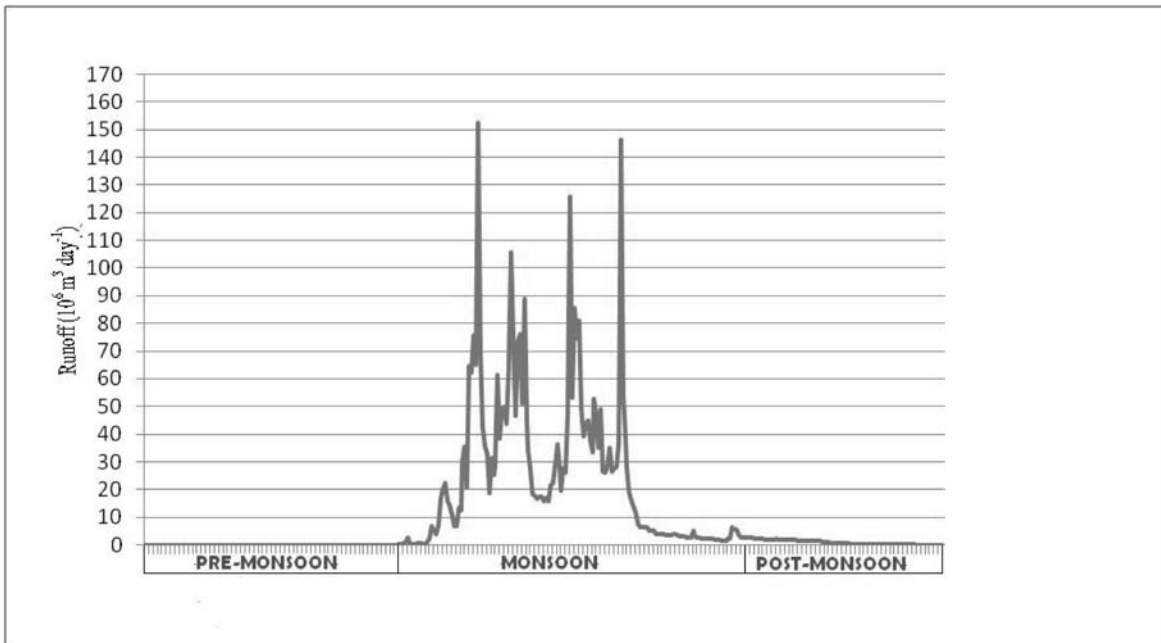


Figure 5: Typical discharge pattern over different seasons.

Supporting Information

SI 01. Water quality parameters, equipments used and the data sources.

Sr. No.	Parameters	Equipment / methods
1	Temperature, Salinity, Depth	CTD Instrument
2	DO,BOD	Winkler's method
3	pH	Eutech pH meter
4	Fresh water volume and Oxygen saturation	APHA equation and FORTRAN program
5	River discharge	CWC (Central Water Commission, Govt. of India)
6	Nutrients, microbiology and water quality	Strickland and Parsons (1972) Grasshoff et al., (1983) APHA (1992)
7	Waste water	PWD (Public Works Department, Govt. of Goa)

SI 02: Codes for oxygen saturation and amount of fresh water calculation

C Program to calculate the Oxygen saturation of an estuary

From temperature and salinity

integer stn

real temp,pH,do2,bod,sal

real a, b,c,d,SCofDO_fresh

real g,h, j,SCofDO_salt

open(10,file='input.txt')

open(20,file='pre.lo_op.txt')

C do i=1,n

read(10,*)

C enddo

n=1

50 read(10,*,end=99)stn,temp,pH,do2,bod,sal

C Calculates the dependence of oxygen saturation on

Temperature

Ta=temp+273.15

a=(1.575701E5)/Ta


```

b=(6.642308E7)/(Ta*Ta)
c=(1.243800E10)/(Ta*Ta*Ta)
d=(8.621949E11)/(Ta*Ta*Ta*Ta)
SCofDO_fresh=-139.34411+a-b+c-d

```

C Calculates the dependence of oxygen saturation on salinity

```

g=1.7674E-2
h=(10.754)/Ta
j=(2.1407E3)/(Ta*Ta)
SCofDO_salt=SCofDO_fresh-sal*(g-h+j)

```

C calculates the saltwater saturation value

```

SS=exp(SCofDO_salt)

```

C calculates the percent of Freshwater

```

percent=(SS/exp(SCofDO_fresh))*100
write(20,30)stn,temp,SCofDO_fresh,sal,SCofDO_salt,SS,
percent
n=n+1
goto 50
99 close(10)
30 format(i1,1x,f5.1,1x,f6.3,1x,f6.2,1x,f6.3,1x,f6.3,1x,f5.1)
stop
end

```

SI 03: Classification of water bodies based on OIP

OIP Values	Type of water
0 – 1	Excellent
1 – 2	Acceptable
2 - 4	Slightly polluted
4 - 8	Polluted
8 - 16	Heavily polluted

SI 04: Classification of water bodies based on TSI

TSI	Chl	P	SD	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5—<0.25	Hypereutrophic

SI 05: Seasonal % freshwater volume at stations in the Mandovi estuary during high tide.

Station	SW monsoon_HT	pre-monsoon_HT	post-monsoon_HT
1	87.6	83.8	83.6
2	86	84.8	91.9
3	96.5	86	93.4
4	98.5	89.2	92.5
5	99.7	90.4	99.7
6	99.7	92	99.9
Avg.	94.67	87.67	93.45

SI 06: Seasonal % freshwater volume at stations in the Mandovi estuary during low tide.

Station	SW monsoon_LT	pre-monsoon_LT	post-monsoon_LT
1	91.3	82.8	83.2
2	90.6	83.8	90.7
3	94.9	84.7	90.9
4	99.9	86	94.7
5	99.9	89	99.6
6	99.9	90.7	99.9
Avg.	96.08	86.17	93.17

SI 07: Factor analysis of the data during the SW monsoon season.

	Factor	Factor	Factor	Factor	Factor
	1	2	3	4	5
Temp	-0.499	0.319	-0.235	-0.005	-0.274
pH	-0.155	-0.069	0.218	-0.804	-0.025
DO	-0.798	-0.096	0.026	-0.080	-0.094
BOD	-0.392	-0.157	-0.203	0.558	0.026
Salinity	0.741	-0.081	0.362	0.399	0.213
SS	0.823	0.059	-0.161	-0.276	-0.326
Turbidity	0.680	0.409	-0.285	-0.106	-0.397
PO ₄	0.820	-0.422	0.054	-0.095	-0.126
NO ₂	0.935	-0.163	0.052	0.074	-0.010
NO ₃	-0.625	0.244	-0.216	-0.325	0.430
NH ₃	0.780	-0.044	0.188	0.314	-0.361
Si	-0.197	-0.154	0.060	-0.050	-0.861
Urea	-0.135	0.680	-0.088	-0.353	0.322
TP	0.606	-0.363	-0.166	-0.350	0.017
TN	-0.104	-0.117	-0.609	0.102	0.171
PHc	-0.190	-0.059	-0.100	-0.318	0.007
Phenol	-0.122	0.183	-0.761	0.055	0.043
Chla	-0.075	0.199	0.708	0.009	0.150
TH	0.939	0.124	0.063	0.180	0.142
Ca Hardness	0.922	0.131	0.073	0.211	0.182
Mg Hardness	0.940	0.123	0.062	0.176	0.137
F	0.944	0.172	0.033	0.133	0.165
SO ₄	0.573	0.421	0.070	0.518	0.057
TVC	0.808	0.246	0.188	-0.101	-0.332
TC	0.395	0.779	0.166	0.224	0.053
FC	-0.035	0.566	0.454	0.187	-0.034
Expl.Var	10.436	2.536	2.259	2.284	1.841
Prp.Totl	0.401	0.098	0.087	0.088	0.071
	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %	
1	10.79	41.48	10.79	41.48	
2	2.82	10.83	13.60	52.31	
3	2.10	8.06	15.70	60.37	
4	2.00	7.70	17.70	68.07	
5	1.66	6.37	19.36	74.45	

SI 08: Factor analysis of the data during the post-monsoon season

	Factor	Factor	Factor	Factor	Factor
	1	2	3	4	5
Temp	0.098	0.184	-0.247	0.206	0.766
pH	0.592	-0.291	0.149	-0.352	0.370
DO	-0.427	-0.138	-0.778	0.061	-0.149
BOD	0.166	0.210	-0.779	0.150	0.092
Salinity	0.874	0.172	0.135	0.121	0.292
SS	-0.528	0.072	0.369	-0.613	0.125
Turbidity	-0.046	-0.627	0.404	0.139	-0.017
PO ₄	0.214	0.295	0.495	0.438	0.075
NO ₂	0.382	0.567	0.103	-0.037	0.386
NO ₃	-0.719	-0.025	0.394	-0.201	-0.273
NH ₃	0.154	0.070	0.332	0.050	0.690
Si	-0.807	0.124	-0.047	0.071	0.167
Urea	-0.154	0.816	-0.047	-0.138	0.211
TP	0.377	0.315	0.027	0.675	-0.139
TN	-0.096	0.783	0.315	0.143	0.105
PHc	-0.127	0.189	0.004	-0.715	-0.498
Phenol	0.334	0.098	0.032	-0.052	0.730
Chla	0.190	0.227	0.048	-0.760	0.057
TH	0.939	0.062	0.176	0.126	0.110
Ca Hardness	0.910	-0.041	0.171	0.036	0.100
MgHardness	0.896	0.044	0.288	0.063	0.142
F	0.845	-0.035	0.054	0.030	0.238
SO ₄	0.764	0.044	0.141	-0.029	0.402
TVC	0.570	0.046	-0.137	0.180	0.096
TC	0.067	0.118	0.036	-0.100	0.505
FC	0.387	0.092	0.594	-0.015	0.149
Expl.Var	7.630	2.549	2.781	2.496	2.996
Prp.Totl	0.293	0.098	0.107	0.096	0.115
	Eigenvalue	% Total	Cumulative	Cumulative	
		variance	Eigenvalue	%	
1	8.84	34.00	8.84	34.00	
2	3.00	11.55	11.84	45.55	
3	2.80	10.77	14.64	56.33	
4	2.06	7.92	16.70	64.25	
5	1.75	6.72	18.45	70.97	

SI 09: Factor analysis of the data during the pre-monsoon season

	Factor	Factor	Factor	Factor	Factor
	1	2	3	4	5
Temp	-0.63	-0.13	-0.15	-0.16	-0.37
pH	0.73	0.04	0.23	0.11	0.00
DO	-0.09	-0.65	-0.13	-0.09	-0.02
BOD	0.07	-0.07	0.04	0.77	0.10
Salinity	0.94	-0.01	-0.08	0.02	0.26
SS	-0.05	0.70	-0.10	-0.24	0.16
Turbidity	0.28	-0.24	0.23	-0.41	0.07
PO ₄	0.00	0.04	-0.17	0.51	0.68
NO ₂	-0.70	-0.06	0.12	0.53	0.01
NO ₃	-0.48	0.01	-0.05	-0.04	-0.78
NH ₃	-0.53	0.14	-0.35	-0.53	0.05
Si	-0.63	-0.12	0.15	0.58	0.17
Urea	-0.04	-0.50	0.35	0.11	0.38
TP	0.26	-0.37	-0.36	0.15	0.13
TN	-0.10	0.38	0.03	0.05	-0.56
PHc	-0.31	0.49	-0.45	-0.22	0.41
Phenol	0.33	0.52	0.02	0.12	-0.24
Chla	0.15	0.46	0.05	0.03	-0.11
TH	0.90	0.09	-0.04	-0.08	0.08
Ca Hardness	0.96	-0.02	-0.12	0.01	0.07
Mg Hardness	0.88	0.09	-0.04	-0.08	0.08
F	0.69	0.35	0.08	-0.10	-0.24
SO ₄	0.92	-0.06	0.06	0.05	0.03
TVC	-0.48	-0.30	0.47	-0.32	0.35
TC	0.02	0.07	0.89	0.29	0.09
FC	0.06	0.08	0.85	-0.14	-0.11
Expl.Var	7.67	2.53	2.57	2.34	2.29
Prp.Totl	0.30	0.10	0.10	0.09	0.09
	Eigenvalue	% Total	Cumulative	Cumulative	
		variance	Eigenvalue	%	
1	7.77	29.89	7.77	29.89	
2	3.31	12.74	11.08	42.63	
3	2.51	9.67	13.60	52.30	
4	2.14	8.22	15.74	60.52	
5	1.67	6.43	17.41	66.95	