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A Study of Water Quality Status of Mangrove Vegetation in Pichavaram Estuary

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Mangrove ecosystem is unique in nature due to the combination of Halophytic plants, animals, birds and aquatic organisms. Such wetland ecosystems possess rich nutrition status that contributes rich bio resources to aquatic flora and fauna. Brackish water within the ambit of Pichavaram plays a pivotal role on growth and development of mangrove community. A study was undertaken to understand the surface water dynamics quality parameters in Pichavaram Estuary. Analysis of water quality parameters was assessed for the period of November 2012. Adequate care was taken to cover all tidal regimes (i.e.) (i) Inlet: the point where the principal feeder opens into the estuary; (ii) Center: the point that gives the general water quality of the estuary; (iii) Outlet: the place where the overflow occurs. Study sites from which samples were collected, were identified adjoining the region of Parangipettai Vellar Estuary and Pichavaram mangrove forest. Ten surface water samples were collected. These were analyzed for physico-chemical parameters such as temperature, pH, salinity, dissolved oxygen and total dissolved solids vary significantly

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among the three regions. All studied parameters were spatially interpolated in GIS environment to understand the distribution of individual nutrient in the ecosystem. The results of the statistical analysis were subjected to cluster analysis for grouping parameters based on similarity and dissimilarities. Individual parameter values were overlaid on the LANDSAT imagery to understand spatial representation of water quality with respect to bio-physical value of the mangrove ecosystem.

Keywords: Water quality parameters; pichavaram; mangroves; spatial interpolation; cluster analysis.

1. INTRODUCTION

Estuaries consist of a complex mixture of many distinctive habitat types that do not exist in isolation [1]. These can typically contain mangrove forests, salt marshes, sea grass meadows, oyster reefs and non-vegetated areas. It is widely accepted that estuaries provide habitat for numerous fauna that include fish and invertebrate species, many of which are economically important. Any significant loss of habitats that are provided by estuaries could drastically affect the local ecological systems and associated fauna [2].

Mangrove occur in diverse environmental settings of geophysical (i.e. climate, tides and sea level) and geomorphological (dynamic history of the land surface and contemporary processes and biological components). Mangroves and its associated ecosystems as biologically most productive, socioeconomically important, and aesthetically attractive while providing food and shelter for many vital biotic species, some that are commercially important [3,4]. Mangroves support a wide variety of ecosystem goods (fuel wood, medicine, construction materials) and services (shoreline stabilization, fisheries breeding and nursery grounds, sedimentation trapping, uptake of nutrients and heavy metals-phytoremediation). They have immense value to ecological processes. Pichavaram Mangrove Forest is said to be the world's second largest mangrove forest which is located in cuddalore district, southern part of Tamil nadu, India. Pichavaram mangroves are surrounded by rivers and lakes and brackish water that changes with seasons and geographic domain. Water quality parameters provide basic scientific information about spatial quality parameters and ecologically relevant toxicological threshold values. These are important to understand critical physical and chemical parameters influencing the aquatic environment. Physical and chemical variables like temperature, rainfall, pH, salinity, dissolved oxygen and carbon di oxide influence growth and vigour of mangroves. Other parameters such as total suspended and dissolved solids, total alkalinity, acidity and heavy metal contaminants are limiting factors for aquatic organisms.

Temperature is a limiting factor in the mangrove environment [5-7]. Water temperature is probably the most important environmental variable for the sustenance of aquatic flora and fauna. pH is one of the vital environmental variable that determines the survival, metabolism, physiology and growth of aquatic organisms. Salinity is a dynamic indicator for the growth of selective species of mangroves in pichavaram where cation exchange system act as chelates in binding salts in ion exchange system. It is expressed as the total concentration of electrically charged ions (cations) in water in part per thousand (‰). The anions include CO_3^-, SO_4^{2-} , Cl^-, $HCO3^-$, NO_3^-, NH_4^{2-}, PO_4^{2-}. Alkalinity of a water body is a measure of its capacity to neutralize acids to a designated pH [8,9].

The tides in Pichavaram mangrove forest are semi-diurnal and vary in amplitude from about 15 to 100 cm in different regions, reaches maximum during monsoon and post-monsoon and a minimum during summer [10]. The rise and fall of the tidal water is through a direct connection with the sea at the Chinnavaikal mouth and also through the two adjacent estuaries. The depth of the water-ways ranges from 0.3 to 3 m [10] which indicates that shallow area predominate in Pichavaram brackish water.

Somjai Sremongkontip et al. [11] describes the paper on Detecting Changes In The Mangrove Forests Of Southern Thailand Using Remotely Sensed Data And GIS. Remote sensing and GIS were used to analyze the changes in the mangrove forest. Mangrove forests have been used by different user groups. Changing of government policies on mangrove forest utilization and management caused the occurrence of three major activities; mangrove forest concession, tin-mining activities and intensive shrimp farming. These activities were considered as the major reasons for changes of mangrove forest areas and led to the degradation of mangrove forest, the loss of mangrove forest and ecological disturbance. Furthermore, it affected the mangrove forest dependence-dwellers.

Marília Cunha-Lignon et al. [12] presented a paper analysis of Mangrove Forest Succession, Using Sediment Cores: A Case Study in the Cananéia –Iguape Coastal System. Sediment cores are an essential tool for the analysis of the dynamics of mangrove succession. Coring was used to correlate changes in depositional environments and lateral sedimentary facies with discrete stages of forest succession at the Cananéia-Iguape Coastal System in south eastern Brazil. A local level successional pattern was examined based on four core series T1) a sediment bank; T2) a smooth cordgrass Spartina alterniflora bank; T3) an active mangrove progradation fringe and; T4) a mature mangrove forest. Cores were macroscopically described in terms of color, texture, sedimentary structure and organic components. The base of all cores exhibited a similar pattern suggesting common vertical progressive changes in depositional conditions and subsequent successional colonization pattern throughout the forest. The progradation zone is an exposed bank, As the substrate consolidates attains the greatest structural development in the mature forest. Cores provide a reliable approach to describe local-level successional sequences in dynamic settings subject to drivers operating on multiple temporal and spatial scales where spatial heterogeneity can lead to multiple equilibria and where similar successional end-points may be reached through convergent paths.

Giri et al. [13] had done a work on Status and distribution of mangrove forests of the world using earth observation satellite data. Our scientific understanding of the extent and distribution of mangrove forests of the world is inadequate. The available global mangrove databases, compiled using disparate geospatial data sources and national statistics, need to be improved. Here, we mapped the status and distributions of global mangroves using recently available Global Land Survey (GLS) data and the Landsat archive. 1000 Landsat scenes were interpreted using hybrid supervised and unsupervised digital image classification techniques. Each image was normalized for variation in solar angle and earth–sun distance by converting the digital number values to the top-of-the-atmosphere reflectance. Ground truth data and existing maps and databases were used to select training samples and also for iterative labelling. Results were validated using existing GIS data and the published literature to map 'true mangroves'. The total area of mangroves in the year 2000 was 137,760 km2 in 118 countries and territories in the tropical and subtropical regions of the world. Approximately 75% of world's mangroves are found in just 15 countries, and only 6.9% are protected under the existing protected areas network (IUCN I-IV). This study confirms earlier findings that the biogeographic distribution of mangroves is generally confined to the tropical and subtropical regions and the largest percentage of mangroves is found between 5°N and 5°S latitude.

Claudia Kuenzer et al. [8] had taken a review on Remote Sensing of Mangrove Ecosystems. Mangrove ecosystems dominate the coastal wetlands of tropical and subtropical regions throughout the world. They provide various ecological and economical ecosystem services contributing to coastal erosion protection, water filtration, provision of areas for fish and shrimp breeding, provision of building material and medicinal ingredients, and the attraction of tourists, amongt many other factors. Mangrove mapping is one of the most demanding tasks in remote sensing, because the remotely sensed signal from mangrove ecosystems is composed of several components and is influenced by a large number of other parameters. In optical data, the spectrum of a pixel containing mangrove is usually influenced by pixel fractions of mangrove leaves, stems, and branches; underlying mudflats; soils; and water surfaces. All of these components differ depending on mangrove species, vigor, age, and season, as well as soil type and water turbidity and quality, among others. Other parameters influencing the spectral signal include plant and leaf geometry, LAI, stand density, and atmospheric conditions, to name a few. Furthermore, the spectral signal, its ―mixing, ‖ and its distinctiveness in optical data vary, depending on the spatial and spectral resolution of the sensors used, ranging from aerial photography (pixels in centimeter to meter range) to highest-resolution spaceborne multispectral data (pixel size in meter range) to multispectral data of medium resolution (10–30 m) to airborne or spaceborne hyperspectral data (pixel size in 1–30-m range, but up to 200 spectral bands). The goal of all remote-sensing–based mangrove mapping and monitoring activities should be the protection of these unique ecosystems, whose value cannot be overestimated. This is especially true with respect to climate change-related sea level rise scenarios globally. Sea level rise would have a severe impact on coastal communities in the tropics and subtropics. Natural mangrove ecosystems are a productive, extremely valuable shield against this threat.

Chandra and Joseph [14] had done a work on Mangrove Forest Distributions and Dynamics in Madagascar(1975–2005). Mangrove forests of Madagascar are declining, albeit at a much slower rate than the global average. The forests are declining due to conversion to other land uses and forest degradation. time-series satellite data of 1975, 1990, 2000, and 2005 were interpreted using a hybrid supervised and unsupervised classification approach. Landsat data were geometrically corrected to an accuracy of ± one-half pixel, an accuracy necessary for change analysis. The post classification change detection approach had been used. The results showed that Madagascar lost 7% of mangrove forests from 1975 to 2005, to a present extent of ~2,797 km2. Deforestation rates and causes varied both spatially and temporally. The forests increased by 5.6% (212 km2) from 1975 to 1990, decreased by 14.3% (455 km2) from 1990 to 2000, and decreased by 2.6% (73 km2) from 2000 to 2005. Similarly, major changes occurred in Bombekota Bay, Mahajamba Bay, the coast of Ambanja, the Tsiribihina River, and Cap St Vincent. The main factors responsible for mangrove deforestation include conversion to agriculture (35%), logging (16%), conversion to aquaculture (3%), and urban development (1%). The analyses show the potential for producing consistent and timely mangrove forest databases of Madagascar using the historical archive of Landsat data. The full potential of remote sensing technology for identifying mangrove forests, measuring the biophysical properties, and detecting forest cover changes can only be realized through a robust and operational mangrove forest assessment and monitoring program. Future research is needed to map very small mangrove areas that were not able to discern with the Landsat resolution.

Marwa and Evan [15] had done a thesis on The Economic Value of Mangroves: A Meta-Analysis. This paper presents a synthesis of the mangrove ecosystem valuation literature through a meta-regression analysis. The main contribution of this study is that it is the first meta-analysis focusing solely on mangrove forests, whereas previous studies have included different types of wetlands. The number of studies included in the regression analysis is 44 for a total of 145 observations. several regressions are included with the objective of addressing outliers in the data as well as the possible correlations between observations of the same study. The possible interaction effects also investigated between type of service and GDP per capita. The findings indicate that mangroves exhibit decreasing returns to scale, that GDP per capita has a positive effect on mangrove values and that using the replacement cost and contingent valuation methods produce higher estimates than do other methods and also there are statistically significant interaction effects that influence the data. Finally, the results indicate that employing weighted regressions provide a better fit than others. However, in terms of forecast performance we find that all the estimated models performed similarly and were not able to conclude decisively that one outperforms the other.

2. METHODOLOGY

2.1 Description of Study Area

The study area, Pichavaram mangrove forest lies in (Lat. 11° 29’ N; Long. 79°47’ E) is located between the Vellar and Coleroon estuaries. The forest occurs on 51 islets, ranging in size from 10 sq km to 2 sq km, separated by intricate waterways that connect the Vellar and Coleroon estuaries [16]. The southern part near the Coleroon estuary is predominantly covered by mangrove vegetation, while the northern part near the Vellar estuary is dominated by mud-flats. The Vellar estuary opens into the Bay of Bengal at Parangipettai and links with the Coleroon River, which is a tributary to the river Cauvery. The mangrove ecosystem is influenced by the mixing of nearby water types such as the neritic, estuarine and freshwater. The mangroves cover an area of about 1100 ha, 40% being covered by water- which 50% by forest, ways and the remaining filled by sand-flats and mud-flats (Fig. 1 and Table 2).

2.2 Satellite Data Analysis

LANDSAT ETM data was downloaded from GLCF website. Satellite data was composed of six bands that area imported as TIFF file format for visualization. They are then imported to (img) format LANDASAT image is represented as

Digital number as of 8 bit multi spectral continuous data products were re-projected WGS84 datum to UTM and WGS84 datum in ERDAS Imagine software Fig. 2.

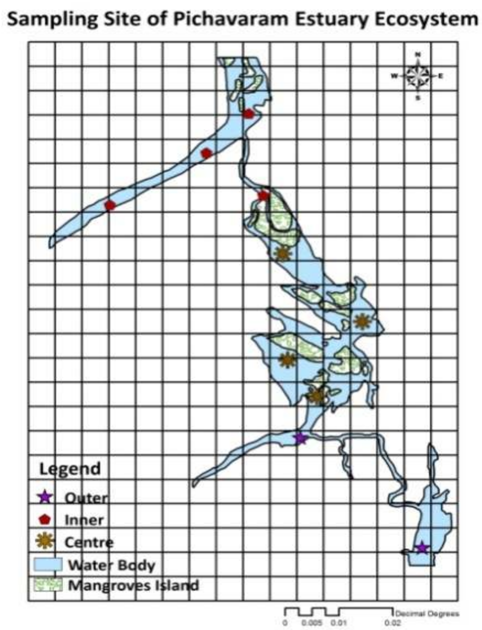

Fig. 1. Sampling points in the study area

Fig. 2. Landsat ETM satellite image of Pichavaram study area

2.2.1 Sampling

Generally three sampling sites were selected for monitoring. They are (i) Inlet: the point where the principal feeder opens into the estuary. (ii) Center: the point that gives the general water quality of the estuary. (iii) Outlet: the place where the overflow occurs. A total of ten locations covering four sample locations in the inlet and centre and two sample location in outer region in Fig. 1 and table 1. Surface water samples were collected during monsoon period of the year 2012. Adequate care was taken to collect samples during low tide conditions. Samples were collected in clean plastics bottles. Collected samples were stored in laboratory as per standard procedure till the analysis is over.

The following physical parameters namely temperature, turbidity, pH, Electrical Conductivity (E.C). Chemical parameters like Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Hardness, Calcium Hardness, Magnesium Hardness, Nitrates, Phosphates, Sulphate, Chlorides, Fluorides, Potassium and Sodium were analyzed for this study.

2.2.2 Cluster analysis

Cluster Analysis was used in this study to examine the differences between the monitoring stations during the four seasons of the year. It shows the complexity of the system and the multitude of contributing sources. Cluster analysis of all sampling station was performed by Bray-Curtis method using Biodiversity Pro ver. 2.0 a open source software. Clustering analysis involve combining of homogenous parameters within the specified samples. The heterogeneous are sorted out based on the distance from the nearest ones. Cluster was split at 40 per cent level at all the sampling points. They were later grouped as a single zone except sampling station 5 pertaining to Chinnavaikal. Similarly clustering was performed for physio-chemical parameters for all sampling station.

Based on the cluster analysis, the concentration of sulphide and organic matter in cluster 3 (i.e. Stations 3 and 4) were high compared to clusters 1 (Stations 1 and 2) and 2 (all sites during the monsoon season).The results yielded that at 10 per cent clustering distance two zones were identified they area zone were in the order of i) K, Mg, So4, Ca, Cl, Na, Total Hardness, TDS and EC zone ii) Nitrite, Tidy test, Free Ammonia, Fluoride, Fe, Po4, Si, Nitrate, pH and Turbidity. Hierarchical Cluster Analysis is the only way to observe how homogeneous groups of variables are formed and K-Means Cluster Analysis only supports classifying observations.

Table 1. Sampling site representing water quality parameters and its range

S.No	Longitude	Latitude	Date of Collection	Sampling Station	Turbidity NTU	pH	EC (micro mho/cm)
1	79.7780	11.4966	16.11.2012	Vellor Mouth	6.2	7.29	42864
2	79.7701	11.4885	16.11.2012	Opp.CAS	3.8	7.10	26950
3	79.7521	11.4778	16.11.2012	New Bridge	5.1	7.08	16739
4	79.7843	11.4677	16.11.2012	Fish Market	4.3	7.09	9974
5	79.7991	11.4537	16.11.2012	Chinnavaikal	5	7.11	3701
6	79.7852	11.4458	16.11.2012	Vaikal suthal	8.6	7.26	47165
7	79.7876	11.4299	16.11.2012	Killai Tourist	4.9	7.32	43509
8	79.8103	11.4073	16.11.2012	Kollidam	6.8	7.46	46735
9	79.7807	11.4797	16.11.2012	Mudasalodai	8.2	7.22	18011
10	79.7907	11.4384	16.11.2012	MGR thittu	6.2	7.24	18488

K-Means Cluster Analysis is used to classify observations through K number of clusters. The idea is to minimize the distance between the data and the corresponding cluster centroid. K-means analysis is based on one of the simplest algorithms for solving the cluster problem, and is therefore much faster than hierarchical cluster analysis. Users should typically consider K-means analysis when the sample size is larger than 100. However, that K-means cluster analysis assumes the user already knows the centroid of the observations, or, at least, the number of groups to be clustered.

For a matrix *X* with *n* observations by *p* variables, initial cluster centres can be specified with a *K*-by-*p* matrix, or chosen from the matrix *X* with a predefined number of clusters.

- Select Initial Cluster Centres from Observations
- Allocate Observations to the Closest Cluster

3. RESULTS

The results exhibited variability in water quality within and between the sample site collections. All the observations were significantly higher at outer region followed by inner and middle region as shown in table 2 and 3. Higher concentration of nutrients at the outer region was attributed to certain environmental and meteorological factors exert remarkable influence in this mangrove biotype. Pichavaram mangrove is saline in nature. This was due to mixing up of sea water with estuarine water. pH was highest (7.46) at Kollidam region and minimum at New Bridge (7.08) (Table 2). The physic chemical variables of mangrove water such as turbidity, pH, EC, TDS, total hardness, calcium, magnesium, sodium, potassium, free ammonia, iron, nitrite, nitrate, chloride, fluoride, sulphate, phosphate and silica vary significantly among the three regions (Table 3).

Electrical Conductivity (3701 - 47165 micro mho/cm) and Total dissolved solids (330.16-32714 mg/l) were more pronounced in mangrove ecosystem. This again was due to mixing of sea water with river water. There was a large variation in chloride concentration (891 mg/L) to (15,345 mg/L) at Vaikal Sudal. Higher value seems to be more pronounced in outer region and centre region and less levels in the inner region. Calcium and magnesium are responsible of increase in salt concentration towards salinity of water. Both the variables have the lowest concentration in inner region, and their level are moderate in Centre region and highest in the outer region.

Total hardness is attributed to sodium concentration in the surface water of the pichavaram region. It is understood that sodium induces hardness in water quality. A linear regression was developed between total hardness and sodium concentration as identified by a positive relationship (r^2-0.8) in Fig. 3. Potassium concentration was lower than sodium concentration invariably at all the sampling points. Mangrove region is possessed higher levels of nitrate and phosphate in Table 3.

4. DISCUSSION

Pichavaram region falls in a tidal region where river water Confluence Sea. Tides action seems to be high in new moon and full moon day's average in other days. Water samples are muddy, due to intermixing of water in soil that makes colloidal system. Colloidal system is rich in nutrients as it contains chelates that combine most of the cautions.

Results from Water samples collected from centre and outer region if the estuary covering the entire spectrum of wetland ecosystem showed that all three regions have its own soil water status, ecological diversity of flora and fauna. The salinity acts as a limiting factor in the distribution of living organisms. Its variation caused by dilute ion and evaporation is most likely to influence the fauna in the intertidal zone [17]. A reflected by the pH and EC values that were observed to be at invariably higher concentrations at all the sampling points.

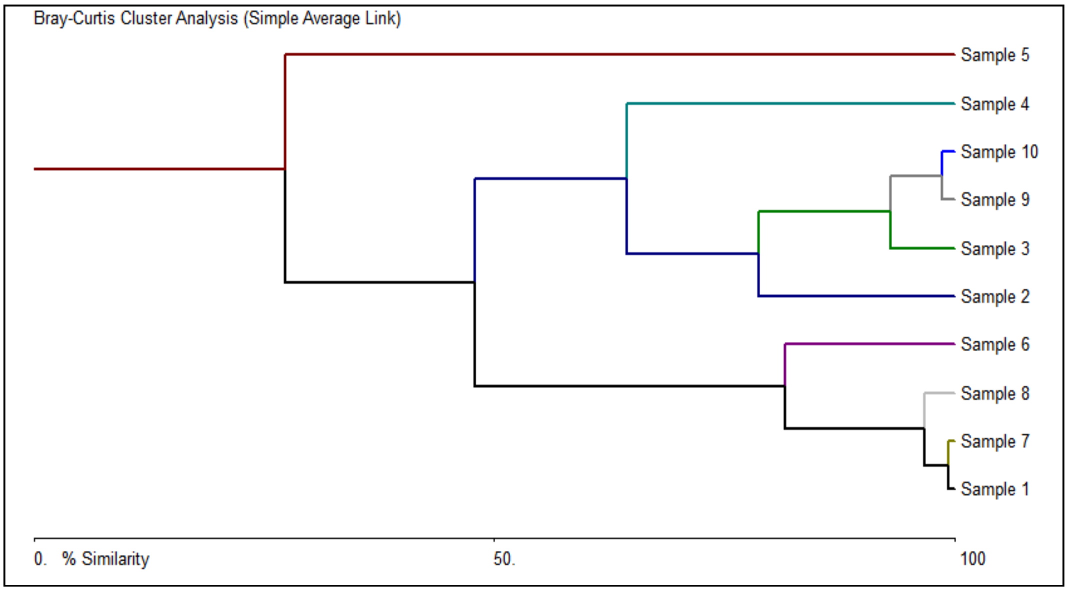

Fig. 3. Cluster analysis for sampling station

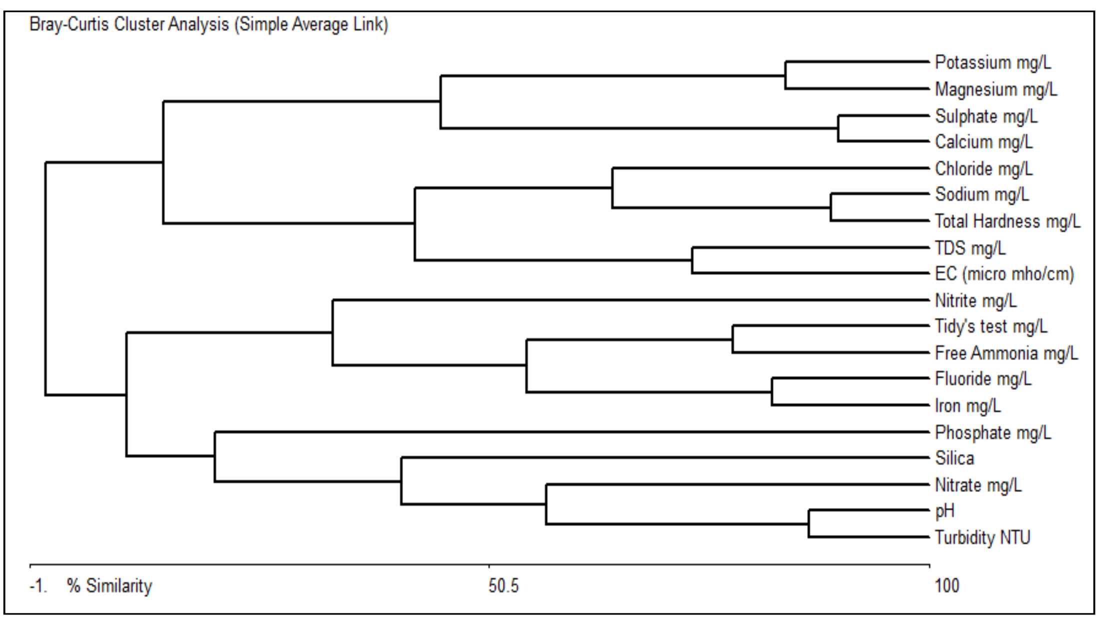

Fig. 4. Cluster analysis for Physico- chemical parameter

Principal component analysis creates variables that are linear combinations of the original variables. The new variables have the property that the variables are all orthogonal. The principal components can be used to find clusters in a set of data. PCA is a variance-focused approach seeking to reproduce the total variable variance, in which components reflect both common and unique variance of the variable. PCA is generally preferred for purposes of data reduction (i.e., translating variable space into optimal factor space) but not when the goal is to detect the latent construct or factors.

The values of sodium, chlorides and sulphate were at higher concentration in the study area that might be due to geomorphology prevailing in that area. Higher EC values were observed in outer region and centre region and less levels in the inner region.

Calcium and magnesium are responsible for increase in salt concentration towards salinity of water. Both variables have the lowest concentration in inner region, and their level are moderate in Centre region and highest in the outer region. Such higher concentration of sodium might be due to absorption of iron and silica as silicate minerals. Higher concentration of nitrates and phosphates are due to leaching of urea and di-ammonium phosphate, ammonium chloride fertilizers from the soil to wetland region through agricultural activities that are carried upon in the adjoining mangrove ecosystem as depicted in Fig. 1. [18] found very clear seasonal fluctuation in the concentrations of Fe, Mn, Cu and Zn in the environmental compartments such as dissolved, particulate and sediment fractions and found the sediments of mangrove which is normally rich in organic matter as a prime sink for these elements that are being brought in by freshwater.

Table 2. Range values of selected variables and its sampling station

Parameter	Range (max/min)		Sampling Site
pH	Maximum	7.46	Kollidam
	Minimum	7.08	New Bridge
Turbidity	Maximum	8.6	Vaaikal suthal
	Minimum	3.8	Opp.CAS
Sulphate (mg/L)	Maximum	2024	Vaaikal suthal
	Minimum	252	Chinnavaaikal
Calcium (mg/L)	Maximum	1840	Vaaikal suthal
	Minimum	168	Chinnavaaikal
Sodium (mg/L)	Maximum	7400	Vaaikal suthal
	Minimum	520	Chinnavaaikal
Total Hardness (mg/L)	Maximum	6800	Vaaikal suthal
	Minimum	680	Chinnavaaikal

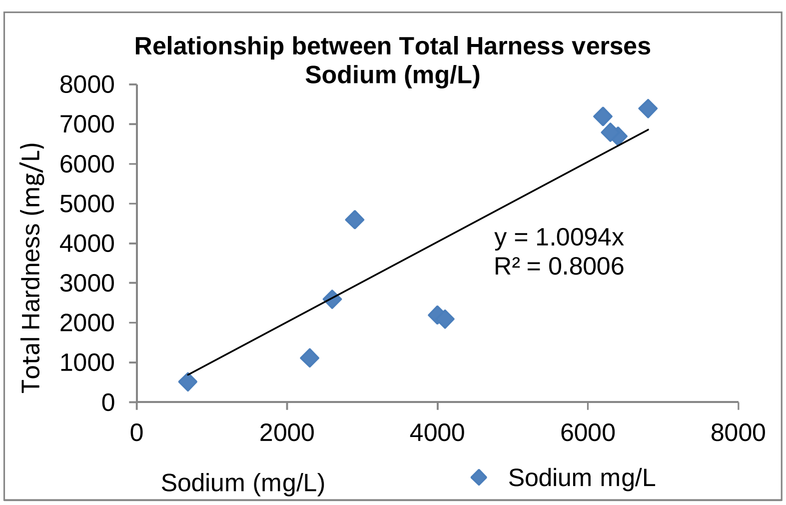

Fig. 5. Depicts a good linear relationship of sodium and total hardness

Table 3. Water sample parameters and its values in (mg/L)

TDS	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Free Ammonia	Nitrite	Nitrate	Chloride	Fluoride	Sulphate	Phosphate	Tidy's test	Silica
30004	6400	1680	528	6700	500	0.4	0.22	0.03	2	14602	0.42	1786	0.1	0.2	16.41
18865	2900	180	216	4600	400	0.5	0.2	0.05	3	7376	0.29	1420	0.4	0.1	16.76
11715	2600	640	240	2600	200	0.5	0.19	2.01	4	4950	0.32	726	0.4	0.1	13.91
6958	2300	600	192	1120	140	0.4	0.22	0.82	4	2970	0.28	520	0.5	0.2	15.3
2264	680	168	62	520	30	0.4	0.04	0.04	4	891	0.31	252	34	0.2	19.52
330.2	6800	1840	528	7400	460	0.5	0.14	0.009	1	15345	0.28	2024	0.1	0.1	16.11
30456	6300	1680	504	6800	400	0.3	0.12	0.05	1	14603	0.26	1826	0.2	0.1	17.8
32714	6200	1640	504	7200	450	0.5	0.16	0.06	1	15097	0.25	1932	0.1	0.1	19.96
12608	4000	880	432	2200	200	0.4	0.13	1.00	3	6039	0.31	832	0.3	0.1	17.29
12942	4100	840	480	2100	200	0.4	0.11	0.79	3	5890	0.42	846	0.3	0.1	18.71

5. CONCLUSION

The study of surface water samples on biologically rich wetland ecosystem exhibited spatial variability of parameters between inner, centre and outer region. Most of the variables showed higher variability in outer region rather than inner and centre region. Salinity influences water quality parameters that promote growth of aquatic flora and fauna in the ecosystem. Intensification of agriculture promotes an increase in nitrate and phosphate content in soil water is detrimental growth of mangroves in pichavaram region if it is excessive.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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