Asian Journal of Water, Environment and Pollution, Vol. 9, No. 2 (2012), pp. 73–84.

Saltwater Intrusion and Its Impact on Koggala Lagoon and Associated Waters, Southern Coast of Sri Lanka

H.B. Jayasiri* and D.D.G.L. Dahanayaka

National Aquatic Resources Research and Development Agency (NARA)
Crow Island, Colombo 15, Sri Lanka
✉ hjayasiri@yahoo.com

Received May 5, 2010; revised and accepted December 14, 2011

Abstract: Saltwater intrusion is a major coastal management problem which leads to the destruction of fishery, breeding grounds and habitat. Several dykes and water regulatory systems have been implemented to prevent salt water intrusion and to regulate water level in the catchment area in the Koggala lagoon. The groyne built at the lagoon mouth helped to keep the outlet open throughout the year for better mixing and water exchange, but it has been a matter of concern for local resource users due to salinity increase in the lagoon. Therefore, the study was focused in salt water intrusion into lagoon and upstream areas and its impact on water quality and drinking water wells of surrounding areas. Monthly mean salinity of the lagoon varied strongly from 20 psu to 34.5 psu in relation to the monsoon rains. During the drought, due to the water level difference between lagoon and the canal created a salt water intrusion into upstream areas through the sluice gates, even the gates were closed. During the period of high salinity (February and March) of the lagoon, surface and bottom salinity levels of the upsteam area were 16 and 22 psu respectively due to saltwater intrusion through the anicut at Warabokka. Moreover, the water exchange and mixing of the lagoon is governed by the gravitational circulation. However during the dry season, tide plays a major role for salt water intrusion and mixing creating well mixed condition. Thus, the lagoons can be classified as a partially mixed estuary. The faunal and the floral compositions of the lagoon had changed markedly due to salt water intrusion. Present analysis indicated that the salinity, dissolved oxygen content and chlorophyll-*a* content mostly affected the abundance and diversity of zooplankton in the Koggala lagoon. Construction of barrier across the rock-fill groyne may minimize the salt water intrusion.

Key words: Koggala lagoon, salt water intrusion, water quality, groyne.

Introduction

Sri Lanka's coastline of 1561 km itself consists of a wide range of geomorphological features such as headlands, bays, lagoons, estuaries, peninsulas, spits, bars and islets. Estuaries and lagoons are bodies of water along our coasts that are formed when fresh water from rivers flows into and mixes with salt water from the ocean. This mixing of fresh and salt water creates a unique environment that brims with life of all kinds—a transition zone between the land and sea. Moreover, saltwater intrusion is a major coastal management problem confronting the conservation of freshwater wetlands, flora and fauna all over the world (Saynor, 2004). This process is natural and leads to significant ecological and morphological changes to coastal freshwater environments. Saltwater intrusion leads to the loss of freshwater vegetation and the spread of saline mudflats into previously vegetated areas. This can lead to the destruction of fishery, breeding grounds and habitat of fish. Coastal lagoons and estuaries

*Corresponding Author

will likely experience reduced freshwater inputs due to the growing demand on this limited resource, which could lead to higher salinities in these systems.

Koggala lagoon is a basin estuary situated along the southern coast of Sri Lanka (06°00′N; 80°20′ E) (Anon, 1988). The lagoon covers 7.27 km^2 and its depth ranges from 1 to 3.7 m. The length and width of the lagoon are 4.8 km and 2 km respectively. The lagoon consists predominantly of open water and encloses 14 small islands, but few are large enough for habitation. The lagoon is bordered by a narrow fringe of mangrove and marsh or paddy lands beyond which is a small and undulating catchment area of 64 km^2. The annual total run-off from Koggala basin is 16.9×10^6 m^3 (CEA, 1995). The Koggala Free Trade Zone (FTZ), air force base and tourist resorts are located within the watershed area of the lagoon.

The main freshwater supply is from the Warabokka Ela that enters the lagoon from the north-west. The only sea outlet is the Pol Oya, located at the south-eastern corner (Figure 1) (CEA, 1995). The main water regulatory system in the lagoon (Pilana-Warabokka Salt water Exclusion Scheme) was constructed in the 1970's by the Irrigation Department with the main aim to prevent intrusion of saline water into neighbouring paddy fields and to regulate water levels in the catchment area. A second project (Koggala Lake Scheme) was implemented in 1980's to extend the protection against instrusion of salt water (Goswami, 2004).

In early 1990's Sri Lanka's third Free Trade Zone (FTZ) was established in the southern part of the lagoon (CEA, 1995). The unplanned removal of sand from the natural sand bar in front of the lagoon mouth for construction of FTZ had been the most destructive process resulting in moving the sand bar towards the lagoon and formation under the bridge. This has threatened the existence of the Kataluwa bridge and a groyne was built during 1997, in front of the lagoon mouth to protect the Kataluwa bridge which is in the main road to Colombo from sea erosion and also as a flood regulatory measure of the adjacent areas.

Consequently the entire lagoon has been influenced by the tidal dynamics with the conversion of the entire lagoon to a high saline water mass as a result of seawater exchange up to the northern part of the lagoon. With the construction of the groyne, water level of the entire lagoon was dropped by 0.5 m when compared to the mean sea level. The average salinity level has increased from 4.8 to 24.1 ppt during 1991 to 2001 (De Alwis and Dasanayaka, 1993). One hundred to one hundred fifty hectares of paddy lands were abundant due to salt water intrusion through the sluice gates of main entrance canals (Warabokka ela and Kerena ela). There had also been a marked change in the faunal and the floral compositions of the lagoon also. The occurrence of marine bivalve *Saccostrea forskalli* (Chemnitz) in the Koggala lagoon is one of the indications for the change of the faunal composition (Gunawickrama and Chandana, 2006). In this regard, present study was carried out to determine the effect of salt water intrusion to the lagoon condition and associated agricultural areas.

Materials and Methods

The present survey was carried out from June 2004 to July 2005. Five sampling stations within the lagoon and one station at the mouth were selected (Figure 1) to measure the physico-chemical and biological parameters such as salinity, temperature, tide, pH, dissolved oxygen content (DO), biological oxygen demand (BOD), water transparency, chlorophyll-*a* content and zooplankton abundance. Monthly sampling and data collection were carried out during the study period. The in situ salinity measurements were carried out in the Koggala lagoon in connected canals and surrounding wells. Salinity, temperature and pH at each sampling site were measured using portable salinity and pH meter and water transparency was measured as secchi disk depth. DO and BOD were analysed by Winklers' method. Chlorophyll-*a* content of water was analysed by spectrophotometric method (Parsons et al., 1984; Parsons and Strickland, 1963). Zooplankton samples were collected by plankton net with a mesh size of 90 µm. Zooplankton samples were analysed for abundance (Goswami, 2004; David et al., 2003; Newell and Newell, 1963; Arvin, 1977). Monthly rainfall data at closest meterological stations of Tittagalla and Handungoda were obtained from Meterological Department of Sri Lanka.

Automatic micro tide gauge was installed at Harumalgoda which was middle region of the estuary, to collect the sea level data in the lagoon. The tide gauge includes a complete data acquisition system with temperature and pressure sensors, microprocessor, computer communication port and battery power supply. It measures the pressure in psi (pounds per square inch) and the factor 0.689 was used for conversion (psi to m). The absolute accuracy of this instrument for sea level measurements is ±1.5 cm, whereas for temperature is ± 0.1 °C.

Flushing time of the lagoon was calculated by the following equations,

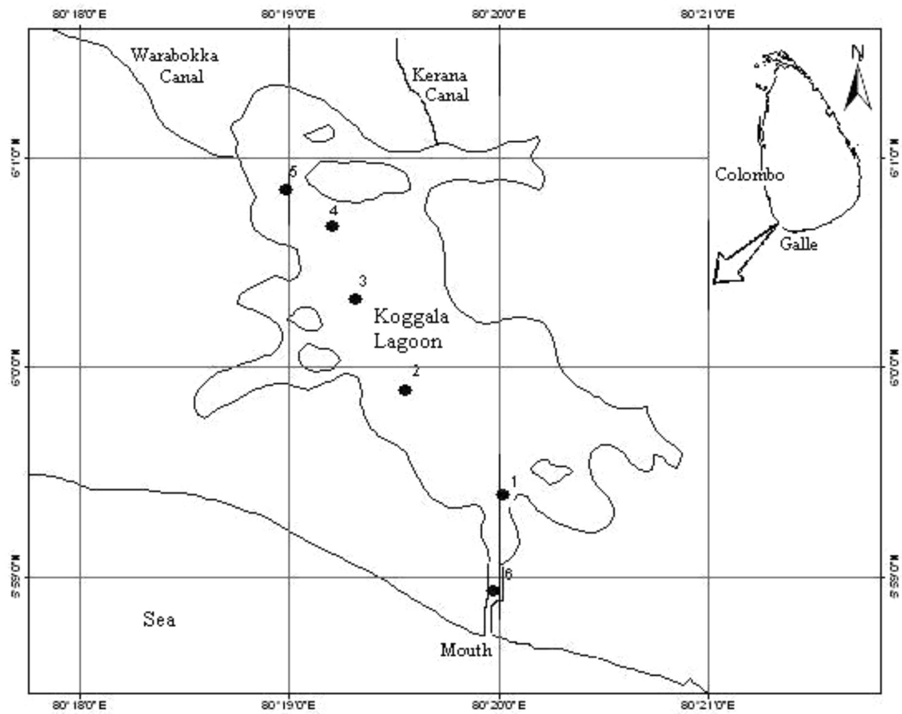

Figure 1: Map of the Koggala lagoon showing sampling stations.

Tidal out flow (T_o) = (T_r) Tidal range (m) × Area of the lagoon (m^2)/0.5 day

and Volume of the lagoon (V_e) = mean depth (m) × Area of the lagoon (m^2)

Flushing time = V_e/T_o

The similarities of sampling sites based on the zooplankton communities were determined by Bray-Curtis similarity coefficient (Bray and Curtis, 1957) using SPSS software package. The Spearman Correlation Coefficient was used to relate the multivariate community structure to environmental variables and to determine the most responsible variables for the inter-site variability of the zooplankton community.

Results

Tide/Sea Level and Temperature Variation

The maximum tidal range in the west coast of Sri Lanka is less than 70 cm (Wijeratne, 2003). However, recorded maximum tidal range of the Koggala lagoon is about 14 cm which is $1/5^{th}$ of the oceanic tide (Figure 2).

Flushing time was calculated for the dry period where there was no river discharge into the lagoon. During the dry season, sluice gates had been closed to prevent the salt water intrusion in to upstream. Therefore, freshwater discharge is assumed to be zero ($R = 0$) during this period. Calculated flushing time of the lagoon is about 10 days. It can be considered as the maximum flushing time of the Koggala lagoon; however, it can be lower during the rainy periods.

Daily temperature of Koggala lagoon varied from 29 to 35 ^{o}C in February–March 2005. High temperature was observed during March 2005. Recorded day and night temperature difference was more than 2 °C (Figure 3).

Salinity Variation in the Lagoon

Monthly mean salinity for the period of June 2004 to July 2005 varied strongly from 20 to 34.5 psu. Surface and bottom salinities followed the similar pattern and were related to the monsoon rains of the area (Figure 4). Minimum and maximum surface salinities were observed during September 2004 due to high rainfall of 422 mm and February 2005 due to lowest rainfall of 50 mm respectively while minimum and maximum bottom salinities were in November and February (Figure 5). Salinity increased from November 2004 to March 2005 with decreasing rainfall (Figure 4). There was stratification due to the salinity differences between surface and bottom during the rainy months. The highest salinity difference between surface and the bottom was observed during the month of September 2004 which was 11 psu (Figure 5).

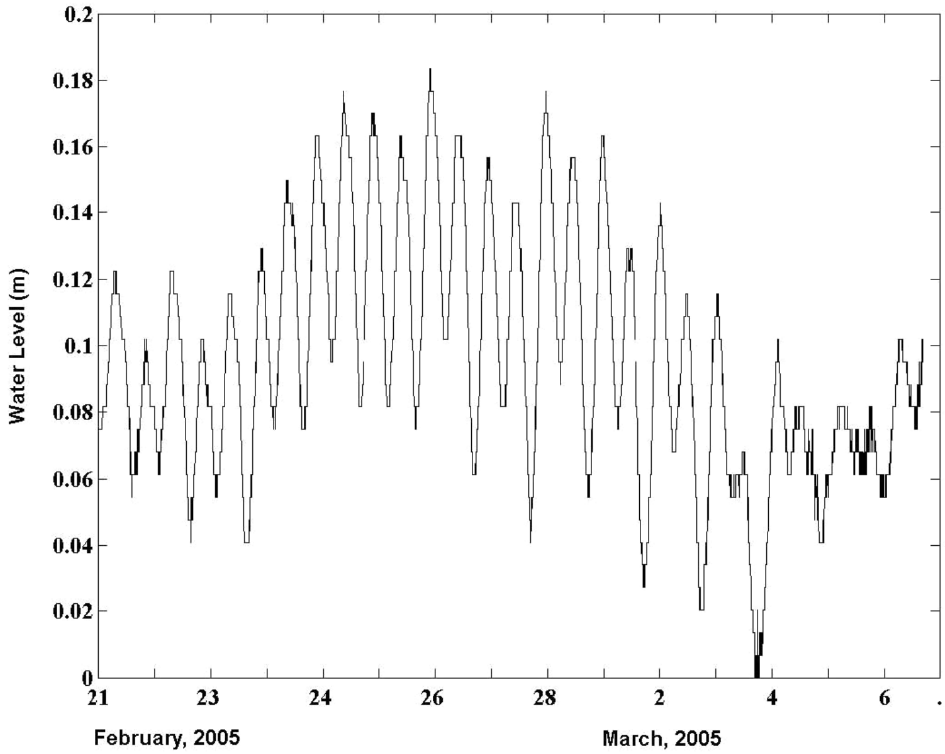

Figure 2: Tidal water level variation of the Koggala lagoon from 21 February to 7 March 2005.

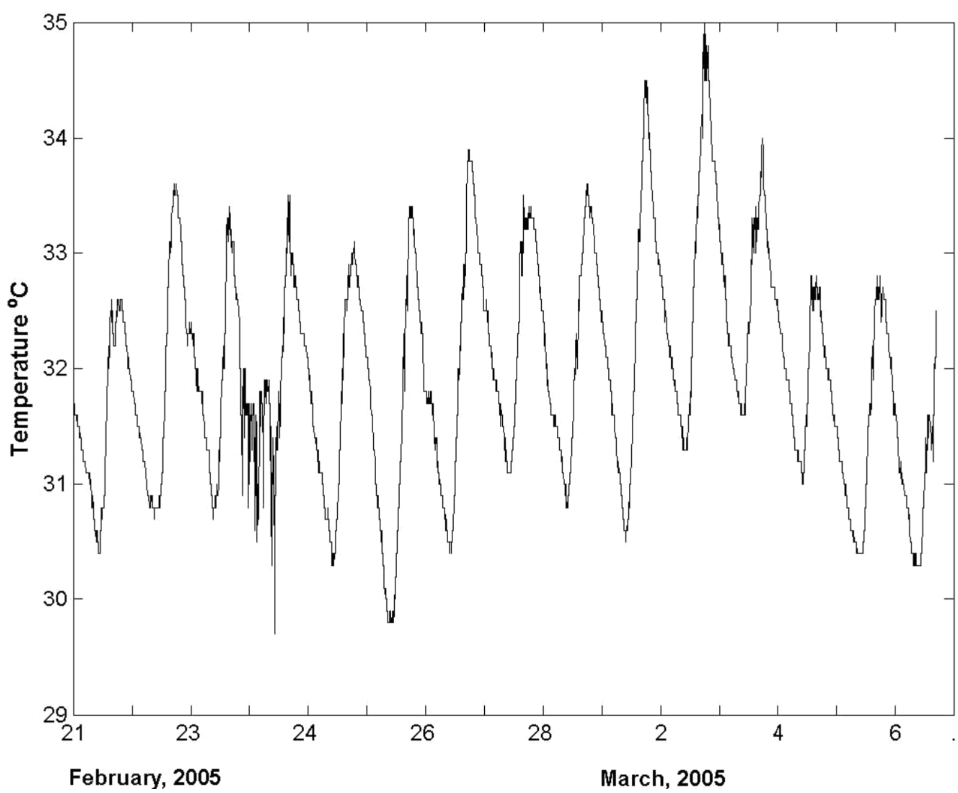

Figure 3: Temperature fluctuation of Koggala lagoon during 21 February to 7 March 2005.

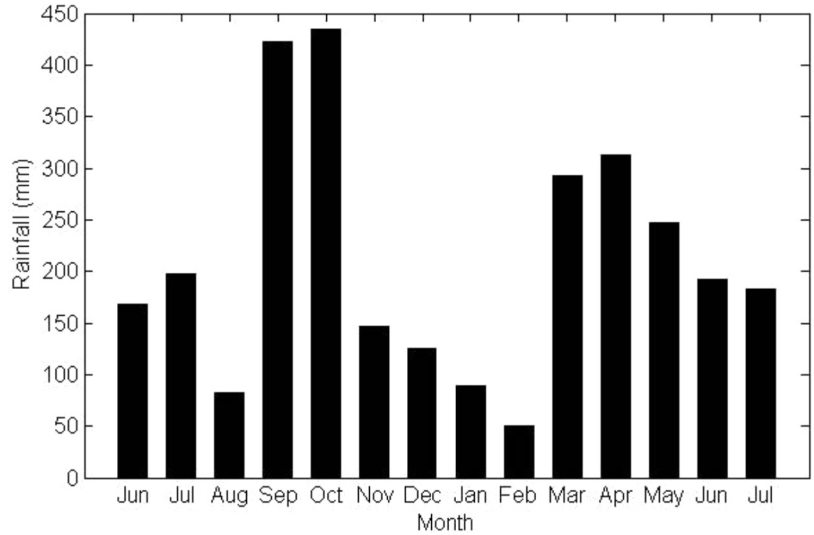

Figure 4: Monthly rainfall at Thiththagalla weather station near Koggala from June 2004 to July 2005.
***Source*: Metrological Department, Sri Lanka.**

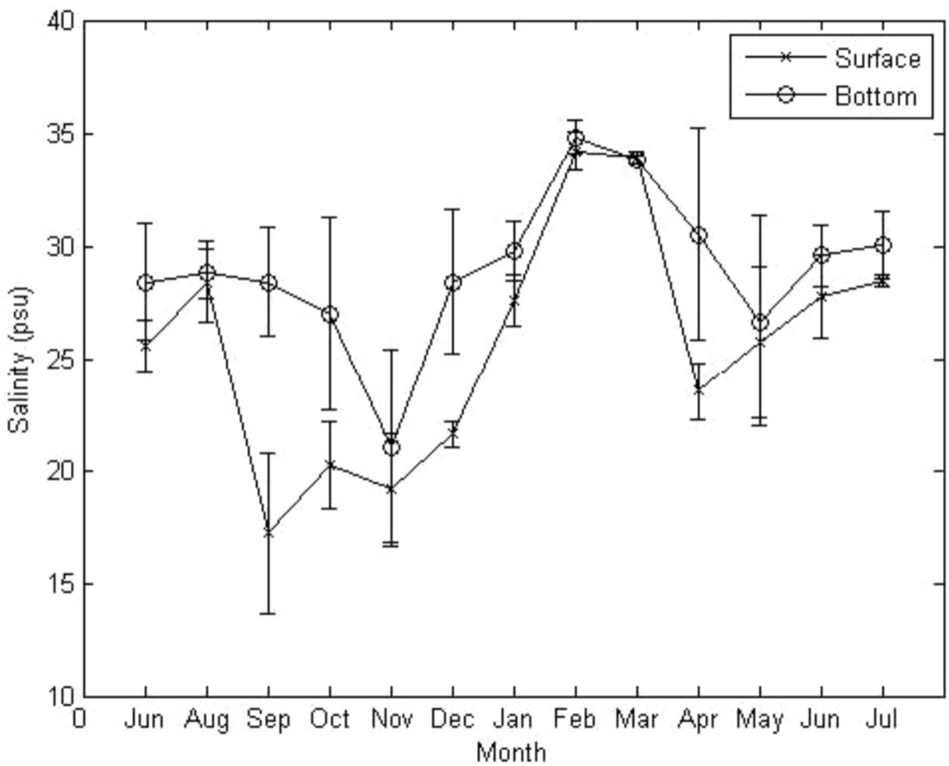

Figure 5: Mean salinity (±SD) of the Koggala lagoon at surface and bottom during June 2004–June 2005.

The lowest salinity of 16 psu was observed during the month of September 2004 and highest salinity was 34 psu (Figure 5). Surface and bottom salinity decreased towards head of the lagoon (Figure 6). However, salinity of the lagoon mouth was not exceeded the oceanic salinity of 34 psu and during the month of September, it reached 16 psu (Figure 6).

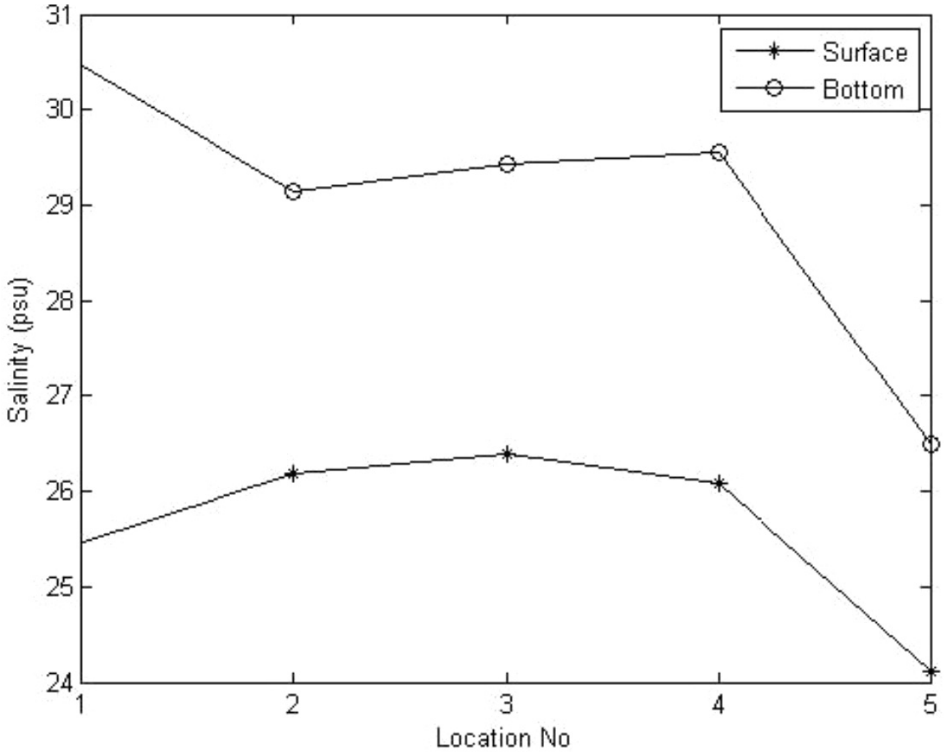

Figure 6: Variation of mean salinity at different locations of the Koggala lagoon during June 2004–July 2005.

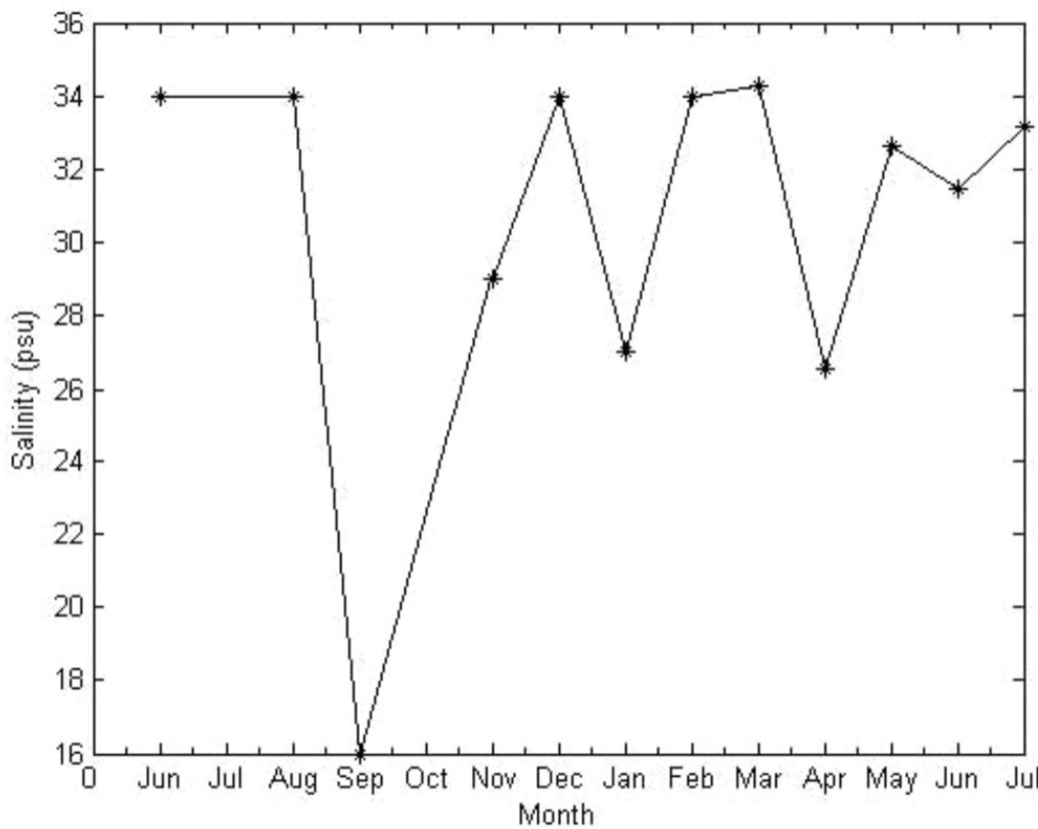

Figure 7: Salinity variation of lagoon mouth during the period June 2004–July 2005.

Salinity Variation at the Freshwater Inlets

Salinity variation at inlets of Warabokka and Kerena ela is shown in Figure 8. During the rainy months (September-October 2004), the sluice gates at Warabokka had been opened to stop the flooding. During the dry seasons (January-February 2005.), they had been closed to stop the salt water intrusion into upstream areas. During the rainy season from September to December 2004, the gates were kept open to stop the flooding of upstream areas and surface and bottom salinities varied from 0-14 and 14-21 psu respectively showing the high salinity at the bottom. During January, the gates were closed and the salinity of the lagoon side varied from 18 psu at the surface and 26 psu at the bottom. Nevertheless in the river side, the salinity was 0 at the surface and 2 psu at the bottom showing no saline water intrusion through the sluice gates during the rainy season. During the months of January and February when there was no rains, the high salinity levels were observed in the river side which was 28 and 30 psu at the surface and 22 and 32 psu at the bottom. During the drought, there was a water level difference between lagoon side and river side which created a salt water intrusion through the sluice gates even though the gates were closed. During the period of high salinity in the lagoon (February and March), surface and bottom salinity of the Maththegoda bridge area where paddy lands were located was 16 and 22 psu respectively due to saltwater intrusion through the anicut at Warabokka. Surface and bottom salinity of the Kerena ela was 34 psu. But, rainfall data showed a 300 mm rainfall during the month of March 2005 (Figure 4). The rain started after the data collection of March (8 March 2005).

The new sluice gate system was built during the study period at Kerena ela to minimize the saltwater intrusion and prevent the flooding of the upstream area. Building of new gates obstructed the study of salinity levels at the Kerana ela. During the study, anicut was open partially or completely. Surface salinity varied from 1 (September) to 33.5 (March) psu at the surface and bottom salinity varied from 8 (December) to 34 (February) psu. During the dry season, the salt wedge can be observed in Warabokka and Kerana ela. Thus, the salt water intrusion was observed in upstream areas which fed freshwater to paddy fields. Due to saltwater intrusion, most of the paddy lands were abandoned.

According to the salinity measurements of 10 selected wells around the Koggala lagoon, there was no reasonable amount of salinity in wells. Salinity measurements were done during the month of March which showed the high salinity of 34 psu in the lagoon. Salinity of wells varied from 0-0.3 psu.

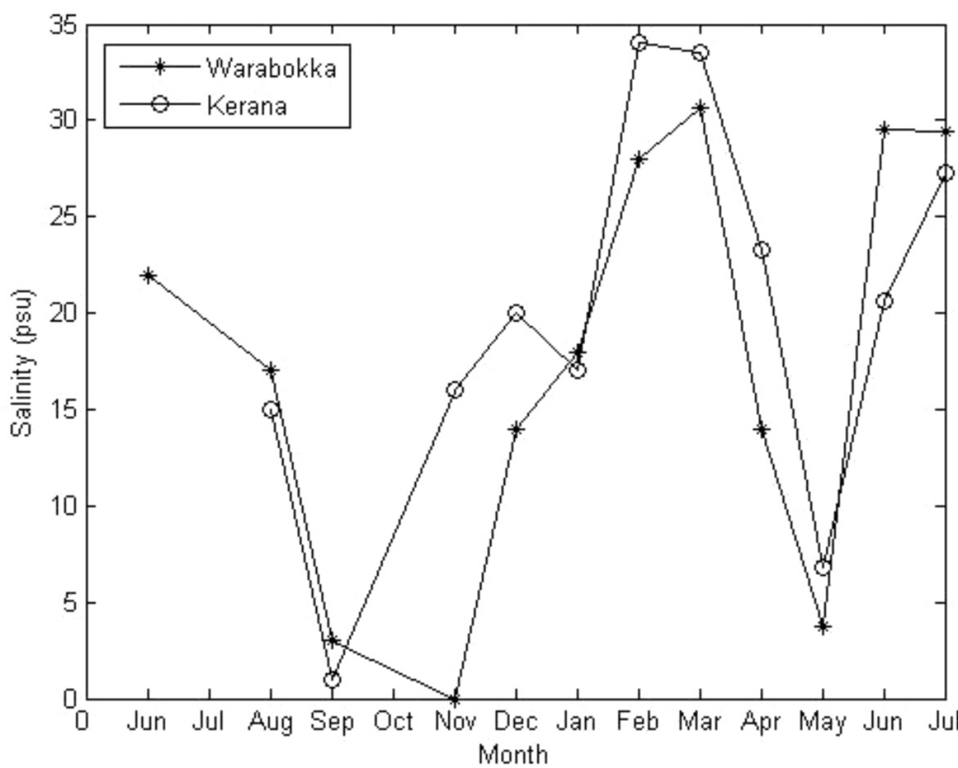

Figure 8: Monthly salinity variation of Warabokka ela and Kerena ela inlets from June 2004 to July 2005.

Chlorophyll-*a* Content

Chlorophyll-*a* which indicates the phytoplankton biomass showed that the lagoon is in mesotrophic state with a range of 3.95 mg m^{-3} in January 2005 and 10.17 mg m^{-3} in March 2005 (Figure 9). However, the months with high chlorophyll-*a* content showed higher standard deviations from its mean value. Also, it indicates that the chlorophyll level is high during the dry period. But, another peak of chlorophyll-*a* was observed during September and October which was period of high rainfall.

Higher chlorophyll-*a* levels were observed during the period of southwest monsoon (July-October) (Figure 9). However the detailed information on spatial distribution shows that chlorophyll-*a* concentration is increasing from the mouth to lagoon head (Figure 10). High chlorophyll-*a* levels were observed at the head due to the nutrient input through the Warabokka Ela and Kerena ela. In each month, highest chlorophyll-*a* content was observed at station 5 (Figure 10).

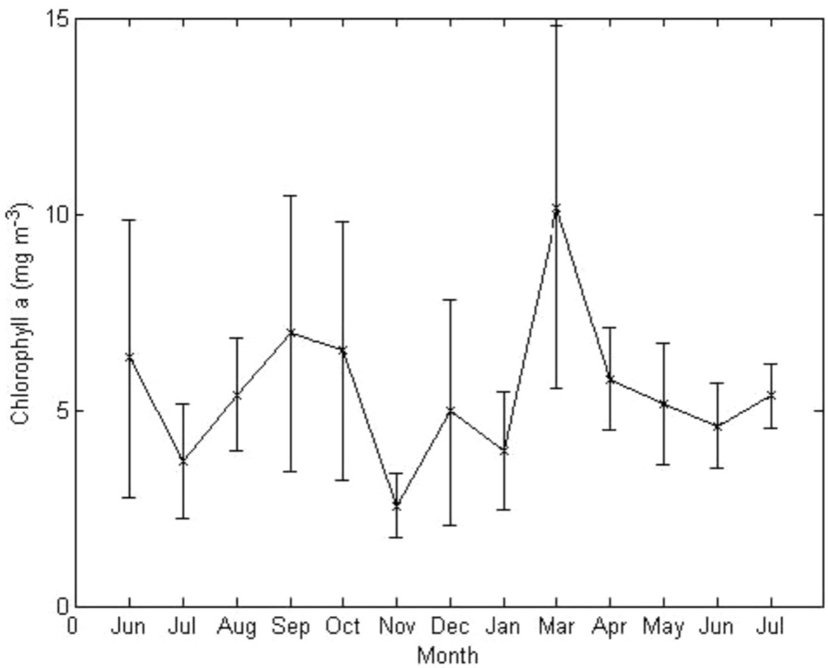

Figure 9. Mean monthly chlorophyll-*a* concentrations (±SD) of the lagoon from June 2004 to July 2005.

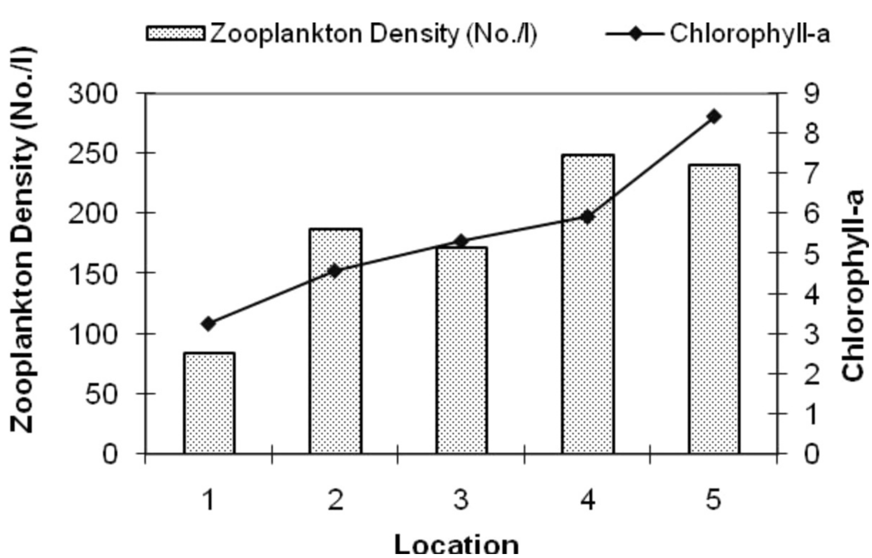

Figure 10: Variation of chlorophyll-*a* concentrations and zooplankton density at different locations of the lagoon from June 2004 to June 2005.

Dissolved oxygen content varied from 7.3 to 12.37 mg/l while BOD varied from 2.9 to 4.97 mg/l (Figure 10). Maximum DO level was observed during the month of September and minimum was observed during April (Figure 11). The pH level was 7.3-7.7 and there was not much fluctuation during the day time (Figure 12). But high standard deviation was observed during the months of August, 2004 and February 2005. The secchi disk depth

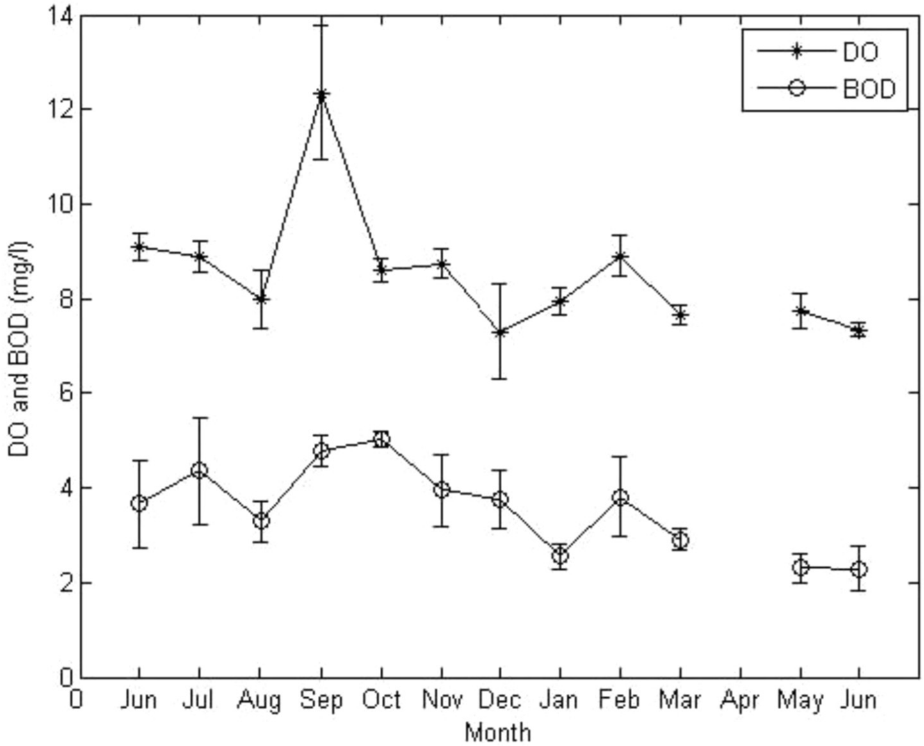

Figure 11: Mean monthly variation of DO (±SD) and BOD (±SD) of the lagoon from June 2004 to June 2005.

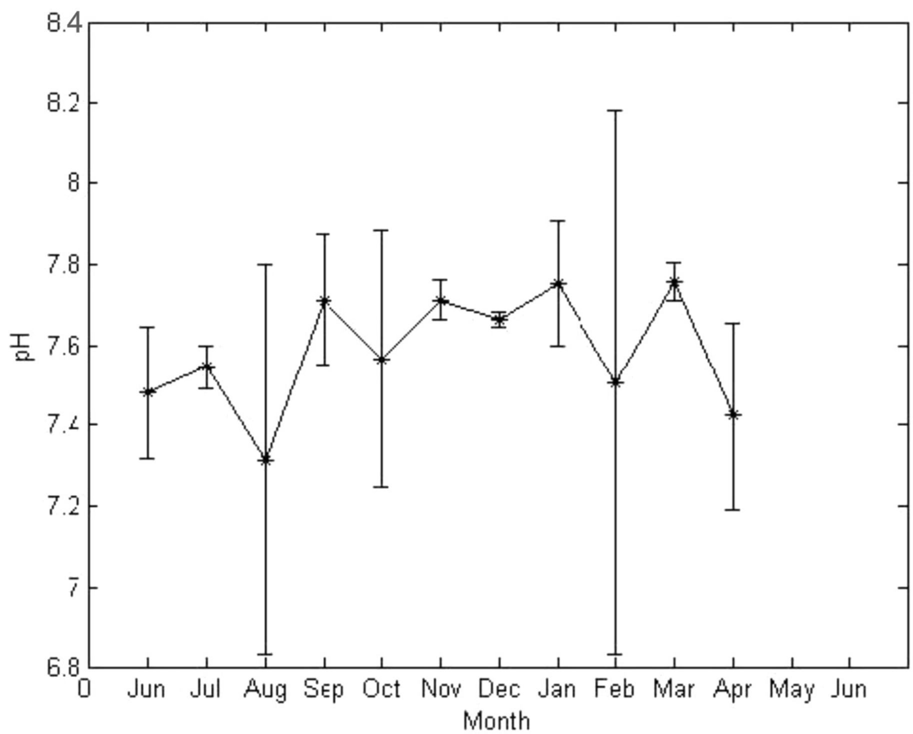

Figure 12: Monthly mean variation of pH (±SD) of the lagoon from June 2004 to April 2005.

of the lagoon varied from 0.5 to 1.7 m and lowest and highest values were observed in October 2004 and June 2005 respectively (Figure 13). Lowest value was observed when the water depth was highest during the rainy season. The water depths at different locations were influenced by net freshwater supply and tidal flow. The water quality was in a good condition due to better water exchange between the lagoon and the ocean through the lagoon mouth.

Zooplankton

Monthly variation of zooplankton abundance varied from 12 to 417 no/l showing a seasonal variation (Figure 14). High abundance was observed during the period of March to June 2005. Spatially, the abundance was increased towards its head. Spatial variation of zooplankton abundance and chlorophyll *a* showed a similar pattern indicating good correlation (r^2 = 0.6748) between zooplankton and phytoplankton communities in the ecosystem (Figure 10). But salinity decreased towards the head of the lagoon showing a negative correlation of zooplankton and phytoplankton with salinity in the lagoon (Figures 6 and 14). During March and September high chlorophyll-*a* levels were observed with relation to the monthly zooplankton abundance. But during March chlorophyll showed a positive correlation with salinity.

According to abundance of zooplankton, Bray-Curtis similarity coefficient indicates the separation of sites which were located at inner areas of the estuary clustering together (Figure 15).

Percentage Similarity

Spearman rank correlation coefficients for permutations of environmental variables, which are statistically significant, are given in Table 1. These results indicate that the combination of salinity, dissolved oxygen content and chlorophyll content mostly affect the abundance and diversity of zooplankton in the Koggala lagoon.

Table 1: Statistically significant values for Spearman Rank Correlation Coefficient ($p < 0.05$) for permutations of environmental variables in Koggala lagoon

Correlation coefficient	*Environmental variables*
0.432	1, 3, 6
0.426	3, 6
0.420	1, 3, 4, 6
0.418	1, 3, 4, 5, 6

Variables: 1 - salinity, 2 - pH, 3 - dissolved oxygen content (DO), 4 - biological oxygen demand (BOD), 5 - turbidity, 6 - chlorophyll-*a*

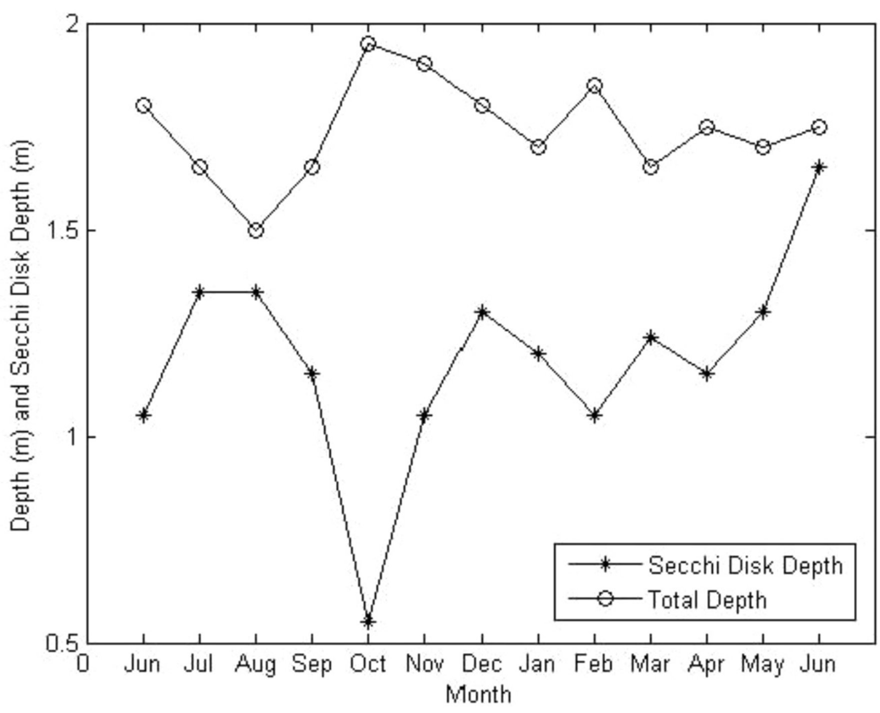

Figure 13: Mean monthly variation of total depth and secchi disk depth of different locations of the lagoon from June 2004 to June 2005.

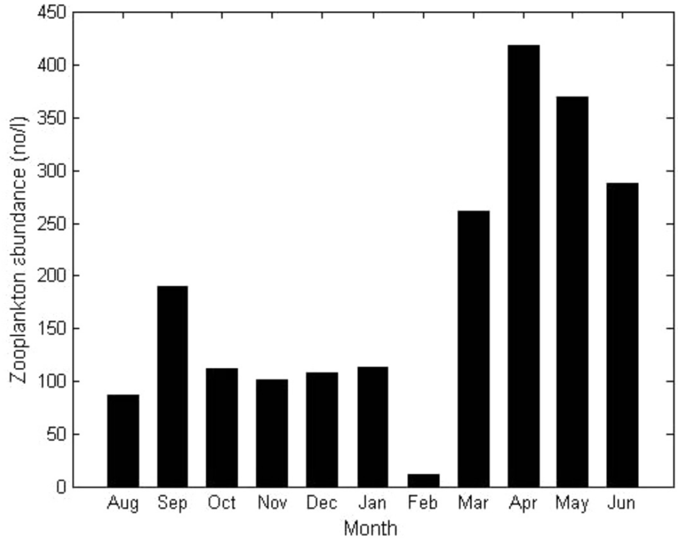

Figure 14: Mean monthly variation of zooplanton abundance of the lagoon from August 2004 to June 2005.

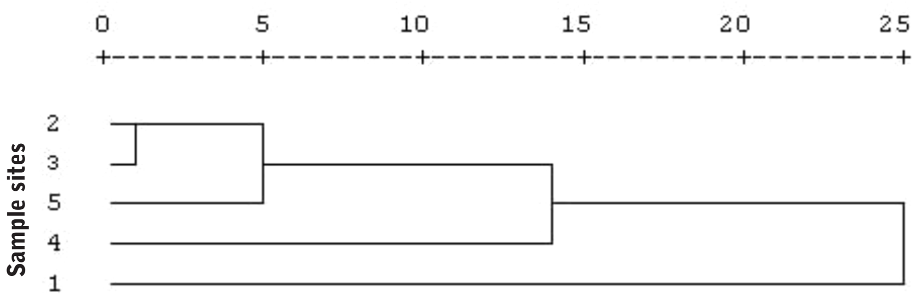

Figure 15: Dendrogram of the Bray-Curtis similarity index for the sampling sites of Koggala lagoon based on the abundance of zooplankton.

Discussion and Conclusion

The groyne has been constructed to stop the coastal erosion at the mouth and prevent flooding of upstream areas. With the construction of the groyne, the lagoon remains open throughout the year. However, sand bar is formed at the mouth to some extent during southwest monsoon period. The lagoon mouth is kept open due to the groyne and it increases the tidal water exchange with the ocean. Due to high water exchange between lagoon and the ocean, flushing time has decreased. The calculated flushing time during the period of lowest freshwater discharge is ten days. Nevertheless, the lagoon salinity has increased due to salt water mixing by tidal flow. However, flushing time during the rainy season could be less than 10 days due to freshwater discharge. Due to lack of fresh water discharges flushing time has not been calculated. The average salinity level has been reported to increase from 4.8 psu during 1991-93 to 24.1 psu during 2001 (Alvis and Dasanayaka, 1993). During the present study, the mean salinity varied from 20 to 34.5 psu at the lagoon and 16- 34 psu at the mouth with a marked variation along the west and the east banks of the lagoon. During the drought, as there was a sea level difference between lagoon and the Warabokka and Kerena ela freshwater inlets, saltwater intrusion took place through the sluice gates. This salt water intrusion has affected the paddy lands of the surrounding areas. Due to salt water intrusion through Warabokka ela and Kerena ela during drought, 300-400 acres of paddy lands were abandoned. The observed salinity levels of wells showed that there was no salt water intrusion into wells. Before opening of the sand bar, chlorophyll-*a* content had been varied from 1.15 to 9.6 mg m^{-3} and after the opening it varied from 2.5 to 10 mg m^{-3} (Alvis and Dasanayaka, 1993) showing a slight increase. However, two peaks of chlorophyll-*a* levels were observed during dry and wet seasons. During the rainy season, chlorophyll-*a* could be high due to high nutrient flux of catchment area. But, other peak of dry season could be due to slow flushing with the open ocean. The DO and BOD levels have been found to vary from 3.2 to 11.8 mg/l and 0.5 to 31 mg/l in 1991-1993 (Alvis and Dasanayaka, 1993). Present study shows different ranges for DO and BOD. Water quality is however in good condition except salinity due to better water exchange with the ocean. Salt water intrusion also affected the floral and faunal composition of the lagoon according to results of the present study.

Freshwater-based fishery in Koggala lagoon now has been turned into a marine-based fishery (Tinil, 2001). It is also reported that the mollusc species now have grown upto a problematic level causing damages to fishermen and their nets (Anon, 2006). Jellyfish species are also abundant during the dry season due to salinity increase of the lagoon. Zooplankton abundance and composition varied with a combination effect of salinity, dissolved oxygen and chlorophyll-*a* content.

It was observed that free floating and littoral aquatic plants like *Najas marina, Salvinia molesta* and *Typha aquestifolia* had almost disappeared. Since these aquatic plants and associated vegetations provide food and habitats for the variety of aquatic organisms, including fish and crustacean species, loss of vegetation may have influenced over the species composition of fish in the lagoon (Anon, 2006; CEA, 1995). The study reveals that construction of barrier across the rock-fill groyne will minimise the saltwater intrusion into lagoon and agricultural areas.

Acknowledgement

The study was funded by National Aquatic Resources Research and Development Agency (NARA) and CRMP (Coastal Resources Management Project). I appreciate the assistance of Mr. Nishantha De Silva, Mr. D.T Mendis, Mr. P Jayasooriya and Mr. P. Wickramasinghe of the Oceanography Division of NARA for field work and laboratory analysis.

References

Anon (1988). National Atlas of Sri Lanka. Survey Department, Colombo, Sri Lanka.

Anon (2006). Final report of Koggala Lagoon study, 2006. Report submitted to Coastal Resources Management Project (CRMP). National Aquatic Resources Research and Development Agency (NARA).

Arvin, P.L. (1977). Introduction to the common marine zooplankton of peninsular Malaysia.

Bray, J.R. and J.T. Curtis (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs*, **27:** 325-349.

CEA (1995). Wetland site report and conservation management plan, Koggala lagoon. Wetland Conservation Project, Central Environmental Authority of Sri Lanka/ARCADIS/ EUROCONSULT.

David, V.P.C., Rowena, G.W., Joanna Hugues, D.C., Christopher, P.G. and B.R. David (2003). Guide to the coastal and surface zooplankton of the south-western Indian Ocean. Marine Biological Association of the United Kingdom, Occasional Publication No 15.

De Alwis, P. and H. Dasanayaka (1993). Water quality of Koggala Lagoon prior to the industrialization of the area. Proceedings of the First Annual Scientific Sessions of NARA.

Goswami, S.C. (2004). Zooplankton Methodology, Collection & Identification—A Field Manual. National Institute of Oceanography, Goa, India.

Gunawickrama, K.B.S. and E.P.S. Chandana (2006). Some Hydrographic aspects of Koggala Lagoon with preliminary results on distribution of the marine bivalve Saccostrea forskalli: Pre-tsunami status. *Ruhuna Journal of Science*, **1:** 16-23.

Newell, G.E. and R.C. Newell (1963). Marine plankton. A practical guide. Hutchinson Educational Ltd., London.

Parsons, T.R. and J.D.H. Strickland (1963). Discussion of Spectrophotometric determination of marine-plant pigments, with revised equations for ascertaining chlorophyll-*a* and carotinoids. *J. Mar. Res*., **21:** 155-163.

Parsons, T.R., Yoshiaki, M. and M.L. Carol (1984). A Manual of chemical and biological methods for seawater analysis. Pergamon Press plc, Headington Hill Hall, England.

Saynor, M. (2004). Supervising Scientist Report: Saltwater intrusion a natural process. Environmental Research Institute of the Supervising Scientist, GPO Box 461, Darwin NT 0801.

Tinil, P.A.T. (2001). Report on status of fisheries in the Koggala Lagoon. National Aquatic Resources Research and Development Agency (NARA).

Wijeratne, E.M.S. (2003). Tidal Characteristics and Modelling of Tidal Wave Propagation in Shallow Lagoons of Sri Lanka. Ph.D Thesis, C51 2003, Dept. of Oceanography. Gothenburg University, Earth Science Centre Series.