Monitoring and evaluation of soil salinity in terms of spectral response using geoinformatics in Cuddalore environs

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ABSTRACT

Soil degradation is a global problem that severely hampers the production of food needed to sustain the growing population. This study is aimed at monitoring, mapping and assessing the soil degradation in the Cuddalore district. Mapping of soil degradation is instrumental in understanding the spatial extent and rate of degradation. Key soil properties, such as pH, salt content, EC and ESP determine the salinity status of soils and this reflects in the spectra of surface samples interacting with organic matter, clay content, etc. Change detection can be assessed by post-classification comparison aiming to uncover the differences between the images of three different periods. The salinity variations in the study area was done using Landsat TM and ETM+ images and the changes were quantified for the years 1977, 2000 and 2009. A computerised soil degradation severity assessment was adopted using geomatic tools to process, manage and analyse the raster and thematic datasets. The indices used in this research are: The Normalized Differential Vegetation Index “NDVI”, Salinity Index, Normalised Difference Salinity Index. SAVI was found to be effective in discriminating plants under severe and moderate conditions of soil salinity and in non-saline conditions. Temporal trend analysis technique was done to detect significant changes in the soil verses vegetation conditions. The results showed a clear deterioration in vegetative cover, an increase of salinity accumulations and a decrease in soil/vegetation wetness of the total study area. Salinity had increased in the study area, with salinity increasing at a drastic rate during the past 30 years.

Keywords: Soil Degradation, Normalised Difference Salinity Index (NDSI), Salinity Index (SI), Soil Adjusted Vegetation Index (SAVI), Normalised Difference Vegetation Index (NDVI)

1. Introduction

Soil degradation poses a significant threat to sustainable growth and human welfare in the society (Wiegand, C et al, 1994). The magnitude of degradation and extent of land degradation are affected by such global processes as climate change, desertification, urbanization and the intensification of agricultural production due to population growth. To counteract deterioration of agricultural lands, improvements are needed in methods of managing and monitoring of soil resources. By mapping the extent of degraded lands, monitoring the situation in erosion-threatened soils and facilitating the use of soil erosion model based environmental information derived from imagery data, remote sensing can provide critical information for planning response measures and assessing their efficiency. (Singh et al, 1994) There are two types of degradation processes. They are physical crust and salinization. Physical or Structural crust is a thin layer formed on soil surface during rainstorm events (Jamalabad et al, 2004). The crust is the result of physical segregation and
rearrangement of soil particles. (Rao et al, 1995). The crust significantly affects many dynamic soil properties such as decreasing infiltration rate, surface roughness, soil water storage and capacity, increasing runoff and soil erosion. Land degradation refers mainly to three processes: soil loss, soil drying, and the deterioration of soil quality. Soil salinity is one of the most common soil-degradation processes, particularly prevalent in both arid and semi-arid areas (Rhoades and Loveday 1990; Ceuppens et al. 1997). Salinity is a natural characteristic of the soil but salinization is caused by some anthropogenic activities. Salinity is defined as the salt accumulation in the soil. (Katawatin et al, 2005, Metternicht et al, 2008). Soil salinization occurs when the weathered soil minerals and salts from irrigation water are not washed away by rain or by the irrigation water itself, instead forming excess amounts of Na+, K+, Ca2+, Mg2+, and Cl− ions (Elnaggar et al, 2007)(Fernandez-Buces et al, 2006). Under natural conditions, this phenomenon characterizes areas of low or decreasing precipitation, where there is poor drainage and rising groundwater level. Globally, salinization of agricultural soils is estimated at 45 Mha, and is growing at between 200,000 and 500,000 hectare per year (UNEP 2007).

2. Objective

The objectives of the study include:

1. To quantify the salinity variations and to do a temporal trend analysis during the time period 1976 to 2010 using Landsat TM and ETM+ images for the period 1976 to 2010 for Cuddalore district.
2. Soil degradation severity assessment to be done with the help of various indices like Normalised Differential Vegetation Index (NDVI), Bare Soil Index and Normalised Difference Salinity Index.
3. To differentiate the plants growing under plants growing under severe and moderate conditions of soil salinity and in non-saline conditions using SAVI.
4. To provide suitable recommendations according to the salinity levels in the study area.

2.1 Study area

The study area lies in the coastal belts and parts of Cuddalore and Chidambaram Taluk of Cuddalore District, Tamil Nadu, India. It is bounded on the North by Pondicherry Union Territory, south by Nagapattinam District, east by Bay of Bengal and west by Panruti and
Virudhachalam Taluks of Cuddalore District. Cuddalore falls in the latitude 11°37′47″ - 11°55′00″N and Longitude 79°31′52″ - 79°50′28″E covering an area of 3696626.03 hec. For the present study eastern part of the district covering an area of around 287337.87 hec has been considered for the study. A small portion of around 82881.16 hec has been omitted as the satellite image was not available for the same seasons. It is limited on the east by the Bay of Bengal and on the other three sides by the Cuddalore region. Gadilam River flows through the town and separates the Cuddalore Old town from the new one. River Uppanar is one of the rivers passing through the industrial coastal town of Cuddalore in southeast coast of India along with River Gadilam in the north, which drains into the Bay of Bengal. The river runs parallel to the coast of Cuddalore to a distance of about 20 km and the tidal influence extends to about 1.5 km. A number of surface water bodies are found in this region, of which Perumal Eri(Lake) in the western side is connected with the river and a large thermal power plant effluent finds its way into the river through this water body. During the past two decades, industrial development has increased three times with many large and small-scale industries being established along the Uppanar river bank. The coastal zone of Cuddalore includes production of fertilizers, dyes, chemicals and minerals processing plants and metal based industries.

3. Geomorphology

The entire district can be broadly classified into three zones. Western Pedi plains of the entire area covered by Mangalur and Nallur blocks. This area is occupied by denudation landforms like shallow buried pediment, deep buried pediment and pediments. Central part of the district is characterized by sedimentary high grounds, elevation greater than 80m of Cuddalore sandstone of Tertiary age. This zone occupies part of Virudhachalam, Kammmapuram, Kurunjipadi and Kattumannarkoil taluks. Rest of the area in the district is covered by eastern coastal plain, which is predominantly by the flood plain of fluvial origin formed under the influence of Penniyar, Vellar and Coleroon River systems. Marine sedimentary plain is noted all along the eastern coastal region. In between the marine sedimentary plain and fluvial flood plains, fluvio marine deposits are noted, which consists of sand dunes and back swamp areas.

3.1 Soil

The soils of the district are classified as the black, red, ferruginous and arenacious. They are again subdivided into clays, loam and sands. Black soils are observed in the Chidambaram and Virddhachalam taluks. The sandy soils are seen along the coast in Cuddalore and
Chidambaram taluks. The younger alluvial soils are found as small patches along the stream and river courses in the district. Red sandy soil is seen covering the Cuddalore sandstone, laterite and laterite gravels occur in parts of Viruddhachlam, Panruti and Cuddalore taluks.

Figure 3: Soil Types

Cuddalore formation, comprising sandstone, sand gravels separated by clay beds and in the unconsolidated sands of alluvium ground water occurs under water table as well as under confined conditions. The distribution of soil types is shown in the table. (Table 1)

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Taluk</th>
<th>Red Soil</th>
<th>Black soil</th>
<th>Alluvial soil</th>
<th>Red loamy soil</th>
<th>Sandy soil</th>
<th>Sandy loamy soil</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cuddalore</td>
<td>18.3</td>
<td>0.55</td>
<td>0.99</td>
<td>1.32</td>
<td>76.6</td>
<td>2.24</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Virudachalam</td>
<td>48</td>
<td>40.4</td>
<td>6.98</td>
<td>2.7</td>
<td>0.78</td>
<td>1.23</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Kaattumannarkoil</td>
<td>35.56</td>
<td>58.9</td>
<td>0.88</td>
<td>2.9</td>
<td>0.42</td>
<td>1.33</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Panruti</td>
<td>76.35</td>
<td>7.39</td>
<td>15.2</td>
<td>-</td>
<td>0.36</td>
<td>0.7</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Thittagudi</td>
<td>35</td>
<td>60.5</td>
<td>3.48</td>
<td>0.7</td>
<td>1.06</td>
<td>0.17</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Chidambaram</td>
<td>18</td>
<td>75.9</td>
<td>3.58</td>
<td>0.6</td>
<td>1.07</td>
<td>0.85</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Soil Testing Laboratory – Agricultural Department, Cuddalore

5. Methodology

The study has been based on three scenes of each of Landsat MSS, TM and ETM+ for the years 1977, 2000 and 2009. Different indices were calculated like the NDVI, NDSI, SI and SAVI (Huete,V et al, 1988). NDVI was calculated to differentiate the area with high and low vegetation cover. Poor vegetation cover will show an indication of the poor soil quality that affects the growth of vegetation. SAVI was also calculated to understand the extent of healthy vegetation cover in the area. Additionally, in order to enhance the differentiation of saline zones, suppressing the vegetation, two indices i.e Salinity Index (SI) and Normalised Difference Salinity Index (NDSI) have been calculated depending on the spectral response of salt-affected soils (Odeh et al., 1995). The formula for extracting the images for various indices are as follows:
Normalised Difference Vegetation Index (NDVI): \[ \frac{[\text{NIR}-\text{R}]}{[\text{NIR}+\text{R}]} \]

Soil Adjusted Vegetation Index (SAVI) = \[ \frac{[\text{IR} - \text{R}]}{[\text{IR} + \text{R} + \text{L}]} * (1 + \text{L}) \]

Normalised Difference Salinity Index (NDSI): \[ \frac{\text{RED} - \text{NIR}}{\text{RED} + \text{NIR}} \]

Salinity Index (SI) = \[ \sqrt{\text{GREEN} \times \text{RED}} \]

The spectral reflectance of saline soils and other categories that cover the study area have been obtained from Landsat image bands. Generally it can be inferred that the spectral response increases with increasing salts content at the terrain surface (Schmid et al., 2008). There is a spectral response contrast between Visible and NIR bands and between NIR and MIR band in salt existing soil. So, these effective band intervals have to be considered to differentiate the background completely bare and salt-affected soil.

4.1 Result and discussion

From the various analysis that was carried out using the Landsat Imageries of three years 1977, 2000 and 2009, it was found out that there has been a continuous deterioration of the soil quality over the period of time. Three indices were calculated to analyse the extent of degradation of soil quality. Normalised Difference Vegetation Index (NDVI) shows the extent of vegetation in the area. (Figure 4) The image of the year 1977 shows 85% of the area covered with vegetation. The year 2000 shows gradual decrease in the vegetation cover, almost 40% of the vegetation cover being lost and the 2009 year image shows only patches of vegetation existing in the area. The SAVI (Soil Adjusted Vegetation Index) also shows the loss of vegetation cover from the three year data taken for the study (Figure 5). The reflectance of the vegetation was considered to calculate the extent of the cover prevailing in the area. Similarly the NDSI (Normalised Difference Salinity Index) and SI (Salinity Index) were calculated to show the extent of salinity prevailing in the study area (Figure 6,7). The spectral reflectance differs in saline and non-saline soils. This has been used in the current study to understand the area of high and low salinity. The images formed from the two indices NDSI and SI shows increase in salinity in the study area. The NDSI differentiates the areas of high salinity and the areas covered with vegetation.

5. Conclusion

Considering the current extent and temporal rate of loss of production soil, the world is facing a severe threat to food production for an increasing global population. Mitigating this threat requires wide regional monitoring and early detection of ‘hotspots’. Integration of remote sensing information sources, environmental information sources, and the use of phenomenological models would be instrumental for this purpose. Salt affected soils are widespread over the world especially semi-arid and some sub-humid regions. Soil salinity has been brought about by natural or human-induced processes and is a major environmental hazard. Recent advances in remote sensing technology have opened new techniques in inventory, characterization and monitoring of degraded lands. Remote and GIS have been effectively used to study the dynamic behaviour of salinity and water-logging. Satellite imageries were visually interpreted to identify the salt affected lands. The multi-temporal LANDSAT images (1977, 2000 and 2009) proved to be very useful to identify and delineate saline soils. Surface accumulated white or white bluish salt crusts are good indicators for the detection and correlation of salinity during dry season.
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Figure 4: Normalised Difference Vegetation Index (NDVI)

Figure 5: Soil Adjusted Vegetation Index (SAVI)

Figure 6: Salinity Index (SI)
From the results it is inferred that most of the Cuddalore region is affected by soil degradation and the credit goes to the anthropogenic factors like increase in industrial activities and excessive withdrawal of groundwater to satisfy the needs of the growing population.

6. References


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