Wetlands are highly productive ecosystems in the biosphere supporting a rich variety of flora and fauna. The Ashtamudi wetlands have been under severe environmental stress due to plethora of anthropogenic activities which drastically destroyed the health of the wetland ecosystems. The anthropogenic activities in the wetland not only affect the scenic beauty and endemicity of the ecosystem but also affecting the valuable biotic resources.

The present study was carried out in the Ashtamudi backwater forming a major part of the Ashtamudi wetland ecosystem which is an important Ramsar site noted for its valuable biotic resources, strong endemicity and scenic beauty. Ashtamudi is the second largest backwater system in Kerala. It is planimetric in shape with eight creeks covering an area of 5598ha and lying between lat. 8°53’ and 9°02’ and long. 76°31’ and 76°41’.

The thesis is broadly divided into seven chapters. Chapter 1, General Introduction gives a detailed background on the unique feature of wetlands, its functions and role in the aquatic ecosystem and also the objectives of the present study. Chapter 2 The Environment, discusses the background of Ashtamudi backwater and the study sites selected for the present investigation. The period of study was from October 2007 to September 2008. Four stations representing different environmental conditions were selected for regular monthly monitoring. The four stations were Neendakara (station I), Chavara (station II), Ashtamudi (station III) and Ashramam (station IV). At
Neendakara (station I), the marine zone, intense fishing activity by mechanized and country canoes are seen. At Chavara (station II), the industrial zone is influenced by industrial effluents mainly from the Indian Rare Earths Limited, Chavara. This zone is also influenced by dumping of organic waste as well as solid waste from various human activities. Ashtamudi (station III) is the brackish water zone free from pollution problems and it is a very important fishing zone. Ashramam (station IV) is the mangrove zone, but major parts of the mangrove vegetation have been destroyed due to various anthropogenic activities.

Chapter 3 on Water quality status of Ashtamudi backwater gives an introduction, detailed review of literature, methodology adopted, results and discussion. The water quality status of the four stations (station I to station IV) was studied in detail. The following aspects were analyzed by using standard methods and result of the study may be discussed as follows.

Meteorological data pertaining to rainfall were obtained from the Meteorological Department, Thiruvananthapuram. The influence of the south west monsoon and its impact on the water quality of the Ashtamudi backwater has been noted. The depth profile of Ashtamudi backwater showed an average depth of 2.66 ± 1.04 m. The peak values of depth were recorded during the monsoon period. Based on the spatial distribution very low depth was noted at Ashramam (station IV: 1.71 ±0.47 m) that was probably due to the disposal and filling of solid wastes from Kollam city. Similarly at Chavara, also the minimum depth observed was probably due to the disposal of very large quantities of industrial wastes from Indian Rare Earths Limited, Chavara.

An annual average water temperature of 30.58±1.69ºC was noticed during the study period with clear stratification between surface and bottom
Summary

Water temperature. Inter annual mean water temperature showed highest during the pre-monsoon and lowest during the monsoon period. Spatially the maximum water temperature (31.75±1.73°C) was recorded at Ashramam and lowest (29.38±1.24°C) at Neendakara. Transparency was minimum at all the four stations during the monsoon period with heavy rainfall and discharge of turbid and muddy waters from all drainage channels around and from the Ashtamudi catchment basin. Similarly during the post monsoon period transparency was high at all the four stations. The annual average transparency of the Ashtamudi backwater was estimated to be 1.19 ±0.33m. The water at station II, Chavara and station IV, Ashramam were extremely turbid throughout the year. The heavy discharges of industrial effluents from the Indian Rare Earths Limited along with other organic and domestic waste dumped in to the area could be the reason for the low transparency values in the Chavara region. Disposal of solid waste from Kollam city was the reason for the highly turbid conditions noticed at station IV. Neendakara and Ashtamudi showed comparatively high transparency than Chavara and Ashramam.

Turbidity values tended to show variation in the surface and bottom waters of the backwater. Inter annual average turbidity value of Ashtamudi backwater was 5.92±3NTU, whereas the high concentration was noticed during the monsoon period. Maximum turbidity (8.82±2.32NTU) and minimum transparency (0.93±0.12m) was recorded at Ashramam whereas maximum transparency (1.40±0.41m) and minimum turbidity (3.25 ±1.21NTU) was observed at Ashtamudi. Spatially, land run off, wave and wind action created a churning movement of the bottom water might be the reason of high turbidity in the Ashramam region during the rainy season. High
content of organic matter in the bottom sediments are the probable reason for the high value of turbidity at station II, Chavara.

The total dissolved solids in an aquatic body can throw light upon various pollutants associated with it. In the present study the concentration of total dissolved solids is very high in the Ashtamudi backwater which extended up to an annual average of 18518.44±4329.42mg/l nullifying the tolerance limit of 3000ppm. In the presence study it was noted that high total dissolved solids persisted in the surface water as well as bottom water during the pre-monsoon period. Alkalinity values showed a definite trend in all the four stations with an annual average of 132.8±43.2mg/l. Bottom water alkalinity exhibited higher values than the surface water at all the four stations. Pre-monsoon recorded high value of alkalinity at all the four stations. The estuary mouth, Neendakara reported high value followed by Ashtamudi, Ashramam and Chavara stations.

The average total hardness of the backwater at the four stations was 4484.5±1295.1mg/l during the study period. Hardness is not a pollution factor but it indicates the quality of water. During the pre-monsoon period maximum hardness was reported at all the four stations. The annual mean of bottom water was found to be higher than that of the surface water. Neendakara reported high value followed by Ashtamudi, Ashramam and Chavara stations. Calcium hardness of the backwater showed an average of 551.9±162.8mg/l. Chavara reported low value followed by Ashramam, Ashtamudi and Neendakara stations.
Very high concentration of chloride was obtained in the Ashtamudi backwater with an average of 11216.7 ± 3701.2mg/l. Pre-monsoon period recorded the highest value at all the four stations. Chloride decreased progressively from Neendakara, Ashtamudi, Ashramam and reached the lowest value at Chavara. The salinity distribution showed a clear stratification between the surface and bottom waters at all the four stations. The annual average salinity in the Ashtamudi backwater was estimated to be 26.3 ±5.4psu. Pre-monsoon period showed the highest salinity in the Ashtamudi backwater. Salinity decreased progressively from the estuary mouth at Neendakara (31.5 ±2.3psu) to Ashtamudi (28.8±2.7psu), Ashramam (22.4 ± 4.8psu) and reached the lowest value at the Chavara (22.4±4.2psu) station.

The water pH values showed definite and wide variations at all the four stations with an annual mean of 7.8±0.6. Inter station differences are significant during the present study. Seasonally highest value of pH was recorded during the pre-monsoon season. Spatially it is noted that the high value at station I, Neendakara and at station IV, Ashramam due to the coagulation of colloidal particles which shifts pH towards the alkaline side. At station II, Chavara the pH was towards the acidic side in most of the months and this might be due to the discharge of acid effluents from the Indian Rare Earths Limited, Chavara. The average conductivity of the Ashtamudi backwater at the four stations was estimated to be 27073.9 ±5708.1 μmhos/cm. Pre monsoon recorded high value of conductivity at all the four stations in Ashtamudi backwater. In the present study, conductivity of water showed higher values at Neendakara (station I), Ashtamudi (station III) and Ashramam ( station IV). This reflects the rich nutrient level at these stations.
Comparatively low concentration of dissolved oxygen was the characteristic feature of the polluted stations like Chavara and Ashramam. A discernible trend was observed in the dissolved oxygen regime, where the surface water was comparatively higher than that of the bottom waters at all the four stations of the backwater. The average dissolved oxygen concentration of 4.4±1.7mg/l was observed during the study. During the present study dissolved oxygen concentration showed a definite seasonal change. Minimum value of dissolved oxygen was noticed during the pre-monsoon period could be due to the minimum fresh water influx, higher temperature and high salinity prevailed in that area of Ashtamudi backwater. Spatially, the decreased level of dissolved oxygen in the industrial site, Chavara compared to other stations due to the possibility of the presence of organic and inorganic impurities present in this water.

BOD values tended to show variation in the surface and bottom waters of the backwater. Inter annual average BOD value of Ashtamudi backwater was 6.9±4.7mg/l. The high dissolved oxygen (5.9±1mg/l) and low BOD (3.1±1.1mg/l) values were observed at Ashtamudi, whereas low dissolved oxygen (2.2±0.7mg/l) and higher BOD values (11.8±4mg/l) were recorded at Chavara. From the spatial distribution, it is clear that the intense stress arising at Chavara (station II) due to industrial pollution led to comparatively higher BOD and low dissolved oxygen values.

Nitrate was minimum at station I (Neendakara) and maximum at station II (Chavara) indicating a clear upward trend from the marine (Neendakara) to the impacted zone at Chavara. Inter annual mean water nitrate showed highest during the monsoon and lowest during the pre-monsoon periods. The annual mean of nitrate in the Ashtamudi backwater
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was 13.8±4.3µmol/l. A clear stratification between surface and bottom water was found in that the bottom water recorded higher nitrate values than the surface water at all the four stations. Spatially, nitrate value was comparatively high at station II Chavara and station IV Ashramam and this can be attributed to the discharge of organic wastes include household waste, municipal sewage and industrial wastes from Indian Rare Earths Limited, Chavara dumping into that area. Nitrite value showed a definite pattern and trend with an annual average value of 1±0.3µmol/l. The low value of nitrite was reported during the pre-monsoon period. Station II (Chavara) reported a high value of nitrite compared to other stations and this is attributed to the direct discharge of industrial effluents and wastes from Indian Rare Earths Limited, Chavara and dumping of organic wastes as well as land run off in to that area. Nitrite value is low compared to the nitrate value in all the four stations which could be due to its unstable nature and nitrite is immediately converted to nitrate and ammonia and its high ability of evaporation.

Spatial variation of ammonia showed a definite pattern of variation. The distribution of ammonia in the surface and bottom waters was characterized by comparatively high concentrations in the polluted zones represented by station II (Chavara) and station IV (Ashramam). The average ammonia of the backwater in the four stations was 5.1±1.6µmol/l. The pre-monsoon period registered highest value at all the four stations. A clear stratification was noticed in the concentration of ammonia that the surface water registered a higher value than the bottom water in all the four stations.

Spatial distribution of phosphate is marked with an increasing trend in values towards Ashramam region (2.4±0.6µmol/l) and decreasing trend towards Neendakara (0.9±0.2µmol/l). Seasonally during the pre-monsoon
period phosphate values showed high values at all the four stations in the Ashtamudi backwater. Bottom water phosphate showed comparatively higher values than the surface water phosphate. The Ashtamudi backwater becomes more polluted at station IV (Ashramam) and at station II (Chavara) and this might be due to the increased rate of surface run off, human interference such as increased application of fertilizers, use of detergents and dumping of domestic sewage and market waste, deposition of avian excreta and fecal contamination. The average N:P ratio of the Ashtamudi backwater was above the Redfield ratio during South West Monsoon period (20.4±0.3), then it decreased to 11.6±1.2 (post monsoon) and attained lowest the value at 8.6±1 (pre-monsoon). From this it is clear that Ashtamudi was phosphorus limited during monsoon season and nitrogen limited during pre-monsoon periods. In post monsoon season, either one of the nutrient like nitrogen or phosphorus are the limiting factor.

The post monsoon recorded peak values in the sulphate content with an annual average of 6804.5±2108.8µmol/l. Sulphate concentration showed progressive decline from the marine to the interior zone of the estuary. Sulphate was very high at all the four stations in the Ashtamudi backwater. When the annual average values were examined a clear stratification between the surface and bottom water sulphate was discernible in that the bottom water values were higher than the surface water at the four stations. Iron showed a clear pattern of seasonal and spatial variations with highest value during the pre-monsoon period in all the four stations. Spatially, Chavara recorded higher value of iron compared to other stations, this is attributed to the discharge of industrial effluents from Indian Rare Earths Limited, Chavara. Neendakara and Ashtamudi recorded lowest value compared to Chavara and Ashramam. Inter annual mean of iron in the Ashtamudi backwater was 0.2 ±0.3mg/l. The
presence of total coliforms in large numbers is indicative of input of sewage in large quantities to the backwater. Annual average value of total coliforms in the Ashtamudi backwater was 389.6±605.6TC/100ml. In the present study, the values were higher than the permissible limit of 500 numbers/100ml specified for waters to be used for swimming and aquaculture. The presence of high value of total coliforms at station II and station IV is a matter of serious concern. In the absence of adequate facilities for the disposal of sewage and silage from human settlements, they are directly discharged into the backwater system. In the present study maximum number of total coliforms was reported in the pre-monsoon and post-monsoon period and lowest population was in the monsoon period.

Chapter 4 on Patterns in Primary Production deals with a brief introduction, review of literature, sampling and analytical methods, results and discussion. Gross and Net productivity values showed distinct variation with respect to seasons and stations in the backwater. Post monsoon showed higher gross and net productivity values in the four stations of the Ashtamudi backwater (GP: 1.55gCm⁻³ day⁻¹ ± 0.59, NP: 1.24gCm⁻³ day⁻¹ ± 0.56). The marine zone, Neendakara showed maximum gross and net production (GP: 1.90gCm⁻³ day⁻¹ ± 0.27; NP: 1.56gCm⁻³ day⁻¹ ± 0.25) followed by Ashtamudi (GP: 1.68gCm⁻³ day⁻¹ ± 0.32; NP: 1.35gCm⁻³ day⁻¹ ± 0.31) and Ashramam (GP: 0.75gCm⁻³ day⁻¹ ± 0.27; NP: 0.54gCm⁻³ day⁻¹ ± 0.25). Minimum gross and net production was reported from the impacted zone, Chavara (GP: 0.63gCm⁻³ day⁻¹ ± 0.26; NP: 0.39gCm⁻³ day⁻¹ ± 0.20). The study has shown that the primary productivity was comparatively lower in the impacted zone, Chavara because the industrial wastes from Indian Rare Earths Limited have considerably disturbed the productivity regime of this zone. Surface and bottom water productivity in the four stations of the Ashtamudi backwater was analyzed.
Chapter 7

Chapter 5, Mesozooplankton composition and community structure describes the composition, distribution, abundance and diversity of mesozooplankton in the Ashtamudi backwater. This chapter deals with a brief introduction, review of literature, methods in field sampling, collection and analysis of mesozooplankton parameters and results and discussion. Qualitatively and quantitatively the mesozooplankton population was comparatively poor in the polluted stations like Chavara and Ashramam. The biomass values were comparatively low at the polluted stations when compared to the non-polluted stations characterized by Neendakara and Ashtamudi. The mesozooplankton in the Ashtamudi backwater belonged to six functional groups. Hydromedusa, Rotifera, Ostracoda, Cladocera, Copepoda and Copepod nauplii. Copepods were the major mesozooplankton functional group present in the Ashtamudi backwater. Eighteen species of mesozooplankton were identified from Ashtamudi backwater where the copepods expressed maximum abundance in all the study stations including 13 species. The population density of mesozooplankton in the Ashtamudi backwater was maximum during the post monsoon period. Community structure of the mesozooplankton has been examined in the context of available information. Maximum diversity of mesozooplankton was observed at Neendakara ($H_1=1.52$), followed by Ashtamudi ($H_1=1.15$), whereas minimum values were noticed at Chavara ($H_1=1.00$) and Ashramam ($H_1=1.02$). The comparatively low diversity index at Chavara and Ashramam coincided with the poor abundance and incidence of mesozooplankton communities arising from stress condition due to pollution in the region.
Cluster analysis was performed for the zooplankton to understand both the monthly and seasonal patterns. Based on monthly distribution pattern of mesozooplankton, 16 significant clusters were formed that displayed red bars under the SIMPROF test indicating that all the similarity in abundance were significant. Maximum similarity of 99% could be observed in two clusters. Maximum similarity of 99% could be observed between February and May at station III and October and November at station III. Based on the seasonal patterns, four significant clusters were formed that displayed red bars under the SIMPROF test indicating that all the similarity in abundance were significant. Maximum similarity as high as 90% could be observed between station I monsoon and station III monsoon and between station I post monsoon and station III post monsoon periods.

In the present analysis, the data of mesozooplankton was used for MDS analysis on monthly and seasonal pattern. The month wise MDS plot showed around 20% similarity for the overall zooplankton population in the study period. Six groupings with 80% similarity were observed and similarity at 60% was observed for two groupings. Month-wise MDS plot for mesozooplankton gave a good ordination having the stress value of 0.06. MDS plot for seasonal distribution gave a good ordination having the stress value of 0.02. The season-wise MDS plot showed around 20% similarity for the overall zooplankton for the study period. 3 groupings with 80% similarity were observed and similarity at the 60% was observed for two groupings.

Chapter 6, Macrobenthos distribution and community structure elaborates the abundance and diversity of macrobenthic fauna in the Ashtamudi backwater. This chapter presents an introduction, review of literature, methods in field sampling, collection and analysis of sediment and benthic parameters
and results and discussion. The macrobenthic fauna belonged to seven groups, Nematoda, Oligochaeta, Polychaeta, Amphipoda, Gastropoda, Bivalvia and Fish larvae. Twenty eight species of macrobenthos were identified from Ashtamudi backwater where polychaetes expressed maximum abundance in all the study stations including sixteen species. In this study six groups were present at Neendakara, four at Chavara, seven at Ashtamudi and five at Ashramam. The population density of benthic fauna in the Ashtamudi backwater was maximum during the monsoon period. Qualitatively and quantitatively the benthic organisms were comparatively poor in the polluted stations. The polychaete, *Capitella capitata* was seen only at Chavara, (Industrial zone) as an indicator species of industrial pollution in the region. The community structure of the macrobenthos has been examined in the context of available information. The maximum diversity of macrobenthic fauna was observed at Ashtamudi ($H^1=2.133$) followed by Neendakara ($H^1=2.112$) stations. The minimum diversity of macrobenthic fauna was noticed at Chavara ($H^1=1.731$) and Ashramam ($H^1=1.731$). The higher diversity index at Ashtamudi and Neendakara represent a degree of stability at these stations. Low diversity and standing stock of macrobenthic fauna in the impacted zone (Chavara) indicates the prevalence of stress condition. The considerably low diversity indices in Ashtamudi backwater during the study indicate the stressed condition of macrobenthic community due to pollution from industrial source and anthropogenic factors.

Sediment quality status of the four stations was studied in detail. The pre-monsoon months showed higher sediment temperature whereas during the monsoon months the temperature was found to be lower. Sediment temperature did not show any definite pattern in the distribution without wide
spatial variations and it followed closely the variations in temperature of the overlying water. Sediment pH was found to be generally acidic at all the stations indicating a prolonged acidic phase in the sediments. Distribution of organic carbon exhibited distinct spatial and seasonal trend. Organic carbon values ranged from 0.13 % to 2.80%. The high value of organic carbon was reported at Ashtamudi (station III) while low value was reported at Neendakara (station I). Organic matter attained its peak in the pre-monsoon period. It ranged from 0.23% to 4.87%. From the sediment grain size (sand, silt and clay) the silt was the dominant followed by clay and sand in the estuary.

Based on monthly abundance pattern of macrobenthos, seventeen significant clusters were formed that displayed red bars under the SIMPROF test indicating that all the similarities in abundance were significant. Maximum similarity of 99% could be observed in ten clusters. Maximum similarity of 99% could be observed between June and August at station III, May and September at station III, February and August at station I, April and September at station I, March and May at station I, July and August at station IV, June and September at station IV, June and August at station II, February and May at station II, March and September at station II. Based on the seasonal patterns, four significant clusters were formed that showed red bars under the SIMPROF test indicating that all the similarity in abundance were significant. Maximum similarity as high as 97% could be observed between pre monsoon and monsoon at station I. Similarity as high as 95% could be observed between pre monsoon and monsoon period at station III, pre monsoon and monsoon period at station II and pre monsoon and monsoon period at station IV.
The month wise MDS plot showed around 20% similarity for the overall macro benthic population for the study period in the Ashtamudi backwater. Three groupings with 80% similarly were observed and similarly at 60% were observed for all the three groupings. Month wise MDS plot for macro benthos gave a good ordination having the stress value of 0.02. The season wise MDS plot showed around 20% similarity for the overall macro benthos for the study period in the Ashtamudi backwater. Two groupings with 80% similarity were observed and similarity at 60% was observed for all the two groupings. Season wise MDS plot for macrobenthos gave a good ordination having the stress values of 0.01. Based on the classification of Clark and Warwick (2001) the four stations at Ashtamudi backwater come under the criteria that Neendakara and Ashtamudi are high quality sites. Ashramam is a moderate quality site and Chavara is a very poor quality site.

**Future outlook and management options for Ashtamudi backwater ecosystem**

- The study has established that the environmental quality and biotic potential of Ashtamudi backwater ecosystem has deteriorated especially in the Chavara and Ashramam regions on account of various anthropogenic interventions. The horizontal and vertical shrinkage of the backwater over the last few decades with reduced river flow and eutrophication was a serious problem in the water body. Time scale analysis has also proved that the backwater is losing its water spread area and trophodynamic character.
Pollution problems from industrial and domestic source need to be immediately regulated. Industrial growth particularly on the banks of Ashtamudi backwater and the Kallada river should be monitored and also regulated to achieve the prescribed water quality standards. Future industrial growth should be planned based on the guidelines laid down by the Central and State Pollution Control Boards.

Mangrove area has shrunken critically due to reclamation, mining and related problems. Efforts are to be made by the State Environment and Forest Departments for increasing the mangrove cover of the area by replanting and conservation of the existing region. As Kollam city is fast increasing in population and future developmental programs, it is imperative that, the mangroves of Ashtamudi estuary could be developed and maintained as a **green lung cover** for the city. Kerala State Pollution Control Board has to also increase its surveillance measures for maintaining the environmental quality of the backwater especially in the industrial zones.

Asharamam and Chavara zones are experiencing increased fecal coliform and contamination from different pathogens due to intense dumping of domestic and municipal sewage from various sources that is leading to many health and social issues. So a collective action is to be evolved by various Govt. Depts. like the Revenue, Health, Pollution Control Board, Forest, Irrigation and others for resolving these issues. Violation and relaxation of the Coastal Regulation Zone (CRZ) norms has been recorded in many regions of the Ashtamudi wetland. So strict enforcement of the CRZ norms for the backwater have to be implemented. National Green
Tribunal suo motu has to monitor and take action on the violations of CRZ norms and initiate appropriate action.

- A regular field based and online environmental monitoring of various sectors of the backwater is needed for keeping the ecosystem and the nearby areas in healthy condition.

- Dredging and sand mining activities should be regulated and the dredged material should not be deposited in the backwater. Deepening of shallow regions in the backwater will improve the water flow and circulation that will reduce nutrient enrichment and also minimize issues on eutrophication. Sand mining especially from the incoming rivers should be limited with quota system that should be enforced by the Local Self Government Bodies.

- The hydrology and regular flows from rivers into the estuary has been seriously affected by waste disposal, unplanned construction of roads and other structures that has led to seasonal flooding and biodiversity loss. So detailed studies on the hydrology of the backwater, salinity, inorganic nutrient regime in different zones, river flows and patterns are to be undertaken before any future development programs are implemented.

- Since tourism activity is on the rise in Ashtamudi and other wetlands of the state, urgent action is required to restrict various pressures associated with this on the wetland and its resources. A carrying capacity based model needs to be developed on the impact of tourism and related pressures in the wetland. Action for protecting small islands and lagoons should be implemented. Special attention should be taken by State Tourism Department for restricting nature tourism without involving any ecological
Modification of the islands and promote mangrove afforestation. Waterbird habitat assessment and monitoring network through training, awareness and participation programmes is to be implemented.

➢ It has been reported that the commercially important traditional fishery are getting vanished while others are becoming a rarity. The native species such as *Horabagrus brachysoma* and *Hyporhamphus* sp., etc. are vulnerable and exotic species has replaced the habitat and niche of these local resources. The life cycle stages of many indigenous species have been disrupted. Schemes to bring back the native species, sanctuaries for propagation of endangered and threatened resources, improving the licencing of major fishery operations –gears and crafts, restricting cod end mesh of gears to 10mm, enhancing cooperatives, establishing exclusive coastal social networking for marketing of resources for common commodity pricing and improving condition of fishers and other dependent population are to be implemented.

➢ Ashtamudi wetland encompassing the backwater was declared a Ramsar site on August 2002, but no serious actions have been implemented by the Government to date to improve the overall ecology and wise use of the wetland for sustainable livelihood measures. The reforms under the Ramsar need to be strengthened. Having the unique backwaters and endemic resources, the Ashtamudi wetland and associated backwater system needs to be considered as a UNESCO world Heritage site for conservation and sustainable utilisation. Geographic identity of the unique and indigenous biodiversity is to be established, which would help in upgrading the wetland to a heritage site.