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Characterisation and Mapping of Salt-Affected Soils in Parts of Nalgonda District Using Hyperspectral Data

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ABSTRACT

The relationship between soil salinity parameters and their influence on soil spectral characteristics were analyzed using both satellite data (LISS-IV) and reflectance data of soil samples collected from targeted sites using Remote Sensing. The site selected for the study were Nalgonda district, Nagarjunasagar Project(NSP) command area located at $16^0$59'34.43'' N,$79^0$19'15.25'' E on top left and $16^0$49'56.64'' N, $79^0$41'53.44''E on right bottom. Global Positioning System (GPS) based soil samples (0-30cm depth). The results showed that among all the observed soil parameters Electrical Conductivity, Exchangeable Sodium Percentage and Cation Exchange Capacity predictions can be made accurately based on partial least square regression models developed from selected wavelengths. Out of the total study area the area under slightly saline-sodic category was 378ha, moderately saline-sodic category was 90 ha, and severely saline-sodic category was 178.43 ha. and the rest of the area was normal

Key words: *Hyperspectral; Partial least square regression; Salt affected soil; LISS-IV*

INTRODUCTION

Waterlogging and subsequent development of soil salinity and/or sodicity are the twin land degradation processes operating upon in the irrigated commands of the arid and semi-arid regions. Globally, an estimated 954.8 million ha of arable land are subject to soil salinization and or alkalinization[11]. Soils are termed saline or salt-affected when the concentration of salt in the root zone exceeds 4 dS m^{-1} [9]. Some of the most unfavourable properties of these soils include high salt content, poor structure, limited microbial activity, very low percolation rates, and other characteristics, which restrict plant growth and human settlement. Salt-affected soils are, generally, encountered in the arid and semi-arid climate and are derived from weathering of indigenous minerals[12] but also occur extensively in sub-humid and coastal zones.

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In fact, non-saline irrigated soils can turn into saline in time when leaching is inadequate to remove salt applied in the irrigation water or drainage is insufficient to prevent a saline ground water table from rising within about 1.5 m of the soil surface[14]. Thus, it affects plant growth and agricultural production. Salt affected landscapes are very sensitive to changes in climatic, edaphic and hydrological conditions in time and space. Salt affected soils are characterized by measuring the chemical soil properties such as pH, ESP (Exchangeable Sodium Percentage) and electrical conductivity (EC) of soil saturated extract.

Multispectral satellite images such as those obtained by the Landsat program provide low or free cost worldwide coverage for four decades. Moreover, salinization problems are concentrated in arid and semi-arid regions, often in developing countries with few economic resources. Although there are more advanced sensors that can provide a more precise quantification of the extent of soil salinity (e.g. hyperspectral), their high cost difficult its extensive use. Therefore, it is necessary to continue investigating the application of multispectral image repositories as a tool to assist in the monitoring and management of saline soils.

There are extensive areas of salt affected soils on all the continents, but their extent and distribution have not been studied in detail. In spite of the availability of many sources of information, accurate and upto date data pertaining to salt affected lands of the world are rather scarce. At the global scale GLASSOD (Global Assessment of Land Degradation) data base indicates that 349.6 M ha of land in arid zones are affected by slight to moderate degree of soil degradation and 42.9 M ha by strong to extreme human-induced land degradation from which 76 M ha was as a result of soil salinization[1]. Soil degradation map of India prepared using GLASSOD methodology[8] showed that an area about 187 M ha representing almost 57% of the total geographical area of the country has been affected by various land degradation problems induced largely by human intervention. The influence of human induced chemical deterioration is observed in 136 M ha (representing 4.1% of the total area) due to salinization and water-logging and in areas affected by submergence of flooding cover about 11.6 M ha.

The characterization, mapping and monitoring of salt affected soils by ground survey is difficult as the salt concentration may vary substantially over short distances and time consuming. The space technology particularly the satellite based remote sensing data of multi-spectral, multi-spatial and multi-temporal can provide reliable, accurate and updated data information on soil resources including state and soil salinity conditions.

Hyperspectral remote sensing data in the form of imaging spectrometer data provide high spatial resolution data in a large number of narrow contiguous spectral bands in the VNIR - SWIR region (400 to 2500 nm). Using hyperspectral remote sensing data continuous response curves of target features in the visible, Near Infrared (NIR) and Shortwave infrared (SWIR) wavelengths can be generated. This continuous spectral response curve is referred to as the spectral signature. As it acquires data in many narrow wavelength bands, it allows the use of almost continuous data in studying the earth's surface. This produces laboratory like reflectance spectra with absorption band specific to object properties and also increases the accuracy of mapping.

STUDY AREA

2.1 Location and Climate

The site is located at $16^0$59' 34.43" N, $79^0$19'15.25" E on top left and 16^0 49' 56.64" N, $79^0$41'53.44"E. in Nalgonda district. The region experiences hot and dry summer throughout the year except during the south-west monsson season. The year may broadly be divided in to 4 seasons. May being the hottest month, the mean daily maximum temperature is about 40^oC (104 F) and the mean daily minimum is about 28^oC (82.4 F) and sometimes the day temperature crosses 44 ^oC during this period. The average rainfall in the district is 772mm. About 71% of the annual rainfall is received by the district during south-west monsoon (*i.e.*, June to September). September is the rainiest month. The variation in the annual rainfall in the district from year to year in large on an average there are 46 rainy days (days with rainfall of over 2.5mm or more). The district is drained by rivers Krishna, Musi, Aler, Dindi, Halia, Kangal, Peddavagu etc., Krishna is the prominent river in this district enters at Yeleshwaram.

MATERIAL AND METHODS

3.1 Collection of Soil samples

The sampling points were selected based on soil variation using satellite image IRS-1C LISS-IV at NRSC, Balanagar, and Hyderabad. Geographic Positioning System (GPS)-based soil samples (0-20cm depth) were collected from parts of Nalgonda and Medak districts. Soil samples collected from each of the sites were dried under shade. The air dried samples was then pounded with wooden pestle and mortar and passed through a 2mm sieve and then stored for determination of various soil properties.

3.2 Collection of Spectral information

3.2.1 Instrument

An analytical spectral device (ASD), a FieldSpec Pro spectroradiometer, was used to collect the surface reflectance of soil samples.

3.2.2 Instrument Calibration

A certain amount of electrical current is generated by thermal electrons with the ASD and always added to the incoming photons of light during spectra collection. This adversely affects the spectra collection and has to be removed. This process is known as “Dark Current Correction”. Spectral data collection requires instrument calibration using a reference panel (“Spectralon” white reference) provided along with the instrument. During the white reference collection, a reference 100% line is available to the user to check the status of the instrument performance. White reference collection includes dark current correction and was repeated every 20 minutes during the collection of sample spectra. This minimizes the effects of the change of light conditions on the recorded spectra. This calibration was repeated several times during the sampling period to establish changing of light conditions or instrument drift. Vegetation spectra were tested to verify the performance of the instrument.

3.2.3 Spectral Data Collection

The field spectra were collected on a clear sky day during bright sunlight between 10:30 am to 12:00 noon to avoid changes in light condition that may adversely effect the spectra. The total number of sample sites where hyperspectral reflectance measurements were collected with ASD spectroradiometer were 35 in number.

3.3 Soil Chemical Analysis:

Soil samples collected were air dried under shade, ground with mortar and pestle, passed through 2 mm sieve and then were used for laboratory analysis after proper labeling. Soil sample analysis was carried out by employing the following procedures

3.4 Instruments and Softwares used

An analytical spectral device, a FieldSpec Pro spectroradiometer, was used to collect the surface reflectance of soil at sampling sites. The ASD radiometer is a portable array-based spectrometer consisting of a spectrometer unit, computer interface, and fiber optic probe. The instrument has two integrated radiometers covering 350 to 2500 nm. The radiometer consists of one silicon photodiode array and two fast scanning thermoelectrically (TE) cooled spectrometers with a spectral resolution of 10 nm. The instrument was operated with 5° full field-of-view (FFOV) foreoptics. A laptop interface with the instrument allows real time viewing of the spectrum recorded.

3.5. Stastistical analysis

Pearson product moment correlation coefficient was used to measure the degree of linear relationship between the measured soil variables with reflectance values as well as absorption feature parameter at obtained wavelength intervals characteristics of a certain soil parameter by using SPSS window version 17.0 (SPSS Inc., Chicago, USA) and Microsoft office (version 2007). The PLSR algorithm has inferential capability, which was used to model a possible linear relationship.

MAPPING

The approach essentially involves a systematic visual interpretation of concurrent and historical satellite multispectral and multi-temporal digital data. Various steps involved are discussed hereunder:

3.6.1 Georeferencing of Satellite Data

The data pertaining to the study area covered by IRS-1C LISS-IV was geo-referenced to digital topographical map of Survey of India, at 1:50,000 scale using image-to-image tie - down routine available in the ERDAS/ ERDAS/IMAGINE version 2014 software, by identifying 24 ground control points. The LISS-IV data were subsequently resampled to 24m pixel dimension using first order polynomial transformation. Similarly the LISS-IV data was rectified using the SISDP LISS-IV and PAN fused data using the same proceedure.

3.6.2Preliminary Visual Interpretation

After geo-referencing IRS-1C LISS-IV data, the areas likely to be affected by soil salinity were broadly identified, based on experience, ancillary information and the terrain conditions by displaying it onto a monitor. Subsequently, the sample areas to be verified in the field are identified and are precisely located on the Survey of India topographical maps of 1:50,000 scale.

3.6.3 Ground Truth Collection

The ground truth data collection was carried out during synchronous to the pass of the NASA -AVRIS field campaign. Apart from *insitu* observations of the areas subjected to salinity/alkalinity, few patches prone for environmental pollution were also studied. Having located sample areas, parcels of land which were interpreted as soil salinity and alkalinity hazard, were precisely marked onto the topographical maps and observations with respect to terrain conditions, namely land use/land cover, micro topography and surface drainage, waterlogging status, *etc.* were made. For salt-affected soils, observations on the presence of salt efflorescence, crop condition-density and vigour, local relief, surface drainage, nearness to canal are made and soil profiles were excavated and soil samples were collected for analysis in the laboratory after studying their morphological characteristics. The hyperspectral radiometric observations were taken in sampling sites using ASD spectroradiometer

3.6.4 Post-field Interpretation

The ultimate delineation of saline areas from satellite multi-spectral data was accomplished digitally on a system with ERDAS/ IMAGINE software. To begin with, the IRS-1C LISS-IV data was displayed and a blank vector layer is overlaid onto the image. Soil samples collected during field visits were analysed in the laboratory and were classified to exhibit the nature of the hazard, namely slightly saline-sodic, moderately saline-sodic and severely saline-sodic soils based on pH, EC, CEC and Exchangeable Sodium Percentage (ESP) values divisions within each category are made based on severity of the hazard .The areas, which were categorized as salt-affected soils were then located in the image. The boundaries of salt affected areas were then drawn in the vector layer which was already superimposed over satellite image, *vis-a-vis* field observations and relief information from topographical map.

RESULTS AND DISCUSSION

The soil reaction in this site varied from neutral to severly alkaline in reaction with pH values ranged from 7.11 to 9.62, EC of the soil samples ranged from 0.17 to 3.60 dSm^{-1} which comes under normal to saline category. The cations of the soil *i.e.,*potassium content of the soils were varied from 2.89 to 16.11 meq/l, sodium content varied from 0.71 to 15.44 meq/l, Calcium content varied from 7.2 to 15.40 meq/l, and magnesium content varied from 4.40 to 8.20 meq/l. The cation exchange capacity (CEC) of the soils varied from 18.12 to 33.04 c mol $[p^{+}]$ kg^{-1} and exchangeable sodium percentage (ESP) of the soils varied from 2.22 to 68.97 % . (Table 4.1)

Table 4.1 Ranges of soil properties for the identified saline soil class in parts of study area

Table 4.1 Ranges of soil properties for the identified saline soil class in parts of study area

	pH	EC (dSm^{-1})	K (meq/l)	Na^+ (meq/l)	Ca^{2+}(meq/l)	Mg^{2+} (meq/l)	CEC (c mol [p+] kg^{-1})	ESP
Normal Soils (15)								
Mean	8.10	0.69	5.08	1.03	11.70	5.72	24.64	3.87
Range	7.1-9.0	0.17-1.45	3.21-10.14	0.71-1.74	8.8-14.4	4.6-8.2	20.82-27.24	2.224-6.326
SD	0.47	0.43	2.34	0.32	2.35	1.11	2.55	1.30
Saline Sodic (slight) (09)								
Mean	7.95	2.39	4.41	2.23	13.02	5.60	25.84	7.37
Range	7.8-8.3	2.05-2.8	2.9-7.34	1.4-3.13	10.4-14.8	4.4-7.2	18.12-33.04	5.383-9.261
SD	0.16	0.26	1.65	0.65	1.59	0.95	5.07	1.34
Saline Sodic Moderately(5)								
Mean	8.37	2.89	6.94	4.52	10.76	5.96	27.92	15.75
Range	7.9-8.7	2.4-3.6	4.84-16.11	2.33-5.94	8.4-12.6	5.0-7.4	22.74-33.3	12.7-18.9
SD	0.35	0.44	5.45	1.49	1.60	0.95	4.85	2.54
Saline Sodic Severe (4)								
Mean	8.72	3.2	4.06	13.97	10.4	5.15	35.02	45.94
Range	7.9-9.6	2.9-3.6	2.89-5.40	13.01-15.4	7.2-12.4	4.6-5.8	27.9-38.03	33.9-68.9
SD	0.81	0.31	1.083	1.17	2.32	0.50	4.79	15.70

4.1 Soil Physico-chemical properties *vs* reflectance behaviour in hyperspectral sensor

To understand the influence of the soil properties on the spectral reflectance curve, correlation studies were carried out with resampled reflectance values at 10-nm intervals for the entire waveband. The results observed was in conformity with the study conducted by Farifteh and Van der Meer[3] which showed that EC and CEC having significant correlation with reflectance from 710 to 750 nm. The soil properties like EC, CEC and ESP showed significant negative correlation strongly at 1870nm (r= -0.363*, 0.384* and 0.376*) wavelength (Figure 4.1). Results indicated that the presence of magnesium dominant salt in soil which absorbed more water because of strong hydration energy of magnesium ion and hygroscopic nature of associated anions such as chloride and sulphate which was reflected by strong absorption dip at 1870nm.

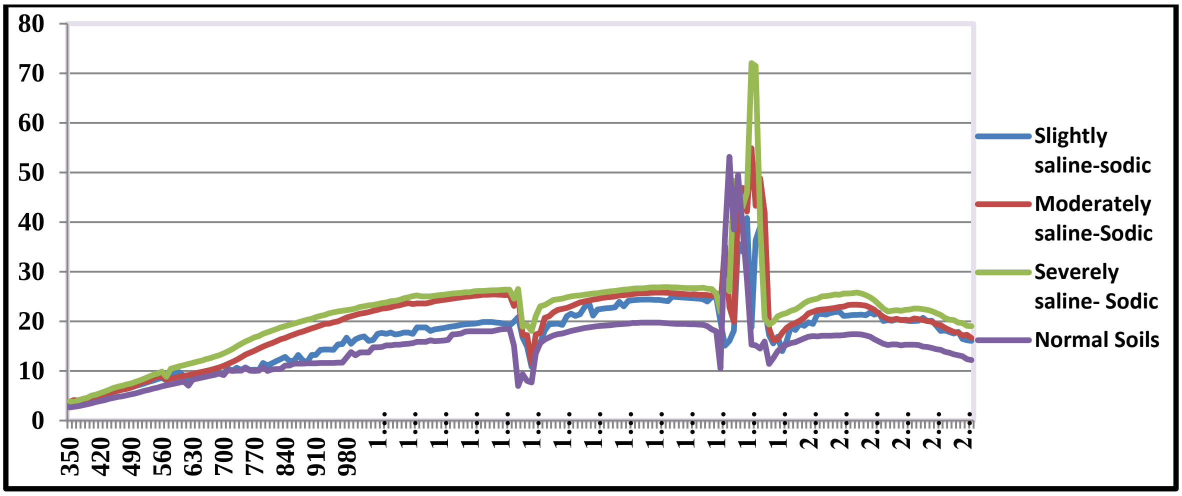


Fig 4.1 .Spectral reflectance pattern of different categories of salt affected soils.

4.2 Prediction of soil properties using Partial least square regression (PLSR) analysis :

Partial least square regression (PLSR) is a method that specifies a linear relationship between a set of dependent (response) variables, Y, and a set of predictor variables, X. The general idea of PLSR is to extract the orthogonal or latent predictor variables, accounting for as much of the variation of the dependent variable(s). In this study, PLSR was used to model correlation between soil reflectance spectra (predictor variables) and soil physicochemical properties of salt-affected soil (response variable). Reflectance data in particular wavelength which was selected from correlation studies of absorption feature parameter and with salinity parameter, *i.e.* EC, ESP, and CEC were used for the PLSR analysis. For every scale of the study field, data used to build the PLSR models were randomly divided into calibration and prediction sets. From the total number of bands, reflectance value at 710-1340 (at 10nm interval) ,1400-1410, 1870-1880,1920-1930, 2140 -2300 (at 10nm interval) bands were used for analysis. Prediction models were developed independently for each soil properties. The results obtained based on PLSR model shows that good predictions of EC can be made more accurately same as the results observed by Mashimbye *et al.*[6]; Farifteh and Van der meer[2]. The equations derived from the PLSR analysis for EC, CEC, and ESP were presented in (Table 4.6) The results showed that among all observed soil parameters EC, ESP, and CEC predictions can be made accurately based on PLSR models developed from selected wavelength, which was in corroboration of findings of Tarik *et al*[13]. The results showed that the predictions of above-mentioned soil parameters can be considered good, because root mean square error (RMSE) and regression coefficient values (R^2) of such soilproperties showed somewhat reasonable correlation compared to other parameters under study Table (4.6) The R^2 values of predicted parameter *vs*. observed parameter for EC, CEC, and ESP. were 0.367, 0.272, and 0.386 respectively as depicted in Figure 4.2 a,b & c.

Parameter	Unit	RMSE	R^2	Equation
EC	dSm-1	0.348	0.367	0.2+0.5*(Ref$_{710}$)+0.2*(Ref$_{720}$)+0.1*(Ref$_{730}$)+5.0*(Ref$_{740}$)+2.6*(Ref$_{750}$)+1.5*(Ref760)+1.4*(Ref$_{770}$)+1.2*(Ref$_{780}$)+1.0*(Ref$_{790}$)+9.4*(Ref$_{800}$)+8.4*(Ref$_{810}$)+7.1*(Ref$_{820}$)+7.2*(Ref$_{830}$)+6.0*(Ref$_{840}$)+5.4*(Ref$_{850}$)+3.6*(Ref$_{860}$)+3.4*(Ref$_{870}$)+2.6*(Ref$_{880}$)+1.3*(Ref$_{890}$)+2.5*(Ref$_{900}$)+3.0*(Ref$_{910}$)+6.4**(Ref$_{920}$)+4.2**(Ref$_{930}$+6.6**(Ref$_{940}$)+1.9**(Ref$_{950}$)+2.1**(Ref$_{960}$)+0.01**(Ref$_{970}$)+1.4**(Ref$_{980}$)+1.2**(Ref$_{990}$)+4.7**(Ref$_{1000}$)-4.4**(Ref$_{1010}$)-6.0**(Ref$_{1020}$)-8.7**(Ref$_{1030}$)-1.0**(Ref$_{1040}$)-1.1**(Ref$_{1050}$)-1.3**(Ref$_{1060}$)1.3**(Ref$_{1070}$)1.2**(Ref$_{1080}$)1.2**(Ref$_{1090}$)1.0**(Ref$_{1100}$)6.4**(Ref$_{1110}$)1.9**(Ref$_{1120}$)+8.6**(Ref$_{1130}$)1.3**(Ref$_{1140}$)+0.02**(Ref$_{1150}$)+3.1**(Ref$_{1160}$)+2.7**(Ref$_{1170}$)+2.6**(Ref$_{1180}$)+2.6**(Ref$_{1190}$)+2.5**(Ref$_{1200}$)+2.4**(Ref$_{1210}$)+2.5**(Ref$_{1220}$)+2.4**(Ref$_{1230}$)+2.4**(Ref$_{1240}$)+2.4**(Ref$_{1250}$+2.3**(Ref$_{1260}$)+2.5**(Ref$_{1270}$+2.7**(Ref$_{1280}$)+3.09**(Ref$_{1290}$)+3.6**(Ref$_{1300}$)+4.4**(Ref$_{1310}$)+5.5**(Ref$_{1320}$)+6.4**(Ref$_{1330}$)+7.2**(Ref$_{1340}$)+0.2**(Ref$_{1400}$)0.1**(Ref$_{1870}$)0.1**(Ref$_{1920}$)+0.4**(Ref$_{2210}$)+0.4**(Ref$_{2220}$)+0.3**(Ref$_{2230}$)+0.3**(Ref$_{2240}$)
ESP	%	12.330	0.386	= 10.8-13.7* (Ref$_{1870}$) -69.2*(Ref$_{2140}$)-62.6*(Ref$_{2150}$) 24.9*2160-12.1* (Ref$_{2170}$)+27.9*(Ref$_{2180}$)+36.0*(Ref$_{2190}$)+65.7*(Ref$_{2200}$)+83.2*(Ref$_{2210}$)+75.0*(Ref$_{2220}$)+45.9*(Ref$_{2230}$)+22.3*(Ref$_{2240}$)+21.3*(Ref$_{2250}$)+10.5*(Ref$_{2260}$)-14.2*(Ref$_{2270}$)-47.6*(Ref$_{2280}$)-49.6*(Ref$_{2290}$)-52.0*(Ref$_{2300}$).
CEC	C mol [p^+] kg^{-1}	5.370	0.272	13.142.8*(Ref$_{400}$)43.6*(Ref$_{410}$)+12.0*(Ref$_{710}$)+8.8*(Ref$_{720}$)+5.7*(Ref$_{730}$)+4.2*(Ref$_{740}$)+3.6*(Ref$_{750}$)-2.0*(Ref$_{1870}$).

4.3 MAPPING OF SALT-AFFECTED AREA :

For mapping the salt affected soils of the study area, their occurrence on the ground and manifestation on the image were studied using the spectral reflectance pattern in the LISS-III and LISS-IV sensor. Similar findings were also observed by Sharma *et al*. [10], Koshal[4] and Kumar[5]. The categorization of salt-affected soil was adopted from Project manual NRC-Land degradation mapping using multi temporal satellite data NRSC 2007. and given in the table 4.7 Based on texture and tonal variation the salt-affected soils were delineated, the boundaries of salt affected areas were then drawn in the vector layer. Fig 4.3

Table 4.7 . Criteria for assessing salt affected soil in black soils/non black soil.

				ESP	
S.No	**Class**	**Salinity (dS/m) black soil**	**Other soil**	**Black soil**	**Other soil**
1	Slightly	2-4	4-8	5-10	15-40
2	Moderate	4-8	8-16	10-20	40-60
3	Severe	>8	>16	>20	>60
S.No	**Type**		**Class included**		
		Slight	Moderate	Severe	
	Saline	S1	S2	S3	
	Sodic	N1	N2	N3	
	Saline-sodic	S1N1	S1N2,S2N1, S2N2	S1N3,S2N3,S3N1,S3N2,S3N3	

Notes: S = Saline, N = Sodic, SN = Saline–sodic.

(Source : Project manual NRC-Land degradation mapping using multi temporal satellite data NRSC 2007).

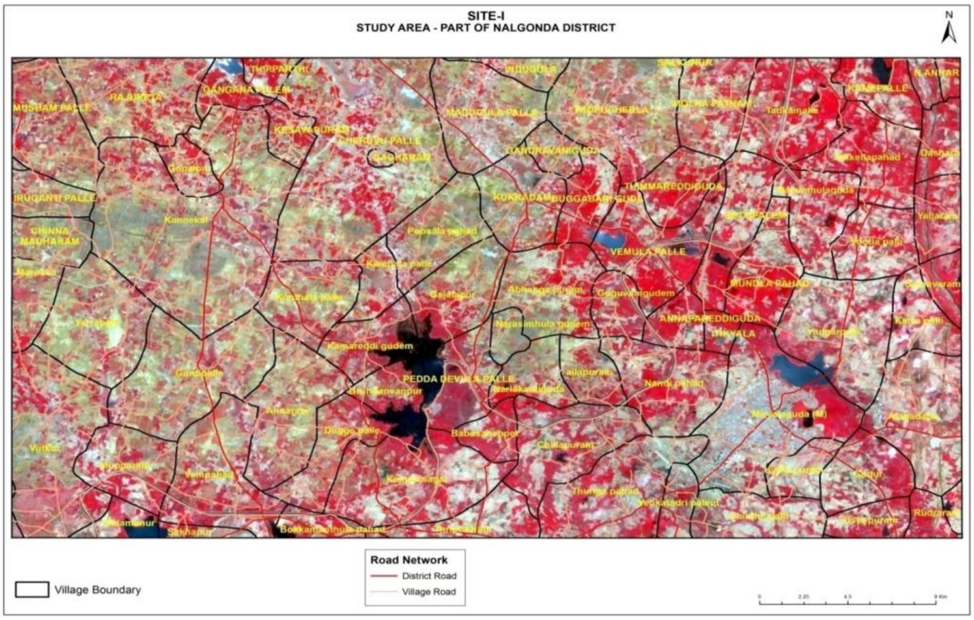
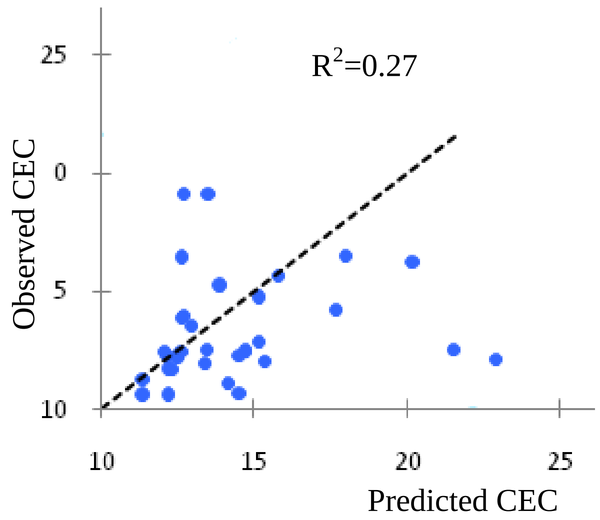


Figure 4.3 Classified image showing salt-affected soils in study area.

a)



b) c)

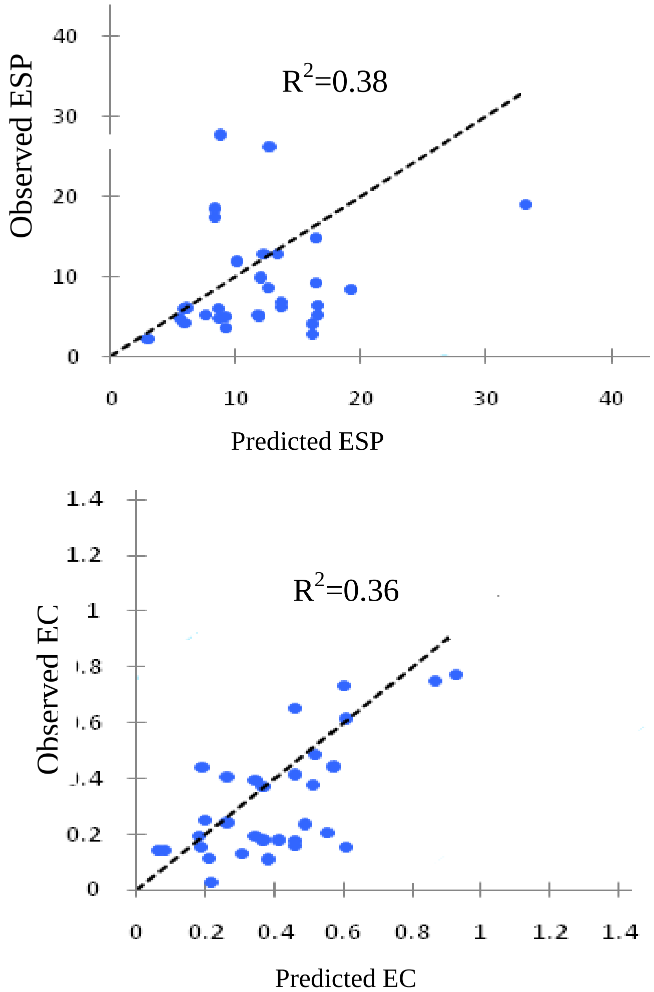


Figure 4.2 Predicted parameters *vs* observed parameters in PLSR model.

	pH	EC(dSm^{-1})	K (meq/l)	Na^+ (meq/l)	Ca $^{2+}$(meq/l)	Mg^{2+} (meq/l)	CEC (c mol [p+] kg^{-1})	ESP
Normal Soils (15)								
Mean	8.10	0.69	5.08	1.03	11.70	5.72	24.64	3.87
Range	7.1-9.0	0.17-1.45	3.21-10.14	0.71-1.74	8.8-15.4	4.6-8.2	20.82-27.24	2.224-6.326
SD	0.47	0.43	2.34	0.32	2.35	1.11	2.55	1.30
Saline Sodic Slightly (9)								
Mean	7.95	2.39	4.41	2.23	13.02	5.60	25.84	7.37
Range	7.8-8.3	2.05-2.8	2.9-7.34	1.4-3.13	10.4-14.8	4.4-7.2	18.12-33.04	5.383-9.261
SD	0.16	0.26	1.65	0.65	1.59	0.95	5.07	1.34
Saline Sodic Moderately (5)								
Mean	8.37	2.89	6.94	4.52	10.76	5.96	27.92	15.75
Range	7.9-8.7	2.4-3.6	4.84-16.11	2.33-5.94	8.4-12.6	5.0-7.4	22.74-33.3	12.7-18.9
SD	0.35	0.44	5.45	1.49	1.60	0.95	4.85	2.54
Saline Sodic Severe (4)								
Mean	8.72	3.2	4.06	13.97	10.4	5.15	35.02	45.94
Range	7.9-9.6	2.9-3.6	2.89-5.40	13.01-15.44	7.2-12.4	4.6-5.8	27.9-38.03	33.9-68.9
SD	0.81	0.31	1.083	1.17	2.32	0.50	4.79	15.70

SUMMARY AND CONCLUSIONS

Based on EC, CEC and ESP the soils were characterized in to slightly saline-sodic, moderately saline-sodic, severely saline-sodic and normal soils. Among the study area, the area under slightly saline-sodic category was 378 ha, moderately saline-sodic category was 90 ha and severely saline-sodic category was 178.43 ha. The Pearson correlation studies were carried out between soil properties and spectral reflectance and it showed that EC and CEC having significant correlation with reflectance from 710 to 750 nm. The soil properties like EC, CEC and ESP showed significant negative correlation strongly at 1870nm (r= -0.363*, 0.384* and 0.376*) wavelength. The PLSR (Partial Least Square Regression) was used to model correlation between soil reflectance spectra (Predictor variables) and soil physic-chemical properties of salt affected soil (response variable). Prediction models were developed for EC, ESP and CEC soil properties. The PLSR model showed the possibility of good prediction or in other words retrieval of EC more accurately than ESP and CEC with the above mentioned bands.

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