ASSIMILATIVE AND HEALING CAPACITY OF COASTAL WATERS AGAINST THE SEWAGE AND EFFLUENTS RELEASED ALONG THE COAST OF VISAKHAPATNAM INDUSTRIAL BELT

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ABSTRACT

Owing to increased anthropological activities, the coastal zone is receiving a vast quantity of sewage waste and industrial effluents. But conflicting views on the impact of these wastes on coastal waters prompted us to take up this study. Four sampling points along the coast were identified and analyzed the collected water samples for nutrients and chlorophyll-a during pre- and post-monsoon seasons. The results indicated that the study area was of mesotrophic type and the coastal water was well oxygenated with mean DO of 5.2mg/lit and was biologically productive at primary level with ambient levels of nutrients excepting slight higher concentrations of nitrate-nitrogen, phosphate-phosphorous and total nitrogen as 17.5 µgm/lit 19.0µgm/lit and 502.8µgm/lit respectively. Further, toxicological studies (bio-assay tests) of discharged effluents and coastal water samples were conducted on selective standard test organisms and compared with the control samples. They revealed that the impact of the discharges on the coastal environment was insignificant.

Keywords: Industrial Impact, Coastal Water Quality, Nutrients, Chlorophyll-a, Toxicity Factor, Mesotrophic.

1. Introduction

The coastal zone of Visakhapatnam industrial belt is receiving a vast quantity of sewage waste and industrial effluents owing to intensified industrial and population growth. Though the Visakhapatnam marine area at harbor and beach was extensively investigated, information on the coastal stretch along the major industrial belt was rather scanty and limited to only a few isolated sites (NIO report, 2006). This may be the reason for conflicting views on the impact of such wastes on the coastal waters. Keeping this in view a comprehensive study was contemplated with the main objective, to assess the status of coastal water quality by measuring the levels of nutrients, chlorophyll-a in the coastal water samples and evaluating the toxicity factor and mortality rate of the selected sensitive organisms subjecting them directly to the discharged effluent and coastal marine water samples. The industrial belt along the coastal area in between 17° 34'30” N to 17° 38'30” N latitudes and 83° 09’00” E to 83° 15’00” E longitudes was chosen for the present study because of high concentration of large and medium industries within the narrow coastal belt. This industrial area has seen rapid industrialization and population growth during the last few decades. The present study area is adjacent to a thermal power plant, upcoming pharma city, an integrated steel plant, a minor port and a number of associated ancillaries (Figure 1).
2. Materials and Method

For the present study, seven sampling points were identified (four sampling points S-1 to S-4 for coastal waters, two sampling points S-6, S-7 of effluent water from discharge channels just before mixing the coastal water and one sampling point S-5 as control sample for coastal water) with the help of Furuno make Global Positioning System (Figure 1). During the period of March (pre-monsoon) and October (post-monsoon) 2010, water quality assessment was done based on two approaches, in the first approach, measurements were performed to study the levels of nutrients and chlorophyll-a in the coastal water samples and in the second approach measurements were made to study the toxicity factor and mortality rate by static bio-assay tests.

**Figure 1:** Map showing location of sampling points along the coast of Visakhapatnam industrial belt.

Both the approaches are complementary. Simultaneous application of these two approaches results in a meaningful assessment of water quality. The water samples were collected in pre-cleaned plastic polyethylene bottles for physico-chemical and biological analysis. The coastal water samples were analyzed for pH, salinity, dissolved oxygen, biological oxygen demand, ammonical nitrogen, nitrites, nitrates, total nitrogen, phosphate-phosphorus, total...
phosphate, silicate–silicon and chlorophyll-a. Standard procedures recommended by the APHA, BIS, ASTM were followed during the sample collection, handling, preservation and analysis to ensure data quality and consistency.

2.1 Toxicological (bio-assay) test

Monitoring the impact of pollutants on aquatic life-forms is a challenging task owing to the differential sensitivities of organisms to a given pollutant. The test species for these experiments were selected based on the following criteria: (a) resident species, (b) sensitive to contaminants in short time period, (c) standard test organism that does not require additional research and (d) specified by standard organizations like BIS, ASTM and APHA. In order to assess the potential effects of pollutants, selective standard species were exposed to different concentrations of the sample for a stipulated time. For this, two methods, IS 6582(p-2): 2001 and ASTM: E 1192-97 were adopted (BIS, 2007; ASTM, 2008). The first method was applied to the effluent water samples collected from the discharge channels. The freshwater fish, *Brachydanio rerio* (Zebra fish) were used to know the acute toxicity and general behavior. Acute toxicity was calculated in terms of toxicity factor (Tf) which denotes the dilution factor of the test water with the highest concentration of effluent to which all fish survive (BIS, 2007). The second method was applied for the marine water samples collected along the coast and post larvae of *Penaeus monodon* (marine water shrimp) were exposed as test species to find out the rate of survival and mortality. In both the cases, the test specimens were collected, acclimatized and prepared for the test as per the above standards.

In order to define the nutrient limitations on biological productivity, we calculated nutrient ratios and compared with Redfield ratios (Si:N:P=16:16:1). And an assessment of status of trophic condition was also evaluated for this study area based on the physico-chemical and biological factors measured.

3. Results and Discussion

3.1 Physical factors

The mean of analytical results of physico-chemical and biological aspects of coastal water samples were summarized in Table 1. The data revealed that the values of pH reported in both the seasons were in the range of 8.00 to 8.18 and falls within the CPCB prescribed SW-II standard. Seasonally lower mean salinity value of 33.65ppt was observed during the end of the rainy season (October) and higher mean salinity value of 34.0ppt during the dry season (March). These values were well within the ambient levels and could be understood that salinity was not influenced by external variations and only a general drop was observed during the month of October. As reported by Vijayakumaran (2005), for Visakhapatnam harbor, prevailing current systems (northerly/southerly) were responsible for this general drop, might also be applicable to this study area. Dissolved oxygen values in both the seasons were seen varying between 4.48mg/lit to 5.92mg/lit and were more than SW-II standard of 4.0mg/lit throughout the study period which indicated the well oxygenated and well mixed conditions in the entire coastal water stretch thereby reflecting a scenario similar to field survey of the Mutyalammapalem coast to Bheemili coast done by Khasim Beebi et al. (2007). The mean values of BOD observed in the range between 1.16-2.86mg/lit indicated the compliance to SW-II standard 3.0mg/lit of CPCB. Thus, the overall data on physical factors indicated the ability of the coastal waters to withstand the impact of sewage and effluents through their assimilative and healing capacity.
3.2 Chemical factors

Nutrients play a vital role in the biogeochemical cycles in the marine environment. Concentrations of nutrients in the study area were clearly displayed the seasonal differences with the lowest mean values during the pre-monsoon (March) and the highest mean values in the post-monsoon season (October). The observed increasing trends of nutrients can be explained by the increased discharge volume due to the seasonal rains and heavy run-offs during monsoon season. The average concentrations of ammonical nitrogen varied between 15.8-22.0µgm/lit which was slightly higher than the international target value of 21µgm/lit (Table 1). Maximum value 28.6µgm/lit at S-4 sampling point in post-monsoon period and minimum 12.6µgm/lit in pre-monsoon period at S-2 sampling point were observed. The mean values of nitrite-nitrogen were varied in between 1.73-2.88µgm/lit which was within the typical concentration of 7.0µgm/lit (Table 1).

Table 1: Mean of analytical results of physico–chemical and biological aspects

| Parameters Analyzed          | S–1 coastal water | S–2 coastal water | S–3 coastal water | S–4 coastal water | Average (entire study area) | Prescribed Standards |
|-----------------------------|-------------------|-------------------|-------------------|-------------------|----------------------------|----------------------|
| pH                          | 8.15              | 8.12              | 8.08              | 8.08              | 8.11                       | 6.5 – 8.5 *          |
| Salinity (ppt)              | 33.73             | 33.46             | 33.82             | 34.26             | 33.82                      | ---                  |
| Dissolved Oxygen mg/lit     | 4.72              | 5.40              | 5.68              | 5.09              | 5.22                       | 4.0 mg/lit, or 50% saturation value whichever is higher * |
| BOD mg/lit                  | 1.95              | 1.16              | 1.33              | 2.86              | 1.83                       | 3 mg/lit *           |
| Ammonical Nitrogen µgm/lit  | 16.4              | 15.8              | 18.3              | 22.0              | 18.13                      | 21 µgm/lit **        |
| Nitrite–Nitrogen µgm/lit    | 2.24              | 1.87              | 1.73              | 2.88              | 2.18                       | 7 µgm/lit ***        |
| Nitrate–Nitrogen µgm/lit    | 10.4              | 13.0              | 16.8              | 29.8              | 17.50                      | 10- 60 µgm/lit as nitrate ** |
| Total Nitrogen µgm/lit      | 583               | 514               | 429.8             | 484.3             | 502.78                     | ---                  |
| Phosphate–Phosphorous µgm/lit| 6.45              | 4.32              | 18.7              | 46.4              | 18.97                      | 1 - 10 µgm/lit as phosphate ** |
| Total Phosphate-phosphorous µgm/lit | 31.3              | 28.3              | 40.6              | 88.0              | 47.05                      | ---                  |
| Silicate–Silicon µgm/lit    | 88.6              | 67.4              | 79.1              | 151.6             | 96.68                      | 2,800 µgm/lit (avg) ** |
| Chlorophyll–a, mg/m³        | 0.77              | 0.93              | 0.93              | 0.58              | 0.80                       | 1.0 mg/m³ #          |

Source: * Water Quality Standards for Coastal Waters Marine Outfalls. SW-II Standard. Central Pollution Control Board, New Delhi. ** South African Water Quality Guidelines for Coastal Marine Waters, 1996. International Target Values for the Natural Marine Environment, Vol.1, pp B-1-B-3. and Chap. 4.2. pp 31. *** Typical concentrations extracted from UNESCO Reports in marine science (UNESCO reports, 1988). # Smith et al., 1999.

The average values of nitrate-nitrogen ranged from 10.4-29.8µgm/lit with highest concentration at S-4 sampling point in post-monsoon season and minimum concentration in pre-monsoon season at S-1 sampling point were observed. Slight higher values were
observed at the study area (17.50 µgm/lit as nitrate-nitrogen) than the international target values of 10-60 µgm/lit as nitrate (Table 1). A similar pattern was observed as far as the nitrite-nitrogen and nitrate-nitrogen concentrations were concerned at Gangavaram port by COMPAS programme, (2010) and Appikonda beach by Khasim Beebi et al. (2007,”a”) . The variability in the concentrations of these dissolved inorganic nitrogen compounds were attributed to the distribution of effluents and oxidation of ammonia into nitrite and finally transformed into nitrate. These nitrogen compounds were derived from direct discharges of crude sewage and industrial effluents (Jones, 2006). The mean value of total nitrogen 502.8 µgm/lit observed in the entire study area indicated the presence of significant quantities of dissolved organic nitrogen. These levels are usually higher in eutrophic and/or organically-polluted waters and organic compounds may contribute the highest fraction of the total dissolved nitrogen (UNESCO reports, 1988). Ammonical nitrogen is a primary product of microbial degradation of organic nitrogen if not used directly by autotrophic algae, vascular macrophytes and microbial heterotrophs for growth; it may be oxidized through nitrification to nitrite and nitrate (USEPA, 2003). This process helped to modulate extreme dissolved inorganic nitrogen concentrations in the entire study area. Sewage and effluents released excessively into the coastal waters of the study area were responsible for high total nitrogen values during the study period. However, other nitrogenous nutrients and BOD remained low with high dissolved oxygen. The mean DO was more than 5.0 mg/lit indicated the sufficient aeration of the study area. BOD generally remained below 3.0 mg/lit (Table 1). Such low BOD values were reported for highly polluted waters of Mangalore harbor by Verlecar et al. (2001) and polluted beaches of Mumbai coast by Zingde and Desai (1987). Constant renewal of waters by semidiurnal tides as reported by Swamy et al. (2000) for Mumbai coast, may also be applicable to this study area which maintains high DO and low BOD values. Although the study area received large quantities of industrial and sewage effluents, excellent mixing and flushing conditions due to tide and wind induced coastal currents as reported by Chandramohan et al. (1984) kept these coastal waters well aerated with high oxygen and low BOD values. These conditions helped in bringing dispersion of organics and other pollutants thereby reducing the severe pollution stress in the study area.

Among the nutrients, phosphate-phosphorus showed a significant variation along the study area with the mean values ranging between 4.32-46.40 µgm/lit. These values were considerably higher than the international target values of 1-10 µgm/lit (Table 1) and corroborated those previously reported for Visakhapatnam harbor (Vijayakumaran, 2005) and Chitrapur beach of Mangalore coast (CPCB reports, 2010). Higher mean value of 88.0 µgm/lit of total phosphate-phosphorous was observed at S-4 sampling point and minimum mean value of 28.3 µgm/lit was observed at S-2 sampling point. Interestingly, higher values of total nitrogen were observed at the sampling point S-1 and higher values of total phosphate-phosphorous were observed at sampling point S-4 (Table 1) indicated the variability of the effluents joining the coastal waters at different locations. Our finding supports the hypothesis of Sara et al. (2010) that each site has a specific hydro chemical response associated with the type and intensity of human activities and local terrestrial and oceanic influences.

Silicate-silicon as a bio-limiting nutrient varied in between 67.4-151.6 µgm/lit in the entire study area showed considerable lower values compared to the concentrations (2,800 µgm/lit) of nutrient type distribution (Table 1). Similar trends were observed at Visakhapatnam harbor (Vijayakumaran, 2005) and M/s. MRPL marine outfall of Mangalore coast (CPCB reports, 2010).
Although nutrients showed fluctuations in relation to the sampling points and seasons, their mean values at the entire study area remained low except for phosphate–phosphorus, total nitrogen and total phosphate–phosphorus. Similar trends were reported for some other coastal region such as Mangalore along the west coast of India (Verlecar et al., 2001).

3.3 Biological factors

Average chlorophyll-a concentrations in the study area were seen varying in between 0.58-0.93mg/m$^3$ (Table 1) with no significant changes during the seasons. The seasonal variations of the chlorophyll-a concentration in the southern Bay of Bengal were found to be insignificant compared to those in the northeastern Arabian Sea (Sagnik dey and Ramesh, 2003). There were no algal blooms which contribute obnoxious conditions even though the highest concentrations of 1.04mg/m$^3$ were observed at S-2 and S-4 sampling points in pre-monsoon season. These values were in total agreement with the results of chlorophyll-a concentration at Visakhapatnam harbor (Vijayakumaran, 2005) and northwest Bay of Bengal (Sarma et al., 2006). The optimal values 0.80mg/m$^3$ of chlorophyll-a (Table 1) in the entire study area indicated the healthy status of aquatic ecosystem with optimal primary productivity.

3.4 Toxicological factors (bio-assay test)

3.4.1 Toxicity factor: A summary of comparison of toxicity factor values for EPA standard and samples collected from the discharge channels which join the sea were shown in Table 2. The maximum toxicity factor observed for the sampling point S–6 was 1.02, it denoted that 23 ml. was the lowest volume of fresh water required to 977 ml. of effluent water at which all fish survive and it was also noticed that at 100% concentration of effluent the fish exhibited abnormal behavior which entailed in erratic swimming with jerky movement. In case of the sampling point S-7, the toxicity factor to zebra fish was 1.00 for all the samples and complied with the EPA standard of toxicity factor ($T_f$ =1.00). Mafalda et al. (2006) carried out in situ bioassays with Chironomus riparius at river basins of North and Central Portugal and observed high survival rate.

Table 2: Toxicological (bio-assay) test report

| Sl. No. | Sampling Points of effluent water samples | Toxicity Factor ($T_f$) | Maximum | Minimum | EPA Standard |
|---------|-------------------------------------------|-------------------------|---------|---------|--------------|
| 1.      | S–6 (discharge channel-1)                 | 1.02                    | 1.00    | 1.00    | 1.00         |
| 2.      | S–7 (discharge channel-2)                 | 1.00                    | 1.00    | 1.00    | 1.00         |

3.4.2 Mortality/Survival rate: The data on the mortality rate of the samples collected from the coastal marine water were tabulated in the Table 3. The post larvae of Penaeus monodon (marine water shrimp) were exposed at five different concentrations of the sample 10,25,50,75 and 100% in order to know the rate of survival and mortality. No mortality was recorded even at 100% concentration for 96 hrs for all the five samples of S–1 to S–5 (including control) during the observation period. This indicated 100% survival and compliance to the tolerance limits specified by the Indian Standard (Table 3). The toxicological studies conducted on test organisms were compared with the control sample and these results revealed that the consequences of the discharges on the whole were insignificant. Similar type of observations were reported by Lenwood and Ronald (1999),
who found the survival rate of 96% - 100% for sheepshead minnow larvae after 8 day toxicity tests conducted in Chesapeake Bay program. Bio-assay tests conducted by Juan Bellas et al. (2001) for heavy metals toxicity using early developmental stages of Ciona intestinalis for marine water quality assessment were found with no marked effect.

### Table 3: Toxicological (bio-assay) test report

| Concentration of the sample collected from S–1 sampling point (coastal water) | Mortality rate % | Survival rate % (96 hrs) | Tolerance limits as per IS: 7967 - 1976* |
|---|---|---|---|
| 24 hrs. | 48 hrs. | 72 hrs. | 96 hrs. |
| 10% sample concentration | 0 | 0 | 0 | 0 | 100 | Not less than 90 percent of test animals shall survive in 96-hour test. |
| 25% sample concentration | 0 | 0 | 0 | 0 | 100 |
| 50% sample concentration | 0 | 0 | 0 | 0 | 100 |
| 75% sample concentration | 0 | 0 | 0 | 0 | 100 |
| 100% sample concentration | 0 | 0 | 0 | 0 | 100 |

Note: Similar observations of mortality and survival rates (%) were found for the samples collected from S-2, S-3, S-4 (costal marine water) and S-5 (control) sampling points.

* IS: 7967 – 1976. Criteria for controlling pollution of Marine Coastal Areas. Bureau of Indian Standards. New Delhi

Changes in water quality may affect all levels of biological organization, from molecules through to communities. The low toxicity factor obtained with the zebra fish (fresh water fish) in the present study was in good agreement with the data of mortality rate conducted on Penaeus monodon (marine water shrimp). The effects of pollutants are generally characterized on survival, reproduction or growth due to physiological alteration in the animal. The experiments demonstrated that the hydro chemical conditions of the coastal waters were in good condition in spite of releasing large quantities of sewage and effluents. This may be because of assimilative and self healing nature of the coastal waters.

### 3.5 Assessment of trophic status of the study area

Trophic status can be described through a number of abiotic as well as biotic parameters. Among the abiotic parameters, plant nutrients and oxygen concentration are usually used for assessing trophic levels, whereas, chlorophyll a concentration, phytoplankton cell number and ecological indices are among the biotic parameters often employed to assess trophic conditions (Sladana Krivokapić, 2008). The classification criteria used to establish the trophic status in the present study area was based on the (EEA selected baseline indicators for state assessment of marine eutrophication) levels of nutrients (abiotic) and chlorophyll-a (biotic) parameters (UNEP/MAP, 2007).

Following the above criteria the status of the present study area was classified (Table 4) as mesotrophic (based on the concentration of nutrients) and oligotrophic (based on the concentration of chlorophyll-a). According to methods used by the Norwegian Environmental Protection Agency, (USEPA, 2003) the present study area can be classified as Class-1 or very good, because of high salinity (above 20 ppt) with lower chlorophyll-a concentrations (below 2.0mg/m³).
Table 4: Criteria adopted for assessment of trophic status of the study area

| Trophic condition | Based on concentration of Nutrients* | Based on concentration of Chlorophyll-a Smith et al., (1999) |
|-------------------|-------------------------------------|----------------------------------------------------------|
| Oligotrophic      | ≤7.0 μg/m/lit NH₄; ≤7.0 μg/m/lit NO₃ | <1.0 mg/m³                                               |
| Mesotrophic       | >7.0 μg/m/lit - ≤28.0 μg/m/lit NH₄; | 1.0 – 3.0 mg/m³                                          |
|                    | >7.0 μg/m/lit - ≤56.0 μg/m/lit NO₃ |                                                          |
| Eutrophic         | >28.0 μg/m/lit NH₄;                 | 3.0 – 5.0 mg/m³                                          |
|                    | >56.0 μg/m/lit NO₃                  |                                                          |

*Source: UEP/MAP, 2007.

3.6 Nutrient ratios

Summary of the nutrient ratios in both the seasons were tabulated in Table 5. Changes in Si:DIN:P ratios affect the phytoplankton succession. The mean Si: DIN ratios were 2.7 and 2.4 for pre- and post-monsoon seasons respectively indicated that the silicate-silicon was not a deficient nutrient as Si: DIN ratios were always greater than two in both the seasons in the entire study period (Table 5). The mean DIN: P ratios found for both the seasons were 2.0 which was much lower than Redfield ratio (Table 5) suggesting nitrogen to be a limiting nutrient for phytoplankton production. In marine waters, nitrogen is often most limiting to phytoplankton growth (Conley, 2000). The mean Si: P ratios in both the seasons were also revealed that the phosphate-phosphorous was not a limiting nutrient in the entire study area (Table 5).

Table 5: Seasonal nutrient ratios of the study area

| Nutrient combinations | Nutrient ratios obtained | Redfield ratios (considered the weights) | Limiting nutrient (based on the Redfield ratios) |
|-----------------------|--------------------------|------------------------------------------|-----------------------------------------------|
| Si : DIN              | Pre-monsoon: 2.7, Post-monsoon: 2.4, Average: 2.6 | 2.0 | Nitrogen |
| DIN : P               | Pre-monsoon: 2.0, Post-monsoon: 2.0, Average: 2.0 | 7.2 | Nitrogen |
| Si : P                | Pre-monsoon: 5.4, Post-monsoon: 4.9, Average: 5.1 | 14.4 | Silicon |

DIN (dissolved inorganic nitrogen) = nitrate nitrogen + nitrite nitrogen + ammonical nitrogen.
Si = Silicate–Silicon
P = Phosphate–Phosphorous.

Changes in nutrient ratios may provide a sensitive indicator for eutrophication (Conley, 2000). Generally, in coastal areas affected by eutrophication, the cases of phosphorus limitation are usually prevailing on the cases of nitrogen limitation (UNEP/MAP, 2007). In present study area, it was observed that the phosphate-phosphorus was not a limiting nutrient during the entire study period and it evidently concluded that the coastal waters were either oligotrophic or mesotrophic but not eutrophic.

From the above observations it could be seen that under mesotrophic conditions, the study area was nutrient enriched but still functioned adequately without the enhanced production of chlorophyll-a. High nutrient concentrations without any corresponding biological impacts may not necessarily result in down grading ecological status (UNEP/MAP, 2007). Thus this classification provides a useful tool for assessing environmental quality and help coastal managers and planners in the decision making.
4. Conclusion

Overall, it may be concluded that the mesotrophic coastal waters of the Visakhapatnam industrial belt were within their assimilative and healing capacity against the pollution caused by the sewage and the effluents. However, caution has to be exercised in discharging organic wastes, such that these extreme loads should not hamper the healing and assimilative capacity of coastal waters. Further, the faulty technologies in the control of waste disposal should be replaced with the available green technologies without any delay.

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5. References

1. APHA., (1998), Standard methods for the examination of water and wastewater. 20th edition. American Public Health Association, Washington, D.C.

2. ASTM., (2008), Standard guide for conducting acute toxicity tests on aqueous ambient samples and effluents with fishes, macro invertebrates and amphibians. pp E 1192–97. The American Society for Testing and Materials. Philadelphia. PA, U.S.A.

3. BIS., (2007), Bio-Assay method for evaluating acute toxicity of industrial effluents and waste waters part-2 using toxicity factor to zebra fish (Brachydanio rerio). IS 6582 (part-2): 2001. Bureau of Indian Standards. New Delhi.

4. Chandra Mohan, P., B. Prabhakara Rao, D. Pankala Rao and T.V. Narasimha Rao., (1984), Studies on coastal processes in the vicinity of Gangavaram Bay. East Coast of India. National Institute of Oceanography. Visakhapatnam. NIO publ. pp E-157-169.

5. COMAPS Programme., (2010), Monitoring of Marine Pollution through Coastal Ocean Monitoring and Prediction System Programme. Gangavaram. Ministry of Earth Sciences, ICMAM. PD, Chennai.

6. Conley, Daniel J., (2000), Biogeochemical nutrient cycles and nutrient management strategies. Hydrobiologia. 410, pp 87–96.

7. CPCB Reports., (2010), Action Plan for Critically Polluted Area: Baikampady Industrial Cluster. Mangalore. Karnataka State. Annexure-III, pp 1-4.

8. Jones, P.D., (2006), Water quality and fisheries in the Mersey estuary. England: A historical perspective. Marine Pollution Bulletin, 53, pp 144–154.

9. Juan Bellas, Elsa Va´Zquez and Ricardo Beiras., (2001), Toxicity of Hg, Cu, Cd, and Cr on Early Developmental Stages of Ciona Intestinalis (Chordata, Ascidiaeae) with Potential Application in Marine Water Quality Assessment. Water Research, 35(12), pp, 2905–2912.
10. Khasim Beebi Sk., Sayeede Khatoon and M.P. Kusuma., (2007a), Physico-chemical characteristics of Steel Plant effluent entering Bay of Bengal at Appikonda Beach. Visakhapatnam. Indian Journal Environmental Protection, 27(2), pp 159-161.

11. Khasim Beebi, Sk., M.S. Jothiswari and S. Ramakrishna Rao., (2007), An Investigation on Suitability of Coastal Waters for Bathing, Recreation, Fish Culture, Commercial Fishing and Salt Manufacturing Purpose. Indian Journal Environmental Protection, 27(2), pp 108-113.

12. Klaus Grasshoff, Klaus Kremling and Manfred Ehrhardt., (1999), Methods of Seawater Analysis, 3rd edn., Wiley-VCH Publication, New York, pp 159-228.

13. Lenwood W. Hall, Jr. and Ronald D. Anderson., (1999), Ambient Toxicity Testing in Chesapeake Bay: Year 9. An Assessment of the Chester and Rappahannock Rivers, Chesapeake Bay Program. Annapolis.

14. Mafalda S. Faria, Ana Ré, João Malcato, Paula C.L.D. Silva, João Pestana, Ana R. Agra, António J.A. Nogueira and Amadeu M.V.M. Soares., (2006), Biological and functional responses of in situ bioassays with Chironomus riparius larvae to assess river water quality and contamination. Science of the Total Environment, 371, pp 125–137.

15. NIO Report., (2006), Rapid Marine Environmental Impact Assessment and investigations to lay a marine pipeline for discharging the effluents. NIO/SP-29/2006. National Institute of Oceanography. Goa.

16. Sagnik Dey and Ramesh P. Singh., (2003), Comparison of Chlorophyll distributions in the Northeastern Arabian Sea and Southern Bay of Bengal using IRS-P4 Ocean Color Monitor data. Remote Sensing of Environment, 85, pp 424-428.

17. Sara, M., Morales-Ojeda, Jorge A. Herrera-Silveira and Jorge Montero., (2010), Terrestrial and oceanic influence on spatial hydrochemistry and trophic status in subtropical marine near-shore waters. Water Research, 44, pp 5949-5964.

18. Sarma, V. V., Y. Sadhuram, N. A. Sravanthi and S. C. Tripathy., (2006), Role of physical processes in the distribution of chlorophyll-a in the northwest Bay of Bengal during pre- and post-monsoon seasons. Current Science, 91(9) pp 1133-1134.

19. Sladana Krivokapić, (2008), Chlorophyll-a As Biomass Indicator in Boka Kotorska Bay, Balwois, pp 27-31.

20. Smith, V.H., G.D. Tilman and J.C. Nekola., (1999), Eutrophication: Impacts of Excess Nutrient Inputs on Freshwater, Marine, and Terrestrial Ecosystems. Environmental Pollution, 100, pp 179-196.

21. Swamy, B.S., U.G. Suryawanshi and A.A. Karande., (2000), Water quality status of Mumbai harbour- an update, Indian Journal of Marine Science., 29, pp 111-115.
22. UNEP/MAP., (2007), Approaches to the Assessment of Eutrophication in Mediterranean Coastal Waters (First Draft) United Nations Environment Programme. Mediterranean Action Plan. Athens. UNEP(DEPI)/MED WG.321/Inf.6. pp 1-102.

23. UNESCO Reports., (1988), Unesco reports in marine science. Eutrophication in the Mediterranean Sea: receiving capacity and monitoring of long-term effects. Report and Proceedings of a scientific Workshop. Bologna. Italy, pp 1-198.

24. USEPA., (2003), Ambient Water Quality Criteria for dissolved oxygen, water clarity and chlorophyll-a for the Chesapeake Bay and its Tidal Tributaries. Office of Water. Washington. D.C.

25. Verlecar N. XIVanand, Somshekhar R. Desai, Anupam Sarkar and S. G. Dalal., (2001), Biological Indicators in Relation to Coastal Pollution along Karnataka Coast. India. National Institute of Oceanography. Dona Paula, Goa. India. NIO publ. pp 1-26.

26. Vijayakumaran, K., (2005), Productivity parameters in relation to hydrography of the inshore surface waters off Visakhapatnam. Journal of Marine Biology. Association of India, 47(2), pp 115 – 120.

27. Zingde, M. D. and B.N. Desai., (1987), Pollution status of estuaries in Gujarat-An overview. Contribution in Marine Science- NIO publication, pp 245-268.