CHARACTERISATION AND MAPPING OF SALT AFFECTED SOILS USING HYPERSPECTRAL DATA IN PARTS OF MEDAK AND NALGONDA DISTRICTS

D.NARESH GOUD.

B.Sc. (Ag.)

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(Soil Science & Agricultural Chemistry)

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BY

D.NARESH GOUD

B.Sc. (Ag.)

THESIS SUBMITTED TO THE PROFESSOR JAYASHANKAR TELANGANA STATE AGRICULTURAL UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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CHAIR PERSON: DR.G.JAYASREE

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

AGRICULTURAL COLLEGE

POLASA JAGTIAL-505529

PROFESSOR JAYASHANKAR TELANGANA STATE AGRICULTURAL UNIVERSITY 2016

CERTIFICATE

Mr. NARESH GOUD. D.has satisfactorily prosecuted the course of research and that thesis entitled "**Characterisation and Mapping of Salt affected Soils using Hyperspectral data in Parts of Medak and Nalgonda districts"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any university.

Date:

(Dr. G.JAYASREE)
Chairperson of the Advisory Committee
Professor and Head
Department of Soil Science & Agril.Chemistry
Agricultural College, Palem
Mahabubnagar district.

DECLARATION

I, **Mr. NARESH GOUD.D.** hereby declare that the thesis entitled "**Characterisation and Mapping of Salt affected Soils using Hyperspectral data in Parts of Medak and Nalgonda districts"** submitted to the **Professor Jayashankar Telangana State Agricultural University** for the degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place: JAGTIAL. **(NARESH GOUD.D)**

Date: **I. D. No. JAM/14-07**

CERTIFICATE

This is to certify that the thesis entitled **"Characterisation and Mapping of Salt affected Soils using Hyperspectral data in Parts of Medak and Nalgonda districts"** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** of the Professor Jayashankar Telangana State Agricultural University, Hyderabad is a record of the bonafide original research work carried out by **Mr. NARESH GOUD.D.** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of investigations have been duly acknowledged by the author of the thesis.

(Dr. G. JAYASREE)
Chairperson of Advisory Committee

Thesis approved by the Student Advisory Committee

Chairperson : **Dr. G.JAYASREE**
Professor and Head
Department of Soil Science & Agril.chemistry
Agricultural College, Palem
Mahabubnagar district.
____

Member : **Sri. K. CHANDRASHAKER**
Assistant Professor
Department of Soil Science & Agril.Chemistry
Agricultural College, PJTSAU
Jagtial-505 529.
____

Member : **Dr.M.MALLA REDDY.**
Professor and Head
Department of Agronomy
Agricultural College, PJTSAU
Jagtial-505 529.
____

Member : **G.SUJATHA**
Scientist-SF
SLRAD/LRUMG.
NRSC, Balanagar, Hyd-37.

Date of
finalviva-Voce

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(NARESH GOUD .D)

Abbreviations

0C	:	Degree centigrade
%	:	per cent
&	:	and
AVRIS	:	Airborne Visual Imaging Infrared Spectrometer
C mol [p+]kg^{-1}	:	Centimoles per kilogram
Ca^{2+}	:	Calcium
CEC	:	Cation Exchange Capacity
cm	:	Centimeters
CO^{3-}	:	Carbonates
dSm-1	:	deci Siemens per metre
EC	:	Electric Conductivity
ESP	:	Exchangeable Sodium Percentage
et al.	:	and others
fig.	:	Figure
GIS	:	Geographical Information System
GPS	:	Global Positioning System
ha	:	hectare
HCO^{3-}	:	Bi-carbonate
HRS	:	Hyper Spectral Remote Sensing
i.e.,	:	that is
IRS	:	Indian Remote Sensing Satellite
K	:	Potassium
kg ha^{-1}	:	Kilograms per hectare
LISS	:	Linear Imaging Self Scanner
meq/l	:	milli equivalents per litre
Mg^{2+}	:	Magnesium
N	:	Nitrogen
Na^{+}	:	Sodium
NDVI	:	Normalised Difference Vegetation index
NIR	:	Near Infrared
nm	:	Nanometers
NRSC	:	National Remote Sensing Centre
OC	:	organic carbon

P	:	phosphorus
pH	:	Soil reaction
PLSR	:	Partial Least Square Regression
RMSE	:	Random mean square error
SAM	:	Spectral Angle Mapper
SAR	:	Sodium Absorption Ratio
SD	:	Standard Deviation
SID	:	Spectral Information Divergence
SSC	:	Soil Salt Content
SSIE	:	Soil Salinity Information extraction
SWIR	:	Short Wave Infrared
VNIR	:	Very Near Infrared

Name of the author	:	**D. NARESH GOUD**
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Department	:	**SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**
Chairperson	:	**Dr. G.JAYASREE**
University	:	**PROFESSOR JAYASHANKAR TELANGANA STATE AGRICULTURAL UNIVERSITY**
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ABSTRACT

The present study **"Characterization and mapping of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts"** was carried out with the objective of characterization of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts and identification and mapping of salt affected soils in targeted sites using Remote Sensing. The two sites selected for the study were site-I 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 and site-II *i.e.*, parts of Medak district located at 17026' 19.73" N , $78^0$19'5.43" E on top left and 17^0 31' 39.47" N, $78^0$8'5.06"E on right bottom. Global Positioning System (GPS) based soil samples (0-30 cm depth) were collected from study area. Hyperspectral reflectance curves were prepared by collecting spectral reflectance values with Field Spec Pro Spectroradiometer ASD, Inc., Boulder, Colorado, USA with a fibre-optic contact probe. Soil physical, chemical and physico-chemical properties were analysed using standard laboratory procedures. Site-I (Parts of Nalgonda district) : The soils are neutral to severely alkaline in reaction with pH ranged from 7.11 to 9.62, the electrical conductivity of the sampling sites varied from normal to severly saline-sodic with values ranged from 0.17 to 3.6 dSm^{-1}, the organic carbon content was low to high and it varied from 0.148 % to 2.108 %. Site-II (Parts of Medak district) : The soil reaction in this site varied from slightly acidic to strongly basic with pH values ranged from 5.78 to 8.73, EC of the soil samples ranged from 0.07 to 3.87 which comes under normal to saline category.

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 areas, in site-I, the area under slightly saline-sodic category was found to be 378 ha, the area under moderately saline-sodic category was 90 ha, severely saline-sodic soils were 178.43 ha and the rest of the area was normal. Similarly in site-II the area under slightly saline-sodic category was 88.53 ha, moderately saline-sodic category was 11.4 ha and severely saline-sodic category was 5.5 ha. An increasing digital number (DN) value with severity of salinity was observed throughout the blue, green red and near infrared under both LISS IV and LISS III data. The test site images were classified and different categories of saline-sodic soils were delineated and mapped. In site –I (parts of Nalgonda district) and site-II (parts of medak district). The spectral reflectance curves were generated using hyperspectral spectro-radiometer data covering a range of 350-2500nm under field conditions. An increasing trend of soil reflectance with increase in wavelength of electromagnetic radiation was observed irrespective of nature of soils. A significant decrease in reflectance at 1380and 1940 nm wavelength was observed which is more prominent in severly saline-sodic soils. It is also observed that saline soils exhibited comparatively very higher reflectance values throughout the wavelength (320-2500) compared to normal soil samples. The Pearson correlation studies were carried out with resampled reflectance values at 10nm intervals for the entire wavelength range. The soil properties like EC, CEC and ESP showed significant negative correlation strongly at 1870nm (r= -0.363*, 0.384* and 0.376*) wavelength. Which indicates that 1870 nm wavelength is the most sensitive band for delineation of salt affected soils. 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 retrieval of EC more accurately than ESP and CEC with the above mentioned bands. The category wise reclamation measures were suggested to improve yield in salt affected soils of the study area.

Chapter I

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 (Szabolcs, 1989). Soils are termed saline or salt-affected when the concentration of salt in the root zone exceeds 4 dS m^{-1} (Richards, 1954). 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 (Tanzi, 1990) but also occur extensively in sub-humid and coastal zones. 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 (Wiegand *et al.*, 1994). 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 (FAO, 1988). Soil degradation map of India prepared using GLASSOD methodology (Oldeman, 1988) 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.

In order to establish sustainable land use system it is important to keep track of the changes in salinity / alkalinity and anticipate further degradation. Further, monitoring of salt affected land is needed so that proper and timely decisions can be made to effectively modify management practices or undertake reclamation and rehabilitation. In order to monitor salinity, first we need to identify the places where salt concentrates and secondly detecting the temporal and spatial changes in this occurrence. Both depend on how salts distribute at the soil surface and within soil mantle.

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.

Salts on the surface can be detected from remotely sensed data either directly from bare soil, with salt efflorescence and crust or indirectly through vegetation and growth as they are controlled or effected by salinity. Surface salinity is a dynamic process leading to constraints in identification of proper behaviour of salt features, spectrally, spatially and temporally. Detection of salts on the surface can be difficult due to the presence of vegetation and other surface features that may contribute to creating spectral confusion with the salt reflectance properties. Various remote sensing data that are used in characterization and mapping of salt-affected soils are aerial photographs, multispectral and hyperspectral remote sensing data.

Broadband multi-spectral remote sensing data has been widely used in mapping and monitoring of salt-affected lands for relatively large areas. Application of broadband remote sensing in salinity studies is restricted due to limitations in spatial and spectral resolution that masks detailed of various kinds of salt-affected lands spectral signatures. There are various problems that interfere in the detection of salt-affected soils by means of remote sensing *i.e.*, the process goes often undetected, especially when salt minerals have not fully effected the soils, the physical boundaries separating saline areas of different degrees are fuzzy, the process of salinization occurs not only at the soil surface but also in the soil profile, which cannot be detected by optical sensors. However, it is very difficult to distinguish the degrees of salinity using broadband multispectral data as there is spectral confusion. Through multi-spectral we can distinguish only 2-3 (strong and medium) classes of salinity levels with spectral confusion between normal soil and moderately salt-affected soil.

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.

Quantitative comparison of surface reflectance in imaging spectrometer data set with known diagnostic reflectance spectra of minerals is usually done using spectral matching techniques or sub pixel classification techniques. The first suite of techniques strives at finding a measure of spectral similarity between known spectrums from a spectral library with unknown imaged pixel spectra; the second suite of techniques tries to derive within pixel surface abundance estimates of a set of spectrally characterized materials. As salt minerals have characteristic features occurring in the VNIR-SWIR region, they can be distinguished from one another. The salt affected areas of varying degree of salinity can be discriminated and spectral features relating to absorption band characteristics of salt minerals can also be mapped with finer detail. Success in discrimination of saline areas of different degrees can be increased if the spectral characteristics of salt-affected soils and the underlying factors are examined. The strength of the relationship between salinity sensitive soil properties such as EC, ESP *etc.,* and their influence on soil spectral characteristics can be analyzed in an efficient way. End members of salt affected soils used for spectral unmixing can be derived from the image itself (called image endmembers), or measured in a laboratory or in field conditions (reference or library endmembers). Thus, the hyperspectral remote sensing data have the potential to improve the accuracy of mapping the extent and characterization of salt-affected soils in comparison to broadband remote sensing data. (Ghosh *et al.,* 2012) In the present study, the feasibility of use of hyperspectral satellite data in characterization and map salt-affected soils has been investigated.

With this back ground, the present study aims at "**Characterization and mapping of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts"** with the following objectives.

Objectives :

1. Characterization of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts.
2. Identification and Mapping of salt affected soils in parts of Medak and Nalgonda districts.
3. To suggest reclamation measures to improve yield in salt affected soils of the study area.

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Chapter II

REVIEW OF LITERATURE

Salinization and alkalinization are the most common land degradation processes, particularly occurring in arid and semi-arid regions, where precipitation is too low to maintain a regular percolation of rainwater through the soil. Under such a climatic condition, soluble salts are accumulated in the soil, influencing soil properties and environment which cause lessening of the soil productivity. The consistent identification of the processes is essential for sustainable soil management. Salinization of soil is a major problem in arid and semi-arid regions with saline shallow water table. This is influenced by climate, soil type, and irrigation water quality and management practice (Jorenush and Sepaskhah 2003). Salinization induced soil degradation occur in areas where saline water is elevated near to ground surface and evapo-transpiration exceeds precipitation. In irrigated area where the water table approaches the ground surface, salt accumulation occurs in areas known as discharge zones.

Remote sensing has been widely used to delineate and map salt-affected areas, using medium to high-resolution satellite imageries. In practice, most of these studies have focused on severely saline areas and have given less attention to precisely detect and monitor of slightly to moderately salt affected areas. The major constraint is related to the nature of the satellite images, which do not allow extracting information from the third dimension of the 3-D soil body *e.g.,* where salts concentrate in subsoil.

A study on **“Characterisation and Mapping of Salt affected Soils using Hyperspectral data in Parts of Medak and Nalgonda districts”** was conducted during 2016-2017 and the brief review of literature pertaining to the study is orderly arranged and presented in this chapter.

2.1 Characterisation of salt affected soils.

2.1.1 Soil salinity :

Dwivedi (1992) used post-monsoon (October month) and pre-monsoon (dry season) Landsat-TM data for delineating moderately saline-sodic soils from slightly saline-sodic soils. While slightly saline-sodic soils support both *kharif* (summer) and *rabi* (winter) crops moderately saline-sodic soils support only paddy crop.

Whiting and Ustin (1999) reported the limited evaluation of the low altitude Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data, for identifying soil salinity and organic matter concentrations in soils using specific spectral bands cited in the literature. The study was a part of a larger investigation for using AVIRIS as the image data layer in developing terrain models to simulate the content and spatial extent of surface soil organic and inorganic carbon.

Ben-Dor and Patkin (2002) assessed DAIS - 7915 hyperspectral airborne sensor data for quantification and generation of soil properties maps of organic matter, soil field moisture, soil saturated moisture, and soil salinity. The method adopted for this purpose was the Visible and Near Infrared Analysis (VNIRA) approach, which yields an empirical model for predicting the soil property. Based on spectral laboratory data that show a significant capability to predict the above soil properties and populations using the VNIRA strategy, the next step was to examine this feasibility under a hyperspectral remote sensing (HSR) domain. After atmospherically rectifying the DAIS-7915 data and omitting noisy bands, the VNIRA routine was performed to yield a prediction equation model for each property, using the reflectance image data on a pixel-by pixel basis revealed images that described spatially and quantitatively the surface distribution of each property. The VNIRA results were validated successfully from a prior knowledge of the area characteristics and from data collected from several sampling points

Howari *et al*. (2003) studied the capability of remote sensing data such as Landsat ETM+, airborne visible/infrared imaging spectrometer (AVIRIS), colour infrared aerial photos (CIR), and high-resolution field spectroradiometer (GER 3700) to extract information about soil salinity. The study used image processing techniques such as supervised classification, spectral extraction, and matching techniques to investigate types and occurrences of salts. Soil salinity groups were established using soil physical and chemical properties and image elements (absorption-reflectivity profiles, band combinations, grey tones of the investigated images, and textures of soil and vegetation covers as they appear in images). The presented remote sensing datasets revealed the presence of gypsum and halite as the dominant salt crusts in the Rio Grande Valley. This information can help agricultural scientists and engineers to produce large-scale maps of salt-affected lands, which will help improve salinity management in watersheds and ecosystems.

Farifteh and Van der Meer (2005) presented results from spectral measurements on salt-affected soils showing spectral variations in the soil for various levels of salt content. In laboratory measurements of salt-affected soils relationships are established between various salinity levels, spectral characteristics and geophysical properties of the soils. These variations in spectral characteristics led to a new approach in the detection and assessment of salt-affected soils. This study reported the findings on the use of laboratory spectroscopy as a first step to diagnose spectral characteristics of salt-affected soils. After reflectance measurements, soil properties, *e.g.* electrical conductivity, that are known to influenced by accumulation of salts were determined for each soil sample. Spectral analysis revealed that severely salt-affected soil samples have diagnostic absorption features somewhat similar to the dominant minerals found in these samples but shape, depth and exact location of the absorption features varies with salt content.

Zewdu *et al.* (2015) assessed the level of salinity in Sego irrigated farm , Ethiopia and to map temporal and spatial distribution of salt affected soils to support management programmes and revealed that 2 % of study area was strongly saline and 54.7 % of the area was non-saline. Overlay model developed from water table, landform, land management type and land cover has revealed that 11.2 % of the study area was non-saline, where as 47.2 % and 3 % was moderately and strongly saline respectively.

2.1.2 Electric Conductivity :

Shi and Huang (2007) investigated the potential utility of laboratory hyperspectral data for evaluating the reclamation levels of saline lands. Soil samples were collected at each sub zone, and they were characterized by high electrical conductivity and sand content and low organic matter; the longer the saline lands have been reclaimed, the lower the electrical conductivity and sand content and the higher the organic matter content. These changing trends of the soil chemical and physical properties can be indicated by the laboratory reflectance spectra of the soil samples. Stepwise discriminant analysis (SDA) was applied to select and identify six salient spectral bands at 488, 530, 670, 880, 1400, and 1900 nm. Using derived discriminant functions, saline lands with different historical years of reclamation were classified with an overall accuracy of 86.6% in a self-test and 89.3% in a cross validation. Finally, this study suggested that remotely sensed hyperspectral data served as promising measures to assess the reclamation levels of coastal saline soil, as opposed to time-consuming field investigations.

Farifteh and Van der Meer (2007b) used HyMap data in predicting salt concentrations in soils from measured reflectance spectra using partial least squares regression (PLSR) and artificial neural network (ANN) techniques. The results of PLSR analyses suggest that an accurate to good prediction of EC can be made based on models developed from experiment-scale data for soil samples salinized by bischofite and epsomite minerals. The ANN models from experiment-scale data set revealed similar network performances for training, validation and test data sets indicating a good network generalization for samples salinized by bischofite and epsomite minerals. The results of this study showed that both methods had a great potential for estimating and mapping soil salinity.

Sharma *et al.* (2011) delineated and characterised waterlogged and salt affected soils in Gandak command area of Bihar on interpretation of IRS-1D LISS-III imageries coupled with ground truth and reported that the EC of salt affected soils ranged from 0.14 to 21.4 dSm^{-1}.

Ghosh *et al.* (2012) made an attempt to characterize and map salt-affected soils using hyperspectral satellite data reported that EC values of salt affected soils varied from 0.16 to 30.70 dSm^{-1}.

Tarik *et al.* (2015) reported that the EC values of salt affected soils varied from 0.20 to 0.70, 2.39 to 3.21, 5.43 to 8.02, 9.10 to 25.1, and 18.5 to 26.6 dSm^{-1}, respectively, for non-saline, slightly saline, moderately saline-sodic, saline-sodic severe and severely saline soil.

George and Suresh Kumar (2015) reported that the EC of salt affected soils ranged from 0.16 to 3.07 for normal soils , 4.28 to 7.70 for slightly saline soils, 8.10 to 10.02 for moderately saline soils and 10.21 to 30.41 dSm^{-1} for severe saline soils.

The EC values of some of the soil samples were high compared to others because of salt accumulation in surface soil resulting from the rise in water table to the surface due to uncontrolled irrigation practices and poor drainage condition in such pockets.

2.1.3 Cation exchange capacity :

Sharma *et al*., (2011) delineated and characterised waterlogged and salt affected soils and reported that the CEC of salt affected soils ranged from 8 to 14 c mol (p+) kg^{-1} soil.

Ghosh *et al*. (2012) has done the spectral characterization and mapping of salt-affected soils using hyperspectral satellite data and reported that the CEC of normal soils ranged from 6.38 - 8.51, slightly salt-affected soils from 9.74 - 16.69, moderately salt-affected soils from 10.61 - 24.96 and highly salt-affected soil from 15.15 – 32.65 (meq/100g) soil

Mandal , 2014 characterized some salt affected soils of Punjab for reclamation and management and reported that soil CEC of salt affected soils ranged from 2.6 to 19.8 c mol (p+) $kg^{-1.}$

Tarik *et al* . (2015) reported that CEC of normal soils ranged from 12.6 to 20.4, slightly saline soils from 20.0 to 21.8, moderately saline-sodic soils from 21.3 to 26.7, severe saline-sodic soils from 22.7 to 77.6 and severely saline soils from 16.7 to 33.0 c mol (p+) kg^{-1}

2.1.4 Exchangeable sodium percentage :

Sharma *et al*. (2011) delineated and characterised waterlogged and salt affected soils in gandak command area of Bihar and reported that the ESP of salt affected soils ranged from 9 to 68 %.

Ghosh *et al.* (2012) reported that the ESP of normal soils ranged from 5.48 - 13.16, slightly salt-affected soils from 14.36 - 15.73, moderately salt-affected soils from 16.27 - 23.95, and highly salt-affected soils from 24.33 - 36.21 in part of Mathura district, Uttar Pradesh

Tarik *et al*. (2015) reported that the ESP values varied from 0.37–2.8, 1.24–3.51, 9.87–12.4, 9.09–66.05 to 0.50–3.82%, respectively, for nonsaline, slightly saline, moderately saline-sodic, severely saline-sodic and severely saline soil.

2.1.5 Soil reaction :

Ghosh *et al*. (2012) made an attempt to characterize and map the salt-affected soils using hyperspectral satellite data in part of Mathura district, Uttar Pradesh and reported that the soil reaction of salt affected soils ranged from 6.87 to 10.20.

Mandal, (2014) characterized some salt affected soils of Punjab for reclamation and management and reported that the soil reaction of salt affected soils ranged from 7.2 to 13.4.

George and Suresh kumar (2015) reported that the soil reaction of salt affected soils ranged from 6.87 to 8.22 for normal soils , 7.68 to 8.40 for slightly saline soils, 8.59 to 10.02 for moderately saline soils and 8.67 to 10.20 for severe saline soils in part of Indo-Gangetic plains, Mathura district, Uttar Pradesh.

The soil reaction of normal soils ranged from 8.01 to 8.70,slightly saline-sodic soils from 8.02 to 8.43, moderately saline-sodic soils from 7.92 to 8.07,severely saline sodic soils from 7.67 to 8.13 and severely saline soils from 8.01 to 8.23. in parts of Ahmedabad district (Gujarat) as delineated by Tarik *et al.* (2015).

2.2 Multi Spectral Remote Sensing in Studying of Salt-affected Soils

Salt-affected soils reveal presence of salts in two different ways in remotely sensed data . a) Directly on bare soil with efforescence and salt crust; b) Indirectly by affecting condition type of vegetation or soil moisture condition. Numerous remote sensing studies had been carried out for mapping and monitoring of salt-affected soils in northern India with variety of optical remote sensing satellite data such as LANDSAT- MSS & TM, SPOT and IRS – LISS: I, II, III and recently using IRS – LISS IV and Cartosat data.

Salt-affected soils in the Indo-Gangetic alluvial plains of northern India are characterized by the presence of salt efflorescence (encrustation) of white to light grayish brown colour and the absence of vegetation cover except for extremely poor growth of grass during monsoon season. Thereafter, these grasses too dry up imparting thereby a barren look. Such soils when looked at the satellite images acquired during peak crop growth period in dry season exhibit extremely good image contrast with the normal soils supporting crops and other vegetation. In the satellite image, salt-affected soils appear as irregular shaped patches in white to light greyish brown while non-salt-affected soils crops and other vegetation are manifested in red colour. Singh *et al*. (1988) delineated two categories of sodic soils, *viz*., (i) moderately (ii) strongly to very strongly sodic soils. Dwivedi and Sreenivas (1998) carried out image transform analysis to delineate saline and alkali soils. Further, for delineation of moderately saline-sodie soils from slightly saline-sodic soils, Verma et al. (1994) found thermal infrared band of Landsat TM data quite useful. The detectability of such soils in the Indo-Gangetic alluvial plains of India is, however, image scale dependant.

Khan *et al.* (2001) have used LISS-II sensor of IRS-IB satellite to analyze the effectiveness of several indicators for the presence of salts, *i.e.,* salinity indices, normalized differential salinity index and ratio of the signal received by the sensors in the 3rd spectral band to others. He had used two classification processes (COMPOSITE MODULE and ISOCLUST function of GIS IDRISI) that performed classification based on specifically created image. Both schemes have shown to perform good classification.

Mandal (2011) delineated and characterised waterlogged salt affected soils in IGNP using remote sensing and GIS. They found that the presence of fine textured and impermeable calcium carbonate layers at a depth below the surface enhanced waterlogging and rise of water table. The preponderance of chlorides and sulphates of sodium, calcium and magnesium was found in the salinised areas. The quality of ponded water was extremely poor and unfit for its reuse.

Sharma *et al.* (2011) delineated and characterised waterlogged and salt affected soils in Gandak command area of Bihar on interpretation of IRS-1D LISS-III imageries coupled with ground truth. They concluded that the presence of calcite and dolomite, higher pH and ESP, abundant CO_3^{2-} and HCO_3^{2-} influenced the geo-chemical cycles and ionic mobility that enhanced the soil alkalization.

Zewdu *et al.* (2015) assessed the level of salinity in Sego irrigated farm , Ethiopia and to map temporal and spatial distribution of salt affected soils to support management programmes and revealed that 2 % of study area was strongly saline and 54.7 % of the area was non-saline. Overlay model developed from water table, landform, land management type and land cover has revealed that 11.2 % of the study area was non-saline, where as 47.2 % and 3 % was moderately and strongly saline respectively.

Koshal (2012) studied the spectral characteristics of saline areas in parts of SW Punjab by using May 2000 Image of IRS ID LISS III and reported that spectral characteristics of normal, moderate and severe saline soils .

Mandal (2014) Characterised some salt affected soils of Punjab for reclamation and management and concluded that the physicochemical characteristics of salt affected soils of southwest and central Punjab showed complex saline and sodic nature. Coarse texture soils under canal irrigation showed development of waterlogging and soil salinity. The presence of concretionary calcium carbonate at sub-surface depths caused poor internal drainage and favoured waterlogging.

Wang *et al.* (2014) suggested that the field derived spectra have some kind of potential to quantitatively monitor soil salinization and concluded that there was no significant correlational relationships between the Normalised Difference Vegetation index (NDVI) and Soil Salt Content (SSC)/EC. The GA-BP model fitted using the vegetation spectrum was superior to a single vegetation index model, where as the predictive ability of SSC was not high due to influences such as plant species difference and vegetation coverage.

Kumar (2014) demonstrated utility of integration of remote sensing and GIS techniques for mapping of waterlogged areas in two blocks of Jhajjar district, Haryana using Indian Remote Sensing Satellite (IRS-Resourcesat-I)-LISS III data acquired during the period of Pre-monsoon (3 March 2009) and post monsoon (10 Oct 2009) and combined the data image interpretation technique with screen digitization to identify the different water logged areas on 1:50000 scale , permanent waterlogged and seasonal waterlogged areas were identified for both the pre and post monsoon seasons under GIS environment. He reported that total seasonal waterlogged area is 9700.8 ha and permanent waterlogged 1964.6.ha. in Jhajjar district of Haryana.

The physicochemical characteristics of salt affected soils of southwest and central Punjab showed complex saline and sodic nature. Coarse texture soils under canal irrigation showed development of waterlogging and soil salinity. (Mandal 2014) The presence of concretionary calcium carbonate at sub-surface depths caused poor internal drainage and favoured waterlogging.

Zhang *et al*. (2015) used the RS image of LANDSAT 8 of March 14, 2014 to extract soil salinity of the Yellow River Delta , and compared the Soil Salinity Information extraction [SSIE] model and Vegetation index NDVI model and found that overall accuracy of SSIE model is 93.04 % and coefficient of kappa is 0.7869, while overall accuracy of NDVI model is 83.67 % and coefficient of Kappa is 0.7017 respectively and concluded that SSIE model is more accurate which indicates significant advantage for soil salinity information extraction.

2.3 Hyperspectral Remote Sensing in Studying of Salt-affected Soils

Application of conventional remote sensing in salinity study is restricted due to the limited spectral bands or wide bandwidth that mask detailed spectral signatures. Success in discrimination of salt-affected soils is somewhat dependent on spectral and spatial resolution, which affects the quality and quantity of the information that can be derived from optical remote sensing imagery. In this respect, imaging spectrometry offers considerable potential by providing large volumes of high spectral and spatial resolution data in a number of narrow contiguous spectral bands. Various analysis techniques adopted for information extraction and mapping of natural resources including soil resources and soil salinity are discussed below:

Whiting and Ustin (1999) reported the limited evaluation of the low altitude Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data, for identifying soil salinity and organic matter concentrations in soils using specific spectral bands cited in the literature. The study was a part of a larger investigation for using AVIRIS as the image data layer in developing terrain models to simulate the content and spatial extent of surface soil organic and inorganic carbon.

Ben-Dor and Patkin (2002) assessed DAIS - 7915 hyperspectral airborne sensor data for quantification and generation of soil properties maps of organic matter, soil field moisture, soil saturated moisture, and soil salinity. The method adopted for this purpose was the Visible and Near Infrared Analysis (VNIRA) approach, which yields an empirical model for predicting the soil property. Based on spectral laboratory data that show a significant capability to predict the above soil properties and populations using the VNIRA strategy, the next step was to examine this feasibility under a hyperspectral remote sensing (HSR) domain. After atmospherically rectifying the DAIS-7915 data and omitting noisy bands, the VNIRA routine was performed to yield a prediction equation model for each property, using the reflectance image data on a pixel-by pixel basis revealed images that described spatially and quantitatively the surface distribution of each property. The VNIRA results were validated successfully from a prior knowledge of the area characteristics and from data collected from several sampling points.

Metternicht and Zink (2003) reviewed various sensors (*e.g.* aerial photographs, multispectral sensors, microwave sensors, video imagery, airborne geophysics, hyperspectral sensors and electromagnetic induction meters) and approaches used for remote identification and mapping of salt affected areas. Constraints on the use of remote sensing data for mapping salt affected areas are shown related to spectral behaviors of salt types, spatial distribution of salts on the terrain surface, temporal changes in salinity, interference of vegetation and spectral confusion with other terrain surfaces.

Howari (2003) studied the capability of remote sensing data such as Landsat ETM+ airborne visible/infrared imaging spectrometer (AVIRIS), colour infrared aerial photos (CIR), and high-resolution field spectroradiometer (GER 3700) to extract information about soil salinity. The study used image processing techniques such as supervised classification, spectral extraction, and matching techniques to investigate types and occurrences of salts. Soil salinity groups were established using soil physical and chemical properties and image elements (absorption-reflectivity profiles, band combinations, grey tones of the investigated images and textures of soil and vegetation covers as they appear in images). The presented remote sensing datasets revealed the presence of gypsum and halite as the dominant salt crusts in the Rio Grande Valley. This information can help agricultural scientists and engineers to produce large-scale maps of salt-affected lands, which will help improve salinity management in watersheds and ecosystems.

Farifteh and Van der Meer (2005) presented results from spectral measurements on salt-affected soils showing spectral variations in the soil for various levels of salt content. In laboratory measurements of salt-affected soils relationships are established between various salinity levels, spectral characteristics and geophysical properties of the soils. These variations in spectral characteristics led to a new approach in the detection and assessment of salt-affected soils. This study reported the findings on the use of laboratory spectroscopy as a first step to diagnose spectral characteristics of salt-affected soils. After reflectance measurements, soil properties, *e.g.* electrical conductivity, that are known to influenced by accumulation of salts were determined for each soil sample. Spectral analysis revealed that severely salt-affected soil samples have diagnostic absorption features somewhat similar to the dominant minerals found in these samples but shape, depth and exact location of the absorption features varies with salt content.

Koshal (2012) ascertained that salt affected soils had a high spectral value in red and near infrared bands. The analyses of digital numbers (DN) of the three classes that is normal, moderate and severe from the satellite data for the month of March were studied. The crop spectral values were examined in green, red and infrared bands. It was observed that in crop affected by severe salinity had a maximum mean DN value of 124.32 in the red band. The crop affected by moderate salinity had a mean DN value of 114.48. The spectral value (DN value) of crop affected by moderate/severe salinity was found to be substantially higher in the red and infrared bands.

Mashimbye *et al.* (2012) reported that the good predictions could be made based on bagging PLSR (Partial Least Square Regression) using first derivative reflectance (Validation R^2=0.85), PLSR using untransformed reflectance (Validation R^2=0.70), NDSI (Normalised Difference Salinity Index) (Validation R^2=0.65), and the untra**n**sformed individual band at 2257nm predictive models. These suggested the potential of mapping soil salinity using airborne and satellite hyperspectral data during dry season.

Amal and Lalit kumar (2014) made an attempt to develop statistical regression models based on remotely sensed indicators to predict and map spatial variation in soil salinity in the Al Hassa oasis and demonstrated that modelling and mapping spatial variation in soil salinity based on regression analysis and remote sensing data is a promising approach, as it facilitates timely detection with a low-cost procedure and allows decision makers to decide what necessary action should be taken in the early stages to prevent soil salinity from becoming prevalent, sustaining agricultural lands and natural ecosystems.

Tarik *et al.* (2015) drawn the relationship between soil salinity parameters and their influence on soil spectral characteristics were analyzed using both satellite data (Hyperion) and reflectance data of soil samples collected from parts of Ahmedabad district of Gujarat, India and concluded that among all the observed soil parameters Electrical Conductivity, Exchangeable Sodium Percentage, Cation Exchange Capacity and Mg^{2+} predictions can be made accurately based on partial least square regression models developed from selected wavelengths.

George *et al.* (2015) made an attempt to map the various soil salinity severity classes using different hyperspectral indices generated using EO-1 Hyperion data and Support Vector Machine (SVM) method, in the Mathura region of Indo-Gangetic plains of India. The SVM technique generated soil salinity map with overall classification accuracy of 78.13 percent, with a kappa coefficient of 0.71. The results indicated highest accuracy in high soil salinity class in comparison to other classes, attaining producers and users accuracies of 85.71% and 90.0% respectively.

2.4 Spectral Similarity Measures

Yingzi (2003) implemented Spectral angle mapper (SAM) that has been widely used as a spectral similarity measure for multispectral and hyperspectral image analysis. It has been shown to be equivalent to Euclidean distance when the spectral angle is relatively small. Most recently, a stochastic measure, called spectral information divergence (SID) has been introduced to model the spectrum of a hyperspectral image pixel as a probability distribution so that spectral variations can be captured more effectively in a stochastic manner. In order to demonstrate its utility, a comparative study is conducted among the new measure, SID and SAM where the discriminatory power of the (SID, SAM)- mixed measure is significantly improved over SID and SAM.

Stefan and Robila (2005) investigated the accuracy of several spectral metrics when used for matching in hyperspectral imagery. Spectral matching is used in many areas such as target detection and spectra classification. Frequent choices for such measures are Spectral Angle (SA) and Spectral Information Divergence (SID) since they provide a limited range for threshold values. In addition, two new measures Spectral Correlation Angle (SCA) and Spectral Gradient Angle (SGA) are developed. Next, we suggest an alternative measure developed by using a Normalized Euclidean Distance (NED). To test the accuracy of the measures we used target information extracted from HYDICE data, and assessment tools such as the relative spectral discriminatory probability and the relative spectral discriminatory entropy. Experimental results suggest that NED outperforms SA, SCA and SGA and is relatively equivalent to SID. Given the reduction in computation time, NED constitutes an attractive measure to be used in spectra matching.

Fernandez *et al.* (2006) have used Landsat –ETM to correlate soil characteristics with the spectral response of plant species and bare soils, integrating an algorithm to allow multi-scale mapping using remote sensors. A Combined Spectral Response Index (COSRI) was calculated for bare soils and vegetation by adjusting the normalized difference vegetation index (NDVI). ECe and SAR were determined in surface soil samples. Correlation coefficients between COSRI and soil salinity were obtained and a model was adjusted to predict soil salinity. The results concluded that the method was an easy, low-cost procedure to map salt-affected soils.

Farifteh and Van der Meer (2007a) demonstrated that salt-affected soils could be discriminated based on their spectral characteristics by establishing a relationship between soil properties and soil spectra and by testing if variations in the spectra of salt-affected soil samples are statistically significant. The measured spectra were examined by the application of spectral matching techniques to quantify the variations and ascertain a relationship that supports the spectral identification of saline soils. The results had showed significant correlations between soil electrical conductivity (EC) and spectral similarity measures, indicating that similarity between the samples spectra decreases as the salt concentration in the soil increases.

2.5 Management of salt-affected soils.

2.5.1 Chemical amendements :

Verma and Abrol (1980) found that improvement in soil properties with the application of gypsum was always greater than pyrites for rice-wheat rotation on sodic loam soil.

Sainberg *et al.* (1982) pointed out that the effect of $CaCl_2$ is short-term, and permeability of non-calcareous soils may decline below that obtained with gypsum, when leached with distilled water. In calcareous soils, which could release calcium through dissolution of native $CaCO_3$,and stated that to reclaim sodic soil, the amount of gypsum required depended on amount of exchangeable sodium in soil.

Swarup *et al.* (1994) reported that gypsum improves hydraulic conductivity, help to reduce pH, inhibit the leaching of P., help for the improvements of soil properties and increases yield of different crops.

Patra *et al.* (1996) reported that management of salt affected soils has significant relevance to very high exchangeable sodium resulting into dispersed soil which is almost impervious to water. Therefore, in such soils sodium must be replaced by another cation such as calcium. Hence, use of amendments containing calcium is recommended for reclaiming sodic soils.

Jiff Simunek and Donald (1997) reported that incorporating gypsum into the top of the soil profile, and application of gypsum-saturated water were shown to be decreasingly less effective reclamation strategies.

Ahmad *et al.* (2001) compared the reclamation effect of different doses of gypsum and equivalent amounts of $CaCl_2$ (industrial by-product) and reported that Soil SAR, ECe and pH decreased by both the chemicals but $CaCl_2$ proved less effective as compared to gypsum in lowering the SAR and ECe.

Joachim *et al*. (2010) reported that there was significant ($P \leq 0.05$) difference on the exchangeable Na^+ when soil was leached after gypsum

Mamoun *et al.* (2012) reported that saline-sodic soil could be reclaimed efficiently with less water using phosphoric acid compared with gypsum. Application of 450 kg/ha of phosphoric acid and an equivalent of 0.5 DW/DS of leaching water.

Mohamed and Abdel-Fattah (2012) reported that application of gypsum combined with water hyacinth compost or rice straw compost enhanced reclamation process and caused more decreases in salinity as well as sodicity.

2.5.6 Organic amendements :

Abrol and Bhumbla (1979) found that for rice, the reduction in ESP was quicker and extended to deeper depths and it was highly tolerant to exchangeable sodium as compared to wheat .

Aziz (1980) reported that saline soils were reclaimed with the cultivation of rice.

Ramzan *et al.* (1982), observed that in reclamation of saline sodic non-gypsiferous soils of Bhalwal district of Sargodha, Pakistan and suggested that, 100 % gypsum requirement plus farm yard manure had the maximum reclamation efficiency.

Rauf *et al*. (1990) reported that biological method of reclamation is less effective as compared to chemical method.

Parvez (1992) on the basis of biological reclamation experiment concluded that under calacareous saline sodic conditions, the fodders gave a high amount of carbondioxide dissolved calcium carbonate causing release of calcium ions and replaced sodium ions from clay complex.

Sadiq (1992) concluded that growing of Sesbania on the salt affected soil for reclamation thrrough green manuring, proved more effective to reclaim the soil from sodicity.

Maskina *et al.* (1993) conducted an experiment from 1986 through 1988 on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Argiustoll-Abruptic Argiaquoll) near Lincoln, *Nebraska* and reported that rice husk could be utilized for reclamation of saline-sodic soils, on account of it's tendency to improve the physical conditions of the soil and its fertility.

Ansari and Khanzada (1995) reported that periodic cultivation of alfalfa, clover, sesbania, berseem, lucern and deep incorporation of these as green manuring and cattle manure improved the saline lands greatly .

Muhammad (1996) conducted an experiment on saline soils of Indus Basin Irrigation System (IBIS) and commented that to reclaim the salt affected soils, the growing and green manuring the leguminous crops add organic matter in the soil, improves the permeability of sodic soil, provides a deeper zone for growth and extension of crop roots.

Gupta and Gupta (1997) emphasized proper selection of crop will help in achieving optimum production under saline conditions for example, wheat, bajra, jowar can be easily grown upto an irrigation water is ranging from 5000 – 10000 μS/cm. On the other hand sugarcane maize, sunflower are semi tolerant crops which can tolerate salinity in the range of 3000-5000 μS/ ., However, alfalfa (*Medicego Sativa L*) is the backbone of salinity reclamation. Alfalfa is long-lived perennial legume, which can fix its own nitrogen when properly inoculated. It has a deep tap root system, once established provide excellent production for many years.

Joachim *et al.* (2007) conducted an experiment on sodic soils in northern Tanzania, usinglocally available organic and inorganic resources and demonstrated that combining farmyard manure with gypsum (FYM + gypsum) as ameliorants is probably the best choice in the improvement of the physical-chemical properties in sodic soils.

Deshmukh (2016) conducted to know the mineralogical and textural characteristics of soils inrelation to soil fertility status of Sangamner area, Ahmednagar district, Maharashtra and suggested that application of FYM, compost and vermi compost including dungs should encourage for reclaiming saline soils.

Chapter III

MATERIALS AND METHODS

The Materials and Methods of the following experiment is described under following sub-heads.

a) Sites Location/Study area.
b) Selection of sampling sites.
c) Collection of soil samples .
d) Collection of Spectral data.
e) Soil Chemical analysis.
f) Methodology of spectral data Collection.
g) Instruments and Softwares used.
h) Statistical analysis.
i) Mapping of salt-affected soils.

3.1 STUDY AREA

The Study area include two different sites :

Site-I Parts of Nalgonda District , Nagarjunasagar Command Area.

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.(Figure 3.1)

3.1.1 Climate

The region experiences hot and dry summer throughout the year except during the South West Monsoon season. The year may broadly be divided into four seasons. It experiences cold season from December to Mid February, summer season from Mid February to first week of June. South West monsoon season from June to September and retreating monsoon or the post monsoon season during October to November.

3.1.2 Temperature

Cold season extending from December to February is followed by summer when both day and night temperatures increase sharply. May being the hottest month, the mean daily maximum temperature is about 40^0C (104.0^0F) and the mean daily minimum is about 28^0C (82.4^0F) and sometimes the day temperature crosses 44^0C during this period. On some days, afternoon thundershowers come as a blessing and though temporarily they bring relief from the oppressive summer heat. By the beginning of October day temperature decreases steadily signaling the withdrawl of monsoon. Day and night temperature decrease rapidly during November. December is the coldest month with the mean daily maximum and minimum temperatures being 35^0C and 20^0C respectively. Sometimes during the cold season, night temperature may drop down to about 10^0C.

3.1.3 Rainfall

The average rainfall in the district is 772 mm. 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. During summer and retreating monsoon season some amount of rainfall is received in the form of thunder showers. The variation in the annual rainfall in the district from year to year is large. On an average there are 46 rainy days. (*i.e*., days with rainfall of over 2.5mm or more).

3.1.4 Rivers

The district is drained by rivers Krishna, Musi, Aler, Dindi, Hallia, Kongal, Peddavagu. Krishna is the prominent river in this district enters at Yeleshwaram in Deverakonda taluka.

3.1.5 Forests

Total forest cover in the whole Nalgonda district accounts for 1,04,806 ha which accounts for 7% of the total area of revenue district. This figure falls far short of the minimum prescribed percentage of forests (*i.e*., 33 1/2%) by the National Forest Policy of 1952. The state average being 24%, this district lags far behind when compared to other districts.

3.2 Site-II Parts of Medak district , ICRISAT area.

3.2.1 Location

The site is located at $17^{0}26'$ 19.73" N , $78^{0}19'5.43"$ E on top left and 17^{0} 31' 39.47" N, $78^{0}8'5.06"$ E in Medak dist.(Figure 3.2)

3.2.2 Topography and Agro-climatic characteristics

About 78% of the rainfall in the district is received during the south-west monsoon, which occurs between June and September. Another 15% of the annual rainfall is received during the north-east monsoon *i.e.,* between October and January. Another 6% of the rainfall is received during the summer months of March to May. The distribution of rainfall is uneven. It has been scanty in recent years during the south west monsoon due to which the crop yields are affected. Generally, the rain fed crops are raised after the onset of south west monsoon during *kharif* season (June to September). In *rabi* season (October to March), the crops are mainly grown under conserved soil moisture.

The mean maximum temperature recorded ranges from 37.8^{0} C to 39^{0} C during the months of March to May and the coldest month in the district is December when the mean minimum temperature ranges from 10.9^{0} C to 13.6^{0} C.

3.2.3 Geology

The district forms part of the tableland of the Deccan and is crisscrossed by different ranges of hills. The rock formation is of the oldest type (archaic gneiss or very old granite like rocks with minerals arranged in layers) and consists principally of peninsular granite complex i.e., pink and gray granites and their metamorphic variations. Isolated peaks and rocky clusters lie scattered all over the district.

3.2.4 Soils

The soils of the district are mainly red earths comprising of loamy sands, sandy loams and sandy clay loams. Red laterite soil is predominant in Zahirabad and Kohir mandals. Regar or black cotton soils, comprising of clay loams, clay and silt clay, are found in Sangareddy, Sadasivapet, Kondapoor, Munipally, Pulkal, Shankarampet (A), Alladurg, Jogipet, Regode, Narayankhed, Manoor, Kangti , Kalher , Narsapur, Kowdipally, Shivampet , Hathnoora and Jinnaram mandals.

3.2.5 Rivers

No major rivers are flowing across the district. But, the "Manjeera", tributary of Godavari river, originates in Bidar district and enters Medak district in the southeastern direction. It flows for about 96 Km. in the western and northwestern taluqs of Narayankhed, Zaheerabad, Sangareddy, Narsapur and Medak. The important streams are the Haldi or Pasupueru and the Kudlair. Pasupueru is the tributary of Manjeera and enters the district from the North and flows through Medak town. Kudlair is in Siddipet Taluk.

3.2.6 Forestry

The total forest area in the district is 96,267 hectares, which constitutes 10.08% of the total geographical area of 9,51,904 hectares. It is far less than the 33 ½ norm fixed by National Forest policy, 1952 as the desirable minimum. As the forests of the district are very limited in extent, it is not meeting the requirements of the district. In order to improve the vegetation, forest life, rains, and climatic conditions and also to combat the ever increasing fuel problems, the Government of India launched various massive national social forestry programs and schemes.

3.2.7 Weather

The average rainfall in the district is 713 mm per annum. The average number of rainy days in the district was 37. The maximum temperature in the district averaged is 38.7^{o}C. The minimum temperature averaged is 11.8 ^{o}C. The lowest minimum temperature of 10^{o}C was recoded at Sadasivpet and Jogipet, while the maximum temperature of 41^{o}C was recorded at Narayankhed and Dubbak. The minimum humidity averaged 47% while the maximum humidity averaged 69.3%.

About 78% of the rainfall in the district is received during the south-west monsoon, which occurs between June and September. Another 15% of the annual rainfall is received during the north-east monsoon *i.e.,* between October and January. Remaining 6% of the rainfall is received during the summer months of March to May.

The long-term average rainfall in the district is at 874 mm per year. But, during the last five years, rainfall was slightly higher at 890 mm only in 2005-06. In all the other four years, the rainfall was quite sub-normal. It was particularly very low at 527 mm in 2004-05 and 541mm in 2002-03. It showed that there have been two severe droughts and two sub-normal years out of five years.

3.2.8 Land use pattern and Land holdings

The total geographical area of the district is 9, 51,904 ha and the net area sown is 4, 23,000 ha, constituting 44.43 % of the total geographical area. Out of the total geographical area of 9.69 L ha, nearly 4.23 L ha are under cultivation. 23.4 % (1.00 lakh hectares) area out of the cultivated area is under double cropping.

3.3 Selection of sampling points

The sampling points were selected based on soil variation using satellite image IRS-1C (LISS-III and LISS-IV) at NRSC, Balanagar, Hyderabad. The sampling points were represented in fig 3.3 and 3.4 for site-I (parts of Nalgonda district) and site-II (parts of Medak district respectively.

3.4 Collection of Soil samples

Global Positioning System (GPS)-based soil samples (114) of 0-30cm 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.

3.5 Collection of Spectral information

3.5.1 Instrument

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

3.5.2 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.

3.5.3 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.

3.6 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 in the Department of Soil science and Agricultural Chemistry , Agricultural College , Jagtial by employing the following procedures

3.6.1 Mechanical analysis

The different particle size fractions of the experimental soil were determined by Bouyoucos hydrometer method as outlined by Piper (1966).

3.6.2 Soil Reaction (pH)

The pH of the soil samples was determined in 1:2 soil : water suspension using a glass electrode pH meter (Jackson, 1973).

3.6.3 Electrical Conductivity (EC)

Electrical conductivity of the soil samples was determined in 1:2 soil : water suspension with a conductivity meter (Jackson, 1973).

3.6.4 Organic carbon

Organic carbon percentage in soil sample was determined by wet digestion method (Walkley and Black, 1934).

3.6.5 Available Nitrogen

Available nitrogen in soil sample was estimated by alkaline permanganate method (Subbiah and Asija, 1956).

3.6.6 Available Phosphorus

Available phosphorus in soil sample was extracted with 0.5 M $NaHCO_3$ and the phosphorus in the extract was estimated spectrophotometrically at 680 nm using ascorbic acid as the reductant (Watanabe and Olsen, 1965).

3.6.7 Available Potassium

Available potassium in soil sample was extracted with neutral normal ammonium acetate and potassium present in the extracts was determined by flame photometer (Jackson, 1973).

3.6.8 Available Calcium and Magnesium

Available calcium and magnesium of the contents of the soil were determined by versenate titration of neutral normal ammonium acetate extract as per the procedure described by Jackson (1973).

.3.6.9 Sodium

Available Sodium content in soil water Extract was estimated using ELICO flame photometer.

3.6.10 Cation Exchange Capacity

Cation Exchange capacity of soil was estimated by neutral normal ammonium acetate method (Jackson 1973)

3.6.11. Exchangeable Sodium Percentage

Exchangeable Sodium Percentage of the soil samples were calculated using the formula

$$ESP = (Na^{+}/CEC) \times 100$$

3.7 Methodology of spectral reflectance collection

To collect the spectral reflectance a Field Spec Pro Spectrometer (Analytical Spectral Device (ASD), Inc., Boulder, Colorado, USA) with a fibre-optic contact probe was employed for field measurements. The instrument covers the visible to SWIR wavelength range (350–2500 nm). The controlling software automatically accounts for the overlap in wavelength intervals using a preset wavelength within the common subset. Reflectance was calibrated against a white panel of known reflectance (spectral on diffuse reflectance panel). The collected soil samples were dried and passed through a 2.00-mm sieve to remove large debris and stones. A portion of each sample was used for spectroscopic measurements.

3.8 Instruments and Software used

An analytical spectral device (ASD), 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. View spec pro software is used for post-processing spectra files that were saved using an ASD instrument.

3.9 Statistical 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.

3.10 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:

3.10.1 Georeferencing of Satellite Data

The data pertaining to the study area covered by IRS-1C LISS-III data and LISS-IV were 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-III 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.

3.10.2 Preliminary 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.

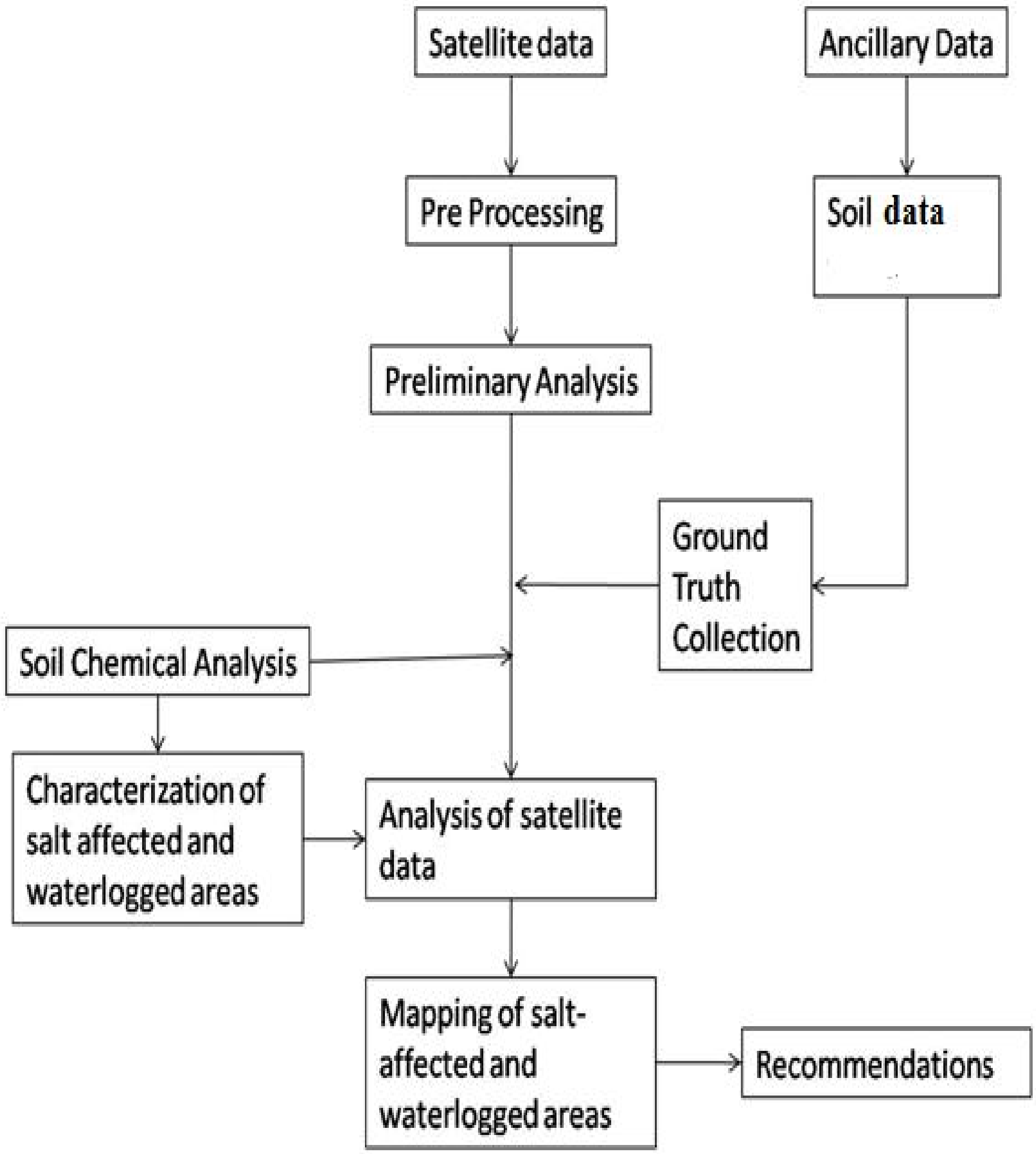
3.10.3 Ground Truth Collection

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 (Fig.3.5)

3.10.4 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-III 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 (Table 4.1 and 4.2). Further divisions within each category are made based on severity of the hazard (Table-4.3 and 4.4). 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.

Approach



Satellite data
Ancillary Data
Pre Processing
Soil data
Preliminary Analysis
Ground Truth Collection
Soil Chemical Analysis
Characterization of salt affected and waterlogged areas
Analysis of satellite data
Mapping of salt-affected and waterlogged areas
Recommendations

Fig 3.5 Soil Spectral data collection in the salt affected field

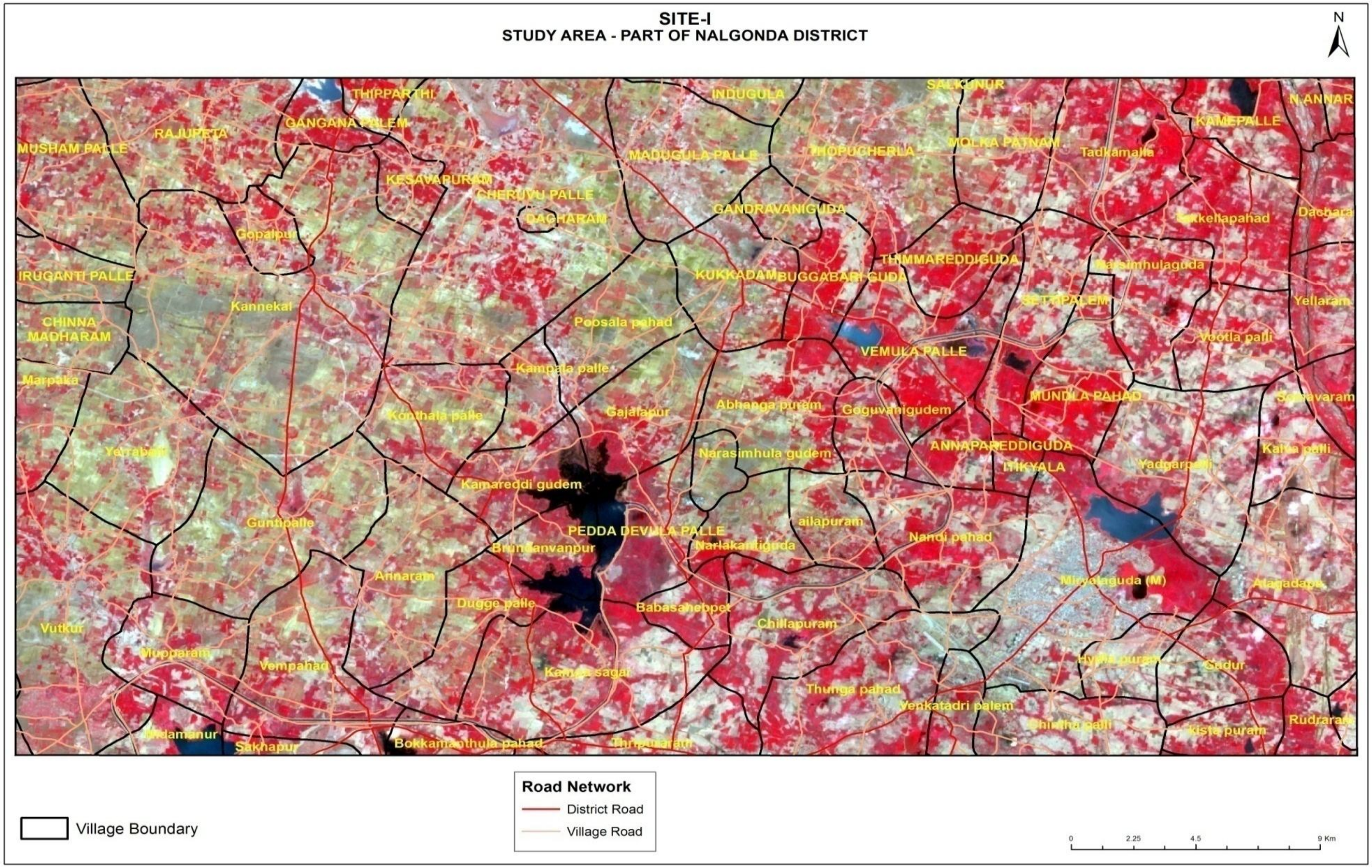


Fig 3.1 Satellite image (IRS-1C) showing study area in Parts of Nalgonda district (Site-I)

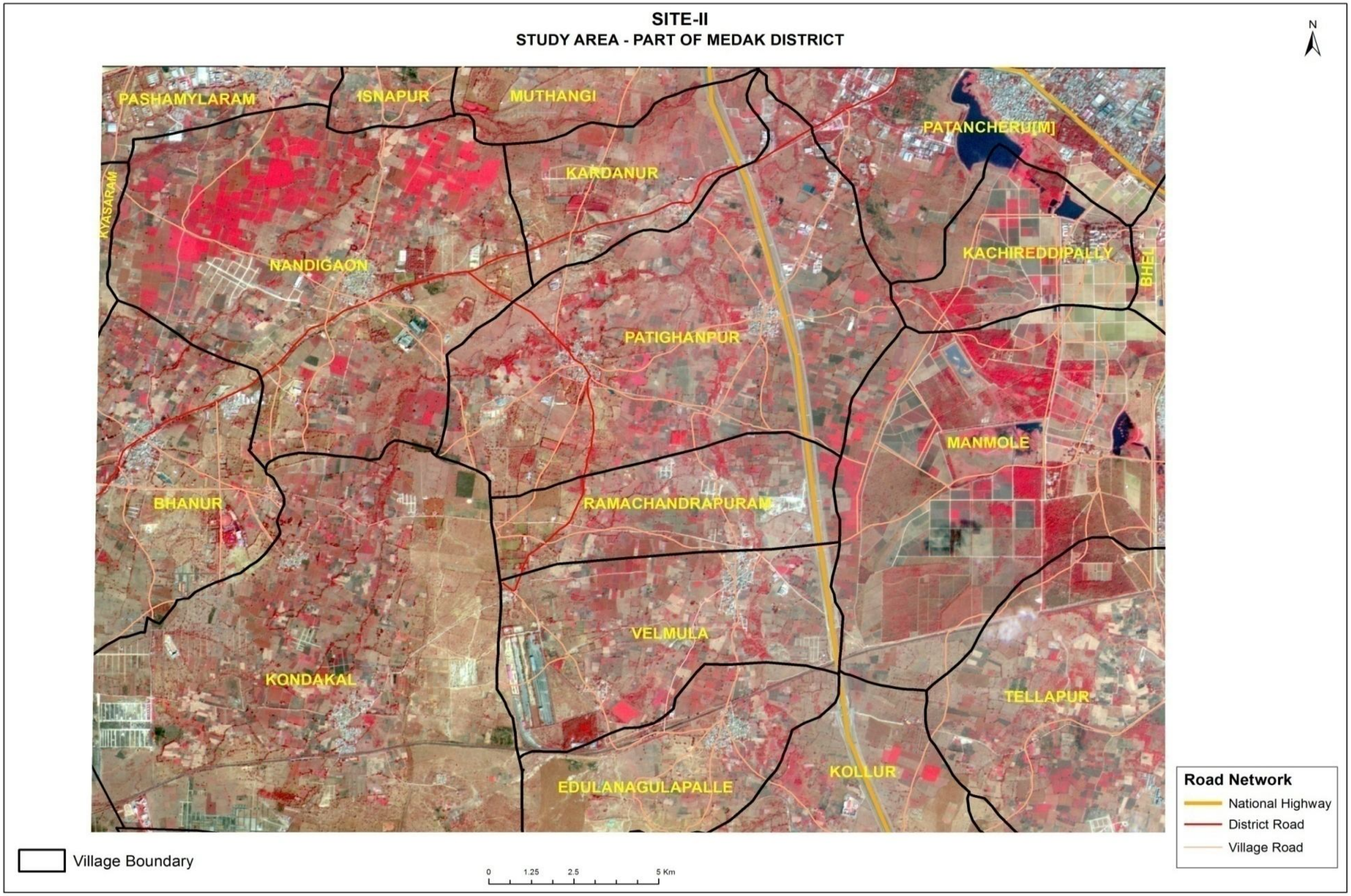


Figure 3.2 Satellite image (IRS-1C) showing study area in Parts of Medak district (Site-II)

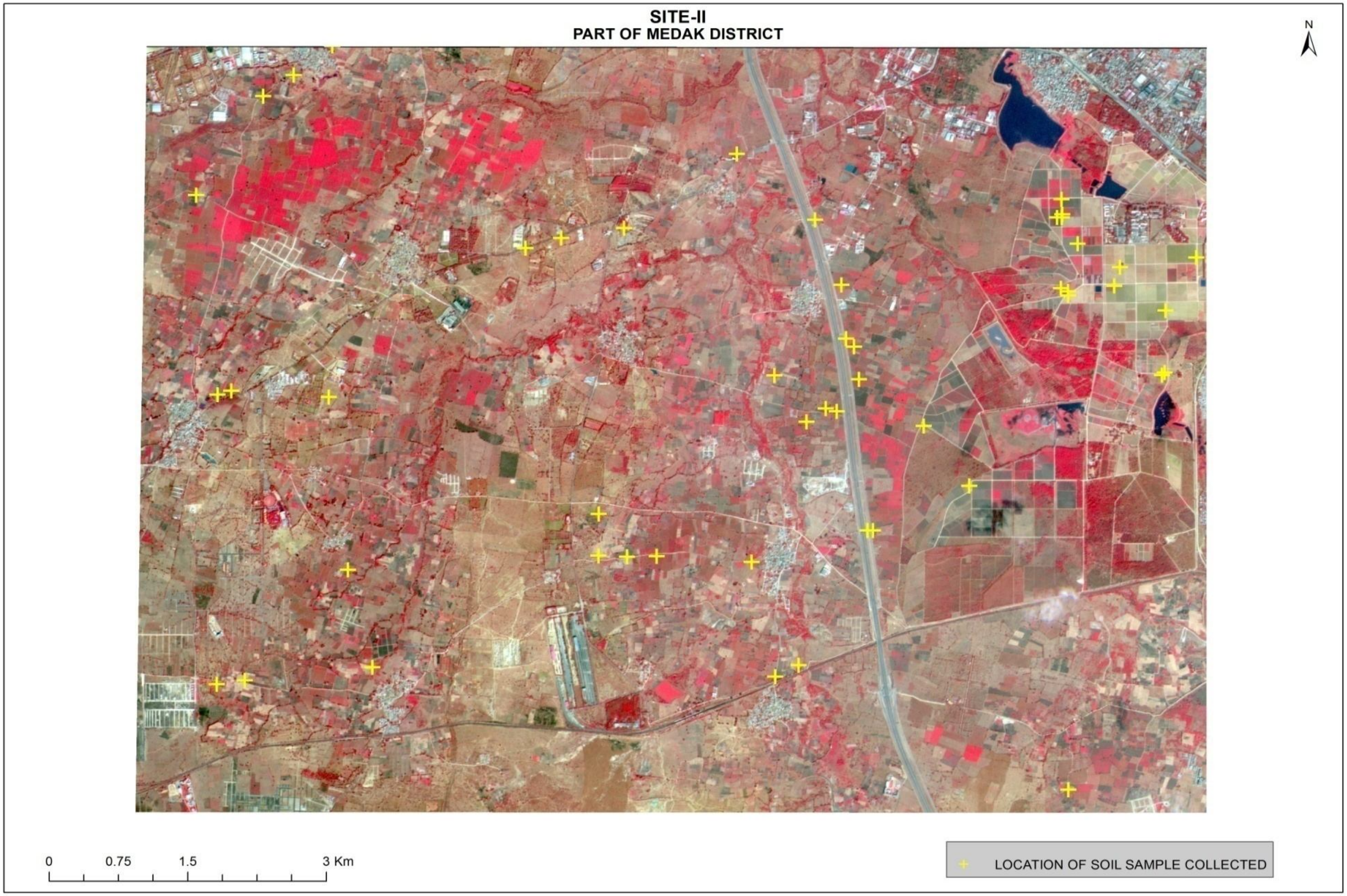


Figure 3.4 Location of soil sample collected in Site-II Parts of Medak district

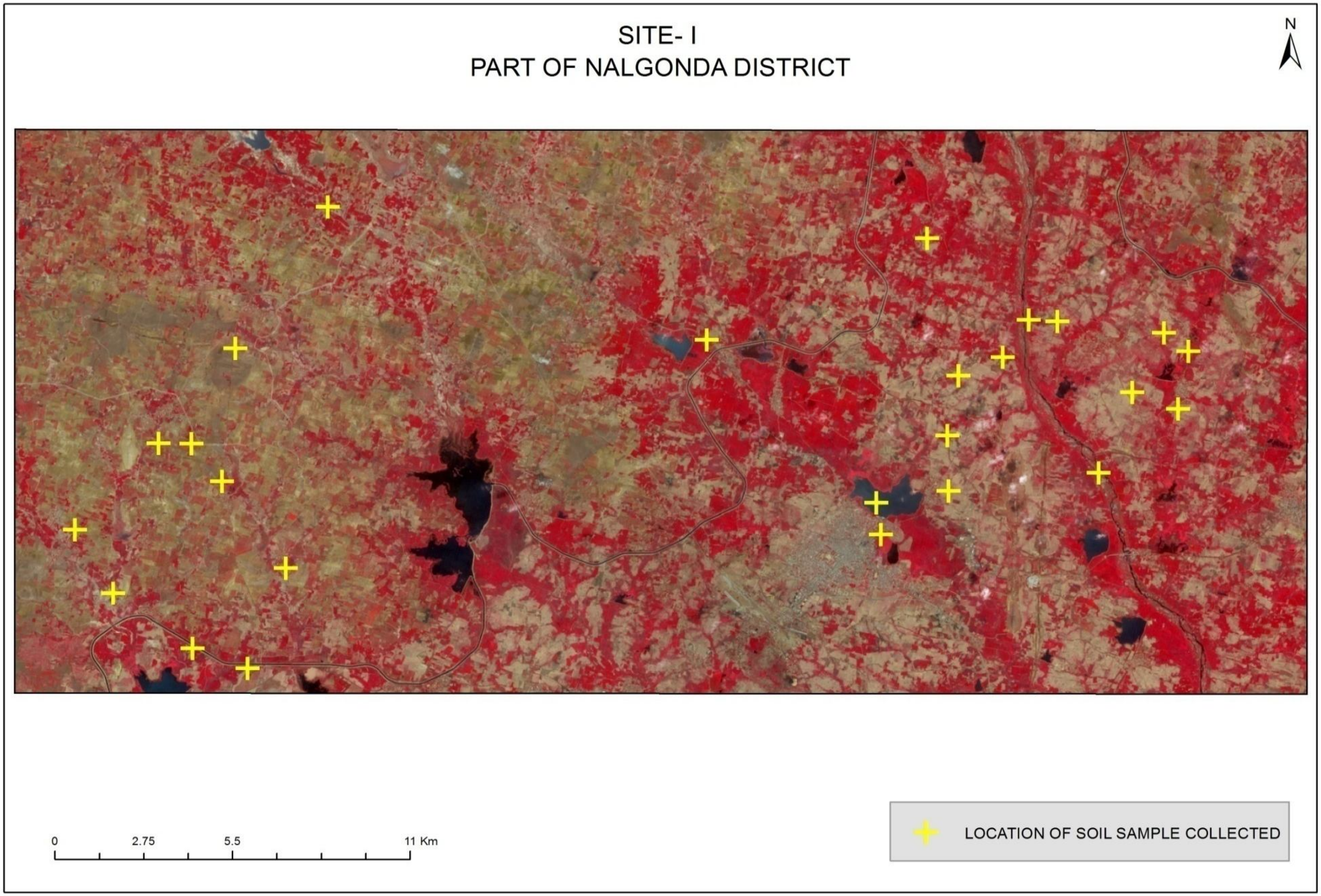


Figure 3.3 Location of soil sample collected in Site-I (Parts of Nalgonda district)

Chapter IV

RESULTS AND DISCUSSION

The results of study on "**Characterisation and Mapping of Salt affected Soils using Hyperspectral data in Parts of Medak and Nalgonda districts"** are presented and discussed in this chapter. The soil samples collected during ground truth were analyzed for their Physical, Chemical and Physico-chemical properties. The surface soil samples (114) were analyzed for soil properties *viz.*, pH, Electric Conductivity (EC), organic carbon percentage, Cation Exchange Capacity (CEC), available Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sodium, and Exchangeable Sodium Percentage (ESP). Based on soil pH, (EC), CEC and ESP values of these soil samples, soils were grouped into normal, slightly saline-sodic, moderately saline-sodic and severely saline-sodic soils. The Physical and chemical properties of the site-I (parts of Nalgonda district) are presented in Table 4.1 and that of site-II (parts of Medak district) are presented in Table 4.2 .

4.1 Site-I : Parts of Nalgonda district :

In general the soils are neutral to severely alkaline in reaction with pH ranged from 7.11 to 9.62 (Table 4.1)

The electrical conductivity of the sampling sites varied from normal to saline with values ranged from 0.17 to 3.6 dSm^{-1}.

In site - I *i.e.*, in parts of Nalgonda district the organic carbon content was low to high and it varied from 0.148 % to 2.108 %.

The Nitrogen content of this site varied as low as 12.60 to 863 kg ha^{-1}. Most of the soil sites are medium in nitrogen content and a positive correlation between organic carbon and nitrogen were observed though correlations were not worked out as it is out of the present study.

The Phosphorus content of soils were varied from 2.19 to 63.62 kg ha^{-1}.

The cations of the soil *i.e.*, potassium content of the soils varied from 2.89 to 16.11 meq/, sodium content varied from 0.71 to15.44 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 %.

4.2 Site-II : Parts of Medak district :

The soil reaction in this site varied from slightly acidic to strongly alkaline with pH values ranged from 5.78 to 8.73.

The EC of the soil samples ranged from 0.07 to 3.87 dSm^{-1} which comes under normal to saline category.

The Nitrogen content varied from low to high and the values ranged from 31.5 to 882 kg ha^{-1}.

The Phosphorus content in the soils varied from 15.4 to 59.8 kg ha^{-1}. It is comparatively lower than the P content of the site-I.

The cations of the soil *i.e.*,potassium content of the soils were varied from 0.36 to 4.03 meq/l, sodium content varied from 0.56 to 7.98 meq/l, Calcium content varied from 9.20 to 15.20 meq/l, and magnesium content varied from 4.60 to 11.40 meq/l.

The cation exchange capacity (CEC) of the soils varied from 18.40 to 30.40 c mol $[p^+]$ kg^{-1} and exchangeable sodium percentage (ESP) of the soils varied from 2.7 to 27.5 % .

4.3 Soil salinity class-Parts of Nalgonda district :

The pH of the normal soils ranged from 7.11 to 9.04, slightly saline-sodic from 7.80 to 8.33, moderately saline-sodic from 7.94 to 8.74 and severely saline-sodic from 7.90 to 9.62. The high pH is recorded in severely saline-sodic soils i.e., 9.62.

The EC (dSm^{-1}) of the normal soils ranged from 0.17 to 1.457 slightly saline-sodic from 2.05 to 2.8 moderately saline-sodic from 2.4 to 3.6 and severely saline-sodic from 2.9 to 3.6. The high EC is recorded in severely saline-sodic soils *i.e.*, 3.6 dSm^{-1}.

The OC (%) of the normal soils ranged from 0.326 to 2.108, slightly saline-sodic from 0.475 to 1.707 moderately saline-sodic from 0.326 to 1.603 and severly saline-sodic from 0.148 to 0.831. The high organic carbon content is observed in normal soils *i.e.*, 2.108%.

The Nitrogen content (kg ha^{-1}) of the normal soils ranged from 157.5 to 461.1, Slightly saline-sodic from 0220.5 to 863.4 moderately saline-sodic from 422.1 to 743.4, and severly saline-sodic from 12.6 to 252.1.The high nitrogen content is observed in moderately saline-sodic soils *i.e.,* 743.4 (kg ha^{-1})

The Phosphorus content (kg ha^{-1}) of the normal soils ranged from 4.9 to 63.6, Slightly saline-sodic from 12.7 to 40. moderately saline-sodic soils from 24.1 to 46.8, and severly saline-sodic from 2.1 to 64.05. The high P content is observed in severly saline-sodic soils *i.e.,* 64.05 (kg ha^{-1}).

The cations *i.e.* Sodium (Na^+) in (meq/l) ranged from 0.8 to 1.74 for normal soils, 1.4 to 3.12 for Slightly saline-sodic soils, 2.33 to 5.94 for moderately saline-sodic soils and 13.0 to 15.44 for severly saline-sodic soils, Potassium (K^+) ranged from 3.21 to 10.14 for normal soils, 2.9 to 7.34 for Slightly saline-sodic soils, 4.84 to 16.11 for moderately saline-sodic soils and 2.88 to 5.4 for severly saline-sodic soils Calcium (Ca^{2+}) ranged from 8.8 to 15.4 for normal soils, 10.4 to 14.8 for Slightly saline-sodic soils, 8.4 to 12.6 for moderately saline-sodic soils and 7.2 to 12.4 for severly saline-sodic soils and Magnesium (Mg^{2+}) ranged from 4.6 to 8.2 for normal soils, 4.4 to 7.2 for Slightly saline-sodic soils, 5.0 to 7.4 for moderately saline sodic soils and 4.6 to 5.8 for severly saline-sodic soils.

The soil CEC in c mol [p+] kg^{-1} ranged from 20.82 to 27.24 for normal soils, 18.12 to 33.14 for Slightly saline-sodic soils, 22.74 to 33.3 for moderately saline-sodic soils and 27.9 to 38.03 for severe sodic soils. The high CEC is observed in severly saline-sodic soils *i.e.*, 38.03 c mol [p+] kg^{-1}

The soil ESP ranged from 2.224% to 6.326% for normal soils, 5.383% to 9.261% for Slightly saline-sodic soils, 12.7% to 18.9% for moderately saline-sodic soils and 33.9% to 68.9% for severly saline-sodic soils. The high ESP is observed in severly saline-sodic soils *i.e.,* 68.9%.

4.4 Soil salinity class- Parts of Medak distict :

The pH of the normal soils ranged from 7.2 to 8.43, slightly sodic from 5.78 to 8.55, moderately sodic from 7.85 to 8.73 and severe sodic from 8.26 to 8.45.

The EC (dSm^{-1}) of the normal soils ranged from 0.07 to 1.47, Slightly saline-sodic from 2.01 to 2.97, moderately saline-sodic from 2.13 to 3.63 and severly saline-sodic from 3.06 to 3.87.

The OC (%) of the normal soils ranged from 0.16 to 1.42, Slightly saline-sodic from 0.14 to 1.648 moderately saline-sodic from 0.04 to 1.158, and severly saline-sodic from 0.32 to 0.772.

The N (kg ha^{-1}) of the normal soils ranged from 100.8 to 882.1, Slightly saline-sodic from 31.5 to 680.4 moderately saline-sodic from 151.2 to 762.3, and severly saline-sodic from 220.5 to 321.6

The P (kg ha^{-1}) of the normal soils ranged from 15.4 to 59.8, Slightly saline-sodic from 17 to 51 moderately saline-sodic from 21.3 to 45.6, and severly saline-sodic from 19.2 to 25.4.

The cations *i.e.*, (Na^+) in (meq/l) ranged from 0.56 to 1.91 for normal soils, 1.03 to 2.378 for Slightly saline-sodic soils, 0.96 to 4.96 for moderately saline-sodic soils and 5.45 to 7.98 for severly saline-sodic soils, Potassium (K^+) ranged from 0.640 to 3.87 for normal soils, 0.36 to 3.73 for Slightly saline-sodic soils, 0.79 to 3.42 for moderately saline-sodic soils and 0.81 to 4.03 for severly saline-sodic soils Calcium (Ca^{2+}) ranged from 9.2 to 14.4 for normal soils, 9.8 to 15.2 for Slightly saline-sodic soils, 9.4 to 13.6 for moderately saline-sodic soils and 9.2 to 13.6 for severly saline-sodic soils and Magnesium (Mg^{2+}) ranged from 3.8 to 11.4 for normal soils, 4.6 to 8.6 for Slightly saline-sodic soils, 5.2 to 7.4 for moderately saline-sodic soils and 4.6 to 8.0 for severly saline-sodic soils.

The soil CEC in c mol [p+] kg^{-1} ranged from 18.54 to 28.3 for normal soils, 19.9 to 26.12 for Slightly saline-sodic soils, 18.4 to 29.04 for moderately saline-sodic soils and 24 to 30.4 for severly saline-sodic soils.

The soil ESP ranged from 2.7 to 4.9 for normal soils, 5. 01 to 9.71 for Slightly saline-sodic soils, 3.8 to 19.5 for moderately saline-sodic soils and 22.7 to 27.5 for saline sodic severe soils.

4.5 Spectral reflectance pattern of soils :

The spectral reflectance curves of the soil samples were generated using hyper spectroradiometer data covering a range of 350–2500 nm of electromagnetic spectrum under field conditions. The observed reflectance values were resampled at 10-nm interval. Results showed an increasing trend of soil reflectance with increase in wavelength of electromagnetic radiation for the studied soil irrespective to the nature of the soils. Results also revealed that although there is a steady increase in reflectance for all the soil samples with increase in electromagnetic wavelength, a significant decreases in reflectance at 1380 and 1940 nm was observed, which is most prominent in severely saline-sodic soil. A significant decrease in reflectance at 1380 and 1940 nm wavelength was observed irrespective of soil samples because of higher absorption due to presence of moisture and hydroxyl ions. The more prominent absorption dips were found in sodic soil as because of the fact it contains the anions such as chloride, sulphates, carbonates in a great extent which are hygroscopic in nature as well as abundant quantity of Mg^{+2} and Na^{+} cations having higher hydration energy which can hold more water. It is also observed that the saline soil exhibited comparatively higher reflectance values throughout the entire wavelengths (320–2500 nm) compared to normal soil samples. Stoner (1979) also reported higher reflectance values in saline soils than in normal soil in entire wavelength range. Severely saline-sodic soils showed very high reflectance throughout the spectrum compared to other soils. But moderately saline-sodic soils displayed low reflectance intensity at 1850 and 1870nm than slightly saline-sodic and normal soils. The main reason of this phenomenon is due to higher amount of moisture present in the samples during spectral measurement. This finding has corroborated with Shrestha *et al.* (2005) who reported that the moderately sodic soils showed low reflectance than slightly and normal because of higher amount of moisture present in the samples during spectral measurement. These differences in reflectance curves (peaks and troughs) of different samples could be due to interaction of various physical and chemical properties of the soils such as pH, EC, ESP, texture and $CaCO_3$ content. The soil reflectance curve is affected by soil physical and chemical properties. The major physical properties of soil which affects the spectral response pattern are soil colour, soil moisture, soil texture, soil structure, soil surface conditions/roughness *etc.* The major soil chemical properties are organic matter content, soil mineralogy, iron and aluminium oxides, salinity, carbonates *etc.* All the physical and chemical properties influence absorption of incident radiation which could be seen as troughs in the spectral reflectance curve. With increase in soil moisture, there will be a decrease in reflectance in visible and infrared regions. Similarly, an increase in organic matter content reduces the soil reflectance. A coarse textured soil reflects more than the fine textured soils.

4.6 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 Pearson correlation matrix showed (Table 4.5)

The results observed was in conformity with the study conducted by Farifteh and Van der Meer (2007a) 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

4.7 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.* (2012); Farifteh and Van der meer (2007b). 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.*(2015). 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 soil properties 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 and c.

Table 4.5 Correlation matrix (Pearson) of soil attributes and reflectance values of selected wavelength

	EC	CEC	ESP
EC	1	.924**	.814**
CEC	0.924**	1	.909**
ESP	0.814**	0.909**	1
400	-0.264	-.0346*	-0.161
410	-0.282	-0.366*	-0.184
710	0.526**	0.400*	0.300
720	0.516**	0.443**	0.306
730	0.447**	0.403*	0.256
740	0.398*	0.367*	0.216
750	0.374*	0.348*	0.196
760	0.364*	0.336	0.185
770	0.362*	0.335	0.183
780	0.360*	0.332	0.181
790	0.360*	0.330	0.179
800	0.359*	0.328	0.178
810	0.358*	0.326	0.176
820	0.358*	0.324	0.174
830	0.358*	0.323	0.175
840	0.357*	0.322	0.173
850	0.357*	0.320	0.173
860	0.355*	0.318	0.171
870	0.355*	0.317	0.171
880	0.355*	0.315	0.169
890	0.354*	0.313	0.168
900	0.357*	0.313	0.168
910	0.355*	0.310	0.166
920	0.356*	0.310	0.166
930	0.361*	0.312	0.170
940	0.364*	0.312	0.171
950	0.378*	0.321	0.181
960	0.381*	0.320	0.181
970	0.374*	0.312	0.174
980	0.375*	0.312	0.174
990	0.373*	0.311	0.173
1000	0.366*	0.304	0.165
1010	0.356*	0.297	.159
1020	0.354*	0.296	0.157
1030	0.351*	0.293	0.154
1040	0.349*	0.292	0.152
1050	0.348*	0.291	0.150

1060	0.346*	0.289	0.149
1070	0.346*	0.287	0.147
1080	0.347*	0.287	0.147
1090	0.348*	0.286	0.146
1100	0.351*	0.285	0.146
1110	0.356*	0.286	0.148
1120	0.360*	0.292	0.154
1130	0.370*	0.293	0.158
1140	0.373*	0.289	0.159
1150	0.380*	0.286	0.161
1160	0.382*	0.283	0.160
1170	0.379*	0.278	0.155
1180	0.377*	0.275	0.153
1190	0.376*	0.273	0.153
1200	0.375*	0.272	0.151
1210	0.375*	0.272	0.150
1220	0.376*	0.274	0.152
1230	0.376*	0.275	0.152
1240	0.376*	0.276	0.151
1250	0.376*	0.276	0.151
1260	0.376*	0.275	0.149
1270	0.378*	0.276	0.151
1280	0.378*	0.273	0.150
1290	0.378*	0.270	0.148
1300	0.378*	0.266	0.147
1310	0.378*	0.258	0.144
1320	0.376*	0.248	0.141
1330	0.366*	0.231	0.133
1380	0.356*	0.215	0.124
1400	0.406*	0.318	0.202
1870	-0.363*	-0.384*	-0.345*
1920	-0.373*	-0.296	-0.245
2140	0.236	0.187	0.340*
2150	0.243	0.195	0.347*
2160	0.261	0.217	0.368*
2170	0.276	0.232	0.381*
2180	0.304	0.262	0.405*
2190	0.326	0.281	0.417*
2200	0.345*	0.302	0.434*
2210	0.365*	0.320	0.446**
2220	0.372*	0.323	0.443**
2230	0.358*	0.308	0.429*
2240	0.349*	0.299	0.419*
2250	0.332	0.285	0.412*
2260	0.314	0.267	0.399*
2270	0.285	0.240	0.381*
2280	0.257	0.212	0.361*
2290	0.244	0.200	0.354*
2300	0.233	0.187	0.347*
2480	0.413*	0.360*	0.407*

4.8 Identification and mapping of salt-affected soils:

Based on characterization the soils of study area they were grouped in to normal, slightly saline-sodic, moderately saline- sodic and severely saline-sodic classes.

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*. (2011), Koshal (2012) and Kumar (2014). 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.

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

S.No	**Class**	**Salinity (dS/m) black soil**	**Other soil**	**ESP** Black soil	**ESP** 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).

It was observed that the salt affected soils were of slightly saline-sodic, moderate and severely saline-sodic type. The spectral behavior of the different categories of salt affected soils in LISS-IV sensor was depicted in Figure 4.3. It can be observed that the DN values increased with increasing severity of the saline class. Same pattern of increasing DN values with increase in soil salinity is observed by Koshal (2012) Similar trend is observed in LISS-III sensor also (Figure 4.4)

From the false colour composite, it may be observed that the saline soils were manifested in bright white to dull white tones and the bright tones is due to the salt encrustation. However, some place the tones are subdued and is due to high moisture content. The delineated salt affected soils were shown in the (Figures 4.5 and 4.6) for the two test sites respectively.

Among the study areas, in site-I, the area under slightly saline-sodic category was found to be 378 ha, the area under moderately saline-sodic category was 90 ha, severely saline-sodic soils are 178.43 ha and the total salt affected land is 646 ha and the rest of the area was normal. Similarly in site-II the area under slightly saline-sodic category was 88.53 ha, moderately saline-sodic category was 11.4 ha and severely saline-sodic category was 5.5 ha.

Hence, about 646 ha area out of 20000 ha of test site-I (parts of Nalgonda district) was affected by salinity and sodicity which was categorized in to slightly saline-sodic, moderately saline-sodic and severly saline-sodic soils. As given in legend in site-I (parts of Nalgonda district) classified image, the yellow colour indicates the slightly saline-sodic, light blue colour /aqua colour indicates moderately saline-sodic soils and dark blue colour indicates the severely saline-sodic soils and the rest of image which is not classified is normal soil. Similarly 105.43 ha of test site-II (parts of medak district) was affected by salinity and sodicity which was categorized in to slightly saline-sodic, moderately saline-sodic and severly saline-sodic soils. As given in legend in site-II (parts of medak district) classified image, , the yellow colour indicates the slightly saline-sodic, light blue colour /aqua colour indicates moderately saline-sodic soils and dark blue colour indicates the severely saline-sodic soils and the rest of image which is not classified is normal soil.

The study by figure 4.5 and figure 4.6 also reported the occurrence of saline sodic soils in this region was due to semi-arid climate with more of ET than the rainfall/precipitation, the salt might have been translocated to the surface along with the capillary water movement. The soils being different variants of vertisols and inceptisols, the appearance of salt affected soils on the image is not manifested fully, unlike in loamy soils of Gangetic plains.

4.9 Management of saline soils :

Management of sodic soils presents difficulties due to their physical and chemical properties , which affect seed-bed preparation, Irrigation practices, drainage, choice of crops and other field operations.

4.9.1 For slightly saline-sodic soils :

a) **Green manuring :**

Application of green manure can help to enhance organic matter content, increase partial pressure of CO_2, low pH, enhance solubility of native $CaCO_3$ and add plant nutrients. Dhaincha (*sesbania*) which is tolerant high ESP and water logging, is an ideal crop. As it grows during (may-June), a lean period for rice and wheat, it also fits in to the crop rotation for sodic soils. Generally 45 days of old Daincha are ideal for green manuring. (Sadiq 1992 , Ansari and Khanzada 1995)

b) **Drainage :**

The alkali soils basically have low infiltration rate, all the rain water accumulates to create suface water logging . Even a low intensity of rains or a normal irrigation may create temporary water logging and anaerobic conditions. To avoid the problem, surface drainage, especially during rainy season is a must.

4.9.2 For Moderately saline-sodic soils and Severely saline- sodic soils.

4.9.2.1 Cultural practices :

a) **Land Levelling and Shaping :**

To ensure proper water management and uniform leaching of salts, the field should be leveled properly. The bigger fields should be divided in to small parcels and leveled . Drastic removal of the surface soil will expose the subsoil containing $CaCO_3$, which can pose difficulties in management and cropping of the area.

b) Plant population :

Because of the hard crust on the surface, germination percentage is often low in sodic soils . Plant population further decreases because of high rate of mortality, especially during early stages of plant growth. This with poor tillering can reduce crop yield.The plant population can be increased by increasing seed rate and reducing the planting distance. In rice crop, better plant population can be obtained by increasing the number seedlings per hill and by gap filling.

c) **Age of seedlings :**

Generally crop tolerance increases with age. In rice, older seedlings (40-45 days have beem found to establish better than young seedlings of 20-25 days old.

d) **Green manuring :**

Application of green manure can help to enhance organic matter content, increase partial pressure of CO_2, low pH enhance solubility of native $CaCO_3$ and add plant nutrients. Dhaincha (sesbania) which is tolerant high ESP and water logging, is an ideal crop. As it grows during (may-June), a lean period for rice and wheat,it also fits in to the crop rotation for sodic soils. Generally 45 days of old daincha are ideal for green manuring.

e) **Selection of crops :**

Crops are very widely in their tolerance to soil exchangeable sodium . In general, rice and other cereals are more tolerant than legumes. Crop tolerance to soil sodicity varies with the stage of growth, variety environmental conditions and level of management.

f) **Drainage :**

The alkali soils basically have low infiltration rate, all the rain water accumulates to create suface water logging . Even a low intensity of rains or a normal irrigation may create temporary water logging and anaerobic conditions. To avoid the problem, surface drainage, especially during rainy season is a must.

g) **Irrigation :**

Irrigation poses peculiar problem due to clogging action of dispersed soil particles and low stability of soil aggregates, which limit the water and air permeability of these soils. Because of this restricted entry from the surface, recharge of depleted soil moisture does not take place during irrigation of alkali soil. Furthermore, during the post irrigation period, the water transmission from the lower layers to upper layers to meet the evapotranspiration needs of the crop is severly restricted by the low hydraulic conductivity of soil. During reclamation, upper soil layer are improved and roots are confined to the 30 cm layer. The limited root growth restricts the depth of moisture extraction following irrigation. All these constraints affect the ability of alkali soil to supply adequate water to the growing plants. The depth and frequency of irrigation depends upon the evaporative demand, nature of plant response to soil water stress, depth of root development and the water storage and transmission characteristics of the soil, light or frequent irrigation should be applied in alkali soils. Normally, a surface method of irrigation such as furrow or basis type flood method is used for alkali soils. Keeping in view their susceptibility to surface waterlogging, the sprinkler method could be promising

h) **Leaching :**

Leaching with water (canal, rain or ground) is the only practical way to remove excess soluble salts from the profile which can be accomplished by ponding of water in properly levelled and bunded fields. The amount of salt leached from the soil profile depends on the quantity and quality of water that passes through the soil. When the salt content of irrigation water is high , the depth of water required for leaching of accumulated salts are more. In light textured soils, normally one unit depth of water per unit depth of soil is required to reduce the salinity level of soil to about one fifth of its original value. The water requirement in medium and fine textured soils is much higher. The actual water requirement depends on the initial salinity and salinity tolerance limits of the crop to be grown. Some soils may need gypsum ($CaSO_4$) for soil physical improvement for leaching. For the leaching to be effective, salt rich leachate must be discharged out of the area by natural ground water flow in groundwater basins or flow in to drains and rivers or artificially through man-made surface drainage system.

4.9.2.2 Chemical Amendments :

The chemical amendments are primarily used for the reclamation of sodic soils. These amendments neutralize the pH of the soil, react on the free sodium carbonate and replace exchangeable sodium by calcium.

a) Gypsum :

It occurs as natural deposits as a white coloured secondary material. Besides mines gypsum, it is also available as a by-product from some chemical industries manufacturing phosphoric acid, tartaric acid, oxalic acid, citric acid, and common salt. Major quantities of by-product gypsum commonly known as phosphogypsum, are produced during the manufacture of phosphoric acid by wet digestion. Verma and Abrol 1980 found that improvement in soil properties with the application of gypsum was always greater than pyrites. Sainberg *et al.*,(1982) stated that to reclaim sodic soil, the amount of gypsum required depended on amount of exchangeable sodium in soil. Swarup *et al.*, (1994) reported that gypsum improves soil properties and increases yield of different crops. Patra et al 1996 reported that , use of amendments containing calcium is recommended for reclaiming sodic soils. Joachim *et al.*, (2010) reported that there was significant ($P \leq 0.05$) difference on the exchangeable Na^+ when soil was leached after gypsum

b) Phospho – Gypsum

In addition to the gypsum, large quantities of by-product gypsum are available from different industries manufacturing tartaric acid, formic acid, oxalic acid, citric acid, common salt and phosphoric acid. Major quantities of by-product gypsum, commonly called as phospho-gypsum are produced during the manufacturing of phosphoric acid by wet process in which rock phosphate is treated with sulphuric acid. For every tonne of P_2O_5 produced, 5.5 t of by-product gypsum containing about 25 per cent moisture are produced. The availability of by-product gypsum from the Indian fertilizer industry is expected to be about 17 lakh tones per year. The phospho-gypsum is reported to contain about 90 per cent $CaSO_4$ and 1 or 2 per cent fluorine. Mamoun et al 2012 reported that saline-sodic soil could be reclaimed efficiently with less water using phosphoric acid compared with gypsum.

c) Press mud

With increase in the number of sugar mills, the availability of press muds a sugar factory waste is increasing. Two kinds of refinery processes are used that give rise to two entirely different by-products. Press mud from sugar factories using carbonation process for juice purification contains about 70% calcium carbonate and 11.0% of organic matter. The solubility of calcium carbonate is only 1-1.2 meq/l and depends upon partial pressure of CO_2 and soil pH. The second form of press mud is derived from sugar factories using sulphitation process. The material contains approximately 9.3% calcium sulphate and 35.8% organic matter.

The beneficial effects of press mud in reducing sodicity could be attributed to its calcium content as well as to produce of CO_2 and organic acids during the decomposition of its organic fraction as below:

$CO_2 + H_2O = H_2CO_3$

$CaCO_3 + H_2CO_3 = Ca\ (HCO_3)_2$

$Ca\ (HCO_3)_2 = Ca^{2+} + 2HCO_{3-}$

$Na - Clay + Ca^{2+} = Ca - Soil + 2Na^{+}$

4.9.2.3 Organic Amendements

a) Tree leaves and barks etc :

It has been observed that the bark of babul (*Acacia sp*.), neem (*Azadirachata indica*) and madar (*Calotropis sp*.) powders are effective in decreasing in soil pH, and ESP and increase the CEC and exchangeable calcium in saline-sodic soils. Not only tree bark and leaves but other waste products like tamarind seeds, safflower hulls and groundnut hulls are also effective in reducing soil salinity.

b) Saw dust :

Saw dust is acidic in nature and contains lignin as a major component of its composition. High content of lignin is known decrease the rate of decomposition. This slow rate of decomposition may be highly beneficial under high sodic conditions, as it maintains continuous supply of CO_2 and organic acids which neutralize the alkali without producing anaerobic conditions in the soil. Moreover lignin rich material is transformed in to humus having high CEC. This increased CEC lowers the ESP and thus economise the reclamation process.

c) Weed, wild herbs and shrubs :

Water hyacinth and other aquatic weeds can be utilized as organic amendments for reclaiming sodic soils since they contain good amount of much needed calcium and magnesium besides other plant nutrients like N and P. Mohamed K and Abdel-Fattah 2012 reported that application of gypsum combined with water hyacinth compost or rice straw compost enhanced reclamation process and caused more decreases in salinity as well as sodicity

Table 4.6 Equation of the model and descriptive statistics of the soil properties developed from PLSR

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

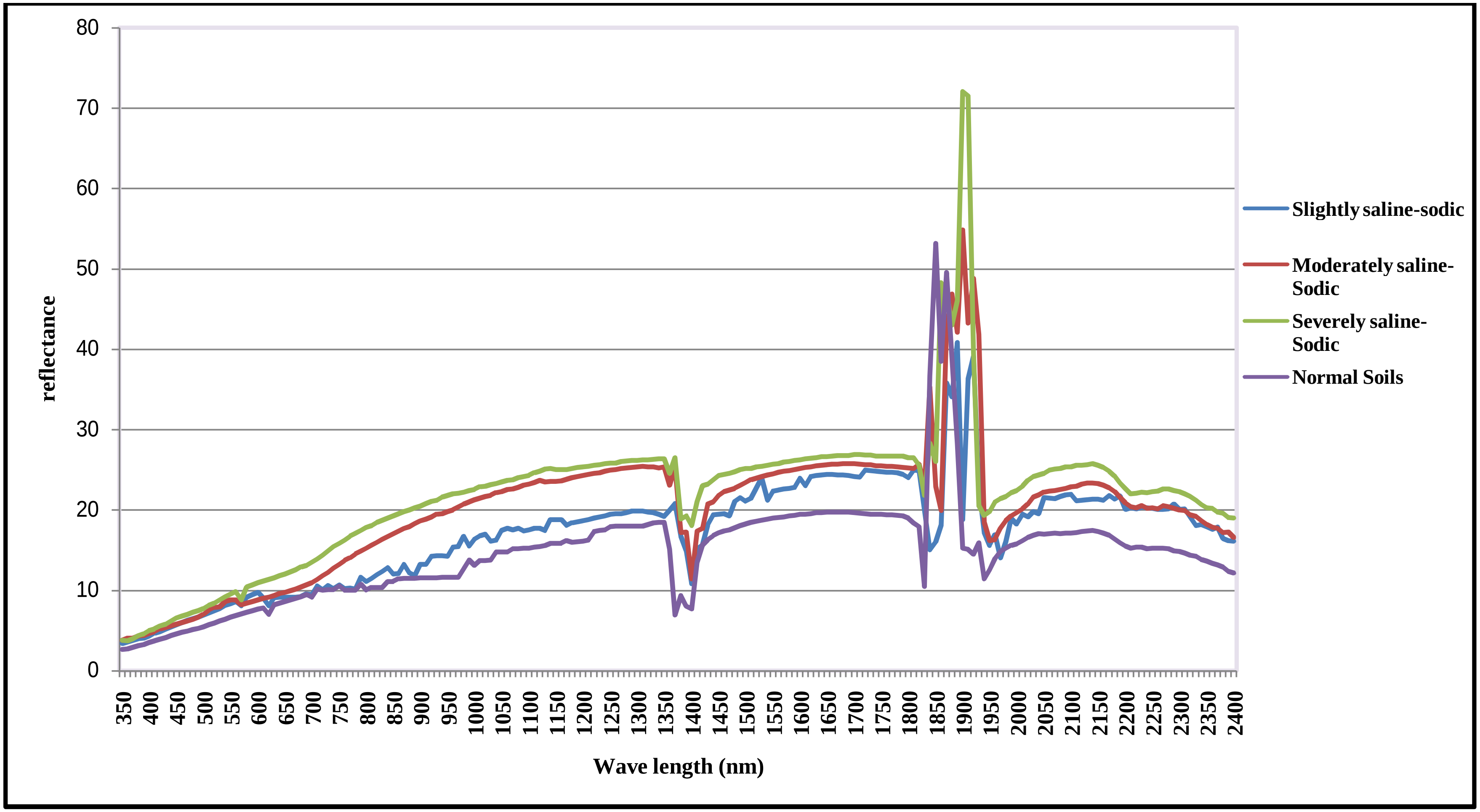


Fig 4.1 .Spectral reflectance pattern of different categories of salt affected soils.

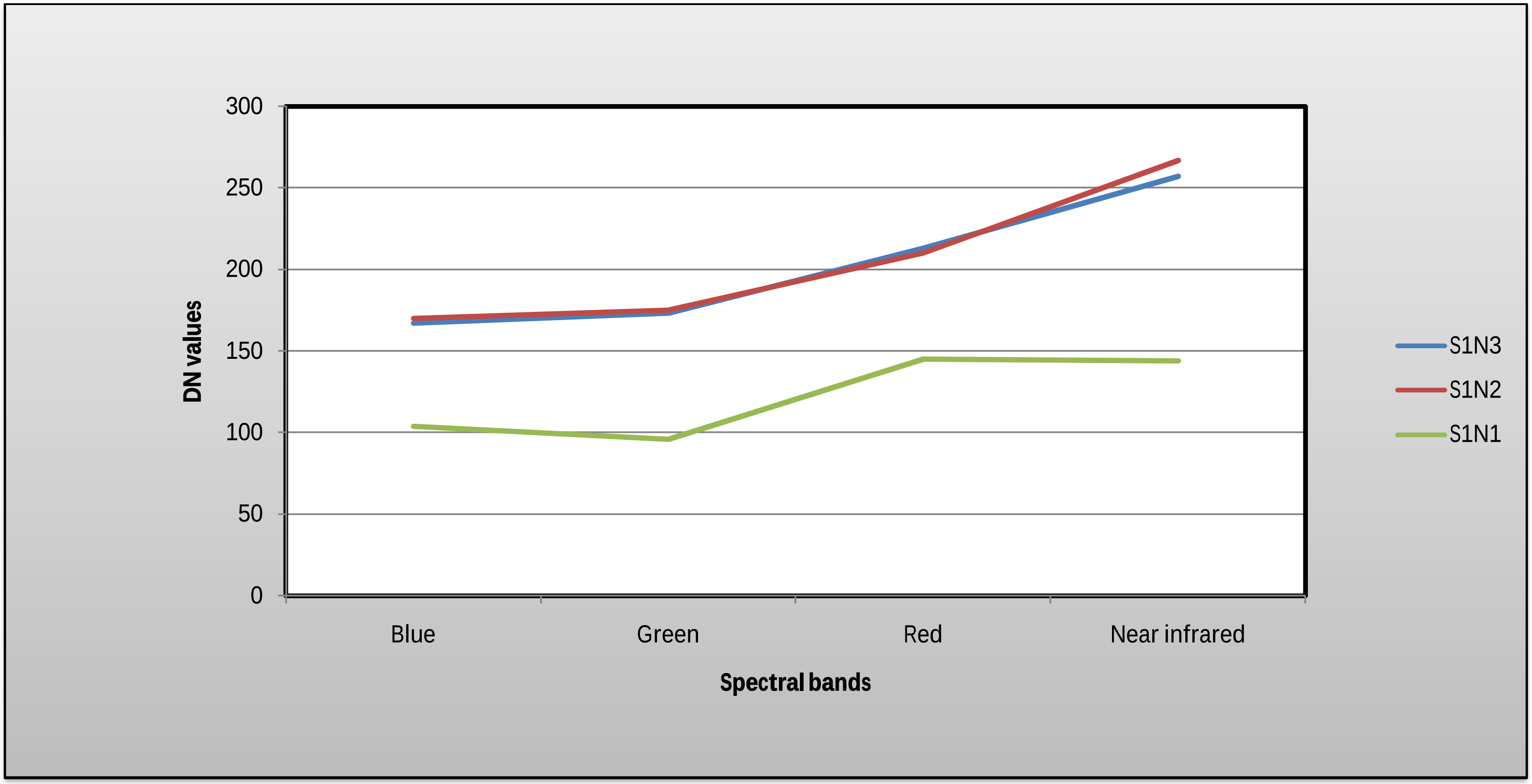


Figure 4.3 DN values at different spectral bands in LISS-III data

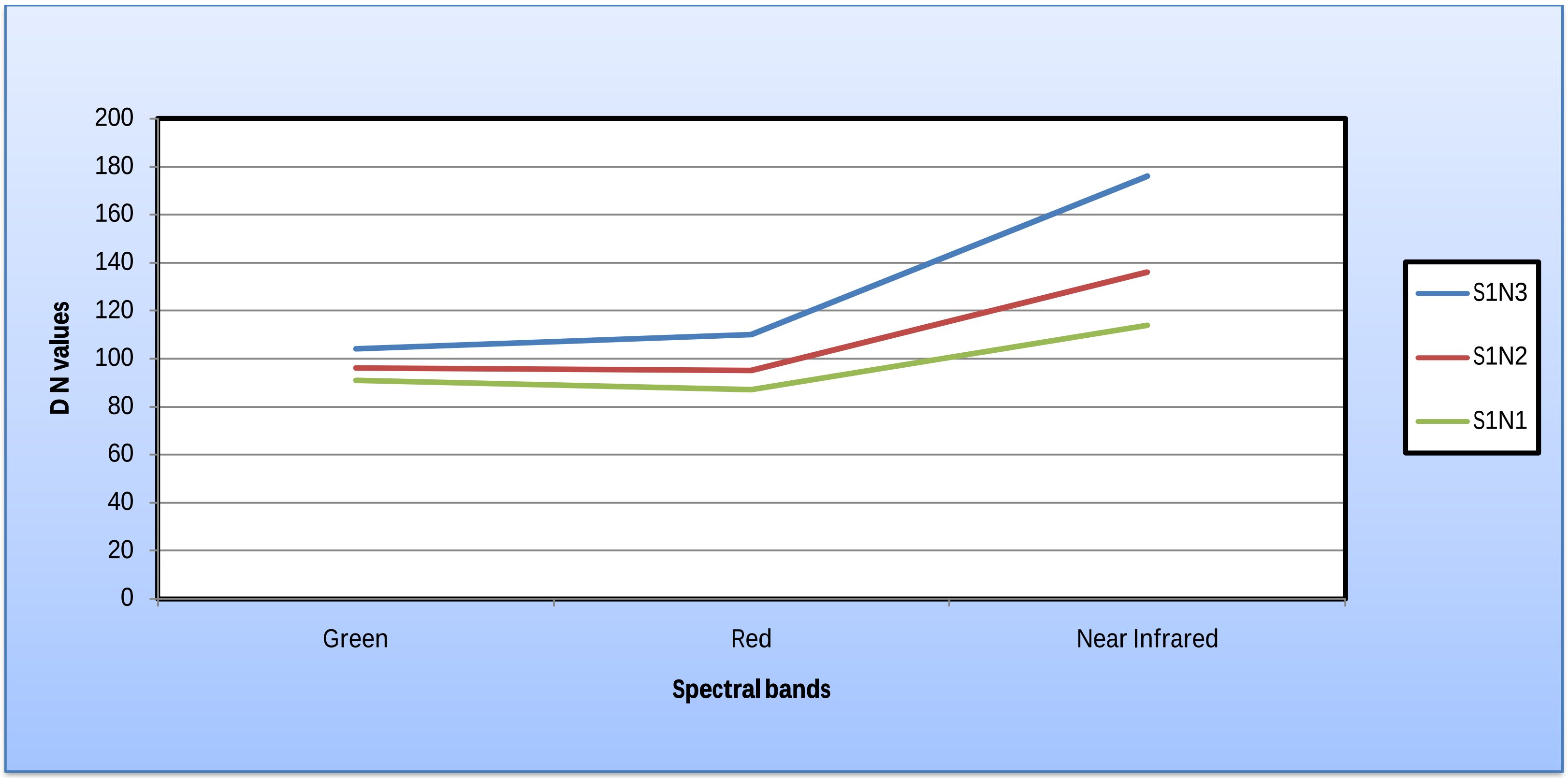


Figure 4.4 DN values at different spectral bands in LISS-IV data,

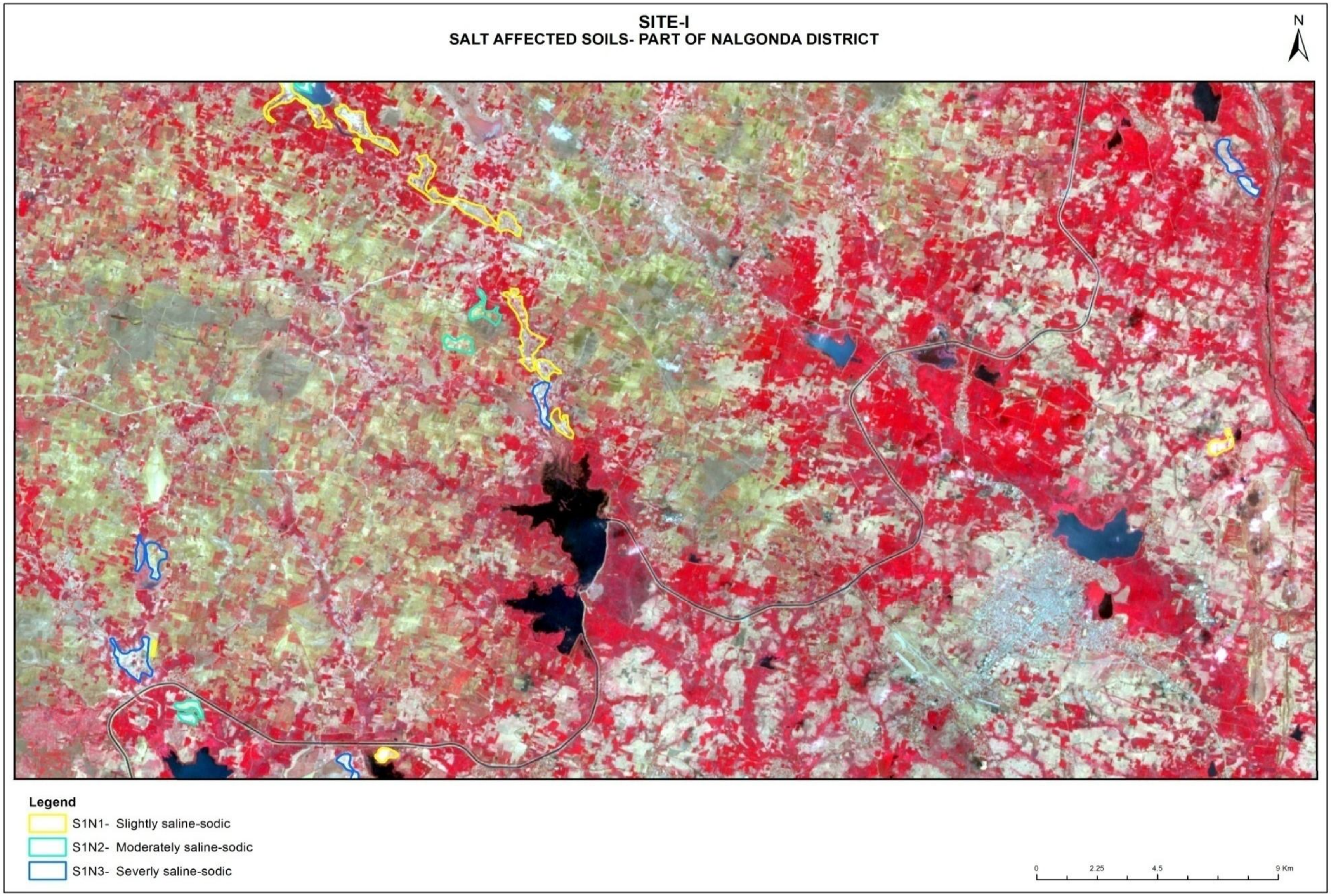


Figure 4.5 Classified image showing different categories of salt affected soils in Site-I (Parts of Nalgonda district)

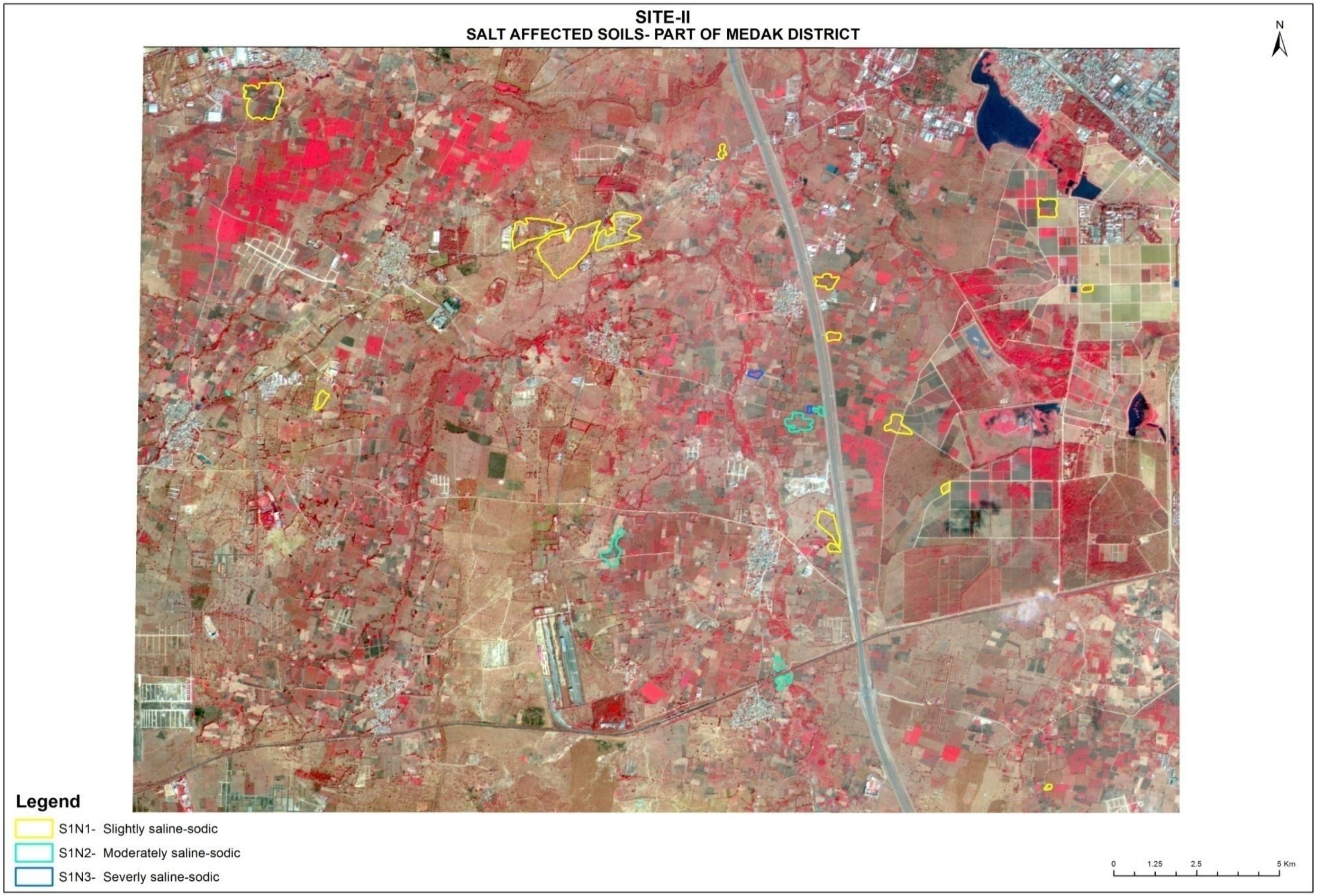


Figure 4.6 Classified image showing different categories of salt affected soils in Site-II (Parts of Medak district)

Table 4.3 Ranges of soil properties for the identified saline soil classes of site-I (parts of Nalgonda district)

	pH	EC(dSm^{-1})	OC (%)	N (Kg/ha)	P (Kg/ha)	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	0.85	348.96	26.78	5.08	1.03	11.70	5.72	24.64	3.87
Range	7.1-9.0	0.17-1.45	0.32-2.10	157.5-461.1	4.9-63.6	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	0.61	156.05	16.27	2.34	0.32	2.35	1.11	2.55	1.30
Saline Sodic Slightly (9)											
Mean	7.95	2.39	0.90	541.83	50.92	4.41	2.23	13.02	5.60	25.84	7.37
Range	7.8-8.3	2.05-2.8	0.47-1.70	220.5-863.4	12.7-40.6	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	0.45	230.97	32.15	1.65	0.65	1.59	0.95	5.07	1.34
Saline Sodic Moderately (5)											
Mean	8.37	2.89	0.87	595.98	34.45	6.94	4.52	10.76	5.96	27.92	15.75
Range	7.9-8.7	2.4-3.6	0.32-1.60	422.1-743.4	24.1-46.8	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	0.47	119.92	9.10	5.45	1.49	1.60	0.95	4.85	2.54
Saline Sodic Severe (4)											
Mean	8.72	3.2	0.38	237.78	20.48	4.06	13.97	10.4	5.15	35.02	45.94
Range	7.9-9.6	2.9-3.6	0.14-0.83	12.6-252.1	2.1-64.05	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	0.31	281.45	29.24	1.083	1.17	2.32	0.50	4.79	15.70

Table 4.4 Ranges of soil properties for the identified saline soil classes of site-II (parts of Medak district)

	pH	EC (dSm^{-1})	OC (%)	N (kg/ha)	P (kg/ha)	K (meq/l)	Na (meq/l)	Ca^{2+}(meq/l)	Mg^{2+} (meq/l)	CEC (c mol [p+] kg^{-1})	ESP
Normal Soils (34)											
Mean	7.97	0.62	0.62	327.52	32.71	2.02	1.01	11.6	6.55	22.36	4.10
Range	7.2-8.43	0.07-1.47	0.16-1.42	100.8-882.1	15.4-59.8	0.64-3.87	0.56-1.91	9.2-14.4	3.8-11.4	18.54-28.3	2.7-4.9
SD	0.32	0.52	0.36	210.72	9.80	0.82	0.22	1.24	1.74	2.01	0.53
Saline Sodic (slight) (30)											
Mean	7.84	2.33	0.70	248.15	30.24	2.08	1.59	11.44	5.84	22.91	6.80
Range	5.78-8.55	2.01-2.97	0.14-1.648	31.5-680.4	17-51	0.369-3.73	1.03-2.38	9.8-15.2	4.6-8.6	19.9-26.12	5.01-9.71
SD	0.74	0.25	0.41	161.81	10.16	0.86	0.39	1.63	0.96	1.82	1.53
Saline Sodic Moderately(14)											
Mean	7.99	3.10	0.66	285.45	29.26	2.21	3.69	11.52	6.2	24.73	14.37
Range	7.85-8.73	2.13-3.63	0.04-1.158	151.2-762.3	21.3-45.6	0.79-3.42	0.96-4.96	9.4-13.6	5.2-7.4	18.4-29.04	3.8-19.5
SD	0.72	0.45	0.33	182.75	7.04	0.89	1.33	1.36	0.82	2.97	4.49
*Saline Sodic Severe (*3)											
Mean	8.34	3.43	0.61	262.37	22.17	2.14	7.04	10.86	6.26	27.46	25.50
Range	8.26-8.45	3.06-3.87	0.32-0.772	220.5-321.6	19.2-25.4	0.81-4.03	5.45-7.98	9.2-13.6	4.6-8.0	24.0-30.4	22.7-27.5
SD	0.10	0.40	0.25	52.74	3.11	1.67	1.38	2.38	1.70	3.23	2.49

Table 4.4 Site-II Medak Soil properties :

Table 4.1 Soil physical, physico-chemical and chemical properties of site-I (parts of Nalgonda district)

SAM ID	Latitude	Longitude	pH	EC(dSm^{-1})	OC(%)	N (kg/ha)	P (kg/ha)	K in meq/l	Na+ in meq/l	Ca^{2+} in meq/lit	Mg^{2+} in meq/l	CEC in c mol (p+) kg^{-1}	ESP	Sodicity class	TEXTURE
NSKC1901	16˚55'9.5"	79˚23'9.47"	8.23	0.44	0.48	157.50	25.02	3.22	1.20	12.4	5.6	24.2	4.96	NORMAL	Loamy
NSKC1904	16˚54'25.7"	79˚24'43"	9.62	2.95	0.22	56.40	2.19	3.58	13.04	7.20	4.6	27.9	68.97	S1N3	ClayLoamy
NSKC1908	16˚55'8.3"	79˚26'6.88"	9.17	3.05	0.15	12.60	10.30	4.38	14.40	10.2	5.2	37.1	38.83	S1N3	Silt loam
NKK 2001	16˚54'23.2"	79˚35'33.6"	7.80	2.21	0.62	554.40	36.29	4.74	2.43	13.8	5.4	28.5	8.53	S1N1	Clay loam
NKK 2004	16˚53'25.2"	79˚35'35.1"	7.95	2.06	1.51	863.40	39.20	2.91	2.28	14.8	7.2	28.2	8.07	S1N1	sandy loam
NKK 2005	16˚55'45.1"	79˚29'45.1"	7.86	2.77	1.71	661.50	38.64	6.23	3.06	14.6	7.0	33.0	9.26	S1N1	Silt clay loam
NKK 2006	16˚57'49.1"	79˚35'10.9"	8.00	2.37	0.48	270.90	38.75	3.31	3.14	11.4	4.8	18.1	8.39	S1N1	Loam
NKK 2007	16˚53'45.2"	79˚38'12.4"	8.01	0.37	2.28	812.70	41.22	7.44	0.80	15.4	4.8	24.1	2.57	NORMAL	Silt loam
NKK 2008	16˚54'26.1"	79˚49'19.5"	7.88	2.82	0.95	686.70	37.86	7.34	2.43	14.2	6.0	32.5	7.49	S1N1	Clay loam
NKK 2010	16˚55'25.5"	79˚35'45"	8.12	2.73	1.60	661.50	46.82	4.71	3.74	12.6	6.4	29.4	12.73	S1N2	Clay loam
NKK 2011	16˚56'24.3"	79˚36'58"	8.33	2.75	0.97	743.40	38.75	4.84	5.94	10.2	7.4	31.3	18.98	S1N2	Silt Clay loam
NKK 2012	16˚54'42.1"	79˚45'55"	8.02	2.42	1.00	711.90	31.81	5.56	1.53	10.4	5.2	22.4	5.38	S1N1	Silt loam
NKK 2016	16˚53'12.5"	79˚34'20"	7.98	0.38	1.40	447.30	38.75	3.27	0.71	14.0	5.4	25.1	2.84	NORMAL	Loamy sand
NKK 2017	16˚55'25.6"	79˚35'45"	7.90	2.44	0.85	636.30	52.64	3.84	1.41	12.8	5.4	24.0	5.87	S1N1	Loam
NAC2101	16˚56'11.72"	79˚38'79.64"	7.11	0.17	0.47	262.50	26.21	2.86	0.95	10.0	5.0	20.8	4.54	NORMAL	Loamy sand
NAC2106	16˚55'52.72"	79˚39'45.43"	8.30	1.20	0.37	461.10	31.14	3.25	0.85	12.6	5.4	24.5	3.48	NORMAL	Loamy sand
NAC2108	16˚54'52.42"	79˚39'35"	7.83	2.15	0.48	270.90	45.33	2.45	1.44	11.4	4.4	21.3	6.77	S1N1	Loamy sand
NAC2110	16˚52'39.5"	79˚34'25"	7.30	0.19	0.77	365.40	46.82	3.22	0.57	10.2	7.2	22.5	2.54	NORMAL	Loamy sand
NAC2111	16˚52'28.5"	79˚34'38"	7.90	3.16	0.33	252.10	64.06	2.89	15.44	11.8	5.0	36.8	41.96	S1N3	Sandy loam
NNG0401	16˚55'48.612"	79˚23'7.44"	8.00	0.33	2.11	233.10	18.14	6.98	1.13	14.8	5.0	30.5	3.70	NORMAL	Clay loam
NNG0402	16˚53'29.94"	79˚22'54.912"	8.03	1.14	0.33	403.20	63.62	8.59	0.85	11.2	5.0	25.6	2.69	NORMAL	Silt loam
NNG0403	16˚54'8.8"	79˚22'22.476"	7.92	0.65	0.37	302.40	4.93	3.71	1.03	13.0	4.6	24.4	4.24	NORMAL	Sandy loam
NNG0404	16˚54'8.82"	79˚22'22.476"	8.47	0.87	0.64	233.10	15.68	6.25	0.85	6.20	7.0	20.3	2.22	NORMAL	Sandy loam
NNG0405	16˚52'38.46"	79˚20'25.692	8.15	1.17	0.67	226.80	18.37	10.15	1.70	8.80	5.4	25.5	5.24	NORMAL	Silt loam
NNG0406	16˚52'38.182"	79˚20'21.048"	8.33	2.29	0.53	220.50	12.77	3.40	2.36	13.8	5.0	24.4	8.60	S1N1	Sandy loam
NNG0407	16˚52'41.7"	79˚20'21.876"	9.04	1.46	0.55	283.50	36.88	6.13	0.93	13.0	5.2	27.2	3.41	NORMAL	clay loamy
NNG0408	16˚51'32.4"	79˚21'1.8"	8.43	1.14	0.48	289.80	9.18	4.82	0.87	11.4	7.2	26.3	3.30	NORMAL	Sandy loam

Table 4.1 (cont.)

SAM ID	**Latitude**	**Longitude**	**pH**	**EC(dSm^{-1})**	**OC(%)**	**N (kg/ha)**	**P (kg/ha)**	**K in meq/l**	**Na^+ in meq/l**	**Ca^{2+} in meq/lit**	**Mg^{2+} in meq/l**	**CEC in c mol (p+) kg^{-1}**	**ESP**	**Sodicity class**	**TEXTURE**
NNG0409	16˚50'35.16"	79˚22'25.5"	7.94	2.41	0.71	560.70	27.10	1.89	5.69	10.8	5.4	22.7	17.37	S1N2	Sandy loam
NNG0410	16˚50'14.892"	79˚23'23.064"	8.20	3.65	0.83	630.00	5.38	5.41	13.02	12.4	5.8	38.3	33.98	S1N3	Clay loam
NNG0411	16˚51'59.688"	79˚24'2.448"	8.71	3.62	0.76	422.10	24.19	7.15	2.33	11.8	5.6	22.9	13.86	S1N2	Sandy clay loam
NNG0412	16˚52'1.344"	79˚24'3.744"	8.74	2.95	0.33	592.20	35.39	16.11	4.91	8.40	5.0	33.3	15.83	S1N2	Clay loam
NNG0413	16˚55'59.088"	79˚31'16.676"	8.03	0.76	1.02	415.80	9.18	3.25	1.66	11.0	8.2	26.2	6.33	NORMAL	Sandy loam
NNG0414	16˚56'1.032"	79˚31'20.892"	8.53	0.20	0.77	340.20	16.58	3.22	1.36	11.6	4.8	22.5	6.03	NORMAL	Sandy loam

Table 4.2 Soil physical, physico-chemical and chemical properties of site-II (parts of Medak district)

SAM ID	Latitude	Longitude	pH	EC (dSm^{-1})	OC (%)	N (kg/ha)	P (kg/ha)	K in meq/l	Na^{+} in meq/l	Ca^{2+}in meq/l	Mg^{2+} in meq/l	CEC in c mol (p+) kg^{-1}	ESP	Sodicity class	TEXTURE
IJG 1502	17°27'56.66"	78°14'26.5"	8.73	3.37	0.33	233.1	21.4	3.42	4.90	11.0	5.2	23.30	18.70	S1N2	Sandy clay
IJG 1503	17°27'52.33"	78°14'18"	7.91	1.12	0.55	226.8	28.1	2.92	0.75	12.6	5.2	22.48	3.32	NORMAL	Clay loam
IJG 1508	17°29'35.47"	78°10'57"	8.50	3.45	0.64	315.2	32.5	2.95	0.96	12.8	7.4	25.12	13.8	S1N2	Clay loam
IJG 1509	17°29'33.66"	78°11'32.76"	6.34	2.03	0.65	239.4	35.5	1.68	1.05	9.80	5.8	20.22	5.20	S1N1	Sandy loam
IJG 1510	17°30'34"	78°12'57.07"	5.78	2.05	0.46	254.3	36.4	1.81	1.28	10.2	5.6	20.74	6.16	S1N1	Loamy sand
IJG 1512	17°28'51.7"	78°13'12.33"	7.70	0.28	0.91	170.1	29.2	2.71	0.94	10.2	6.0	21.12	4.44	NORMAL	Clay loam
IJG 1513	17°28'36.24"	78°13'12.5"	8.43	1.19	1.32	882.1	19.5	2.33	0.98	12.2	5.8	22.50	4.36	NORMAL	Sandy clay loam
IJG 1514	17°28'36.36"	78°13'33.85"	7.62	0.75	0.15	156.7	27.4	1.23	0.98	14.4	7.0	24.80	3.96	NORMAL	Clay
IJG 1517	17°28'34.76"	78°14'8.7"	8.55	2.28	0.61	138.6	22.5	1.00	2.02	10.8	5.0	21.08	9.56	S1N1	Loamy
IJG 1601	17°26'29"	78°09'15.5"	8.27	2.41	0.91	184.2	29	1.89	1.58	10.2	6.8	19.90	6.34	S1N1	Sandy clay
IJG 1603	17°26'37.6"	78°08'59.5"	8.00	2.01	0.19	447.3	29.4	1.26	1.24	12.0	5.8	22.50	5.52	S1N1	Silty clay loam
IJG 1604	17°26'38.4"	78°08'58.2"	7.20	0.36	0.55	436.2	41.9	2.11	0.94	11.4	5.4	21.36	4.39	NORMAL	Clay loam
IJG 1605	17°26'29.05"	78°08'35"	8.10	2.57	0.17	762.3	24.5	1.96	4.52	12.8	7.4	29.04	16.70	S1N2	Clay
IJG 1609	17°26'39.2"	78°08'16.8"	8.08	3.43	0.98	604.8	33.5	2.08	2.88	9.40	6.8	18.40	10.90	S1N2	Sandy clay loam
IJG 1610	17°26'55.2"	78°09'29.9"	8.18	2.17	0.61	415.8	19.6	1.78	2.26	12.6	5.2	23.30	9.72	S1N1	Silt clay
IJG 1611	17°26'55.9"	78°09'27.3"	8.29	2.35	1.47	283.5	33.1	2.15	1.29	10.2	5.4	21.06	5.13	S1N1	Silt clay
IJG 1612	17°27'49"	78°09'42.1"	8.15	1.07	0.53	359.1	30.4	1.21	0.98	10.8	9.6	23.80	4.13	NORMAL	Clay loam
IJG 1613	17°27'46.6"	78°10'53.3"	8.23	0.17	0.30	875.5	28.7	2.37	0.89	12.6	8.8	21.50	3.34	NORMAL	Sandy loam
IJG 1614	17°27'48.2"	78°11'3.5"	8.24	2.25	0.80	187.2	29.4	1.04	3.12	11.6	6.8	24.40	12.8	S1N2	Clay loam
IJG 1616	17°27'53.7"	78°11'50.2"	8.34	3.39	0.77	243.5	22.4	1.77	2.23	10.6	5.8	22.30	10.00	S1N2	Clay loam

Table 4.2 (cont.)

SAM ID	Latitude	Longitude	pH	EC (dSm^{-1})	OC (%)	N (kg/ha)	P (kg/ha)	K in meq/l	Na^{+} in meq/l	Ca^{2+}in meq/l	Mg^{2+} in meq/l	CEC in c mol (p+) kg^{-1}	ESP	Sodicity class	TEXTURE
IJG 1618	17˚28'29.8"	78˚11'40.7"	8.53	3.23	0.74	182.7	21.3	3.42	3.72	9.80	6.6	25.12	14.80	S1N2	Silty clay
IJG 1802	17˚31.8'53.25"	78˚14'36.5"	8.20	1.32	0.19	201.6	38.4	2.03	1.01	9.80	9.6	21.40	4.13	NORMAL	Sandy loam
IJG 1808	17˚27'47.5"	78˚10'45.5"	6.45	3.05	0.67	245.7	29.5	0.79	2.25	10.0	5.8	20.20	11.10	S1N2	Loam
IJG 1809	17˚26'45.4"	78˚10'39.4"	8.09	2.41	1.17	680.4	17.0	0.72	1.92	12.4	5.8	22.40	8.55	S1N1	Silt clay
IJG 1812	17˚30'35.5"	78˚14'35.5"	8.05	3.63	0.89	135.5	25.7	2.95	4.94	12.2	6.0	27.50	18.00	S1N2	Sandy clay
IJG1813	17˚30'40.5"	78˚14'38.5	6.34	2.13	0.53	149.1	31.2	1.77	3.97	10.4	6.6	24.30	16.30	S1N2	Clay loam
IKK 1502	17˚30'42"	78˚14'30"	7.80	0.22	0.39	239.4	48.5	1.14	0.56	12.2	5.2	20.30	2.78	NORMAL	Silty clay loam
IKK 1506	17˚30'42"	78˚14'40"	7.80	2.55	0.25	151.2	51.0	1.30	1.13	12.8	6.0	22.54	5.01	S1N1	Silt loam
IKK 1510	17˚29'58"	78˚14'42"	5.78	2.64	0.56	264.4	35.5	2.78	1.16	11.0	5.8	23.10	5.04	S1N1	Silt clay
IKK 1513	17˚29'55"	78˚14'45"	8.18	1.14	1.34	182.7	28.7	1.26	1.13	11.6	7.6	23.36	4.84	NORMAL	clay
IKK 1515	17˚28'47"	78˚14'51"	8.00	2.89	0.33	352.6	31.5	1.82	1.24	13.6	4.8	22.82	5.44	S1N1	clay
IKK 1516	17˚28'47"	78˚14'53"	8.00	0.14	0.53	686.7	30.5	3.87	0.97	12.8	8.0	27.08	3.59	NORMAL	clay
IKK 1517	17˚27'12"	78˚16'06"	8.11	2.97	0.61	516.6	20.2	3.42	1.51	12.2	5.6	24.50	6.16	S1N1	Sandy clay loam
IKK 1623	17˚29'31"	78˚14'39"	7.95	3.24	1.08	156.0	38.5	2.65	5.08	12.0	6.4	27.80	18.30	S1N2	Silty clay loam
IKK 1626	17˚29'32"	78˚14'35"	8.45	3.37	0.73	245.0	19.2	4.03	7.98	9.20	8.0	30.40	26.30	S1N3	Clay loam
IKK 1629	17˚29'27"	78˚14'28"	8.62	3.31	0.04	151.2	22.5	1.26	4.96	13.4	6.2	26.90	18.50	S1N2	Silty clay
IKK 1631	17˚29'43"	78˚14'47"	7.98	1.08	0.25	264.6	28.7	3.83	1.16	11.8	6.8	24.50	4.75	NORMAL	Silty clay
IKK 1632	17˚30'38"	78˚15'39"	8.26	3.06	0.77	321.6	21.9	1.60	5.45	9.80	6.2	24.00	22.70	S1N3	Clay
IKK 1634	17˚29'44"	78˚14'16"	8.30	3.87	0.33	220.5	25.4	0.81	7.70	13.6	4.6	28.00	27.50	S1N3	Clay
IKK 1637	17˚28'36"	78˚13'23"	8.05	3.28	1.16	315.0	31.7	3.26	5.30	11.8	5.2	27.10	19.60	S1N2	Clay
IKK 1801	17˚30'51.3"	78˚16'59.1"	7.72	1.01	0.83	270.9	42.5	0.64	1.33	12.4	6.4	21.50	4.67	NORMAL	Clay
IKK 1802	17˚30'50.9"	78˚16'0.2"	8.40	2.45	0.30	56.70	29.5	3.73	1.51	11.8	5.6	24.10	6.26	S1N1	Sandy clayloam
IKK 1804	17˚30'44.1"	78˚16'0.4"	8.08	0.12	0.50	100.8	47.2	1.81	0.88	12.4	5.2	23.10	3.80	NORMAL	Clay loam
IKK 1805	17˚30'45.3"	78˚16'0.6"	8.07	2.55	1.17	226.8	41.3	1.51	1.49	10.2	7.6	22.80	6.55	S1N1	Clay
IKK 1807	17˚30'44.1	78˚15'58.7"	8.10	0.24	0.06	187.0	30.8	1.74	0.88	12.2	6.0	22.50	3.90	NORMAL	Clay
IKK 1809	17˚30'34.5	78˚16'6.4"	8.38	1.39	1.00	214.2	28.9	3.02	0.89	11.2	4.6	21.10	4.20	NORMAL	Clay

Table 4.2 (cont.)

SAM ID	Latitude	Longitude	pH	EC (dSm^{-1})	OC (%)	N (kg/ha)	P (kg/ha)	K in meq/l	Na^+ in meq/l	Ca^{2+}in meq/l	Mg^{2+} in meq/l	CEC in c mol (p+) kg^{-1}	ESP	Sodicity class	TEXTURE
IKK 1811	17°30'15.1"	78°16.3.2"	8.16	0.11	0.83	138.6	22.9	2.83	0.85	11.4	6.2	22.50	3.79	NORMAL	Silty clay loam
IKK 1812	17°30'16.8"	78°16'3.2"	8.05	0.15	0.92	346.5	40.5	2.33	0.86	11.0	5.0	22.20	3.87	NORMAL	Silty clay loam
IKK 1813	17°30'17.9"	78°16'0.51"	7.89	0.13	0.88	478.8	41.5	1.57	1.19	12.4	5.0	23.90	4.98	NORMAL	Silty clay
IGS 1501	17°29'45.5"	78°15'4.5"	8.47	2.36	0.15	144.9	19.0	1.26	1.16	10.8	5.0	20.50	5.68	S1N1	Clay
IGS 1502	17°19'33"	78°13'04"	7.20	2.26	0.85	199.0	48.5	1.14	1.30	10.6	6.2	20.22	6.45	S1N1	Sandy loam
IGS 1503	17°29'34"	78°10'52"	8.09	1.27	0.53	882.0	59.8	1.31	0.97	9.20	6.2	18.54	4.31	NORMAL	Loam
IGS 1504	17°31'6"	78°09'07"	7.65	0.18	0.36	405.0	36.5	2.33	1.11	10.6	5.2	20.30	4.58	NORMAL	Clay loam
IGS 1505	17°29'50"	78°10'45"	7.76	0.11	1.10	129.0	35.7	1.51	1.19	10.2	9.4	21.50	4.86	NORMAL	Loam
IGS 1506	17°31'6"	78°14'01"	8.01	2.54	0.33	31.50	42.4	3.28	1.90	11.0	5.2	22.94	8.30	S1N1	Sandy clay
IGS 1601	17°13'35"	78°30'47"	8.35	2.14	0.39	85.00	22.9	2.10	1.71	12.2	5.6	23.10	7.39	S1N1	Silt loam
IGS 1602	17°30'38"	78°13'20"	7.23	2.76	0.56	156.0	45.5	3.69	1.51	11.8	5.4	24.90	6.05	S1N1	Clay loam
IGS 1603	17°30'30"	78°12'44"	8.10	2.08	0.15	195.3	28.6	2.18	1.54	11.8	5.0	23.12	6.65	S1N1	Loamy sand
IGS 1605	17°30'45"	78°12'25"	8.42	2.19	1.29	81.90	29.2	2.76	1.49	12.4	5.4	24.90	5.97	S1N1	Clay
IGS 1606	17°31'15"	78°11'45"	8.32	0.09	0.27	215.0	25.1	1.82	1.16	11.8	8.4	21.40	4.74	NORMAL	Clay
IGS 1607	17°30'48"	78°10'38"	8.78	1.47	0.68	165.0	35.3	1.61	1.05	15.0	5.2	22.30	4.33	NORMAL	Sandy clay
IGS 1608	17°31'38	78°11'45"	8.16	0.09	0.34	245.0	18.6	1.51	0.93	12.0	5.4	21.28	3.83	NORMAL	Clay loam
IGS 1609	17°31'30"	78°09'27"	7.97	2.06	0.67	132.3	27.4	1.47	1.26	11.8	4.6	20.52	6.14	S1N1	Sandy loam
IGS 1610	17°31'46"	78°10'46"	6.75	2.03	0.85	75.60	21.9	0.69	1.11	12.2	5.6	21.10	5.25	S1N1	Sandy loam
IGS 1611	17°31'33"	78°11'18"	8.22	1.14	0.80	315.0	15.4	3.51	0.89	12.2	6.2	25.70	3.45	NORMAL	Clay loam
IGS 1612	17°31'35"	78°11'07"	8.15	2.27	0.77	149.0	20.5	2.10	1.55	11.6	8.6	26.12	5.31	S1N1	Clay
IGS 1613	17°31'25"	78°11'07"	8.09	2.22	0.94	428.4	22.9	2.75	2.13	9.80	8.4	24.50	8.68	S1N1	Clay loam
IGS 1614	17°29'45"	78°11'25"	8.01	2.49	1.65	560.7	25.4	2.89	2.17	10.6	7.2	25.78	8.43	S1N1	Sandy clay
IGS 1615	17°31'44"	78°11'32"	8.01	0.62	1.43	409.5	24.7	2.61	1.27	10.4	8.8	20.30	4.48	NORMAL	Clay loam
IGS 1616	17°31'29"	78°10'45"	8.08	2.34	1.40	352.8	21.9	3.35	1.69	12.8	5.4	24.82	6.81	S1N1	Clay loam
IGS 1617	17°31'45"	78°11'29.5"	8.18	0.21	0.30	327.6	21.5	2.77	0.91	10.6	3.8	20.84	3.40	NORMAL	Silty clay
IGS 1618	17°30'15"	78°09'45.1"	7.80	1.43	0.31	265.0	39.7	2.38	1.16	12.4	11.4	28.30	4.08	NORMAL	Clay loam
IGS 1803	17°30'23"	78°15'50"	8.15	1.09	0.70	154.0	18.3	1.45	0.85	10.2	5.2	20.08	3.40	NORMAL	Silty clay

Table 4.2 (cont.)

SAM ID	Latitude	Longitude	pH	EC (dSm^{-1})	OC (%)	N (kg/ha)	P (kg/ha)	K in meq/l	Na^{+} in meq/l	Ca^{2+}in meq/l	Mg^{2+} in meq/l	CEC in c mol (p+) kg^{-1}	ESP	Sodicity class	TEXTURE
IGS 1804	17˚30'19"	78˚16'20"	8.41	2.08	0.88	325.0	20.4	2.53	2.31	5.80	5.8	24.30	9.51	S1N1	Sandy loam
IGS 1805	17˚30'10"	78˚16'39"	7.85	3.11	0.43	315.0	45.6	1.72	2.90	13.6	4.6	24.84	11.70	S1N2	Loam
IGS 1806	17˚29'47"	78˚16'39"	7.89	0.07	0.48	238.5	41.3	0.73	1.91	12.4	6.6	22.50	8.48	NORMAL	Loamy sand
IGS 1807	17˚29'46"	78˚16'38"	7.58	1.35	0.70	321.3	28.1	1.79	0.91	10.4	6.0	20.90	4.36	NORMAL	Silt loam
IGS 1809	17˚29'4"	78˚15'28"	8.09	2.17	0.59	245.7	53.6	1.69	1.81	15.2	5.2	24.84	7.28	S1N1	Clay
IGS 1810	17˚29'26"	78˚15'11"	8.09	2.16	0.39	69.60	25.5	1.83	2.38	13.2	5.8	24.82	9.58	S1N1	Clay
IGS 1811	17˚30'26"	78˚16'22"	7.49	0.08	0.16	255.0	41.3	1.40	1.03	10.0	5.4	21.64	4.16	NORMAL	Clay loam
IGS 1812	17˚30'30"	78˚16'50"	7.40	0.13	0.91	390.6	36.7	1.28	0.85	11.6	6.2	23.70	3.59	NORMAL	Sandy clay

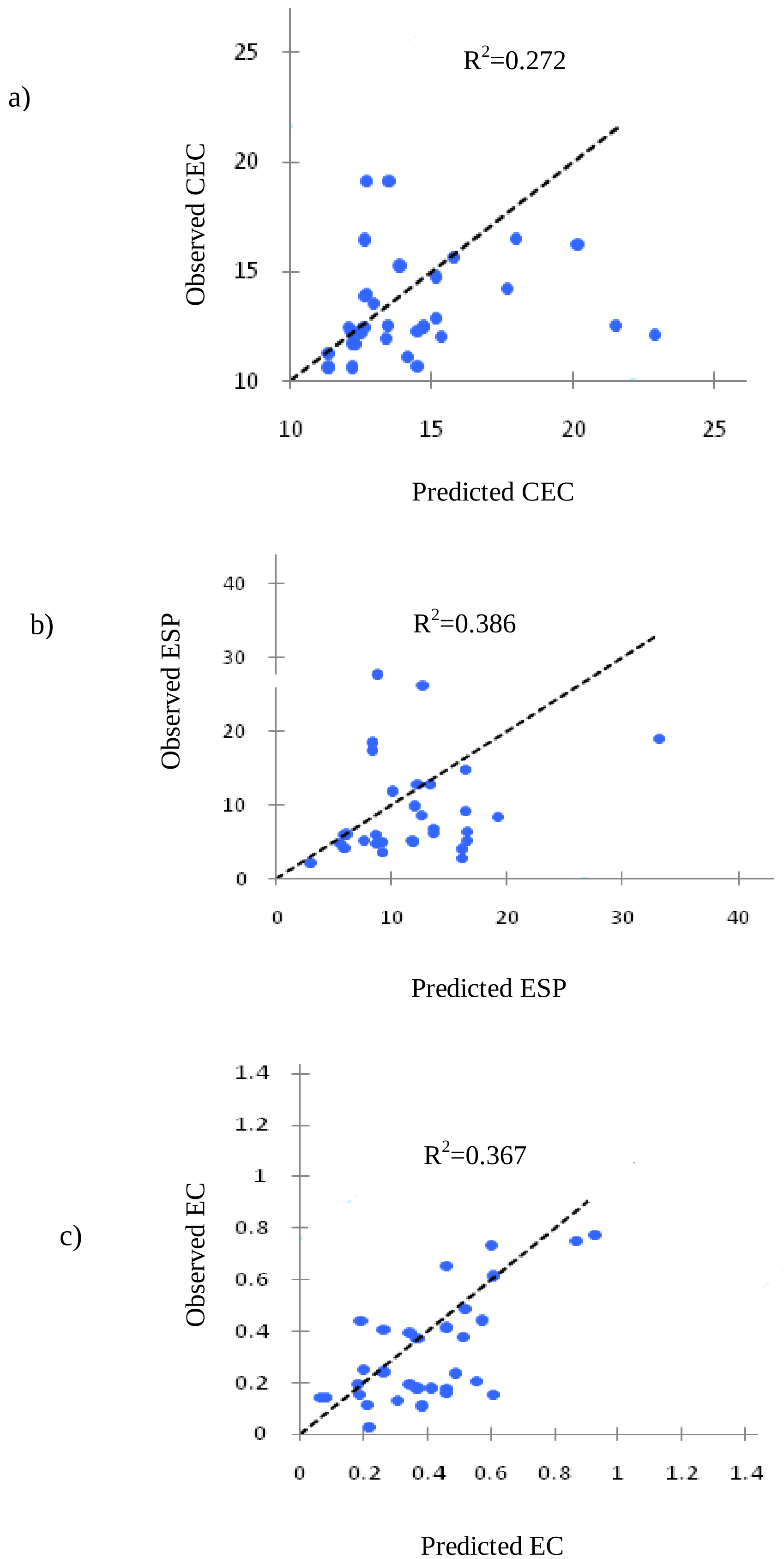


Figure 4.2 Predicted parameters *vs* observed parameters in PLSR model.

Chapter V

SUMMARY AND CONCLUSIONS

Salinization and alkalization are the most common land degradation processes, particularly occurring in arid and semi-arid regions where precipitation is too low to maintain a regular percolation of rain water through soil .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 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.

A study was conducted on **"Characterization and mapping of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts"** with the objective of characterization of salt affected soils using hyperspectral data in parts of Medak and Nalgonda districts and identification and mapping of salt affected soils in targeted sites using Remote Sensing.

The two sites were site-I 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 bottom right and site-II *i.e.*, parts of Medak district located at $17^0$26' 19.73" N , $78^0$19'5.43" E on top left and 17^0 31' 39.47" N, $78^0$8'5.06" E on bottom right.

Global Positioning System (GPS) based soil samples (0-20cm depth) were collected from parts of Nalgonda and Medak. Soil samples collected from each of the sampling points were dried under shade. The air dried samples were then pounded in wooden mortar and pestle and passed through a 2mm sieve and then stored for determination of various soil properties.

To collect the spectral reflectance a Field Spec Pro Spectrometer (Analytical Spectral Device (ASD), Inc., Boulder, Colorado, USA) with a fibre-optic contact probe was employed for field measurements. The instrument covers the visible to SWIR wavelength range (350–2500 nm). The controlling software automatically accounts for the overlap in wavelength intervals using a preset wavelength within the common subset. 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.

Soil physical, chemical and physico-chemical properties were analysed using standard laboratory procedures as given in 3.6.

Site-I : The soils are neutral to severely alkaline in reaction with pH ranging from 7.11 to 9.62, the electrical conductivity of the sampling sites varied from normal to severly saline-sodic with values ranged from 0.17 to 3.6 dSm^{-1}, the organic carbon content was low to high and it varied from 0.148 % to 2.108 %, the Nitrogen content of this site varied as low as 12.60 to 863 kg ha^{-1}, Phosphorus content of soils were varied from 2.19 to 63.62 kg ha^{-1}, 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 to15.44 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 %.

Site-II : The soil reaction in this site varied from slightly acidic to strongly alkaline with pH values ranged from 5.78 to 8.73, EC of the soil samples ranged from 0.07 to 3.87 which comes under normal to saline category. nitrogen content varied from low to high and the values ranged from 31.5 to 882 kg ha^{-1}, the phosphorus content in the soils varied from 15.4 to 59.8 kg ha^{-1}, the cations of the soil *i.e.,* potassium content of the soils were varied from 0.36 to 4.03 meq/l, sodium content varied from 0.56 to 7.98 meq/l, Calcium content varied from 9.20 to 15.20 meq/l, and magnesium content varied from 4.60 to 11.40 meq/l, the cation exchange capacity (CEC) of the soils varied from 18.40 to 30.40 c mol $[P^{+}]$ kg^{-1} and exchangeable sodium percentage (ESP) of the soils varied from 2.7 to 27.5 % .

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 areas, in site-I, the area under slightly saline-sodic category was found to be 378 ha, the area under moderately saline-sodic category was 90 ha, severely saline-sodic soils are 178.43 ha and the rest of the area was normal. Similarly in site-II the area under slightly saline-sodic category was 88.53 ha, moderately saline-sodic category was 11.4 ha and severely saline-sodic category was 5.5 ha.

The digital number (DN) values increased with increasing severity of the saline class was observed throughout the blue, green, red and near infrared (NIR) in both LISS IV and LISS III data.

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.

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. Prediction models were developed independently for each soil property. The results obtained based on PLSR model showed that good predictions of EC can be made more accurately.

Based on characterization of the soils of study area were delineated in to normal, slightly saline-sodic, moderately saline sodic, severely saline-sodic soils. 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. 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.

Reclamation measures were suggested from the literature to improve yield in salt affected soils of the study area. The category wise reclamation measures were suggested. *i.e.,* for slightly saline-sodic soils, application of green manure and proper drainage and for moderately and severe sodic-soils, following cultural practices (Land leveling and shaping, increasing seed rate to increase the plant population, age of seedlings, selection of crops, drainage and irrigation practices has to be followed along with chemical amendments like gypsum, phospo-gypsum and press mud , organic amendments like tree leaves, saw dust, weed, wild herbs and shrubs.

Conclusions

- The soil physical, physico-chemical and chemical properties of site-I (Parts of Nalgonda district) and site-II (parts of medak district) were analysed and salt-affected soils were characterized and classified in to different categories *viz.,* slightly saline-sodic, moderately saline-sodic and severly saline-sodic soils.
- An increasing digital number (DN)value with severity of salinity was observed throughout the blue, green red and near infrared under both LISS IV and LISS III data.
- The test site images were classified and different categories of saline-sodic soils were delineated and mapped. In site –I (parts of Nalgonda district) and site-II (parts of medak district).
- In the test area of 20,000 ha *i.e.,* satellite image of 20x10 km area, about 3 % area found to be degraded by salts in Nalgonda district *i.e.,* Nagarjuna sagar project (NSP) left canal command area. However, only 0.5% of the test site area was affected by salts in parts of Medak district. The results clearly indicate severity of salt-affected soils in command area of major irrigation projects was due to indiscriminate use of irrigation water than that of rainfed area, though both were under semi arid climate.
- The spectral reflectance curves were generated using hyperspectral spectro-radiometer data covering a range of 350-2500nm under field conditions. An increasing trend of soil reflectance with increase in wavelength of electromagnetic radiation was observed irrespective of nature of soils. A significant decrease in reflectance at 1380and 1940 nm wavelength was observed which is more prominent in severly saline-sodic soils. This decrease was observed irrespective of soil sample because of presence of hydroxyl ions . The more prominent absorption in saline sodic soil due to anions such as chlorides, sulphates and

carbonates in a great extent which are hygroscopic in nature as well as abundant in quantity of Mg^{2+} and Na^{+} cation having higher hydration energy. It is also observed that saline soils exhibited comparatively very higher reflectance values throughout the entire wavelength (320-2500) compared to normal soil samples.

- The Pearson correlation studies were carried out with resampled reflectance values at 10nm intervals for the entire wavelength range. The soil properties like EC, CEC and ESP showed significant negative correlation strongly at 1870nm (r= -0.363*, 0.384* and 0.376*) wavelength which indicates that 1870 nm wavelength is the most sensitive band for delineation of salt affected soils.
- 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.
- Reclamation measures were suggested from the existing literature to improve yield in salt affected soils of the study area. The category wise reclamation measures were suggested.

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