6. SUMMARY

The present study highlights the physicochemical parameters of water and sediment, total heterotrophic, denitrifying and enzymatic bacterial populations registered in the selected sampling stations (S-I to S-III) of Thengapattinam estuarine environment. The monthly variations of physicochemical parameters, diversity of total heterotrophic, denitrifying bacterial population in water and sediment and the enzymatic bacterial population present in the sediment were studied for two consecutive years from January 2010 to December 2011. Water and sediment samples from the experimental stations (S-I to S-III) were collected and analyzed in the laboratory using standard methods. Simultaneously total heterotrophic, denitrifying and enzymatic bacteria were also analyzed using the standard procedures. The results obtained in the present study were subjected to relevant statistical analysis and summarized below.

WATER ANALYSIS

- The experimental estuarine environment showed an increase in atmospheric temperature during non monsoon period. Two-way analysis of variance (ANOVA) showed that the variation between stations was statistically not significant ($P > 0.05$); but the variation between seasons was highly significant ($P < 0.01$). This parameter showed a significant positive correlation with water temperature, carbon dioxide, sulphate, salinity, electrical conductivity, biological oxygen demand and iron ($r = 0.502$ to 0.992; $P < 0.05$) and a significant negative correlation with dissolved oxygen, nitrate, nitrite, bicarbonate, ammonia, copper, magnesium and zinc($r = -0.502$ to -0.679 ; $P < 0.05$) at various stations during the study period.

- The water temperature was low during monsoon when compared with non monsoon period in all sampling stations. Two-way ANOVA test revealed that the variation between stations was statistically not significant ($P > 0.05$) but the variation between seasons was statistically significant ($P < 0.01$) during the study period. Water temperature showed a significant positive correlation with atmospheric temperature, carbon dioxide, electrical conductivity, sulphate, calcium and salinity ($r = 0.523$ to 0.992; $P < 0.05$). But it showed a significant negative correlation with dissolved oxygen, nitrite, nitrate, ammonia, bicarbonate, copper, magnesium and zinc ($r = -0.515$ to -0.777; $P < 0.05$) at selected sampling stations.

- Monthly mean data showed a slightly acidic pH in all the selected sampling stations. Very low pH was recorded in January at S- II andS- III during the study period. Two-way analysis revealed that the variation in pH between stations and seasons was not statistically significant ($P > 0.05$) in both the years of study period. pH showed a significant positive correlation ($r = 0.652$ to 0.671; $P < 0.05$) with dissolved oxygen and negative correlation ($r = -0.528$ to -0.750 ; $P < 0.05$) with silicate and sulphate in selected stations during the study period.

- The salinity recorded in S-I was high when compared to S-II and S-III. An increase in salinity was recorded in December 2010 and April 2011 in S-I and S-II. Salinity variation may be attributed to rain fall, closing and opening of bar mouth. Analysis of variance revealed that the variation in salinity between stations and seasons was statistically not significant ($P > 0.05$) in 2010 whereas; it was significant ($P < 0.05$) in 2011. Further salinity was correlated positively with electrical conductivity, carbon dioxide, calcium, sulphate, manganese, zinc, atmospheric and water temperature, magnesium and iron ($r = 0.901$ to 0.508; $P < 0.05$) and correlated negatively with dissolved oxygen, copper, silicate, ammonia, nitrite and zinc ($r = -0.536$ to -0.845; $P < 0.05$) in various stations.

- Dissolved oxygen showed a wide range of variations in the sampling stations. High values were recorded during northeast monsoon and low values were registered during non monsoon period. ANOVA test showed a significant ($P < 0.05$) variation between stations; whereas, between seasons it was highly significant ($P < 0.01$) during the study period. It showed a significant positive correlation ($r = 0.536$ to 0.733; $P < 0.05$) with bicarbonate, nitrite, sulphate and pH. But the correlation was significantly negative ($r = -0.515$ to -0.864; $P < 0.05$) with atmospheric temperature, water temperature, carbon dioxide, salinity and electrical conductivity in different sampling stations.

- High concentration of carbon dioxide was reported during non monsoon period when the mouth of the estuary was closed. Two-way ANOVA test revealed that carbon dioxide showed a significant variation ($P < 0.01$) between stations and seasons during the study period. The carbon dioxide showed a significant positive correlation ($r = 0.506$ to 0.921; $P < 0.05$) with atmospheric temperature, water temperature, salinity, electrical conductivity, biological oxygen demand, calcium, sulphate, and iron and also exhibited a significant negative correlation ($r = -0.502$ to -0.774; $P < 0.05$) with nitrite, dissolved oxygen, copper, nitrate, bicarbonate and ammonia in different experimental stations.

- The biological oxygen demand recorded in S-II and S-III were higher than S-I during the study period. Maximum BOD was recorded in S-II during non-monsoon period. Two-way analyses indicated that the variation between stations and seasons was statistically not significant ($P > 0.05$). It was significantly correlated positively with silicate, calcium, sulphate, water temperature, atmospheric temperature, and carbon dioxide ($r = 0.537$ to 0.708; $P < 0.05$) in various stations.

- A wide range of difference in bicarbonate was recorded during the study period. Statistical analysis revealed that the variation in bicarbonate between stations was statistically significant ($P < 0.05$) and the variation between seasons was statistically not significant ($P > 0.05$) during the study period. Bicarbonate exhibited a significant positive correlation with electrical conductivity, magnesium, dissolved oxygen and calcium

($r = 0.519$ to 0.730; $P < 0.05$) and the correlation was negative with atmospheric temperature, water temperature, dissolved oxygen, carbon dioxide and sulphate ($r = -0.502$ to -0.616; $P < 0.05$) at different stations.

- Seasonal changes in the electrical conductivity showed the highest mean values during non monsoon period. The two-way ANOVA showed that the variation between stations and seasons was statistically not significant ($P > 0.05$). Electrical conductivity showed a significant positive correlation with salinity, water temperature, magnesium, carbon dioxide, bicarbonate, calcium, sulphate, atmospheric temperature and silicate ($r = 0.500$ to 0.927; $P < 0.05$). It also exhibited a significant negative correlation with dissolved oxygen, silicate, nitrite, ammonia, copper and zinc ($r = -0.519$ to -0.825; $P < 0.05$) at different sampling stations.

- High calcium content reported in S-II and S-III may be due to the addition of sewage, detergents and retting effluent. Two-way analysis revealed that the variation in calcium between stations and seasons was statistically not significant ($P > 0.05$) during 2010 and 2011. Calcium was positively correlated with biological oxygen demand, bicarbonate, magnesium, water temperature, salinity, carbon dioxide, sulphate, manganese and zinc ($r = 0.502$ to 0.927; $P < 0.05$) and correlated negatively with silicate, copper, phosphate, carbon dioxide, nitrite and ammonia ($r = -0.507$ to -0.697; $P < 0.05$) at various stations.

- Seasonal change in magnesium was high during non monsoon period and low values were recorded in monsoon season. Two-way ANOVA indicated that the variation in magnesium level between stations was statistically significant ($P < 0.05$) but at the same time the variation between seasons was statistically not significant ($P > 0.05$). Magnesium showed a significant positive correlation with electrical conductivity, calcium, bicarbonate, salinity and silicate ($r = 0.519$ to 0.884; $P < 0.05$) and also exhibited a significant negative correlation with atmospheric temperature, water temperature, iron, nitrite and ammonia ($r = -0.534$ to -0.695; $P < 0.05$) at selected stations.

- Seasonal fluctuation in silicate showed high values during the southwest monsoon season. Two way analyses showed that the variation in silicate content between stations was statically significant ($P < 0.05$) but the variation between seasons was statistically more significant ($P < 0.001$) in both the study period. Silicate exhibited a significant positive correlation with copper, ammonia, biological oxygen demand, electrical conductivity, nitrite, ammonia and magnesium ($r = 0.500$ to 0.832; $P < 0.05$) and the correlation was negative with pH, salinity, calcium, manganese, zinc, and iron ($r = -0.511$ to -0.796; $P < 0.05$) at selected stations.

- Phosphate content in the water sample showed seasonal changes and the maximum value was recorded during northeast monsoon in S-I but in S-II and S-III high values were observed during non monsoon period. Two-way ANOVA indicated that the variation between stations and seasons was statistically not significant ($P > 0.05$). Phosphate was significantly correlated positively with water temperature, sulphate nitrate, zinc and iron ($r = 0.519$ to 0.903; $P < 0.05$) and correlated negatively with calcium, nitrite and ammonia ($r = -0.507$ to -0.737; $P < 0.05$) in the sampling stations.

- Nitrite content recorded in the sampling station was high during southwest monsoon season and low during non monsoon period. Two-way analysis revealed that the variation in nitrite content between stations and seasons was statistically not significant ($P > 0.05$). Nitrite established a significant positive correlation with copper, nitrate dissolved oxygen, silicate and sulphate ($r = 0.509$ to 0.992; $P < 0.05$) and it showed a negative correlation with carbon dioxide, water temperature, atmospheric temperature, salinity, magnesium and electrical conductivity ($r = -0.500$ to -0.703; $P < 0.05$) in different sampling stations.

- Nitrate content showed seasonal variation in the sampling stations. Maximum value was registered during monsoon season and low values were recorded in non monsoon period. Data on two-way analysis revealed that the variation in nitrite content between stations and seasons was statistically not significant ($P > 0.05$). Nitrate exhibited a significant positive correlation with phosphate, nitrite and ammonia ($r = 0.625$ to 0.913; $P < 0.05$) and negative correlation with atmospheric temperature, water temperature phosphate sulphate and carbon dioxide ($r = -0.518$ to -0.737; $P < 0.05$) in various stations.

- High ammonia content was registered at S-III. This may be due to the discharge of domestic sewage from nearby houses. The two-way analysis of variance revealed that variation between stations and seasons was statistically not significant ($P > 0.05$) in both the years of study period. It was significantly correlated positively with silicate, manganese, nitrite and copper ($r = 0.500$ to 0.810; $P < 0.05$) and the correlation was negative with dissolved oxygen, atmospheric temperature, water temperature, electrical conductivity, salinity, calcium, magnesium, manganese, carbon dioxide, phosphate, zinc and iron ($r = -0.525$ to -0.779; $P < 0.05$) in selected sampling stations.

- High sulphate content was recorded during northeast monsoon in S-III and this may be due to mixing of sulphate rich effluents from husk retting grounds. Data on two-way analysis revealed that variation in sulphate content between stations and seasons was statistically not significant ($P > 0.05$) in both the years of study. Sulphate exhibited a significant positive correlation with atmospheric temperature, water temperature, salinity, electrical conductivity, calcium, carbon dioxide, biological oxygen demand, phosphate, nitrite, manganese, zinc and iron ($r = 0.515$ to 0.792; $P < 0.05$). But it showed a significant negative correlation with dissolved oxygen, bicarbonate, salinity, nitrate, pH and copper ($r = -0.503$ to -0.864; $P < 0.05$) in the selected experimental stations.

- Manganese showed seasonal variation. High manganese concentration was reported during non monsoon period and it was low during monsoon.

The two-way analysis of variance revealed that manganese content between stations and seasons was statistically more significant ($P < 0.05$) in both the years of study period. Manganese showed a significant positive correlation with salinity, calcium, sulphate, zinc and iron ($r = 0.500$ to 0.945; $P < 0.05$) and a negative correlation with silicate and copper ($r = -0.535$ to -0.970; $P < 0.05$) in various stations.

- Zinc showed seasonal variation and low values were recorded during southwest monsoon period. Two-way ANOVA indicated that the variation of zinc between stations was statistically not significant ($P > 0.05$) in both the years of study. But the variation between seasons was statistically not significant ($P > 0.05$) in 2010 and significant ($P < 0.05$) in 2011. Zinc was significantly correlated positively with salinity, calcium, phosphate, sulphate, manganese and iron ($r = 0.502$ to 0.945; $P < 0.05$) and correlated negatively with atmospheric temperature, water temperature, electrical conductivity, silicate, copper and ammonia ($r = -0.522$ to -0.928; $P < 0.05$) in various stations.

- Copper showed maximum value during southwest monsoon and minimum during non monsoon. Two-way analysis revealed that the variation between stations was not statistically significant ($P > 0.05$) in both the years of study but variation between seasons was statistically significant ($P < 0.05$) during the study period. Copper exhibited a significant positive correlation with silicate, nitrite and ammonia ($r = 0.509$ to 0.832; $P < 0.05$). It also showed a significant negative correlation with manganese, zinc, iron, sulphate, salinity, carbon dioxide, electrical conductivity, calcium, atmospheric temperature and water temperature ($r = -0.513$ to -0.970; $P < 0.05$) in different stations.

- Iron showed an irregular pattern of distribution. Maximum value was recorded in S-II. Analysis of variance revealed that the variation between stations was statistically not significant ($P > 0.05$) but the variation between seasons was statistically more significant ($P < 0.01$) during the study period. The iron showed a significant positive correlation with atmospheric temperature, water temperature, electrical conductivity, nitrite, phosphate, salinity, carbon dioxide, ammonia, sulphate, manganese and zinc ($r = 0.543$ to 0.900; $P < 0.05$) and negative correlation with silicate, nitrite, copper, magnesium and ammonia ($r = -0.534$ to -0.935; $P < 0.05$) in various stations.

SEDIMENT ANALYSIS

- Sediment pH showed wide fluctuations during the study period. Low pH values were recorded in S-II and S-III. Two-way ANOVA test revealed that the variation between stations and seasons was statistically significant ($P < 0.01$ and $P < 0.05$) during 2010 and 2011 respectively. pH showed a significant positive correlation with phosphorous, copper, potassium and iron ($r = 0.515$ to 0.848; $P < 0.05$) and negative correlation with electrical conductivity ($r = -0.505$ to -0.816; $P < 0.05$) in different stations.

- High EC values were recorded during non monsoon period and low values were noticed during monsoon season. Analysis of variance indicated that the variation between stations was statistically not significant ($P > 0.05$) but the variation between seasons was statistically significant ($P < 0.05$). EC is significantly correlated negatively with pH, phosphorous, iron, potassium, zinc, organic carbon and nitrogen ($r = -0.505$ to -0.826; $P < 0.05$) in selected stations.

- Total nitrogen content was high during monsoon and low values were recorded during non monsoon period. Two-way analysis indicated that the variation between station and season were statistically significant ($P < 0.05$) during the study period. It showed a significant positive correlation with organic carbon, potassium zinc, manganese phosphorous and iron ($r = 0.502$ to 0.871; $P < 0.05$) and negative correlation with electrical conductivity at selected sampling stations.
- Phosphorus content recorded in the sampling stations was very low during the study period. Seasonal fluctuation showed maximum values during monsoon and minimum in non monsoon. The two-way ANOVA test revealed that the variations in phosphorus content between stations and seasons were statistically significant ($P < 0.05$) in both the years of study. Phosphorous showed a significant positive correlation with potassium, organic carbon, nitrogen, copper and iron ($r = 0.507$ to 0.814; $P < 0.05$) and the correlation negative with electrical conductivity ($r = -0.532$ to -0.783; $P < 0.05$) in various stations.
- Maximum value of potassium was recorded during southwest monsoon period. The two-way ANOVA revealed that the variation between stations

was statistically not significant ($P > 0.05$) but the variation between seasons was statistically more significant ($P < 0.01$) during the study period. Potassium exhibited a significant positive correlation with phosphorus, organic carbon, nitrogen, zinc and iron($r = 0.502$ to 0.822; $P < 0.05$) and it showed significant negative correlation with electrical conductivity ($r = -0.563$ to -0.810; $P < 0.05$) in different stations.

- Organic carbon noted in the sampling stations was very low due to sandy sediment. Two-way ANOVA test revealed that the variations in sediment organic carbon between stations and seasons were statistically significant ($P < 0.05$). Organic carbon showed a significant positive with nitrogen, potassium, phosphorus, manganese, zinc and iron ($r = 0.502$ to 0.871; $P < 0.05$) and negative correlation ($P < 0.05$) with electrical conductivity in various stations.

- Copper, zinc, manganese and iron recorded in the sampling stations showed maximum values during monsoon season and minimum in non monsoon period. The two-way ANOVA revealed that the variation in sediment copper between stations was statistically not significant but the variation between seasons was statistically significant ($P < 0.05$) during the study period. It showed a significant positive correlation with phosphorus, pH and iron ($r = 0.544$ to 0.848; $P < 0.05$) at selected sampling stations. Two-way ANOVA test revealed that the variation in sediment zinc between stations was statistically not significant ($P > 0.05$) in 2010 and it was statistically significant ($P < 0.05$) in 2011. But the variation in sediment zinc was statistically significant between seasons ($P < 0.05$) during the study period. Zinc was correlated positively with organic carbon, nitrogen, manganese, potassium, phosphorous and iron ($r = 0.514$ to 0.871; $P < 0.05$) but it showed a significant negative correlation with electrical conductivity($r = -0.524$ to $- 0.613$; $P < 0.05$) at various stations.

- Analysis of variance revealed that the variation in sediment manganese between stations was statistically not significant ($P > 0.05$) during 2010; whereas it was more significant ($P < 0.01$) during 2011. On the other hand variation between seasons was statistically significant ($P < 0.05$) during the study period. It was significantly correlated positively with organic carbon and nitrogen ($r = 0.590$ to 0.786; $P < 0.05$) in various stations. The two-way ANOVA test revealed that the variation in sediment iron content between stations was statistically significant ($P < 0.05$) during 2010 whereas; it was not significant ($P > 0.05$) during 2011. But the variation between seasons was statistically significant ($P < 0.05$) in the study period. Iron showed a significant positive correlation with potassium, phosphorous, organic carbon, nitrogen, copper and zinc ($r =0.542$ to 0.772; $P < 0.05$) and the correlation was negative with electrical conductivity ($r = -0.578$ to -0.704; $P < 0.05$) at various stations.

DENITRIFYING BACTERIAL POPULATION ANALYSIS

- Total heterotrophic, denitrifying and enzymatic bacterial population in the selected sampling stations were highly fluctuated. The present study revealed that the dominant denitrifying bacteria in the experimental stations were; *Pseudomonas sp. and Bacillus sp.* The percentage of *Pseudomonas sp.* was comparatively more than that of *Bacillus* sp.

- In 2010, the total bacterial count in water was high in June at S-III and low in March and September at S-I. During 2011, minimum bacterial count was recorded in January and May at S-I and the maximum was in October at S-III. The mean monthly bacterial count was maximum at S-III and minimum at S-I during the study period. In sediment, total bacterial count was high in June at S-III and low in March at S-II and the mean monthly bacterial count showed a minimum value at S-I and maximum value at S-III during 2010. In 2011, maximum bacterial count was noticed in July at S-II and minimum population was recorded in February at S-III. The mean monthly bacterial count was maximum at S-II and minimum at S-I.

- In 2010, the percentage of denitrifying bacterial population in water was high in April at S-II and low in September at S-I. The mean monthly average of denitrifying population was maximum at S-III and minimum at S-I. In 2011, high percentage was recorded in June at S-III and low in December at S-I. The mean monthly average of denitrifying population was maximum at S-III and minimum at S-I. In 2010, the percentage of denitrifying bacterial population in sediment was high in October at S-II and low in March at S-I. The mean monthly average of denitrifying population was maximum at S-II and minimum at S-III. In 2011, high and low percentage of denitrifying bacteria was recorded at S-II in July and March respectively. The mean monthly average of denitrifying population was maximum at S-III and minimum at S-I. During the study period, the denitrifying bacteria recorded were *Pseudomonas sp.* and *Bacillus* sp. In all the sampled stations *Pseudomonas sp.* was high when compared to *Bacillus sp*.

- The total heterotrophic bacterial population recorded in the selected sampling stations showed a significant positive correlation with sediment total nitrogen (r^2 = 0.570 to 0.689 and r^2 = 0.588 to 0.863) during 2010 and 2011 respectively. Likewise the percentage of denitrifying bacterial population also showed a significant positive correlation (r^2 = 0.758 to 0.908 and r^2 = 0.815 to 0.869) with total nitrogen during the study period.

- In 2010, starch hydrolyzing bacteria in sediment sample was high in October at S-III and low in March at S-I. In 2011, minimum starch hydrolyzing bacteria was observed in February and maximum in July at S-II. The minimum monthly average of starch hydrolyzing bacterial population was recorded at S-I and maximum at S-III during the study period. In 2010, the casein hydrolyzing bacterial population was maximum in October at S-II and minimum in March at S-I. But in 2011, the maximum values were observed in July at S-II and in October S-III and minimum casein hydrolyzing bacterial population was observed in May 2011 at S-I. The minimum monthly mean casein hydrolyzing bacterial population was noticed at S-I and maximum at S-III during the study period.

- Seasonal variation of starch and casein hydrolyzing bacterial populations were less in non monsoon period at S-I and more in southwest monsoon period at S-III. At the same time in 2011, maximum casein hydrolyzing bacteria were observed in S-III during northeast monsoon and minimum values in non monsoon period. The starch hydrolyzing bacterial population recorded in the selected sampling stations showed a positive correlation with sediment total nitrogen (r^2 = 0.487 to 0.586 and r^2 = 0.498 to 0.533) during 2010 and 2011 respectively. But the casein hydrolyzing bacteria showed a significant positive correlation (r^2 = 0.874 to 0.937 and r^2 = 0.893 to 0.940) with total nitrogen during the study period.