RESEARCH ON THE CONTROL OF WATERLOGGING AND SALINIZATION IN IRRIGATED AGRICULTURAL LANDS

A Methodology for Identification of Waterlogging and Soil Salinity Conditions Using Remote Sensing

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EXECUTIVE SUMMARY

Diagnosis of waterlogging and soil salinity in any region is an essential pre-requisite to plan a land reclamation project. Diagnosis with conventional techniques has been a time consuming and laborious exercise. With the advent of remote sensing (RS) and geographical information system (GIS), diagnostic procedures have been made easier and cheaper. In spite of this progress, it was found that a sound step-wise methodology for the identification and diagnosis has been lacking. Therefore, under the Indo-Dutch Network Project on "Research on the Control of Waterlogging and Salinization in Irrigated Agricultural Lands", a component of this activity was taken up. This report documents the 8 studies that have been carried out under the project. Basic feature of these studies could be summarised as follows :

- The studies could broadly be grouped to cover Indo-Gangetic plains (3), heavy clay or black soils (3) and sandy soils (2).
- The study areas are all located in the semi-arid regions covering the states of Andhra Pradesh, Gujarat, Haryana, Karnataka and Rajasthan.
- The extent of the area under the studies ranged from 5,000 ha to 3,50,000 ha.

Although, it has not been possible to follow a single methodology in all the studies, yet finally, within a broad framework, a methodology based on visual and another for digital interpretation could be recommended. Amongst the several ground truth data collection procedures attempted, grid-wise approach and discrete observation point approach were found unsatisfactory. To minimize the time and labour, a stratified sampling approach for ground truth data collection could be formulated. No one legend could be finalized, yet various alternate legends are made available to suit specific situations.

The studies have allowed to draw several conclusions and identify limitations that would have wide applications in the use of RS and GIS methodology for diagnosis of waterlogging and soil salinity. We believe that this report will help the readers to avoid pitfalls and to decide upon many issues to clearly chalk out a path in the application of this methodology to identify waterlogging and soil salinity conditions.

CONTENTS

1. GENERAL BACKGROUND

Agriculture is a key sector in India's economy, contributing about 35% of the Gross Domestic Product and employing 65% of its adult population. Of the total population of over 1000 million, more than 30% live below the poverty line and about 75% live in rural areas, depending directly or indirectly on agriculture. One-third of the agricultural labour force are women and agriculture is the main source of employment for women in rural areas. Annual agricultural growth has been modest at 2.6% per annum over the last 25 years. Development plans of the Government of India (GoI) and State Governments give priority to alleviating poverty and creating employment, particularly in rural areas. Considerable irrigation potential has been created in India to sustain agricultural production against the vagaries of rainfall that is scarce and unevenly distributed in space and time.

The introduction of irrigated agriculture, however, in arid and semi-arid regions of the country has resulted in the development of the twin problem of waterlogging and soil salinization, with considerable areas either going out of production or experiencing reduced yield. It is estimated that an area of nearly 8.5 million ha is affected by soil salinity and alkalinity, of which about 5.5 million ha in the irrigation canal commands and 2.5 million ha in the coastal areas. The problem of increasing salinity caused by the rise of the water table and the lack of drainage is considered as a major environmental problem that threatens the capital investment in irrigated agriculture and its sustainability.

GoI's long-term strategy is to stimulate agricultural growth and promote rural development through improved water and land management, enhanced efficiency of irrigation and drainage networks, strengthened research activities, increased attention to environmental protection, and improved rural infrastructure.

Investment programmes, to address these elements and to re-establish growth, are of high priority in the Tenth Five Year Plan of GoI and State Governments. It is planned to double the food grain production in the next two decades. This can only be achieved through a concerted effort on all fronts including the reclamation of waterlogged salt-affected lands in all irrigation command areas. Irrigated agriculture will continue to be the mainstay of progress in the Indian agriculture to ensure food and nutritional security through crop diversification.

2. THE PROJECT

During 1995, the Governments of India and The Netherlands agreed upon collaboration in the Network Operational Research Programme on the Control of Waterlogging and Salinization in irrigated Agricultural Lands. The programme started on 1 November 1995 upon approval by the Government of India through the Side Letter and ended on 30 April 2002.

The programme aimed at the development of appropriate location-specific drainage and reclamation technologies for solving the problems of waterlogging and salinity in canal commands of India. It also envisaged developing practical survey methods for diagnosis of problems of waterlogging and salinity. Further it aimed at establishing competent Centres in these fields. From here on, the programme is referred to as the Indo-Dutch Network Project for short.

2.1 Project Outline

The Indo-Dutch Network Project was planned and executed with the use of the Objective Oriented Project Planning (OOPP) technique. Based on the overall and project objectives, the results and corresponding activities were formulated in a logical framework (Table 1).

The project had four overall objectives:

1. Increase of agricultural production from salt-affected lands through application of proper soil and water management practices along with other agro-techniques
2. Prevention of deterioration of productive land through adoption of appropriate soil and water management practices
3. Improvement of social-economic conditions of small and marginal farmers of these lands
4. Developing expertise for handling reclamation projects in India

From these overall objectives, two Project Objectives were derived:

1. Strengthened research capacity of CSSRI and the four State Centres, especially in the field of waterlogging and salinity control
2. Enhanced awareness on drainage and related water management for the control of waterlogging and soil salinity at State and Central level

The overall and project objectives were translated in eight project results (Table 1). For each result an Objectively Verifiable Indicator was formulated to monitor whether the Project achieved the results as planned. This has resulted in a list with means of verification specifying how the indicators are reported. However, the conditions needed to reach these results were not always within the competence or mandate of the Project, and were therefore considered as outside factors, although with importance for the Project. These conditions, sometimes also referred to as risks but in this project as Important Assumptions, were monitored. The results were translated in a set of activities (Table 2). These activities formed the basis of the research conducted by the participating Network Centres. In the subsequent annual work plans the activities were further specified based on the reported progress.

Table 1. Overall logical framework Indo-Dutch Network Project – objectives and results

	Objectively verifiable indicators	Means of verification	Important assumptions
Overall objectives			
1 Increase of agricultural production from salt-affected lands through application of proper soil and water management practices along with other agro-techniques; 2 Prevention of deterioration of productive land through adoption of appropriate soil and water management practices; 3 Improvement of social-economic conditions of small and marginal farmers of these lands; 4. Developing expertise for handling reclamation projects in India.			
Project objectives			
1 Strengthened research capacity of CSSRI and the four State Centres, especially in the field of waterlogging and salinity control	By April 2002 CSSRI and the four State Centres will have published quality reports on the control of waterlogging and soil salinity	• Review by experts	• Acceptance of Project results at policy level
2 Enhanced awareness on drainage and related water management for the control of waterlogging and soil salinity at State and Central Level	By April 2002 there will be ample documentary evidence of enhanced awareness on waterlogging and salinity control at village, State and Central level	• Check on relevant documents	• Investment in improved water management
Results			
1. A methodology for identification of waterlogging and soil salinity conditions using reomote sensing	By April 2002 CSSRI and the State Centres will have published a joint report with a methodology to identify waterlogging and soil salinity conditions	• Joint report • Progress reports	• Continued support of ICAR and State Agricultural Universities • Continued involvement of trained staff • Involvement of relevant staff available at CSSRI for networking • Acceptance of project results by end-users (Ministries, farmers, contractors, pipe manufacturers)
2. Recommendations on waterlogging and salinity control based on drainage pilot area research	By April 2002 CSSRI and State Centres will have published a joint report on combating waterlogging and soil salinity	• Joint report • Progress reports	
3. Appraisal of irrigation and drainage practices by computer simulations.	By April 2002 CSSRI and at least 2 State Centres will have published a joint report on the appraisal of irrigation and drainage practices by computer simulations tested in the drainage pilot areas	• Joint report • Progress reports	
4. Improved human resources at CSSRI and the four State Agricultural Universities through training	By April 2002, 50% of the project staff and 100% of the scientific staff will have participated in a training activity	• Progress Reports • Interviews • Back-to-office reports	
5. Operational Training Centre at CSSRI	By April 2002 CSSRI will have developed 3 training modules and conducted at least 2 national training courses in the new training Centre	• Field check • Review of curricula • Course evaluation reports	
6. Enhanced awareness at State and Central level on the necessity of an agricultural drainage policy	By April 2002 at least 3 State Governments will have expressed their willingness to prepare an agricultural drainage policy as documentary evidence	• Check of relevant documents	
7. Enhanced awareness at farmers' level on improved irrigation and drainage for control of warelogging and salinity	By April 2002 in at least 2 State Centres a Pilot Area Farmers Committees will have been established	• Progress repors • Meeting with farmers	
8. Advice on drainage and related water management	By April 2002 CSSRI and the State Centres have each given at least 20 working days/ year advice to others	• Progress reports	

Table 2. Overall logical framework Indo-Dutch Network Project-activities

	Activities	Important assumptions
1.1 1.2 1.3 1.4 1.5	Identify study area Develop physical facilities for remote sensing Develop a methodology Map waterlogged and salt-affected areas Report on methodology and its applicability	• Qualified staff at Centres • Timely approval of proposals by the competent authorities
2.1 2.2 2.3 2.4 2.5 2.6 2.7	Select pilot areas in farmers' fields Conduct a drainage experiment Conduct a water management experiment Conduct a socio-economic study Conduct a cost-benefit analysis of drainage Conduct other related studies Formulate recommendations	• Qualified staff at Centres • Timely approval of proposals by the competent authorities • No climatic catastrophe • Full co-operation of the relevant organisations • Full co-operation of farmers
3.1 3.2 3.3 3.4	Select computer models Acquire physical facilities Conduct computer simulations for diagnosis and prediction Report on the appraisal	• Qualified staff at Centres
4.1 4.2 4.3	Participate in training activities in India Participate in training activities abroad Conduct or participate in in-service training activities	• Qualified staff at Centres
5.1 5.2 5.3 5.4	Construct and furnish training centre and hostel Prepare a programme for National Training Courses Develop training modules on - Land Drainage - Management of Problem Soils - Use of Poor Quality Water for Agriculture Conduct National Training Courses	• Qualified staff at CSSRI • Identified need for National Training Courses • Full co-operation of the relevant organisations
6.1 6.2 6.3 6.4 6.5 6.6 6.7	Train field-level workers on the need for drainage Conduct workshops & seminars on the need for drainage Include officers from interested agencies in the Project Implementation Committees (PIC's) Prepare and distribute appropriate literature Promote awareness by public relation activities Conduct a desk-study on the institutional and organisational set-up of agricultural drainage in other countries Prepare a background document for State Agricultural Drainage Policies	• Qualified staff at Centres • Co-operation of State and Central organisations
7.1 7.2 7.3 7.4 7.5 7.6	Undertake excursions to drainage projects Train extension workers and farmers on drainage Conduct farmers' days Prepare and distribute appropriate literature Involve local farmers in project activities Establish Pilot Area Farmers Committee	• Qualified staff at Centres • Full co-operation of farmers
8.1 8.2 8.3 8.4 8.5	Assist others with training courses Assist others with drainage design Advise others on drainage and related water management Advise others on diagnosis and mapping of problem soils Report on the advises rendered	• Qualified staff at Centres • Requests for advice

2.2 Implementing Agencies

The Executive Authorities of the Indo-Dutch Network Project were the Indian Council of Agricultural Research (ICAR) and the Royal Netherlands Embassy (RNE), New Delhi. The implementing agencies of the Indo-Dutch Network Project were:

- The Central Soil Salinity Research Institute (CSSRI), Karnal, as coordinating centre (focal point) for the following state centres:
- The Acharya N.G. Ranga Agricultural University (ANGRAU), with office facilities at Bapatla.
- The University of Agricultural Sciences, Dharwad (UASD), with office facilities at Bheemarayanagudi and Gangavathi
- The Gujarat Agricultural University (GAU), with office facilities at Navsari
- The Rajasthan Agricultural University (RAU), with office facilities at Hanumangarh

The Supporting Agency from The Netherlands was the International Institute for Land Reclamation and Improvement (Alterra-ILRI), Wageningen.

2.3 Reporting

Several options were considered to bring out the final report of the project. In the end, it was decided to bring out 4 different volumes. While the first three volumes deal with the Project Results 1 to 3, the fourth volume provides an overview of the accomplishments in the human resource development and establishment of a training center (Project Results 4-5). It was decided that the information on activities related to enhanced awareness and advise on drainage rendered by the centers (Project Results 6 to 8) would form a part of the individual reports that would be brought out by the Network Centres.

3. THIS REPORT

This is the completion report of Result # 1 of the Indo-Dutch Network Project (IDNP) for Operational Research on the Control of Waterlogging and Salinity in Irrigated Agricultural Lands. The specific objective of the work towards Project Result # 1 has been to develop a methodology for identification of waterlogging and soil salinity by Remote Sensing. IDNP started in November, 1995 and in March 2002 a Workshop was held to present the achievements of the Project.

The work for this project result is partly carried out at CSSRI, Karnal (Fig. 1), which also co-operates with the Bheemarayanagudi (UASD, Karnataka) Centre. The Centres at Bapatla (ANGRAU, Andhra Pradesh) and Navsari (GAU, Gujarat) have sought co-operation with local specialist institutions, the National Remote Sensing Agency (NRSA) in Hyderabad, and the Remote Sensing and Communication Centre (RESECO) in Gandhinagar, respectively. The Hanumangarh (RAU, Rajasthan) Centre had also entered into an agreement with the State Remote Sensing Agency (SRSA) in Jodhpur.

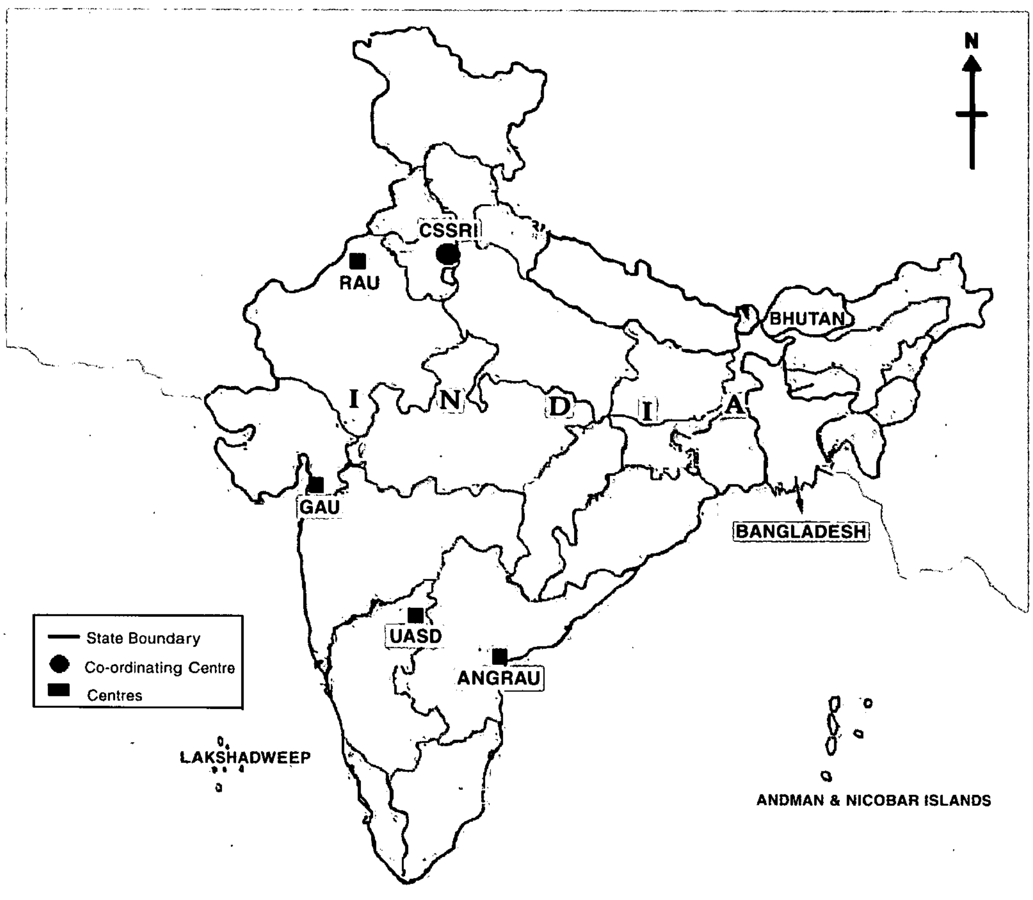


Figure 1. Map of India showing network centres

4. LITERATURE REVIEW

4.1 Background

Waterlogging and soil salinity are the two major problems affecting the agricultural productivity and sometime becomes too severe to take it out from economic crop production. In India, it is estimated that about 6.0 m ha land is affected from various nature and order of waterlogging and about 8.5 m ha land is affected from different degrees of soil salinity. The demarcation of the location and assessment of the extent and severity of waterlogging and soil salinity are pre-requisite 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 waterlogging and salinity, particularly in large areas. The objective of this chapter is to present a review on selected papers on application of RS and GIS for studying the waterlogged and salt-affected areas. The review also accounts the data sources, relevant image processing and GIS techniques and accuracy assessment procedures.

4.2 Definitions of Waterlogging and Soil Salinity

Several agencies have given different definitions of waterlogging and soil salinity. On the basis of criteria given by the National Commission on Agriculture (1976) and Ministry of Water Resources (1991), waterlogged / critically waterlogged areas may be defined where water table is within 2 m from the surface (Table 3).

Table 3. The criteria adopted by different agencies for waterlogging

Waterlogging	National Commission on Agriculture (1976)	Ministry of Water Resources, GoI (1991)
Waterlogged/Critical	Water table < 1.5 m	Water table < 2 m
Potentially waterlogged		Water table 2-3 m
Safe area		Water table > 3 m

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 EC_e (electrical conductivity of the saturation extract of soil, dSm^{-1}), pH_s (pH of the saturated soil paste) and ESP (exchangeable sodium percentage of the soil):

- **Saline soils** : These soils have an EC_e more than 4 dSm^{-1} at 25 ^0C, pH_s less than 8.2, an ESP less than 15 and a preponderance of chlorides and sulphates of sodium, calcium, and magnesium.

- **Sodic soils :** Sodic soils have a pH_s more than 8.2, ESP of 15 or more and a preponderance of carbonates and bicarbonates of sodium. The EC_e may be high if originating from salts capable of alkali hydrolysis; otherwise it should be less than 4 dSm^{-1} at 25^0C.
- **Saline-Sodic :** Saline-sodic soils have pH_s greater than 8.2 at 25 ^0C, EC_e 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 4, however, the severity may vary with the type of soil and crop.

Table 4. The criteria for soil salinity/sodicity

Key to degree of salinity/ sodicity	Salinity EC_e (dSm^{-1})	Sodicity	
		pH_s	ESP
Slight	4-8	8.2-9.0	<15
Moderate	8-25	9.0-9.8	15-40
Strong	>25	>9.8	>40

4.3 Remote Sensing for Mapping Waterlogging/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 waterlogging and soil salinity investigation, this may be useful where ponded water, high water table areas, saline water, salty soil, and salt-affected vegetation give contrasting reflectance with other landscape features so that they can be unambiguously distinguished.

Application of RS for surveying and mapping of waterlogged and salt-affected soils began with the use of black and white photography. The relatively dark appearance provides the information about waterlogging whereas the bright appearance provides information about salinity due to the efflorescence of salt crust. The effect of waterlogging/salinity on crops provides the information on waterlogging/salinity indirectly. The aerial photographs have been used to delineate units based on the combination of geo-morphological 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 waterlogging and 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 waterlogging and 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 waterlogged and 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.

4.3.1 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. Wildman (1982) found that plant response is a more accurate means of detecting poorly drained soils in California mainly because of a build-up of the water table. He also indicated that 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 and SPOT data can be used to identify this colour. Baber (1982) 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. Choubey (1997) used temporal IRS-IA-LISS-I FCC data for 1988, land use and drainage maps to delineate waterlogged areas and area sensitive to waterlogging in the Tawa command. The results were validated with water table data, which indicated that about 80 km^2 was affected by waterlogging and 140 km^2 area was sensitive to waterlogging (where the water table was between 0 and 3 meter). Since the water table cannot be detected directly from satellite observations, the best integrative indicator can be the crop stress due to high water table.

The information about drainage basin area and drainage pattern can be obtained from satellite imagery. Barret and Curtis (1976) indicated that stream channel development and network, stream length and the location of ponds and lakes can be mapped from Landsat-MSS data. 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. Drainage network mapping have been done by the use of Digital Elevation Model (DEM) as a part of GIS analysis by some researchers. Jenson and Dominque (1988) developed software to extract topographic structure and to delineate watersheds and overland flow paths from DEM. The computer generated drainage lines and watershed polygons and the four-point linkage information can be transferred to vector based GIS for further analysis. Comparison between these computer generated features and their manually delineated counterpart generally indicated close agreement. Bouarfa and Zimmer (1994) used GIS to diagnose and map waterlogging and salinity risks in the Mediterranean region and to investigate drainage needs.

4.3.2 Salt-affected Soils

Application at field level

The acquisition time of the RS 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. On the other hand, Siderius (1991) found that salinity is best expressed at the end of the irrigation or rainy season when the plots are bare. Goossens et al. (1993a) analysed 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.

Mougenot et al. (1993) conducted studies with 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 millimetre 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 radio-metric 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) 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. TM bands 5 and 7 are frequently used to detect soil salinity or drainage anomalies (Moulders and Epema, 1986; Menenti et al., 1986; Zuluaga 1990; Vincent et al. 1996). 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 (Agbu et al., 1990). Landscape position and percent slope were not important as site characteristics that predict satellite spectral variables. Depth to reduced colour, which is indicative of soil moisture regime, was significantly correlated to the near- infrared band. Measured soil properties were tested in terms of their usefulness in predicting SPOT spectral response. Significant correlation among spectral data and subsurface properties confirm the association that exists, perhaps due to genetic influence on surface soil properties by subsurface properties. The latter adds to the potential usefulness of satellite digital data in separating mapping units for soil surveys. 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. Rao and Venkataratnam (1991) studied the spectral behaviour of salt-affected soils of Indo-Gangetic Alluvial Plain and concluded that 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. In addition, variation in the Sun elevation angle and moisture content were also found to modify the observed spectral response of salt-affected soils.

Spatial resolution has significant effect on enhancing the identification of salt-affected soils and crops. Manchanda (1984) observed that Landsat-MSS is of limited use to identify saline plots due to its low spatial resolution. Joshi and Sahai (1993) 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. Metternicht and Zinck (1996) conducted a study following an approach to map salt and sodium affected surface, combining digital image classification with field observations of soil degradation features and laboratory determination. Salinity-sodicity classes were associated using the electrical conductivity and pH values. The neighbourhood operator with spatial and spectral characteristics defined constraints determined the spectral objects constituting the training set. The main cause of spectral confusion masking degrees of salinity and sodicity was abundance of salt tolerant vegetation cover, top soil textures and the mixture of top soil properties in field conditions.

Microwave remote sensing has also shown encouraging results for its relationship with dielectric constant and electrical conductivity. Sreenivas et al. (1995) conducted laboratory studies with different textured soils for studying the influence of soil salinity and sodicity on the complex dielectric behaviour of soils as a function of volumetric soil moisture using an I-band (1.25GHz) dielectric probe. It was concluded that the soil salinity has no influence on the real part of the dielectric constant whereas the imaginary part is dependent and increases with increase in salinity for all the soils considered. It was also concluded that the real part is more dependent on the soil moisture and the imaginary part on the soil salinity. The sodicity of a soil had no effect either on real or imaginary part of the dielectric constant. This study has shown a theoretical basis for separating the saline soils from sodic soils at I-band frequencies under moist soil conditions.

However to fully establish the utility of the microwave data for salinity appraisal there is a need to conduct rigorous field experiments under different frequencies, polarization and look angles to establish optimum sensor configuration.

Application to large areas

Remote sensing is an important tool for mapping and surveying of waterlogged and salt-affected 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 / sodicity in the United States of America (Wiersma and Horton, 1976), India (Singh et al., 1977; Venkataratnam, 1983), Iraq (Al Mahawili, 1983) and Canada (Sommerfeldt et al., 1985). Most authors are able to distinguish only 2- 3 classes (strong and medium) of salinity levels with errors between moderately saline and normal soils.

Visual interpretation using photoimagery: Evolution of the salinity begins with small and irregular bare soil patches. Narayan et al. (1989) studied entire Indian territory (329 m ha) using Landsat-MSS FCC of 1:10,00,000 scale and categoriesed wasteland as salt-affected, gullied or ravined, waterlogged or marshy, undulating upland with or without scrub, jhum or 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 (Manchanda and Iyer, 1983). Joshi and Sahai (1993) used Landsat-TM data for mapping of salt-affected lands along the Saurashtra coast.

Singh (1994) conducted a study using aerial photographs and Landsat-TM data to monitor changes in the status of salt-affected soils in the Kanpur district (U.P.). 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. Survey of India toposheets were used for transferring the Landsat based salt-affected maps. Sethi et al. (1996) used IRS data in the Ukai-Kakrapar command area and concluded varying degree of success in mapping salt-affected soils.

Kalra and Joshi (1997) used Landsat (MSS & TM), SPOT and IRS (LISS-I & II) FCC images during fallow period (April, May), *rabi* crop (January / February), rainfed crop (October) 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 and sodic soils due to RSC water 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.

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. Singh and Dwivedi (1989) used Landsat-MSS digital data over parts of Uttar Pradesh, India and delineated salt-affected soils on an interactive multi-spectral data analysis system (MDAS). 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 were also mapped. Dwivedi (1996) used principal components analysis for monitoring the salt-affected soils of the Indo-Gangetic alluvial plains. It was concluded that the principal components analysis of temporal Landsat-MSS data reveals an overall significant change in brightness and greenness of the terrain. However, these changes have not been found related with the spatial extent and distribution of salt-affected soils.

Goossens et al. (1993b) used contextual classifier for soil salinity mapping. They built a 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.

Singh and Srivastava (1990) used microwave radiometers for identifying the problems of waterlogging and salinity in coastal regions. Numerical calculations of brightness and temperature have been carried out over one and two layered models representative of waterlogged and salt-affected areas. The results presented in their study showed the utility of microwave radiometers in mapping of waterlogged and salt-affected areas.

Digital analysis using surface radiative and 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. Rondeaux et al. (1996) review the merits of the most classical and updated vegetation indices recommended for application in agronomy. Bastiaanssen (1998) presented a comprehensive list of these indices for specific purpose.

Many papers described salinity detection through its impact on the vegetation. Studies showed that reflectance from single leaves (with the example of cotton) depend on their chemical composition (salt) and morphology. They observed that (i) visible reflectance of leaves from plants growing on salt-affected soils is lower than reflectance of non-salt-affected leaves before plant maturation and higher after (ii) near-infrared reflectance increases with leaf maturation and (iii) middle infrared reflectance decreases without water stress due to a succulent effect and increases in other cases. Cell thickening induces thicker leaves (as succulent vegetation) causing decrease in transmittance and therefore, in reflectance as compared to higher reflectance from normal crop in near infrared region. 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. Dale et al. (1986) recommended hierarchical procedures of classification for types of vegetation at macro-scale and vegetation condition at micro-scale. The work of Steven et al. (1992) showed that chlorotic canopies could be distinguished from healthy canopies. As compared with a healthy crop, the response of the biophysical parameters of a salt environment is manifested in a low fractional vegetation cover, low LAI, high albedo, low surface roughness, and high surface resistance. Mougenot et al. (1993) noted that salinization affects the leaf angle orientation (leaf roll) and increases chlorosis, both of which are best observed in the near infrared and middle infrared bands. The final stage of soil salinization results in increased brightness, which is detectable from the visible part of the spectrum with very low vegetation and high surface albedo. The investigations of Vidal et al. (1996) in Morocco and Vincent et al. (1996) in Pakistan are based on a classification-tree procedure. In this procedure, the first treatment is to mask vegetated from non-vegetated areas using NDVI. Then the brightness index is calculated to detect the moisture and salinity status on fallow land and abandoned fields. The approach of Vincent et al. (1996) was suitable for locating blocks that had malfunctioning drainage networks. Two classes based on levels of soil salinity could be mapped with an accuracy of 70 percent. Areas of high salinity were 66 percent accurate and non-saline areas were 80 percent accurate. Pulido et al. (1998) used plant indicator method to detect salinity due to depressed yield in Maxican irrigation district. Ambast et al. (1999) presented a digital approach for identification and mapping of waterlogged and salt-affected crop area based on bio-physical parameters (surface radiation, vegetation index and moisture indicator) using Landsat-TM data. These methodologies need to be further validated in different agro-ecological conditions before they become operational.

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 analysed. 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 affect the 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.

Hoogerwerf et al. (1992) studied salinity and sodicity of soils in the Hola Irrigation Scheme in Kenya. Based upon a detailed survey in a 405 ha area consisting of 45 irrigation blocks, the spatial variability of pH, EC and ESP was studied. The data were analysed using geo-statistical procedures. The GIS was used to handle large amounts of data and to compare the effects of different land use scenarios.

Interesting studies were conducted by Chaturvedi et al. (1983) and Singh and Srivastav (1990) using microwave brightness and thermal infrared temperatures synergistically. Synergetic use of satellite measurements to map soil salinity physically is a new concept. Although the results were not perfect, the integration of multiple sensor data has set new directions for research on soil salinization. The physical conditions of the surface soil can be obtained with a combination of optical and passive microwave data. Larger wavelengths (L-band, P-band) are capable of penetrating the soil.

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 atttempted to develop, within a broad framework, a methodology for diagnosis of waterlogging and soil salinity conditions using remote sensing.

5. METHODOLOGY FOR APPRAISAL OF WATERLOGGING AND SOIL SALINITY, GOHANA, HARYANA (CSSRI)

5.1 Introduction

Most studies related to salinity mapping have been conducted for relatively large areas with only limited field data. This study was carried out in an area of only 5,000 ha where extensive data on soil (chemical) properties, water levels and a large set of satellite images was available. Detailed analyses could be done on image classification, the dynamics of waterlogging and salinization, and the relation between image characteristics and EC_e-pH measured on the ground. The dynamics of the waterlogging and salinization was demonstrated using a multi-temporal data set. Various interpolation techniques were used to assess the spatial variation of point observations.

5.2 Study Area

The study was conducted in the Gohana sub-division of Sonepat district of Haryana, between latitude 29° 2' to 29° 7' N and longitude 76° 42' to 76° 48' E (Fig. 2). Five villages namely Lath, Katwal, Rewara, Moi and Bali are located inside the study area along the side of the Jawahar Lal

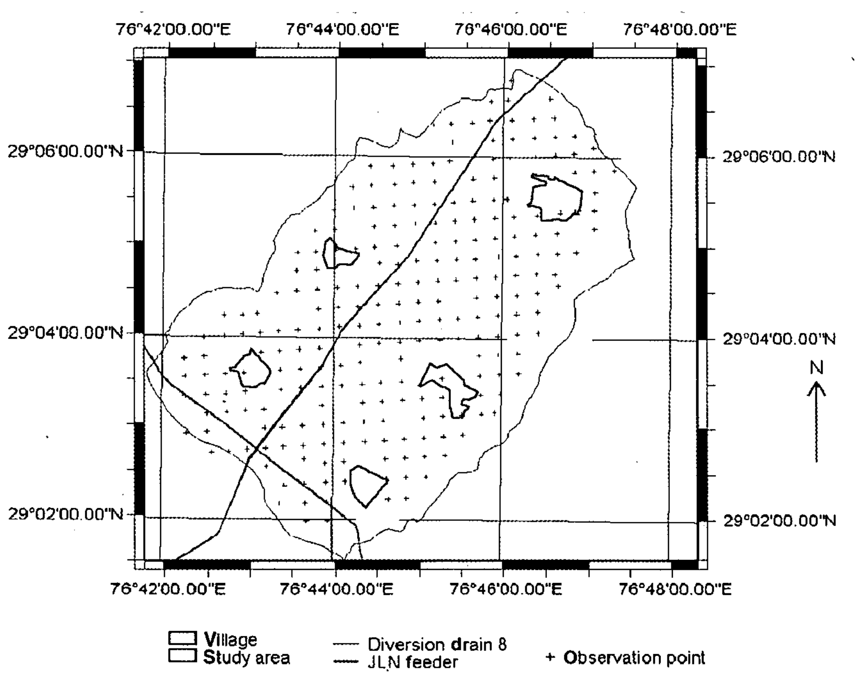


Figure 2. Overview of Gohana study area including observation network

Nehru (JLN) feeder and parallel Bhalaut branch. In the southwest, the area is bounded by diversion drain number 8. The study area is facing the problems of waterlogging and salinity. The introduction of irrigation through canals led to increasing water table in the area. The area has an almost flat topography. The climate of the area is semi-arid. The average annual rainfall in the last 23 years is 550 mm out of which 80% occurs during the period from July to September. The average annual evapotranspiration is 1650 mm. The soil is alluvial in nature with a textural range in the topsoil varying from sandy loam to silt loam.

5.3 Methodology

A large number of satellite images from various satellites with different spectral and spatial resolution were available (Table 5). In 1995, a large data set on EC_e, pH, pre- and post-monsoon water table depth was collected (Table 6).

Table 5. The images and the type of satellite data used in the study

Date of Images	Type of Satellite
1 October, 1988	IRS 1C
3 January, 1989	SPOT2
12 November, 1994	IRS 1B
22 November, 1995	Landsat-5 TM
17 February, 1996	IRS 1B
1 April, 1996	IRS 1B
6 June, 1996	IRS 1B
28 June, 1996	IRS 1B
12 November, 1996	IRS 1B

Table 6. Data on point observations made in Gohana study area during 1995

Item	EC_e (dSm^{-1})	pH	Water table, June (m)	Water table, October (m)	Elevation (m)
Minimum	1	7.4	0.6	0	221.8
Maximum	48.4	9.1	4.9	3.5	222.9
Average	5.7	8.1	2.9	1.7	222.3
Standard deviation	4.9	0.3	1.0	0.9	0.3

The number of observations for EC_e/pH, water table and elevations are 238, 84 and 96 respectively.

5.3.1 Dynamics of Salinization and Waterlogging using Supervised Classification

For the delineation of the saline and waterlogged areas within the irrigation command, the commonly recommended supervised classification was used. The following five classes i.e. cropped area, ponded water area, waterlogged area, saline area and salt-affected crop area were identified on the satellite image. To illustrate the dynamics, the classification was done on the SPOT image of January 1989, the TM image of November 1995 and the February image of 1996. The generated raster map was filtered using majority filter in order to correct the wrongly classified pixels.

Care was taken to select for each class a reasonable homogeneous area, which was indicated in the sample statistics. Once the sample set was ready for all the classes, the supervised classification was attempted and the classified map was obtained. Statistics of area distribution of the various classes was analysed. It is indicated that a good set of ground truth was not available for all the dates. The training-sets were established mostly based on insight of the cropping patterns and the location in the study area.

5.3.2 Spatial Distribution of EC_e

An attempt was made to verify the applicability of interpolation techniques for predicting the salinity at different locations from a limited number of point observations. A total of 238 soil samples were analysed for the determination of EC_e values. Various types of interpolation procedures were executed on 224 points, excluding 14 points that were used to assess the interpolation results. Nearest neighbour, moving average, trend surface, and moving surface interpolation techniques were used. Once the interpolated map was prepared, the interpolated (estimated) values of salinity for the 14 selected points were compared with the measured ones.

The degree of correctly assessing the salinity values by different technique was decided on the basis of minimum value of error term defined as follows:

Error term = Observed values - Estimated values

To compare the accuracy of the interpolation methods, the Students'-t distribution test was applied on predicted values calculated using various interpolation techniques.

5.4 Results

In Fig. 3, the result from the classification can be seen. In Table 7, the area-wise distribution of the main classes excluding villages and the infrastructure is given. It is clear that the outcome of the classification depends not only on the satellite configuration but also highly on the date of the recording. Classification differences due to spatial and radiometric resolutions could not be assessed.

The sowing of wheat starts from mid-November and the fractional vegetation cover remains low in the month of January. A large part of the bare lands have a dark colour and are seen as wet, which may be due to the winter rains. This resulted in a large area classified as 'waterlogged'. In the month of November large area is bare, hence the cropped area is low. A large area with dry,

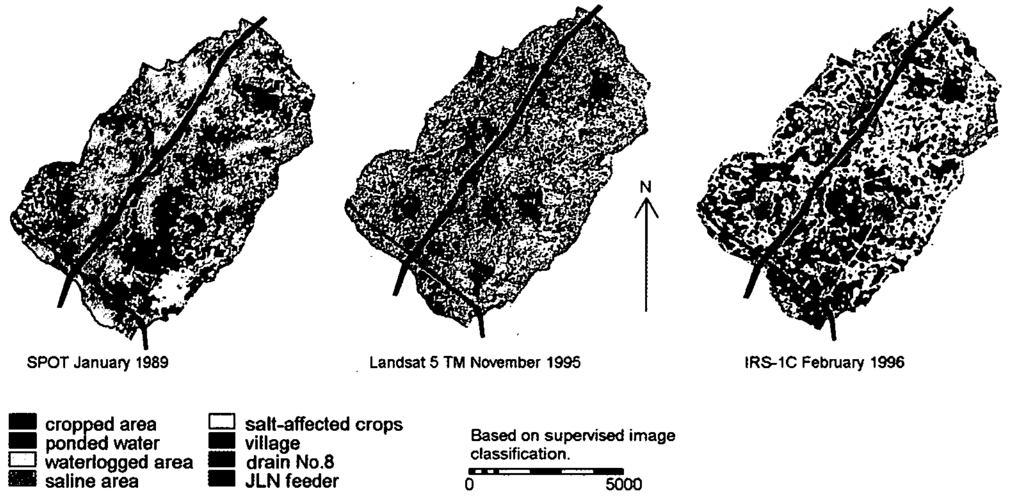


Figure 3. Dynamics of soil salinization and waterlogging in the study area

bare soils have a relatively high reflectance resulting in a large area classified as 'saline'. Not many soils seem to be wet.

A large area is cropped in February. Winter 1996 was very wet such that over a large part of the area crops could be grown. Most likely the class 'salt-affected crops' is not well classified. Some delay in crop growth could have occurred due to adverse moisture conditions. When evaluating the spatial variances, it was observed that the class representing ponded water area was relatively stable both in size as well as in location. Most cross-over took place between salt-affected crops, waterlogged and cropped areas.

Table 7. Extent (%) of various classes based on supervised classification

Class	January 1989 SPOT	November 1995 Landsat-TM	February 1996 IRS
Cropped area	27.3	17.7	31.8
Ponded water area	1.6	2.9	1.2
Waterlogged area	41.8	6.8	6.4
Saline area	9.3	43.9	11.9
Salt-affected crops	12.5	21.2	41.2

5.4.1 Spatial Distribution of EC_e Levels through GIS Interpolation

The t-tests revealed that for all the methods, the minimum level of significance were quite high indicating the limitation of interpolation techniques for predicting the salinity in the field. The interpolation technique using 'trend surface of the 4th degree' gave the best result out of the methods tested. The result clearly indicates that EC is a point-observation containing limited spatial information. 20-30 meters away from the measurement the EC can be totally different.

5.5 Conclusions

- Satellite images can be used to get insight in the dynamics of the salinity and waterlogging in the area. However general conclusions, even on broad classes such as cropped area, saline areas etc., have to be drawn with great care.
- A good knowledge of cropping pattern, meteorological conditions at recording time of the image and agricultural practices are needed in order to correctly assess the classification results.
- In the irrigation command, it is observed that salinity developed at a particular location has no relationship with the nearby point locations.
- The variation of reflectance properties of different land uses in an irrigation command affected with waterlogging and salinity problems makes it possible to diagnose the waterlogging and salinity affected area.

5.6 Recommendations

- A more elaborate study need to be undertaken on the information content of the various images within one crop cycle and in-between crop cycles. An attempt should be made to obtain land cover data for the study at the time the images were taken.
- Local farmers could be asked to indicate good / poor and waterlogged areas. Local knowledge could be helpful in understanding the dynamics of the system.
- Field data should be procured in a more systematic way. A good pre-field satellite image interpretation could be helpful to set-up a stratified sampling scheme. With the stratified sampling, expected differences in EC, pH, water table and crop status between indicated classes should come out.
- The use of additional thematic layers such as elevation, water table and physiography to improve the results should be explored. Relational modelling in which these layers are introduced should be attempted.

6. MAPPING SOIL SALINITY USING DIGITAL IMAGE ANALYSIS AND GIS, SONEPAT DISTRICT, HARYANA (CSSRI)

6.1 Introduction

Large irrigation systems in India lack accurate information on the extent and distribution of the problem of waterlogging and salinity. At the national level, this greatly handicaps policy formulation and project preparation. A study was undertaken to identify and map saline soils and waterlogging using digital analysis of satellite data. Field data were used to determine the dominant land cover classes and to assess the accuracy of the digital classification. Spatial and attribute data were integrated in a GIS to obtain a digital database which can be used for soil salinity assessment and management.

6.2 Study Area

An area in the Sonepat district in the State of Haryana, located between latitude 29° 00′ to 29° 15′ N and longitude 76° 30′ to 77° 00′ E, was selected. The area is a part of the low-lying flat Indo-Gangetic basin. The average annual rainfall is 550 mm and the annual evapotranspiration is 1650 mm. Introduction of irrigation coupled with poor surface drainage and poor quality groundwater are mainly responsible for the regional problems of waterlogging and secondary salinization in agricultural fields.

6.3 Methodology

A Landsat-TM scene comprising of all seven bands for a cloud free date (22nd November 1995) was obtained. In the same period fieldwork was done. Survey of India topographic maps on 1:50,000 scale were used for geo-referencing and base map creation. The soil map 1:250,000 scale, showing units in association of soil families, and other ancillary data on groundwater quality and water table depth, crop growth stages and prevailing farming practices were reviewed and used during image analysis and the selection of training sets. ILWIS 2.3 software was used for image processing and geo-information handling. The detailed flow chart of the methodology is shown in Fig. 4.

A spatial database was standardised to a single reference and all non-spatial data were taken on the observation point. A spatial database has been prepared on the basis of Survey of India toposheets (1:50,000 scale) and thus a graticule of 2 maps forms the base reference of the study area.

After editing and verification procedures the information was stored as database consisting of:

1. A map in digital format on the extent and distribution of saline soils.
2. Spatial distribution of geo-referenced soil types.
3. Spatial distribution of geo-referenced canals, roads and drains.

4. Location of villages, ponds and sampling sites.
5. The attributes of soils such as pH, EC, $CO_3 + HCO_3$, Na, Ca+Mg, texture, slope, etc.
6. Spatial relationship of soils to infrastructure facilities so necessary for developing management plans.

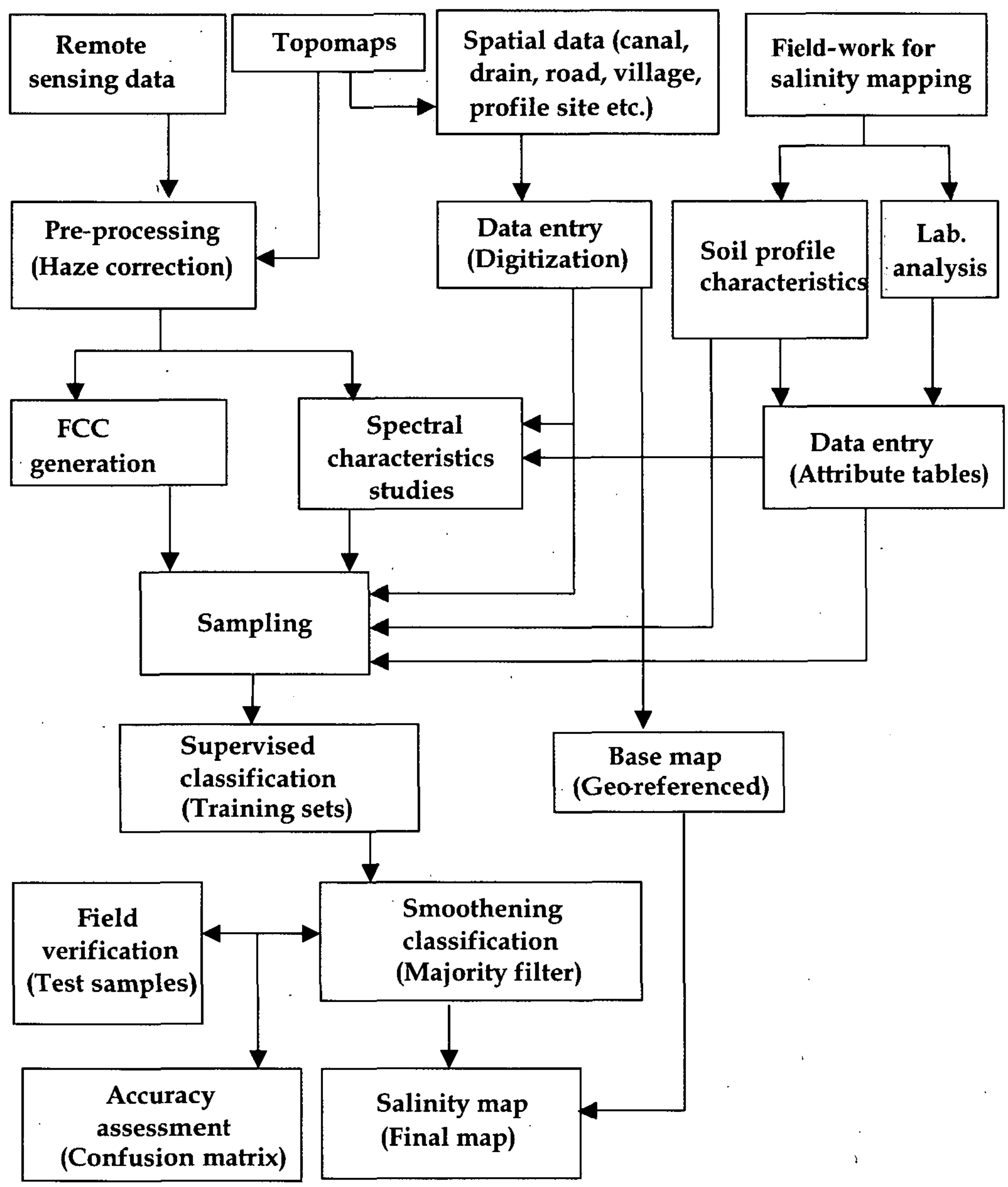


Figure 4. A flow chart for salinity mapping using digital image analysis and GIS

6.3.1 Ground Truth for Soil Salinity Assessment

An initial field traverse was made to record various degrees of salinized areas. Seventeen soil profiles were studied for field morphology. Horizon-wise soil samples were collected for laboratory analysis. Random auger bores and surface sampling was also done to correlate with image signatures. The soil samples were analysed for soil pH_s, EC_e, soluble ions, soil texture and organic matter for salinity assessment. Morphologically, all the soils are similar in colour, texture, structure, distribution of pores and roots. In saline soils, shallow water table and capillary rise of water is common leading to a moistened appearance of soil surface with presence of salt crusts. However, the saline soils near village Lath (profile no. 17) have a compact and dense petrocalcic layer at 80-90 cm depth which restricts free capillary rise of groundwater and keeps the salt crust on the surface in a relatively dry state. The soils with higher degree of salinity have predominance of neutral salts comprising mainly, chlorides and sulphates of sodium, calcium and magnesium. The sodic soils with a thin 2-5 mm thick, platy structure on the surface have a dense and compact solum restricting water movement, higher pH_s (9.9 to 10.2) and dominance of CO_3 and HCO_3. The total salt content in saline soils is much larger than in sodic soils.

6.3.2 Satellite Image Analysis

Haze correction was applied on TM band 1. Eleven well distributed tie points on canal, drain and road intersections, clearly identifiable both on the map and image were used for geo-referencing the image. In the present case the Lambert Conical Conformal map Projection was used. A FCC consisting of band 4 (red), band 3 (green) and band 2 (blue) was used for further analysis.

Spatial, spectral, field and laboratory data were used in deriving salinity and land cover classes and also in the selection of training sets for each of the classes. The position of the clusters and class statistics were continually checked through the feature space. After preliminary training sets, clustering of pixels in the feature space was found overlapping in salinity classes of lower degree of salt concentration. Based on the field observations and critical examination of laboratory data, a number of training sets were redesigned. Subsequently the classification was done using maximum likelihood classifier. Different threshold values were iterated based on the variance and covariance of clusters. A threshold value of 30 gave the most satisfactory results. After classification, a majority filter was applied.

6.4 Results

At the recording of the image, most of the agricultural area have early stage of wheat. The negative effects of salts on wheat crop have been reflected because of its sensitivity to salts at the initial stages of growth subduing full vegetative growth. Nine spectral classes, 5 representing various levels of saline and sodic conditions of the soils and 4 representing normal cropped area, sand dune, submerged soil, and waterlogged soils were identified (Table 8; also see Fig. 5).

The classification algorithm was able to separate areas based on the degree to which they are affected by salinity compounds. Best results were obtained when, slightly saline soil class was merged with nil to very slightly saline class and Ca-dominated salinity class was merged with the moderately saline soil class. The other classes representing higher salinity and sodicity ranges did not require any merging. The high relief (>5 m) sand dunes represented by extreme dry conditions and coarser soil texture could be segregated from highly saline soils. During fieldwork it was observed that some salts were accumulating on field bunds in the normal cropped area. However due to scale limitation it could not be detected during digital analysis.

Table 8. Cover classes with area (EC_e and pH_s derived from soil profiles)

Serial No.	Class	EC_e (dSm^{-1})	pH_s (-)	Area (%)
S1	Nil to slightly saline soils	4-10	8.0-8.4	32
S2	Moderately saline soils	10-25	8.2-8.4	25
S3	Highly saline soils (Dry salts)	25-40	8.5-8.8	3
S4	Highly saline soils	25-55	8.7-8.9	1
S5	Sodic soils	10-20	9.9-10.2	1
S6	Sand dunes (>5 m)	< 1	< 8.5	1
S7	Submerged soils	—	—	2
S8	Waterlogged soils	—	—	3
S9	Normal cropped area	—	—	32

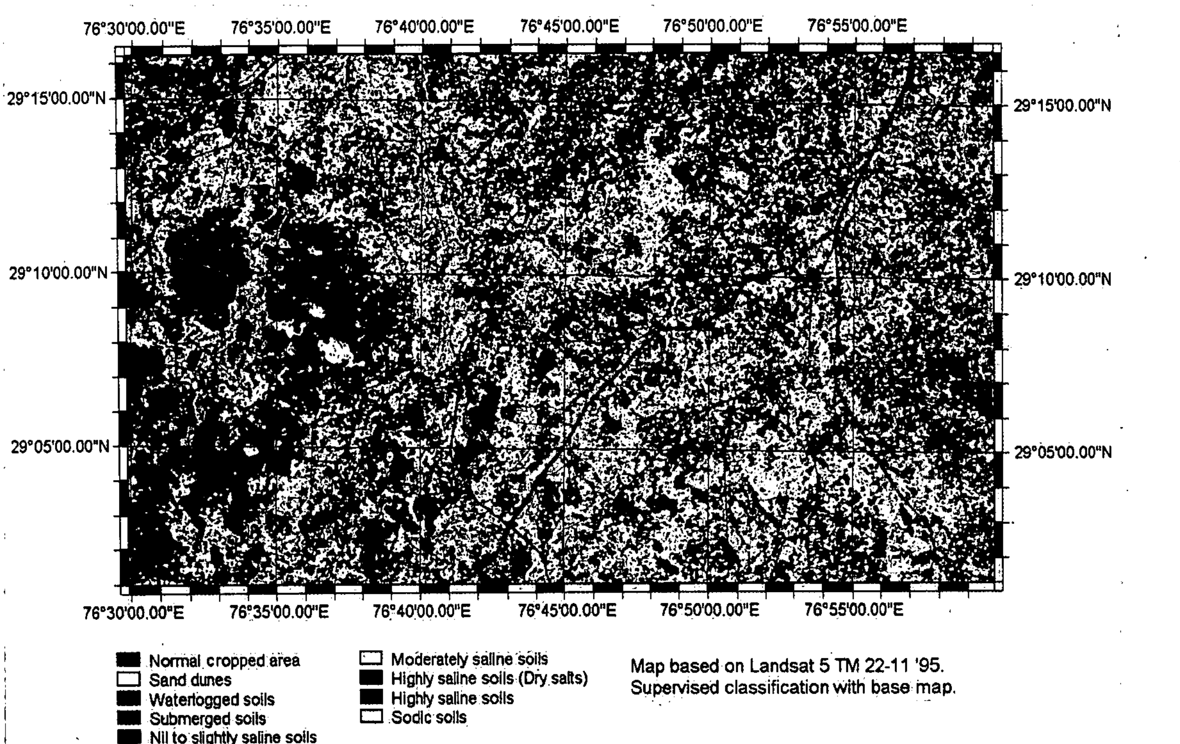


Figure 5. A classified image of the study area

The area statistics show that 11 percent area under the categories: highly saline, highly saline with dry salts, sodic, waterlogged, submerged and sand dunes is totally out of cultivation. 25 percent having moderate salinity can produce one average yielding crop during the *kharif* season mainly due to dilution of salts due to rains. 32 percent belonging to nil to slightly saline with sporadic occurrence of salinity appear to be most vulnerable to further degradation due to the rising trend of water table of poor quality groundwater. Thus, only 32 percent area is left with no problem.

6.4.1 Classification Accuracy

Based on field evidence more than 150 test pixels for each class were identified to assess the classification accuracy through a confusion matrix. The confusion matrix not only allows assessment of accuracy as a whole but also for each individual class. An overall classification accuracy of 87 percent and average reliability of 85 percent was achieved (Table 9). The cropped area, waterlogged soils, highly saline and sodic soils could be classified on the image with a high degree of confidence (>87%). The nil to slightly saline and moderately saline soils were partly intermixing.

Table 9. Confusion matrix for assessing supervised image classification accuracy

Clsm/Tstm	S1	S2	S3	S4	S5	S6	S7	S8	S9	Total
S1	311 (71)	80 (18)	0	2	1	0	15	27(6)	0	436
S2	39 (18)	167 (77)	0	10	0	0	0	1	0	217
S3	4	5	123 (80)	6	4	11	0	1	0	154
S4	0	1	14	164 (80)	2	12	0	0	0	193
S5	5	5	0	0	150 (90)	0	0	0	0	160
S6	0	0	24	0	0	149 (86)	0	0	0	173
S7	3	0	0	0	0	0	296 (90)	4	13	316
S8	42 (10)	0	0	0	0	0	20	351 (85)	0	413
S9	0	0	0	0	0	0	9	0	738 (99)	747
Rel.	77	65	76	90	96	87	87	91	98	

Clsm = Classified map; Tstm = Test map, Rel = Reliability, For S1, S2 ...., Refer table 8.
Figures in parenthesis indicate "percentages"
Average reliability: 85 (%); Overall accuracy: 87 (%)

6.4.2 Spectral Classes of Saline Soils

The spectral reflectance of soil is governed by many factors. In the present study, the area was homogenous in terms of topography, surface soil colour, texture, mineralogy and agricultural

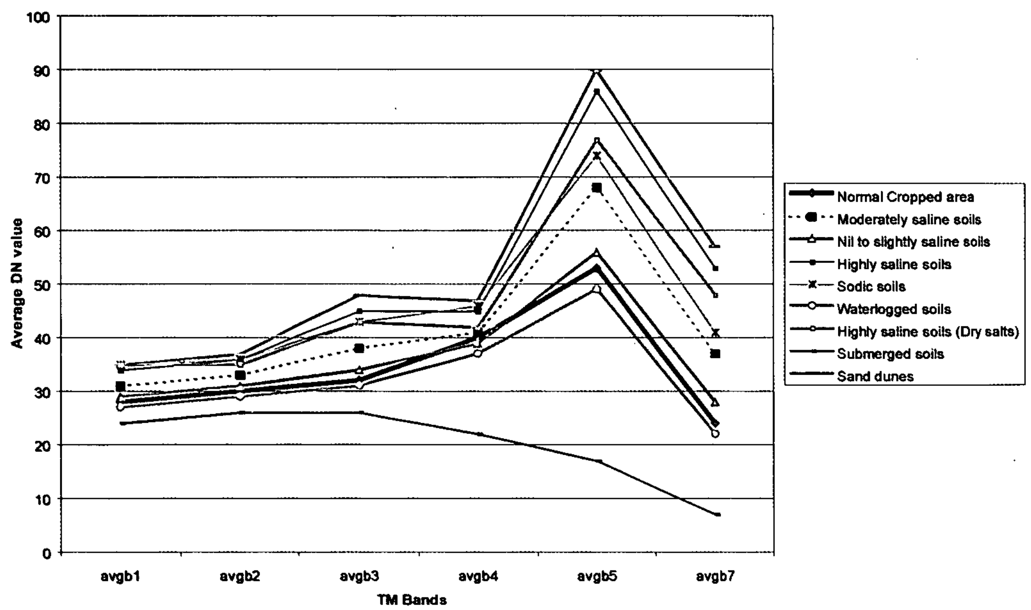


Figure 6. Spectral signatures of salt-affected soils

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 (Fig. 6). It is observed that saline and sodic soils have similar spectral response in red and near infrared bands (DN values 45-46) but a significant increase in spectral reflectance is observed in case of saline soils (DN 86) as compared to sodic soils (DN 74) in middle infrared band (band 5). This observation is extremely useful as it helps the segregation of saline soils from sodic soils, which is most important from the reclamation point of view. In the thermal band, the coarse textured dry sand dunes have a high emission compared to all categories of salt-affected soils.

6.5 Conclusions

- The November 1995 image of Landsat TM5 proved to be very useful in identifying and delineating saline/sodic soils with various levels of degradation in the central irrigated part of Haryana.

- The study showed that surface accumulated white salt crusts are a good indicator for the detection and correlation of salinity during the dry season.

- Sodic and saline areas reflect almost similar in band 3 (red) and band 4 (near infrared band). But sodic soils could be separated from saline soils based on their spectral characteristics in band 5 where increase in reflectance is relatively less in case of sodic than saline soils.
- The saline soils of the area have been mapped with an average reliabilityof 85% while the overall classification accuracy was 87%.
- The image processing and GIS capability of ILWIS was demonstrated in integrating image features with a geo-referenced base map.

6.6 Recommendations

- In order to assess the 'universality' of the method applied, it is recommended to execute similar studies in pilot-areas in the Indo-Gangetic plain having similar agro-ecological conditions.
- To understand dynamics of soil salinity, it is recommended to analyse multi-date satellite data complimented with sound fieldwork. In the fieldwork, attention should be paid to the correct positioning of the observation points through the use of GPS. Physiography, land drainage conditions and information on groundwater depth and quality should be used during analysis.
- The November data proved to be useful in identifying various stages of salinity degradation. The usefulness of other dates to monitor salinity built-up in a crop cycle should be assessed. Promising indicators such as NDVI and albedo could be used.

7. DELINEATION AND CHARACTERISATION OF SALT-AFFECTED AND WATERLOGGED SOILS IN IGNP (PHASE I), RAJASTHAN (CSSRI)

7.1 Introduction

The Thar Desert occupies about two-third part in the State of Rajasthan. Traditionally, agriculture in this region depends on the scanty rainfall. Irrigation was introduced in this area by commissioning Indira Gandhi Nahar Pariyojona (IGNP). The total irrigation potential is estimated as 13.87 lakh hectares. Canal irrigation has brought a significant change in the cropping pattern. The traditional rainfed subsistence crops have been replaced by cash crops. On an average annual area sown has increased by 200% after introduction of canal irrigation. As a result of canal irrigation, most part of the Ganganagar district experienced a significant increase in crop production. However, irrigation has also brought problems such as waterlogging and soil salinity, which not only degraded the good irrigated agricultural lands but also devastated the village hamlets. As a consequence, most part of the areas around the main canal where water delivery is comparatively high experienced high water tables and water stagnation particularly in the low-lying flats and depressions. Canal seepage, surface irrigation practices, sandy soil texture and the presence of hard impermeable layer at shallow depth are found to be among the several factors responsible for the development of water ponding, high water table and secondary salinization in the command area.

7.2 Study Area

The study area lies between 29°00' and 29°40' N and 74°00 and 74°40' E. The area is irrigated through the main canal (Indira Gandhi Canal) and its branches such as Rawatsar, Naurangdesar distributary and Suratgarh branch. About 59% of the land is non-irrigable and 80% of the irrigable land is sandy in nature (FAO/UNDP, 1971). Sandy plain, floodplain, dunes, depression, interdunal flat are the common landforms of the area. Aeolian sand and fluventile sediments are the major geological formations leading to the development of the vast sandy plain. The quaternary alluvium sediment forms major hydro-geological formations. Fig. 7 gives an overview of the selected study area. The areas selected for detailed studies on waterlogging and salinity are indicated with 'W' and 'S' respectively.

The groundwater conditions are highly variable. It occurs at shallow depth in the low-lying inter-dunal flats close to the main canal where waterlogging condition appeared. Based on the continuous monitoring of the groundwater data, the water level is reported to increase at an alarming rate.

Pearl millet, sorghum cluster bean, sesamum, in the *kharif* and wheat, gram, in the *rabi* season, are mainly grown. Besides, paddy, sugarcane, cotton, mustard, is also cultivated in the irrigated areas. Climatic parameters categorise the soils in Ustic and Hyperthermic soil moisture and temperature regimes respectively. The light texture, presence of subsurface fine textured / mixed kankar ($CaCO_3$ nodules)/gypsum impermeable layer and absence of natural surface drainage are some of the principal constraints limiting sustained irrigated agriculture.

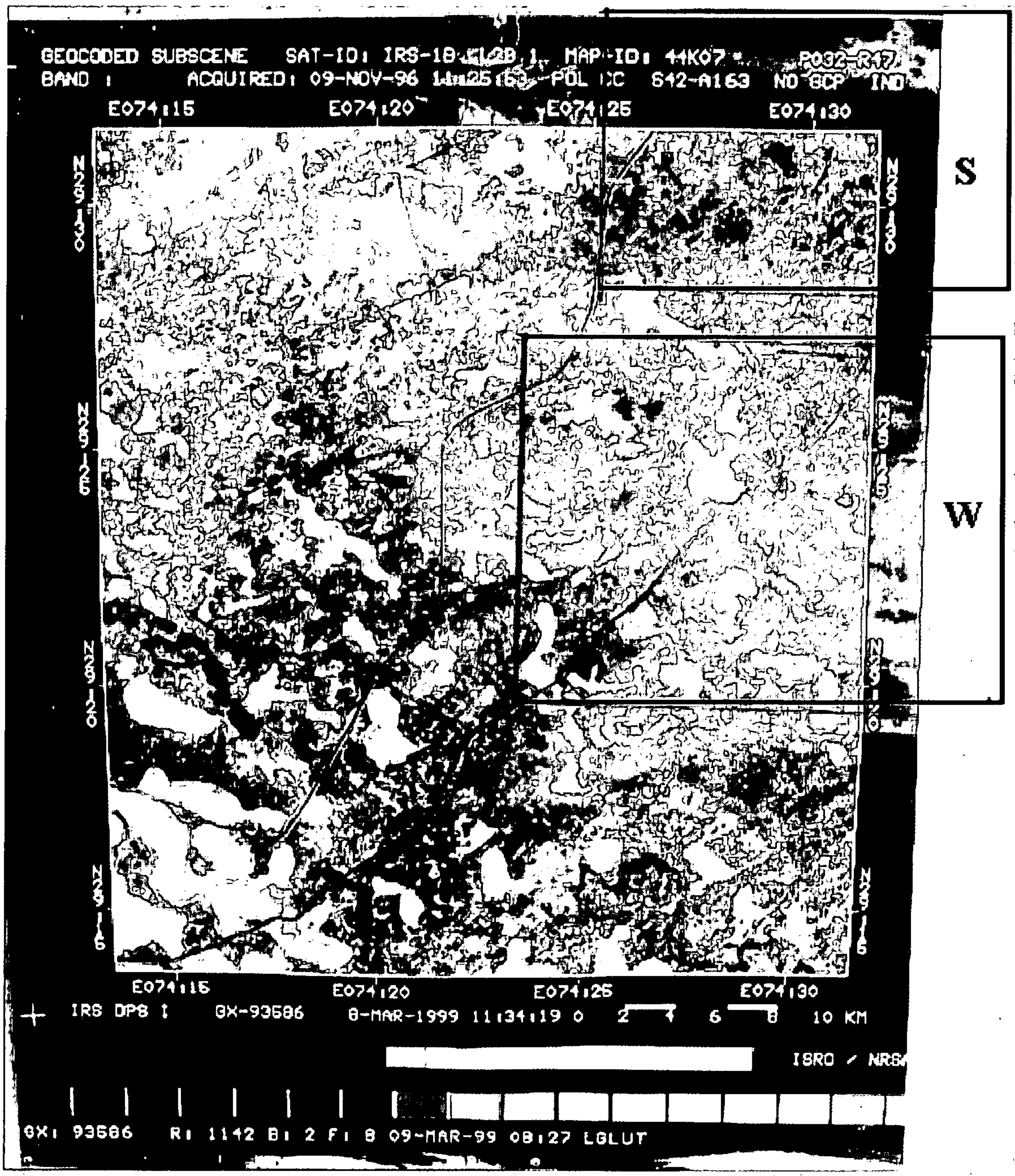


Figure 7. A FCC showing study areas for waterlogging (W) and salt-affected (S) studies

7.3 Methodology

The IRS LISS II imageries of February, November 1996 and June 1998 were used for the identification of the waterlogged areas and salt-affected soils. For detailed analysis, IRS digital data of February 1996 were processed. The imageries were geo-referenced using tie-points method, thereafter geo-coded through re-sampling. A colour composite was prepared using band 4, band 3 and band 2 of the LISS II data. (see also the flow chart in Fig. 8).

7.3.1 Preparation of the Base Maps

The basemaps indicating permanent settlements such as roads, railways, river, streams, village boundaries, city, towns, tehsils, irrigation network were prepared in GIS. For this, Survey of India toposheets were used as reference material. The permanent fixtures were transferred in digital format through digitisation. Initially, the SoI toposheets were geo-referenced using UTM co-ordinate system. For this, the co-ordinates of the toposheets were converted into the UTM values in meters using transform co-ordinate function in ILWIS. Finally, eight toposheets on 1:50,000 scales covering the study area were digitised. A part of the study area indicating permanent features and irrigation network is used as base-layer to support mapping of waterlogging and soils salinity in the command area.

7.3.2 Interpretation of IRS Data

False colour composites of selected sections of the study area pertaining to waterlogged and salt-affected areas were visually interpreted overlaying the base map and other ancillary information. Based on the differential manifestations of tone, texture, pattern on the satellite imageries, the image elements were identified and further verified during field checks. The interpreted units were digitised (on-screen) to create a polygon map. The area statistics were generated through histogram analysis.

7.3.3 Characterisation of Soil Samples

Field check was done during the post monsoon season for spot identification and images correlation. Based on the image interpretation, sampling sites for soils profiles were selected and representative soil profiles were studied for morphological characteristics (Soil Survey Staff, 1995). The water samples were collected from the accumulated seepage lakes *(Tal)*, auger bore and profile pits. The water table depths were recorded at selected locations.

Standard methods were followed for determining the mechanical composition, calcium carbonate (<2 mm size), organic matter, cation exchange capacity and exchangeable sodium percentage (Jackson, 1967). Saturation extract of the soils were prepared and analysed for pH_s, EC_e, soluble cations and anions and water samples were analysed for pH, EC_w, Na^+, K^+, Ca^{2+} $+Mg^{2+}$, CO_3^{2-} + HCO_3^{-1}, Cl^{-1}, and SAR for quality appraisal using standard methodology (Richards, 1954). Based on the morphological and chemical data, the soils were characterized and classified as per Soil Taxonomy.

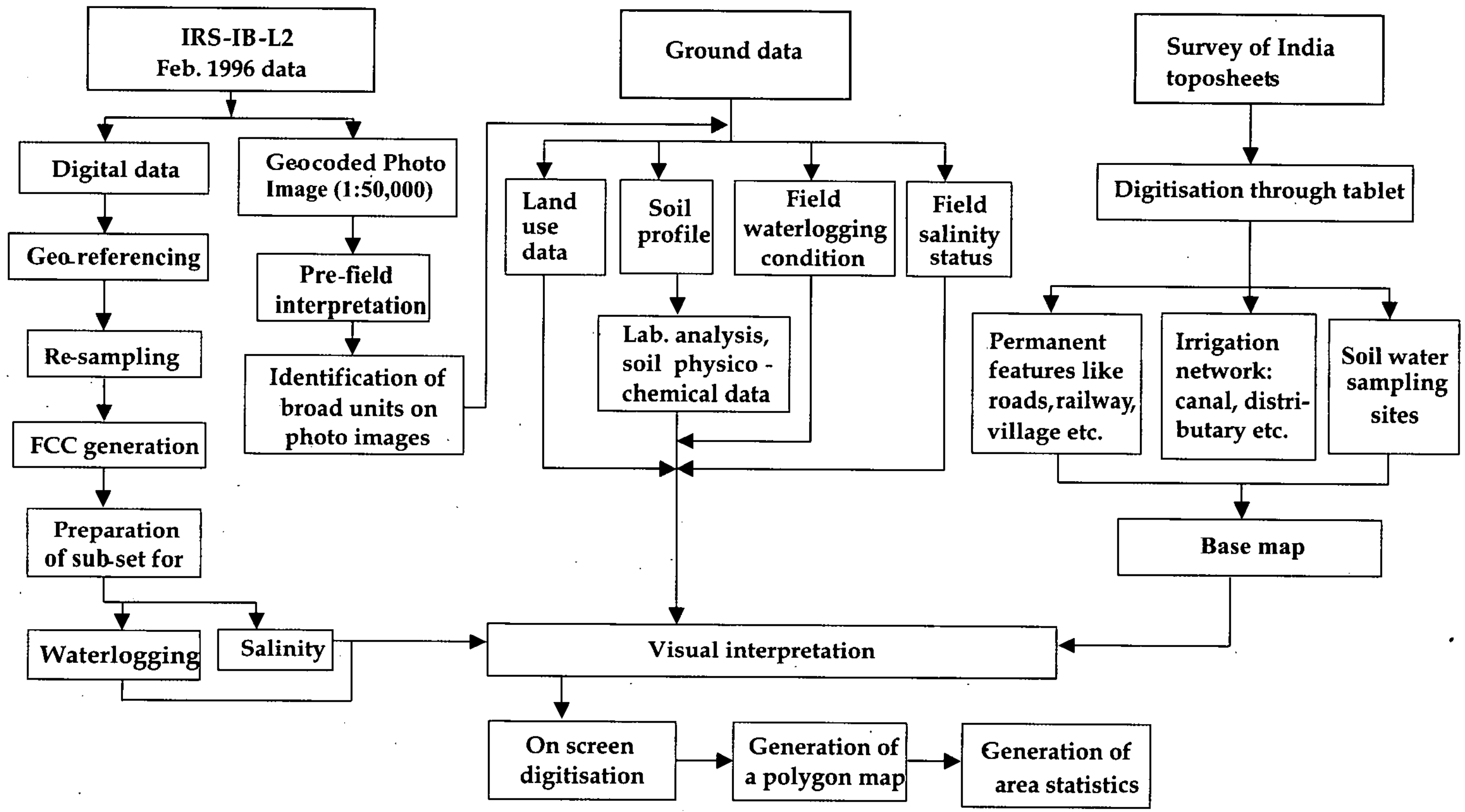


Figure 8. A flow chart of the adopted methodology

7.4 Results

7.4.1 Soil Characteristics

The soil morphology showed coarse texture, poor structure, weak consistency and presence of abundant $CaCO_3$ nodules within the control section of soil profiles. Little iron and manganese concretions/mottling around micro-pores were observed in the subsurface horizons. A weak to violent effervescence was observed due to the presence of kankar layer within the saturated zone of the soil profile. The soil contains an appreciable quantity of soluble salts (EC_e ranging from 1.9 to 50.0 dSm^{-1}) comprising of chlorides (13 to 902 meq/l). In many cases, the quantity of magnesium showed higher preponderance indicating the presence of magnesium bearing minerals in the parent material. Sodium was often found to exceed calcium and magnesium in the severely affected zones. The soils were classified as Ustorthent, Ustifluvent, Ustipsamment, Torripsamments and Torrifuvent at the sub-group level.

7.4.2 Waterlogged Areas

Prominent waterlogging was identified from the image elements of dark blue to blue/black tone. This class is indicated in Fig. 9 as 'Ponded water'. This phenomenon occurred due to seepage and accumulation of irrigation water and is mostly confined to the localized low-lying areas. Statistical analysis showed that at the test site, about 12% of the area was affected due to surface ponding (Fig. 9). Besides, ground truth verification of some areas under irrigation, showing light to dark grey tone intermixed with reddish mottles in the images, were found to possess shallow water table depth ranging from 0 to 1.5 m.

7.4.3 Soil Salinity Features

Visual interpretation of the IRS LISS II data of February and November 1996 identified salinity features in patches of 10-40 ha by a mixed spectral response of white and grey to yellowish white tones classified as 'surface salt efflorescence'. During ground verification, salt accumulation (2-3 cm depth) was found to be associated with the 'ponded water' class with salt grasses. During post-monsoon ground truth, a thin layer of salt accumulation was found in the irrigated areas co-existing with vegetative cover. Soil physico-chemical data indicated accumulation of salts in the subsurface layers of some soils. This phenomenon indicates operating process of secondary salinization in the normal soil areas. Image interpretation could only delineate the thick salt efflorescence on the bare soils. The area statistics showed that it occupies about 11% of the selected area (Fig. 10).

7.5 Conclusions

- Not much difference was observed on the November and February images. Both the images could give similar visual interpretation results. The June image gives a mixed picture, only the permanently submerged areas could be identified.

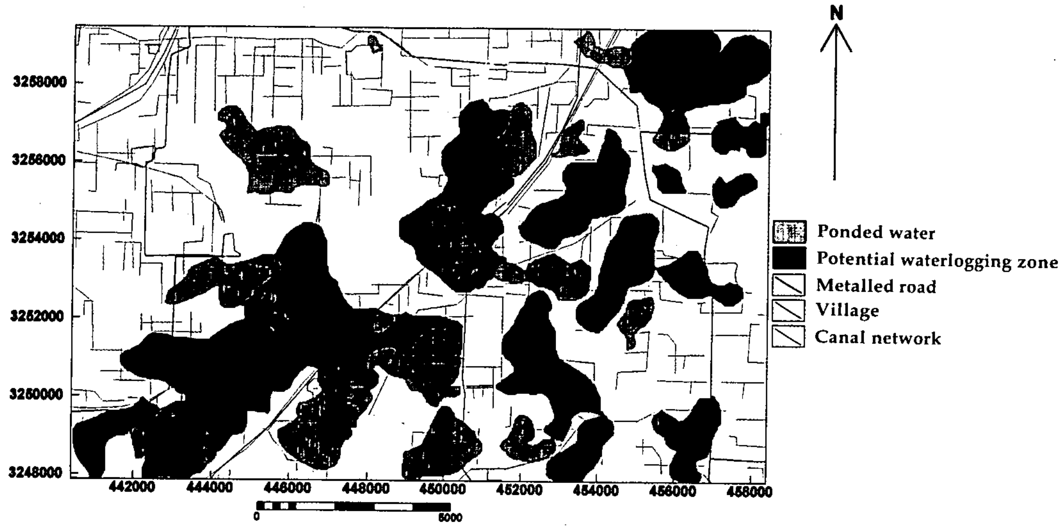


Figure 9. Waterlogged areas in the part of IGNP command

Figure 10. Salt-affected areas in the part of IGNP command

- Interpretation of IRS data easily revealed the 'ponded water' class.
- On the image, no differentiation could be made between critical and potential waterlogging so they are merged. Tone difference could be observed between the normal cropped and the above-mentioned classes.
- A good relation was found between the characteristics of image elements and the ground observations of ponded water, normal cropped and highly salinized areas.
- Visual interpretation revealed presence of surface soil salinity as salt efflorescence on the bare soil. Ground truth studies also found salt accumulation in the subsoil zones indicating secondary salinization. This was not expressed on the images.

7.6 Recommendations

- Temporal data over a period of ten years could be used for monitoring the changes of the extent of waterlogging and secondary salinization. Either February or November images could be used. Groundwater levels, crop yields and surface salinity levels should be monitored at a regular interval in various representative parts of the command area. Additional field observations should be taken at the time of the satellite overpass.
- After pre-field visual interpretation, a stratified sampling of basic soil parameters and crop status should be collected to provide additional information on the spatial variation of the waterlogging condition and salinity status.
- Digital image processing such as supervised classification supported by GPS assisted ground truth should be undertaken to fully utilize the potential of the satellite images.

8. MONITORING AND EVALUATION OF IRRIGATION SYSTEM PERFORMANCE IN SALINE IRRIGATED COMMAND, BHALAUT DISTRIBUTORY, HARYANA (CSSRI)

8.1 Introduction

In irrigated agriculture where waterlogging and soil salinity prevail, information on state/severity of these problems under cropped condition and their adverse impact on crop production would be helpful to understand the dynamics of intra-seasonal waterlogging/ salinity and to forecast crop production. In the past, most studies pertaining to delineation of waterlogged/salt-affected areas were mainly confined to bare soil condition. Therefore, this study was initiated with the objective to identify the waterlogging/salinity conditions in irrigated cropped land. Surface radiative properties, vegetation indices and moisture indicators have been used to identify the severity of waterlogging/salinity in the Bhalaut distributary of the Western Yamuna Canal system in Haryana.

8.2 Study area

The study was conducted in the Bhalaut distributary command covering an area of about 19,000 ha. The project area is located between 28^{0}45' to 29^{0}15' N latitude and 76^{0}30' to 76^{0}55' E longitude. Climatically, the study area falls in semi-arid region with an average annual rainfall of 545 mm and average annual evapotranspiration of 1650 mm. The average minimum and maximum temperature fluctuates between 5-45 ^{0}C, respectively. The soil is mainly alluvium, light textured categorised as sandy loam to loamy sand. In the study area, the soil salinity varies between 0-12 dSm^{-1} in 0-60 cm layer at the time of harvest of wheat crop. In the soils, salts are mainly calcium, magnesium and sodium chloride. The water table ranges from 1 to 5 m below the soil surface. The *warabandi* system is followed for water distribution from the canal.

8.3 Methodology

8.3.1 Image Selection

In the study area, the performance of irrigation system is mainly of concern during the middle to late *rabi* season, when evaporative demand is high and soil salinity increases to a great extent. Wheat is the major crop during the *rabi* season (more than 80% area) and phenologically, it attains maximum vegetative growth by middle of February and hence the effect of cultural practices minimises afterwards. The severe problem of waterlogging is observed in the beginning of the crop growth, which tapers down and is least at the time of crop harvest. However, in many low-lying areas, it remains severe throughout the season. The requirement of irrigation water during ripening period (3rd week of March onwards) also decreases. Considering all these aspects, the ideal time for selection of satellite remote sensing image specially for assessing irrigation system performance was considered from middle of February to middle of March. The availability of cloud free Landsat-TM data for this period was explored. As no cloud free data were available for the said period, therefore, a quadrant scene (approx. 75,000 ha) of Landsat 5-TM on a clear sky day (30th January 1996 for Path/Row-147/40) was procured. A flow chart of the adopted methodology for identification of crops affected by waterlogging and soil salinity is shown in Fig. 11.

8.3.2 Data Pre-processing and Spectral Characteristics

The sub-scene was geometrically corrected on a state plane coordinate system (scale-1: 50,000). The in-band planetary reflectance was determined for visual interpretation of spectral pattern of different land uses. The spectral reflectances for various land uses (using ground information) in different band spectrum were retrieved. It showed that water has in general lower reflectance in all the bands than all other features. The cropped land has higher reflectance than water in all the bands. Due to the influence of high moisture, waterlogged crop has low reflectance than the normal crop in all the bands whereas the salt-affected crop has higher reflectance in bands other than red and near infrared (NIR). The reflectance from bare soil and salt surface are higher than the cropped land except in NIR band. The reflectance from saline surface is higher than bare soil and other features but lower than bare soil in middle infrared region. This is mainly due to the hygroscopic characteristics of many salts or due to the high moisture content of fresh salts. On the basis of spectral characteristics of different land uses, a land use classification in the irrigated command has been made.

8.3.3 Surface Radiative Indicators

For the analysis of waterlogged and salt-affected surface crops, various surface radiative property indicators i.e. surface albedo (α), different band ratios for salinity index 1(SI1 = 5/7), salinity index 2 (SI2 = (4-5) / (4+5)) and salinity index 3 (SI3 = (5-7) / (5+7)) are used.

8.3.4 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. Among several vegetation indices, normalised difference vegetation index (NDVI) has been used for generating the crop condition map.

8.3.5 Moisture Indicators

The moisture indicator is determined as evaporative fraction (Λ) using relationship $\Lambda = \lambda E / (\lambda E + H)$. A model, Surface Energy Balance Algorithm for Land, SEBAL (Bastiaanssen, 1995) has been applied on Landsat-TM sub-scene to solve the surface energy balance equation:

$$Rn = G + H + \lambda E$$

where Rn is the net radiation flux density (W m^{-2}), G the soil heat flux density (W m^{-2}), H the sensible heat flux density (W m^{-2}) and λE the latent heat flux density (W m^{-2}). The model combines analytical and empirical relationships to obtain distributed Rn, G and H fluxes. λE flux is obtained as the residue of the surface energy balance.

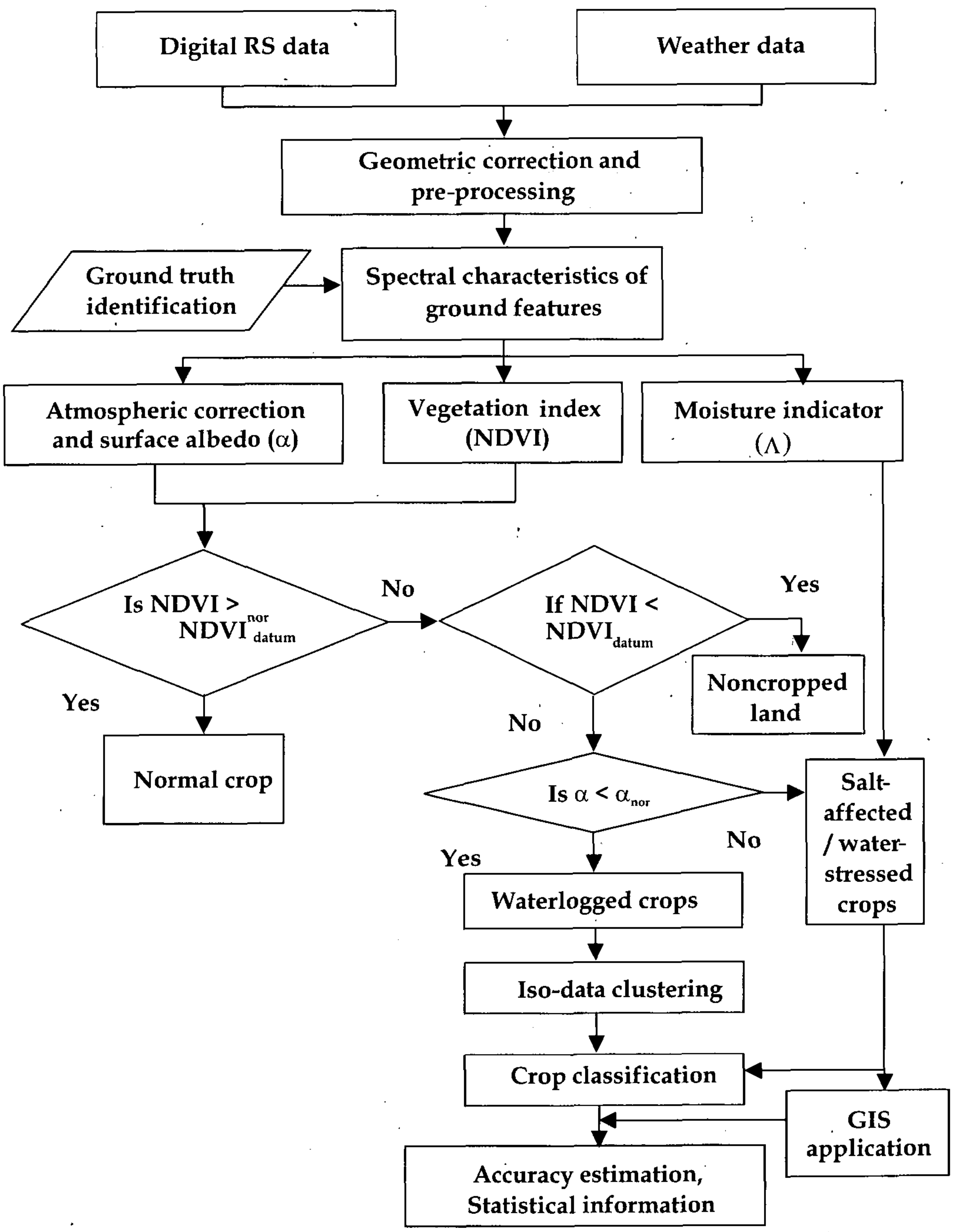


Figure 11. A flow chart for identification of crops affected by waterlogging and soil salinity

8.3.6 Identification of Waterlogged and Saline Bare Surfaces

The lack of vegetation or scattered vegetation on waterlogged land and highly salt-affected soil surface makes it possible to detect waterlogged land and saline surfaces directly from the remote sensing measurements. The waterlogged land and saline surfaces have very distinct reflectance characteristics and can be identified with low α - low NDVI and high α - low NDVI, respectively. Well-developed saline efflorescence and crusts are always associated with high reflectance in visible and NIR on photographic data. However, reflectance reveals information of the first few millimetres of the top horizon and therefore, the possibility of underestimation exists. Reflectance of saline surface increases with increasing wavelength up to NIR and decreases in the middle infrared bands. However, the difference in spectral radiance of bare soil and saline surface in visible and NIR range is very small and therefore, the possibility of over estimation exists. Use of band 5 and 7 for determining threshold α could reduce this error. The use of information in MIR and IR bands along with visible and NIR bands will provide precise information on soil surface with salt crust.

8.3.7 Identification of Waterlogged and Salt-affected Crops

A scatter-gram between surface albedo and NDVI is plotted for assessing severity of waterlogging and salinity in cropped area (Fig. 12). After evaluating the histogram of α and NDVI, an approach,

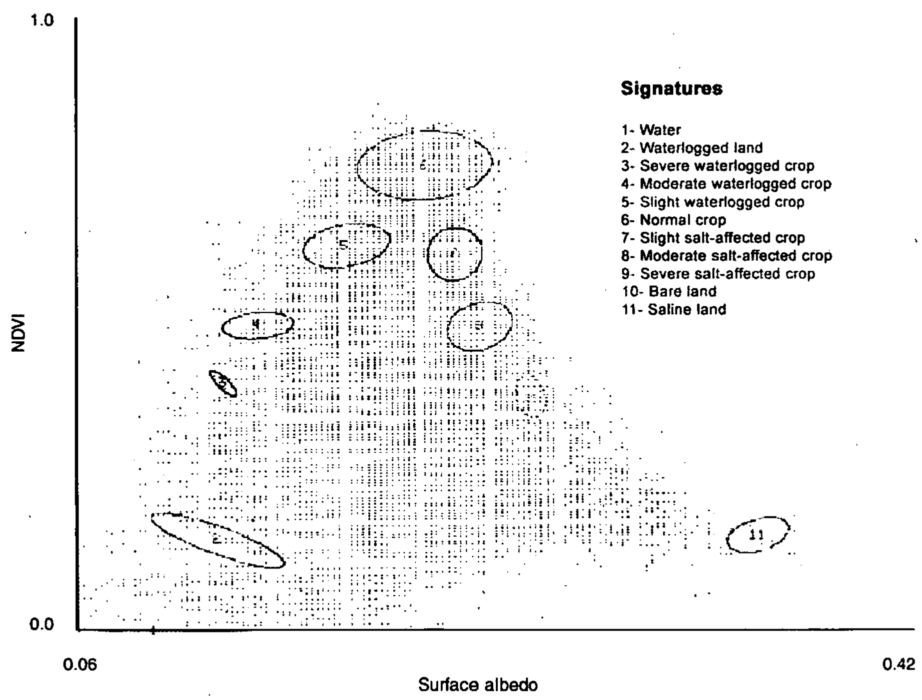


Figure 12. Scatter-gram between surface albedo and NDVI

based on a guiding principle that the surface albedo decreases with increase in waterlogging and increases with increase in salinity, has been developed. The reduction in crop condition is considered in both the cases. The various signatures are generated assigning the α and NDVI values. The signatures for bare soil and saline surface are assigned based on their spectral characteristics explained earlier.

The generated signatures are evaluated on plots of scatter-gram for all combinations of surface radiative property indicators (α, SI1, SI2 and SI3), agronomical indicators (NDVI and LAI) and moisture indicator (Λ). It is observed that the scatter-gram between surface albedo and NDVI has high separateability than all other radiative property indices. On evaluation of pixel by pixel values of NDVI and α colour composite, a kind of biased is observed due to the arbitrary selection of seed pixel and maximum likelihood classification procedure and therefore, another procedure was used to delineate and classify only waterlogged crops.

8.3.8 Methodology for Assessing Waterlogged Crops

The procedure consists of the following steps :

1. To suppress the non-waterlogged cropped land, apply an equation $\alpha^{nor} - \alpha_{(x,y)}$ on α image.
2. To suppress the non-cropped area, apply an equation $NDVI_{(x,y)} - NDVI_{dat}$ on NDVI image and to suppress normal cropped area apply $NDVI^{nor} - NDVI^{dat}_{(x,y)}$.
3. The suppressed α and NDVI images are recoded by assigning values 0 (for values ≤ 0) and 1 (for values > 0) and multiplied in order to prepare a mask for waterlogged crops.
4. The mask is applied on α and NDVI image to select the waterlogged crops only.
5. Iso-data clustering operation was performed to generate the waterlogged crop classes based on average values of α and NDVI of the clusters (Table 10).
6. A linear regression is developed for waterlogged crop class number with α and NDVI and extrapolated for preparing waterlogged crop class.

   $$WLCCN = 23.14 - 124.35 * \alpha_{(x,y)} + 4.02 * NDVI_{(x,y)}$$

   where WLCCN is the waterlogged crop class number, $\alpha_{(x,y)}$ the distributed surface albedo, $NDVI_{(x,y)}$ the distributed NDVI.

Table 10. Selection of average α and NDVI values obtained by iso-data clustering

Waterlogged crop class number	α	NDVI
Slightly waterlogged (1)	0.156	0.69
Moderately waterlogged (2)	0.161	0.57
Highly waterlogged (3)	0.147	0.46
Severely waterlogged (4)	0.142	0.38

8.3.9 Methodology for Assessing Salt-affected Crops

The scatter-gram between α with Λ for assigned classes in first classification showed a decrease in Λ for highly salt-affected crops. This indicated that the classification based on α and NDVI includes reduction in NDVI due to salt stress as well as water stress and in both cases α increases.

As Λ is a measure of relative water availability in the command, it is included for improved classification of salt-affected crops. An equation is designed to scale up the crop class taking into account the fact that increase in α and decrease in NDVI represents increase in salinity. Also a scale-down factor is included to take into account the decrease in salinity due to decrease in evaporative fraction. The equation to classify the salt-affected crops class number (SACCN) is expressed as:

$$SACCN = (\alpha_{(x,y)} - \alpha_{dat}) * \frac{\alpha_{(x,y)}}{\alpha_{nor}^{avg}} * \frac{NDVI_{nor}^{avg} - NDVI_{dat}}{NDVI_{(x,y)} - NDVI_{dat}} * \frac{\Lambda_{nor}^{avg}}{\Lambda_{(x,y)}}$$

where SACCN is the salt-affected crop class number, α_{nor}^{avg} the average surface albedo for normal crop, $NDVI_{nor}^{avg}$ the average NDVI for normal crop, $NDVI_{dat}$ the minimum NDVI value for crops, Λ_{nor}^{avg} the average evaporative fraction for normal crop, $\Lambda_{(x,y)}$ the distributed evaporative fraction. The application of equation is not straight forward as it gives error due to algebraic limitation and therefore, applied in parts to classify the salt-affected crops. The signatures are evaluated on scatter-gram between crop class with α, and NDVI in different combinations. This showed a good response in all categories.

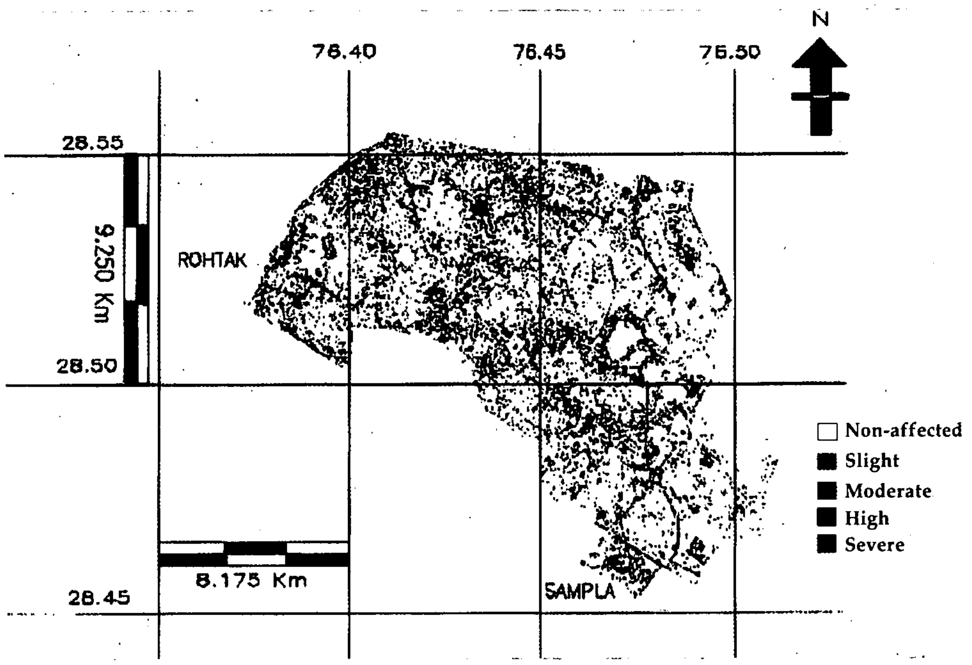
8.3.10 GIS Application

A map of the project area was digitised through Arc-Info package of GIS and transformed to real world coordinate system to extract the command area of Bhalaut distributary and the four watercourse commands at tertiary level. The digitised map has been used to create the polygons and extracting information from various images for the command of Bhalaut distributary (Bt), tertiary unit at head of Bhalaut distributary (Bt1), tertiary unit at tail of Bhalaut distributary (Bt3), tertiary unit at head of Asan minor of Bhalaut distributary (Bta1) and tertiary unit at tail of Asan minor of Bhalaut distributary (Bta3). The statistics for the analysis of variability in water supply, crop condition/yield and waterlogging/soil salinity in cropped land have been generated.

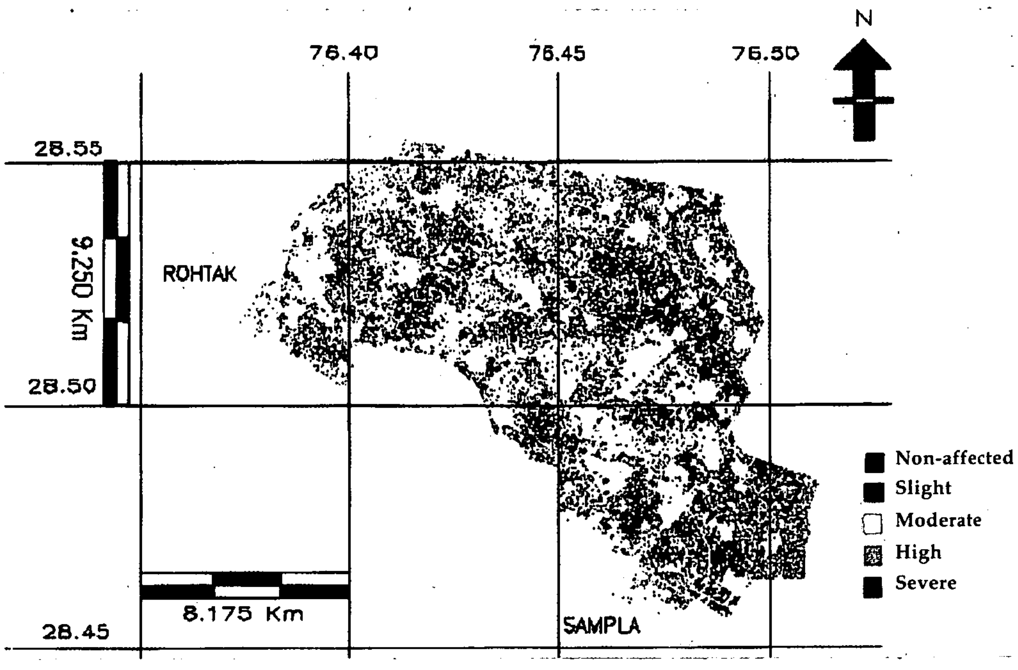
8.4 Results

The analysis of waterlogged crop image has shown severely waterlogged crops close to the vicinity of branch canal and distributary (Fig. 13a). A total 14 percent area suffers from various degrees of waterlogging in the Bhalaut distributary. At tertiary level, the spatial distribution of waterlogged crops indicated higher area under severe waterlogging at the lower reach of watercourse located at the head for Bt1 and Bta1. The waterlogged crop area reduces at the tail end of the distributary and minor for Bt3 and Bta3.

A total of 23 percent area was found suffering from various degrees of soil salinity in the cropped land of the command of Bhalaut distributary (Fig. 13b). The crop affected with different salinity



(a)



(b)

Figure 13. (a) Waterlogged and (b) soil salinity affected crop area in the Bhalaut distributary command

levels at tertiary level indicated an increase in cropped land affected from soil salinity at the lower reach of the watercourse command. The statistics of area under different level of salt-affected crop at different location of the watercourse command indicated an increase in salt-affected crop in tail ends both in case of Bhalaut distributary, Bt3 and at Asan minor, Bta3.

8.5 Conclusions

- The presented approach based on surface radiative properties, biomass depression and moisture indicator seems promising for identification and assigning the extent and severity of waterlogged / salt-affected cropped land using remote sensing data along with geographical information system.
- The analysis, based on this approach, indicated relatively higher area under waterlogged crops close to the head of the distributary than tail reaches, whereas an increase in crop area affected from soil salinity with respect to distance from head of the distributary / watercourse.
- Based on the image characteristics, a total 14% area under crops suffers from various degrees of waterlogging, whereas 23% area suffers from different levels of salinity in Bhalaut distributary.

8.6 Recommendations

- The presented approach has been applied on one satellite data set. It is recommended that the approach may be validated and used on temporal RS data for waterlogging/salinity identification and assessment under cropped condition.
- Looking to the small area under consideration in a distributary command, the study needs to be carried out at the level of branch canal where higher variation of waterlogging / soil salinity on cropped land is expected.

9. MAPPING OF SALT-AFFECTED AND WATERLOGGED AREAS IN PART OF NAGARJUNA SAGAR PROJECT (NSP), PRAKASAM DISTRICT, ANDHRA PRADESH (ANGRAU/ NRSA)

9.1 Introduction

Under Indo-Dutch Network Project, a study was taken up to map salinity and waterlogging in a part of the Nagarjuna Sagar Project (NSP) right canal command area using satellite data. The study was conducted in collaboration with Agriculture and Soils Group, National Remote Sensing Agency (NRSA), Hyderabad. The general features of the study area, methodology adopted and results obtained are discussed in the following sections.

9.2 Study Area

The study area is a part of the NSP Right Canal Command falling in the Prakasam district in the State of Andhra Pradesh. It lies between latitudes 15^{0}45′ 00″ to 16^0 10′ 00″ N and longitudes 80^0 00′ 00″ to 80^{0}15′ 00″ E covering an area of 74,000 ha. The average annual rainfall is about 798 mm. The geological formations of the study area consist of granites, gneisses, and coastal and deltaic alluvium. The various physiographic units encountered are residual hills, inselbergs, pediments, pediplains and broad valleys. The majority of the soils of the study area are black in colour, deep to very deep, heavy textured and moderately to poorly drained. The red soils are encountered on pediment and residual hills. The soil moisture regime is 'Ustic' and the soil temperature class qualifies for 'Hyperthermic'. A wide variety of crops like rice, chillies, cotton, vegetables, maize, sesamum and pigeon pea are cultivated in the test site.

9.3 Methodology

The methodology is based on the visual interpretation of satellite data. Along side with limited ground truth, analysis of soil samples and characterisation of salt-affected soils a final map is made. A flow chart is given in Fig. 14. The study area is covered by IRS-1C / LISS-III data of path-102 / row-62 of 14th April 2000. Available satellite data of March 1999 were also referred during image interpretation. Both images were cloud free. Since, most crops have been harvested at this time, so the soil can easily be seen on both images. Survey of India topographical map on 1:50,000 scale , climatic data, geology, groundwater, crop information etc., were collected and used as collateral data in the study. The Survey of India topo map was used to prepare base map for ground truth collection. A few prominent ground control points like road intersections, road and stream / canal cutting points etc., were also marked on the base map. The base map was scanned for use in digital data processing.

Digital processing of the satellite data was carried out using ERDAS IMAGINE software. The scanned base map was geo-referenced for which a polyconic projection and Everest spheroid is used. The base map was vectorised and coverages for roads, canals, settlement, etc., generated. In the next stage, the LISS-III data of IRS-1C were registered similar to the projected base map by identifying common ground control points both on the base map and on the image. Subsequently LISS-III data were re-sampled using nearest neighbourhood algorithm using first order polynomial transformation. The data were linearly stretched to improve overall contrast of the imagery.

9.3.1 Preliminary visual interpretation

The enhanced FCC image of the study area was displayed on 1:50,000 scale on monitor. Based on previous experience (including Phase-1 study), FCC were visually interpreted for salt-affected soils and waterlogged areas with the help of image elements like tone, texture, pattern, association etc. The salt-affected soils usually appear in different tones of bright white to dull white with medium to coarse texture on FCC print in the background of normal soils due to presence of salts.

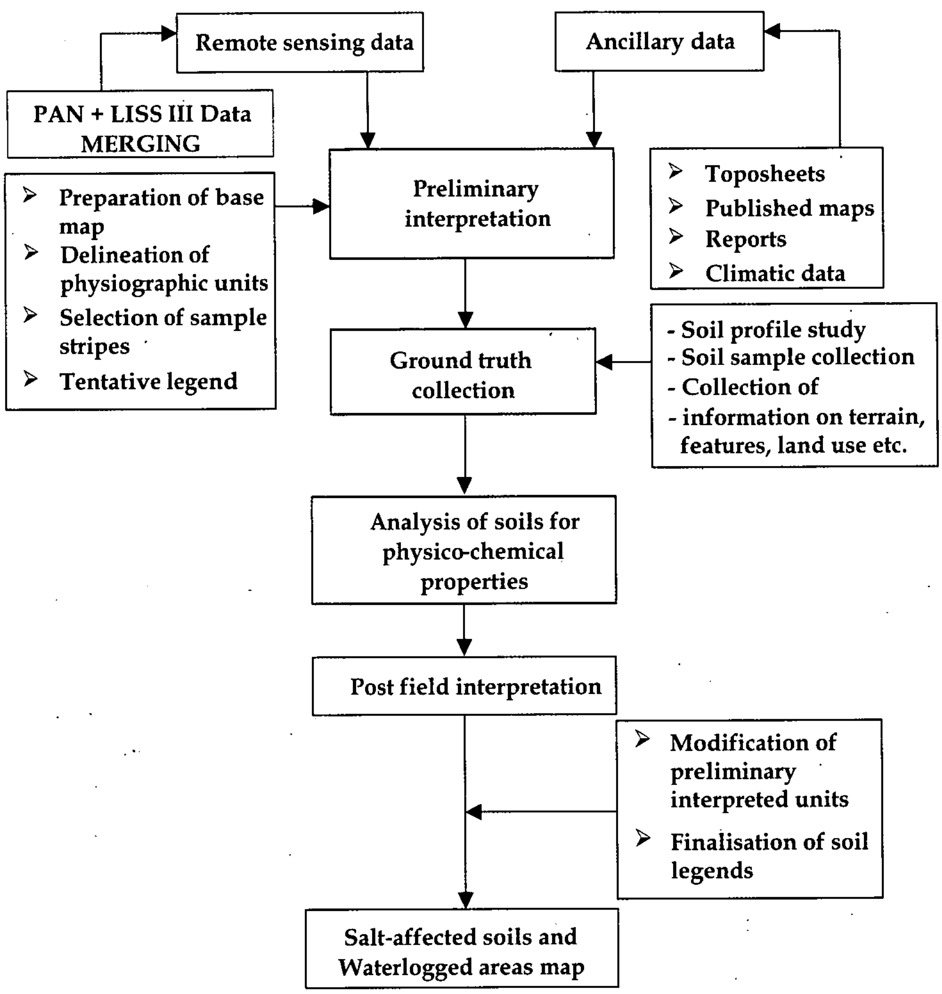


Figure 14. A flow chart of the methodology to map salt-affected and waterlogged areas using visual interpretation

The landforms (from existing landform maps) associated with the occurrence of salt-affected soils are also considered during interpretation. The obstructions to natural drainage like roads, railway lines, canal network etc. can easily be identified on the FCC image. The waterlogged ponded areas appear on FCC image in various shades of dark blue to black tone with smooth texture. Additional pre and post-monsoon images were used to identify permanently waterlogged area. An interpretation key was developed. A tentative legend was also prepared. A map showing preliminary interpreted units on FCC with base details was generated before going into the field.

9.3.2 Ground Truth Collection

Initially rapid traverse of the test site was made to identify the sampling points on the FCC image and in the field. Detailed field investigations were carried out in various physiographic units to observe the broad physiographic-soil relationship. In total, ground truth was collected at 29 sites, of which 15 were in salt-affected area and others in non-salt-affected area. The soil samples from salt-affected and other areas were collected from 0-15 cm, 15-30cm and 30-45 cm. The pH and EC of the soil samples were also tested in the field using pocket pH and EC meters and soil samples were collected for laboratory analysis. At each site, the associated terrain characteristics, land use/land cover, crop information etc., were collected.

9.3.3 Analysis of Soil Samples

All the soil samples collected during fieldwork were analysed for pH, EC_e, exchangeable and water soluble cations, mechanical analysis etc.

9.3.4 Post-field Interpretation

This step consisted of modification of preliminarily interpreted mapping units on FCC of satellite data in the light of field information and soil physico-chemical data. The tentative legends prepared during the pre-field work were also finalized. The salt-affected areas for the study site were finalized on computer monitor and all polygons of salt-affected soils were categorized into different classes of salt-affected soils based on the criteria indicated in Table 4. A final thematic map was created by combining the 'salt-affected soils and waterlogged' polygons from the interpretations and the base map.

9.4 Results

The FCC imagery and the map showing salt-affected soils and waterlogged areas are presented in Fig. 15 and Fig. 16 respectively. The results obtained are discussed as follows:

9.4.1 Salt-affected Soils

The salt-affected soils are encountered at the lower slopes of the terrain and occupied 4 % of the total study area. They are mostly encountered in the 'broad valley' physiographic unit and in

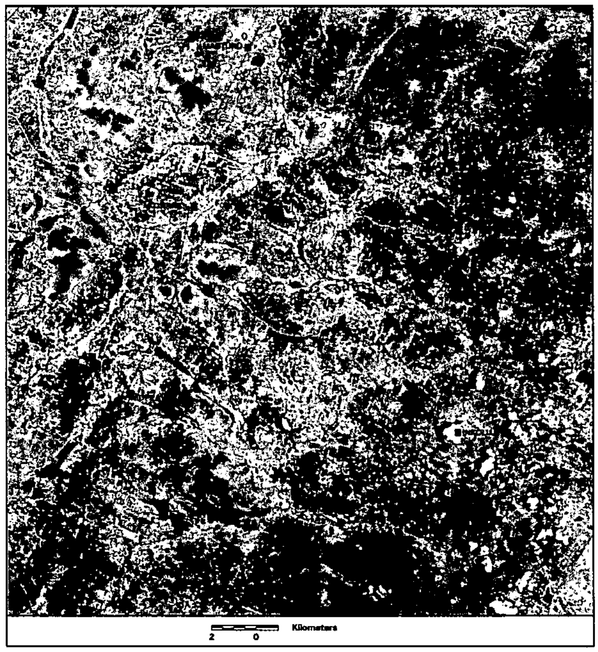


Figure 15. IRS-1C LISS III FCC image for a part of the Nagarjuna Sagar Project

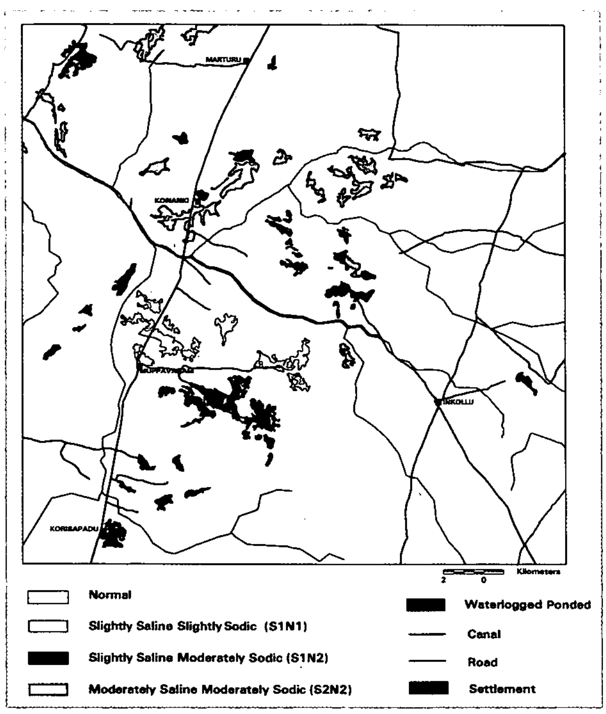


Figure 16. Salt-affected soils and waterlogged areas in the part of Nagarjuna Sagar Project

adjacent upland areas. They are classified in to saline-sodic soils. The saline-sodic soil's were divided into three classes based on the degree of salinity and sodicity as shown below:

- Slightly saline and slightly sodic – S1N1
- Slightly saline and moderately sodic – S1N2
- Moderately saline and moderately sodic – S2N2

The spectral reflectance curves of salt-affected soils along with other major land use classes are given in Fig. 17. It can be clearly seen that the salt-affected soils exhibited higher spectral reflectance value compared to the other classes in Band III. The S2N2 class was having the highest spectral reflectance values in all IRS-1C spectral bands followed by S1N2 and S1N1 classes.

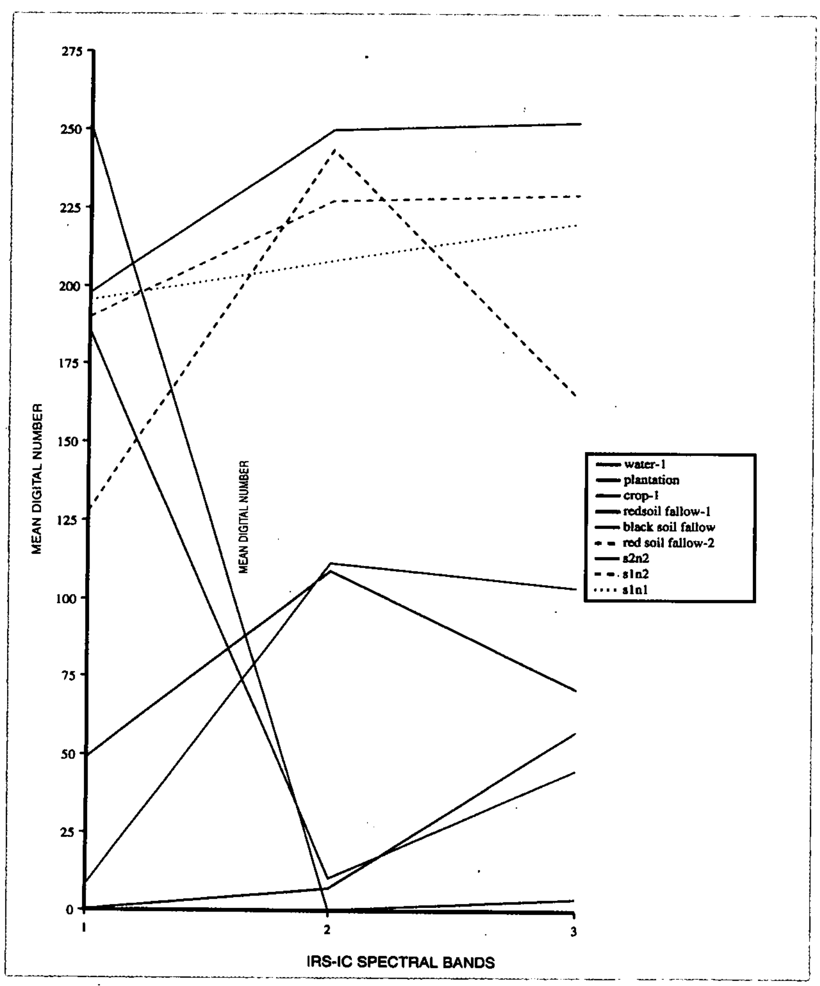


Figure 17. Spectral reflectance curves of salt-affected soils and other land use classes

During the field visit it was observed that the S1N1 class was supporting good crop and grasses during summer season. The S2N2 class was having salt encrustation, which was responsible for higher spectral reflectance values.

9.4.2 Waterlogging

The problem of waterlogging in terms of surface ponding under NSP right canal command area was limited to a few pockets. Remotely sensed data enabled to identify such areas that were small irregular with dark bluish tone with smooth texture on the FCC print. An area of 50 ha was found under this category.

9.5 Conclusions

- Remotely sensed data from IRS-IC LISS-III sensor of April 2000 enabled to identify and map the salt-affected soils and waterlogged areas at 1:50,000 scale.
- The appearance on the image of waterlogged salt-affected soils is quite different compared to other land use classes.
- Ground truth revealed that the salt-affected soils could be categorised into saline-sodic soils based on their physico-chemical properties. They were further sub-divided on the basis of degree of salinity and / sodicity into three classes.

9.6 Recommendations

The major recommendations that emerge from the study are as follows:

- In the present study single date satellite data were used to map the salt-affected and waterlogged areas. Future use of satellite data during pre-monsoon, monsoon and post-monsoon could be made use of to properly identify the salt-affected soils and waterlogged areas.
- Digital remote sensing techniques need to be attempted to possibly detail the mapping of salt-affected soils and waterlogged areas. Correlation of the typical spectral reflectance patterns of salt-affected soils with degree of salinity / sodicity is to be investigated for further classification in terms of salinity/sodicity.
- The AP Groundwater Department information and detailed knowledge of the waterlogging status of the 7,000 ha area around Konanki should be used in future digital analysis to investigate the possibility to classify the area with water table depth between 0 and 1.5 m below the soil surface.

10. IDENTIFICATION AND DELINEATION OF SALT-AFFECTED SOILS IN THE SURAT BRANCH OF UKAI-KAKRAPAR COMMAND, GUJARAT (GAU/ RESECO)

10.1 Introduction

Since past 10-15 years, a decline in crop productivity is being observed in the Ukai-Kakrapar command area in the State of Gujarat. This decline could be attributed to the rise in water table and/or the secondary salinization. In order to assess the extent of salinity / sodicity problem in the command area, a representative branch *i.e.* Surat branch was selected for the survey purpose. In the present study, two approaches *i.e.* 1) conventional and 2) application of use of remote sensing for this purpose were attempted.

10.2 Study Area

The study was undertaken in the Surat branch of Ukai-Karapar command (UKC) wherein the waterlogging and salinity problems dominantly exist. The selected branch falls under the Kakrapar command of the project.

10.2.1 Kakrapar Command

The Kakrapar weir and the related canal network were completed in 1954 and regular irrigation in the command was commenced in 1957. This canal system provides irrigation facilities to about 2 lakh ha out of the total 4 lakhs ha area covered under Ukai-Kakrapar command area. The area caters to the villages of Chorasi, Olpad, Kamrej, Palsana, Mangrol, Mandvi and Bardoli talukas of Surat district, Mahuva, Navsari and Gandevi talukas of Navsari district and Chikhali and Valsad talukas of Valsad district. This area is broadly divided in 7 zones based on river basins. The area includes about 64,450 ha *Khar* land (salt-affected) and 15,860 ha Non Productive Area (NPA). Geographically, the area lies between 20° 31′ to 21° 29′ N latitude and 72° 34′ to 73° 20′ E longitude. Out of these seven zones of Kakrapar command, the selected Surat branch serves the zone between Tapi and Mindhola.

10.2.2 Surat Branch

The Surat branch originates from Left Bank Main Canal (LBMC) at 20.6 RD from Kakrapar weir. The length of this branch is 52.8 km with a design discharge of 44.8 cumecs (1582 cusecs). The distributaries bifurcating from Surat branch are Nagod, Katargam and Dumas. The main crop during *kharif* is paddy and sugarcane is the predominant annual crop.

10.2.3 Climate

Climatically the command can be categorised as sub-humid to semi-arid depending upon the location. The rainfall is more on the southeastern portion of the command in Valsad district

(1800 mm) and gets reduced as it moves towards North and West. The command in the coastal region also receives lower rainfall as compared to the southeastern part of the command.

10.2.4 Soils

Most of the soils in the command area are deep with high clay (40-60%) content. The permeability of the soils is low to very low and at many places ill-drained. In addition to coastal salinity, secondary salinization is also on the rise in inland areas. The soils are low to medium in available N (0.44-0.70), medium to high in available P (26-33 kg/ha) and high in available K (350-870 kg/ha). In general, no micro-nutrient deficiencies of severe nature are observed except that of zinc (< 0.5 ppm) in coastal area.

10.2.5 Cropping Pattern

In the command area, the present cropping pattern consists mainly of sugarcane (62 %) and paddy (14 %). This clearly indicates the predominance of high water consuming crops. Although only 18 percent area was earmarked for sugarcane in the suggested cropping pattern at command level, it occupies more than double the projected intensity.

10.2.6 Groundwater Table and Quality

The following indications emerged from the periodical monitoring of water table fluctuation and groundwater quality of 58 wells in Surat branch:

- The groundwater quality during pre-monsoon 1998 indicate that 40 percent were either saline or highly saline. Similarly, the water quality of 7 percent of wells was sodic.
- There has been steady increase in water level at a rate of about 0.3 m annually in mid reach followed by 0.24 m in tail portion, while in head reach the rate was 0.06 m. Based on this, about 40 percent of the area can be considered as critical from waterlogging point of view.

10.3 Methodology

10.3.1 Conventional Method

The methodology followed for characterisation of salt-affected soils was as follows:

1. Soil sampling at 100 ha grid, covering 125 villages of Surat district, conducted during summer seasons of 1998 and 1999.
2. In 378 randomly selected fields, 6 soil sample were drawn up to 90 cm depth at an equal interval of 15 cm.
3. Processing and analysis of samples for salinity (EC_e) and sodicity (pH, ESP) parameters
4. Tabulation, categorisation and abstraction
5. Mapping and presentation (GIS)

10.3.2 Methodology for RS Study

An attempt was made to explore the feasibility of identifying different degrees of salt-affected soils in the canal command area through remote sensing techniques (See flow chart in Fig. 18). 13 neighbouring villages of Surat branch command were selected and their boundaries were put into Arc/Info GIS system. IRS LISS III + PAN-merged data were procured covering 9 villages. The cadastral vector data of these villages were rectified and superimposed on the image.

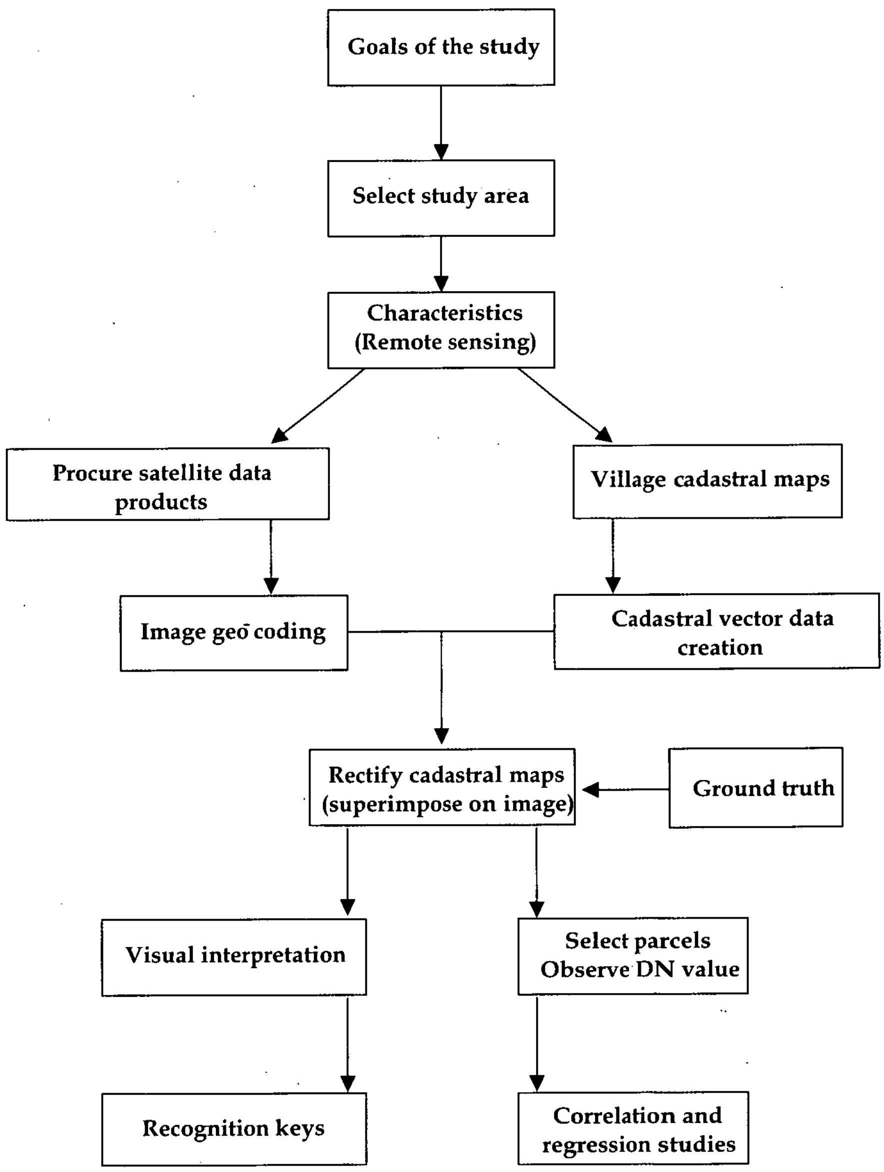


Figure 18. A flow chart of the adopted methodology.

Qualitative observations were made using ground truth and visual interpretation. As it was not possible to pinpoint the actual location in the 100 ha grid sample it was decided to concentrate only on the samples of two villages, namely, Segwa and Morthana with different levels of salt-affected soils and where parcel-wise data were available. The mean DN values were converted to radiance for correlation studies with EC_e and ESP.

10.4 Results

10.4.1 Conventional Studies

The information regarding the sampled area along with the means and ranges of $pH_{(1:2.5)}$, EC_e (dSm^{-1}) and ESP are given in Table 11. The range and mean values of different talukas (blocks) covered by Surat branch revealed that $pH_{1:2.5}$ values were ranging from 6.80 to 9.30 with a mean of 7.90. Similarly, EC_e (dSm^{-1}) and ESP values were ranging from 0.5 to 21.4 and 1.5 to 48.9 with a mean of 1.70 and 7.5, respectively. Among the talukas, Chorasi recorded relatively higher mean values of pH (8.1) and ESP (9.4) than rest of the talukas. However, salinity problem (EC_e 2.2 dSm^{-1}) was more in Bardoli taluka.

Table 11. Salinity and sodicity status in Surat branch of Kakrapar command

Taluka	No. of villages	No. of Samples	GCA (ha)	CCA (ha)	pH (1:2.5)	EC_e (dSm^{-1})	ESP
Bardoli	33	111	11043	10181	7.0-9.3	0.5-15.5	1.0-23.0
				(7.9)	(2.2)	(6.9)	
Kamrej	48	170	17288	15111	6.8-9.0	0.5-21.4	1.5-48.9
				(7.8)	(1.6)	(7.1)	
Chorasi	22	46	5646	4520	7.2-8.9	0.7-4.4	3.4-21.8
				(8.1)	(1.8)	(9.4)	
Palsana	22	51	6921	6184	6.9-8.9	0.6-2.8	2.4-46.7
				(7.9)	(1.2)	(9.2)	
Total	125	378	40898	35996	6.8-9.3	0.5-21.4	1.5-48.9
				(7.9)	(1.7)	(7.5)	

( ) = Mean values.

At branch level, distribution of soils into different categories of salt-affected soils revealed that about 37 percent of the area suffers from problems of salinity or sodicity or both (Table 12). Between the salinity and sodicity problems, sodicity was higher in Chorasi as compared to rest of the talukas. The saline-sodic soils were almost nil in the command, except in Bardoli taluka where it was to an extent of 5 percent. The maps describing of salt-affected soils in the branch command were prepared (Fig. 19 and Fig. 20).

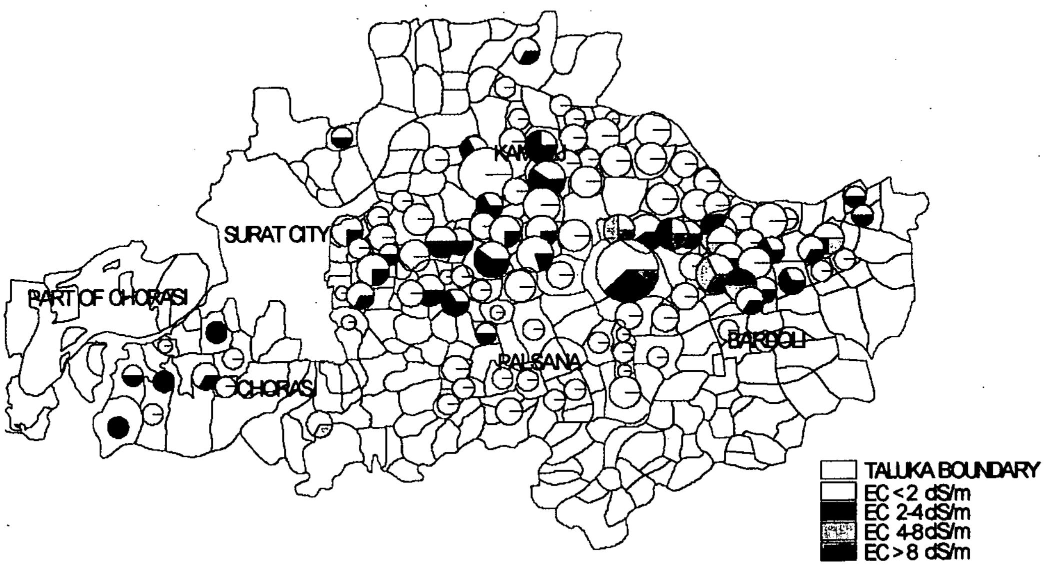


Figure 19. Salinity classes distribution in the soils of Surat Branch

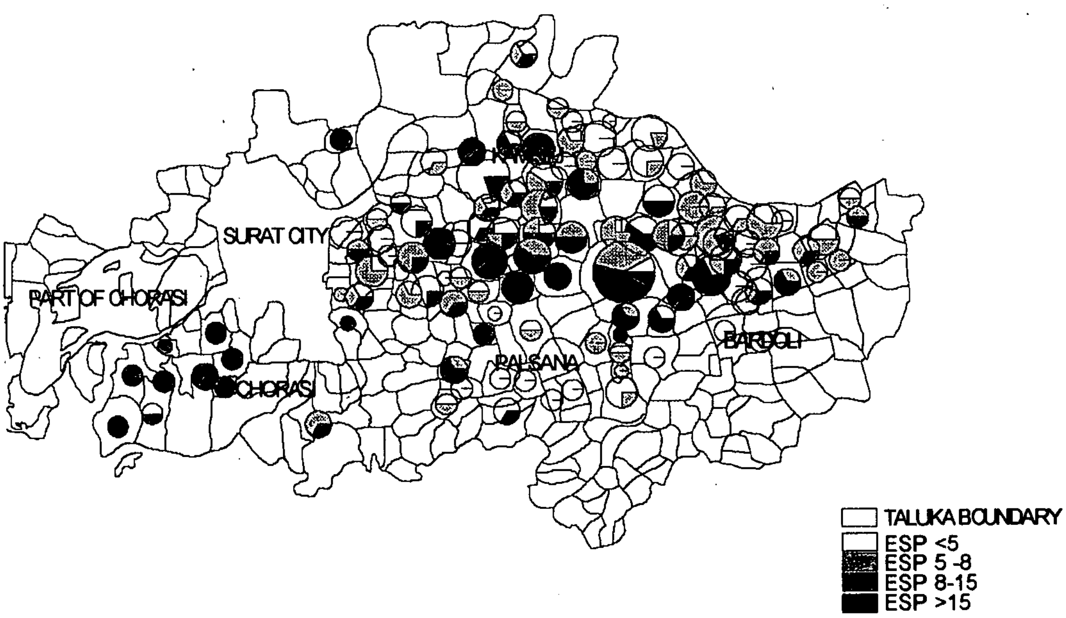


Figure 20. Sodicity classes distribution in the soils of Surat Branch

Table 12 . Area (%) under different salinity and sodicity classes in Surat branch command

Classes	Talukas				
	Bardoli	Kamrej	Chorasi	Palsana	Average
Normal	64	69	32	72	63
Saline	2	1	16	–	3
Sodic	29	30	52	28	33
Saline-Sodic	5	–	–	–	1
Total area (ha)	**9927**	**14866**	**5174**	**6033**	**36000**

10.4.2 Remote Sensing Studies

On the satellite image, it was observed that areas having good vegetative cover had no problems of salinity / waterlogging. On the ground, in the non-cropped areas, some fields with different tones are present. Those with greenish / dirty whitish tones were found to indicate sodicity / salinity condition of the soil. This is not revealed visually in the LISS III image unless the problem is severe and manifests over an area of more than 3 ha. However, attempts were made to correlate the salinity / sodicity status expressed in the ESP and the EC_e of the soils with spectral radiance and NDVI values. Out of several bands tried, a slight positive correlation exists between band 2 (green - 0.52- 0.59 μm) and band 3 (red -0.62-0.68 μm) with the ESP (see Fig. 21)

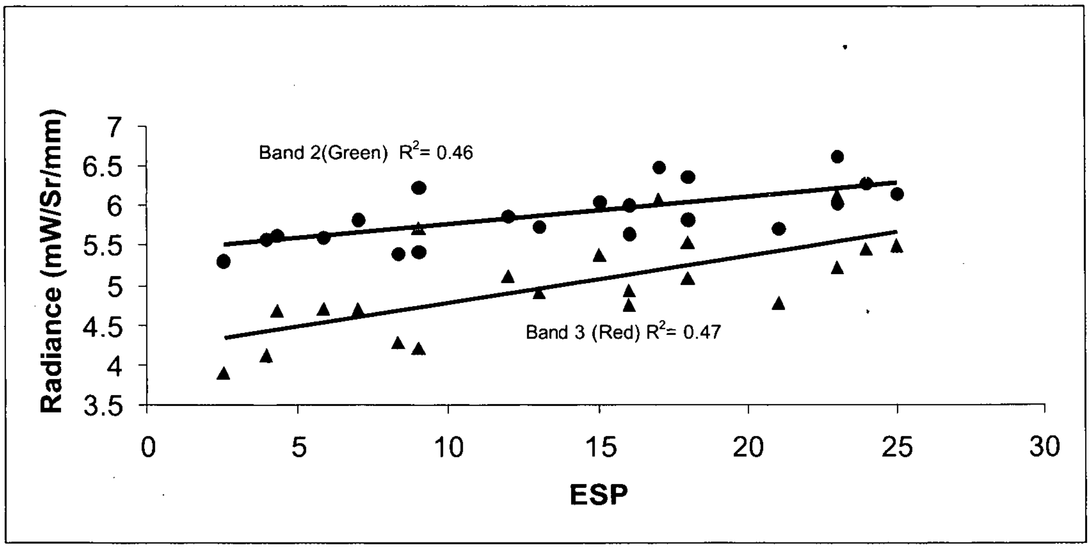


Figure 21. Relationship of ESP with radiance in band 2 and band 3 (n=21)

10.5 Conclusions

Based on the conventional survey, following conclusions are drawn:

- In Surat branch command, the extent of salt-affected soils is about 33 percent with highest coverage in Chorasi taluka (63%).
- Sodicity problem is more acute than salinity
- There is possibility of using these conventional maps to identify the patterns on the digital satellite image of the same area.

Based on the RS study, following conclusions are drawn:

- On the image of April, the salt-affected (saline and sodic) soils in individual fields can be detected through visual interpretation of PAN-LISS III fused images. PAN merged data allows detailed interpretation at field level. Medium or high saline soils appear as dirty white to white, greenish tinge indicate presence of high sodicity levels.
- Use of images such as IRS LISS III (23.8 m spatial resolution) allows identification of salt-affected areas larger than 3 ha by visual interpretation.
- Correlation studies between EC_e and radiance for different bands were not significant.
- A slight positive correlation was observed between ESP and radiance for the green and red bands. High sodic levels in vertic Ustochrepts of South Gujarat could be traced using this method.

10.6 Recommendations

- The encouraging results for application of RS methodology to identify sodicity in heavy textured soils need be field verified intensively, as in the present study only 21 samples have been used.
- Relationship between vegetation indices and EC_e / ESP levels during cropped conditions should be studied.
- To assess the strengths of satellite images, other dates of satellite recordings should be analysed.

11. METHODOLOGY FOR MAPPING WATERLOGGED AND SALINE AREAS IN PART OF HANUMANGARH DISTRICT, RAJASTHAN (RAU)

11.1 Introduction

The Thar Desert occupies almost two-third of the total area in the State of Rajasthan in the north west part of the state. All along, it has been agriculturally unproductive. To make these lands agriculturally productive, Rajasthan Canal project was started in 1958, amd was later renamed as Indira Gandhi Nahar Pariyojana (IGNP) in 1984. One of the major negative manifestation of IGNP is rise in the water table and development of waterlogging. High temperature, presence of excessive water soluble salts in soils (one of the soil characteristics of the Thar desert) and high rate of evapotranspiration have caused the twin problem i.e. secondary salinization and accumulation of salts on top soils or in sub-soil horizons. Particularly, the Tibbi and Rawatsar parts of N-W Rajasthan are facing an acute problem.

11.2 Study Area

Hanumangarh district consists of aeolian, flood plain and desert plain soils with widespread sandy, barren or well cultivated fields, sand dunes of varying heights and well-levelled plains for cultivation. Aeolian soils were formed by the deposition of fine loamy sand by wind and water erosion in the past. These soils are deep with sand to loamy fine sandy soil texture. These are calcareous, draughty and characterised by poor drainage due to underground impervious layer at shallow depths. The problems of waterlogging and salinity are directly related with low uneven topography, seepage from the water bodies and light soil texture.

11.3 Methodology

Hard copies of IRS 1B, LISS II of May 1997 and IRS 1D, LISS of May 2000 were used for identification of the waterlogged and saline soils. The site lies between $74^0$15' - 74^0 45' East longitude and 29^0-29^0 45' N latitude. Base maps pertaining to each image were prepared, using GIS, by indicating permanent settlements, railway lines, road, village tehsils boundaries and irrigation network etc (Fig. 22).

On the basis of the ground truth and the different characteristics of tone and texture, the geo-coded images were visually interpreted. Classes and interpretation keys were developed. The ground characteristics of such features were identified during field checks. The extent of the interpreted units were statistically analysed for final mapping.

According to ground features, physico-chemical analysis data and image characteristics, a base map of the site was prepared for all the layers and polygons in May 1997. It was revised in May 2000 with the help of IRS-ID images for getting better results. The final visual interpretation was scanned and digitised on screen. Fig. 23 shows the flow chart of the methodology. The total area mapped is 3, 31,712 ha.

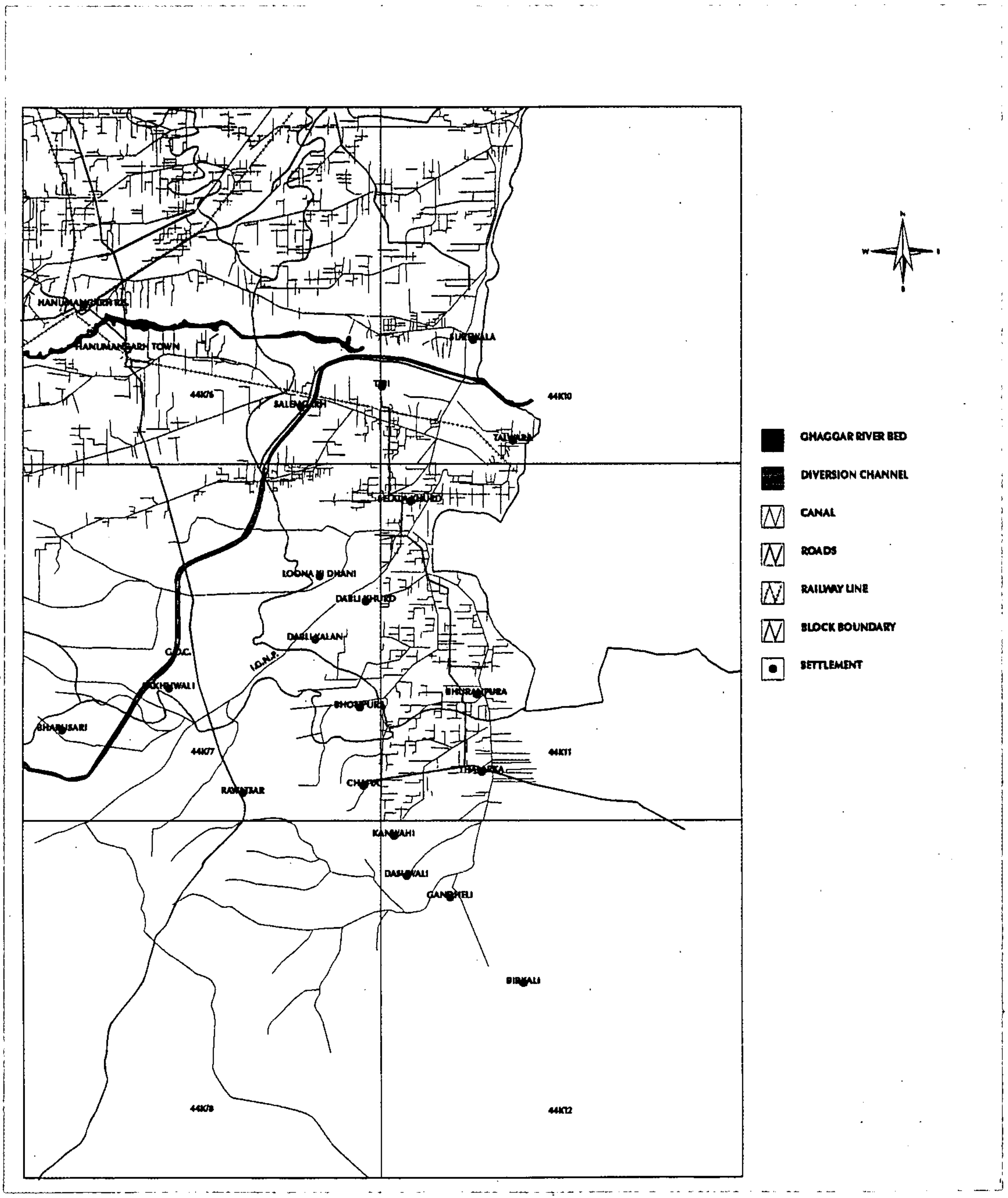


Figure 22. A base map of the part of the Hanumangarh district

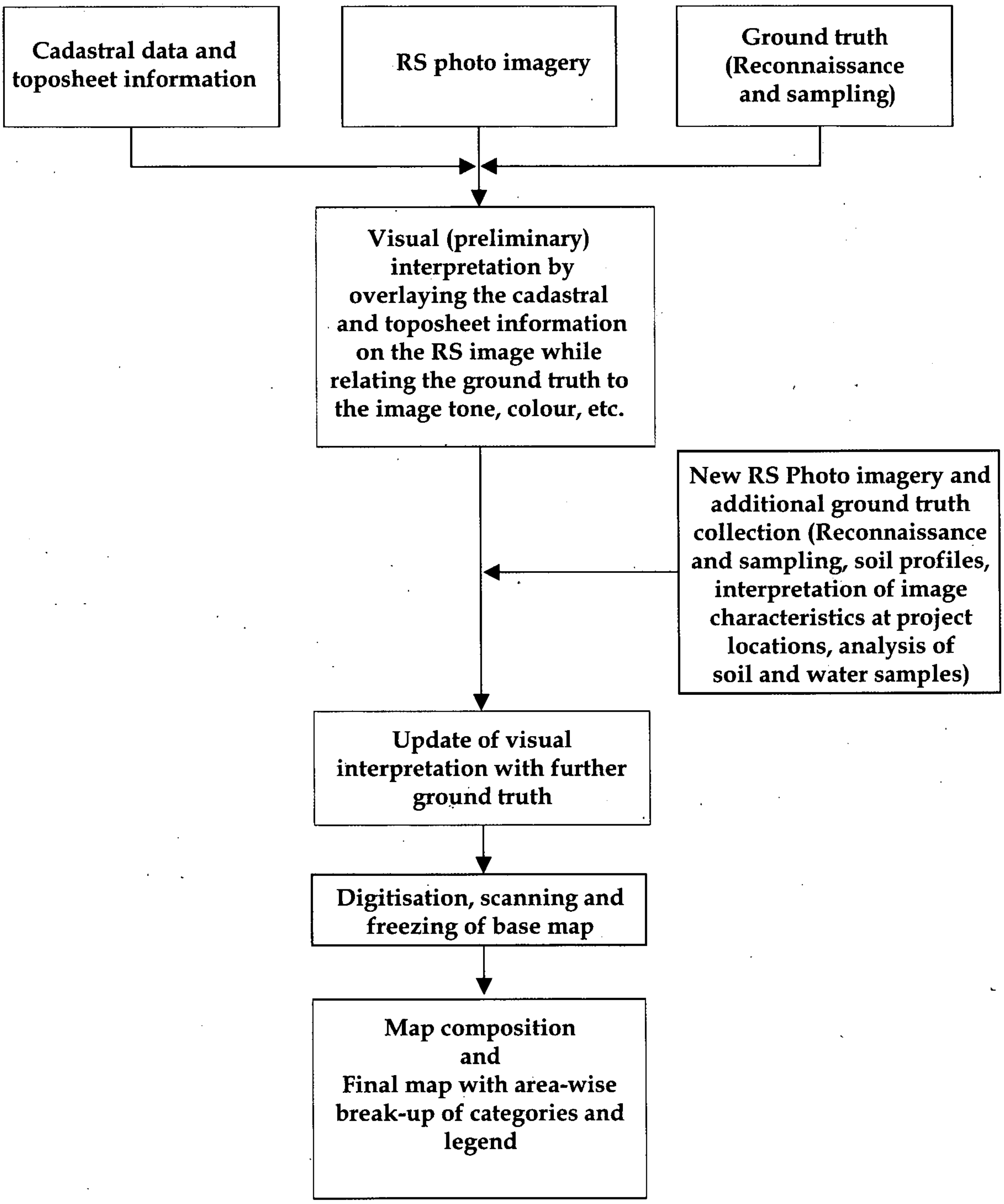


Figure 23. A flow chart of the methodology adopted for mapping

11.4 Results

Based on the field investigations, the laboratory analyses and the image interpretation, six classes could be identified (Table 13) (final map is shown in Fig. 24):

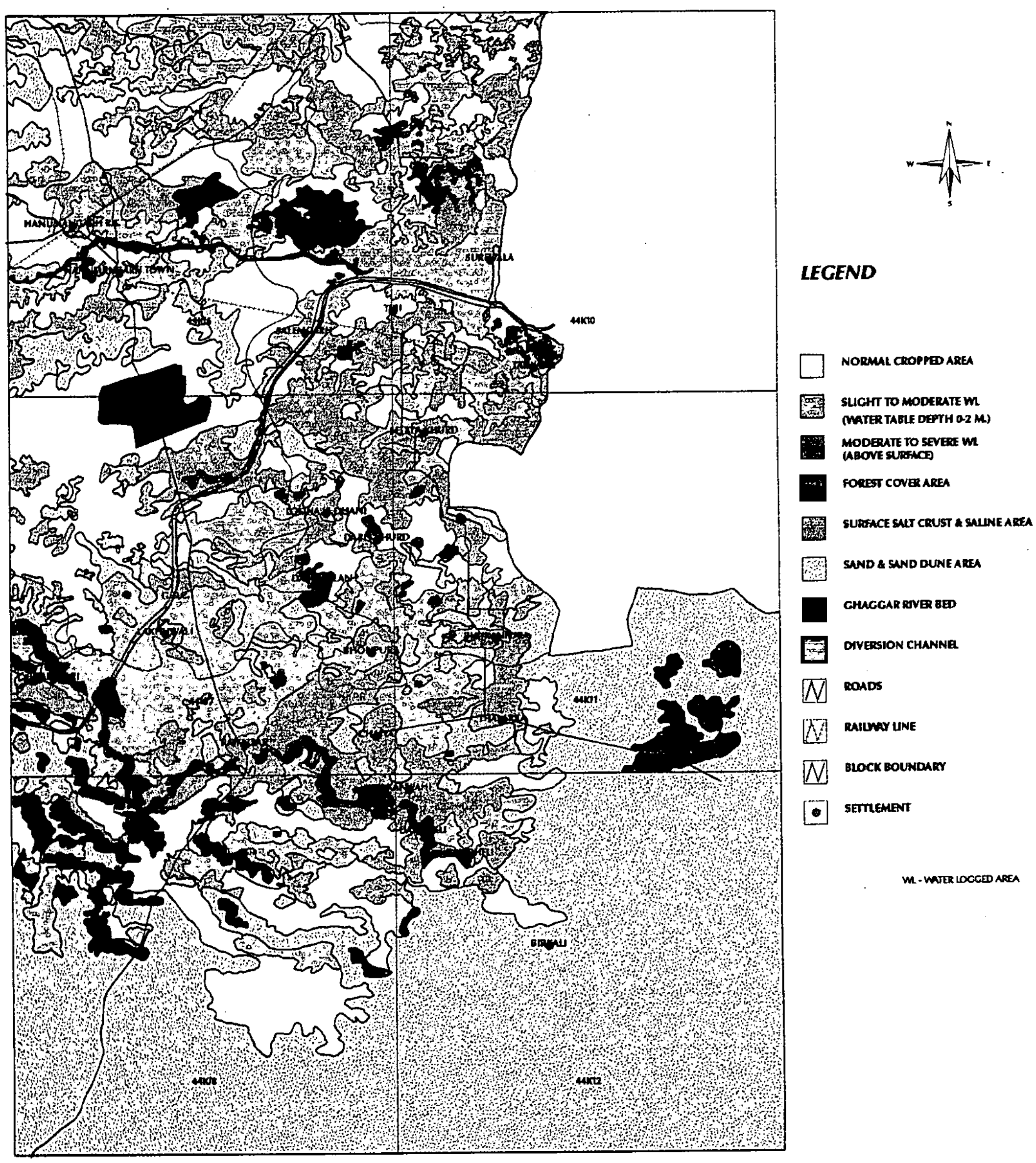


Figure 24. Waterlogged and salt-affected areas in part of the Hanumangarh district

11.5 Conclusions

- The methodology has shown its usefulness in identification of relatively large contiguous area with specific characteristics.
- Areas with salt crusts and with ponded water could easily be identified.
- The study identified some river-like feature in the image that turned out to be a depression in the land scape. This could only be detected through space and eventually led to finding the possibility to dispose of the excess water of the area.

Table 13. Interpretation keys and areal extent (%) of classified features

Serial No.	Features	Image characteristics on false colour composite imagery	Map symbol	Area extent (%)
1.	Normal cropped area	Bright red, red dark pink or pink depending on crop condition (EC_e 2 to 8 dSm^{-1})	Yellow	22
2.	Slight to moderate waterlogging problem	Light blue to dark blue with red patches (EC_e 8 to 16 dSm^{-1})	Light blue	16
3.	Moderate to severe waterlogging problem	Dark blue (darkness depending on thickness of water column on soil surface and concentration of dissolved salts) (EC_e 16 to 32 dSm^{-1})	Violet	3
4.	Forest cover	Dirty red and pink (dirty red for tree canopy and pink for weeds etc.)	Dark green	4
5.	Surface salt crust and saline area	Dull to bright white surrounded by light blue tone (Dry salt encrustation is bright white while wet encrustation is dull white) EC_e 32 to >200 dSm^{-1})	Light grey	15
6.	Sand and sand dune area	Light yellowish tone	White	40

11.6 Recommendations

- Digital analyses and periodic monitoring of the area using satellite imagery should be explored.

12. EXTENT AND CHARACTERISTICS OF SALT-AFFECTED SOILS IN THE SHORAPUR TALUKA, UPPER KRISHNA PROJECT, KARNATAKA (CSSRI/UASD)

12.1 Introduction

The Upper Krishna Project located in Karnataka aims at providing canal irrigation to the chronically drought prone areas of Gulbarga, Bijapur and Raichur districts. The project on its full development will irrigate 8.43 lakh hectares (4.25 lakh ha in stage I and 4.18 lakh hectares in stage II). Since its initiation in 1982 a potential of 2 lakh ha has been developed. The pre-irrigation survey indicated that 27.6 thousand ha was salt-affected.

12.2 Study Area

Shorapur Taluka was the first to receive irrigation water from the Krishna left bank canal. Located between 76° 15′ to 76° 56′ E longitudes and 16° 10′ to 16° 35′ N latitudes and extending over an area of 1,66,951 ha, Shorapur is extensively affected by the problems of salt-affected soils and secondary salinization. In Phase - I of the project (Shorapur Taluka), the canal provides irrigation through a series of distributaries. Seepage water and over-irrigation have led to extensive waterlogging and considerable decline in the agricultural productivity of the lands. Agriculture has been considerably affected due to the adoption of a changed cropping pattern by the farmers. Increasing salinity and waterlogging are taking their toll on the hitherto dry farming region. Earmarked for a detailed inventory of salt-affected soils, the taluka has all the representative geological and soil types found elsewhere in the project area and is an indicator of the advantages and disadvantages of introducing an irrigation system.

12.2.1 Geology/Geomorphology

The geology in Shorapur taluka is influenced greatly by the formation of the Deccan trap. The formations consist of rocks of Dharwar system, Peninsular complex, rocks of Bhima series and Basalts. Exfoliating basalts overlay limestones that in turn lie over shales. The basalts, granite - gneiss and schists are the parent materials of the red and black soils and a major source of salts in the soils. Red soils mix with black soils range from being coarse textured on the upper slopes to fine textured agricultural lands at lower elevations. These soils are also salt-affected. The geomorphology of the region consists of undulating uplands and hill slopes, gently undulating midlands and broad and narrow valleys between the hills.

12.2.2 Cropping Pattern

The major crops grown in Shorapur Taluka are groundnut, green gram and pearl millet and to some extent sorghum during *kharif* and sorghum, safflower and some wheat during *rabi*. Red gram is the main bi-seasonal crop. After the advent of irrigation, the cropping pattern changed to some extent. The main crops grown during *kharif* were green gram, hybrid pearl millet, groundnut and sunflower. During *rabi* groundnut, sunflower and sorghum were major crops. There has been a sharp drop in area under sunflower since 1999. On the other hand, the area under cash crops such as cotton and chilli, which are considered bi-seasonal, has been increasing in the last five years. The response to shift in high value crops has been rather slow. In waterlogged and saline soils farmers also grow paddy, which is banned in UKP.

12.3 Methodology

For the study, Survey of India topographic sheets (56 D/10,11,14 and 15), IRS-1B LISS-II photo-image (on 1:50,000 scale) for the period March 1997 and digital IRS-LISS III data have been used. Intensive ground truth in the form of profile and auger bore studies and related information on topography, geomorphology, land use and other land cover parameters were collected. A final visual interpretation was done of all hardcopies after the evaluation of the field data (see flow chart in Fig. 25).

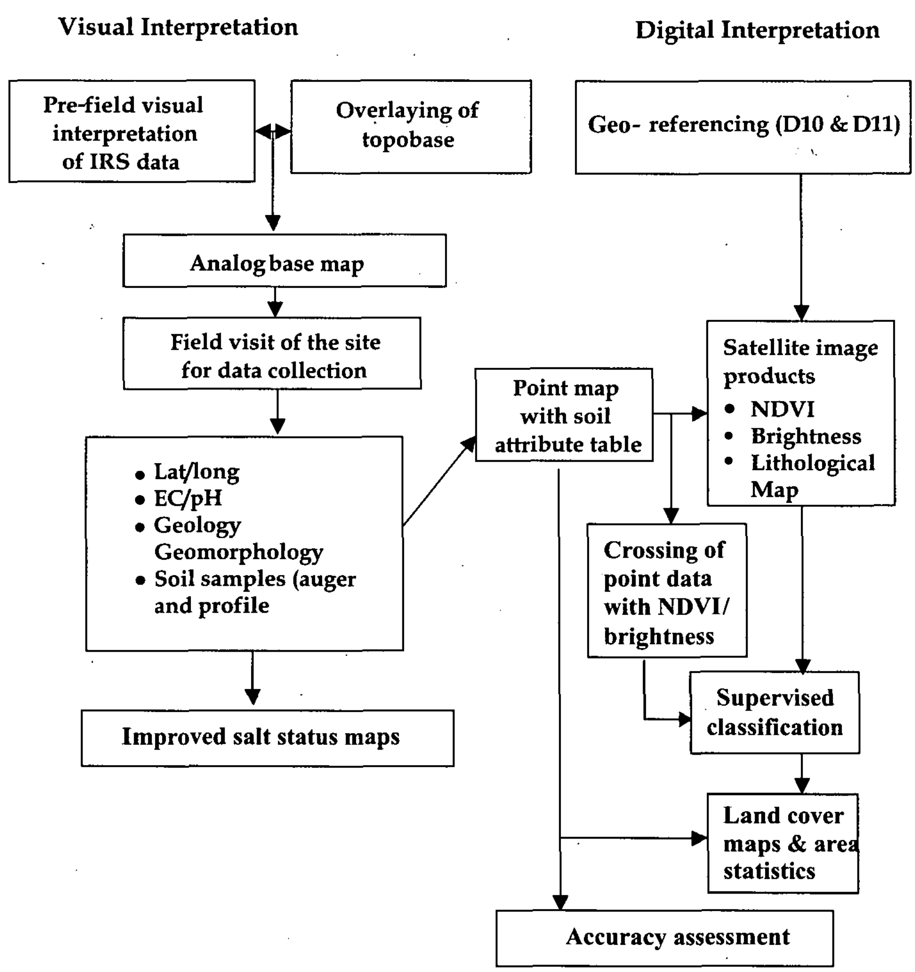


Figure 25. A flow chart of the methodology

For D-10 and D-11 toposheets, point maps with attribute tables were created indicating the location and content of the field observations. On the corresponding 1999 images a digital analysis has been done. The point observations were grouped in the following classes saline, sodic, saline-sodic and normal. For these points brightness and NDVI values were extracted from the image. The values for each class were evaluated.

12.4 Results

12.4.1 Pre-field Interpretation

Satellite data of IRS LISS II corresponding to topographical sheet no 56D/7, D/10, D/11, D/14, D/15 were interpreted visually before proceeding into the field. Salt-affected soils were delineated based on tone, colour, size etc. The topobase was then overlayed on the interpreted image to prepare a base map for conducting the survey.

12.4.2 Ground Survey

In the command area, the major cause of soil degradation has been irrigation. Observations indicate that waterlogging and salinity are a direct result of over irrigation and seepage from the canal. A physiographic and geomorphic analysis of ground and visual data testify to the presence of salts in specific landforms and is related mainly to the piedmont area, the sideslopes, the dissected valleys and the flood plain of the river Krishna. We found that salinization occurs especially in the valleys and on lower slopes. However saline-sodic soils were found to occur even on side slopes of the low granatic hills covered with red soils. Uplands with red soils overlying black soils also have saline-sodic soils while the black soils of the valleys are saline in nature (Table 14). The salts in the soil have originated from the weathering of minerals such as feldspars, which abound in granatic rocks and basalts. Even soils occurring in close proximity of red soils also show accumulation of salts due to their physiographic position.

Soil profiles and auger samples were collected from Kowdimatti, Talwargera, Kakera, Manghial, Shettikera, Hunsagi and other sites in Shorapur and the areas bordering Shahpur Taluka in traverses using the base maps made from toposheets and collated through visual interpretation. The soil samples were processed and analysed in the laboratory for their physico-chemical characteristics and classified according to the Soil Taxonomy. The pH of the soil samples ranged from 8.2 to 10.5 and was determined in the 1:5 soil-water extract. The EC (1:5) varied, ranging from 1.2 to 33.5 dSm^{-1}. The average pH was 8.9 with a standard deviation of 0.69 and the average EC (1:5) was 4.2 dSm^{-1} with a standard deviation of 6.4. A number of pedons were studied for their morphological features and laboratory characterization.

All the soils were calcareous and were characterized by high EC and ESP. These soils can, therefore, be called saline-sodic. The EC in all cases shows a sharp decrease with depth suggesting upward movement of salts. In all the pedons, drainage was found impeded as evidenced by low chromas in the lower-solum. Free water table was present in Talwargera, Devikeri and Devapur-J.

Table 14. Physiography and soils in Shorapur Taluka

Physiographic unit	Soils	Nature of salt-affected soils
Hills/rock outcrop	–	–
Plateau	–	–
Sideslopes/ Piedmont	Mostly red soils	Saline-sodic
Narrow valleys	Black soils	Saline
Broad valleys	Black soils	Saline
Uplands	Red over black & black soils	Saline-sodic
Level lands	Black soils	Saline
Lowlands	Black soils	Saline and saline-sodic, often waterlogged

12.4.3 Visual Interpretation

Visual interpretation keys were prepared taking into account image characteristics of the landforms in the region. Salt-affected soils appeared white, blue white, green white and white mottled with red. Salt-affected areas in red soils had a yellow-white appearance on the images. Rock outcrops, sand and calcretes on the imagery had characteristics similar to salt-affected soils therefore intense ground truth was carried out to correctly identify and demarcate these features and classify them separately from salt-affected soils on the imagery. The base map was updated, corrected and redrawn to evaluate the area under each category identified.

Based on image characteristics salt-affected soils were designated with classes based on severity as moderately affected, severely to moderately affected and severely affected in terms of area affected as under <40%, 40-75% and >75% affected and the brightness on the imagery (Table 15). The total area covered and surveyed was approximately 1.2 lakh ha. Fig. 26 shows a small part of the interpretation result.

Table 15. Image characteristics and area under salt-affected soils in Shorapur Taluka

Image characteristics	Class	Area (ha)	Total salt-affected area (%)
White	Severely (>75%)	7035	33
Blue white/ Green white	Severely to Moderately (40-75%)	8339	40
Blue/ green white Mottled with red	Moderately (<40%)	5722	27

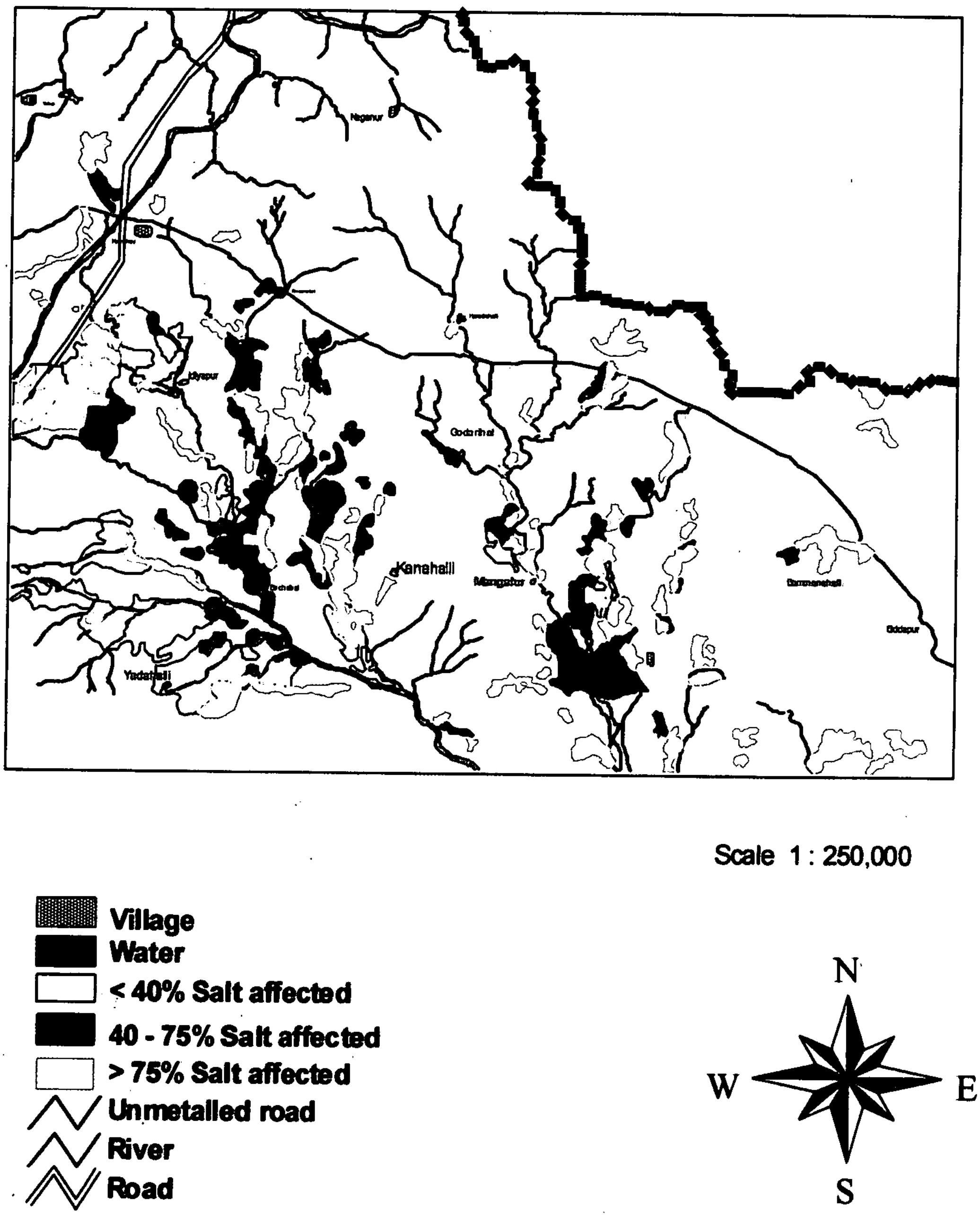


Figure 26. A part of the study area showing salt-affected soils based on visual interpretation

12.4.4 Digital Image Processing and Analysis

The digital images corresponding to D-10 and D-11 (March 1999) were geo-referenced. Subsequently the NDVI and the brightness values were examined. The brightness values were calculated as follows:

Brightness index = $\sqrt{}$ (DN in red band)^2 $\ast$ (DN for near infrared)^2

These values were used to establish corelation between brightness index and $EC_{1:5}$.

Details of lithology were transferred on to the digital format. Point data collected in the field along with their latitude and longitude were also transferred to digital images. The point $EC_{1:5}$ / pH data (60 points) of salt-affected soils are transferred on the digital data in accordance with their appearance on the images and associated land cover classes. A supervised classification was carried out and land cover maps were prepared (Fig. 27). For only a limited number of points and classes a rough accuracy assessment could be carried out. The supervised classification results were compared with the point data. It was possible to identify the severely affected saline-sodic soils

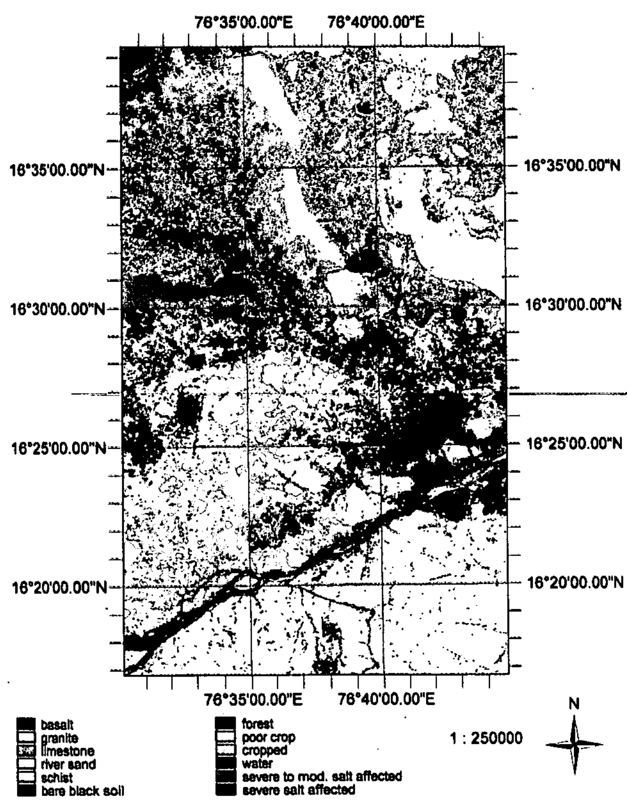


Figure 27. A land cover map prepared using supervised classification

with the greatest accuracy of 85 percent. The other cover classes were not significantly accurately classified.

There was a wide variation in EC_e values observed in the field and therefore, relationships between EC_e values with mapping classes could not be found. The highest EC value did not relate to the highest DN value and vice versa, essential to form mapping criteria. The digital analysis also shows a much larger area affected by salinity through the digital study of IRS LISS III data than was identified on the LISS II hard copies using visual interpretation.

In effect, salt efflorescence of encrusted barren lands has been correctly detected on the 1999 images, however it has not been possible to detect sodic soil from saline soils and to identify a difference between 1 and 20 dSm^{-1} in either image/digital data. Besides, classes are very hard to define because the soils may not be just either saline or sodic but a combination of both and their appearance on the images was greatly influenced by the presence of moisture, parent materials and other ground conditions. Logically $EC_{1:5}$ should relate to the brightness index for mapping and classification. The brightest soils on the images did not have the highest EC (Fig. 28).

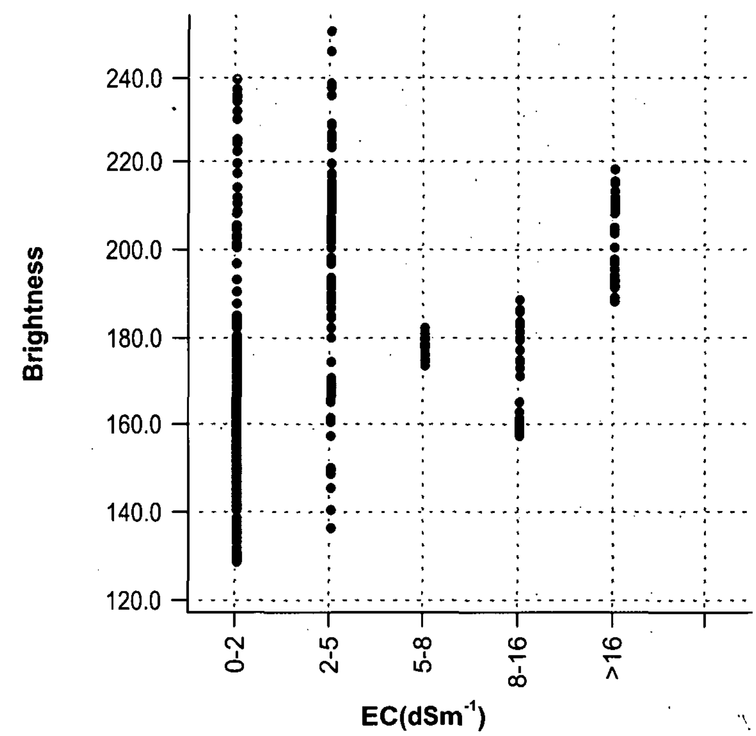


Figure 28. Brightness-EC (1 : 5) relationship for observed locations

Analysis showed that wherever the pH was high, the patches appeared bright. Despite high salinity, if pH was less than 8.5, the patches appeared in blue. The sites with highest EC did not appear as white as those with high pH alone.

12.5 Conclusions

- Using ground data it was possible to identify the physiographic locations of salt-affected soils on sideslopes/narrow valleys, broad valleys, uplands, level lands and lowlands under waterlogging and relate it to the nature of salt-affected soils. Profile studies indicate that the salt-affected soils of Shorapur Taluka, are mainly saline-sodic in nature.
- Through visual interpretation, salt-affected soils could be identified and classified in 3 classes namely 'moderate' (<40% affected), 'severe to moderate' (40-75% affected) and 'severe' (>75% affected). The total salt-affected area in Phase-I was 21,096 ha of which severely salt-affected lands that appear white on the imagery cover 33% of the area, severely to moderately affected that are blue white/green white on the imagery are 40%, and moderately affected soils on the images appear blue/green white mottled with red and are 27% of the total salt-affected area respectively.
- It was found that EC and pH do not relate to the reflectance patterns on the images .i.e. the soils with the highest reflectance that appear as brightest soils on the images do not have the highest EC. EC is extremely variable in the field and cannot be fitted into any mapping criterion.
- Using the same data sets as used for the classification, it was possible to identify the severely affected saline-sodic soils with the greatest accuracy of 85 percent. The other classes identified were not significantly accurate or were not available in the point data set.
- The areas affected by salt could be identified and demarcated on the images but it has not been possible to map and relate conjugated images, and to directly incorporate laboratory analytical data in any form into mapping criterion.
- The inability to map EC from 1-20 dSm^{-1} and problem of coping with the spatial variability of salinity and producing results in digital format that are stable over large geographical areas were encountered.

12.6 Recommendations

- The emphasis in all salinity mapping will now have to shift to a better understanding of crop indices and crop stress under salt-affected conditions. Also the application of hyperspectral and recently launched satellites (such as ASTER) for the identification of salt-affected soils has to be investigated in detail.
- For the registration of field observations the use of GPS is highly recommended.

13. CONCLUSIONS AND FUTURE DIRECTION OF WORK

Under the Indo-Dutch Network Project Research Result #1 *"A methodology for identification of waterlogging and soil salinity by remote sensing"*, 8 studies using visual and digital analysis were taken up, covering broadly three soil groups i.e. Indo-Gangetic alluvial plains (Western Yamuna Canal, WYC), Sandy arid irrigated land (Indira Gandhi Nahar Pariyojna, IGNP) and heavy clay or black soils (Ukai Kakrapar Project, UKP; Upper Krishna Project, UKP-I; Nagarjuna Sagar Project, NSP). In these studies multi-satellite, multi-spectral and multi-temporal remote sensing data have been used. The extent of the area under these studies were ranging from 5,000 to 3,50,000 ha.

13.1 Conclusions

The conclusions have been drawn for three broad soil groups. Two methodologies, one based on visual and another for digital interpretation are shown in Fig. 29 and Fig. 30.

13.1.1 Alluvial Soils of the Indo-Gangetic Plains

- Two categories of waterlogging i.e. ponding water and waterlogged soils were successfully identified.
- Surface salt-encrustation was found as a good indicator for salinity identification during dry periods.
- Saline soils with EC_e > 10 dSm^{-1} could be identified with an accuracy level of 85% and saline soils could be differentiated from sodic soils.
- A relationship between albedo and NDVI (*rabi* season) was found promising in detecting depression of biomass due to waterlogging and salinity stress. However, this requires further investigation for other soil groups as well.

13.1.2 Black Soils

- Surface ponded area could be mapped easily.
- Severely sodic (ESP > 20; pH > 9.0) and saline-sodic soils (EC_e>10; pH > 8.5) could be identified with an accuracy of 80%.

13.1.3 Sandy Soils

- In sandy soils, two categories of waterlogging i.e. surface ponded area and waterlogged areas (depth to water table<1.5 m) were identified.
- Moderately and highly saline soils could be identified. However, use of thermal band seems promising for differentiation between saline and sandy soils, which exhibits similar reflectance. This observation needs further investigation.

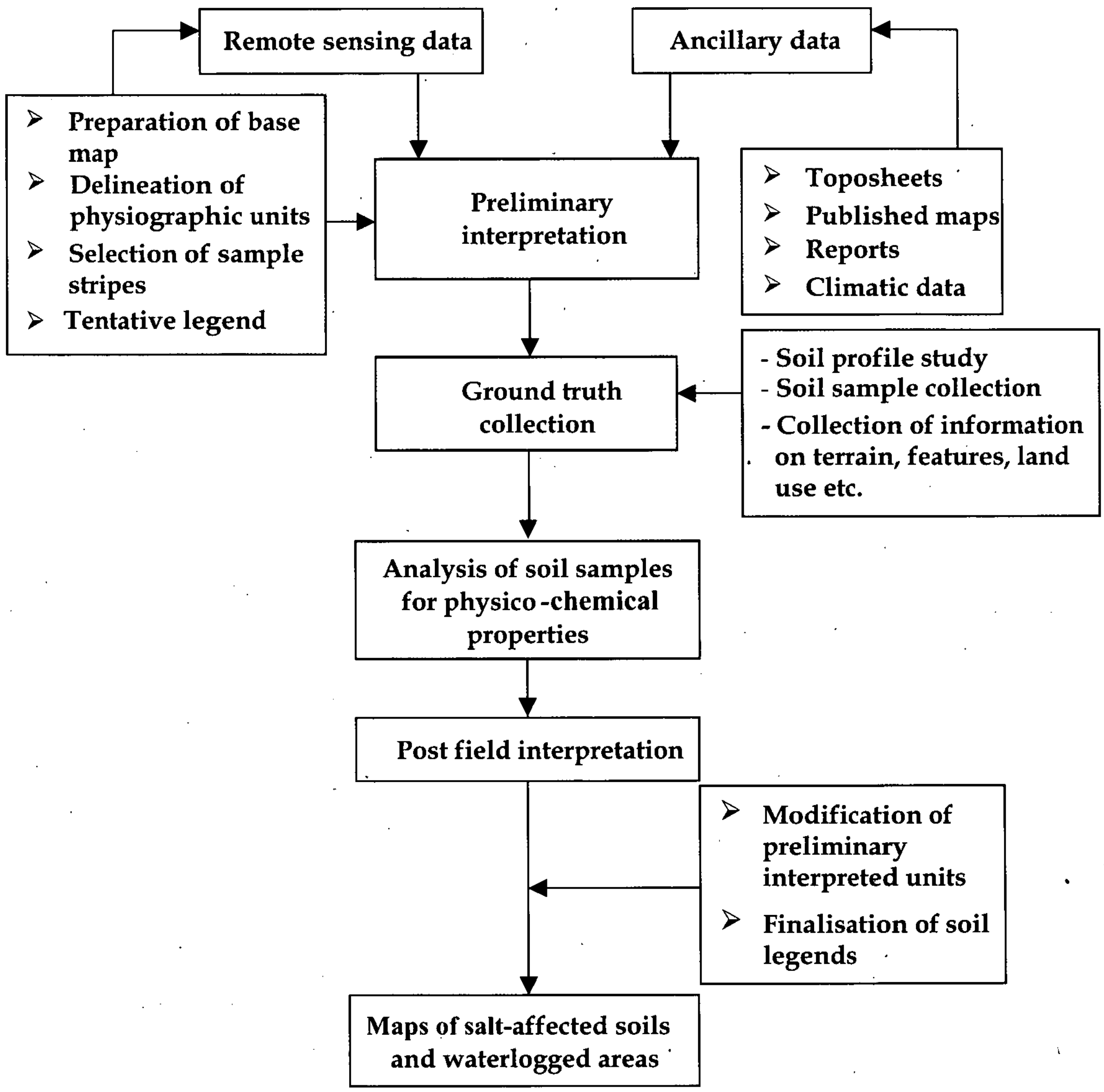


Figure 29. A flow chart of the methodology for mapping salt-affected and waterlogged areas using visual interpretation

13.1.4 General

- Remote sensing data of November and February/March were found optimal for mapping salinity.
- Minimum mapping area is 2 ha at 1:50,000 scale due to cartographic limitation.

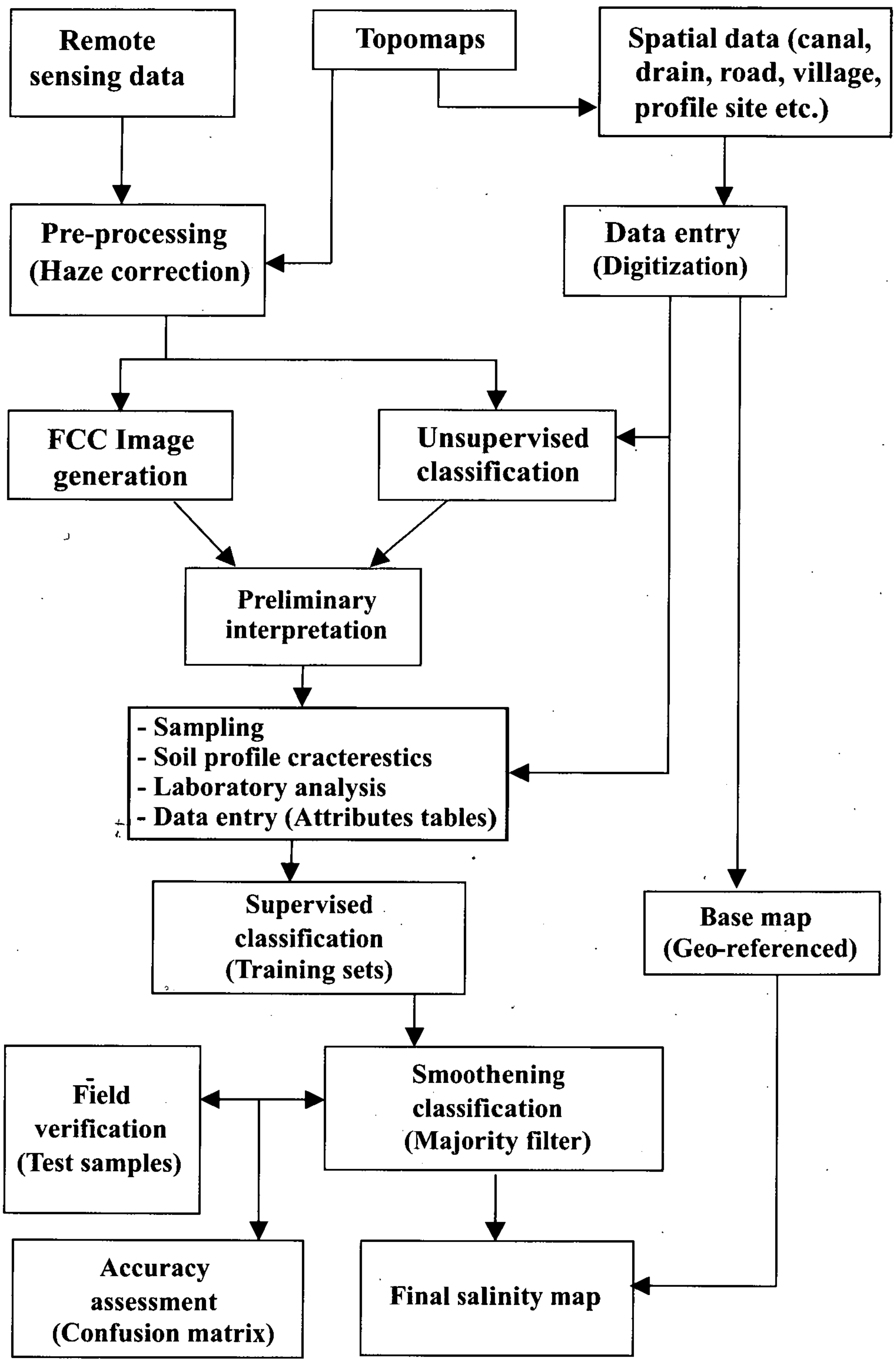


Figure 30. A flow chart for salinity mapping using digital image analysis and GIS

13.2 Ground Truth Procedure

Stratified sampling approach is recommended. In this approach, observation points or areas are selected based on a preliminary interpretation of the satellite images. For each class, a limited number of locations are checked. The field observations have to be well distributed over the image and have to capture the heterogeneity (Within and between classes) of the area. Two independent field data sets are created. One dataset is used to derive the spectral classes for the supervised classification. The other set is used for the accuracy assessment. The field observations can be points, however, normally these observations are fields or parts of fields. A minimum of 100 pixles per class is required for a supervised classification. After the field visit and a classification, the interpreter can decide to merge classes or create additional classes. The interpreter can also decide to do a two-tier approach. Those classes that can be separated spectrally are classified using a supervised classification procedure. Other classes might be separated based on a visual interpretation. In the latter case, digitising directly from the screen is a good working method. Finally both interpretations are merged. Always a confusion matrix has to be made to assess the accuracy of all classes combined and each class separately.

13.3 Limitations

- Current sensors enable to identify and map surface ponded areas but have limitations to identify the subsurface waterlogging directly. Nevertheless, classification of areas having a 0–1.5 m water depth could be done based on actual point observation of groundwater and in turn extrapolation to the whole of the study area.
- Current sensors have a limitation of identifying lower level salinity directly, due to broad bandwidth.

13.4 Future Direction of Work

A good start has been made at the Centres with the work on remote sensing. Several methodologies have been tried and applied. In general, it is expected that further analysis using digital classification will improve on the classification accuracy achieved so far.

- The physiographic mapping of the study areas, groundwater contours and drainage pattern along with RS should be tried in future for improving the classification results.
- Forthcoming sensors with narrow bandwidths should be applied for improved identification of waterlogged and salt-affected soils.
- In order to better understand the dynamics of waterlogging and salinization, images should be periodically analysed for well-monitored areas.

13.5 Lessons Learnt

- The objective to aim at the development of just one methodology proved unrealistic. The methodology within a broad framework clearly depends upon the size of the study area, field data in hand, resources and the level of experience with remote sensing techniques.

- It was not possible to arrive at a common legend. Some studies utilized the presently used legends but others based on ground truth and some spectral characteristics also presented 2-3 severity classes. As such different studies have different legends.
- The commonly used grid-wise collection of ground truth for waterlogging as well as salinity, did not lead to readily applicable ground truth for classification purposes. Measurement at discrete observation points was also unsatisfactory since an insignificant low spatial correlation between the salinity developed at a particular location to the nearby location was observed.
- In most studies many soil parameters to various depths (up to 120 cm) were collected. As far as interpretation and digital classification is concerned, it did not help to improve the quality of interpretation / classification.
- One session of field work is not enough. Interpretation and classification need to be rechecked in the field. However, efforts need to be made to minimise the time-span between the date of the images and final field visit to improve the relaibility of the accuracy assessment and final interpretation.
- For accurate positioning of the ground observations and measurements on the images and toposheets, use of GPS is of paramount importance.

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ABBREVIATIONS

AICRP	All India Co-ordinated Research Project
ANGRAU	Acharya N.G. Ranga Agricultural University
AP	Andhra Pradesh
CADA	Command Area Development Authority
CSSRI	Central Soil Salinity Research Institute
FCC	False Colour Composites
GAU	Gujarat Agricultural University
GIS	Geographical Information System
GPS	Global Positioning System
ICAR	Indian Council of Agricultural Research
IDNP	Indo-Dutch Network Project
IGNP	Indira Gandhi Nahar Pariyojana (Irrigation project)
IIRS	Indian Institute of Remote Sensing
ILRI	International Institute for Land Reclamation and Improvement
ISRO	Indian Space Research Organisation
MTR	Mid Term Review
NRSA	National Remote Sensing Agency
NSP	Nagarjuna Sagar Project
RAU	Rajasthan Agricultural University
RESECO	Remote Sensing and Communication Centre
RS	Remote Sensing
RSAC	Remote Sensing Application Centre
SRSA	State Remote Sensing Agency
SRS	Satellite Remote Sensing
UASD	University of Agriculture Sciences, Dharwad
UKP	Ukai-Kakrapar Project (Gujarat)
UKP	Upper Krishna Project (Karnataka)
UP	Uttar Pradesh