CHAPTER 5

REMOTE SENSING ANALYSIS OF LACUSTRINE ECOSYSTEM AROUND KALVELI AND ITS ENVIRONS

5.1 INTRODUCTION

In continuation of the previous chapter, Kalveli lake is studied to understand the effect of tidal influence through Yedayanthittu lagoon, which is located in its northern part, connected to the Kalveli lake by Buckingham canal. In this part of the coastal tract, development of a lagoon waterbody near Yedayanthittu is observed. It may be due to the progressive aggradation process leading to the emergence of land part leaving behind few remnants of ancient waterbodies that has not severed connection with the present coast line. Typically, the area showed development of many micro-relief features such as marsh and tidal flats beside aeolian sand deposits. Similar to Pulicat lagoon, Yedayanthittu lagoon and Kalveli lake contribute ecological significance to the coastal area but in a relatively lesser dimension. They support wide variety of flora and fauna which are mostly halophytic in nature and fauna thriving on the food cycle observed in the lacustrine habitat.

In this area, low degree of flushing by tidal interaction allows evolution of small habitats providing enough micro nutrients to organisms, which in turn provide food to larger prey animals and birds. There also exists a dynamic interaction between fresh water and tidal water during monsoon period followed by gradually receding of tidal water interaction that encourage many flora of salt tolerant and fresh water species thriving together. This in turn, set the food cycle in motion supporting many flora and fauna including migratory birds making the study area a more significant one in terms of habitat ecology. Hence, an information based correlative approach, such as the present study bringing out ecologically significant wetland features is carried out.

In this context, present study attempts to gather spatial information of Kalveli ecosystem, types of wetland categories their extent and their relationship with the
presence of flora and landuse observed in the area using remote sensing satellite data. Further, spectral signatures and reflectance value of wetland features around Kalveli are also studied and remote sensing image is analysed to extract subtle information of the study area. A brief physical description of the study area attributing its physiographic and climatic setting is discussed in the following section.

5.2 DESCRIPTION OF KALVELI LAKE AND YEDAYANTHITTU LAGOON

Kalveli is the second largest brackish water lake in south India. It is located nearly 20 Km north of Pondicherry in the Villupuram district of Tamil Nadu. In vernacular language Kalveli is correctly pronounced as “Kazhuveli”, which means a vast open space or land which is not under cultivation. Kalveli watershed is spread over a vast area forming a main storage unit during monsoon and adjacent area rely upon the lake for their agricultural and domestic purposes. The lake is connected to sea at its northern end through Yedayanthittu lagoon. The shape of the lake is almost parallel to the coastline, which again may be indicator of its nature, a part of lagoon ecosystem, during geological past. Because of its unique position and connectivity to sea, the lake has two distinct parts. It shows an estuarine or lagoon influenced northern part and fresh water as its southern part. The lake forms a unique environment with fresh water inundating the lake during monsoon and sea water interaction at its northern part throughout the year developing a mixed lacustrine ecosystem.

The study area enjoys a sub-tropical climate with hot summer and mild winter with monsoon aiding the water resources. The temperature ranging from as low as 25ºC to as high as 40ºC and receives maximum rainfall during northeast monsoon from October to December. Monsoon is mainly during October, November and December by northeast monsoon and relatively lesser during southwest monsoon (August and September). The relative humidity is very high around 76% due to its proximity to sea.

Proximity to sea and sea inlet in the form of estuarine and lagoon has led to the development of salt harvesting, reed gathering and fishing that supports the economic
activities of the local communities around the study area besides agriculture, cutting and gathering fuel wood for domestic and commercial purposes.

Figure 5.1 Remote sensing satellite Image of Kalveli and its environs

Satellite image of the study area as shown in Figure 5.1 depicts Yedayanthittu lagoon and Kalveli lake and landform setting of the coastal area. General appraisal of the satellite image showed a linear beach exactly demarcating the sea and land portion of the study area. Adjacent to beach in landward side, dunes are present and even among them, a more stabilized sand deposits covered with intense agricultural activities and relatively lesser stabilized sand deposits with plantation and scattered shrubs are seen. On the western side of sand deposits, man-made canal is seen connecting the lake with the lagoon and estuarine at its mouth in the northern side. Along the canal and
around the lagoon and estuarine mouth, saltpan fields are evident by their typical rectangular field pattern filled with brackish water. This forms the last stand of area where tidal influence into land may be seen and west of this part is observed with lateritic upland and flat terrain covered with vegetation.

Due to the continuous diurnal tidal interaction at its mouth and seasonal tidal influence into the lake developed significant wetland features that support variety of flora and fauna of both fresh water and brackish water habitats. Such an environment encouraged to study the lacustrine ecosystem using satellite data so as to extract spatial information of the study area forming a baseline reference for further ecological and environmental studies. Since, repetitive coverage of remote sensing satellite generates temporal data, an insight on the spectral behavior of various wetland features and dependant flora would be significant to understand the inherent character of the ecosystem. Such an approach would also be meaningful since it could provide a comprehensive idea on location specific and pixel based effective changes in the ecosystem. A detailed discussion on spectral information of wetland categories and associated flora extracted using image processing techniques is carried out in the following section.

5.3 IMAGE ANALYSIS OF THE KALVELI LAKE AND ITS ENVIRONS

As discussed in the previous section, image analyses of remote sensing satellite data could be useful in extracting pixel level information about features. Complexities of spectral signature by various wetland features due to their heterogeneous nature make such information extraction an arduous one. Also, identification and delineation of wetland features and their spatial extent is very difficult owing to the dynamic interaction between sea and terrestrial condition exerting influence on spectral properties of wetland features of the coastal habitats. Confusion among pixel values is the limiting factor since spectral reflectance value (spectral signature) of many of the features because of the inherent mixing of features without clear boundary separation. To meet and overcome such challenges, any one method of image analysis may not suffice and requires combination of techniques.
In the process of extracting such information two comprehensive approaches could be made. Firstly, broader information on delineation of boundaries of various coastal wetland features using various image processing techniques and secondly more focused spectral analysis are carried out. Techniques such as Principal Component Analysis (PCA), composition of vegetation and moisture stress around the coastal area using NDVI, grouping of pixels based on textural element and edge enhancing for boundary delineation apart from unsupervised clustering and supervised classification are carried out to understand the general setting of the coastal wetland features of the study area. This is further followed by spectral analysis of these features. A detailed description of the above techniques is discussed in the following section.

5.3.1 Principal Component Analysis (PCA) of Kalveli lake and its environs

The technique of Principal Component Analysis (PCA) has tremendous application in image processing of satellite data (Craig et al., 2011). PCA is often used to reduce dimensionality of multispectral data set without losing the information. At the same time, it helps to enhance certain subtle features especially in the case of land use and land cover (LULC) features and aids in appreciating their spatial extent. To amplify further, in the present study, the Landsat TM satellite image with selective four bands (in the visible and NIR region excluding SWIR and TIR) data has been compressed and reduced to generate three component axes thus facilitating visual interpretation for wetland features along the coast line. Also, it has helped to demarcate between land and water that has been used as baseline information for generating sample sets in supervised classification and ground truth verification (Lei, et al., 2007). In the present context, PCA has helped to increase the interpretability of the satellite image and thus has helped in improving the accuracy in extraction of information on various wetland features.

The resultant output generated after implementing PCA using ERDAS Imagine image processing software is depicted below in Figure 5.2. Figures depicted in 5.2 A, 5.2 B and 5.2 C revealed the setting of various wetland features and their boundaries. First component axis of PCA has brought out almost 80% of the information on wetland features.
features of the study area followed by second and third rotation with other information. The output of PCA3 in color has revealed distinction among various wetland classes, which has helped to appreciate the coastal environment of the study area.

The examination of PCA 3 output in color format has distinctly showed the presence and extent of tidal interaction ad various wetland features around the lacustrine ecosystem. The turbid water along the coastline and its influence into the lagoon, estuarine and northern parts of the lake are evident. Moreover, such inlet of tidal water through the estuary and lagoon are used in harvesting of salt by constructing saltpans along the lagoon boundary at its western part and along the canal till reaches the lake. Such interaction has led to development of salt marsh and marshy vegetation in the mouth of the lake, which s connected to the canal besides some salt tolerant halophytes and conventional freshwater vegetation. Sand deposits along the coast have been clearly brought out and agricultural activities on either side of the lake and around the Kalveli lake are also enhanced. Plantation crops are seen around the lagoon, estuarine area and sand deposits along the coastline. In short, PCA analysis has helped to bring out various wetland features around the lagoon and the lake, as well as, to some extent, their spatial boundaries. Since the study is located amidst agricultural activities, pattern of vegetation and information on soil moisture are gathered from implementing NDVI, which is discussed in the following section.
5.3.2 NDVI Analysis of Kalveli lake and its environs

Normalized Difference Vegetative Index (NDVI) is a statistical estimation of spectral values of the photosynthetic output (chlorophyll) in a pixel in a satellite image. Physiological status of plant may be given by the photosynthetic potential such as concentration of chlorophyll a and b and carotenoids (Danks, et al., 1983; Gamon and Surfus, 1999; Young and Britton, 1990) that controls the plant stress. The stress may be provided by estimating pigment concentrations (Filella, et al., 1995). Plant stress in turn, may be given out as spectral reflectance influenced by concentration of chlorophyll, leaf area index (LAI) and its interaction with red and near-infrared (NIR) spectral regions. Thus, NDVI in remote sensing satellite data, measures the amount of the vegetative cover on the land surface over wide areas. Dense vegetation shows up very strongly in the imagery, and areas with little or no vegetation are also clearly identified. NDVI also identifies water and ice. It takes values between -1 and 1, with values 0.5 indicating dense vegetation and values <0 indicating no vegetation. It helps in monitoring vegetation conditions and hence, plays a significant role in crop monitoring.

Implementation of NDVI in the present study has helped to understand the soil moisture condition, both wet condition and dry condition, apart from revealing zones of high vegetative density. From the figure 5.3, it may be observed that the resultant image showed various levels of grey scale from dark to white. As stated above, grey levels represent NDVI values of various objects with “zero” value is shown as dark color representing water and “1” as sand. Here, the waterbody, sea water is clearly demarcated and the coastline is lucidly delineated. Estuarine and lagoon mouth is amply enhanced along with the canal connecting the lake with sea at its mouth in the north through the lagoon. Large patches of “white” tone may represent sand deposits and any changes in the extent of white tone or replaced by gray colored pixels may indicate changes in landuse pattern. Also, any changes in the digital values of NDVI processed pixels temporally, at particular place or coordinates, may indicate dynamic vegetative status.
Thus, NDVI image help in establishing the intrinsic relationship between the lake and the lagoon in the study area. It also helps in extracting such valuable information which could be used for further analysis using temporal data and to understand the presence or absence of vegetation around the study area. Apart from such analysis, an inversion of color of pixels may help in corroborating and at the same time bring out some subtle information of wetland features as discussed in the following section.

5.3.3 Color inversion Analysis of Kalveli lake

Color inversion is a simple manipulative technique that changes the Red, Green and Blue (RGB) colors into intensity, hue and saturation (HIS). The pixel values of RGB (0 to 255) are reduced between 0 and 1. The success of such technique lies in its simplicity and to bring out subtle features and to appreciate such information with respect to wetland studies along the coastline of the study area. It also helps in
demarcating different with clarity providing vast understanding of the wetland features and such processed image is shown in Figure 5.4.

![Figure 5.4 Color inversion image of Kalveli lake and its environs](image)

The figure illustrates distinctive pattern highlighting major colors thus enhancing pixels of similar spectral values leading to the inference of certain major wetland categories. Sea is clearly separated by its distinct light green color and the same color pattern is seen around the estuarine as well the lagoon waterbodies. Moreover, the color pattern is also seen along the canal but abruptly changes at the mouth of the Kalveli lake. This may help in understanding the extent of tidal interaction in the lagoon and the canal; and also limited tidal influence in the northern periphery of the lake as well. Sand deposits such as beach, and stabilized dune deposits are shown in brownish yellow and similar color pattern is also seen between the lagoon and the lake at their western part suggesting the presence of coastal dune deposit. This may lead to the inference on the shoreline oscillation during geological past.
Vegetations are represented by different shades of violet color representing different plant species such as *Casuarina* along the coast, *paddy* cultivation near the lake and the northern part above the lagoon and cultivated crop vegetation and natural vegetation mostly *Prosopis* in the western part of the study area. Small patches of brown color in the lagoon and in the northern part of the lake are also observed which may indicate the presence of *marsh* vegetation. Thus, inversing the color separation has aided in a broader understanding of wetland features along the coast and the landuse features in the western part of the study area. Color manipulation of pixels has helped to identify certain major wetland features around the lagoon and the lake. The boundaries of such features may be well brought out using edge detection technique, which is discussed in the following section.

### 5.3.4 Edge detection of wetland boundaries around Kalveli lake

As explained in the previous chapter, edge detection in an image is carried out by statistical filters that enhance and suppress the values of pixels, which in turn, brings out information on the boundary condition of objects. Thus, boundaries of linear and curvi-linear objects are detected either by their sharp continuities or abrupt discontinuities in a satellite image. Apart from many man-made features such as roads, railways, buildings and agricultural fields, abrupt changes due to spectral anomaly suggesting subtle features may also be brought out. The resultant image derived from applying such technique is shown in Figure 5.5.

From the image it could be observed that boundaries of many linear and curvi-linear objects are brought out apart from separating pixels of high variance. The sea and the land boundary is delineated more precisely than any other methods, since water and land have different spectral properties and tend to segregate clearly. Apart from spectral separability of land and water, many linear features such as canal, roads and agricultural fields are clearly separated. Boundaries of lagoon water body and Kalveli lake is also clearly enhanced. While examining lagoon waterbody, many field patterns are visible and they may be inferred as *saltpans*. Similar field pattern are also visible along the canal as well.
Significantly, wavy or curvi-linear pattern is seen within the lake at its northern boundary, which may be due to the crenulation marks generated by the receding column of water in the lake at different stages or period of time. Such information could be more meaningful while assessing the tidal influence into lake and indirectly throw light on the flora and fauna supported by such waterbody. Linear coastal landform such as beach and sand deposits are well enhanced apart from small spit at the estuarine mouth at the northern part of the study area.

All the above techniques and their resultant image have brought out salient features of the lacustrine environment of Kalveli area. Techniques such as PCA, NDVI, color inversion and edge detection have brought out significant information on the major wetland features such as estuary, lagoon, lake, beach, sand deposits, marsh, marsh vegetation and salt pans that area prevalent in the study area.
With the broader understanding of the wetland features by image analysis of the study area, a more specific spectral analysis of individual wetland features from satellite data is carried out.

### 5.4. SPECTRAL ANALYSIS OF KALVELI AND ITS ENVIRONS

The image processing techniques have provided ample information about salient wetland features around Kalveli lake and its environ along with their environmental setting. Such an analysis of the satellite image could provide sufficient baseline data for further in depth local analysis of the selected lacustrine ecosystem near Kalveli.

Spectral properties plays a pivotal role in identifying various wetland features and the related DN values may be similar or slightly varying due to the influence of the local setting. Moreover, objects in nature are heterogeneous and hence may not reflect the property of a “pure” sample and DN values may vary based on the predominant feature of an environment. Such an approach helps in building up a spectral database of features under different environment setting. Thus, similar to Pulicat ecosystem as discussed in the previous chapter, spectral analysis of Kalveli lacustrine ecosystem is studied. In this ecosystem, predominant features include estuary, lagoon, lake, beach, sand deposit, saltpans and marsh and plant species of both salt tolerant and fresh water. To cater such a requirement, a regional pattern of DN values of select wetland and vegetation features as well as spectral characteristics of pixel based individual features area discussed in the following section.

#### 5.4.1 Spectral profile of wetland features around Yedayanthittu lagoon - Kalveli lake

For the convenience of analysing spectral profile of various wetland features, the image is split into two parts with the former showing estuary and lagoon (Figure 5.6 A) and the latter the Kalveli lake (Figure 5.6 B). Such splitting up of image is to facilitate a more comfortable study of various features around the lagoon and the lake.
In the figure 5.6A, “sample 1” to “sample 5” represents lagoon water near the estuarine mouth, in the lagoon, beach, vegetation and salt pan respectively. Similarly, in the figure 5.6B, “sample 1” to “sample 4” represents marsh vegetation, salt marsh, mudflat, and agricultural vegetation respectively. A cross-sectional profile of these samples of both the parts of the study may reveal the significance of spectral reflectance being influenced by major constituent particles of the features. For example, percentage of chlorophyll content in vegetation, mineral constituents in soil, soluble or suspended solids in water and so on. Any changes in the ratio of constituent particles may influence the spectral reflectance of features at subtle level and hence range of DN values is adhered to recognize major spectral pattern of wetland features.

The illustration shown in Figure 5.7 depicts spectral profile of various wetland features and their typical reflectance in three prominent spectral bands around Yedayanthittu lagoon. The spectral profile reflects the nature of group or “cluster” of pixels representing a particular feature. Such profiling could be used to compare features of same identity at different settings or even temporally to understand the dynamism associated with that environment.
In the present study, sample points 1 to 5 represents lagoon water at its estuarine mouth, lagoon water slightly away from the sea mouth, beach, agricultural vegetation
and saltpans. Each of these five features may reflect tidal influence and its associative influence on the wetland and in turn, the influence over the landuse environment around Yedayanthittu lagoon and Kalveli lake.

In the first sample representing estuarine mouth, diurnal influence of tide is visible through the spit like opening. Standing water column at this part shows high reflectance at the first band relative to the second spectral band and shows lowest at the third band. This reiterates the spectral character of water showing high reflectance at “blue” band and absorption at “red” band. The second sample, little farther away from the mouth and at the center of the lagoon shows similar spectral trend of first sample and adheres to the spectral behavior of waterbody. But still, there exists some little variation between the lagoon water at the mouth and water at the center of the lagoon, which is evident from the illustration of sample 2 as shown in Figure 5.7. It showed a relatively higher reflectance in band 2 when compared to sample 1. But the pattern in band 3 again showed absorption band of water though of slightly high DN values than estuary.

Followed by this the third sample is “beach”, which showed higher spectral reflectance values in all the three bands. It showed a similar reflectance pattern in both band 2 and band 3 though a slightly higher value in band 3. But the values are relatively less in band 1. Since beach is constituted by silica particles, it showed a higher reflectance values than any other features including barren soil except snow and cloud. The fourth sample is agricultural vegetation showing high reflectance in band 3 relative to bands 1 and 2. Vegetation, in general, shows higher reflectance in red and NIR region of ems and the same is shown in the three bands. The fifth sample is “saltpan”, which shows a mixed reflectance pattern combining both sea water as well as salt. A similar attempt to show the spectral profile of various features around the Kalveli lake is discussed below with the help of illustration.

In the figure illustrated in Figure 5.8, sample area such as marsh vegetation, mudflat, marsh, agriculture and saltpans are depicted showing their spectral pattern within the feature class.
Figure 5.8 Surface plot of spectral reflectance of sample sites around Kalveli Lake
The spectral profile of “marsh vegetation” shows progressive increase in spectral reflectance from blue band to red band. The increase reflectance value is also very smooth and not as conspicuous as “vegetation”. The reflectance pattern suggests predominance moisture and clay constituent and increase in red reflectance may indicate the influence of shrub like halophytes present in the marshy area.

Second sample area showing “mudflat” appears dried up and hence a low reflectance in both the first and second bands. The increase in the reflectance value in band 3 may be due to the saline surface and the mineral constituent in the area. When it is flooded with water and have moisture it may show a reversal in reflectance pattern showing high DN values in first band.

The third sample “marsh” shows almost a uniform reflectance showing a slight increase in DN values in the third band similar to that of marsh vegetation but showing a slightly higher value in the red band.

The fourth one is “agriculture”, which shows an increase in DN value in red band. The pattern may also suggest an influence of soil reflectance and vegetation not dense as that of the sample taken around the lagoon. Saltpan, filled with saline water, shows higher reflectance value in both first and second bands and akin to the reflectance pattern akin to the saltpan near the lagoon.

Saltpans show unique spectral pattern since they are the culmination both sea water and soil. Because of this, when they are filled with water, they show lesser reflectance but replicating the pattern of freshwater, that is high reflectance in blue and absorption in red, and when they are dry they tend to higher DN value because of the reflectance of salt crystals behave like sand.

The spectral analysis is further followed by the spectral signatures individual features at pixel level rather than group or cluster of pixels, since they may tend to show their inherent reflectance value, which is discussed in the following section.
5.4.2 Pixel based spectral DN values of wetland features around Yedayanthittu lagoon - Kalveli lake

In continuation of the samples studied as clusters for their spectral pattern, digital number (DN) values of individual objects at pixel level are studied to understand their spectral pattern. Since, clusters may inadvertently mixed with other classes also, individual pixels as points portray a better information on the spectra behavior of objects.

Figure 5.9A. Spectral sample points around Yedayanthittu Lagoon

Figure 5.9B. Spectral sample points around Kalveli lake

In the present section, similar to the discussion above, DN values of pixels representing specific wetland features are extracted. Such spectral information of
individual objects are significant because position of such pixels could be marked using coordinates used for comparison at a later date using temporal satellite data. This would help in assessing and monitoring the changes in the physico-chemical constituents of objects at that particular coordinate at a specific interval of time.

This may be discussed in detail with illustrations showing positions of points selected for depicting various wetland features in different parts of the study area. Using such observation, a table showing DN values of wetland features are also prepared. For the convenience of depiction and discussion, the study area is shown in two parts as shown in the previous section – a lagoon in the northern part and lake in the southern part of the study area as shown in Figure. 5.9 A and Figure 5.9 B.

The observation made from the satellite data and the subsequent field investigation revealed absence of vast stretch of tidal flats as evident around Pulicat lagoon. In this part of the study area, an inlet of sea water at the northern part developing an estuarine and lagoon environment is observed. The waves and tidal action develop a longitudinal sand bar, spit, at its mouth. The sand bar shows accretion during low tide and non-monsoon period and washed away during monsoon period. The spit in a way acts as a regulator to the volume of sea water entering and receding in this part. This in turn, becomes instrumental in developing marsh and marshy vegetation in and around the lagoon. The structure of the lagoon is controlled by the elevated sand deposits on either side of the lagoon. The again reiterates that the coastal morphometry implies connectivity with sea and these waterbodies both lagoon and lake and may be the paleo remnants of earlier coastline of geological past.

In the study area, mostly marsh, marsh vegetation, salt marsh, saline area, lagoon, salt pans, stabilized dune sand and beach are the predominant categories. Sample points representing all these categories are selected as shown in the above figures. Moreover, to understand the tidal influence into the lake in the southern part (Kalveli lake) through the lagoon and canal, sample points of water at various locations on these features are studied. Similarly, salt pan, salt marsh, marsh, water and other vegetation are selected in and around Kalveli lake. DN values of spectral reflectance of the wetland features of Yedayanthittu are tabulated in Table 5.1, which could form
as a baseline database for wetland studies using remote sensing satellite data. Further, such extraction of spectral details could also be significant for digital classification of wetland features, especially while implementing supervised classification.

Table 5.1 DN values of some of the wetland features in and around Yedayanthittu Lagoon

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Wetland feature around Yedayanthittu Lagoon</th>
<th>Band 1 (blue)</th>
<th>Band 2 (Green)</th>
<th>Band 3 (R / IR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Sea water</td>
<td>25</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>S2</td>
<td>Estuary / Lagoon</td>
<td>37</td>
<td>34</td>
<td>20</td>
</tr>
<tr>
<td>S3</td>
<td>Lagoon</td>
<td>38</td>
<td>37</td>
<td>19</td>
</tr>
<tr>
<td>S4</td>
<td>Saltpan</td>
<td>32</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>S5</td>
<td>Salt marsh</td>
<td>38</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>S6</td>
<td>Canal water</td>
<td>43</td>
<td>41</td>
<td>24</td>
</tr>
<tr>
<td>S7</td>
<td>Barren Sand</td>
<td>71</td>
<td>109</td>
<td>109</td>
</tr>
<tr>
<td>S8</td>
<td>Agriculture</td>
<td>36</td>
<td>37</td>
<td>98</td>
</tr>
</tbody>
</table>

The pixel wise spectral reflectance values shown above clearly shows the behavior of various wetland features as recorded in the remote sensing satellite data. The values also showed their variation with respect to changing physico-chemical condition or environment from where the samples are studied. To appreciate the varying levels of such features, the DN values of various wetland features are depicted using a bar chart as shown in Figure 5.10.

When the DN values “water” is examined, it showed different values for sea water, estuarine water near the mouth, lagoon water, stagnated water in salt pans and finally water flowing through the canal. Though “water” is the common feature in all the above sample points, their physical condition and chemical constituents vary with their distance away from the sea. This makes such an approach of studying pixel based sample points of features very significant and emphasizes the utility of remote sensing data in monitoring pixel based environment studies.
Moreover, such variations in the spectral reflectance also indirectly lead to inference of the limit of the tidal water inflow into the lake. This may also be used to understand the degree of tidal interaction and study the limit up to which the salinity transgress into the Kalveli lake water. Table showing (Table 5.2) DN values of some of the selected wetland features around Kalveli lake is shown below.

### Table 5.2 DN values of some of the wetland features in and around Kalveli Lake

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Wetland feature around Kalveli lake</th>
<th>Band 1 (blue)</th>
<th>Band 2 (Green)</th>
<th>Band 3 (R / IR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Saltpan</td>
<td>45</td>
<td>42</td>
<td>28</td>
</tr>
<tr>
<td>S2</td>
<td>Salt marsh</td>
<td>75</td>
<td>97</td>
<td>102</td>
</tr>
<tr>
<td>S3</td>
<td>Lake water</td>
<td>53</td>
<td>58</td>
<td>56</td>
</tr>
<tr>
<td>S4</td>
<td>Mud with vegetation</td>
<td>38</td>
<td>38</td>
<td>77</td>
</tr>
<tr>
<td>S5</td>
<td>Marsh vegetation</td>
<td>47</td>
<td>53</td>
<td>61</td>
</tr>
<tr>
<td>S6</td>
<td>Mudflat</td>
<td>46</td>
<td>53</td>
<td>68</td>
</tr>
<tr>
<td>S7</td>
<td>Agriculture</td>
<td>42</td>
<td>46</td>
<td>105</td>
</tr>
</tbody>
</table>
Among these features, *saltpan* and *salt marsh* are the resultant of storing up of salt water for salt harvesting, which supports the major economic activity of this part besides agriculture. The lake is mainly fed by many ephemeral rivers and first order streams during monsoon. This supersedes the influx from tidal water and the lake remains relatively filled with fresh water and supports the local requirements such as drinking water and agricultural activities. During monsoon, the overflowing storm water from sea may not have much head against the tidal water through the canal. As the monsoon weakens, tidal water may influence the lake through the lagoon and the canal and feed the lake with saline water. This is the reason many *saltpans* thrive along the canal and at the northern periphery of Kalveli lake. Such interaction generates many interesting wetland features in and around lake such as *mudflat, mud with vegetation, marsh vegetation, salt marsh* and *saltpans*. The spectral reflectance of such wetland features listed in the above table is also depicted using bar chart so that their relative spectral pattern in terms of DN values could be appreciated and shown in Figure 5.11.

The examination of chart reveals that though agriculture and *mud with vegetation* represents flora their difference in species and background influences the spectral reflectance pattern and in turn their DN values. In the former case, agriculture, it is cultivated and the background may be dry soil with silt and small amount of clay. In
the case of “mud with vegetation”, it is observed with predominance of clay soil with moisture and plants thriving on them are mostly small shrubs. Such variations has direct influence in the spectral values recorded by the sensors of the remote sensing satellites and thus making the satellite data a formidable tool in extraction of information about wetland features, especially dynamic features in coastal ecosystem and environment. Also, information thus extracted may lead to inference not only on the physical condition of the wetland features but also chemical and biological environment.

DN values of such wetland features and the information interpreted from such spectral reflectance values could be used as baseline data for grouping of “similar” pixels and classify them on their similarities, which is discussed in the following section.

5.5 CLASSIFICATION OF WETLAND FEATURES AROUND KALVELI LAKE

As discussed in the earlier sections, spectral signatures of objects vary individually based upon their inherent constituent, its surrounding and the influence of the constituents of their adjacent objects. In nature, not many features are absolutely pure and always influenced by her their surrounding environment. In actuality, the DN values showing spectral reflectance values of various wetland features do reflect the spectral character of that feature along with the spectral character of its surroundings. Hence, the DN values may slightly vary depending upon the background reflectance of the environment or terrain setting despite their similarity in constituents or similarities in floral species. But, it could be noted that the spectral reflectance pattern of the feature, irrespective of their environment setting, would adhere to their specific pattern though the DN values of these features may sometimes site specific. Based on this fact, pixels of digital remote sensing data may be grouped to segregate various features implementing classification techniques - unsupervised classification and supervised classification. In the present study, both unsupervised and supervised techniques are applied to understand the spatial relationship among various features and delineation of wetland features around Kalveli lake.
5.5.1 Wetland features around Kalveli lake using unsupervised classification technique

To understand the spatial pattern of wetland features around Kalveli lake, unsupervised classification technique has been implemented on the digital Landsat TM data and the resultant output image is shown in Figure 5.12. From the image, it could be observed that sea water because of its size and uniformity in reflectance pattern has been separated out clearly. Turbid water along the shoreline is separated and shown in dark blue color, and the same pattern is seen in the lagoon too. This implies a tidal inlet into the lagoon and the sea water is also used for salt harvesting activities. Regular shape and field pattern showing bluish color lead to the inference of presence of saltpans and filled with sea water through the lagoon. The brown color patch within the saltpan fields and around the lagoon water may indicate the presence of tidal marsh. The sea water shown in dark blue color extends well into the canal and peters out near the mouth of the lake implying the limit of tidal influence into the lake through the lagoon and canal.

Another larger waterbody, Kalveli lake at the southern part is clearly demarcated and present with many wetland features. A clear demarcation of Kalveli lake from the other features revealed the distinct spectral contrast between the Kalveli waterbody and the adjacent features. Within the lake again the yellow color showed presence of stagnating water within the lake; pixels colored with dark yellow color showed the presence of marshy area and light pink color showing mudflat within the lake. Light pink color in the image around the lake at its northwestern periphery showed presence of salt marsh and saline area. Similarly, beach and coastal sand deposits are also shown in the same color since both the features though different appears physically same showing similar reflectance values. Since, the classification is unsupervised, such confusion and mixing up of pixels are possible but would help an analyst enhancing such physically similar appearing features so that they can be carefully assessed and separated while generating “training sets” for supervised classification.
Vegetation in and around the lake are shown in red and green colors representing crops and natural vegetation respectively. A small green color patch well within the lake would reaffirm the inference of green color as natural vegetation, since it could only be *mud with vegetation* or *marsh* vegetation and could not be of cultivated crop vegetation. But as explained earlier, unsupervised clustering of pixels would include a wider range of DN values for vegetation rather than specific DN value or spectral signature for specific flora. Such limitation of this technique imposes on the degree of accuracy of distribution of floral types in and around the lake. At the same time, such technique provides very valuable information pertaining to the spatial pattern of various features such as *vegetation*, *barren soil*, *sandy area*, *saline area*, *saltpan*, *lagoon*, *fresh waterbody*, *marsh*, *mud flat* and *sea water*. Such pattern recognition is useful while interpreting and delineating wetland features for subsequent studies and provide significant knowledge on the spectral behavior of various wetland features.

The technique in its simplicity provided intrinsic information on wetland features around the study area and paved way for a more refined supervised segregation of
features using training sets with spectral signatures of objects as basis. A detailed description of the same is explained in the following section.

5.5.2 Wetland features around Kalveli lake using supervised classification technique

With the knowledge derived from the spectral analysis and clustering or unsupervised classification technique, “training sets” are generated. Sample sets of such features based on range of DN values and their mean value is applied on the digital image of the study area to derive various ecologically significant wetland features in and around Yedayanthittu lagoon and Kalveli lake. The extent of tidal influence into the lake through the lagoon and canal and the resultant local human interface in the form of salt harvesting activities and other ecologically sensitive saltwater – freshwater interface features are brought out. For the convenience of description and discussion, the study area is sub-divided into two parts with the upper one showing wetland features in and around Yedayanthittu lagoon and the lower part showing wetland features in and around Kalveli lake (Figure 5.13 A and Figure 5.13 B).

The examination Figure 5.13 A, on its first impression revealed a clear separation of land and sea and again separating turbid water along the coastline from the sea water. Inland waterbodies are again delineated as separate class features since they are fresh water in nature and vary in spectral DN values. Thus, distinction among waterbodies having various conditions are separated in the supervised classification owing to the training sets generated using the knowledge derived from spectral analysis and unsupervised clusters.

Secondly, lagoon waterbody which plays a crucial role in developing the ecosystem of the study area is well demarcated. Its boundary and associated features within the lagoon area are lucidly brought out. Marsh vegetation and marsh within the lagoon are shown as linear shape and as a small patch respectively imply the presence of wetland ecosystem of Yedayanthittu lagoon.
Much of the sea water entering into the lagoon supports the thriving saltpan activities around the lagoon and the field pattern showing such activities are clearly brought out. The most interesting aspect of the classification output image is the extent of tidal
water through the lagoon into the canal and it abruptly stops near the mouth of the Kalveli lake, which may imply the presence of direct freshwater and saltwater wedge. This in turn, develops a lacustrine ecosystem where both saltwater and freshwater habitats co-exist. Apart from this, salt pans are seen all along the periphery of the lagoon (shown in pink color), and development of salt marsh around the pans. Natural vegetation such as Prosopis and some halophytes are seen near the salt marsh. Barren land on the western part of the salt pans and marsh may suggest the influence of salinity in the adjoin areas and development of salt marsh.

Besides these wetland features in and around the lagoon, sand deposits such as beach and spit are clearly extracted and shown as linear features along the coastline. In the output image it is shown in yellow color and in some places, the deposits are thick enough to show ridges and may imply presence of beach as well as stabilized dune sands. Presence of vegetation, mostly Casuarina sp., and prolonged cultivation activities, including paddy cultivation, have stabilized those sand deposits. The sand deposits are mostly confined along the shore and acts as buffer between the lagoon and sea. The cultivation activities also suggest shallow aquifer in the sand deposits that supplement crop water requirement. But, any excessive exploitation may lead to the contamination of water by salt water intrusion. The information thus derived on the nature and extent of wetland features are ecologically significant throwing intrinsic relationship among them and their influence on the coastal environment of the study area.

In continuation of this, analysis of the resultant image of Kalveli lake (Figure 5.13 B), showed that sea and land mass is clearly segregated and water within the lake is also clearly shown. Turbid sea water due to shore waves is separated and it marks the boundary of coastline followed by a linear sandy beach. Sand deposits in some places are wider and imply the continuation of stabilized sand deposits. Presence of vegetation on this shoreland feature emphasizes cultivation activities and the sand deposits are stabilized. Light blue color within the lake showed the extent of water spread at that period of time and its extent is seen at its mouth in the northern part where it is connected to the canal. Around the water column within the lake is the presence of marshy area which has oozy silty clay followed by marsh vegetation.
which is shown red in color. This is again interspersed with the presence of mudflat and mud with vegetation that are mostly thrive in fresh water. The peculiarity of the presence of both fresh water and salt tolerant flora may be due to the periodical interaction between fresh water drained by channels and streams into the lake and the tidal water through the lagoon.

In this part of the study area, as in the case of Yedayanthittu lagoon area, saltpans are identified along the canal and the entire eastern periphery of the lake and sporadically in the western periphery as well. While separating saltpans, confusion among the spectral signatures between saline area and barren soil exist and has caused to some extent, overlap of features. Barren soil, apart from sand deposits, on the western part of the lake is delineated separately by the technique and is shown in light grey color in the resultant output image.

Presence of huge patch of vegetation, shown in light and dark green color, between beach and the lake is observed. Pixels showing light green color represent cultivated crops such as paddy and groundnut and dark green color indicated Casuarina plantation species. The pattern of vegetation follows a definite shape giving an elevated appearance. Lake water supports the agricultural activities as well as the other domestic requirements. Dark brown color patches around the lake and in the western parts represent natural vegetation such as scrubs and shrubs mostly Prosopis plant species.

The supervised classification techniques applied on the study area has brought out many significant information on the tidal influence and its extent into the lake, interaction between freshwater and saline water, development of various wetland features and human activities in the form of construction of saltpans, apart from the extent of features such as beach, spit, stabilized sand deposits and vegetation. The spatial extent of various wetland features as extracted from the image analysis – spectral analysis, unsupervised classification and supervised classification may be verified in the field by comparing the map coordinates with the ground coordinates using hand held GPS (Global Positioning System) instrument in the study area, which is discussed in the following section.
5.6 FIELD VERIFICATION OF WETLAND ECOSYSTEM AROUND KALVELI LAKE

Field investigation around the study area – Yedayanthittu lagoon and Kalveli lake - has helped to bring out the significance of remote sensing data in studying ecosystem. *Marsh* vegetation around the lagoon and vegetation in the *salt marsh* of Yedayanthittu lagoon clearly verified well with the spectral signatures observed in the satellite data. Field investigation of both macro – and micro-flora reiterated the importance of temporal analysis of satellite data in assessing and monitoring the ecosystem. Moreover, such knowledge on coastal ecosystem throws light on the intrinsic behavior of the ecosystem which could be used for integrated development activities along the coastal area.

Many of the wetland features such as *mudflat, tidal marsh, salt marsh, marsh vegetation, mud with vegetation*, which are delineated from the satellite data collaborated well with the field findings. The delineation of their intricate boundaries could be well brought out in the satellite image rather than the field survey. The variations in the spectral signatures and resultant color and tonal variations in the image coincided well with the observed features in the field. For example, smooth tone, light brownish red color is separated as an individual feature, *mud with vegetation*, by digital classification from similar smooth tone and brown in colored *mudflat*. Similarly, *tidal flat* is separated from *mudflat* by their unique differences in their tone and color which are well represented by spectral DN values in the digital image. Such patterns are well depicted in the following photographs taken in the field. The field investigation also revealed the influence of backwater in the spectral reflectance value of *tidal / mudflat* giving an apparent “dark” color when laden with moisture and “white” color in dry condition which in turn directly duly reflected in their spectral values.
In the first two photographs, Figure 5.14 A and B, *mudflat* in Kalveli and Yedayanthittu showed differences in their color and appearances which may be due to the constituents with the former is mostly of sand and silt and latter showing silt and
clay. Such change in composition also influences moisture retention by soil and hence the former dries up relatively faster while the latter slow. This in turn, along with other parameters such as salinity, alkalinity and other aspects may nurture many micro-organisms both flora and fauna, thus evolving an ecosystem for coastal habitats. As shown in Figure 5.14 D, the primary and secondary producers invite avians and form a healthy ecological cycle in the study area. Kalveli – Yedayanthittu combined ecosystem attracts many shore birds and migratory birds. Some of the birds seen in this area are Black and White stork, Night Heron, Black and White Ibis, Flamingo, Common Teal, Spotbilled Duck, Brahminy kite, Egyptian vulture, Indian Shikra, Lapwing, Golden Plover and so on. The spotting and identification of so many birds in Kalveli area by Ornithologist suggest a healthy and balance ecosystem.

Similarly, such wetland features with their connectivity to sea support many micro and macro flora such as algae, mangroves, *Suaeda* grass of Amaranthaceae family apart from many invasive and shore land wild plant species such as *Prosopis juliflora*, *Datura metel*, *Ziziphus sp.*, *Ipomea carnea*, *Typha angustifolia*, *Tephrosia purpurea*, and so on. These plants and algae apart from invasive plants generate enough nutrients for many micro-organisms and in turn fishes and molluscsans in the study area. Few algae similar to that of Pulicat lagoon is observed in this area too. They include *Enteromorpha sp.*, *Chaetomorpha sp.*, *Bryopsis plumose* and *Hypnea sp.*, are seen in the study area. They are generally observed in the stagnated water pools along the tidal flats and salt marshes (Figure 5.15).

Unlike Pulicat lagoon, Kalveli ecosystem does not have an elaborate micro-relief features such as sub-tidal, intermediate and high tidal flats because the dynamics of tidal action are not as direct as in the case of Pulicat and most of its energy is dissipated by channelized lagoon inlet and shore land forms such as elevated beach ridges and dune landform. Hence, tidal influx is more focused into the lagoon and loses its energy during low tide period. Lagoon, with its unique setting among shore landform such spit, beach, and coastal dune sand deposits control the wetland features and encourage development of salt marshes rather than tidal flats.
Figure 5.1 Types of flora around Yedayanthittu and Kalveli environ

- Ziziphus jujuba along with reed grass
- Prosopis, Suaeda and Mangrove
- Mangrove and other halophytes along the backwater canal
- Ziziphus jujuba along with reed grass
The distribution of flora along Yedayanthittu lagoon and their significant relationship with some of the prominent wetland features observed during the field survey is listed below in Table 5.3. These coastal wetland features play an ecologically significant role in influencing the lagoon ecosystem, which act as an excellent habitat for marine organisms of varied flora and fauna.

### Table 5.3 Wetland features around Yedayanthittu lagoon

<table>
<thead>
<tr>
<th>S. No</th>
<th>Wetland Features of Yedayanthittu lagoon</th>
<th>Flora present and their ecological significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tidal Marsh</td>
<td>Supports algae such as <em>Enteromorpha</em> sp., <em>Bryopsis</em> sp., <em>Chaetomorpha</em> sp.. Nutrients for juveniles and breeding ground.</td>
</tr>
<tr>
<td>2.</td>
<td>Salt marsh</td>
<td><em>Avicenna</em> sp., nutrients for juveniles and other molluscs.</td>
</tr>
<tr>
<td>3.</td>
<td>Mudflat</td>
<td>Reeds, grass, <em>Datura</em> sp., and <em>Suaeda</em></td>
</tr>
<tr>
<td>4.</td>
<td>Marsh</td>
<td>Algae. Micro nutrients for juveniles</td>
</tr>
<tr>
<td>5.</td>
<td>Marsh vegetation</td>
<td><em>Avicennia</em> sp., halophytic plants. Shelter and nutrients for aquatic and flora and fauna</td>
</tr>
<tr>
<td>6.</td>
<td>Saltpan</td>
<td>Wild invasive plants such as <em>Prosopis juliflora</em> and <em>Ipomea carnea</em>, used as fuel wood and as fencing plants respectively</td>
</tr>
<tr>
<td>7.</td>
<td>Spit</td>
<td>No vegetation</td>
</tr>
<tr>
<td>8.</td>
<td>Beach</td>
<td>Stunted bushes, grass, and <em>Prosopis juliflora</em>.</td>
</tr>
<tr>
<td>9.</td>
<td>Sand deposits (Stabilized)</td>
<td><em>Datura metel</em>, <em>Ziziphus</em> sp., <em>Ipomea carnea</em>, <em>Typha angustifolia</em> etc., and these are used as fencing materials, and in some cases leaves as animal feed. Agriculture is also practiced in some parts along with <em>Casuarina</em> plantation.</td>
</tr>
</tbody>
</table>

A similar table is also prepared for area around Kalveli lake and since Yedayanthittu and Kalveli are the salt water and fresh water interface, most of the area shows similar plant species except absence of proliferating algae and mangroves. Absence or lesser
dense of such floral species distinguish them from completely lagoon water environment and at the same time infrequent and sporadic presence of the similar flora indicate a dynamic interaction between fresh and marine water around Kalveli. Moreover, presence of *saltpans* along the eastern periphery of the lake suggests an active tidal interaction in this area. Relationship between wetland and flora is shown in Table 5.4. Presence of agriculture activities suggests the limit of tidal influence into the lake and role of Kalveli lake in supporting such practices.

**Table 5.4 Wetland features around Kalveli lake**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Wetland Features of Kalveli lake</th>
<th>Flora present and their ecological significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Salt marsh</td>
<td><em>Avicenna</em> <em>sp.</em>, nutrients for juveniles, fishes and other molluscs.</td>
</tr>
<tr>
<td>2.</td>
<td>Mudflat</td>
<td>Presence of sporadic distribution of reeds, wild grass, <em>Datura sp.</em>, <em>Prosopis juliflora</em> and <em>Suaeda</em>.</td>
</tr>
<tr>
<td>3.</td>
<td>Marsh</td>
<td>Empty with sporadic presence of algae that are useful as micro nutrients for fishes and juveniles.</td>
</tr>
<tr>
<td>4.</td>
<td>Marsh vegetation</td>
<td>Mostly wild plant species such as <em>Datura</em> and <em>Prosopis sp.</em>.</td>
</tr>
<tr>
<td>5.</td>
<td>Mudflat vegetation</td>
<td>Presence of dense distribution of reeds from March to July, wild grass, <em>Datura sp.</em>, <em>Prosopis juliflora</em> and <em>Suaeda</em>.</td>
</tr>
<tr>
<td>6.</td>
<td>Saltpan</td>
<td>Sporadic presence of <em>Datura sp.</em>, and active presence of as <em>Prosopis juliflora</em>.</td>
</tr>
<tr>
<td>7.</td>
<td>Beach</td>
<td>Very few bushes and <em>Prosopis juliflora</em>.</td>
</tr>
<tr>
<td>8.</td>
<td>Sand deposits (Stabilized)</td>
<td>Similar to Yedayanthittu, presence of <em>Datura metel</em>, <em>Ziziphus sp.</em>, <em>Ipomea carnea</em>, <em>Typha angustifolia</em> etc., are seen. Apart from that, presence of intense agriculture practiced in this area distinctly demarcates the tidal influence and the fresh water support from the lake for irrigation. <em>Casuarina</em> plantation is also cultivated actively.</td>
</tr>
</tbody>
</table>
Also, along the southern periphery of the lake, small parcels of land is cultivated for paddy and harvested before the onset of monsoon and supply of fresh water draining into the lake by the surface runoff and streams in this area.

From the table, a lucid understanding on the relationship between various wetland features in the study area and the predominant flora could be made. Interaction of tidal and freshwater in the study area developing wetland ecosystem and their study using remote sensing satellite data and collaborative field investigation relating various flora with wetland features has brought out ecologically significant information.

5.7 SUMMARY

Kalveli lacustrine ecosystem is unique in its setting as it has developed due to the interaction between tidal water from the sea through the Yedayanthittu lagoon and the fresh water drained in to it by streams and channels. It supports many flora and fauna of both fresh water and salt water because of its naturally developed tidal water and lake water interactive ecosystem. Because of this reason, a more careful and elaborate spectral analysis is carried out separately around Yedayanthittu lagoon and Kalveli lake. The analysis revealed that even similar wetland features showed certain variations in spectral values due to the degree of tidal action emphasizing that the spectral values of features could be influenced by the local environment setting or terrain setting though adhering to their specific spectral pattern. Further analysis based on the spectral information using classification techniques – unsupervised and supervised – has brought out subtle features and highlighted wetland features such as stabilized coastal sand dune deposits, tidal marsh in the lagoon, mudflat, marsh and marsh vegetation apart from beach, saltpans and vegetation pattern. The features thus derived using above techniques could be used as baseline information about the Kalveli ecosystem. With all the baseline information of both Pulicat ecosystem and Kalveli, temporal analysis of satellite data to study changes in the spatial area and pattern is carried out using spatial GIS techniques, which is discussed in the following chapter.