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Community Zonation and Periodical Soil Salinity Incline Mapping of Mangrove Ecosystem

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Abstract

Soil salinity plays a key role in forming mangrove community zonation patterns along the coastline. In order to assess the community zonation of mangroves distributed along varying soil salinity gradient in the reserve forests of Pichavaram, Tamil Nadu the present study used spatial modelling approach. Based on the Importance Value Index (IVI), the study concentrated on major mangrove species such as *Avicennia* spp, *Rhizophora* spp, *Excoecaria agallocha*, *Acanthus ilicifolius*, *Bruguiera cylindrica*, *Lumnitzera racemosa*. The average annual soil salinity was recorded between 12 to 35 psu. Spatial modelling clearly indicated that the Pichavaram mangrove community patterns were distributed with euhaline, polyhaline, mesohaline, oligohaline and limnatic zones of soil salinity. Further, spatial modelling showed that mangrove species were site specific according to their soil salinity. The finding will help improve species specific natural conservation and restoration in the near future.

Keywords: *Mangroves, salinity gradient, distribution pattern, spatial modelling, importance value of index*

Introduction

Mangrove ecosystems are dynamically influenced by various factors (soil salinity, frequency of tidal inundation, sedimentation, soil chemistry, freshwater inputs and groundwater availability) resulting in complex patterns of mangrove community structure and function (Field, 1998). The amount of freshwater discharge into the wetland determines the overall availability of soil, water salinity and the availability of sediment nutrients for vegetative growth (Woodroffe, 1992). Mangrove soils can be considered halotropic soils and mangroves are salt-tolerant forest ecosystems spreading in the coastal tracts of tropical and subtropical regions (Polidoro et al., 2010; Thornton, 1965). About 73 species are considered true mangroves. Of these, 69 species are reported from the Indian and Pacific regions, (Spalding et al., 2010). True mangroves (e.g., *Avicennia* spp. and *Rhizophora* spp.) tolerate higher soil salinity and their tolerance varies among the species more than between non-mangroves (Kathiresan and Thangam, 1990; Kathiresan et al., 1996).

Mangrove cover is spread over an area of 4,740 km^2 in India (about 0.14% of the country's total geographical area) and Tamil Nadu mangrove cover of 39 km2 area was assessed along the south coastal stretch (FSI, 2015). Since the salinity variations found to be common in the mangrove regions. Community zonation based on salinity and soil parameters has been reported by many authors (Watson 1928; Bunt and Williams 1981; White et al., 1989; Aragones et al., 1998). Currently, remote sensing has been proved to generate information on many components in the coastal environment (Nayak et al., 1992, Navalgund & Bahuguna, 1999). The data are useful in mapping the mangrove density-wise (Nayak et al., 1992) and also to map dominant communities of mangrove patterns. Habitat maps derived from remote sensing techniques are widely used to assess the status of coastal resources and serve as a basis for coastal planning, conservation, management, and monitoring (Green et al., 2000; Nagendra, 2001). The present study combines the data from the field and from remote sensing, to analyse and identify the mangrove distribution patterns and to fill the knowledge gaps in mangrove zonation pattern and its relationship with soil salinity variations along Pichavaram mangrove ecosystem.

Materials and methods

Study area

Pichavaram mangrove forest formed along the southeast coastal district of Cuddalore between (Lat. 11° 29' N; Long. 79°47' E) Vellar and Coleroon estuaries (fig. 1). The Vellar and Coleroon estuaries and mangroves in Pichavaram cover an area of about 941 ha in 2011 (Gnanappazham, 2014). The fresh water flow comes for non-perennial rivers of vellar and Coleroon rivers in the form of runoff during rainy time. At the same time sea water, continuously flowing diurnal inundation in this region. About 75 - 90% of total rainfall was recorded during the north-eastern monsoon, while low rainfall was recorded during south-west monsoon (April - June) accounting to an annual average rainfall of 914.4 cm (IMD, 2015).

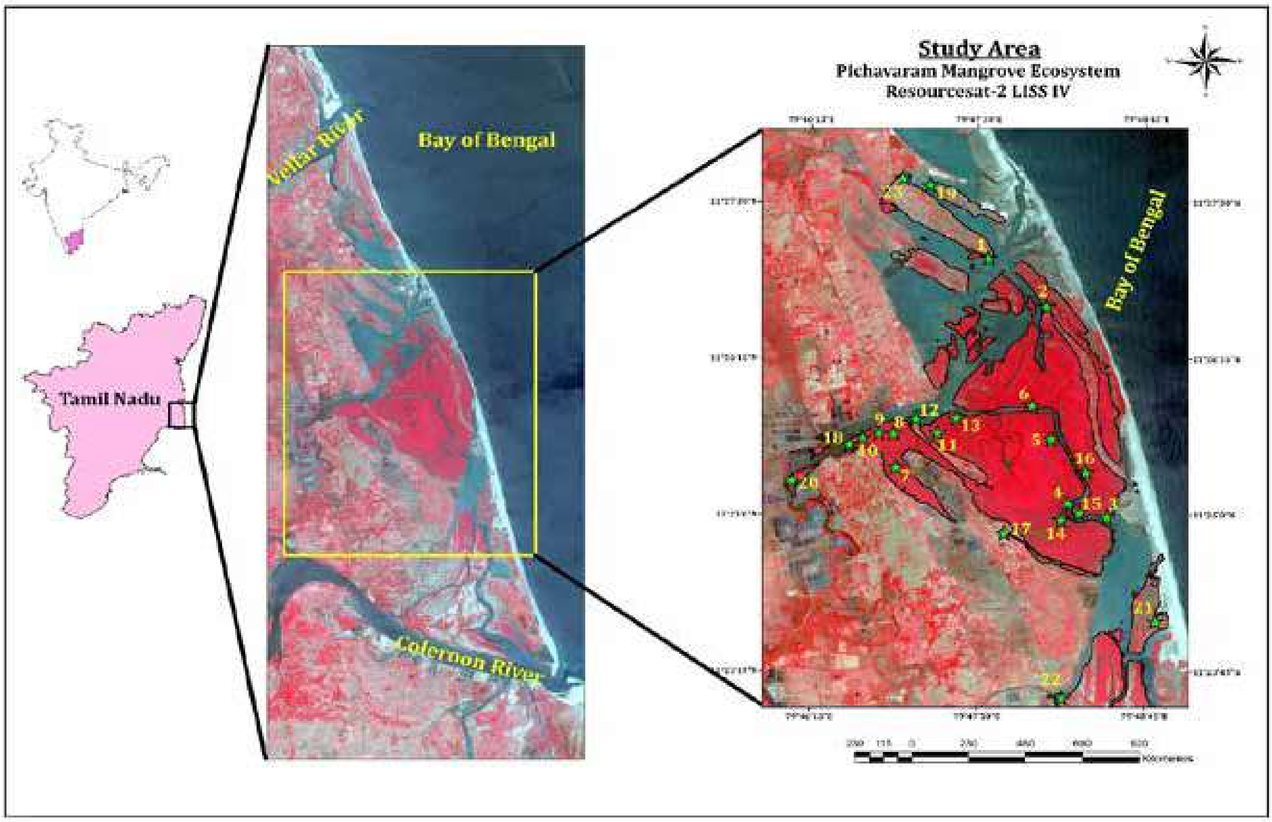

Fig. 1. Satellite imagery showing study area with mangrove forest (dark red patches)

Mangrove survey

Pichavaram mangrove vegetation survey was carried out with selected 23 sampling sites in the period of January to December 2015. In this study, all the 23 sampling were 20×20 m in dimension and 10 m away from the creek (i.e. Which approximate occupies more than 15 pixels (approximately 87 m) in a LISS IV data Importance Value Index (IVI) was calculated by applying the principles of Misra (1968) and Muller- Dombois and Ellenberg (1974).

Importance value Index (IVI)

$$= \text{Relative frequency } (RF_i)\ \% + \text{Relative dominance } (RD_o)\ \% + \text{Relative density } (RD_i)\ \% \quad (1)$$

Soil sampling

Soil sampling was conducted based on the mangrove vegetation survey. Selected sites of 23 quadrats with three different depths (10, 15, 30 cm). Soil samples were collected and instantly measured (EC and pH) by using field instrument WTW pH 310. Soil salinity derived from the electrical conductivity of the soil by following standard protocol (Misra, 1968).

(2)

Where, EC = $\textbf{Salinity (psu)} = 0.062 \times EC \times \frac{\%\ of\ water\ in\ soil}{100} \times 10$
Electrical conductivity (m mho cm^{-1} or dS m^{-1} or mS cm^{-1})

Image processing and geographical model

Habitat type classification of Pichavaram mangrove forest was performed using Geocoded Resourcesat-2 LISS IV dataset (15 July 2015, and Path-102; Row-65) with less than 5% cloud cover was acquired from National Remote Sensing Agency (NRSA) data centre (NDC) Hyderabad, India. The Classification was performed using a visual interpretation of colour composite (FCC) with bands 4, 3, 2 displayed at the scale of 1:25,000 followed by Ajai *et al.*, 2012. Data processing of spatial mapping illustrated in the below Fig. 2. Satellite image processing was done by using ERDAS 9.1 and ArcGIS 10.2 version. Soil salinity value of 23 sample points were interpolated in the study area boundary (excluding sandy area) to prepare a rasterized soil salinity maps classification of soil salinity gradient mapping in ArcGIS (Banerjee and Ananda Rao, 1989).

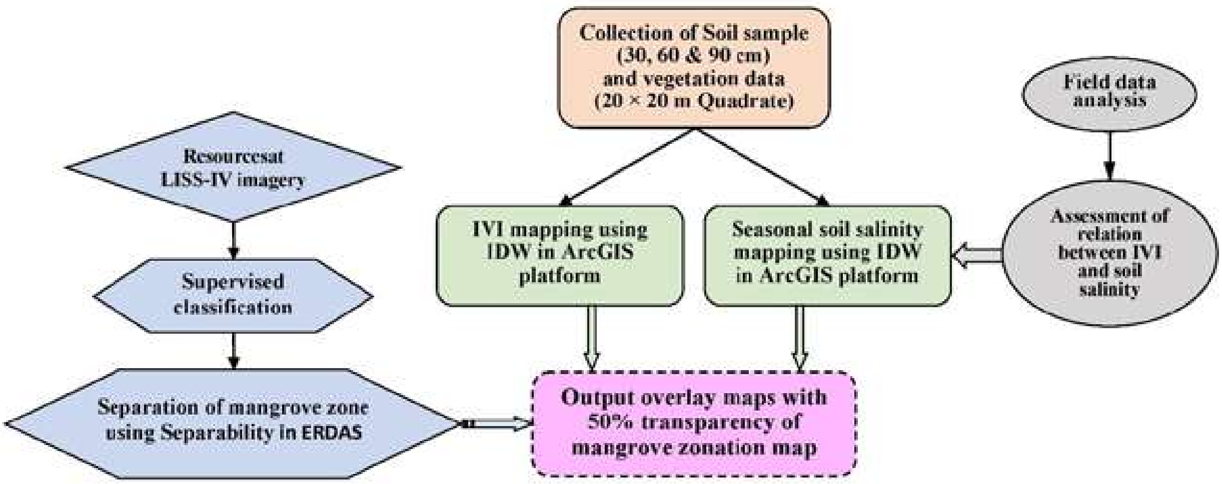

Fig. 2. Short schematic representation of methodology

The study identified *Avicennia* spp dominated forest but the species level distribution of the *Avicennia* spp was not identified. Generally, two *Avicennia* spp are found in this place – *Avicennia marina* and *Avicennia officinalis* as back mangroves while *Rhizophora* spp. Patches were found in waterfronts and *Excoecaria agallocha* and mixed vegetation (i.e. Salt marshes, other true mangroves, and some terrestrial plants) in the landward sides. This has been done to retrieve the distribution of these species within the *Avicennia* spp. dominated community, *Rhizophora* spp. community patches and other mixed vegetation patches. A soil salinity map was prepared by interpolation technique from the field data in GIS environment. IVI maps of the concerned species are prepared from the soil salinity map using the developed relation between them. Then using these IVI maps species priority map was prepared and finally distribution of the two *Avicennia* spp., *Rhizophora* spp. community patches and other mixed vegetation patches were extracted from the community zonation map and priority maps.

An IWD (Inverse weighted distance) method of interpolation was adopted in ArcGIS environment to interpolate the soil salinity from 23 known points with the areas of island having same soil type.

Fig. 3. Mangrove zonation map of Pichavaram.

Supervised classification of the present study area mapping clearly indicating the distribution of mangroves in Pichavaram (Fig. 3)

Results

Distribution pattern

Out of 11 true species in Pichavaram mangrove ecosystem, with an exception of *Acanthus ilicifolius* (herb), all remain tree within 23 quadrats sampling sites. *Avicennia marina* and *Avicennia officinalis* were the two *Avicennia* spp. found and also the considerable density of *Avicennia marina* and *Rhizophora* spp. were observed in the whole region of Pichavaram. Along the river bed of the study area, *Rhizophora* spp. was found as dominant species and the soil salinity was recorded as moderate. Six taxa of true mangroves were studied for Importance Value Index (Fig. 4). The higher IVI was recorded for the species of *Avicennia* spp. (99.59) at site 10, followed by *Rhizophora* spp. (98.27) at site 8 and *Acanthus ilisifolius* (99.58), whereas the lower IVI was recorded at site 20. Based on the analysis, *Avicennia* spp. and *Rhizophora* spp. occupied 55% area of Pichavaram mangrove ecosystem.

Fig. 4. Percentage of Importance Value Index (IVI) for six mangrove species

Based on the mangrove survey, three land cover categories were identified in Pichavaram, 1. *Avicennia* forest dominated principally by *Avicennia marina* and *A. officinalis*; 2. *Rhizophora* forest dominated by *R. apiculate* and *R. mucronata;* 3. Mixed forest dominated by a mixture of mangrove species in Pichavaram like *A. marina, A. officinalis, R. apiculata, Excoecaria agallocha, Bruguiera cylindrica, Aegiceras corniculatum, Luminitzera* racemose, *Ceriops decandra and acanthus ilicifolius.*

Table. 1. Distribution of major mangrove species in quadrats

S. No.	Mangrove species / sampling sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1.	*Acanthus ilisifolius*	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
2.	*Aegiceras corniculatum*	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-
3.	*Avicennia marina*	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+
4.	*Avicennia officinalis*	-	-	+	-	+	+	-	-	+	+	-	-	+	+	+	+	-	+	+	-	+	+	+
5.	*Bruguiera cylindrica*	-	-	-	-	+	+	-	-	+	-	-	-	+	-	-	+	-	-	-	-	-	+	-
6.	*Excoecaria agallocha*	-	-	+	+	+	-	-	-	+	-	+	-	-	+	-	-	+	+	-	-	-	-	-
7.	*Luminitzera racemose*	-	-	-	+	-	+	-	+	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-
8.	*Rhizophora apiculata*	-	+	-	-	+	-	-	-	+	-	-	+	+	+	-	-	-	-	-	-	+	+	+
9.	*Rhizophora mucronata*	-	+	+	+	+	+	+	+	-	-	-	+	-	+	+	-	-	-	+	-	+	+	+
10.	*Rhizophora annamalayana*	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
11.	*Ceriops decandra*	-	-	-	+	+	-	-	-	+	-	-	-	+	+	-	+	-	+	-	-	-	-	-

+ Present - Absent

Mapping based on IVI

Among these mangroves, Importance Value Index (IVI) was applied to generate the spatial maps for Pichavaram and the results showed the gradients of IVI for six different mangrove taxa. In the central part of the Pichavaram and some of the western part, IVI was found to be high due to naturally rehabilitation process and non-anthropogenic activity restricted by forest department compared to opposite direction of the region. It might also be due to the proper plantation and afforestation management activities are proceeding in this region.

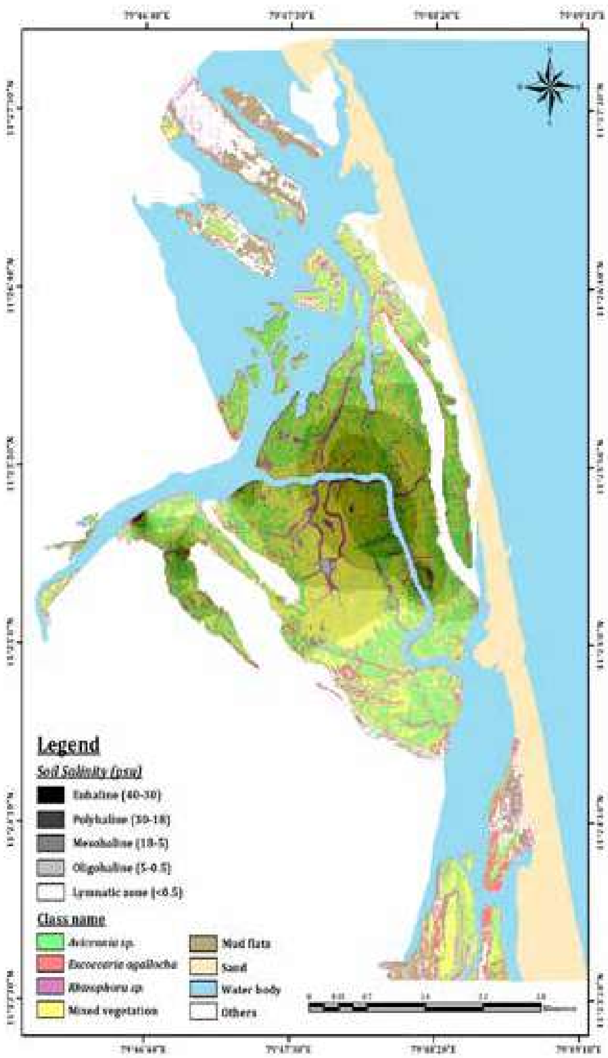

Fig. 5. Pichavaram mangrove with the IVI mapping

Seasonal soil salinity mapping

Spatial maps of soil salinity with varying seasons were shown in the fig (5a, 5b, 5c, 5d). The highest soil salinity was recorded during the summer season (35,64 psu) while the lowest was observed during monsoon season (12.09 psu). This might be highly influenced by the vellar, coleroon and Chinnavaikal water resources.

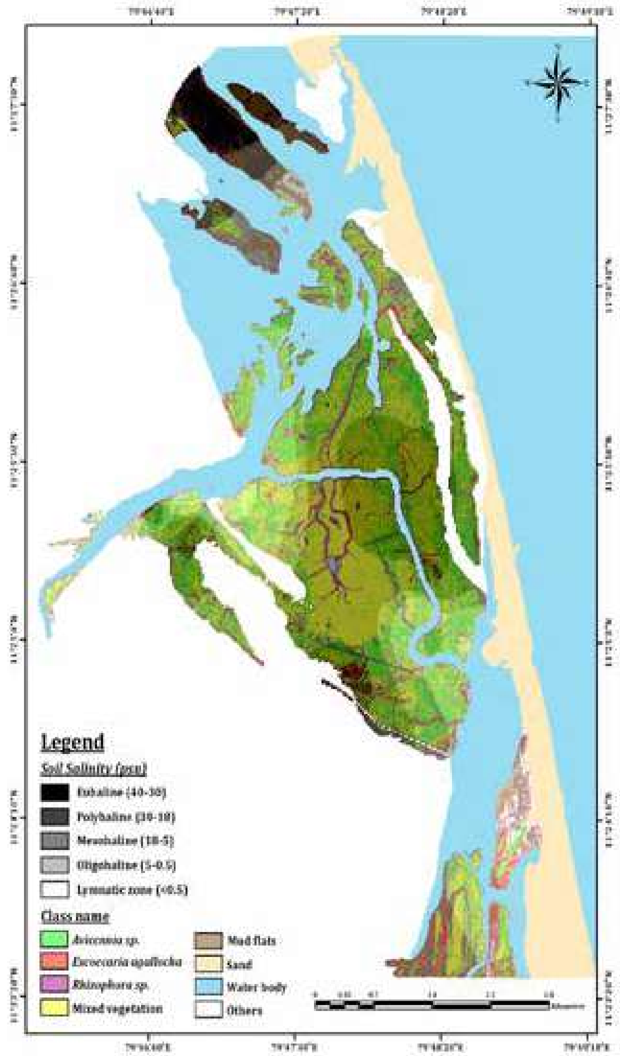

Fig. 5a. Soil salinity (*psu*) distribution pattern in the Pichavaram area during Post-monsoon season

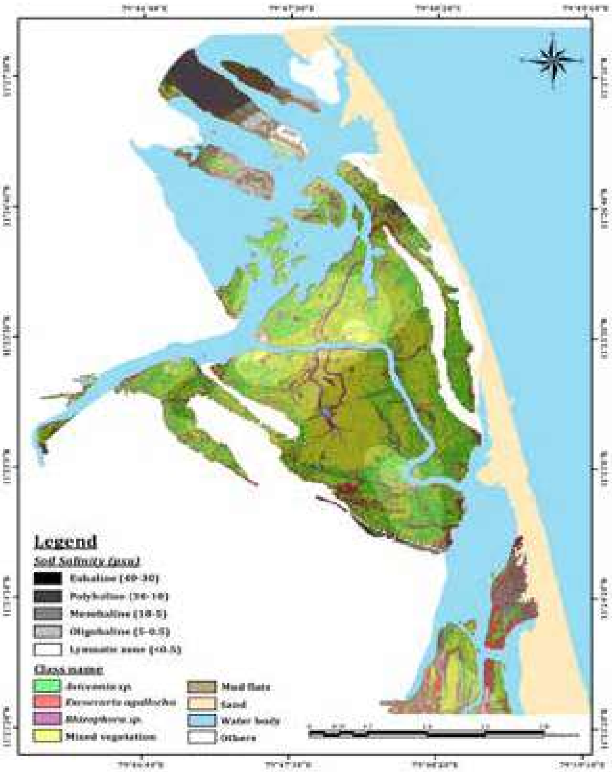

Fig. 5b. Soil salinity (*psu*) distribution pattern in the Pichavaram area during Summer season.

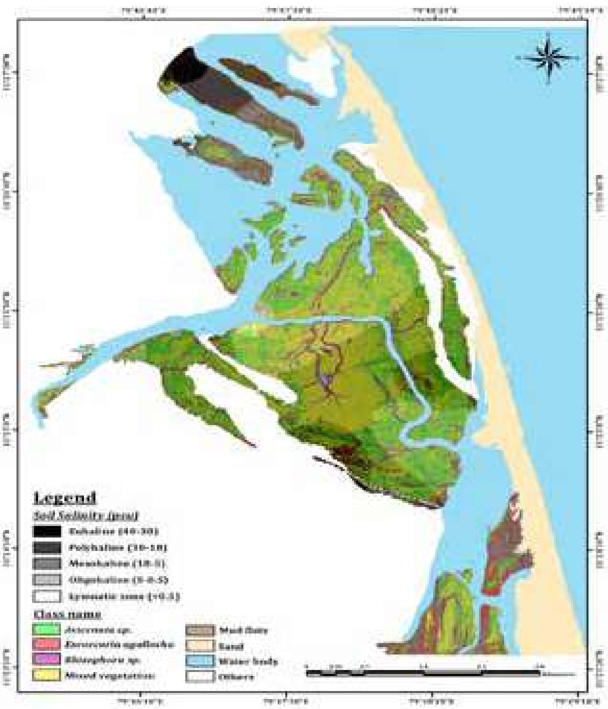

Fig. 5c. Soil salinity (*psu*) distribution pattern in the Pichavaram area during Premonsoon season.

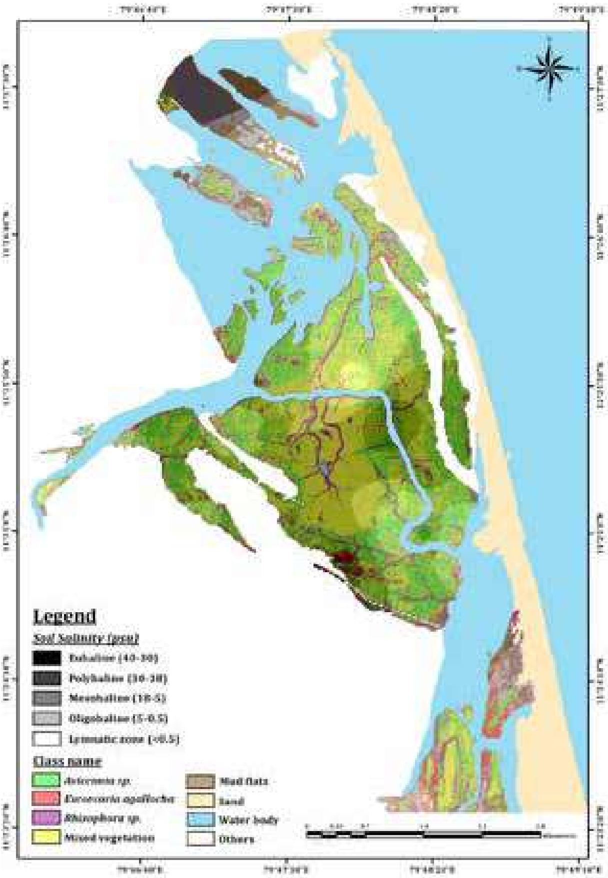

Fig. 5d. Soil salinity (*psu*) distribution pattern in the Pichavaram area during Monsoon season

Discussion

Avicennia marina and *Avicennia officinalis* were the two *Avicennia* spp. found in Pichavaram mangrove ecosystem, of which the former species was found to be salinity tolerant and dominated than the latter species. The brackish water that accumulates in the bowl-shaped mangrove soil substratum during monsoon makes the system hypersaline during summer. This situation is evident in degraded areas at Pichavaram where the soil salinity goes up to 100 psu (MSSRF, 1998). Two distinct zones of *Rhizophora* and *Avicennia* spp. can be identified in the study area, where *Rhizophora* zone occurs along the tidal creeks and channels with a width ranged between 5 and 12 m and height of 4-7 m. The zone pattern of *Avicennia* starts behind the *Rhizophora* zone showed the width ranged between 20 and with a pure community accounting for more than 9.54 ha of the area. Along the river bed of the study area, *Rhizophora* spp. was found dominant and the soil salinity recorded as moderate. *Avicennia marina* also found to be dominant in those areas, but the soil salinity was recorded as moderate to high. Considerably, Importance Value Index (IVI) were highly recorded for *Avicennia* spp. (99.59) followed by *Rhizophora* spp. (98.27). Other species occupied 55% in the Pichavaram mangrove ecosystem were recorded, of which *Excoecaria agallocha* (15.65) showed low IVI.

The area of *Avicennia* spp. occupied 9.54 ha and *Rhizophora* spp. 3.31 ha were calculated through remote sensing and GIS. The wetland has monospecific domination of *Avicennia marina* (Forsk.) vierh., while other species like *Rhizophora mucronata, Rhizophora apiculata* and *Excoecaria agallocha* showed their presence but in low abundances. (Kathiresan, 2000; Selvam *et al*., 2002). The dominance of *Avicennia* spp. in the inwards side might be due to monoculture practice of afforestation taken place in the past. Large mudflat formation found along the Pichavaram mangrove wetland and Vellar estuary showed contrary to beach formation from direct interaction with the Bay of Bengal. Similarly, tidal water inflow to the wetland is reduced due to the formation of new sand spit in the mouth of river Coleroon (Kathiresan, 2000). From field observation, intertidal mudflats are found between mangroves and hence high tidal mudflat was observed on the northern and eastern part of Pichavaram.

Soil salinity range in sundarbans (17.3 psu and 23.8 psu) correlates with optical salinity and high species diversity (Matilal *et al*., 1986; Pal *et al*., 1996). Cintron et al. (1978) reported that salt tolerant species like *Avicennia* spp could be adapted up to 90 psu soil salinity, but their growth is very less. Higher soil salinity was recorded in summer (April-June) of 35.64 psu showing the seawater influence from the mouth of Vellar, Coleroon and Chinnavaikal, whereas it is lowered (12.09 psu) during monsoon season (October-December). In Pichavaram mangrove ecosystem, an exclusive patch of *Rhizophora apiculata* and *Rhizophora mucronata* was found in sheltered areas especially along the creeks and main canal, where the tidal currents have an impact with 3.31 ha area. *R. apiculata* and *R. mucronata* were found dominating the outer part of the mangrove island facing the seaward area. This indicates that mangroves can survive in a terrestrial environment with slightly higher soil salinity. The seasonal salinity maps have not showed any drastic variations in Pichavaram mangrove ecosystem, unlike in the past.

Spatially interpolated seasonal soil salinity map shown the gradient of soil salinity and 50% overlay of mangrove zonation map. The visualization of the mangrove zonation with soil salinity gradient can be easily understood in GIS platform. In Premonsoon and Postmonsoon seasons, the maps were overlayed and there was no much drastic variation in soil salinity were observed when compared to Monsoon and Summer. Importance Value Index map (i.e. Relative frequency, Relative dominance and Relative density) also showed the growth of mangroves in Pichavaram mangrove ecosystem. From the central part of Pichavaram mangrove ecosystem, rich vegetation was found and moved towards the seaward side which decreased mangrove vegetation gradually. Preferably, the zone of a pattern of Pichavaram mangrove ecosystem expressed the whole region and based on the literature

gradient along vegetation pattern in the present study area.

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