Summary

The Vembanad Lake is the largest backwater system in Kerala. The hydrographic condition of the lake depends mainly on the intrusion of sea water associated with tides and influx of fresh water from the rivers. The lake receives huge quantities of mineral nutrients, municipal and industrial wastes, pesticides, organic wastes and land and agricultural runoff which lead to eutrophication. Pollution and bacterial contamination has special significance due to deleterious effects on human health.

After the cocommissioning of the Thanneermukkom Barrage in 1976, the southern region of the lake has become a predominantly fresh water zone. Restricted flow and prevention of natural flushing by tides has led to stagnation of water which becomes heavily polluted during summer. The prevention of salinity intrusion has resulted in the choking of the lake by water weeds such as Salvinia and Water Hyacinth.

Understanding the sources and fates of environmental contaminants, regulating their discharge or remediating polluted sites requires detection of the presence of materials of interest and measurement of their concentrations. Knowledge on the biogeochemical processes is also important in understanding a lake ecosystem.

The study has been carried out to assess the water and sediment quality, Water quality index, Sodium absorption ratio, trace metal concentrations and spatial and temporal trends in trace and heavy metal concentrations.

In the present study, water and sediment samples were collected from the lake and analysed for seasonal variations in temperature, pH, EC, TDS, salinity, turbidity, DO, BOD, COD, alkalinity, acidity, chloride, phosphate, nitrate, TH, Na, K, Ca, Mg, Total coliform, SAR, WQI and trace metals such as Fe, Zn, Cd, Cu, Ni, Pb, Mn and Cr. Sediment samples were analysed for textural characteristics, physicochemical parameters
such as pH, EC, TSS, LOI, OC, OM, TN, TP, elemental ratios, and concentration of heavy metals such as Fe, Zn, Cd, Cu, Ni, Pb, Mn and Cr. Correlation and regression analyses, analysis of variance, factor analysis, cluster analysis and discriminant analysis were used for the interpretation of data.

The results and conclusions of the study can be summarised as follows:

The physicochemical characteristics of Vembanad Lake exhibited temporal and spatial diversity due to the influence of fresh water discharge from the rivers, salinity intrusion through the Thanneermukkom barrier, various physicochemical process that take place in the system and anthropogenic activities. The waters were fresh during monsoon, when water was flowing towards the sea, which gradually became brackish during the post- monsoon and pre-monsoon periods due to salinity intrusion.

pH values were within permissible limits during monsoon but decreased significantly during the post-monsoon and pre-monsoon seasons. Changes in pH were evident at stations receiving nutrient rich effluents. The water quality parameters such as EC, TDS, salinity, TH, chloride, sulphate, sodium, potassium, calcium, magnesium and iron increased significantly during the post and pre-monsoon seasons. Trace metal concentrations in water were below permissible levels and most often below detectable levels and did not exhibit significant variation, except for iron, which ranged 1.52 to 2.70 mg/L during post-monsoon.

While DO decreased, BOD and COD increased from monsoon to pre-monsoon through post-monsoon. The BOD levels of locations on the southern and eastern regions of the lake were much higher compared to samples from the eastern side. Bacterial contamination increased during the pre-monsoon and post-monsoon seasons. Water quality exhibited deterioration during pre-monsoon and post-monsoon periods as indicated
by the WQI and SAR. The trace-metals such as Cd, Pb, Mn, Zn and Ni were below detectable level during the three seasons.

Concentrations of fluoride, sulphate, ammonia, nitrite, nitrate and phosphate exhibited significant variation during the study period. Concentration of ammonia exhibited a gradual increase from post-monsoon to pre-monsoon. The excessive accumulation of phosphate and nitrate promoted the growth of aquatic weeds.

Textural studies indicated that the southern part of the Vembanad Lake was blanketed mainly with sediments rich in clay and silt. The locations on the western side were rich in sand and coarser fractions. The sand content generally increased towards the northern region. In bulk sediment, the trace-metal concentration was controlled mainly by the textural composition of the sample.

The low pH values indicated that the sediments were highly acidic. The acidic nature increased during the pre-monsoon season. EC and TSS were high and exhibited spatial and temporal variations with maximum values during Pre-monsoon. Electrical conductivity was directly related to the soluble salt concentration of sediment. The acidic pH and high LOI indicated richness of organic matter in the sediments.

The high values for OC, OM and TN indicated contamination of sediments with organic matter. The maximum concentrations were observed during the post-monsoon season. These parameters exhibited an increase with silt and clay percentage of sediments. It was observed that the concentration of phosphate remained high at stations where agricultural and related activities were intense. There was significant seasonal and temporal variation in sulphate content of sediments.

High C/N ratios were registered during monsoon and post monsoon. The sources of organic carbon in the sediments were of terrestrial origin. C/P ratio could be used as an index of pollution due to domestic sewage in any aquatic environment. The factors
contributing to low N/P ratios may be increased nitrogen content of sewage and fertilizer runoff reaching the lake.

The sediments were severely contaminated with heavy metals such as iron, zinc, copper, nickel, lead, manganese, and chromium. Cadmium was present in a few samples. Metal concentrations exhibited spatial diversity, upstream to downstream, except for cadmium because of a large number of non-detections. The spatial distribution of heavy metal concentration indicated that all the sampling units in the study area were more or less contaminated due to anthropogenic activity.

Contaminated sediment and water have an impact on all forms of life. Various species of algae accumulate heavy metals like lead, zinc, nickel, chromium, manganese, cadmium, etc. from water and sediments. This could be a serious threat to humans because the metals bioaccumulated through fish and other aquatic animals is consumed by man. A recent study by the health department has found that pollution of Vembanad Lake was the major reason for the occurrence of many diseases among a large number of people living in the surrounding area.

Chemometrics methods were used for the classification and comparison of different samples and evaluation of pollution sources. Seasonal, spatial and polluting effects on the quality of lake water and sediments were examined by exploratory data analysis. One-way ANOVA indicated that the values for pH, turbidity, EC, DO, BOD, COD, salinity, TDS, total hardness, chloride, etc differed significantly with location of the stations. One-way ANOVA indicated significant spatial variation for pH, turbidity, EC, DO, BOD, COD, salinity, TDS, TH, chloride, ammonia, sulphate, TC, sodium, potassium, calcium, and magnesium differed significantly with location of the stations during pre-monsoon, alkalinity during monsoon. Two-way ANOVA indicated significant temporal variation in water quality. Significant spatial variations were observed for temperature, pH, turbidity, BOD, CO₂, alkalinity, Fe, Cu and Zn during the study period. Significant
temporal variations were evident for silt, sand, pH, EC, TSS, TN, TP, sulphate, Cr and Ni and spatial variation for sand, silt, clay, pH, EC, LOI, TSS, OC, OM, TN, TP and sulphate Fe, Cu and Zn.

Highly significant correlations (r>0.900) among water and sediment parameters were determined and linear regression equations obtained. Multiple linear regression equations were obtained for pH, EC, salinity, TDS, alkalinity, DO, BOD, COD and TH. Regression equations could be used for continuous and real-time estimation of nutrient, bacteria and other constituent concentrations of water and sediment samples from Vembanad Lake which may be helpful for determining high constituent concentrations in time to prevent adverse effects on fish and other aquatic life or the recreational use of the water body.

Factor analysis of water quality parameters generated four significant factors that explained 86.83% of variance. Factor 1 was strongly correlated to salinity incursion. Factor 2 indicated pollution due to sewage and agricultural runoff. Factor 3 was an index of oxygen demanding organic substances water and factor 4 indicated pollution by nitrogenous organic matter such as sewage and animal wastes. PCA of sediment parameters generated four significant factors which explained 81.17% of variance. Factor 1 was an indicator of pollution due to forest humus and terrestrial organic matter. Factor 2 indicated pollution due to anthropogenic sources, factor 3 by salinity incursion and pollution from anthropogenic sources and factor 4 indicated siltation due to soil erosion and agricultural activities.

Cluster analysis divided all 30 water samples into 3 clusters. Water samples belonging to cluster 1 were the most polluted. Cluster 2 samples were less polluted and had 9 cases out of ten during post-monsoon. Pre-monsoon samples belonged to clusters 1 and 2 which meant moderate to heavy pollution. Cluster 3 samples were the least polluted. Cluster 3 had all the ten cases during monsoon. Cluster analysis divided the 30 sediment
samples into 2 clusters. Cluster 1 consisted of 14 and cluster 2 had 16 samples. Cluster 1 samples (pre-monsoon and post-monsoon) were more polluted than cluster 2 (samples from the northern locations and during monsoon). Cluster analysis may be used for rapid assessment of samples and for future classification by reducing the sampling frequency and number of sites. This may help in reducing costs without losing significance.

In spatial discriminant analysis pH, EC, salinity, TDS, fluoride, phosphate, ammonia were the most discriminating parameters for water samples. DA classified 59.2% of the cases correctly. pH, EC, TSS, TN, TP, cadmium and \[\text{SO}_4^{2-}\] were the most discriminating parameters for sediment samples. 96.7% of the samples were correctly classified. The temporal DA results of water showed that the most significant discriminating parameters were EC, salinity, TDS, fluoride, phosphate, nitrate and ammonia. Salinity intrusion and anthropogenic pollution due to sewage and agricultural runoff discriminated between seasons. Results of temporal DA for sediments indicated that salinity, decay of organic matter, anthropogenic pollution and agricultural runoff discriminated between seasons. Thus, discriminant analysis rendered considerable data reduction.

Identification and estimation of pollutants is necessary before decisions can be made and action taken. The present study could generate sufficient data regarding the seasonal distribution of pollutants in water and sediments of Vembanad Lake, which may help in regulating their discharge and remediating polluted sites. Detailed and comprehensive investigations on the sources and fate of these contaminants is essential but beyond the scope of this work.