

Addis Ababa
University
(Since 1950)



**SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES**

**SPATIAL DISCRIMINATION AND MAPPING OF
SOIL SALINITY USING REMOTE SENSING AND
GIS TECHNIQUES IN THE MIDDLE AWASH BASIN**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF
ADDIS ABABA UNIVERSITY IN THE PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
REMOTE SENSING AND GIS**

BY: MEKAMU KEDIR

ADVISOR: Dr. SYED AHMAD ALI (ASSOCIATE PROFESSOR)

July 2007

SPATIAL DISCRIMINATION AND MAPPING OF SOIL SALINITY USING REMOTE AND GIS TECHNIQUES IN THE MIDDLE AWASH BASIN

**Dissertation submitted for Partial Fulfillment of the Requirements for the
Award of the Degree of**

MASTER OF SCIENCE

In

**Remote Sensing and Geographical Information Systems (GIS)
Addis Ababa University, Addis Ababa, Ethiopia**

BY

Mekamu Kedir

JULY 2007

ACKNOWLEDGMENT

First and foremost I would like to thank the Almighty ALLAH for all the things he has done for me.

My sincere thanks goes to my advisor Associate Professor Syed Ahmad Ali for his valuable comments, unreserved supervision and guidance. I am also greatly indebted to Dr. Fantaw Abegaz whom without his great effort and guidance this study would not see the light.

I would like to thank the department of Earth Sciences, for their kindness to facilitate the entire necessary administrative procedure to carry out the study.

I am grateful to the Ministry of Water Resources; Awash Basin Authority and Melka Worer Research Center for providing me the data needed for this thesis as well as for letting me use library service.

I wish to thank my sincere friends Seid Yhdego and Amare Degefaw for their continuous moral support and encouragement.

Finally it is hardly possible to find appropriate words to express my gratefulness to my family especially Ummi and Aby.

LIST OF TABLES

List of tables.....	vi
List of Figures.....	vii
Acronyms	vii
Abstract.....	ix
1. INTRODUCTION.....	1
1.1 Background and Problem Statement.....	1
1.2 OBJECTIVES	3
1.2.1 General Objective.....	3
1.2.2 Specific objectives	3
2. LITERATURE REVIEW	4
2.1 Background	4
2.1.1 Definition of Soil Salinity	4
2.2 Remote Sensing for Mapping Soil Salinity.....	5
2.2.1 Salt-affected Soils	6
2.2.2 Waterlogging.....	8
2.2.3 Application to large areas	9
3 Materials and Methods.....	13
3.1 Description of the study area.....	13
3.1.1 General background.....	13
3.1.2 Climate.....	14
3.1.3 Geomorphology, Soil and Parent Material	14
3.1.4 Land Use and Vegetation.....	15
3.1.5 Drainage.....	16
3.2 Data and materials used.....	16
3.3 Methodology	17
3.3.1 Saline Soil Mapping	17
3.3.2 Salinity Index	17
3.3.3 Vegetation Indicators	17
3.3.5 Land Use Classification.....	18
3.4 Data analysis	21
3.4.1 Sample site Selection for fieldwork and data collection	21
3.4.2 Band Selection	21
3.4.3 Spectral Classes of Saline Soils	23
3.4.5 Spatial Distribution of E _{Ce}	26
3.4.6 Overlay Analysis	29
4. RESULTS and Discussion	33
4.1 Distribution of the Salt-affected Areas on Satellite Images.....	33

4.1.2 Salt-affected Areas Characterized by Salinity Levels.....	33
4.2 RESULTS FROM DIGITAL CLASSIFICATION	33
4.2.1 Results from Unsupervised Classification.....	34
4.2.2 Results from Supervised Classification.....	36
4.2 Results from Indices Analysis.....	37
4.3 Empirical Models Using Soil.....	41
4.4 Result from Overlay analysis.....	43
4.4.1 Canal VS Map of salt affected soil generated from NDSI	43
4.4.2 Drainage Vs Map of salt affected soil generated from NDSI.....	44
4.4.3 Soil Versus Map of salt affected soil generated from NDSI	45
4.4.4 Water Table versus Map of salt affected soil generated from NDSI	46
5. Conclusions and Recommendations	47
5.1 Conclusion	47
5.2 Recommendations	49
REFERENCES	50
Appendix	52

LIST OF TABLES

TABLE 2.1 THE CRITERIA FOR SOIL SALINITY /SODICTY	5
TABLE 3.1 DATA TYPE AND THEIR SOURCES.....	16
TABLE 3.2 APPLICATION OF BANDS FOR DIFFERENT FEATURE IDENTIFICATION.....	21
TABLE 3.3 CORRELATION MATRIX OF BANDS	22
TABLE 3.4 GENERAL OVERVIEW OF THE DATA USED FOR ANALYSIS.....	26
TABLE 3.5 CLASSIFICATION OF WATER DEPTH	31
TABLE 4.2 SALINITY LEVEL AND EXTENT DERIVED FROM EMPIRICAL MODEL	41

LIST OF FIGURES

FIGURE 3.1 LOCATION MAP OF THE STUDY AREA	13
FIGURE 3.2 SOIL AND LANDFORM MAP.....	15
FIGURE 3.3 GENERAL WORKFLOW OF THE STUDY	20
FIGURE 3.4 SPECTRAL REFLECTANCE PROFILE OF THE STUDY AREA (2001 IMAGE).....	24
FIGURE 3.5 TCC AND FCC OF THE ETM+ IMAGE.....	25
FIGURE 3.6 EC SAMPLE LOCATIONS.....	27
FIGURE 3.7 LOCATION OF PIEZOMETRIC DATA.....	27
FIGURE 3.8 REGRESSION ANALYSES BETWEEN ECE AND NDSI	28
FIGURE 3.9 THE MODEL USED FOR PREDICTION OF SOIL SALINITY	29
FIGURE 3.10 THE BUFFERED CANAL LAYOUT	30
FIGURE 3.11 BUFFERED DRAINAGE LAYOUT	30
FIGURE 3.12 PIEZOMETRIC LOCATIONS	31
FIGURE 3.13 INTERPOLATED WATER TABLE	31
FIGURE 3.14 PERCENTAGE AREA OF THE MAJOR SOIL TYPE IN THE STUDY AREA.....	32
FIGURE 4.1 AREA OF DIFFERENT LANDUSES	35
FIGURE 4.2 LANDUSE FROM UNSUPERVISED CLASSIFICATION	35
FIGURE 4.4 SUPERVISED CLASSIFICATIONS	37
FIGURE 4.5 SALINITY LEVEL DETERMINED FROM NDSI.....	40
FIGURE 4.8 SALINITY LEVEL DERIVED FROM EMPIRICAL MODEL.....	42
FIGURE 4.9 SALINITY MAP GENERATED FROM EMPIRICAL MODEL.....	42
FIGURE 4.10 SALT AFFECTED AREA VERSUS CANAL.....	43
FIGURE 4.11 SALT AFFECTED AREA VERSUS SURFACE DRAINAGE LINES	44
FIGURE 4.12 SALT AFFECTED AREA VERSUS MAJOR SOIL.....	45
FIGURE 4.13 SPATIAL DISTRIBUTION OF SALT AFFECTED SOIL VERSUS WATER TABLE DEPTH.....	46
FIGURE 4.14 SALT AFFECTED AREA VERSUS MAJOR SOIL.....	46

ACRONYMS

AIP	Amibara Irrigation Project
Ds/m	Decisiemn per meter
ESP	Exchangeable Sodium Percentage
ETM+	Enhanced Thematic Mapper
FCC	False Color Composition
GIS	Geographic Information System
IAR	Institute of Agricultural Institute
IRS	Indian Remote Sensing
MSS	Multi Spectral Scanner
LAI	Leaf Area Index
NDSI	Normalized Difference Salinity Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
pHs	Power of Hydrogen
RGB	Red, Green, Blue
TCC	True Color Composite

ABSTRACT

This research deals with the identification and mapping of salt affected soils in Middle Awash. The analysis was made based on remote sensing data of Landsat ETM+ image, Electrical conductivity (EC) of soil sample taken in the same year when the image was captured and some other ancillary data. Remote sensing techniques employed were visual interpretation, digital image processing and indices like Normalized Difference Salinity Index (NDSI) and Normalized Difference Vegetation Index (NDVI).

An attempt has been made to identify salt affected area by visual interpretation using both TCC and FCC. From the unsupervised and supervised classification 1930ha and 887.3ha areas have been mapped as highly saline. The result obtained from unsupervised classification is larger in area extent. However the result obtained from NDSI was not only in area wise but also the level of salinity as highly saline, moderately and slightly saline, determined based on the reflectance value. Out of the total area 10% are mapped as highly saline. Attempt has been made to indirectly identify salt affected area using NDVI and the result showed similar area distribution of salt affected area.

A regression analysis between EC values of small areas confined only in Melka Sadi area and the corresponding reflectance value in the NDSI image offer a polynomial relation of order two. The model obtained used to derive a salinity map and 16 and 0.9 dS/m of maximum and minimum EC level respectively was estimated. The spatial distribution of salt affected area derived from NDSI and model has shown similar pattern but different area extent.

Overlay analysis of salt affected area and soil, canal, drainage and water table has been made to assess the spatial distribution as well as the relationship with this features and the result revealed the spatial distribution not highly influenced by the features being considered.

Key word: NDSI, EC, Soil salinity

1. INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

Soil salinization is becoming an increasing problem, especially in arid and semi arid regions and whenever irrigation is practiced. Soil salinity and alkalinity are mainly caused by natural and cultural (secondary salinization) factors. While climate, natural drainage, topographic properties, geologic structure, parent material, distance to the sea are natural factors; unsuitable irrigation methods and water quality, insufficient drainage, poor land management are cultural factors. Saline, saline-alkaline and alkaline soils are usually seen in the hollow and flat topographies in the arid and semi arid climatic conditions. For purposes of definition, saline soils are those that have an electrical conductivity of the saturation soil extract of more than 4 dS/m at 25°C (Richards, 1954). This value is generally used the world over although the terminology committee of the Soil Science Society of America has lowered the boundary between saline and non-saline soils to 2 dS/m in the saturation extract.

In some part of the world like Ethiopia, the population is growing very fast and therefore attempts are made to increase the agricultural production. Recently it is reported that about 10% of presently arable lands are affected by salinity (Tabet et al., 1997). Other reports showed that approximately one third to one half of all irrigated lands have salt problems; the majority of which is in less developed arid regions. And, each year, millions of hectares of irrigated lands go out of production due to salt. In fact, there is already twice as much salty land as there is irrigated land. So many scientists suggest that we have finally reached the point where there are no new "virgin" lands left to salinize. (Simpson, D., et al., 2000) Thus monitoring of saline degraded land has always been a primary issue for efficient irrigation systems management and rehabilitation policies.

The irrigation potential in the Ethiopian Rift Valley is estimated at 790000ha, distributed over the different basins. However, most of the irrigation developed to date is located in the Awash basin.

In relation to the irrigation development the salt affected soils in Middle Awash Valley have been a challenge to agricultural production. Study has been carried out in Amibara irrigation project on four thousand hectares and it was concluded that the main cause of salinity found to be poor irrigation water management, shallow saline ground water table. Generally after the irrigation project was commenced salinity became very severe and therefore many productive agricultural lands were abandoned and sterile (Tadese and Abegase, 2000). In order to deter the ongoing soil salinization through efficient irrigation and effective salinity control it requires periodic information of soil salinity levels and distributions within the crop root-zones and fields.

The problem of detection, monitoring and mapping of salt affected soils especially with conventional practical methodology which is complicated by its spatially variable and dynamic nature caused by the effects and interactions of varying edaphic factors (soil permeability, water table depth, salinity of perched groundwater, topography, soil parent material, geohydrology), management induced processes (irrigation, drainage, tillage, cropping practices), as well as by climate-related factors (rainfall, amount and distribution, temperature, relative humidity, wind).

In a time when the need for repeated measurements and extensive sampling requirements are met, the expenditure of time and effort to characterize and map a salinity condition with conventional soil sampling and laboratory-analysis procedures becomes prohibitive.

Therefore a more rapid, cost effective measurement technology is needed. Recent advances in the application of remote sensing technology in mapping and monitoring degraded lands, especially in salt affected soils, have shown great promise of enhanced speed, accuracy and cost effectiveness. The approach to the problem of delineating saline soils using remote sensing data and GIS techniques has been proved in many recent studies to be most sufficient (Sharma and Bhargava, 1988, Rao et al., 1991, Srivatava et al., 1997, Dwividi et al., 1998). This study is therefore aimed at mapping of salt affected soils in using remote sensing indicators

(Different salinity indices and Vegetation index) and image classification techniques that is based on different spectral characteristics of different kind of surfaces.

1.2 OBJECTIVES

1.2.1 General Objective

- The general objective of this study is to map salt affected soils using remote sensing techniques

1.2.2 Specific objectives

- To discriminate and map salt affected soils by direct and indirect methods
- To assess and evaluate the spatial distribution of salt affected soils against irrigation canal, drainages, soil maps and water tables
- To apply different salt indices to detect salt affected area

2. LITERATURE REVIEW

2.1 BACKGROUND

Soil salinity is one of the major problems affecting the agricultural productivity and sometime becomes too severe to take it out from economic crop production. The demarcation of the location and assessment of the extent and severity of soil salinity are prerequisite for any reclamation programme. However, the conventional methods of soil sampling and land surveying demand huge human resource, and are time consuming, difficult and costly. Moreover, the dynamic nature of these problems makes it further difficult to use conventional methods for comparison purpose in large areas. Remote sensing (RS) and geographical information system (GIS) offers convenient solutions to map the extent and severity of salinity. The objective of this chapter is to present a review on selected papers on application of RS and GIS for studying the salt-affected areas.

2.1.1 Definition of Soil Salinity

Several agencies have given different definitions of soil salinity. The most widely accepted definition of salt-affected soils is as defined by the United States Department of Agriculture, USDA (Richards, 1954). The definition is based on E_{ce} (electrical conductivity of the saturation extract of soil, dSm-I), pH_s (pH of the saturated soil paste) and ESP (exchangeable sodium percentage of the soil):

I. Saline soils : These soils have an E_{ce} more than 4 dSm⁻¹ at 25⁰C, pH_s less than 8.2, and ESP less than 15.

II. Sodic soils: Sodic soils have a pH_s more than 8.2, and ESP of 15 or more. The E_{ce} may be high if originating from salts capable of alkali hydrolysis; otherwise it should be less than 4 dSm⁻¹ at 25⁰C.

III. Saline-Sodic: Saline-sodic soils have pH_s greater than 8.2 at 25 OC, E_{ce} greater than 4 dSm⁻¹ and the ESP greater than 15. These soils have formed due to a combined process of salinization and sodification.

A general guideline for the degree of soil salinity / sodicity is given in Table 2.1; however, the severity may vary with the type of soil and crop.

Table 2.1 The criteria for soil salinity /sodicty

Key to degree of salinity/sodicity	Salinity E _{Ce} (dsm ⁻¹)	Sodicity	
		pH	ESP
Slight	4-8	8.2-9.0	<15
Moderate	8-28	9.0-9.8	15-40
Strong	>25	>9.8	>40

2.2 REMOTE SENSING FOR MAPPING SOIL SALINITY

The essence of remote sensing is the measuring and recording of the electromagnetic radiation emitted or reflected by the earth's surface. For soil salinity investigation, this may be useful where salty soil, salt-affected vegetation, saline water, pond water and high water table area give contrasting reflectance with other landscape features so that they can be unambiguously distinguished.

Application of remote sensing for surveying and mapping of salt-affected began with the use of black and white photography. The relatively bright appearance provides the information about salinity due to the efflorescence of salt crust. The effect of salinity on crops provides the information on salinity indirectly. The aerial photographs have been used to delineate units based on the combination of geomorphological differences and differences in grey tones. Attempts were also made to relate the differences in the grey tones with the salt content. After the launch of the first operational earth observation satellite, Landsat in 1972, with visible and near infrared bands, it became easy to map large areas and to repeat mapping frequently. For the appraisal of soil salinity problems, spectral, spatial and temporal characteristics of these twin problems are to be considered to assess their extent and severity. Indirect features like landscape may help to identify the problems of soil salinity. Relative elevation is one of the most evident landscape features in relation

to salinity and moisture provided by saline and shallow groundwater table. At present, the identification and mapping of saline soil is a combination of

- (i) visual interpretation of photographs
- (ii) digital analysis of false colour composite (FCC) and
- (iii) digital analysis of surface radiation and vegetation index.

All methods require ground truth information for calibration and validation. The actual use depends on the specific aim of the survey, data availability, human skill and availability of time and money.

2.2.1 Salt-affected Soils

2.2.1.1 Application at field level

The acquisition time of the Remote Sensing data is important for the identification of soil salinity. Venkataratnam (1983) used temporal Landsat-MSS images of pre-monsoon, post-monsoon and harvest seasons to map soil salinity in the State of Punjab, India and concluded that the spectral curves of highly and moderately saline soils change considerably throughout the annual cycle, which significantly complicates the time composition procedure. Johnston and Barson (1990) reviewed RS applications in Australia and found that discrimination of saline areas was most successful during peak vegetation growth. In other periods the low fractional vegetation cover of salinized area could not be distinguished from areas that were bare due to overgrazing, erosion, or ploughing. And it was found that salinity is best expressed at the end of the irrigation or rainy season when the plots are bare. Goossens et al. (1993a) (as cited in Salman, 2000) analyzed the beginning, middle and end of the growing season in the western Nile Delta and concluded that single image may be suitable for detecting severely salinized soils but that more gradations can be determined using temporal images.

INDA (2002) reviewed studies conducted by different researchers on direct observations on bare soils and indirect on vegetation cover. For the visible part of the spectrum, the soil reflectance of salt cover areas was found to be prominent.

Bands in the middle infrared gave information of moisture content which was often associated with salt content differences and some information on type of salts. The lack of vegetation or scattered vegetation and highly salt-affected salt surface makes it possible to directly detect salt on the surface.

It is to be pointed out that reflectance in visible and infrared bands provides only information of the first millimeter of the top horizon of the bare soils. Often, the characteristics of the surface are found to be different from the layer below. Ground observations and radiometric measurements indicated that the main factors affecting the reflectance are the quantity and mineralogy of salt, moisture, colour and roughness. The evaluation of soil surface remains under the influence of external factors as groundwater quality and variation of depth, wetting/drying cycles and wind. On the contrary, pure and thick salt crust or sand deposits can be used as calibration site for reflectance measurements. Many researches described salinity detection through use of vegetation on the basis of the fact that reflectance from single leaf depends on their chemical composition (salt) and morphology.

Metternicht and Zinck (1996) cited in concluded, based upon their studies related with ground observation and radiometric measurement in the visible and near-infrared wavelengths, that the main factors affecting the reflectance are the quantity and mineralogy of salts together with soil moisture, soil colour and terrain roughness which in turn are controlled by different combination of salts and type of soil surface, texture and organic matter content. Salts influenced surface features includes the soil crusts with or only little evidence of the presence of the salts. The crusted soil surfaces are generally smoother than non-saline surfaces and causes higher reflectance values in the visible and near infrared bands. Apparently, the physiological status of the crop is best manifested at TM 5 and 7, while TM bands 3 and 4 are better suited to describe the overall crop development. The multiple regression analyses between SPOT spectral data and soil morphological, physical, and chemical properties showed that many surface and some subsurface soil properties were significantly correlated.

Brightness index proved to be a more useful spectral parameter if surface soil properties are to be extracted from satellite data, but ratio of the values in red and infrared band seems to be a better technique to employ when subsurface soil properties are of interest. Moulders (1987) remarked that in general, bands in the near and middle infrared region give reasonable information on soil moisture and salinity. Steven et al. (1992) confirmed this finding by showing that near to middle infrared index is a better indicator for chlorosis occurring in stressed crops (normalized difference for TM bands 4 and 5). This new ratio is immune to colour variations and provides an indication of leaf water potential. The spectral behavior of salt-affected soils as compared to normal cultivated soils showed relatively higher spectral response in visible and near-infrared regions. Further, strongly saline-sodic soils were found to have higher spectral response as compared to moderately saline-sodic soils. The vegetation cover modifies the overall spectral response pattern of salt-affected soils especially in the green and red spectral bands.

Spatial resolution has significant effect on enhancing the identification of salt-affected soils and crops. Since Landsat-MSS is of limited use to identify saline plots due to its low spatial resolution. Many researchers compared the accuracy of TM, MSS, and SPOT and found TM to be the superior multi-spectral radiometer for soil salinity mapping. Digital classification techniques help in improving the identification and mapping of salt-affected soils or crops.

2.2.2 Waterlogging

Excess soil moisture can cause a change in soil colour and a change in soil reflectance properties, which can be easily detected by remote sensing. Plant response is one means of detecting poorly drained soils in California mainly because of a build-up of the water table. On the other hand due to the accumulation of organic matter, soil colour is generally darker in poorly drained areas than well-drained soils.

The visible bands in Landsat- MSS data can be used to identify this colour. Baber (1982) (as cited in INDA 2002) pointed out that colour infrared photography could indicate drainage problems by soil moisture saturation or plant stress. Shallow water tables exhibit an increase in surface moisture, which can be detected from visible reflectance and microwave emissivity.

The information about drainage basin area and drainage pattern can be obtained from satellite imagery. GIS helps in assessing the waterlogging and drainage problem by identifying the drainage network and its characteristics in a basin besides the information on presence of high water table, high morphology, soil colour, plant stress and drainage water collection in lower spots.

2.2.3 Application to large areas

Remote sensing is an important tool for mapping and surveying of salt-affected and waterlogged soils for relatively large areas. The knowledge of the actual conditions at the earth surface makes it possible to interpret the satellite images. However, it is very difficult to distinguish the degrees of salinity through remote sensing techniques due to lack of specific absorption bands and spectral confusion. In the past, Landsat data have been used for separating different levels of soil salinity. Most authors are able to distinguish only 2- 3 classes (strong and medium) of salinity levels with errors between moderately saline and normal soils.

2.2.3.1 Visual interpretation using photoimagery:- Evolution of the salinity begins with small and irregular bare soil patches. INDA (2002) reviewed a study carried out for the entire Indian territory (329 m ha) using Landsat- MSS FCC of 1:1,000,000 scale and categorized wasteland as salt-affected, gullied, waterlogged or marshy, undulating upland with or without scrub, forest blank, sandy areas (coastal or desert), barren hill ridge or rock outcrops and snow covered/glacial areas. The interpretation technique was supported by intensive ground data and geographical knowledge of the area. An accuracy of 80 to 90 percent has been achieved in the identification and mapping of wastelands when compared with the ground survey. Rao and Venkataratnam (1991) used Landsat- TM standard FCC and delineated strongly sodic soils as bright white patches with fine texture, and

moderately sodic soils as dull white to strong brown. Underestimating of surfaces covered with salts using remote sensing was attributed to confusion with slightly saline and non-saline soils. Aerial photographs and Landsat-TM data could be used to monitor changes in the status of salt-affected soils. Aerial photographs on a 1:40,000 scale and standard FCC image on 1:50,000 scale provided a minimum delineation of 2 ha size. In this study FCC enlarged on the 1:50,000 scale were visually interpreted using image interpretation elements as clues to delineate salt-affected soils. Based upon the colour variation, two classes of salt-affected soils i.e., severely and moderately salt-affected soils could be distinguished. Severely salt-affected soils with thick salt efflorescence on the surface appear as white patches whereas, moderately salt-affected soils appears light bluish green in colour. According to Kalra and Joshi (1997) Landsat (MSS & TM), SPOT and IRS (LISS-I & 11) FCC images during fallow period April- May, January /February crop, rainfed crop (October) were used and evaluated the capability of multi-sensor data for delineating salt-affected soils in arid Rajasthan. *It was concluded that the moderately and severely salt-affected soils could be mapped from any season's FCC of Landsat, SPOT and IRS.* However, the summer season images provided the maximum extent of salt-affected soils. Saline soils due to saline irrigation based on peculiar tone and pattern could be mapped separately by using irrigated crop season (January) images supplemented by knowledge of the quality of irrigation water used. The differentiation between the saline and sodic soils was possible only by the use of multi-date imagery (October and January) and the clue provided by the cropping pattern.

2.2.3.2 Digital analysis: Remote sensing investigation on soil salinity can be divided into the delineation of salt-affected soils under

- (i) bare condition and
- (ii) cropped condition.

Salinized and cropped areas can be identified with a salinity index based on greenness and brightness that describes leaf moisture as influenced by salinity, with classical false colour composites of separated bands, or with a computer assisted

land surface classification (Kauth and Thomas, 1976; Hardisky et al., 1983; Steven et al. 1992; Vincent et al., 1996). Essentially, a brightness index is meant to detect high levels of brightness appearing at high levels of salinity. The contributive power of false colour composites and visual interpretations is demonstrated in most studies. The unique patterns of geomorphologic shapes are thought to be helpful in discriminating the salinization process from a physiographic perspective.

Based on the spectral response of these soils and subsequent correlation in the field by studying terrain characteristics and soil profiles, besides salt-affected soils, other categories such as normal soils, forests, water bodies, river sand, gullies and ravines could be mapped. Salman (2000) has reviewed application of remote sensing in contextual classifier for soil salinity mapping with a built GIS to link the location of the irrigation feeders and drainage master canals in the western Nile Delta with digital elevation data and satellite classifications. Soil salinity risks are considered to be proportional to the distance of field from the main irrigation canals, as well as to the field elevation difference with the main irrigation canals. TM bands 2,3,4,5,6 and 7 were used to classify three different stages of waterlogging according to a simple supervised procedure.

2.2.3.3 Digital analysis using surface vegetation index: A vegetation index is a common spectral index that identifies the presence of chlorophyll. Various crop indices have been derived using the fact that chlorophyll strongly absorbs the light energy in the red part and highly reflects in the near-infrared part. Various researchers for specific analyses have proposed number of vegetation indices. Many papers described salinity detection through its impact on the vegetation. An inverse relationship is observed between reflectance and salinity, since salt content induces less plant cover (decreasing of density, LAI, and height) and some times slight salt deposition on surface associated with vegetation have similar reflectance as that of normal cropped area (Richardson et al., 1976; Everitt et al., 1977). Salt tolerant plants are good references of salinity level on salt marshes but require good calibration. Contrasted associations of vegetation and bare soils can be more useful for salinity detection than individual surface types.

Although the soil profile cannot be evaluated on remotely sensed imagery, spectral characteristics of earth surface features that are indicative of subsurface conditions can be analyzed. Because satellite multi-spectral data denote changes that aid in locating mapping units they hold great promise for soil surveys and land use planning. Some relationships have been established between soil properties and spectral data. While most of these properties have been from the surface soil, subsurface properties that influence some surface characteristics were considered. Although satellite sensors observe only the ground surface, actually both surface and subsurface soil conditions are affected by common genetic factors. Both subsurface conditions and surface conditions are plant canopy. Therefore, when satellite imagery depicts a pattern based on a different spectral response, it is not unreasonable to attempt some inferences about subsurface soil patterns.

In sum, sincere but limited attempts have been made in the past to identify the waterlogging and soil salinity problems using remote sensing. However, most of the studies have been site specific. Apparently, methodology for identification of these problems is still lacking. Therefore, several studies were attempted to develop, within a broad framework, a methodology for diagnosis of waterlogging and soil salinity conditions using remote sensing.

3 MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 General background

The Amibara Irrigation Project is located in East Central Ethiopia between 9°N and 9.5°N latitude and 40°E and 40.5°E longitude (Figure 3.1). The project was internationally funded project to develop the Middle Awash Valley of Ethiopia for irrigated agriculture. About 10,285 ha of land were brought under gravity irrigation by the end of 1982. The project planed to grow cotton as a cash crop and maize for local consumption. The 10,285 ha under gravity included 1,462 ha have the banana farm and 300 ha of Melka Werer Research Center (IAR). The farm development did not include construction of drainage systems (Halcrow, 1982, and Szablkc, 1974). As a result of this the productive land was abandoned due to salinity problem. Poor drainage and lack of appropriate irrigation water management were the main causes, which facilitated secondary salinization. From five to eight years after the scheme development, about 33% of the total area became saline. At present about 40% of the total area is out of production due to salinity.

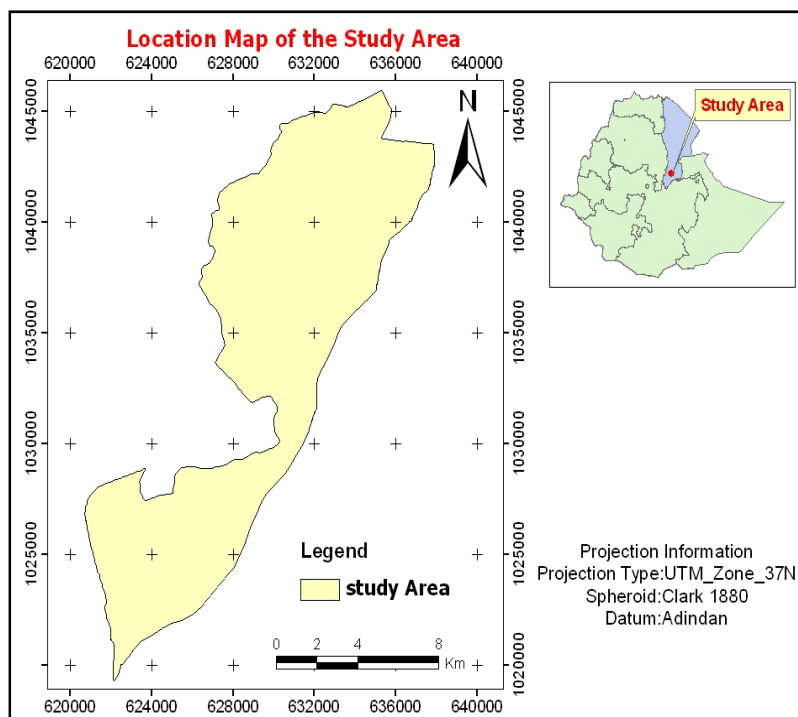


Figure 3.1 Location map of the study area

3.1.2 Climate

The mean annual rainfall is around 562 mm, accumulated with the long and short rains. However, significant variations occur from year to year. The mean maximum temperature is 35⁰C and means minimum falls up to 19⁰C. The mean annual free water evaporation as recorded by the class a pan is around 3000 mm. As a result of this, the soil is dry for a longer period. This hinders any great leaching of soluble salts or complete leaching of the salts.

3.1.3 Geomorphology, Soil and Parent Material

The main geomorphological unit may be recognized as the recent alluvial plain, which resulted from the Awash River basin. Flooding and sedimentation have only been reduced, since Koka Dam and Awash River embankment have been built. However, below the dam still high sedimentation, flooding and erosion is going on. The parent material of the soils may be grouped as volcanic materials, general skeletal soils of ancient alluvial and colluviums, varying in phase: fine, saline, sodic and recently deposited alluvium at the Rift Valley depressions adjacent to Awash River (Italconsult, 1969 and Halcrow, 1982). The soil of the study area is predominantly Eutric Fluvents, order Fluvisols. Vertisols are the second dominant soil order of the study area.

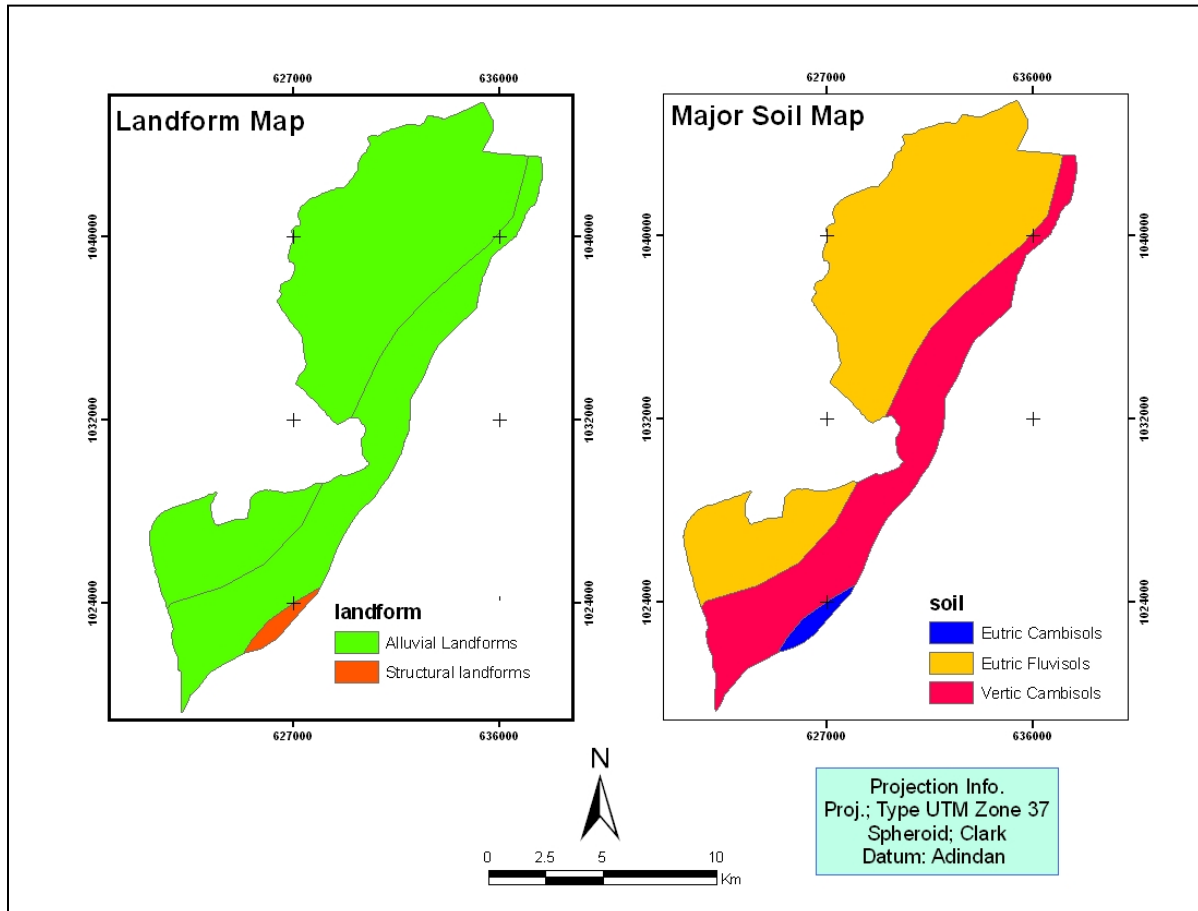


Figure 3.2 Soil and landform map

3.1.4 Land Use and Vegetation

Banana, pasture and some orchards mainly characterized the land use pattern of the study area. Vegetation of the study area varies according to soil salinity level and soil moisture. In most of the saline fields, Tamarix sp. Salvadora persica, which forms round thickets with other species grow very well. Acacia Longispinia or Acacia tortolis var. Spirocarba and cyperus sp., perform well in low saline fields. The presence of Cyprus sp., Arundo sp., phragmites sp., is noted in a place where the water ponds. Newly introduced tree species such as Azadrachata Indica (neem), Eucalyptus camaldulences, Casuarinas Equisitifolia, prosopis sp., are seen at every edge of the fields.

3.1.5 Drainage

The recent data on the rate of salinization showed that increasingly large areas were out of cultivation. This has been attributed to the rising saline water table above critical level (1.5 m) and related salt problems resulting from poor water management practices. In effect, upsetting the balance in the water-bearing horizon and bringing soluble salts up to the root zone. Due to variable textural distribution of the soil in the soil horizon matrix coherent internal soil drainage problem is also common. It was reported by Amibara Irrigation Project (AIP) water management unit that the ground water rise at Melka-Sadi was almost at the rate of 0.50 cm per year (Halcrow, 1986 and Sogreach, 1965).

3.2 DATA AND MATERIALS USED

For this research project the following materials were used

- Satellite image Landsat ETM+(path and row of 167/54; February, 2000)
- Topographic maps of 1:50,000 scale
- Thematic maps of soil, geology, landforms and other maps
- Other ancillary data
- GPS

ArcGIS 9.1 and ERDAS 8.7 software

Table 3.1 Data type and their sources

Data type		Possible sources
Topographic map		Ethiopian Mapping Agency
GPS reading		Field data collection
Thematic maps	Soil type classification map	<ul style="list-style-type: none"> • Ministry of Water Resources • Awash Basin Authority • Worer Research Center • Ministry of Agriculture and Rural Deveopment
	Landform and geology map	
	Irrigation canal and drainage layout	
	Piezometric data map	

3.3 METHODOLOGY

3.3.1 Saline Soil Mapping

The problem of detecting, monitoring and mapping salt-affected soils is known to be a difficult matter, since salinization is a dynamic process. The approach to delineate saline soil using remote sensing data and GIS techniques has been proved in many recent studies to be most efficient (Sharma & Bhargava, 1988, Rao et al., 1991, Srivastava et al., 1997, Dwividi et al., 1998). This study aims to differentiate the salt-affected area from non salt-affected areas using digital image classification and remote sensing techniques. For this research both unsupervised and supervised techniques were applied to the ETM+ data coupled with ground truth.

3.3.2 Salinity Index

In order to enhance the saline zones and suppressing the vegetation, the index : Normalized Difference Salinity Index (NDSI) is proposed in this study. NDSI is the ratio of the difference of the red to NIR and divided by the summation of the two. This concept has emerged from the Red Edge concept for vegetation vigor mapping. In red edge concept, the spectral reflectance of NIR is divided with red band, which gives very high values for vegetation than other features on Earth. Here if the inverse is considered then for vegetation low values will be obtained thus suppressing the vegetation and highlighting the soil. NDSI is computed as follows:

$$\text{NDSI} = (\text{Band 3} - \text{Band 4}) / (\text{Band 3} + \text{Band 4})$$

The value range of NDSI is between 1 and –1 and areas having value greater than 0 or nearly 1 are mapped as bare soils which intern classified as salt affected area.

These are found useful than individual bands particularly in emphasizing saline soil regions. The strongly visible salt-affected lands were then extracted from the final classified image to make a thematic map. The sum of all the extracted salt-affected soils was prepared, considering the rest of area as slightly saline to normal lands

3.3.3 Vegetation Indicators

Chlorophyll has a strong spectral absorption in the visible region at 0.475 and 0.65 μm and thus provides information on vegetation condition. A vegetation index, normalized difference vegetation index (NDVI) has been used for generating the vegetation condition. Since the lack of vegetation or scattered vegetation on highly salt-affected soil surface makes it possible to detect saline surfaces directly from the remote sensing measurements. Since saline surfaces have very distinct reflectance characteristics and can be identified with low NDVI value is also an indirect indication of vegetation stress due to salinity.

3.3.4 Empirical Models Using Soil Salinity (EC values) and Spectral Reflectance (raster value)

The procedure employed were by identifying the location of sampling point sources on satellite data. The corresponding reflectance of soil samples from different sampling zones are retrieved for different bands and indices. An empirical model for NDSI Vs salinity level (EC) has been prepared using regression analysis.

It has been observed that empirical model of spectral reflectance for different bands vs. soil salinity has offered poor coefficient of correlation. However NDSI vs. Salinity level has offered relatively high coefficient of correlation 52 (Figure 3.8) than others. This empirical model for NDSI has been extended for whole image and different salinity has been identified. The advantage of this model being generalized through GIS is that it directly gives the salinity level at any point in the image.

3.3.5 Landuse Classification

Landuse classification in this study was performed by digital image classification. Digital image classification is defined as the process of sorting all the image pixels into a finite number of classes or categories of data. The categorization is based on the data file values of individual pixels and it follows a set of criteria. Two major approaches are generally known: supervised and unsupervised classification. In

supervised classification, spectral signatures were developed from specified locations in the image. These specified locations were given the generic name 'training sites'. The training sites used as inputs for ERDAS 8.7 to develop spectral signatures for the selected areas. After the training sites were developed ERDAS used this information, along with the various images of different bandwidths, to create spectral signatures from the specified areas. These signatures then used to classify all pixels in the scene. Landsat ETM+ bands used were bands 1-5 and 7. The classification program then acts to cluster the data representing each class.

The Maximum Likelihood classifier was used because this algorithm applies the rule that the geometrical shape of a set of pixels belonging to a class often can be described by an ellipsoid. Consequently, pixels are grouped according to their position in the influence zone of the class ellipsoid.

The second attempt made to classify the various land uses was done using unsupervised classification techniques. Unsupervised classification techniques do not require specifying any information about the features contained in the images. Since in *unsupervised classification* any individual pixel is compared to each discrete cluster to see which one it is closest to. A map of all pixels in the image, classified as to which cluster each pixel is most likely to belong, is produced (in black and white or more commonly in colors assigned to each cluster).

This then interpreted as to what the color patterns may represent in terms of classes that are actually present in the area.

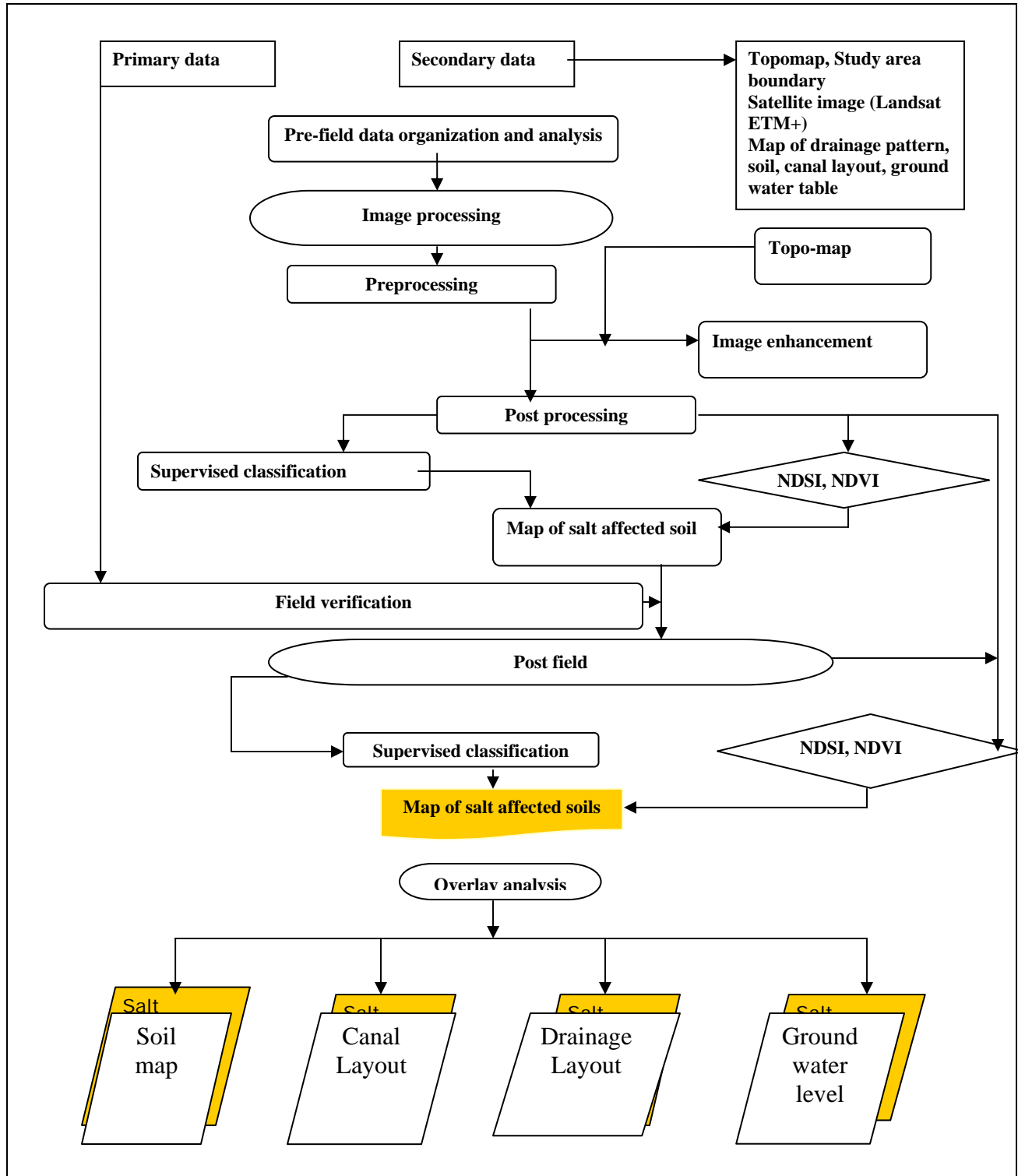


Figure 3.3 General workflow of the study

3.4 DATA ANALYSIS

3.4.1 Sample site Selection for fieldwork and data collection

Since it was difficult to identify all the land cover classes only by interpreting satellite images, ground truth data collection through fieldwork were need to be conducted. As salt affected areas are clearly identified from other features since it has higher reflectance in many bands however it is difficult to differentiate salt affected area from sand soils. Therefore sample sites that are identified as salt affected were used for image analysis.

3.4.2 Band Selection

In this research band selection was done through the analyses of: Reflectance properties of features, Correlation matrix of the bands and Spectral reflectance curve of known features in all bands. Spectral profile was generated from the image using ERDAS IMAGINE 8.7.

3.4.2.1 Application of Bands for features identification

The basic premise of remote sensing (satellite images) is that different objects do have different reflectance properties at different EMS (electromagnetic spectrum) interacting with them since all objects vary with internal structure, morphology and chemical composition. The figure below clearly shows which bands are more sensitive with which features. During the study the spectral behavior of different objects has been primarily referenced with this table and band selection has been performed.

Table 3.2 Application of bands for different feature identification

Band	Band Name	Application
0.45-0.56	Blue	-Soil and vegetation discrimination -Cultural/Urban features
0.52-0.56	Green	-Green vegetation mapping and cultural/urban

		features
0.63-0.69	Red	-Vegetated and non vegetated mapping -Cultural/urban features
0.76-0.90	NIR	-Delineation of water body -Soil moisture discrimination
1.55-1.75	MIR	-Vegetation moisture discrimination -Soil moisture discrimination -Differentiation of snow and ice
10.4-12.5	TIR	-Vegetation and soil moisture analysis -Thermal mapping
2.082.35	NIR	-Discrimination of mineral and rocks -Vegetation moisture analysis

3.4.2.2 Analyses of the Correlation Matrix

Satellite data often show a degree of correlation, meaning that when the spectral values in one band are high the values in another band are expected to be high as well. The correlation matrix of the spectral bands contains useful information about the redundancy of information and selection of optimal band combination for interpretation purpose. If the bands show strong correlation (value near to 1.0) this indicates that the bands usually contain similar information. When those bands are visualized the minimum interpretability among different feature would be noticed. Below, Table 3.3 represents the correlation matrix of the sub scene that was clipped by the study area boundary.

Table 3.3 Correlation matrix of bands

	B1	B2	B3	B4	B5	B7
B1	1	0.9242	0.8374	0.0491	0.7512	0.7566
B2	0.9242	1	0.9132	0.0559	0.8512	0.8441
B3	0.8374	0.9132	1	-0.2139	0.8427	0.9400
B4	0.0491	0.0559	-0.2139	1	0.1074	-0.2537
B5	0.7512	0.8512	0.8427	0.1074	1	0.8881
B7	0.7566	0.8441	0.9400	-0.2537	0.8881	1

From this table it can be observed that there exists high correlation among visible (band 1-3) and mid-infrared bands (band 5 & 7). It means that there is a high redundancy of information within those bands so it makes more sense to select the bands, which contain minimum redundancy. Therefore, one band from the visible region, the near infrared and one from mid-infrared can be selected for the best separability in the salt affected areas using Landsat ETM+.

3.4.3 Spectral Classes of Saline Soils

The spectral reflectance of soil is governed by many factors. In the present study, the area was relatively homogenous in terms of topography, surface soil color, texture, mineralogy and agricultural practices. The only major differences were soil chemistry, expressed in the form of surface accumulated salts. A substantial increase in the spectral response of salt-affected soils was noted.

The spectral value of salt-affected soils is substantially higher than the normal soils in all the bands (Figure 3.4). It is observed that saline soils and harvested dry soil have similar spectral response in band 5 and but saline soils has significantly higher reflectance in all other bands.

This observation is extremely useful as it helps the isolation of saline soils from other soils, which is most important from the reclamation point of view.

3.4.4 True and False Color Composite Image Preparation

To enhance the visualization of the salt affected area and to prepare the image for the future classification various false color composite were made. In this study three TCC and FCC were found to be more useful for the process of discriminating different features in the study area. The different True and FCC band combinations used in this research are FCC-1 and FCC-2 of ETM+ 4-3-2 & 4-5-3. The best image combination used for salt affected soil identification and current land use status mapping were the TCC prepared using bands 3, 2, 1 (RGB) (see Figure 3.3).

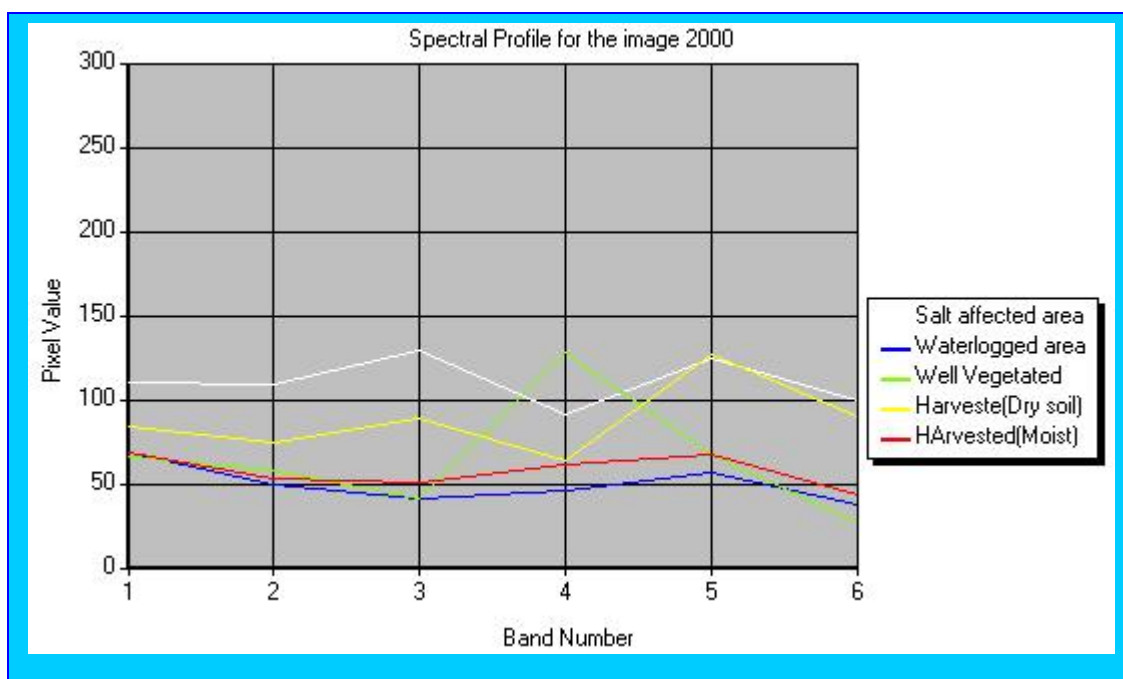


Figure 3.4 Spectral reflectance profile of the study area (2001 image)

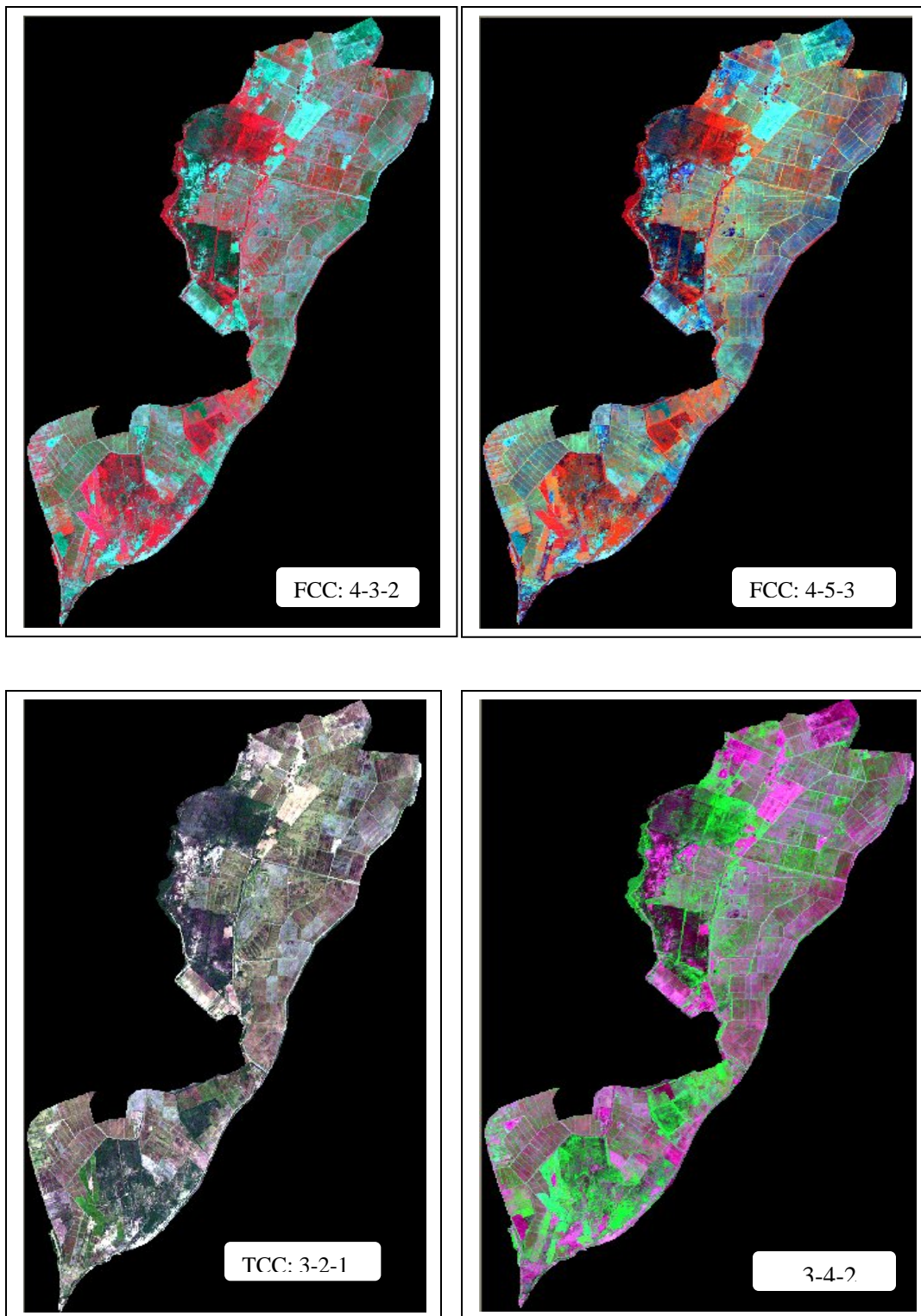


Figure 3.5 TCC and FCC of the ETM+ image

3.4.5 Spatial Distribution of ECe

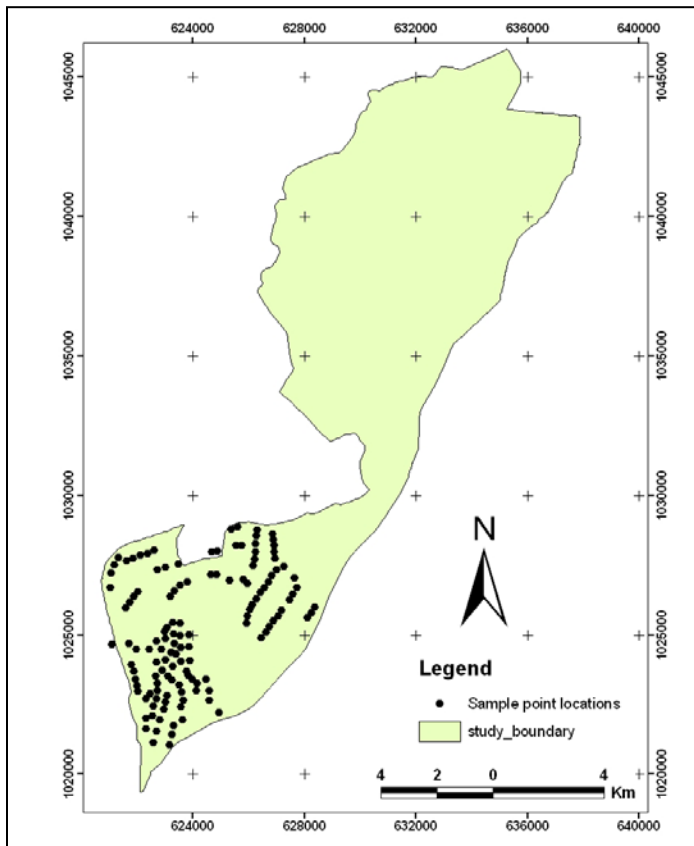
An attempt was made to predict the salinity level at different locations from a limited number of point observations. A total of 131 EC values from a known points locations were used. (Source of EC/pH is Wondimagegn (2001) unpublished and Piezometric data from Awash basin Authority)

Table 3.4 General overview of the data used for analysis

Item	EC (dS/m)	pH	Water table (m)		
			February	March	April
Minimum	0.47	7.93	1.56	2.00	1.90
Maximum	27.04	8.77	6.78	6.87	6.90
Average	2.31	8.52	3.72	3.91	3.99
Standard deviation	3.90	0.16	1.37	1.62	1.41

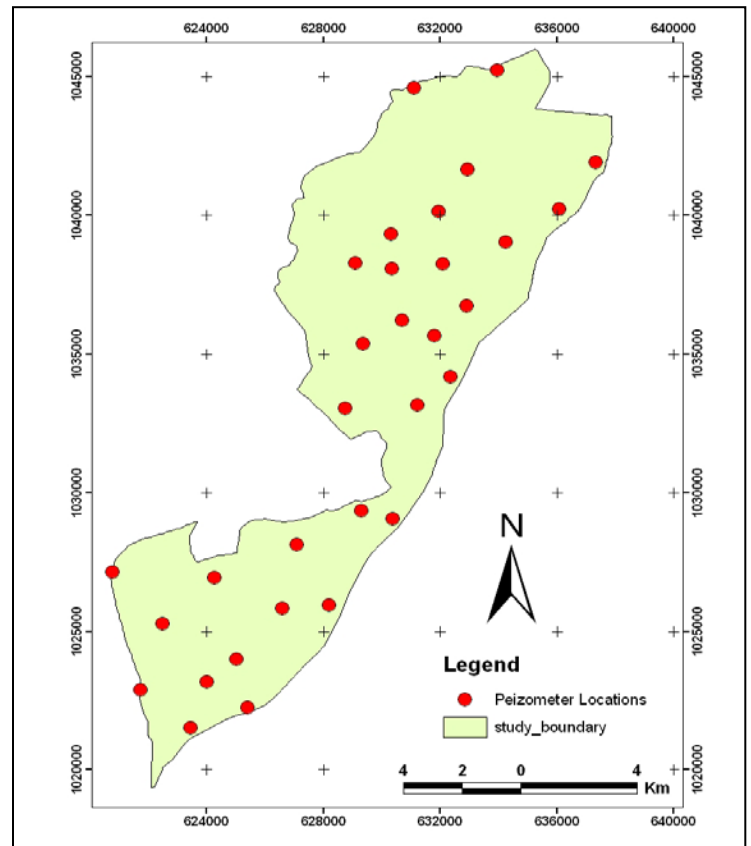
The total number for EC/pH and Water table are 131 and 30 respectively on predicted values calculated using various interpolation techniques. (Source of EC/pH is Wondimagegn (2001) unpublished and Piezometric data from Awash basin Authority)

The locations of the Ec values being used are spatially confined only in the Melka Sadi state farm (see figure 3.4). The procedure employed to predict the salinity level at unsampled locations was using the scatter plot of point locations of EC verses the corresponding raster values of NDSI map extracted using ArcGIS Spatial Analyst Extension (Extract values to points). Based on the scatter plot the best fit line which can model the interdependence of EC and NDSI raster value was determined.



(Source: Wondimagegn (2001) unpublished)

Figure 3.6 EC sample Locations



(Source: Awash basin Authority)

Figure 3.7 Location of Piezometric data

The approach used involves integrating remote sensing data, Geographic Information System (GIS), and spatial analysis to predict soil salinity.

1. The field locations of the sampled soil salinity used was retrieved from farm plot centers (Since the EC values used are representative of single farm plot) and a point map was generated.

2. The location of soil salinity data used was tied to the corresponding points on the image.

- The soil salinity data are tested against the band 3 and band 4 as well as the normalized difference vegetation index (NDVI) and Normalized Difference Salinity Index (NDSI)

- The EC value and the corresponding raster value have been plotted on a scatter diagram and the best fit line and equation determined.

The regression analysis between the EC values and the corresponding raster value has shown relation with R^2 of 62% and correlation of 52%(Figure 3.6). Based on this relation a regression model has been formulated. The graph blow shows the scatter diagram and the fit plot line.

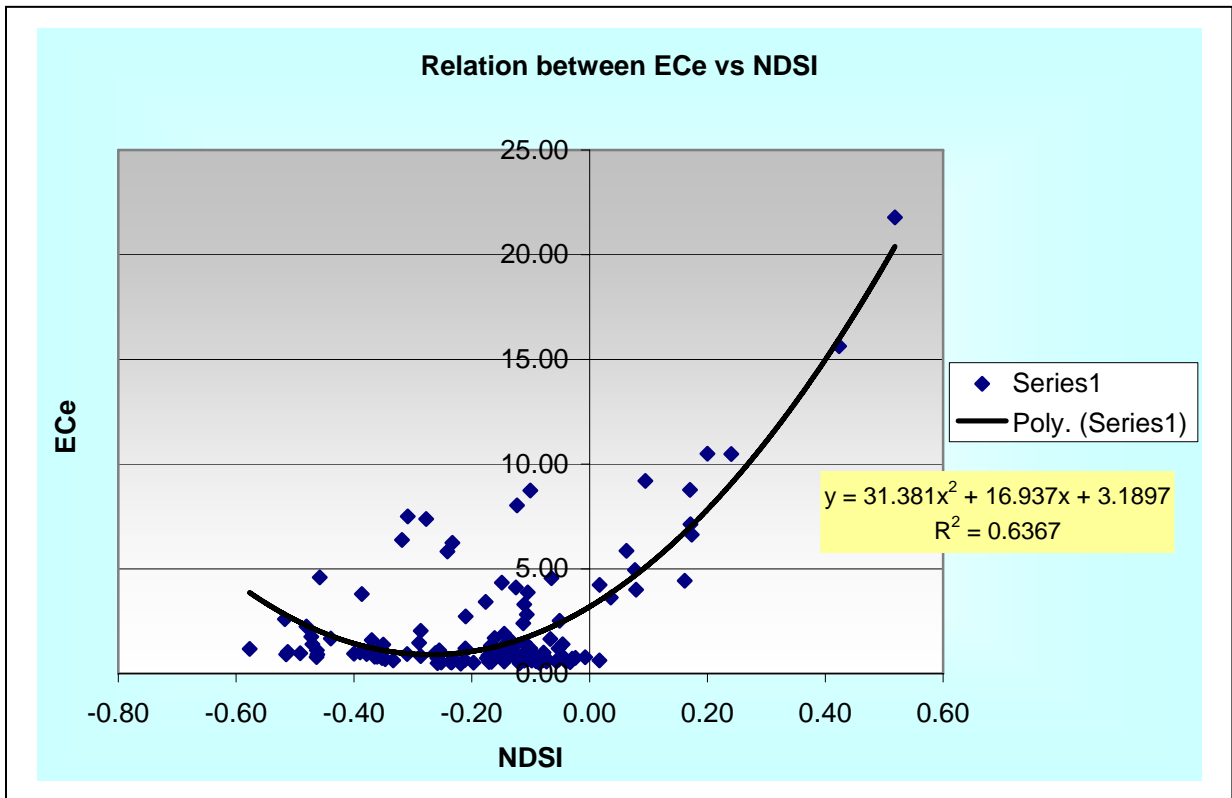


Figure 3.8 Regression Analyses between ECe and NDSI

Based on this regression model a raster map that predict soil salinity for all of the study area has been generated using the model builder in ArcGIS (Figure 3.7)

$$Salinity = 31.381x^2 + 16.937x + 3.1897$$

Where X represents the raster value of NDSI map

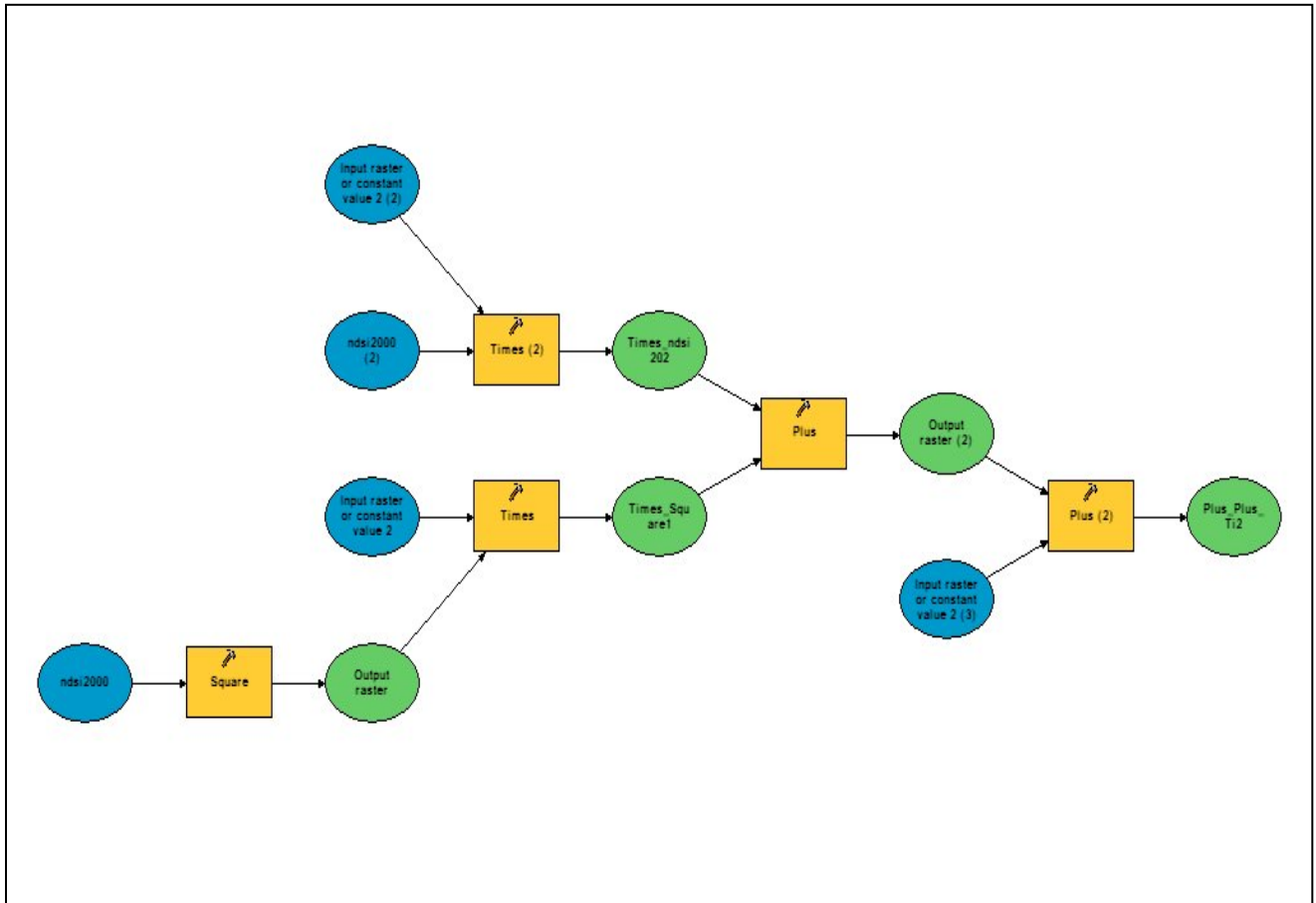


Figure 3.9 The model used for prediction of soil salinity

3.4.6 Overlay Analysis

The spatial distributions of salt affected area were evaluated based by overlaying with different features. Among the factors being considered were Canal and drainage layout, soil and piezometric data.

3.4.6.1 Preparation of features for overlaying

3.4.6.1.1 Drainage and Canal Layout: Both drainage and canal layout were digitized from the map that depict the drainage and canal layout, farm plot partition, piezometric reading location and other features. For the purpose of overlay analysis the digitized canal and drainage layout has been buffered with 100m distances. Since

the problem associated with malfunctioning of canal and drainage is not confined to only along the line rather their effect would be manifested some distance both sides along the canal and drainage line.

Therefore the overlay analysis has been done using 100m buffered drainage and canal layout. The figures below (Figure 3.8 & 3.9) shows the buffered canal and drainage line used in overlay analysis.

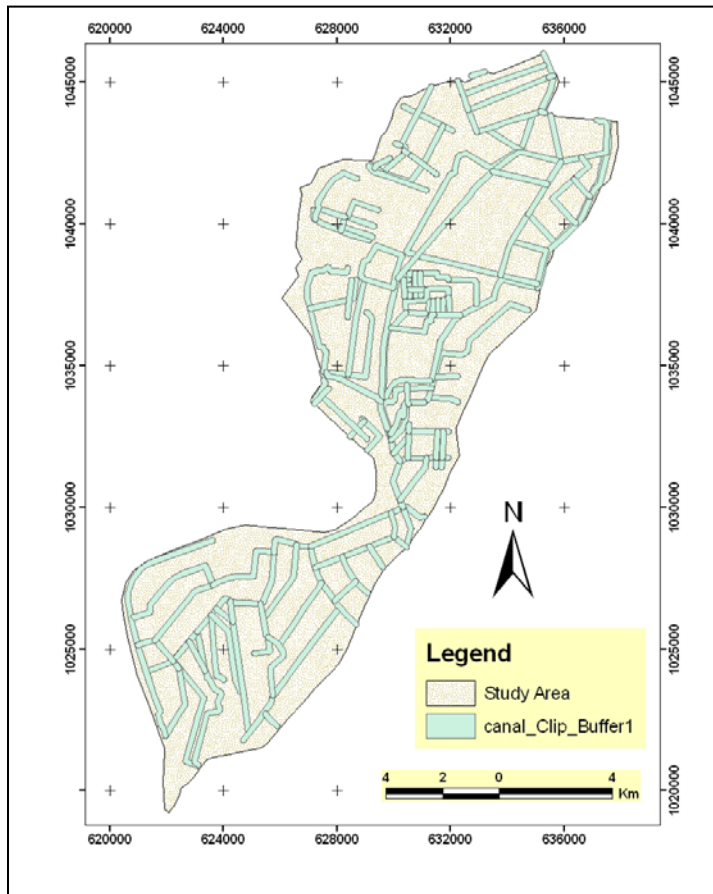


Figure 3.10 The buffered canal layout

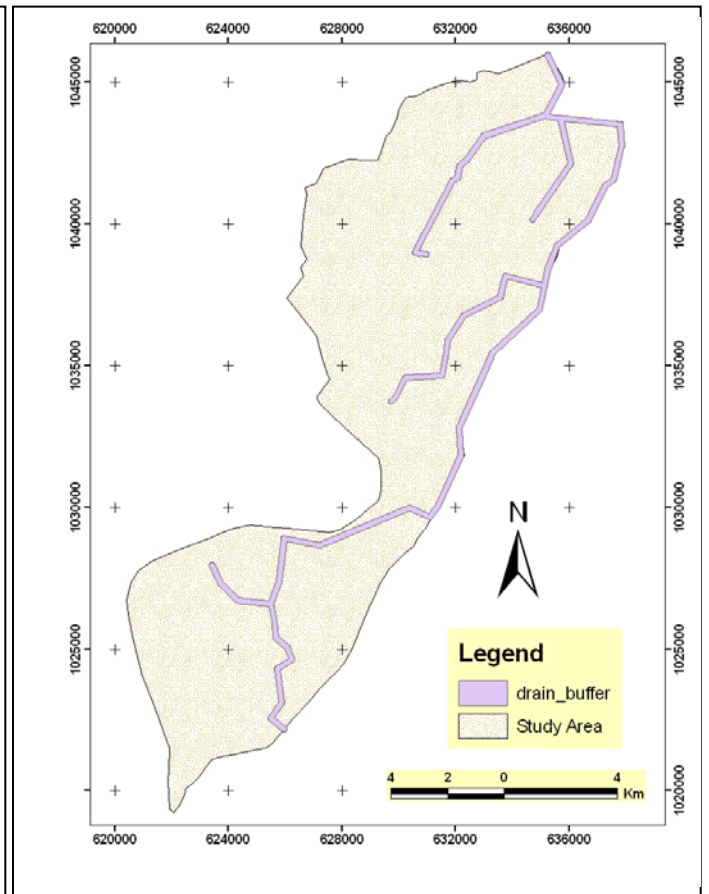


Figure 3.11 Buffered drainage layout

3.4.6.1.3 Piezometric data in order to assess the spatial distribution of salt affected area with respect to ground water table the piezometric data that has been collected in the same month as of the image being interpreted were used. Since soil salinity problem has closely related with shallow water depth, the salt affected area mapped were overlaid

with the ground water table depth. Therefore the piezometric data has been interpolated to generate a continuous surface. For the purpose of interpolation a total of 31 piezometric data distributed through out the study area were used (Figure 3.10). Inverse weighted distance (IDW) has been adopted as a method for the purpose of interpolation. Accordingly based on the ground water depth the entire area has been classified as critically waterlogged, potentially waterlogged and safe area.

Table 3.5 Classification of water depth

Depth (m)	Water logging level
1-2	Critically waterlogged
2-3	Potentially water logged
>3	Safe area

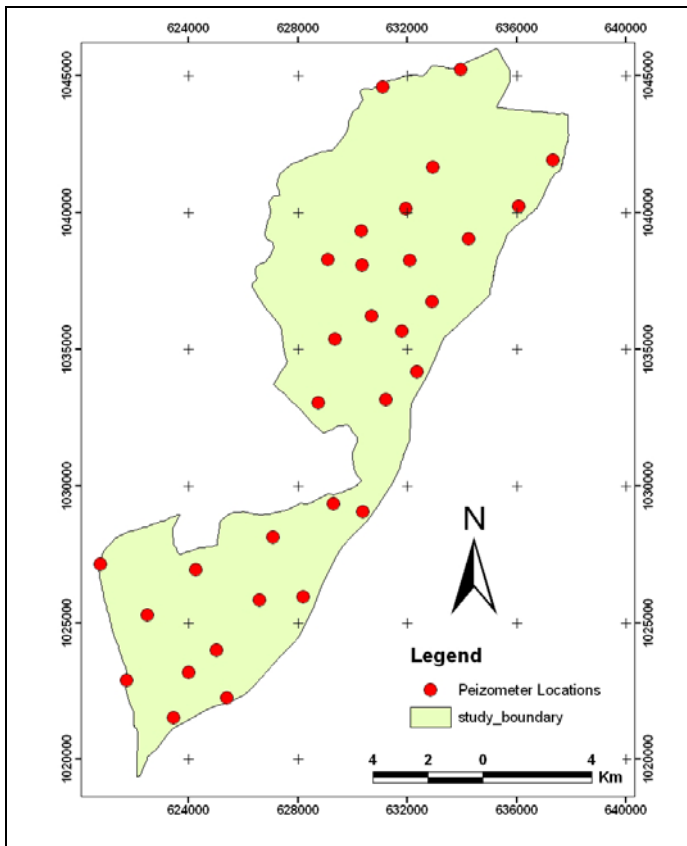


Figure 3.12 Piezometric locations

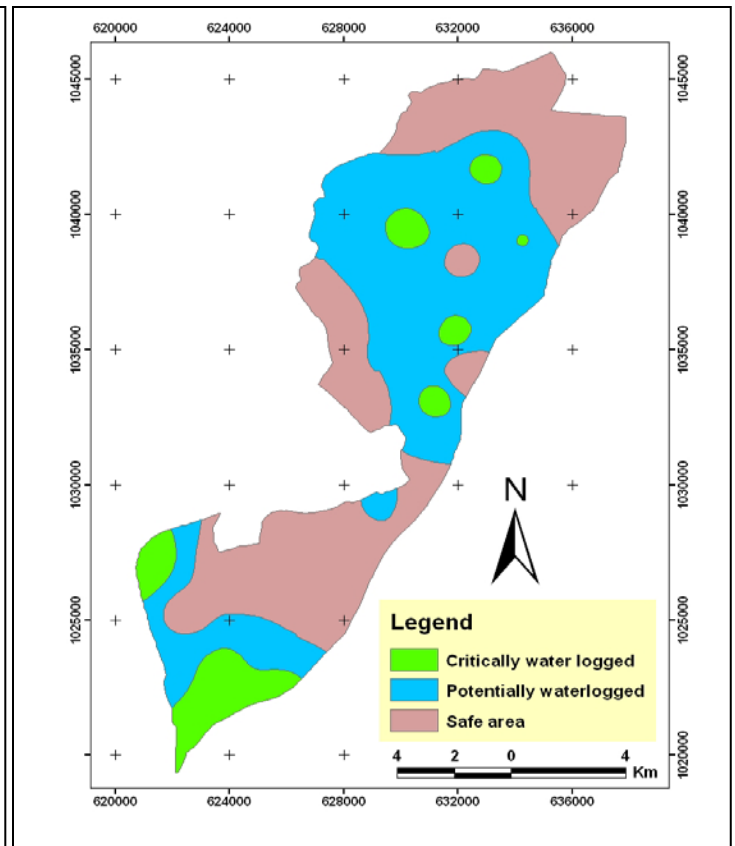


Figure 3.13 Interpolated Water table

3.4.6.1.4 Soil map: The soil map being used for the overlay analysis (Figure 3.2 in description of the study area) has a scale of 1:1,000,000. The major soils considered are Eutric cambisol, Fluvisol and Vertic cambisol.

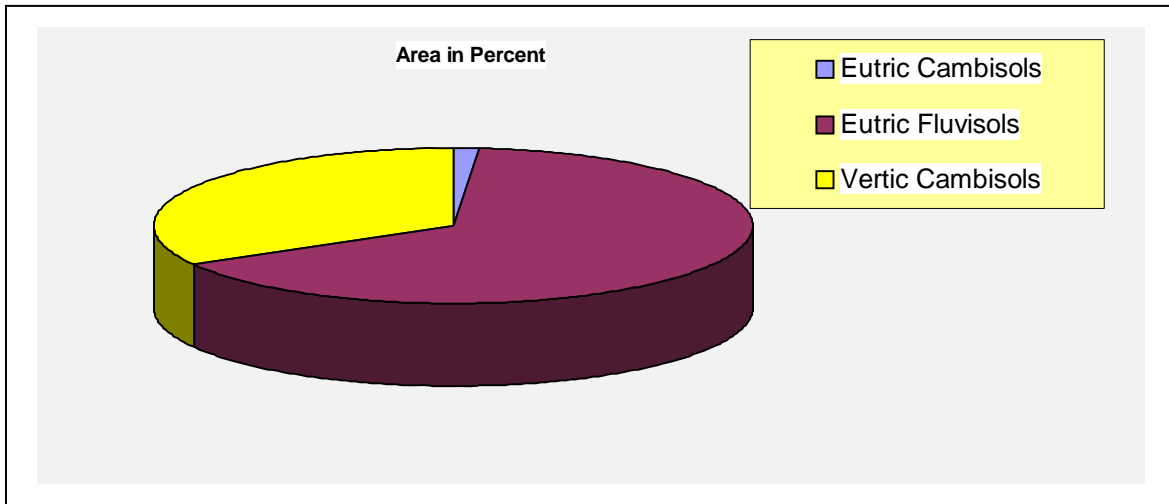


Figure 3.14Percentage area of the major soil type in the study area

4. RESULTS AND DISCUSSION

4.1 DISTRIBUTION OF THE SALT-AFFECTED AREAS ON SATELLITE IMAGES

4.1.2 Salt-affected Areas Characterized by Salinity Levels

Based on visual interpretation of ETM+ satellite image, coupled with ground truth, the study area are categorized into three salinity levels:

- 1) Severe salinity,
- 2) Moderate salinity, and
- 3) Slight salinity, respectively.

The assumption used in classifying the image was based only on the relative reflectance of features on the image. The result derived from visual interpretation would not considered as much acceptable. However it gives a clear idea about the reflectance properties of salt affected area as well as identifying other features.

4.1.2.1 Severe salinity mostly occurs where the relative reflectance is very high as compared to other features. Different researches as reviewed have showed that the reflectance of salt affected area is higher in much of the bands other than other feature. On the Standard False Color Composite 4-3-2, the severely salt-affected areas are mostly represented in very bright color with some small amounts of other colors. The texture of these areas is very fine. (Figure 3.3)

4.1.2.2 Moderate salinity Moderately salt-affected areas are normally shown in light blue color on the False Color Composite. They also show fine texture with few mottled spots of other colors.

4.1.2.3 Slightly salt affected they are normally shown in pinkish white color on the False Color Composite. They normally show a few red or pink mottled textures.

4.2 RESULTS FROM DIGITAL CLASSIFICATION

Apart from visual interpretation on satellite imagery to determine possible salt affected areas, the satellite images were also classified using ERDAS software, both by unsupervised classification and supervised classification method.

4.2.1 Results from Unsupervised Classification

The result from unsupervised classification of ETM+ data is shown in Figure 4.2. The results from unsupervised classification show the general idea that landuse in the study area can be properly categorized into a maximum of 5 classes or less. Based on background knowledge, i.e. geographic information, the results of this automatically classification can be summarized as follows:

The Landuse classified as:

- Class 1- Cropped area 1
- Class 2- Cropped area 2
- Class 3- Harvested moist
- Class 4- Moderate to slight Salt-affected areas and/or fallow ground
- Class 5- Severely salt affected-area

From the unsupervised classification the area wise distribution of each type of land unit is given in the figure 4.1. From the figure, out of the total area 34.3% classified as salt affected area. Even though categorizing the classified image based on the salinity level was difficult, depending on the image-interpreting element in the original image generally classified as severely and moderately to slightly saline soil. This result has to be verified with further detail analysis and intensive ground verification.

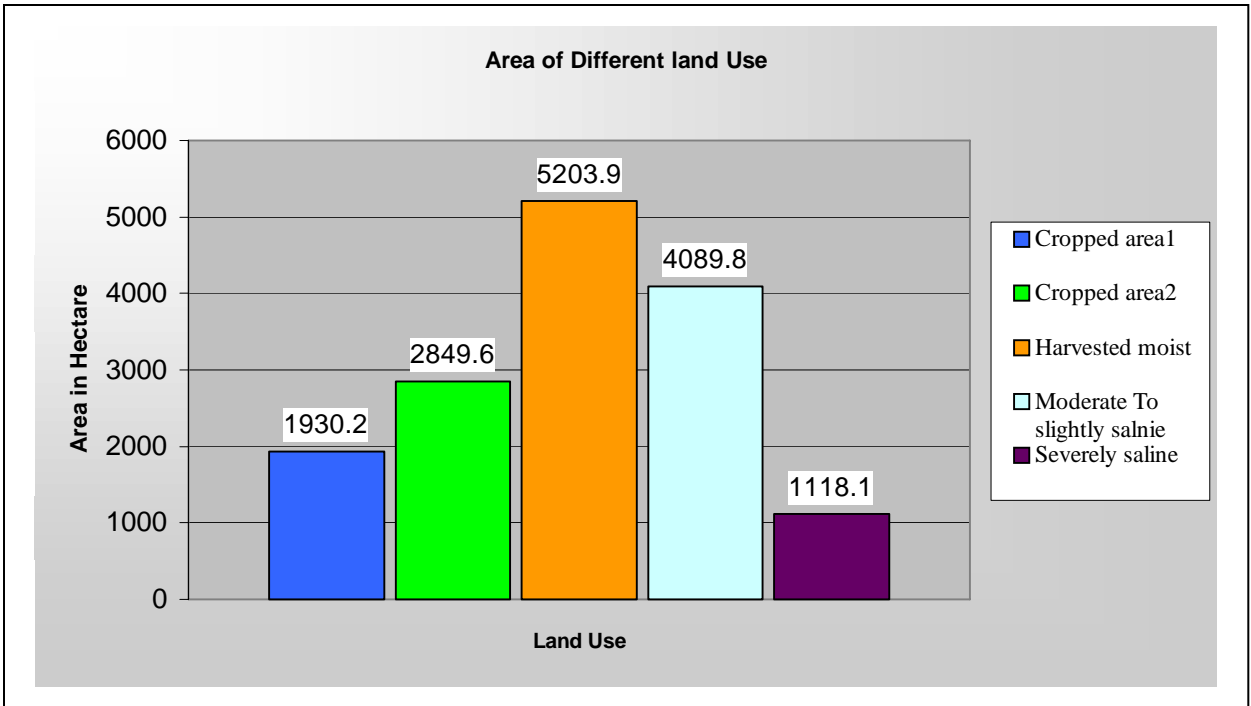


Figure 4.1 Area of different Landuses

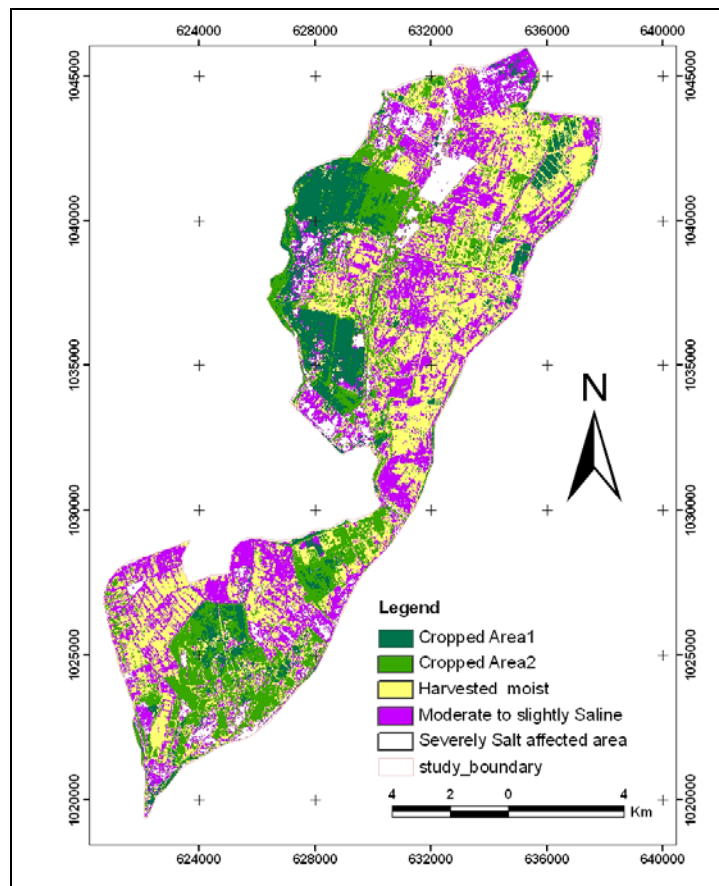


Figure 4.2 Landuse from unsupervised classification

4.2.2 Results from Supervised Classification

The results from Supervised classification of ETM+ data are shown in Figure 4.4.

These results can be summarized as follows:

Since salt affected area, settlement, bare and dry soil has similar reflectance after field visit areas generally which were classified as salt affected area before field check has been identified and masked out from the overall analysis.

As a matter of fact that soil salinity is a dynamic process that means it changes with time (it differs season to season), the training area given for the supervised classification is based on the knowledge base. The training areas given are based on the reflectance signature and different band combination. As previously mentioned from correlation matrix of bands different band combinations were used (Mainly of 4-3-2, 5-4-3...)

During field check some places especially in the central part are still showing salinity effect. Informal discussion and field visit with the experts of Melka Worere Research Centers has also used as an input for post classification. The result of final supervised classification shown in the (figure 4.4) revealed 16.8% of land has been classified as salt affected area. (Figure 4.3)

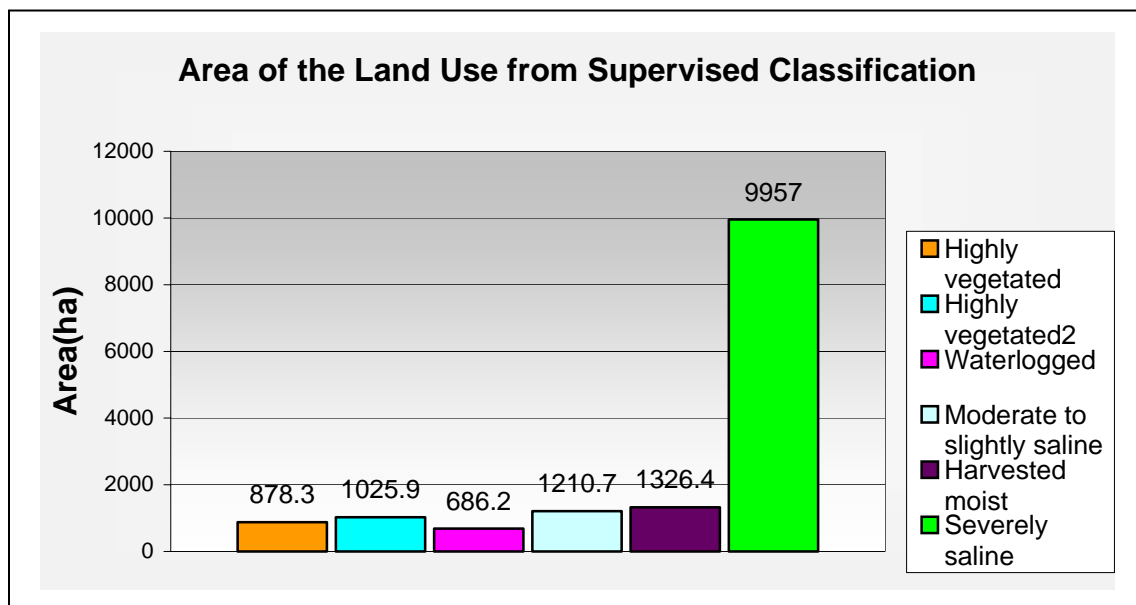


Figure 4.3 Aerial extent of soil salinity derived from supervised classification

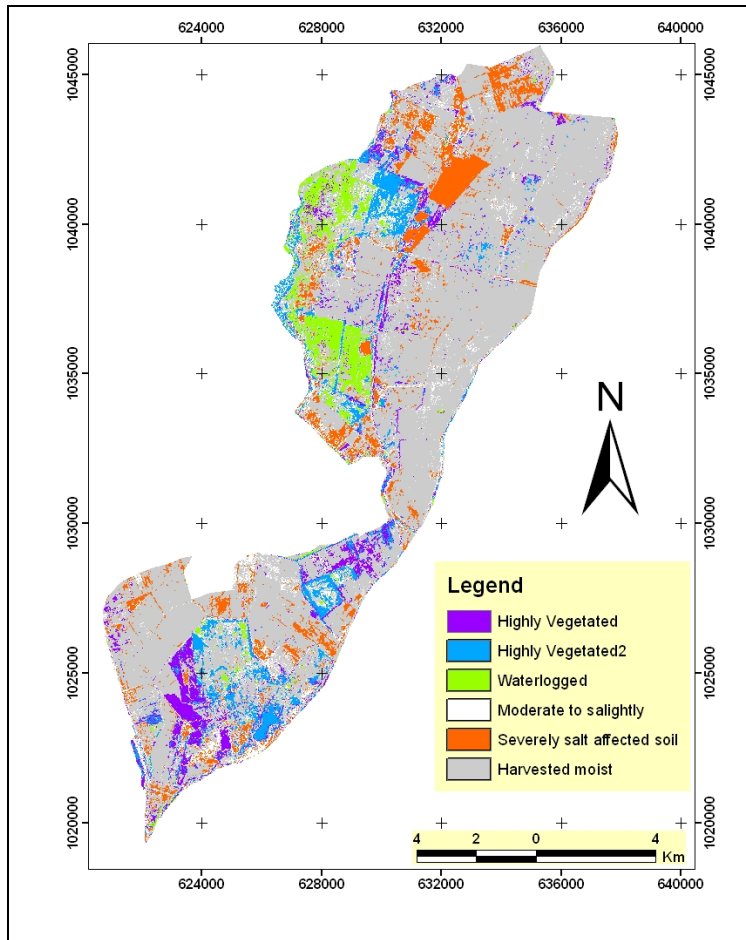


Figure 4.4 Supervised classifications

For further assessment about the spatial distribution of the salt affected area was done by over laying different features which are considered to have direct or indirect relation.

4.2 RESULTS FROM INDICES ANALYSIS

After getting the potential and/or salt-affected areas from image classification, remote sensing indicators employed were the Normalized Differential Salinity Index (NDSI) and the Normalized Vegetation Index (NDVI).

The index used to enhance the saline zones and suppressing the vegetation was NDSI (is the ratio of the difference of the red to NIR and divided by the summation

of the two). Since the spectral reflectance of NIR is divided with red band, which gives very high values for vegetation than other features.

Reflectance variations of vegetation on the image are attributed to the different species of vegetation and their densities, which together provide evidence of shallow groundwater table conditions and saline agricultural areas. Favorable growth conditions prevail in regions where the water table is situated below the area of influence of evapotranspiration, that is, within 10m depth (as cited in Nasir 2000). An indication of whether scanty vegetation in an area is due to high water table depth or salinity can be investigated using Normalized Differential Vegetation Index (NDVI) that easily grasp the state of vegetation. The NDVI for the area can be expressed as:

$$\text{NDVI} = (\text{NIR Band} - \text{Red Band}) / (\text{NIR Band} + \text{Red Band})$$

From the result of NDSI it has been observed that areas with high raster value or high reflectance has been delineated as area affected by salinity problem. And once areas having high reflectance value have been identified, based on their reflectance value the level of the salinity has been determined.

Since the range of the reflectance value is between 1 and -1, areas having 0 and lower than were classified as none saline and some of them as waterlogged. However the rest reflectance value greater than 0 were classified as from slightly saline to highly saline. Attempt has been made to verify the result with the help of ground truth and discussion with researchers in MelkaWorer Research Center. In the NDSI image the salt-affected areas, depicted in white color, could be roughly differentiated from those of non salt-affected areas, water logged (in blue color) and vegetation (in green color). Being salinity problem dynamic in nature as it even varies with time and the image used was a captured 2000 ground truth only gave slight indications of the presence of salt affected area. However the extent of the soil salinity problem in the study area found to be increasing. The salinity level

being classified in NDSI is given in figure 4.6. The area wise distribution is given in the figure 4.5.

Out of the total area 10% are classified as highly saline and distributed through out the study area. In all irrigations sites specifically in the Amibara Irrigation Project its central and in many part of Melka Worer Research Center and Melka Sadi State farm has found to be classified as highly saline.

The problem of salinity in the study area was also indirectly identified using NDVI. Excess soil salinity causes poor and spotty stands of crops, uneven and stunted growth and poor yields, the extent depending on the degree of salinity. The primary effect of excess salinity is that it renders less water available to plants although some is still present in the root zone. This is because the osmotic pressure of the soil solution increases as the salt concentration increases. Apart from the osmotic effect of salts in the soil solution, excessive concentration and absorption of individual ions may prove toxic to the plants and/or may retard the absorption of other essential plant nutrients. The overall adverse effect of salinity manifested in low reflectance of the red band. Therefore in salt affected area the NDVI value has found to be low. From the image of NDVI image it was found that areas that was mapped as salt affected area using NDSI, also give low NDVI value. The classified map is given in the figure 4.7.

The adverse effect of salinity manifested in stunted growth of vegetation.

Table 4.1 Salinity level determined from NDSI in percent

Class Name	Area (ha)	Percent
Water Logged	1064.925	7.3%
None Saline	3274.18	22.4%
Slightly saline	4501.165	30.8%
Moderately Saline	4304.194	29.5%
Highly Saline	1459.045	10%

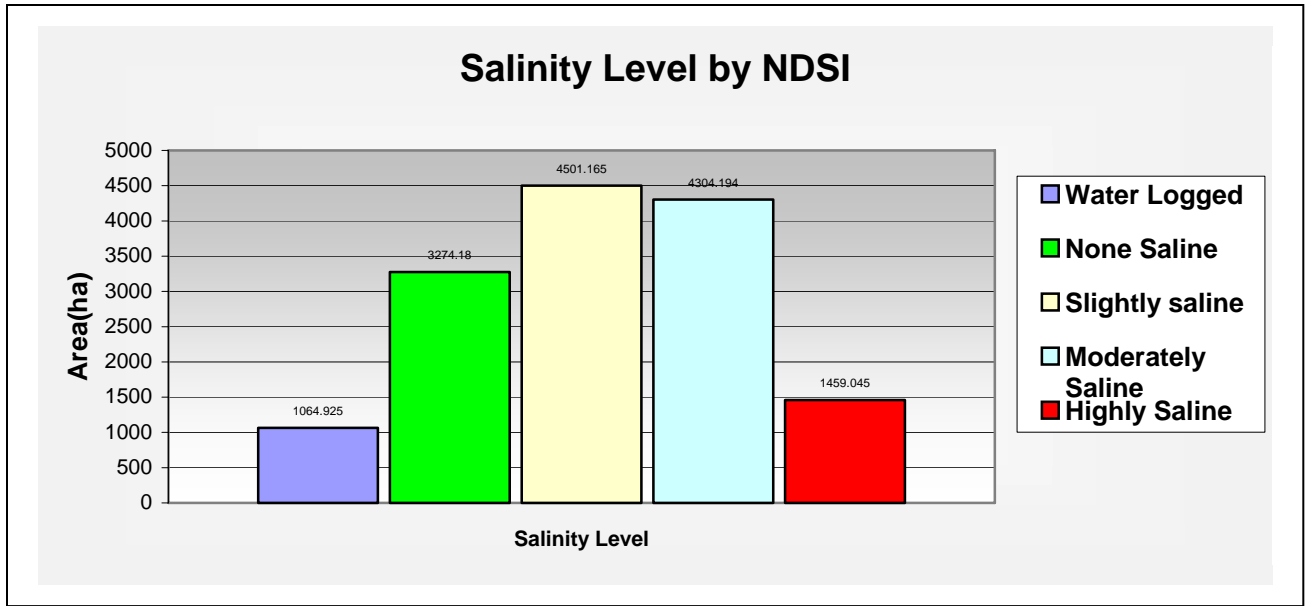


Figure 4.5 Salinity level determined from NDSI

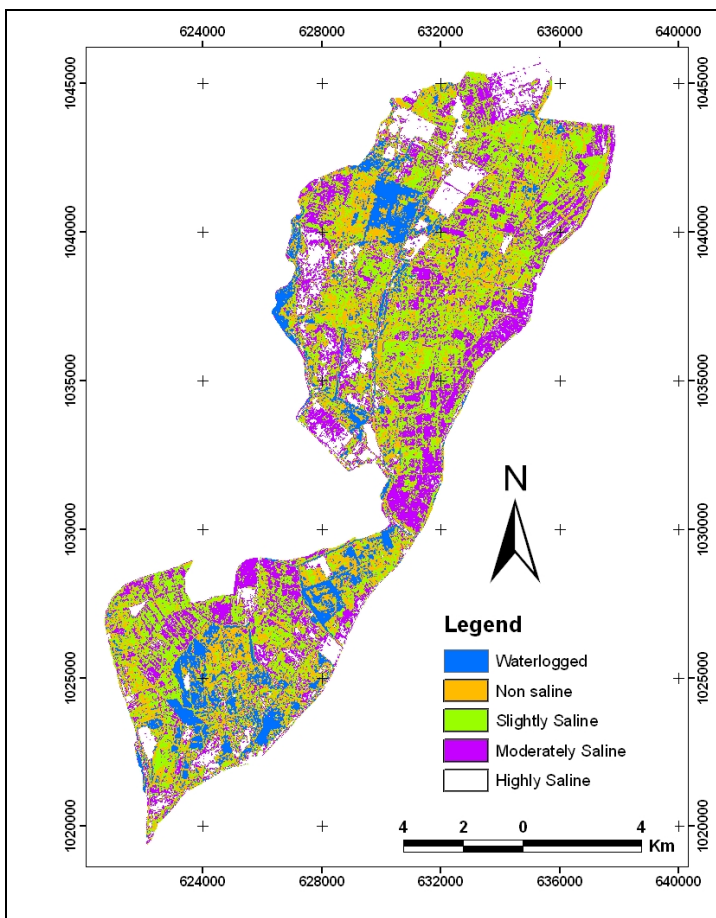


Figure 4.6 Map of NDSI

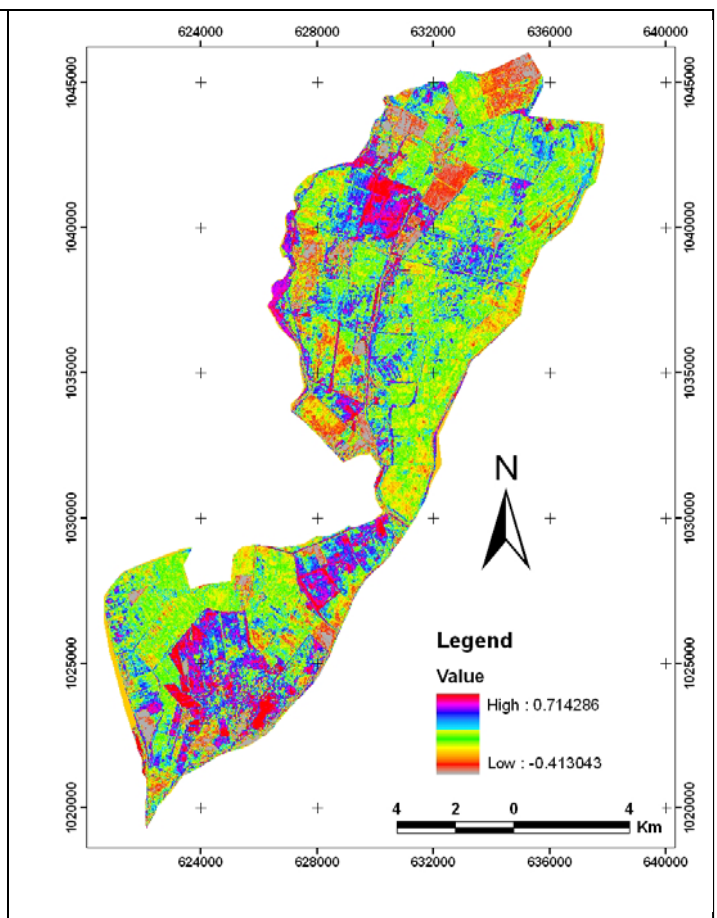


Figure 4.7 Map of NDVI

4.3 EMPIRICAL MODELS USING SOIL SALINITY (EC)

Empirical model for EC_e Vs NDSI has been prepared using regression analysis:

$$\text{Salinity} = 31.381x^2 + 16.937x + 3.1897$$

Where x is the spectral reflectance/ salinity index.

It has been observed that empirical model of EC vs NDSI has offered coefficient of determination 63% and correlation of 0.52. This empirical model has been extended for whole image using modeler builder in ArcGIS and salinity levels are divided into four groups. The advantage of this model being generalized through GIS is that it directly gives the salinity level at any point in the image (Figure 4.9).

These empirical models have been applied on the complete area, which enhances some new areas of high salinity. From the predicted salinity map four ranges of salinity level has been generated. The summary of salinity level, extent of the area in hectare and percentage wise has depicted in the table and graph below (Table 4.2 & Figure 4.8)

The spatial distributions of salt affected land derived from empirical model were checked by comparing it with salt affected area derived from NDSI.

Table 4.2 Salinity level and extent derived from empirical model

Item	Salinity level	Salinity Extent	Area (ha)	Area in %
1	0.9-4	Non Saline	13510.47915	89.2
2	4-8	Moderately Saline	1420.056675	9.4
3	>8	Highly Saline	213.053175	1.4

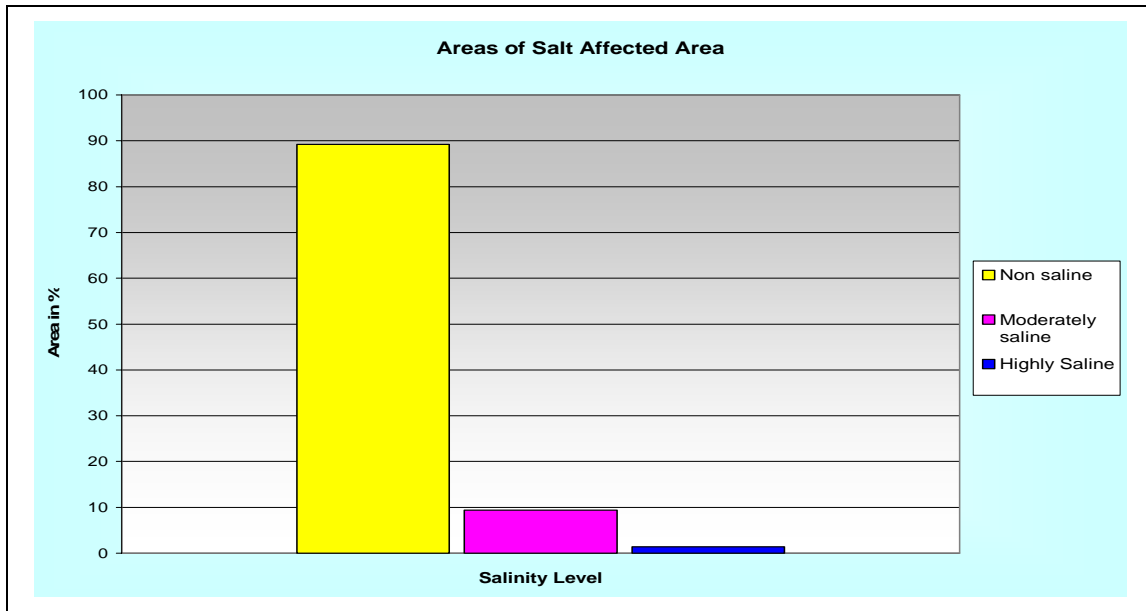


Figure 4.8 Salinity level derived from empirical model

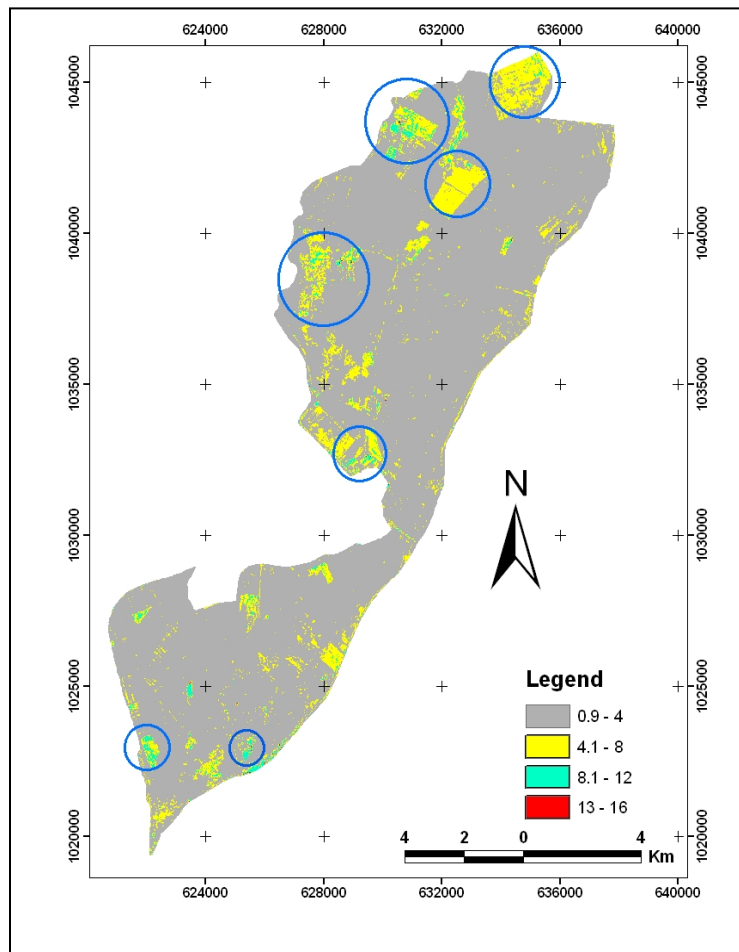


Figure 4.9 Salinity map generated from empirical model

4.4 RESULT FROM OVERLAY ANALYSIS

After salt affected area identified attempts have been made to assess their spatial distribution in relation to some factors. The factors being considered are:

- Canal
- Drainage
- Water table
- Soil

4.4.1 Canal vs Map of salt affected soil generated from NDSI

The total area being identified, as salt affected soil is 636.8ha, out of this value 20.8%(133ha) are laying within 100m from the canal line (Figure 4.10). According to different literature poor irrigation water management system leads to secondary salinization. Secondary salinity, resulting from modern irrigation, occurs because of accelerated redistribution of salts in the profile by high water tables or use of insufficient water to leach salts out of the soil (Asif and Ahmad, 2000).

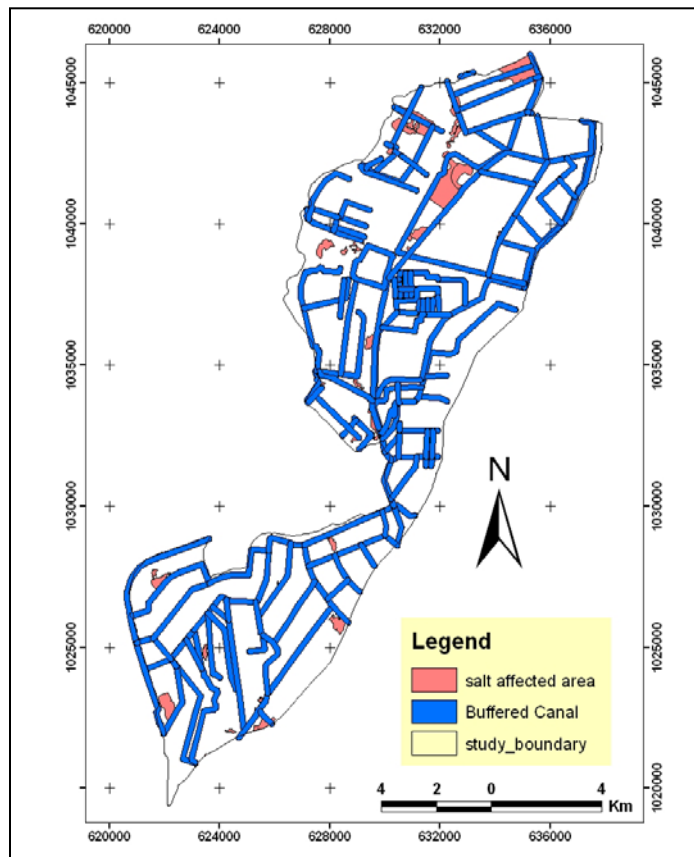


Figure 4.10 Salt affected area versus canal

4.4.2 Drainage Vs Map of salt affected soil generated from NDSI

The area of salt affected soils that resides within 100m distance of drainage is found (Figure 4.11) to be only 6% (43ha). This result indicates the contribution of the surface drainage in eliminating excess water relatively good. Since in many areas drainage problems arise because of the accumulation and stagnation excess irrigation water on the soil surface.

Surface drainage problems usually arise due to slopes that are too flat or to slow water penetration because of structural instability of the soils or to uneven land (Asif and Ahamad, 2000). Therefore the surface drainage of the study area can be evaluated as good since the problem of soil salinity around drainage area is low. However, salt affected areas that are away from drainage line salt accumulation may be due to poor drainage system. But further investigation has to be done to see their relationships.

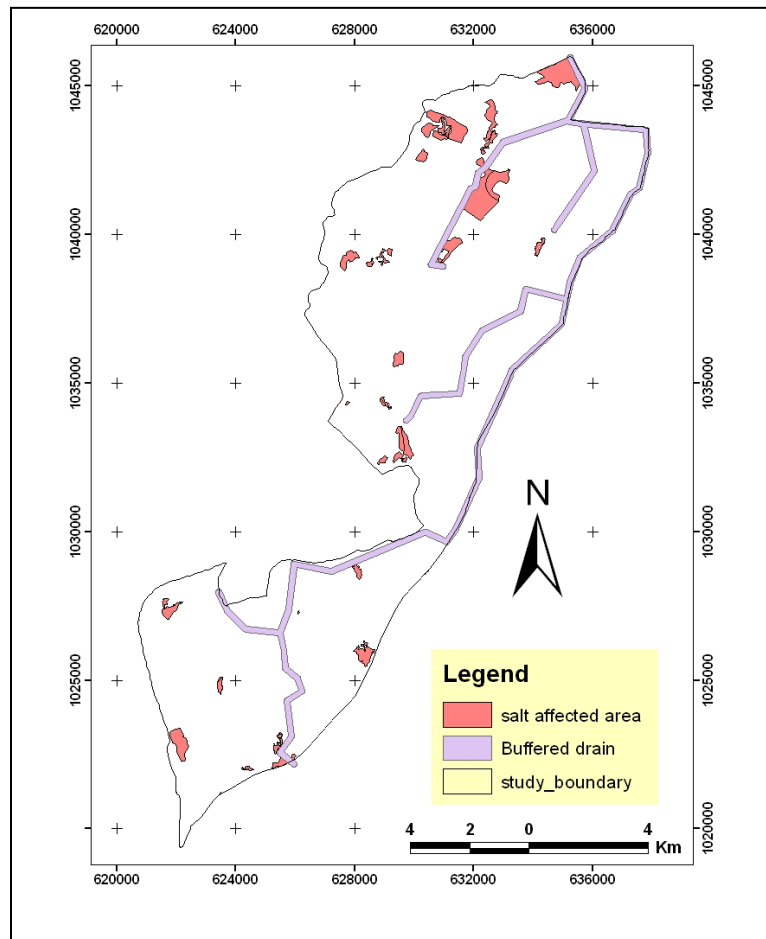


Figure 4.11 Salt affected area Versus Surface drainage lines

4.4.3 Soil vs Map of salt affected soil generated from NDSI

In the study area there are three major soil types: Eutric Cambisol (1.4% of the total area), Eutric Fluvisols(65.2%) and Vertic Cambisol(33.4%). From the overlay analysis, out of the total of 636.8ha of salt affected area 2.8% resides on Cambisol, 14.3% is on Vertic cambisol and the rest 81.9% of salt affected area found on Eutric Fluvisol which by far occupies the major area (Figure 4.12). This result indicates the relative distribution of salt affected area is not significantly affected by soil type. Since all type of soils are comparably affected according to their aerial extent.

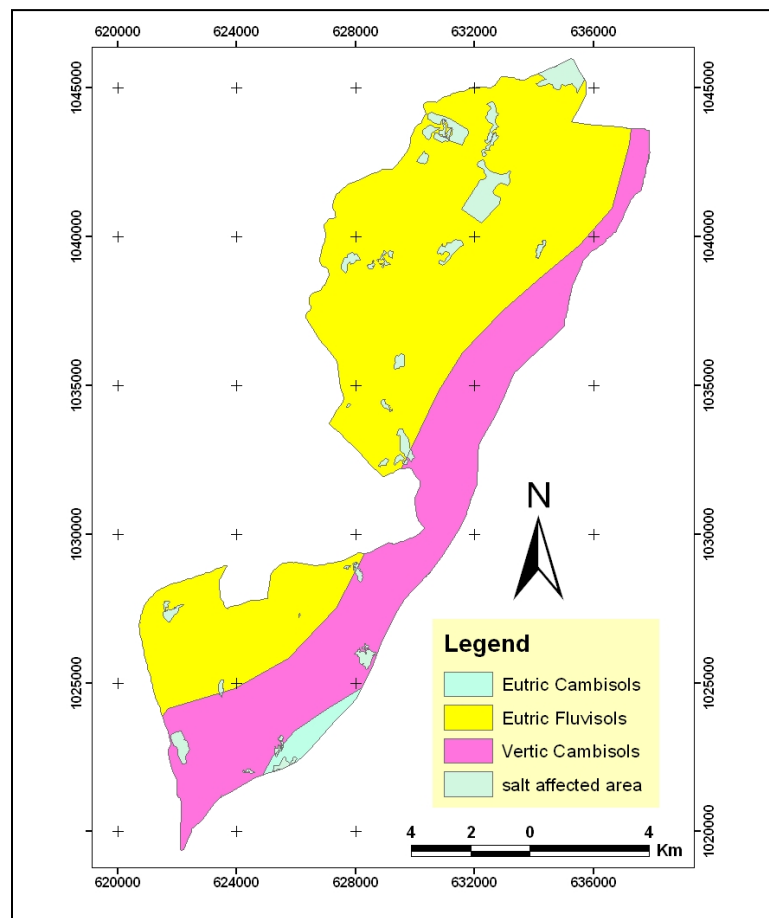


Figure 4.12 Salt affected area Versus Major soil

4.4.4 Water Table vs Map of salt affected soil generated from NDSI

The spatial distribution of salt affected area has been assessed based on the classification of water table depth (Table 3.3.5)

From the overlay analysis the result is summarized in the graph below.

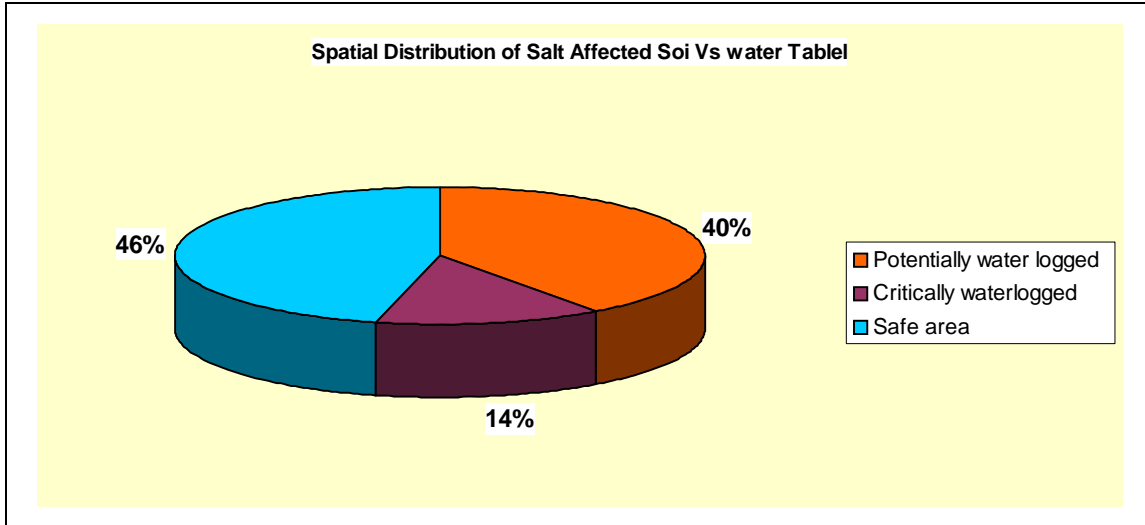


Figure 4.13 Spatial Distribution of salt affected soil versus water table depth

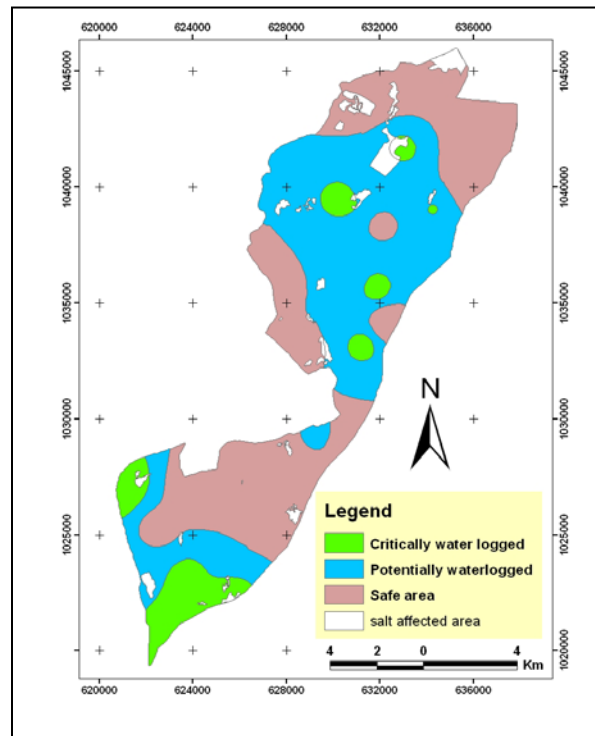


Figure 4.14 Salt affected area Versus Major soil

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Soil salinity is one of the major problems affecting the agricultural productivity and sometime becomes too severe to take it out from economic crop production. The demarcation of the location and assessment of the extent and severity of soil salinity are prerequisite for any reclamation programme.

This research deals with the identification and mapping of salt affected soils in Middle Awash. The analysis was made based on remote sensing data of Landsat ETM+ image, EC Electrical conductivity of soil sample taken in the same year when the image was captured and some other ancillary data. Since for different types of surfaces the amount of reflected solar radiation varies with the wavelength, which makes it possible to identify various kinds of surfaces or classes in a satellite image and distinguish them from each other by the differences in reflectance. In this study the area has been classified in different level of salinity based on their reflectance value in composites of bands as well as their ratio.

The visual interpretation, supervised and unsupervised classification was found to be a good indication of soil salinity. However the result obtained from those methods varies in aerial extent, the spatial location being determined as salt affected area are similar. Therefore, visual interpretation and image classification are found to be important in salinity mapping.

From the indices analysis particularly the Normalized Difference Salinity Index (NDSI) has shown the not only the extent of salt affected area but also the level of salinity based on their reflectance value. From the total area only 10% found to be highly affected. The indirect method that indicates the presence of soil salinity being employed (Normalized difference Vegetation Index, NDVI) has resulted in the darker tone or low raster values, specifically in areas where identified as salt

affected area by other methods. Therefore the application of the NDSI and NDVI are found to be good indicators of the presence of soil salinity.

Statistical analysis has been done for EC values and the corresponding raster value of the NDSI image. It was found that EC comparatively related to the reflectance patterns on the NDSI images i.e. in most of the cases the areas with the highest reflectance that appear as brightest on the NDSI images do have the highest EC. Since EC is variable in the field, the relation was fitted into second order polynomial with R^2 of 63%.

Using the regression model derived salinity map was generated and the maximum and minimum EC value predicted were 16 and 0.9dS/m respectively. The spatial distribution of salt affected area has been checked against salt affected area mapped from NDSI and it was found that they have similar pattern in distribution but in different extent. It can be concluded that remote sensing indicators supported with less ground data but representing entire area could give good result.

From the result obtained from the overlay analysis it is possible to assess the spatial distribution of salt affected area in relation to different features. Since soil salinity particularly in irrigated area is attributed to the problem of poor drainage, malfunction of canal and shallow water table. Overlaying the map of salt affected area could indicate the relation of salinity with these features. In this study the result of overlay analysis has shown the pattern of salt affected area and no significant relation was found.

Generally it can be concluded that the problem of salt affected area can be identified and mapped using direct indicators (NDSI) and indirect indicators (NDVI).

5.2 RECOMMENDATIONS

From the overall work and results obtained the following recommendations has been put as:

- The statistical method used for modeling the soil salinity was extrapolated using small sample points to areas other than sampled area. Therefore in order to have more acceptable result samples to be used should be representative of the study area.
- Despite the fact that the empirical method is simple and easy to apply the entire relationship changes with time and location. This therefore, requires frequent field visits to adjust the parameters being considered (both field salinity level as well as images)
- The empirical method detects only the salts on the surface of the soil and gives a poor idea about the conditions below the surface; so subsurface information should be obtained indirectly with other methods. Since the indirect method applied in this study i.e. NDVI, only reveals the presence of soil salinity not the extent.
- Using Landsat ETM+ image it is possible to map salt affected area. The spatial resolution of satellite images still limits to detect small patches of salt affected area. Therefore high-resolution images should be applied to map small area.
- This study has been carried out using a single season image of a year, inherently however salinization is extremely varied within seasons and hence a single season image cannot adequately map salinity. Therefore in order to map soil salinity adequately multi temporal image particularly in different season of a year should be applied.

REFERENCES

- Baber, J.J. Jr.** (1982). Detection of crop conditions with low-altitude aerial photography. In *Remote Sensing for Resource Management*, C.J. Johannsen and J.L. Sanders, eds. Soil Conser.Soc. Am. 407-412.
- Dale, P.E., Hulsman, K. and Chandica, A.L.** (1986). Classification of reflectance on color infrared aerial photographs and sub-tropical salt-marsh vegetation type. *Int. J. of Remote Sensing*. 7:1783-1788.
- Indo-Dutch Network Project (IDNP).** 2002. A Methodology for Identification of Waterlogging and Soil Salinity Conditions Using Remote Sensing. CSSRI, Kamal and Alterra-ILRI, Wageningen.PP.78
- Ital Consult,** 1969, Melka Sadi Amibara Proposed Irrigation project Feasibility Study. PartII.V.II. Soile Science
- Johnstone, R.M., and Barson, M.M.** (1990). An assessment of the use of remote sensing techruques in land degradation studies. Australian Department of Primary Industries and Energy, Bureau of Rural Resources, Canberra, Australia. Bulletin 5. pp 64
- Joshi, M.D., and Sahai, B.** (1993). Mapping of salt-affected land in Saurashtra coast using Landsat satellite data. *Int. J. of Remote Sensing*. 14(10):1919-1929.
- Kalra, N.K. and Joshi, D.C.** (1997). Evaluation of multi-sensor data for delineating salt-affected soils in arid-Rajasthan. *Journal of the Indian Society of Remote Sensing*. 25(2):79 91.
- Kauth, R.J., and Thomas, G.S.** (1976). The tasseled cap: A graphic description of spectral temporal development of agricultural crops as seen by Landsat. In *Symposium on Machme Processing of Remotely Sensed Data*. New York: Institute of Electrical and Electronics Engineers. 14-51.
- Moulders, M.A.** (1987). *Remote sensing in soil science*. Developments in Soil Science 15. Elsevier Publication, Amsterdam.
- Nasir M. K. and Yohei S.** (2000), Land degradation due to hydro-salinity in semi-arid regions Using GIS and Remote sensing, Department of Biology and Environmental Engineering, Graduate School of Agricultural and Life Sciences, The University of Tokyo 1-1-1 Yayoi, Bunkyo-ku, Tokyo 133-8657, Japan

Richardson, A.J., Gerbermann, A.H., Gausmann, H.W. and Cuellar, J.A. (1976). Detection of saline soils with skylab multi-spectral scanner data. *Photogrammetric Engineering and Remote Sensing*. 42:679-684.

Salman.A and Mubeen-ul-Din. A, 2000, Using the State-of-the-art Remote Sensing and GIS for monitoring waterlogging and Salinity, International Water-Management Institute,Lahore, Pakistan

Sharma, R.C., and Bhargawa, G.P., 1988. Landsat imagery for mapping saline soils and wetlands in north-west India. *International journal of remote sensing*, 9,pp.69-84.

Sir William Halcrow and Partners,1986, Amibara Irrigation II Melka Sadi Pilot drainage Scheme. Final Report. V.II Swinden, U.K

Tabet, D., Vidal,A., Zimmer, D., Asif, M., Kuper, M., and Strosser, P., 1997. Soil salinity Characterization in SPOT images, A case study in one irrigation system of teh Punjab, Pakistan. Physical measurements and signatures in remote Sensing, Guyot & Phulin Eds- Balkema,pp.795-800

Taddese G., And Abegaz, F. (1999). The Nature and Properties of Salt Affected soils in Middle Awash Valley of Ethiopia <http://www.cgiar.org>

T.J., Jaggard, F.M. and Andrieu, B. (1992). Monitoring responses of vegetation to stress. In *Remote Sensing from Research to Operation: Proceedings of the 18th Annual Conference of the Remote Sensing Society*. University of Dundee, 15-17, Sept. 1992. Ed. A.P. Cracknell and R.A. Vaughan, Nottingham, UK.

APPENDIX

Chemical properties of soils of Melka Sedi State Farm fields F3/2 to F3/4 sampled in 2001

Field No	ECe(dS/m)	pHe	ESP
F3/4/46	0.69	8.61	9.44
F3/4/47	0.69	8.71	10.19
F3/4/48	0.57	8.56	9.16
F3/4/49	0.47	8.59	8.55
F3/4/50	0.66	8.57	9.17
F3/4/51	0.58	8.71	9.23
F3/4/52	0.51	8.57	7.48
F3/4/53	0.57	8.57	7.42
F3/3/33	0.69	8.73	11.65
F3/3/34	1.2	8.57	15.36
F3/3/35	0.72	8.57	12.68
F3/3/36	1.53	8.46	14.32
F3/3/37	2.82	8.26	10.32
F3/3/38	0.89	8.5	11.9
F3/3/39	0.72	8.57	10.93
F3/3/40	0.68	8.62	10
F3/3/41	0.86	8.56	9.9
F3/3/42	0.67	8.53	10.19
F3/3/43	0.71	8.53	13.62
F3/3/44	3	8.27	10.71
F3/3/45	1	8.61	10.48
F3/2/22	8.03	8.35	33.78
F3/2/23	6.24	8.35	31.08
F3/2/24	2.4	8.38	13.1
F3/4/54	0.55	8.65	12.05
F3/4/55	0.74	8.61	9.15
F3/4/56	0.57	8.74	7.37
F3/2/25	1.23	8.54	8.81
F1/2A/20	0.61	8.53	10.87
F3/2/26	1.63	8.54	8.6

Field No	ECe(dS/m)	pHe	ESP
F3/2/27	0.74	8.77	7.88
F3/2/29	3.87	8.32	10.91
F3/2/30	0.86	8.43	9.87
F3/2/31	0.63	8.7	9.89
F3/2/32	0.74	8.65	7.34
F3/1/16	0.77	8.74	9.69
F3/1/17	1.48	8.51	11.46
F3/1/18	0.62	8.7	13.41
F1/28/73	0.74	8.57	7.84
F1/28/74	0.5	8.62	8.39
F1/28/76	0.54	8.63	9.26
F1/20/64	0.59	8.69	9.57
F1/20/65	0.75	8.63	8.62
F1/20/67	0.49	8.68	9.17
F1/20/69	0.54	8.72	8.26
F1/20/70	0.63	8.63	7.64
F1/28/57	0.56	8.74	9.3
F1/28/58	0.62	8.67	8.52
F1/28/59	0.62	8.66	9.19
F1/28/60	0.55	8.64	8.44
F1/28/61	0.61	8.53	9.35
F1/28/62	0.74	8.45	8.75
F1/28/63	0.86	8.52	10.2
F1/2A/16	0.65	8.53	13.09
F1/2A/17	0.79	8.54	10.35
F1/2A/18	0.64	8.57	10.79
F1/2A/19	0.56	8.54	10
F1/2A/21	0.69	8.59	11.01

Field No	Ece	pHe	ESP
F1/1/3	21.78	7.93	12.6
F1/1/4	32.28	7.86	19.33
F1/1/5	1.67	8.55	11.58
F1/1/6	17.44	8.02	16.14
F1/1/7	5.5	8.25	12.83
F1/1/8	4.13	8.34	10.32
F1/1/9	1.6	8.39	11.08
F1/1/11	15.63	8.17	14.55
F1/1/14	0.92	8.64	11.28
F1/1/15	0.88	8.64	9.29
F1/20/22	1.9	8.36	11.95
F1/20/23	2.73	8.34	10.51
F1/20/24	2.83	8.35	11.58
F1/20/25	2.45	8.4	12.69
F1/3/26	7.2	8.26	12.93
F1/3/28	7.5	8.25	13.33
F1/3/30	1.45	8.51	11.92
F1/3/31	1.2	8.4	11.11
F1/3/32	1.4	8.32	15.7
F1/3/33	0.83	8.44	
F1/3/34	4.34	8.14	10.99
F1/3/35	0.87	8.45	9.71
F1/3/36	0.84	8.36	8.52
F1/3/37	0.73	8.37	8.3
F1/3/38	0.66	8.4	7.62
F1/3/39	0.06	8.38	7.16
F1/3/40	0.67	8.41	8.48
F1/3/41	0.61	8.43	7.27
F1/3/42	1.74	8.28	7.84
2C30	0.95	8.69	10.4
F1/3/43	0.94	8.44	11.13

Field No	ECe	pHe	ESP
F1/28/44	5.83	8.29	9.27
F1/28/45	1.65	8.27	8.73
F1/28/46	0.53	8.4	7.77
F1/28/47	0.67	8.35	8.07
F1/28/51	0.52	8.42	9.86
F1/28/52	0.64	8.44	8.46
F1/28/54	0.53	8.42	7.96
F1/28/68	0.47	8.36	7.2
3A3	0.94	8.54	11.7
3A4	0.8	8.55	11.14
3A5	0.93	8.71	10.79
3A7	1.38	8.72	13.35
2A2	1.11	8.61	11.75
2A3	20.04	8.21	22.26
2A4	4.59	8.48	13.38
2A5	0.92	8.53	11.63
2A6	3.42	8.42	13.83
2C13	3.8	8.48	18.21
2C14	2.25	8.5	14.6
2C15	1.33	8.58	16.06
2C18	1.03	8.66	13.6
2C19	1.47	8.62	13.2
2C20	1.11	8.68	11.08
2C21	1.33	8.67	14.59
2C23	0.97	8.61	8.96
2C24	1.18	8.68	10.84
2C25	1.4	8.66	12
2C26	1.76	8.58	12.8
2C27	14.11	8.72	12.6
2C28	0.73	8.62	11.89
2C29	0.63	8.51	12

Field No	ECe	pHe	ESP
2B1	0.8	8.59	11.2
2B2	1.43	8.55	9.2
2B3	1.01	8.61	10.16
2B4	0.78	8.61	9.57
2B5	0.79	8.64	11.24
2B6	2.6	8.49	14.58
2B7	0.78	8.55	8.73
2B8	0.87	8.54	10.1
2B9	0.64	8.63	8.53
2B10	1.32	8.6	14.25
2B12	1.2	8.52	9.49
1C1	0.63	8.52	9.8
1C2	0.93	8.65	12.21
1C3	7.38	8.2	22.67
1C4	9.2	8.29	14.97
1C8	1.06	8.61	13.41
1C11	0.91	8.58	12.38
1B1	4.55	8.42	12.61
1B2	1.1	8.73	9.8
1B3	0.88	8.66	9.03
1B4	0.98	8.68	10.11
1B5	1.09	8.67	10.67
1B6	1.01	8.62	10.74
1A1	1.04	8.68	11.46
1A2	0.99	8.6	8.91
1A3	0.86	8.68	9.24
1A4	1.01	8.6	10.23
1A5	2.52	8.5	9.78
1A6	16.7	8.2	12.4
1A7	8.74	8.23	10.73
1A8	3.3	8.41	11.68
1A9	6.38	8.28	10.73

Source Wondimageng, PhD (2000, Unpublished)

D E C L A R A T I O N

I here by declare that the dissertation entitled “**SPATIAL DESCRIMINATION AND MAPPING OF SOIL SALINITY USING REMOTE SENSING AND GIS TECHNIQUES IN THE MIDDLE AWASH BASIN**” has been carried out by me under the supervision of Dr. Syed Ahmad Ali, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2007 as a part of Master of Science programme in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa

Date: July 16, 2007

Mekamu Kedir

C E R T I F I C A T E

This is certified that the dissertation entitled “**SPATIAL DESCRIMINATION AND MAPPING OF SOIL SALINITY USING REMOTE SENSING AND GIS TECHNIQUES IN THE MIDDLE AWASH BASIN**” is a bonafied work carried out by under my guidance and supervision. This is the actual work done by Mekamu Kedir for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa.

Dr. Syed Ahmad Ali

Associate Professor,

Department of Earth Sciences

Addis Ababa University

Addis Ababa