SR-1/2002-2003

APPLICATION OF REMOTE SENSING AND GIS IN WATERLOGGING STUDIES

NATIONAL INSTITUTE OF HYDROLOGY

ROORKEE

2002-2003

EXECUTIVE SUMMARY

Waterlogging is one of the major land degradation processes that restrict the economic and efficient utilisation of soil and land resources in command areas. Since Independence, various irrigation schemes, for providing water for agriculture and drinking have been taken up by central and state agencies in India. In these schemes very little effort have been made for proper drainage. Due to obstruction of natural drainage by way of construction of roads, railways, aerodrome, various structures etc., causes the ponding of monsoon runoff on the upstream of the structures. This has happened at many places, which in turn has disturbed the surface hydrology of the areas. Subsurface waterlogging occurs due to rise in water table and water remaining in the root zone, which adversely affects the crops because of inadequate ground water drainage.

In veiw of this situation it is becoming imperative not only to monitor the problem over time and space but also to look at it in totality for its prevention and control. Waterlogging information had been generated through conventional surveys using cadastral maps and / topographical sheets - a tedious, time-consuming and impractical process, especially in rugged or inaccessible terrain. The conventional means are however, not only difficult and time consuming but also laborious due to vagaries of the weather. Remote sensing is one of the key tools in monitoring local, regional and global environment issues. The development of aerial photograph interpretation and the subsequent advances in satellite remote sensing and image processing techniques have enabled the detection, mapping and monitoring of waterlogged areas in a timely and cost-effective manner. Advantages of the information acquired by satellite remote sensing are of synoptic coverage, repetitive and the easiness to compare the data before, during and after monsoons.

This report attempts to present the information about the extent of waterlogging , conventional methodology in brief and application of remote sensing technique in detail.

CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Waterlogging is understood as stagnation of water on the land surface, but considering the production process it is described as a situation of adverse air water proportion in soil system with respect to a crop along with its acceptable level of productivity response. Waterlogging can be caused by excess soil moisture due to periodic flooding, overflow by runoff, over-irrigation, seepage, artesian water and impeded sub-surface drainage. These conditions affect the growth and yield of crops and in course of time, such land turns saline or alkaline and ultimately becomes unfit for cultivation. Under irrigated conditions, farmers supply uncontrolled irrigation water, thereby, the water in excess to field capacity is added to the ground water table. With subsequent irrigation done injudiciously, the excess water induces the raising of ground water table. Sometimes waterlogging in the low lying areas is also observed which is due to seepage from irrigated uplands and seepage from canal water. Inadequate water management practices further aggravates the situation, which culminates into waterlogging and increase in soil salinity. Also the obstruction of natural drainage by way of construction of roads, railways, canals and various other structures causes the ponding of monsoon runoff on the upstream of the structures. Intensive irrigation without adequate drainage contributes substantially to a rising ground water table. (MOWR, 1996; Navalawala, 2000)

A special committee of Central Board of Irrigation and Power (CBIP) suggested the following basis for defining waterlogging: (MOWR, 1996)

" A area is said to be waterlogged when the water table rises to an extent that soil pores in the root zone of a crop becomes saturated, resulting in restriction of the normal circulation of air, decline in the level of oxygen and increase in the level of carbon dioxide. The water table, which is considered harmful, would depend upon the type of crop, type of soil and the quality of water. The actual depth of water table, when it starts affecting the yield of the crop adversely, may vary over a wide range from zero for rice to about 1.5 meters for other crops"

1.2 Waterlogged area

There are no universally accepted criteria to declare a land waterlogged. Different states have followed different norms (MOWR, 1991). Attempts have been made to estimate the waterlogged area by different agencies at different points of time. The Irrigation Commission

(1972) estimated that an area of 6.00 M ha. was affected by waterlogging. The Ministry of Agriculture (1984-85) reported that an area of 8.53 Mha was suffering from waterlogging. The Working Group (1991) set up to identify the areas suffering from waterlogging and soil salinity estimated it at 2.46 Mha. The CWC estimated 1.61 Mha of land affected by waterlogging mostly due to rise in water table.

The working group on Problem Identification in Irrigated Areas of Ministry of Water Resources MOWR (1991) adopted the following norms for identification of the waterlogged areas:

i) Waterlogged areas : Watertable within 2 m of land surface

ii) Potential area for waterlogging: Watertable between 2-3 m of land surface

iii) Safe area : Water table below 3 m of land surface

Tanwar (1986) had earlier suggested an area with water table within 2-3 m as critical area. 3-5 m as protected area and more than 5 m as safe area.

There are different approaches to express the water table depth below soil surface i.e.

i) Depth of water table pre-monsoon (April/May),

ii) Depth of water table post-monsoon (Oct/Nov), and

iii) Average water table depth over a season or year

iv) Sum of excess water days (SEW number) above a particular depth of water table.

Whereas all these approaches are important and of interest for one or other purpose, the most practical approach appears to be defining waterlogged areas based on depth of water table pre-monsoon and or post-monsoon. A low water table at pre-monsoon is essential to avoid salinity build up in the root zone and successful production of kharif crops (Summer crops). Equally important is an optimal low water table during post-monsoon, keeping in view timely plantation and successful production of Rabi crops (Winter crops).

Keeping in view these considerations, the following norms suggested for the classification of different categories of waterlogged areas. (Ram S, 1996):

Waterlogged area:

Water table within 2 m of soil surface during pre-monsoon (April-May).

And/or

Water table within 1m of soil surface during post-monsoon (Oct-Nov.)

Critical area for waterlogging

Water table between 2-3m of soil surface during pre-monsoon

and/or

Watertable between 1-2m of soil surface during post-monsoon

Potential areas for waterlogging:

Watrertable between 3-5m of soil surface during pre-monsoon

and/or

Water table between 2-3 m of soil surface during post-monsoon.

Safe Area

Water table more than 5 m of soil surface during pre-monsoon

And/or

Water table more than 3m of soil surface during post-monsoon.

1.3 Types of waterlogging

Based on the presence of water on the land surface or near surface, waterlogging has been classified into two categories

(i) Surface waterlogging

(ii) Subsurface waterlogging

Surface Waterlogging:

Surface flooding occurs due to water stagnation on the land surface as a result of inadequate surface drainage. This is a very common problem during pre-monsoon season. Degree of stagnation and period for which water stagnates on the land surface, depend upon the developmental activities like land leveling, sand mining, construction of canal network, roads and railways, which obstruct the natural drainage.

Subsurface Waterlogging:

Sub-surface waterlogging occurs due to rise in water table and water remaining in the root zone, which adversely affects the crops because of inadequate sub-surface drainage. This is caused due to inter basin transfer of water to irrigated lands in arid and semi-arid regions, which interferes with the normal hydrological cycle. It creates imbalance between the recharge to ground water and the sub-surface discharge through natural flow.

1.4 Causes of Waterlogging

Waterlogging is caused by the interaction of a number of factors such as lack of provision of adequate drainage in irrigated areas, seepage of water from canals and distributaries, siltation of dams, lack of land development before application of irrigation water, adoption of unsuitable cropping pattern, poor water use efficiencies etc. Figure-1 sums up the reasons for waterlogging in irrigation commands (Bowonder and Ravi, 1987).

Causes of waterlogging are summarised below (Bhatt 1994):

Water is very crucial for successful rising of crops. Crops must be supplied with water in the required quantities for their optimum growth, particularly at the critical stages of crop growth. Irrigation provides crops and plants with water needed for their growth. However, development of irrigation potential with canals may also have negative environmental impact. Water percolates down into the ground by seepage from the conveyance system and during application of irrigation water in the fields. This disturbs the pre-existing natural ground water balance, especially at locations where natural drainage is inadequate due to topographic, soil or other reasons. Accumulation of water causes the rise in ground water table. In the absence of sufficient withdrawal, the rise of groundwater table continues. When water table reaches the root zone of the crops, it causes waterlogging, rendering the land unsuitable for further agriculture use. The general causes of waterlogging are given as follow:

Inadequate surface drainage

Waterlogging is caused due to inadequacy of drainage. This may arise due to clogging of the natural drains by silts and aquatic vegetation. The prolonged flooding or inundation of land results in heavy percolation of water into the ground and rise in water table.

Seepage from canals

When a canal system with unlined channels is introduced, water percolates from the channels and is added to ground water reservoir. This causes a general rise in the water table in the region. The seepage from the canals, rivers and reservoirs also cause waterlogging. The seepage in the canal may be maximum at its 30- 40% of the total amount of water diverted at the head works, when the main canal, distributaries and field channels are unlined.

Obstruction and Obliteration of natural drainage

The obstruction of natural drainage due to the construction of irrigation channel, road or rail embankments inundate the area and render it waterlogged. Sometime cultivators plough up and obliterate an existing natural drainage also, which results in stoppage of flow of storm water resulting in flooding and waterlogging.

Obstruction of sub-surface drainage

Existence of an impermeable stratum at a relatively shallow depth below the ground surface will prevent downward movement of water in the sub-surface and result in creation of a perched water table condition, which may cause water logging. Any natural or artificial barrier in the ground water flow can cause the waterlogging such as grouting of the foundation of the reservoirs.

Over irrigation of fields

Excessive irrigation will increase seepage of the water into the ground and, thus, abating the waterlogging.

Nature of soils

Waterlogging also depends upon the nature of soil. Soils with low permeability, e.g. black cotton soil are prone to waterlogging due to over irrigation because it does not allow water to percolate down easily.

Incorrect and defective methods of cultivation

The incorrect and defective methods of cultivation may result in creating pools of stagnant waters and consequent waterlogging of land.

1.5 REMEDIES

Joshi (1994) has outlined the remedies for waterlogging. These are listed below:

Conjunctive use of the surface and the groundwater: In case of good groundwater quality for the irrigation, the conjunctive use of the surface and the groundwater should be adopted. This acts as vertical drainage to the excess water. After the draft in the groundwater, the aquifer is replenished by the seepage. Part of the water again recharges the groundwater and the rest is evaporated and transpired.

Canal lining: The areas where the groundwater quality is poor, lining of canal lining can be resorted to.

Horizontal drainage: The horizontal drainage systems can be installed for remediation of both surface and subsurface waterlogging.

Water management: Water management e.g. irrigation methods, agronomic practices, land leveling and other on farm developments can improve the waterlogging conditions.

Waterlogging occurs in canal command areas. Thus, there will be overlap in the appraisal technique in waterlogging and irrigation system studies. The relevant action in the context of waterlogging are listed below:

Conjunctive use: The conjunctive use of the surface and the groundwater can ameliorate the waterloging.

Construction of the drain: The drains can be constructed to reclaim the waterlogged areas.

Bio drainage: Trees can be planted in the waterlogged areas. They affect drainage though evapotranspiration throughout the year.

Cropping pattern: Suitable cropping pattern may be planned that utilize the standing water in the waterlogged areas e.g. paddy cultivation.

There are many management aspects required to be investigated in large canal system. For this various actions are taken in many countries. One of the actions is appraisal of the project. The appraisal is done in a short time. A team does the appraisal with members derived from various disciplines. The aspects to be addressed include irrigation scheduling, cropping pattern, environmental problem in the command, etc. In an appraisal various existing data e.g. documents, maps, etc. are collected. Discussions are held with farmers and field visit is made. The technique such as remote sensing is also used to study cropping pattern and other related aspects.

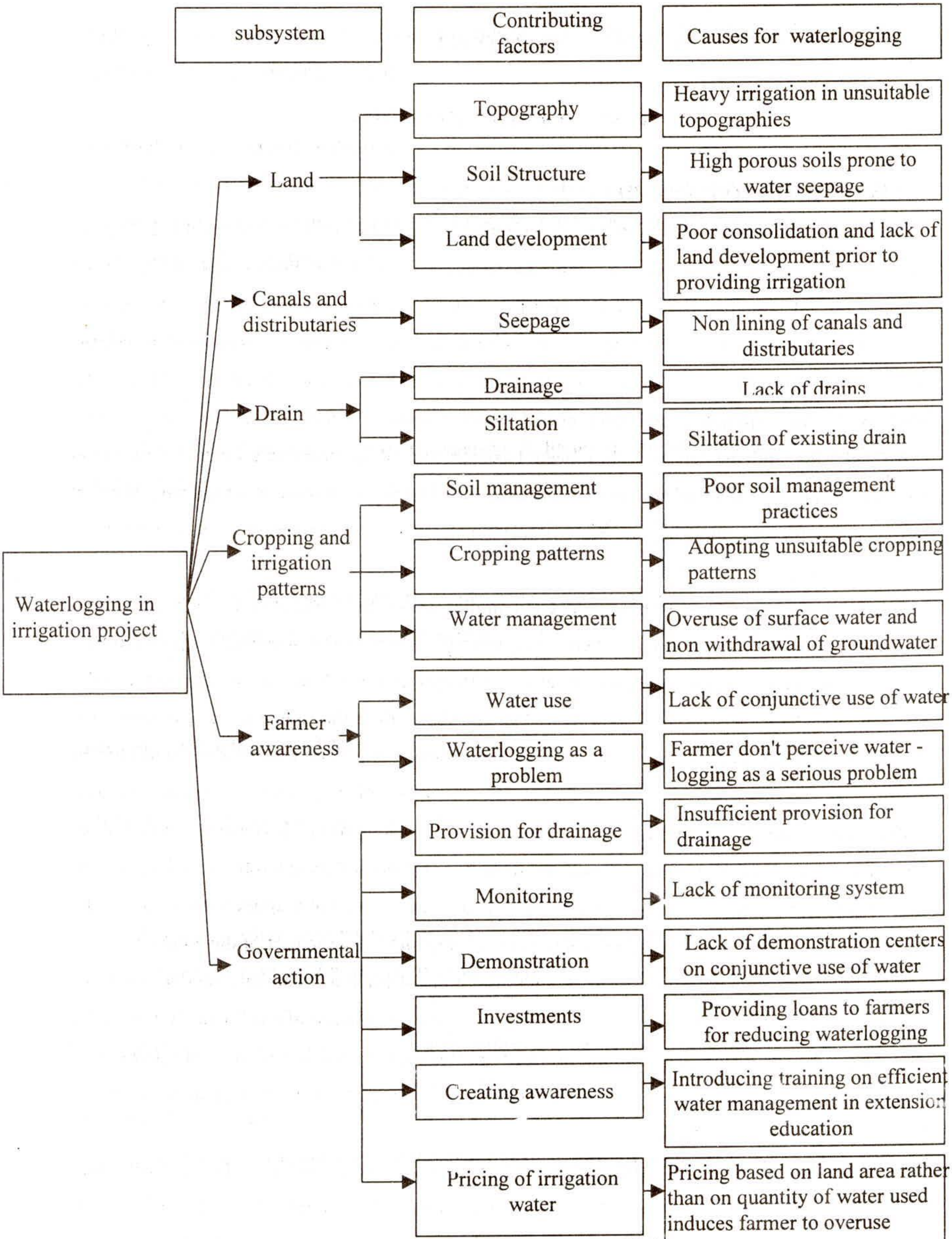

Figure 1: The Causes of waterlogging in irrigation projects (MOWR, 1991)

CHAPTER 2

STATUS OF WATERLOGGING

2.1 WATERLOGGING IN INDIA

Development of water resources for irrigation is as old as the history of mankind. The use of tanks, wells and small inundation canals for irrigation purpose has been practiced since time immemorial. A large number of canals constructed during the British rule for extensive irrigation during rabi crop season to sustain agriculture and to avoid strain on the economy due to intense and frequent famines, are still in use. These canals were later used for cultivation of kharif crop also. With this experience and background water resources development has been greatly expedited after Independence. It has been basically aimed at providing intensive irrigation facilities, to produce hydropower, to control floods, to meet the requirements of industry, thermal power and domestic supplies, etc. Many impressive irrigation works and big canals have been constructed (Bahadur, P., 1996).

With the experience of these works and similar works the world over, it has been realized that there are many adverse environmental impacts of a canal irrigation project such as climatic changes, pollution of surface and groundwater, waterlogging, soil salinity and/or alkalinity, health hazards etc. Several examples are available to show that the neglect of environmental requirements at the planning stage of a project has created situations, which either could not be rectified or were rectified at significant cost. Out of many adverse effects of canal irrigation, water logging and deterioration of soil fertility are most serious ones. It is estimated that about one half of the area in the country served by surface irrigation is threatened by waterlogging and soil salinity and/or alkalinity. Flat slope, poor drainage, excessive water application to fields, and unlined canal systems are some of the causes of waterlogging. A large part of the command areas are found waterlogged within ten years of commissioning of Bhakra, Chambal, Gandak and Sarda Sahayak canal systems etc (Bahadur, P., 1996). Owing to introduction of canal irrigation systems, the farmers have obtained quite stable productivity but they started facing an acute problem of waterlogging and soil salinity due to seepage from the major canal system in most of the developing countries like India.

In India, way back in 1876, the "Reh Commission" was appointed to find out why large tracks of land, which had once been fertile, had deteriorated. The commission traced the cause to the construction of big canals and the extensive use of irrigation water, which had resulted in increasing the amount of soluble salts on the surface. Also, in 1925, the then Punjab Government constituted a Waterlogging Enquiry Committee to study and report on the extent and causes of waterlogging which had assumed serious proportions in the irrigated areas and to indicate preventive measures. The committee suggested certain remedial measures and accordingly some drainage schemes were executed in Punjab. The total area benefited from these schemes was about 160,000 hectares. Similarly, the Bombay Public Works Department took up the initiative to tackle the problem of waterlogging in the Deccan by forming a Special Irrigation Research Development Division in 1916. It carried out valuable investigation and the Maharashtra State has implemented a number of drainage schemes. All these efforts, no doubt very useful and good beginnings were confined to a particular area, and not at a national level.

In India, the waterlogging problem has been accentuated in 1950's and 60's. Later, due to increase in the vertical drainage, there was again decline in the water table giving respite to the problem. Further, there was continual development in irrigation by inter- basin water transfer. This has further caused increase in waterlogging after 1980's.

The first attempt to focus the attention on this vital problem was made by the Irrigation Commission (1972), which tried to collect the information on waterlogging due to irrigation. On the basis of Questionnaire, sent to the States, all areas where the depth of water table varies from 0 -1.5 meters were taken as waterlogged areas. According to the responses as received from the States, it was estimated that 4.84 million hectares were affected by waterlogging in the States of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Maharashtra, Rajasthan, Madhya Pradesh and Karnataka. Whereas, it was considered that waterlogging was not a serious problem in the states of Assam, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Gujrat, Nagaland, Himachal Pradesh and Jammu & Kashmir (except for some areas in the Kashmir Valley).

The second attempt at the national level was made by the National Commission on Agriculture (1976) which compiled the information and put the figures at 5.986 million ha as the extent of waterlogged area in the country out of which 3.4 M.ha are subject to surface flooding, mostly in the States of West Bengal, Punjab, U.P., Gujrat, Tamil Nadu and Kerala and the remaining 2.6 Mha as the area having high water table particularly in Punjab, Haryana, U.,P., some parts of Rajasthan, Maharashtra, etc. The commission also estimated that saline and alkali soils, together, constitute an area of 7 M.ha out of which 4.5 M.ha is under salinity and 2.5 M.ha under alkalinity. Subsequently, efforts at estimating affected areas were made but were not well-coordinated. Thus, despite the existence of such serious problems in the country, there has been no systematic/comprehensive survey so far in order to firm up the total areas affected by waterlogging and soil alkalinity and salinity. According to the recent estimate made by the Ministry of Agriculture an estimated 8.53 M.ha, have been subjected to waterlogging, whereas the extent of salt-affected areas and Saline (including coastal saline soils) are 3.581 M.ha and 5.50 M.ha respectively. The working group constituted by the Ministry of water Resources (1991) reported an area of 2.46 million hectare suffering from waterlogging in irrigation commands. The state wise details are given in Table1. The areas include from states of Punjab, UP, Haryana, Rajasthan and Maharashtra. The working group also estimated that 3.3 M Ha had been affected by soil salinity/ alkalinity in irrigation commands.

World Bank (1991b) argued that the figures of waterlogged and salt-affected reported by Agriculture Commission could be a substantial underestimate. Some 3 M Ha are estimated to be waterlogged on irrigated lands, but only part of the waterlogging is said to be induced by irrigation. In order to isolate the effects of over irrigation, the Ministry of Water Resources estimated the area affected in irrigation commands and came up with figures of 1.5 M Ha for water logging, 3.1 M Ha for soil salinity and 1.3 M Ha for soil alkalinity (Vaidyanathan, 1999, Shah et al., 1998).

According to the Eighth Five-year Plan (GOI, 1992), a total of 17.61 M Ha of area is suffering from the problems associated with irrigation such as waterlogging (8.53 M Ha), soil alkalinity (3.58 M Ha) and salinity and sandy area (5.5 M Ha) (Gulati, 1999). Official estimates reckon the command area lost in waterlogging and salinity to be around 3 to 4 M Ha, while another study estimated that 7 M Ha have already gone out of farm production, and 6 M Ha are being seriously threatened (World Bank, 1998). The Ninth Five Year Plan (GOI, 1999) has conceded that there has been no systematic or comprehensive survey undertaken so far to assess the conditions of these areas and to assess the cost-effective remedial measures for the water logged areas. Thus, even as the extent of problem of water logging and soil salinization keep increasing, as is evident from above figures, there are no efforts to take action even to learn as to what exactly is the situation. The basic reason for the waterlogging of the canal commands is that drainage aspect has not been given proper attention in irrigation commands in India (Vaidyanathan, 1999).

While in most parts of India, such problems on irrigated lands are localized to particular commands and most frequently to localised areas in such commands; a particularly serious problem is developing in parts of Northwest India (large parts of Punjab mainly Southwest part of the state) and Haryana and parts of Rajasthan and Gujarat). Before irrigation development, water tables were generally at more than 25 meters depth. The rate of rise of the water table since irrigation began in the late 19 th century, has in some areas been of the order of 25 to 30 cm/year. This had no impact until the water table reached the root zone from saline groundwater sources. The first signs of irrigation-induced waterlogging and soil salinization was reported in the 1920s and the problem began to become widespread in certain districts of Punjab and Haryana from 1950s. Crop wise yields are affected and some areas can no longer be cultivated. Over 0.6 M Ha in Northwestern India are estimated to be affected by waterlogging. The 1891 commission appointed by the British concluded that inefficient drainage was the problem. Solution was in making the canals follow the naturally drainage lines, as Indians had done before the British canals were built, or construction of fresh drainage facilities (Goldman, 1994).

The problem is becoming widespread and acute. Recent studies have indicated that there has been a considerable increase in the water table in a number of irrigation command areas all over the country due to improper water management. According to Ministry of Water Resources, in AP, the Krishna River delta has experienced a 2 to 4.4 m rise in the water table. In Karnataka, the Chitradurga area has experienced 2 to 6.8 m increases. In MP, the rise has been 2 to 9.3 m in certain areas. In Faridkot, Punjab, the rise has been 2 to 11.2 m (Vaidyanathan, 1999).

In large parts of Haryana, the impact of irrigation over many decades has caused the groundwater table to rise, resulting in severe waterlogging and salinisation. Crop yields have declined significantly. Already, water logging problem has developed on about 250 000 Ha of land in northwest India, and it is foreseen that some 3 M Ha may be in jeopardy over the next 30 to 50 years. The incidence of flooding also increases as the water table approaches land surface (World Bank, 1994).

Recent studies have indicated that there has been considerable rise in water table in number of irrigation commands in Madhya Pradesh, Haryana, Karnataka, Punjab, Uttar Pradesh etc. where proper water management practices are lacking. In a few projects, where there has been conjunctive use of ground water with that of surface water in a planned manner, there has been a fall in the water table. As far as unlined canals and distributaries are concerned, a study undertaken in 1967 reveals that about 71% of the water is lost in transit from the reservoir to the field with the break up as under:

Canals	15%
Distributaries	7%
Water courses	22%
Field losses	27%
Total losses	71%

India has a wide range of climatic, physiographic and geo-hydrologic conditions leading to different patterns of waterlogging problems. Broadly, the drainage problem in India may be divided into five geographical units, which are briefly described as follows (Rana & Ghosh, 1996):

North West India

This area covers the semi-arid part of the Indo-Gangetic plains lying in Punjab, Haryana, North-West Rajasthan & Western Uttar Pradesh where twin problems of water logging and salinity exists. The area lacks in natural drainage and the under ground water is brackish in many places in the region. The soil also contains soluble salts in many areas.

Central Peninsular India

This Zone covers Madhya Pradesh, Maharashtra, Karnataka and central and western parts of Andhra Pradesh. Characteristically, this hardpan area with shallow soils and irregular topography. Waterlogging in this region is of local nature caused by seepage from canals and deep percolation from wet fields. Incidental salinity occurs in the naturally mineralised areas.

Eastern Plains and Deltas

This region covers Gangetic plains of Uttar Pradesh, Bihar and West Bengal and low land plains and deltas of Orissa, Andhra Pradesh and Tamil Nadu. Water logging in this region is mainly rainfall induced and salinity an incidental problem excepting marine salinity in the coastal area.

Coastal Gujarat

This coastal part of the command areas in Gujarat is affected by excess soil salinity. The problem is mainly of marine origin compounded with low rainfall and poor soil drain ability.

Usar Land of Western Gangetic Plains

This region comprises of major part of Uttar Pradesh and part of Bihar. Land in this region has high sodicity in the upper soil layer occurring in low rainfall areas. Usar land is generally found in enclosed depressions varying from small to medium sizes. Prolonged ponding of the surface water is considered to be cause of sodicity and the problem has been further aggravated after irrigation development.

Preventive/Remedial measures in states (Rana & Ghosh, 1996)

Structural measures adopted in India for relieving waterlogging are mainly surface drains and open sub surface drains. Pipe or tile sub surface drains have been used isolatedly on experimental basis in small plots as pilot projects. Chimney drains have also been constructed at places in Maharashtra in black-cotton soils.

Vertical sub surface drainage has been attempted particularly in Punjab and Harayana where mix of groundwater and canal water in suitable proportion is being used in irrigation. Reclamation efforts made by various state Governments are briefly brought out as follows:

Andhra Pradesh

Waterlogging has been experienced in three projects, namely, Sriramsagar, Nagarjunasagar and Tungabhadra projects. Total area affected is 266 Tha. Spread over 28%, 15% and 17% of the Culturable Command area (CCA) of these projects respectively. Salinity/Alkalinity problem to some extent has been observed in both Nagarjunasagar (left canal) and Tungabhadra Project. Total affected area being 5.0 Tha and 22 Tha respectively. Overuse of irrigation seepage from the canals and absence of adequate drainage are the main causes of the problem.

Presently, assessment and monitoring of the problem is underway. Groundwater level is being monitored on regular basis and mapping of the waterlogged and salt affected areas has been taken up through National Remote Sensing Agency (NRSA). Besides, the State Governments is providing subsidies and initiating pilot project studies for conjunctive use of water.

Bihar

Total waterlogged area in Bihar is reported to be (619 Tha) and salt affected area is 224 Tha affecting mostly the Gandak command. The Kosi project also had drainage problem to an extent of 182 Tha, which has now been brought down to 73 Tha. Meandering rivers in North Bihar due to the numerous low-lying areas forms Main cause of the problem. Natural drainage has also been obstructed by way of various infrastructure developmental works, encroachment on the drainage channels and siltation.

Gujarat

In Gujarat total waterlogged area in 1989 was reported as 72 Tha of which 22.6 Tha was critically affected. Saline area was reported to be about 79 Tha and 75 Tha in Mahi right bank canal command and Kakrapar project respectively. Problem of Gujarat is low rainfall, flat topography and marine salinity. Until recently, the state initiative was confined to improve of surface drainage only. However, at present Water and Land Management Institute (WALMI) Anand has initiated pilot sub-surface horizontal pipe drainage projects in collaboration with Central Soil Salinity Research Institute (CSSRI) and experimenting on various spacing and filters.

Karnataka

In Karnataka waterlogging and salinity problem has been reported as 24.54 Tha and 51.36 Tha respectively in various project commands namely, The Bhadra, Upper Krishna, Malaprabha, Ghataprabha, Tungabhadra, Kabani, Harangi, Hemavathy, and Krishnarajasagar. However, the problem of Hemavathy project is of alkalinity and the area affected is 17 Tha. The area affected by waterlogging and salinity/alkalinity is about 1.4% and 3% respectively.

As remedial measure, open field drains are being constructed and linked to main drains to improve surface drainage and thereby lower the watertable. Besides, the State Government has also undertaken a pilot project on left bank canal of Tungabhadra Command in collaboration with Dutch government to study and find solution to the drainage problem.

Madhra Pradesh

In Madhya Pradesh, the Chambal command was developed with inadequate drainage. As a result about 67 Tha area was found to be waterlogged during a study carried out in 1969.

As a remedial measure, 18 pilot schemes were taken up initially followed by Chambal drainage project phase II & I. Thus, the end of 7th plan reclaimed total area of 57 Tha. The drainage works mainly comprised of construction of seepage drains parallel to main canal, main drain cleaning, deepening, extension, outfall cleaning and construction of field drains.

Maharashtra

The state of Maharashtra has adopted a very comprehensive approach towards irrigation development by way of creating new CCA on one hand and following up the post-irrigation developments in these commands on the other almost simultaneously. The Directorate of Irrigation Research Development (DIRD) has been monitoring water table and salinity/alkalinity level of 36 major canals covering an area of 1069 Tha. At present area affected by waterlogging and salinity is about 2 to 3 % of total Irrigation Command of major projects.

The problem in Maharashtra arises from poor drain ability of the deep black cotton soil existing in the top layer. Besides, at places semi-impervious hard layers (murram) are also encountered at Shallow depth, which leads to rise in water table with introduction of irrigation.

The DIRD has adopted multi-pronged approach towards the problem, comprising of pre-irrigation soil survey, damage demarcation, carrying out applied research for irrigation management, planning, construction and maintenance of drainage projects, fixing limits for sugarcane area in different commands and miscellaneous training, education and publicity programs. Till 1993-94, total 550 drainage, open sub-surface drainage and chimney drains etc.

Orissa

Major problem in the state is from drainage congestion. Waterlogging has been observed in an area of about 196 Tha in the Mahanadi basin. The main problem lies in deltaic region contributing about 114.2 Tha affected land.

Causes of the problem are attributed to high seepage from canals, inadequate command area development work, riverbed at higher level than adjoining areas and breach of flood embankments. The rainfall and irrigation induced waterlogging problem has not been properly assessed to distribute the area and magnitude separately.

In order to tackle the problem, an integrated comprehensive plan known as Delta Development Plan (DDP) has been under consideration which envisages (I) development of catchment areas and improvement of drainages (ii) modernisation of Canal system and (iii) conjunctive use of surface and ground water.

Tamilnadu

Complete data of the state is not available at present. Waterlogging problem exists in Cauvery system in the Thanjavur deltaic region affecting an area of about 18 Tha (5% of CCA). Besides, salinity and alkalinity in the canal system has been indicated as 201.12 and 27.48 Tha respectively.

Cause of the problem is attributed mainly to the depressions in the flat topography combined with lack of drainage facilities. The state Irrigation Department has already taken up improvement of the drainage system. Among the 696 major and minor drains in the delta area 343 drains had already been deepened and widened till 1988. Remaining drains were being augmented in the VIII plan.

Uttar Pradesh

In U.P. major drainage problem is reported in Sharda Canal Commad. A survey conducted by Remote Sensing Application Centre, U.P. in 1990 indicated that about 260 Tha was affected due to salinity/alkalinity and 23.6 Tha due to waterlogging. Major causes of the problem are identified as seepage from canal and lack of adequate drainage.

As for remedial measures, the State Irrigation Department has taken up lining of the Canal system and construction of drains. Besides, improved water management practices are being attempted through Command Area Development Program.

Punjab, Haryana and Rajasthan

Problem of these states is more of regional nature. In Northwest, the upper reaches receive good rainfall during the monsoon months. As a result, some of the salts are washed out by surface runoff and some infiltrate down and transported by lateral groundwater movement. The situation in the lower arid and semi-arid region is fundamentally different. Here, rainfall is insufficient to produce large runoff and there is no regular regime of surface or groundwater. In consequence, the entire salt load gets deposited in the groundwater and the water table also rises up simultaneously. The situation is further worsened due to the presence of saline groundwater of geological origin at several places. Coverage of saline groundwater area in Punjab, Haryana and Rajasthan are reported to be 2,400 sq.km., 5,650 sqkm and 10,000 sq.km. respectively. Disposal of saline drainage effluent in this region also suffers as drainage into the three trunk drains in the command namely the Sutlej in the north-west, Yamuna in the east and Ghaggar in the south-west is constrained on account of environmental and riparian concerns, particularly in non-monsoon months. Disposal into the natural depressions in the desert through Ghaggar is also not favoured as the local farmers cultivate its floodplains being very fertile. So, at present the saline drainage is remaining confined within the command area itself. Other problematic features of the region are saucer shaped topography of the central Haryana without having any drainage outlet. In Rajasthan, existence of hard pan in the command of Indira Gandhi Nahar Priyojna-II (IGNP) at varying depths between 5 m to about 20m leads to drainage problem while the regional groundwater levels are at 20m to 60m below ground level.

According to the study carried out by WAPCOS, there are 18 problematic pockets of which 16 are in Haryana and one each in Punjab and Rajasthan. Largest of them is in Punjab with a total area of 219 Tha of which 87Tha is in falling water table zone. The problem area in Rajasthan lies in the IGNP stage-I command having a total area of about 50 Tha. The problem areas in Haryana are in varying sizes between 500 ha to 22.6 Tha.

Causes of the local problem in Punjab and Haryana are inadequacy and obstruction of surface drainage and seepage from canals. In Rajasthan the problem area lies in the vicinity of natural depressions that store surplus floodwaters of the Ghaggar river. The cuase of the problem is mainly attributed to seepage from canals and storage in the Ghaggar depressions. Total area having water table within 3 m bgl in Punjab, Haryana and Rajasthan are about 200 Tha, 275 Tha and 50 Tha respectively, though total critically affected area would be about 76 Tha.

The measures for prevention being taken are lining of canals, improvement of surface drainage system, improvement of water management practices and conjunctive use of surface and groundwater. In Rajasthan, attention is now being given to the drainage problem and at present regular monitoring of water table is in progress. All the three states are also contemplating to initiate suitable Action Research Program to arrive at a feasible solution to the overall drainage problem of North - West India.

2.2 Status of waterlogging in World

In the world the problem of waterlogging and salinization can be divided in to three regions namely arid/ semi arid, temperate and humid. Much of the North America and West Europe is covered by temperate climate and drainage development has been large in these developed countries. The drainage technologies for these regions and arid and semi arid regions are more similar and thus, this given better opportunity to the arid and semi arid region to adapt to the agriculture drainage. In Comparison to water logging, salinization is more serious concern in the later regions. These regions are mainly covered by irrigated agriculture in the developing regions.

The development of drainage in the developed countries has taken place in spurts i.e. in 1920- 1930's and is also driven by need for food security. The development has taken place mainly through effort by government with little private participation. This has laid solid institutional network and expertise in the area. Very little development has taken place in Africa and South America. Thus, this is the area where begining is to be made. In developing countries also government adopting the model presented by developed countries tackles the drainage problem.

Very little private participation has also started in India, Egypt and Pakistan. The proportion of the governmental spending as compared to private spending still remains high all over the world. The reasons for this can be the need to protect the natural resources.

The technology for amelioration of the problem is available in the developed countries. For the developing countries, non-availability of the technology can hinder the effort to reclaim the land resources. Various world bodies have put efforts in the direction. Foreign assistance e.g. through World Bank etc. has played important role in capacity building and research and development in these areas (Smedema and Walter 1998).

Arid zone

Poor irrigation water management and inadequate drainage have caused much valuable irrigated land to become waterlogged and salinised. It is estimated that world wide, between 20 and 30 million ha of irrigated land have already become seriously affected by this problem while the affected area is estimated to grow by 1 to 2 million ha. per year which is of the same order as the annual growth of the world's irrigated area. The world's irrigated area is currently estimated to stand at 260-270 M.ha. but the waterlogging and salinity problem is essentially restricted to the estimated 100 M.ha. of irrigated land located in the arid zone.

Humid Tropics

Much of the land in the humid tropical zone becomes heavily waterlogged during the monsoonal rainy season. To a large extent, this is a natural condition of this land but especially in the semi-humid tropics, this waterlogging has been aggravated by the introduction of irrigation which has altered the natural hydrology of the land and, together with other infrastructral developments, has obstructed the natural drainage ways. The involved area is enormous, stretching all around the globe and covering major parts of Central and South America, Central Africa and South and East Asia.

CHAPTER 3

CONCEPTS OF REMOTE SENSING AND GIS

3.1 GENERAL

The satellite remote sensing due to its repetitive coverage and synoptic view leads to the identification of water resources potential along with the field data. It not only analyses the surface water potential but also the ground water. Recent high-resolution images provide valuable database for solving the issues related to water resources. Remote sensing and GIS technologies offer a wide range of applications suitable for water resource investigation. Large amount of database has to be analysed for proper planning and decision-making for water resources. In this context GIS technology is being used for large database management, to explore, analyse and manipulate data. The GIS plays a vital role in various issues and challenges, like identification of potential sites for construction of new reservoirs and suitable sites for new bore wells through integrated thematic analysis. Also GIS can answer the questions related to location, condition, trends and patterns. It helps in modelling the water resources potential and to develop a geo spatial data model of the water resource features of the landscape. Many of the parameters required to model runoff and non-point source water pollution potential are geographic in character and are obtained from geographic sources like soil maps, topographic maps, land use maps, and aerial photographs.

3.2 REMOTE SENSING

The term 'remote sensing' is used for a variety of techniques to obtain information about objects 'at a distance'. To realise this, some sort of link has to be created between the object and the observer. This link may consist of sound waves or electromagnetic waves. Sound waves, e.g. in sonar or acoustic topography, provide an excellent means to obtain information under water about the shape of the sea bottom or the internal structures of water masses. However, remote sensing, in general, refers to observation of the earth's (or ocean's) surface or of the atmosphere by using electromagnetic waves.

Various satellites having sensors which operate both in optical as well as in microwave region of electro magnetic spectrum at different spatial resolutions (Table 1) can be used for deriving valuable information on surface waterlogged and drainage congested areas.

Table 1: Details of various satellites and sensors for monitoring and mapping of surface waterlogged and drainage congested areas

Remote sensing windows	Satellite	Sensor	Spatial resolution in meters	Revisit period in days
Optical	IRS-1B	LISS-I LISS-II	72 36.5	22 22
	IRS-1C	LISS-III WiFS PAN	23.5 188 5.8	24 5 24
	IRS-1D	LISS-III WiFS PAN	23.5 188 5.8	25 5 24
	IRS-P3	WiFS	188	5
	LANDSAT-1-3	MSS	79	18
	LANDSAT-4-5	MSS	82	16
Optical/thermal	LANDSAT-4-5	TM	30	16
	SPOT 1 and 2	HRV	20	Nadir 26 days: Off Nadir 1,2 & 5 days depending on Latitude
Microwave	ERS 1,2	C Band VV Polarisation	30	16-18
	RADARSAT*	C Band HH Polarisation	100 (ScanSAR wide)	3 (at mid-latitudes)

*** Different resolution at different beam modes**

In view of the properties of the atmosphere, traditionally two windows are used:

1. Optical window, wavelengths from 300 - 1000 nm
2. Thermal window, wavelengths from 3000-14000 nm.
3. Microwave window, wavelengths from 1 mm - 1 m.

3.2.1. Optical remote sensing

The optical window is often subdivided into a reflective optical part (300-3000 nm) and a thermal infrared part (3000 - 14000 nm). Remote sensing, generally, refers to taking images of objects on or near the earth's surface, by means of observations from aeroplanes, satellites, space stations, balloons or fixed points like towers. Both airborne and satellite-based remote sensing systems view the earth from overhead, with aeroplanes generally providing very high spatial resolution over limited areas, and satellites providing lower resolution but over the entire planet.

Reflectance characteristics of different objects

Reflectance is the percentage of energy reflected to the total energy incident on a body. It is the ratio between radiations off the surface (outgoing) to the total radiation incident on the surface (incoming). We see an object green because only green energy is reflected in the visible spectrum. Thus, blue coloured objects reflect blue only or red coloured objects reflect red only which is perceived by the eye. 'Blue', 'Green', and 'Red' are the three fundamental colours. Pure black or pure white are not a colour at all. Other colours such as magenta, violet, yellow, cyan etc. are the mixing of three basic colours RBG in different proportions.

Figure 2 illustrates the relative response (reflectance) of common Earth targets for the visible and near infrared portion of the spectrum. Water has a very low reflectance at a wavelength of 1.1 μm (less than 10%) compared to that of vegetation (around 50%).

Water reflectance is the sum of a specular component and an internal scattered component. The specular reflectance is perceived as 'sunlight' from the platform. Because of strong absorption in the middle infrared, the magnitude of the scattered component is chiefly derived from the shorter wavelengths, particularly those in the visible range. The infrared band(s) are eminently suited for mapping water bodies because of the absorption, and near zero reflection.

In Figure 2, a number of spectral reflectance curves of water bodies are shown. Curve W1 pertains to clear, deep ocean water. The radiation is mainly due to scatter within the water (specular reflection not considered), causing a weak upwelling radiation. Transmittance is high and the reflectance depends on the chlorophyll content. Clear lake water is represented by curve W2. The relative high intensity in the part of the spectrum between 0.40 and 0.6 μm causes a bluish-green colour in nature. The red wavelengths are partly absorbed and those beyond in the near infrared are fully absorbed. Shallow, clear water is shown by curve W3. The depth to which light can penetrate depends on the wavelength, about 10 m in the 0.5- 0.6 μm waveband and less than 10 cm in the 0.8-1.1 μm range. Water with a high and moderate suspended solid load is represented by curve W4a and b respectively. The scattering in the blue and green band causes an increase in reflectance in relation to clear water. The brownish yellow colour of a high-suspended load in rivers is due to a strong reflection in the red band. Water with suspended healthy algae containing chlorophyll is shown by W5. A closed cover of floating green vegetation, such as water hyacinth, is represented by curve W6. The curve is typical of healthy green vegetation.(Meijerink et al., 1994)

Radiometric Normalization

All the satellite data acquired are radiometrically normalized to bring down the variations in spectral reflectance due to sun elevation differences and radiometric gain settings. Initially, the Digital Numbers (DNs) values are converted to radiance values using the gain settings and saturation radiance values provided in the header file of satellite data (IRS-1A LISS-II, IRS-1D LISS-III and IRS-P3 WiFS). And for Landsat-TM images, the values are provided by Morkham and Barker (1986) are taken. Later corrections for sun elevation angle variations are made using cos θ correction (where θ is the sun elevation angle). The radiance values are scaled using a common linear scaling factor.

$$L\lambda = LMIN\lambda + \left(\frac{(LMAX\lambda - LMIN\lambda)}{QCALMAX}\right)*QCAL$$

Where :

QCAL = Calibrated and quantified scaled radiance in units of DN, digital numbers

LMINλ = Spectral radiance of QCAL=0

LMAXλ = Spectral radiance at QCAL = QCALMAX

QCALMAX Range of rescaled radiance in DN

Lλ = Spectral radiance

3.2.2 Thermal Remote Sensing

This section covers the basic concepts of thermal remote sensing, state-of-the-art, and its potential in the detection of waterlogged areas.

For most natural bodies, the thermal emission is mainly in the infrared region (3 to 15 μm). In the case of sun, numerous starts, and high temperature radiators, their high temperature leads to emission in the visible and ultra violet (UV) regions of the spectrum. In addition to the thermal radiation, the heat conduction property of the surface layer is a key factor in its response to the periodic heat input from the sun. Another parameter of particular interest for thermal remote sensing is thermal inertia (P), which, according to Price (1977) can be defined as:

$$P = (k\rho bC)^{0.5}$$

Where :

K is the soil thermal conductivity ($W.m.^{-1}.K^{-1}$)

ρb is soil density ($kg.m^{-3}$)

C is the soil mass heat capacity ($J.m^{-1}K^{-1}$)

In thermal remote sensing, the measured variable is the outgoing ascending thermal irradiance R_L emitted by the surface. The subscript L denotes long wave radiation, to emphasize the fact that most of the terrestrial radiation emitted by the Earth's surface, as mentioned earlier, is in the 8-14μm range of the spectrum. It could be expressed as (Oke, 1987):

$$R_L = E\sigma T^4_s + (1-E)R_L$$

E = the surface emissivity

σ = the Stefan-Boltzamnn constant ($W.m^{-2}K^4$)

Ts = the surface temperature (K)

R_L = the incoming longwave irradiance from the sky ($W.m^{-2}$)

For clear skies, the second term is often neglected because sky emission is weak for dry air and because land surface emissivities, with a few notable exceptions, are near unity. This sky emission term can, however, be important for overcast conditions or for atmospheres characterized by high water vapour contents. Soil temperatures are controlled not only by meteorological factors and thermal property of surface and diurnal temperature variation, but also by thermal properties of the underlying material. Near surface soil temperatures may be indicative of sub-surface characteristics.

The intervening atmosphere distorts the thermal images of soils via the process of absorption, scattering and re-emission. Terrestrial surface temperature measurements made by remote sensing instruments are attenuated by the Earth's atmosphere. The atmosphere modifies observed brightness temperatures by either increasing or decreasing upwelling radiation received by the sensor. A thermal formulation of the thermal radiance received by the satellite has been given by Schott and Volchok (1985) and is expressed by:

$$L(h) = T(h)EL_T + T(h)\rho L_D + L_A(h)$$

Where :

L(h) is the thermal response received by the sensor ($W.m^{-2}sr^{-1}$)

T(h) is the atmospheric transmittance up to altitude h

E is the surface emissivity

L_T is the blackbody radiance of the soil surface at temperature T($W.m^{-2}sr^{-1}$)

ρ is thermal surface reflectance (ρ=1- E)

L_D is the downwelling thermal atmospheric radiance, equal to thermal radiance divided by π, and

$L_A(h)$ is the ascending atmospheric radiance received by the sensor.

Thermal infrared sensors measure the radiometric temperature of the ground, which is a function of atmospheric absorption and scattering of emitted radiation, the ground temperature, and spectral emissivity of the ground. As the atmospheric effects are, generally, constant across the imaging field, the patterns on a thermal infrared image primarily record variations in spectral emissivity and ground temperature. Emissivity affects not only the radiometric temperature of a soil but also the surface temperature of the soil through radioactive heat transfer.

3.2.3 Micro Wave remote sensing

Beside the optical and thermal remote sensing microwave remote sensing can also be used for waterlogging studies. However, microwave remote sensing has application only in detection of soil moisture. Microwave techniques for measuring soil moisture include both the passive and active microwave approaches, with each having distinct advantages. The theoretical basis for measuring soil moisture by microwave techniques is based on the large contrast between the dielectric properties of liquid water and of dry soil. The large dielectric constant for water is the result of the water molecule's alignment of the electric dipole in response to an applied electromagnetic field. For passive microwave remote sensing of soil moisture from a bare surface, a radiometer measures the intensity of emission from the soil surface. This emission is proportional to the product of the surface temperature and the surface emissivity, which is commonly referred to as the microwave brightness temperature.

3.3 IMAGE INTERPRETATION

The main objective of image interpretation is to derive information about features displayed in an image. It is defined as the act of examining images for the purpose of identifying objects and finding their significance. The extraction of information depends on image analyst's experience, power of observation, imagination and patience. It also depends on his understanding of the basic principles of an image interpretation.

3.3.1 Visual Interpretation

It is a traditional method for deriving information on various natural resources. There are certain fundamental photo elements or image characteristics seen on the image, which aid in the visual interpretation of satellite imagery. Tone/colour; texture, shadow, shape, size, location and season etc. and their association are some of the basic image characteristics on which visual interpretation is based. Some of the shortcomings of the visual interpretation are:

(a) It is difficult to get consistent result from different interpreters

(b) It is difficult to achieve precise registration of multi-band and temporal images

(c) Human can only detect the difference between 8-16 different shades of gray and the range of gray values recorded on the film is limited. Thus, nowadays we go for digital image processing.

3.3.2 Digital Image Processing

Any pictorial image can also be represented in digital form, so that the patterns of image brightness forms an array of numeric values which can be conveniently added, subtracted, multiplied, divided, and in general subjected to statistical manipulations that are difficult or impossible, if the image is available in pictorial form. Digital analysis encompasses a broad set of operations by which remotely sensed data are subjected to operations that yield information or enhanced data. It must be remembered that digital analysis is not totally free from human interactions. It requires significant inputs from the analyst while making decisions, thus providing information at faster rate, with high quality output, when compared with manual interpretations.

Image processing systems require various input/output devices, central processing unit (CPU), data storage devices and system consoles for man-machine interaction. Adequate image display facilities are important in the processing of an image.

The image processing software required in remote sensing applications could be broadly, grouped such as Data input routines, Pre-processing routines, Image display routines, Image enhancement and filtering routines, Classification routines, Image output routines.

An idealized sequence for digital analysis can be broken up into four specific groups;

(a) Pre-processing

(b) Enhancement,

(c) Analysis and Classification, and

(d) Data Presentation.

Preprocessing

Pre-processing operations prepare satellite data for subsequent analysis, usually by attempts to correct or compensate for systematic errors. In the pre-processing operations, data are displayed for inspecting characteristics and quality, present histograms, scattergrams or statistical summaries that permit the operator to assess image quality and thereby determine subsequent preprocessing steps (if any) that may be necessary. In addition, they compensate for radiometric and geometric errors.

Enhancement

Image enhancement is the modification of an image to alter its impact on the viewer. Therefore, enhancement operations are normally performed on image data prior to visual interpretation efforts. They increase the apparent contrast between the features in the scene and thus improve its interpretability.

Most of the individual scenes consequently make use of only a small portion of the full dynamic range. To produce an image with the optimum contrast, it is important to utilize the full brightness range of the display medium. If the range of image values is uniformly expanded to occupy the total range of the display device, then this process is referred to as linear stretch. There are other stretching techniques also available.

Analysis & Classification

The image processing methods that have been used include level slicing, spatial image enhancement, spectral enhancement (Principal component, Tasseled Cap and Normalized Difference Vegetation Indices). One of the most often used methods of information extraction is multi spectral classification. The process of multi spectral classification may be performed using either of the two methods: supervised or unsupervised method.

In a supervised classification, the identity and location of some of the land cover types, such as urban, agriculture, wetland, and forest, are known a priori through a combination of fieldwork, analysis of aerial photography, maps, and personal experience. The analyst attempts to locate specific sites in the remotely sensed data that represent homogeneous examples of these known land-cover types. These areas commonly referred to as training sites because the spectral characteristics of these known areas are used to "train" the classification algorithm for land cover mapping of the remainder of the image. Every pixel both within and outside these training sites is then evaluated and assigned to the class of which it has the highest likelihood of being a member.

In an unsupervised classification, the identities of land cover types within a scene are generally not known a priori because either the ground truth data are not available or surface features within the scene are not well defined. The computer is required to group (cluster) pixel data into different spectral classes, according to some statistically determined criteria, and it is then the responsibility of the analyst to label these clusters into various classes.

Principal Components Analysis (PCA)

Principal Components Analysis (PCA) is a spectral enhancement, which can be used to compress the information content of a multi spectral data set (Sabins 1997). PCA uses mathematical algorithms to transform *n* bands of correlated data into *n* principal components, which are uncorrelated, such that the coordinate axes of the components are mutually orthogonal. The first principal component (PC-1) describes most of the variation of the brightness values for the pixels of the original bands (Jensen 1996). Subsequent components explain less and less of the data, with the final PC usually corresponding to atmospheric noise in the data rather than any ground features (Sabins 1997). The main benefit of principal components analysis is that it can reduce the amount of data (bands) without losing much of the information and typically reducing redundancy (Jensen 1996). In principal components analysis on three bands, the majority of the information contained within the three bands would be explained by PC-1. Thus, this one layer of data could replace the three original bands without much loss of information. This has been attempted in this study.

Density Slicing Of Single Band

In many studies remote sensing data have been used to determine the extent of water bodies/waterlogging using simple classification procedures, usually with an infra red band. These studies have relied on the water bodies having a unique spectral response in this range of Electro Magnetic Radiation (EMR) when compared to the surrounding landscape. The infrared band classification gives a much better representation in the water related features than do the visible bands. The range of the density slicing determined from the water training areas covers almost the entire range of the data in each visible band. Each of the visible bands displays a unimodel histogram with no indication of a separate group of data for water pixel. The infra red bands display a bi-model histogram with a darker mode consisting mostly of water pixels. The density slicing ranges for infra red band starts at near zero, meaning that water pixels are the darkest in the image.

NDWI Approach

There are numerous vegetation indices developed to estimate vegetation cover/water area etc. with the remotely sensed imagery. A vegetation index is a number that is generated by some combination of remote sensing bands. The most common spectral index used to evaluate vegetation cover is the Normalized Difference Vegetation Index (NDVI). McFeeters (1996) developed an index similar to the NDVI, which is called the NDWI. This stands for the Normalized Difference Water Index. Any instrument having a green band and a near infrared band can apply this index. The NDWI was derived using principles similar to those that were used to derive the NDVI. The NDWI is calculated as follows:

$$\mathrm{NDWI} = \frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \qquad (2)$$

where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using green light wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When equation (2) is used to process a multi spectral satellite image that contains a reflected visible green band and an NIR band, water features have positive values; while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI for water features is then from zero to one. Multiplying equation (2) by a scale factor (e.g. 255) enhances the resultant image for visual interpretation. In the output obtained water related features were identified.

Tasseled Cap Transformation

There are numerous methods available for enhancing spectral information content of satellite data. The Tasseled cap transform compressed the total information into three bands: greenness, brightness and wetness. Besides expressing a large amount of image variability within three bands, tasseled cap bands could be directly related to physical scene characteristics. The Tasseled Cap Transformation is similar to PCA in that it attempts to reduce the amount of data layers (dimensionality) needed for interpretation or analysis. This enhancement uses mathematical equations to transform the original *n* multi spectral bands into a new *n*-dimensional space. One of the two more important layers is known as the soil brightness index (SBI). This index shows bare areas such as agricultural fields, beaches, and parking lots as the lightest features. The other is the green vegetation index (GVI), which is an indicator of vegetation status since it displays areas with healthy, green vegetation as the lightest feature. The name "tasseled cap" comes from the fact that when the greenness and brightness of a typical scene are plotted perpendicular to one another on a graph, the resulting plot usually looks like a cap (Jensen 1996).

A Tasseled cap transformation to data from the Landsat TM has been given (Crist and Cicone, 1984). The coefficients for wetness functions are:

TM Band	1	2	3	4	5	6	7
	0.1509	0.1793	0.3299	0.3406	0.306	-0.7112	-0.4572

One of the main reasons for supporting the use of the Tasseled-Cap Transformation method against, for example, the principal component technique is that the coefficients of the transformation are defined a priori.

3.4 GEOGRAPHIC INFORMATION SYSTEM (GIS)

The term Geographic Information System may be explained as follows

'Geographic' stands for spatial data. These are the data, which are associated with a specific place or places on Earth's surface, sometimes called as 'geo-referenced'.

'Information' may be viewed as data with added knowledge.

'System' refers to the integration of user and machine (hardware and software) able to input, manipulate and present data.

Therefore, we can say that GIS is a general-purpose computer-based technology for handling geographical data in digital form. It is designed to capture, store, manipulate and perform analyses of spatially distributed data. It contains both geometry data (coordinates and topographical information) and attribute data (i.e., information describing the properties of geometrical objects). In GIS we can make the presentation of results in both graphic and report form, with a particular emphasis upon preserving and utilizing inherent characteristics of spatial data.

3.4.1. Main Functions Of GIS

- All GIS operations can, in principle, be done manually, but many tasks are so time consuming that they can be manually performed only for very small research areas. By using computers and their graphics facilities and a GIS software, the laborious tasks can be performed with ease. The early concepts of map handling by a computer had a serious drawback in that they could not handle the tabular or attribute data in conjunction with spatial features. This led to the development of additional methods and techniques where the spatial and attribute data both could be handled and integrated so that the outputs are more meaningful for planners and decision-makers. The upcoming of this technology has enhanced our capability not only of map handling but also of map manipulation and analysis. Therefore, using a GIS:

- Users can interrogate geographical features displayed on a computer map and retrieve associated attribute information for display or further analysis.
- Maps can be constructed by querying or analysing attribute data.
- New sets of information can be generated by performing spatial operations (such as polygon overlay) on the integrated database.
- Different items of attribute data can be associated with one another through a shared location code.

Before any spatial analysis or modelling operations can be carried out in a GIS, it is necessary to input the requisite data. Data input is the procedure of encoding data into computer-readable form and writing the data to the GIS database. The data to be entered in a GIS are of two types - spatial data and associated non-spatial attribute data. The spatial data represent the geographic location of features. Points, lines and areas are used to represent geographic features like a street, a lake or a forestland. These data will normally be obtained from one or more of the following sources:

- Existing maps
- Aerial photographs
- Satellite imageries
- Existing digital data
- Other GIS data bases

Remote sensing is an important source of data for GIS analysis and conversely, GIS data can serve as an important aid in image analysis. The need of integration of GIS and remote sensing is thus inevitable, and is rapidly emerging because of the complementary role played by these technologies.

Database provides facilities to perform several operations commonly required in manipulation of attribute data. These operations include:

- Retrieving data from the existing datasets
- Updating, editing and/or transforming the existing datasets

- Inserting new data into existing datasets
- Adding new datasets to the database
- Deleting data from existing datasets
- Removing datasets from the database

3.4.2. Spatial Data Structure

Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as :

Vector and Raster

Vector storage implies the use of vectors (directional lines) to represent a geographic feature. Vector data is characterized by the use of sequential points or vertices to define a linear segment. Each vertex consists of an X coordinate and a Y coordinates. Vector lines are often referred to as arcs and consist of a string of vertices terminated by a node. A node is defined as a vertex that starts or ends an arc segment. One coordinate pair, a vertex, defines point features. Polygonal features are defined by a set of closed coordinate pairs. In vector representation, the storage of the vertices for each feature is important, as well as the connectivity between features, e.g. the sharing of common vertices where features connect.

Raster data models incorporate the use of a grid-cell data structure where the geographic area is divided into cells identified by row and column. This data structure is commonly called raster. While the term raster implies a regularly spaced grid other tessellated data structures do exist in grid based GIS systems. In particular, the quad tree data structure has found some acceptance as an alternative raster data model.

3.4.3. Capabilities Of GIS

The power of GIS lies in its ability to analyse spatial and attribute data together. The large range of analysis procedures can be divided into four categories:

i) Retrieval, reclassification and measurement,

ii) Overlay,

iii) Distance and connectivity,

iv) Neighbourhood

Retrieval, Reclassification and Measurement Operation:

In these functions retrieval of both spatial and attribute data are made and only attribute data are modified. New spatial elements are not created.

Retrieval operations:

These involve the selective search and manipulation and output of data. Retrieval operation includes the retrieval of data using:

- Geometric Classifications
- Symbolic Specifications
- A name of code of an attribute
- Conditional and logical statement

- Retrieval operations on the spatial and attribute data involve the selective search and manipulation, and output of data with out the need to modify the geographic location of features or to create new special entities. Retrieval operations include:
- Retrieval of data using geometric classification. Specifying the spatial domain of a point, line or area, retrieve all spatial entities and non-spatial attributes contained in the entire or in position of that spatial domain.
- Retrieval of data using symbolic specifications.
- Retrieve data using a name of code of an attribute. Retrieve using a name or code of an attribute. Example, retrieve effective depth and dominate texture of a given soil.
- Retrieval of data using conditional and logical statements. Retrieve data that satisfy alphanumeric conditions using logical expressions. Example retrieves all soil series with a pH range of 6.0 to 7.5 and silty clay texture.

Reclassification Procedures:

This procedure involves the operations that reassign thematic values to the categories of an existing map as a function of the initial value, the position, size or shape of the spatial configuration associated with each category, for instance a soil map reclassified into a permeability map. In a raster based GIS, numerical values are often used to indicate classes. A cell might be assigned value to indicate a class. For example a cell might be assigned the value 1 to indicate an agriculture land, 2 for forestland, and so on. Classification is done using single data layer as well as with multiple data layers as part of an overlay operation.

Measurement Functions:

Every GIS provides some measurement functions. The measurement of spatial data involves the calculation of distances, lengths of lines, area and perimeter of polygons. The measurements involving points include distances from a point to a other point, lines or a polygon enumeration of total number as well as the enumeration of points falling within polygon.

Overlay Operations:

Overlaying of maps results in the creation of a map where the values assigned to every location on that map are computed as a function of independent values associated with that location on two or more existing maps. Overlaying operation creates a new data set containing new polygons formed from the intersection of the boundary of the two or more sets of separate polygon layers. Arithmetical and logical overlay operations are common in all GIS software packages.

Arithmetical overlay includes operations such as addition, subtraction, division and multiplication of each value in a data layer by the value in the corresponding location in the second data layer. Logical overlay involves the selection of an area where a set of conditions is satisfied.

Neighbourhood operations:

Neighbourhood operations involve the creation of new data based on the consideration of 'roving window' of neighbourhood points about selected target locations. They evaluate characteristics of an area surrounding a specified target location. In all neighbourhood operations it is necessary to indicate one or more target locations, the neighbourhood considered around each target and the type of function to be executed on the attributes within the neighbourhood. The typical neighbourhood operations in most GIS are search function, topographic function and interpolation.

Interpolation:

Interpolation is the procedure of predicting unknown values using the known values at neighbouring locations. The neighbouring points may be regularly or irregularly spaced. Interpolation programs employ a range of methods to predict unknown values including polynomial regression, Fourier series, moving averages, and krigging, etc.

3.5 DIGITAL ELEVATION MODELS

One of the capabilities of GIS is the description of the topography of a region. Techniques used in the computer description of topography are called as Digital Elevation Model (DEM). DEM's are arrays of numbers that represent the spatial distribution of terrain altitudes. Main data sources for DEM's are ground surveys, existing topographic maps, photogrammetric stereomodels and surveys done by radar or laser altimeters carried in aircrafts and spacecrafts.

Various data structures are in use for DEMs, each with their own merits and shortcomings. There is no structure, which satisfies all requirements; much will depend on the purpose and also on the computer facilities available. The basic structures are the line model, the triangulated irregular network and the grid network.

The classical form of representing topography is the contour line mapping. The contours can be represented digitally as a set of point-to-point paths (vectors) of a common elevation. The line model describes the elevation of terrain by contours (stored as Digital Line Graphs i.e. the x,y coordinate pairs along each contour of specified elevation). Typical GIS operations based on the line model are carried out by overlaying the contours on to thematic maps or remotely sensed classifications.

An alternative approach to producing DEM's relies upon determination of significant peaks and valley points in the terrain, which is then represented by a collection of irregularly spaced points connected by lines. The TIN model splits up the true surface into triangular elementary planes. The terrain surface is sampled by points (nodes) that are located at positions, which capture the terrain characteristics.

The grid-based methods may involve the use of a regularly spaced triangular, square or regular angular grid. The element area is the cell bounded by three or four adjacent grid points, depending upon the method. The raster based GISs use the square grid networks. The advantage of the regular grid method is the simplicity of the data storage usually as sequential z coordinate along the x (or y) direction, with a specified starting point and grid spacing.

The most common method of acquiring elevation data in a digital raster format is to digitize the contours from a topographic map and apply an interpolation method to transform the contour data into a DEM. Although the quality of DEM essentially depends on the topographic map used, the interpolation algorithm used for DEM resampling has also a significant influence. The interpolation algorithm used for DEM resampling may be designed according to different requirements. Many technique aim at minimising the RMS-error; this criterion is the one most commonly applied in DEM quality assessment. On the contrary, some other techniques tend to preserve the terrain texture.

DEM can be put in use in variety of applications. The most common products derived from DEM relate elevation, slope, aspect, convexity/concavity of terrain etc. Considerable research has been carried out in the field of drainage network extraction and watershed boundary delineation by hydrologists and geologists.

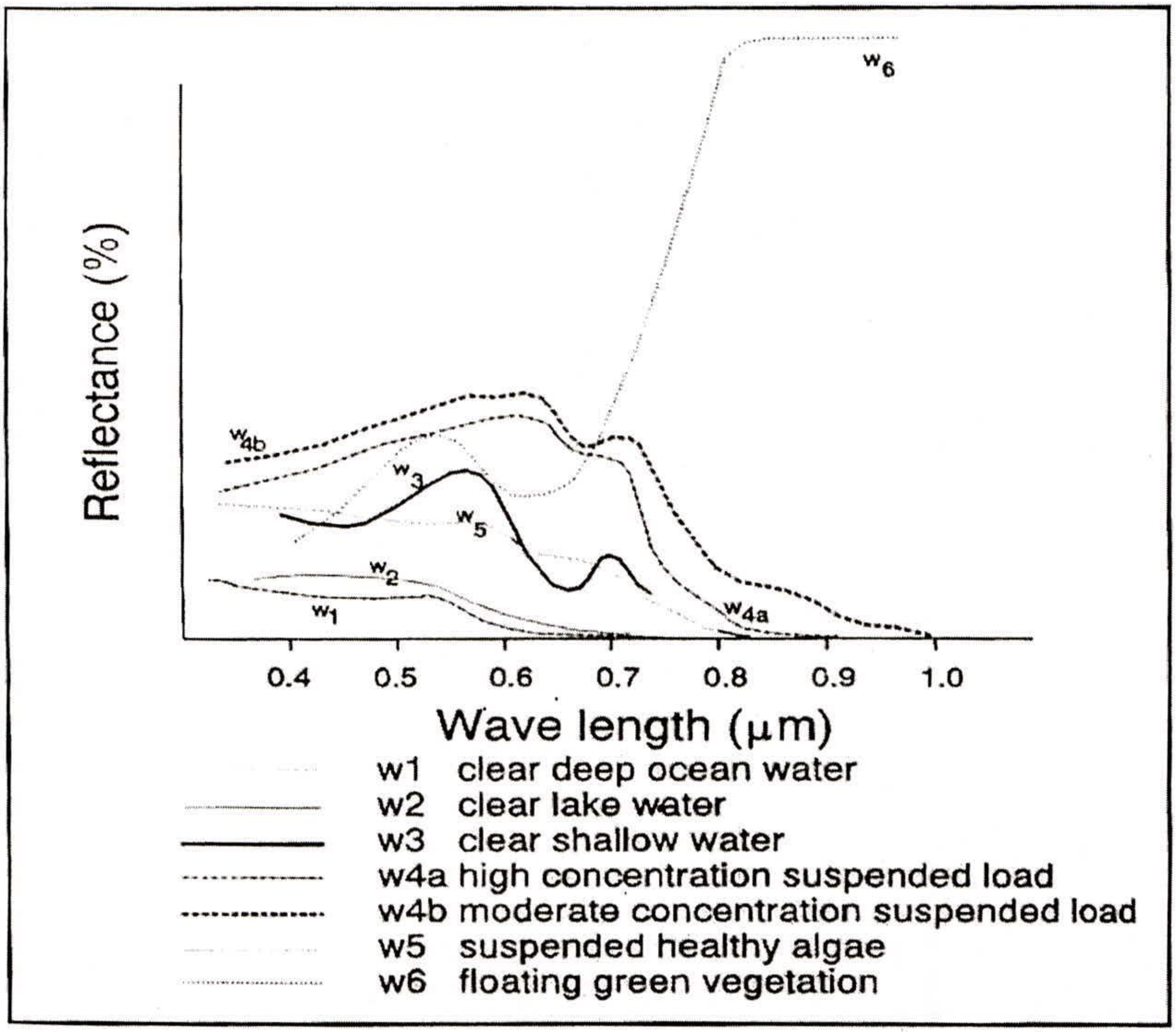

Figure 2: Possible reflectance curves of water bodies

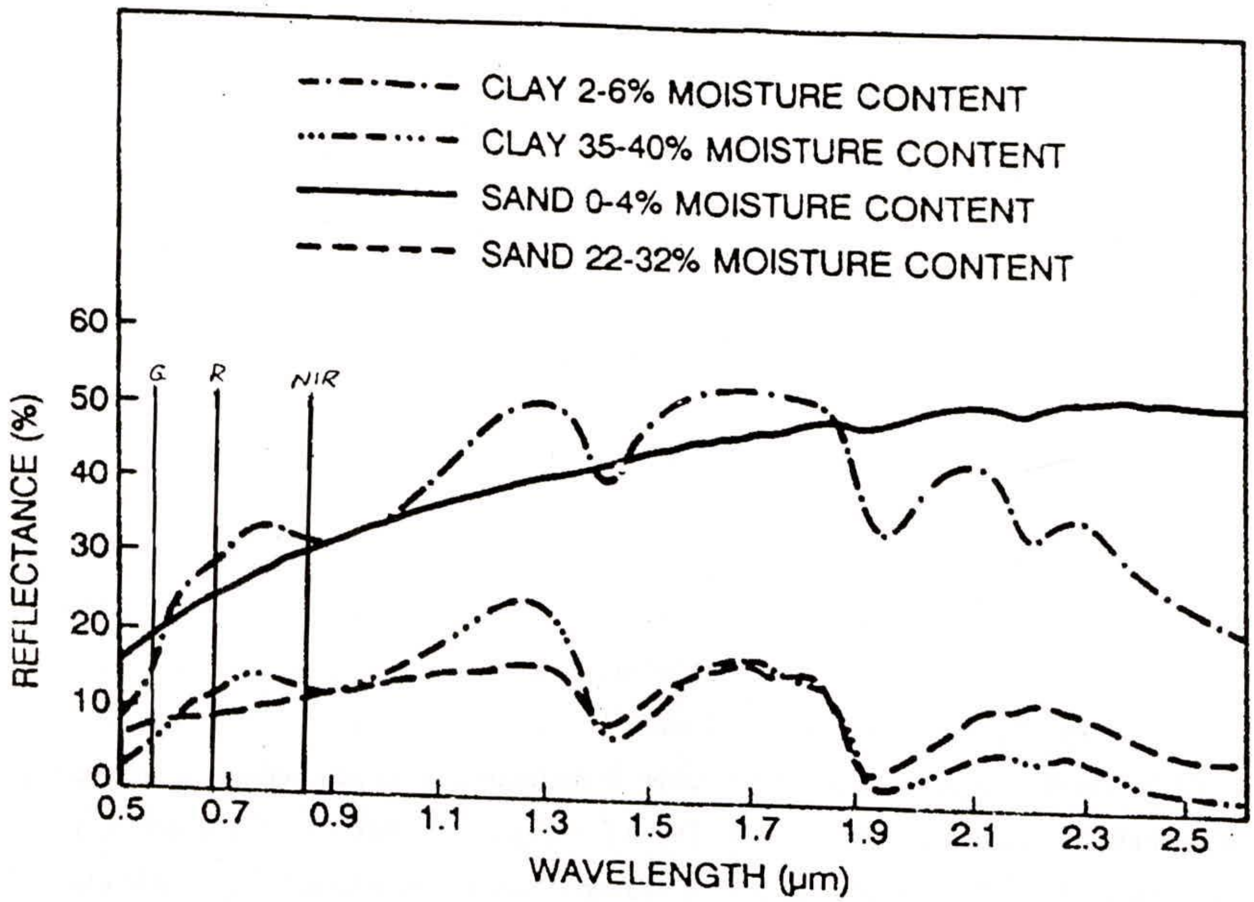

Figure 3: SPECTRAL REFLECTANCE CURVES FOR SOIL

CHAPTER 4

REVIEW OF WATERLOGGING STUDIES USING REMOTE SENSING

Results of the studies undertaken in the country so far, clearly demonstrate the usefulness of remote sensing techniques in detecting and monitoring waterlogged areas. Systematic mapping of land degradation in India started in late fifties, though mostly confined to mapping soil erosion and salt-affected soils. During sixties and early seventies aerial photographs were employed in deriving information on degraded lands. The launch of the first Earth Resources Technology Satellite (ERTS-1), later named as Landsat-1 in July 1972, opened a new vista in mapping and monitoring natural resources including degraded lands by virtue of providing synoptic view of the terrain in the narrow and discrete bands of the electromagnetic spectrum on a repetitive basis. Digital analysis of Landsat-MSS data using Multi spectral Data Analysis System (MDAS) was conducted for the first time at National Remote Sensing Agency for delineation of degraded lands (Venkataratnam and Rao, 1977).

Sharma and Bhargava (1988) have studied salt-affected soils and wet lands in the Mathura distt., Uttar Pradesh. FCC (bands 4,5 and 7) of the Landsat MSS is used. The area is traversed by Yamuna River; Agra left bank canal and many drains from Rajasthan and Harayana. The Agra canal has caused rise in the groundwater table. Waterlogging is also caused due to the drainage congestion caused by the Agra canal. The waterlogged area has standing water or higher groundwater table. Tone/colour and drainage pattern is used to map visually. Colour has been in many shades of blue for the waterlogged areas and has been the main characteristic used for the mapping. The waterlogged area with vegetation is seen in blue and magenta color. No distinction is made in various sub-classes of the waterlogged areas. The extent is 143 sq. km. 15 points have been checked in the field through depth measurements in the dug wells and soil auger bores. The depth varies from 1 to 2.5 m. The scale of mapping is 1:250,000.

Choubey (1994) has studied the waterlogging in the IGNP stage-1 in Rajasthan. The Landsat TM FCC of March 1990 at 1:250,000 scales is used. The canal takes off from the Harike barrage located on the confluence of the Satluj and Beas in Harayana. The command area is 15430 sq. km. covering 5 districts in the north western Rajasthan. The consolidated vindhayan sandstone with shale between sandstone beds lies at nearly 155 m depth. The water bearing alluvial is overlaid on the sedimentary rock and is 120 to 200 m thick. It mainly comprises sands.

Clays, silts and kankar texture is also found. The area is tapped for the groundwater through bore-cum-dug well from 20 to 35 m thickness of the aquifer. In the stage-1, Suratgarh and Namshera branches and main feeder canals are completed. The satellite data are visually interpreted. The area with bluish color is identified as waterlogged. The perennial vegetation area is seen in red or pink color. Extent of the waterlogging areas standing water is 82 sq. km. in the IGNP canal command area. The depth contours and EC contours area superimposed on the map. The area is enclosed within 6 m depth contour. At some places the water table depth is as small as 1.5 m. In the other area, the contour depth increases from 6 to 21 m.

Dwivedi (1994) carried out a study of salt affected area mapping using Landsat MSS data of Feb. 1975 and March 1990 data. The study was carried out in Farrukhabad, Manipur and Etawah districts of Uttar Pradesh. Also waterlogged area has been mapped using Landsat Thematic Mapper FCC using visual interpretation approach.

Dwivedi et al. (1999) carried out a study of soil salinity study using Principal component analysis, ratioing, differencing and intensity-hue-saturation (IHS) transformation. In this study, the temporal behaviour of salt affected soils in the Indo-Gangetic alluvial plains of Uttar Pradesh has been studied using Landsat MSS data for 1975 and 1993. The results indicated that the third principle component, image differencing, and ratioing of the first two MSS bands for two periods have brought out substantial information associated with the temporal behaviour of salt affected soils.

Choubey (1997) has mapped waterlogged areas in the Tawa Canal command area in the Narmada basin using satellite remotely sensed data. The extent of the gross command is 3330 sq. km. The digital data for IRS LISS-1 sensor for the pre and post monsoon dates are used. Broad land use classes are agriculture, scrub, fallow and water. The areas around the rivers are scrubland. Since the introduction of the canal irrigation there has been rise in the groundwater level at select stations ranging from 5 to 11 m. The satellite data are processed using the digital density slicing technique. The water pixels in the band-4 (Infra red) have values 9-15 and 20-25 for respectively reservoir and ponds. Thus, the waterlogged and susceptible areas are delineated respectively applying the slices 15-26 and 27-28 respectively in the DN (Digital numbers). The waterlogged and the susceptible area delineated are respectively 49 to 93 sq. km. and 144 sq. km.

Extent of the waterlogging in IGNP has been 2027, 220, 44 and 94 sq.km. respectively in the sensitive, critical, waterlogged with standing water and waterlogged with shallow water table. The % area in the command is respectively 39, 4, 0.8 and 1.6 of the total command of 5250 sq. km. Command Area Development Authority in 1991 vide (Choubey 1994). Many irrigation command areas are effected by the waterlogging problem in India, e.g. The commands of the projects on Chambal in Rajasthan and Madhaya Pradesh, Tawa in Madhya Pradesh, Satluj (IGNP) in Rajasthan, Kosi, Gandak in Bihar, Tungabhadra and Malapraba in Karnataka, Sriramsagar, Nagarjunasagar in Andhra Pradesh, Ukai (Kakrapar), Mahi (Kadana) in Gujrat and Sarda Sahayaka, Ramganga in Uttar Pradesh etc. (Joshi 1994).

Dwivedi et al. (1999) have studied the waterlogging and the soil salinity- alkalinity in the Nagarjuna Sagar left bank canal command area using the visual interpretation of the satellite imagery and the ground truth data. Data of the IRS LISS-1 and Landsat TM sensors are used. The study area comprises parts of three districts in the Andhra Pradesh namely Nalgonda, Krishna and Khammama. The soils are red and reddish- yellow and black soils. The later is found only in 35% of the area. The texture of the black soil is heavy (sandy clay to clay). The red and reddish- yellow soils are shallow to deep. The geology is granite- gneissic complex, sandstone, limestone and shale. The later three are found along the river. The salinity is caused due the feldspar mineral in the parent rock. The waterlogging occurs only is 13 sq. km. area. The cause of waterlogging is storage of the water in the depressions. The presence of clay pan/ bedrock is also found to occur at shallow depth. The waterlogging is only seasonal. The colors in the satellite FCC are different shades of blue and cyan.

In order to locate the water logged conditions in Sharda-Sahayak command of U.P. state, a part of IRS 1B FCC of March 1994 at 250,000 scale covering part of Sai-Gomti interstream region spreading from Barabanki to Raebareli, has been taken up for analysis. Canal induced waterlogging can be clearly observed on the satellite image, mainly along the Sharda-Sahayak main feeder and Jaunour branch. Such conditions have been identified by dark blackish tone. Besides, areas of dark pinkinsh tone and smooth appearance indicate areas susceptible to water logging. (Agarwal and Garg, 2001)

WAPCOS (2001) carried out waterlogging studies in seven command areas. MOWR sponsored a study on waterlogging in five canal commands covered under CAD programme, namely Ramganga canal command (Uttar Pradesh), Chambal canal command (MP), Ukai Kakrapar canal command (Gujrat), Gurgaon canal command (Harayana) and Nagarjunasagar right canal command (AP). The study was assigned to WAPCOS (India) Ltd. And has since been completed. Further MOWR (CAD Wing) has assigned to WAPCOS another study on similar lines for the seven commands representing diverse agro-ecological situations. The commands are: Sharda canal command (UP), Western Yamuna canal command (Harayana), Tungbhadra canal command (Karanatkta), Sri RamSagar canal command (AP), Mahanadi Delta stage-1 command (Orissa) and Mahanadi Delta stage II command (Orissa) and Kosi canal command (Bihar). The objectives of this study was to make a quick assessment of the problem of waterlogging due to rise in water table as well as drainage congestion based on available data and reconnaissance survey by way of delineation of problem area, identification of causes, and outlining preventive and remedial measures.

Dwivedi and Sreenivas (2002) have mapped the waterlogged area in a part of the Indira Ghandhi Nahar Pariyojana (IGNP). The IGNP area lies in Ganganagar and Bikaner districts of Rajasthan. The area is underlain by alluvial plain of Ghagghar river. The soil is aeolian in origin. The topography consists of dunes and inter dune depressions. Drainage are not well defined. Palaeo channels of Ghagghar are present. Subsurface lenses of gypsum and sandy clay are found at varying depths. The elevation varies from 167.5 m to 240 m. The area is in general devoid of trees except presence of some xerophytes. A part of the study area is visually interpreted. Landsat MSS 1975, 1985, IRS LISS-1 1990 and Landsat TM 1995 are used. The Denuded area respectively since 1985, 1999, 1995 are 115, 118 and 72 sq. km. The area with vegetation in all years is 756 sq. km.

Arora & Goyal (2002) discussed various causes of waterlogging in IGNP Stage I as high water allowance, excessive seepage from canals, continuous ponding of Ghaggar depressions, lack of use of ground water for irrigation and absence of natural drainage outfall, etc. They concluded that a comprehensive socio-economic survey must be undertaken to visualize negative socio-economic aspects of waterlogging.

Arora & Goyal (2003) highlighted the use of geographical information system (GIS) in development of conceptual groundwater model. Various layers of information such as canal network, recharge zones, subsurface geology and digital terrain model (DTM) of Hanumangarh and Sriganganagar districts were developed in GIS and were then transferred to finite difference grid for developing mathematical groundwater flow model of the area.

CHAPTER 5:

ASSESSMENT OF WATERLOGGING

Land degradation due to waterlogging and subsequent salinization and/or alkalinization has been so enlarged that it is now being regarded as a global environmental problem. It is, therefore, important to monitor land and water management scenarios causing severe land degradation and low productivity. Monitoring of waterlogged areas can be carried out by

i) Field surveys (Conventional Method)

ii) Remote Sensing

5.1CONVENTIONAL METHOD

Measurement of water table depth

To find the depth of the water table, open wells or observation wells are commonly used. Secondary data collected by the various state organizations or Central Ground Water Board are usually used to ascertain the problem of waterlogging. The data are obtained for pre-monsoon and post-monsoon period. The information thus collected is used to draw well hydrographs and depth of water table to prepare the maps subsequently. The well hydrograph would reveal the rising or falling trend of the water table at a given location while the water table map would give information on the extent and degree of the problem. Normally this type of map is used to justify the drainage project for an area. However, at certain places piezometers are placed to confirm the presence of hydrographic pressure.

Various surface geophysical methods, such as, resistivity method, electromagnetic methods are also used to measure the depth to water table. A new development in electromagnetic methods is the Ground Penetrating Radar (GPR), which can be used for investigations of waterlogged area. Ground penetrating radar is a nondestructive geophysical method that produces a continuous cross-sectional profile or record of subsurface features, without drilling, probing, or digging. Ground penetrating radar (GPR) profiles are used for evaluating the location and depth of buried objects and to investigate the presence and continuity of natural subsurface conditions and features.

Ground penetrating radar operates by transmitting pulses of ultra high frequency radio waves (microwave electromagnetic energy) down into the ground through a transducer or antenna. The transmitted energy is reflected from various buried objects or distinct contacts between different earth materials. The antenna then receives the reflected waves and stores them in the digital control unit.

5.2 REMOTE SENSING

5.2.1 GENERAL

Waterlogging information had been generated through conventional surveys using cadastral maps and/topographical sheets - a tedious, time-consuming and impractical process, especially in rugged or inaccessible terrain. The conventional means are however, not only difficult and time consuming but also laborious due to vagaries of the weather. It is prudent to use such emerging technique with an emphasis to its application in semi-arid areas. Remote sensing is one of the key tools in monitoring local, regional and global environmental issues. The development of aerial photograph interpretation and the subsequent advances in satellite remote sensing and image processing techniques have enabled the detection, mapping and monitoring of waterlogged areas (Venkataratnam 1980, Sharma and Bhargawa 1988, Dwivedi 1992, Wheaton et al, 1992) in a timely and cost-effective manner.

Satellite remote sensing coupled with Geographical Information System (GIS) has a powerful role in monitoring and mapping of surface waterlogged and drainage congested areas. Advantages of the information acquired by satellite remote sensing are of synoptic coverage, repetitive and the easiness to compare the data before, during and after monsoons.

Remote sensing data acquired in the visible, near infrared (IR) and short-wave infrared (SWIR) regions have shown encouraging results in providing information on spatial pattern of waterlogging (Kalubarme et al., 1981, Sahai et al., 1985; Sharma and Bhargava, 1988). Such studies have, however, enabled detection of waterlogged areas with either standing water (surface ponding) or a thin film of water at the surface or the land with wet surface, using Landsat-MSS and TM; and Indian Remote Sensing Satellite IRS-1A/-1B/-1C/-1D Linear Imaging Self-scanning Sensor (LISS-I, -II and -III) data.

Both pre- and post-monsoon period data are required for delineation of seasonally or temporally waterlogged area, and perennially waterlogged areas. Pre- and post-monsoon period satellite data for current as well as historical period have to be interpreted/analysed. The detection and delineation of waterlogged areas through computer-assisted digital analysis approach, is based solely on their spectral response pattern as seen in the image or as portrayed in the changes in spectral radiance or brightness temperature values of space-borne multi-spectral data. This, in turn, is a cumulative effect of terrain's relief, vegetation cover, wetness, etc. Since not only image elements but also associations in terms of terrain conditions, are taken into consideration while delineating waterlogged areas, instead of computer-assisted digital analysis approach, on-the-screen visual interpretation approach is also employed. In the FCC, water is represented by dark blue or black colour. Colour of shallow water sightly changes from dark blue to light blue. Waterlogged areas are, generally, confined to low-lying areas in the vicinity of the canal, local depressions and lower element of the slope. Such areas have either standing water or a thin film of water or surface wetness. And the areas subject to waterlogging due to rising ground water table do not manifest such surface features. Such areas support a healthy vegetation stand during summer when the evapo-transpiration is very high and the vegetation in the neighbouring areas virtually whither. This feature along with the observations on the depth of groundwater table could be used as a surrogate measure for delineation of areas subject to waterlogging due to rising ground water table.

Initially, a reconnaissance traverse of the area has to be made to assess the accessibility and to precisely locate sample areas. Having located sample areas, parcels of land which were interpreted as experiencing waterlogging condition have to be precisely marked onto the topographical maps and observations with respect to terrain conditions, namely land use/land cover, micro topography and surface drainage, waterlogging status, etc. have to be made after recording their precise location with the help of a Global Positioning System (GPS). Observations can also be made outside the sample areas randomly, in order to validate the relationship already established between image elements and salt-affected soils and waterlogged areas.

5.3 METHODOLOGIES ADOPTED IN INDIA

In India some of the organizations are working to delineate waterlogged area using remote sensing. The methodologies adopted by three national organizations are discussed below.

5.3.1. National Remote Sensing Agency (NRSA, 2001)

National Remote Sensing Agency, Hyderabad has carried out a waterlogging study in Mahanadi stage-1 command covering part of Orissa state. The approach essentially involves, data base preparation and a systematic on-the-screen visual interpretation of both concurrent as well as historical space borne multi spectral and multi-temporal digital data. Various steps involved are discussed hereunder:

Preparation of Database

Preparation of database involves geo-referencing, radiometric normalization and analysis and interpretation. A schematic diagram of the approach is appended as Figure 4, and the details of the steps involved are given hereunder:

Geo-referencing

The command area is covered in one Landsat-TM/IRS-1D LISS-III scene, and spread over in four IRS-1A/1B LISS-II scenes. To begin with, the IRS-1D LISS-III data of the command area acquired during May, 1999 was digitally co-registered to Survey of India topographical maps at 1:50,000 scale and resample to 24m spatial resolution using first-order polynomial transform using ERDAS/IMAGE software version 8.4. The digital data, thus generated, was used as a reference for geo-referencing other satellite data sets. Subsequently, the Landsat-TM digital data co-registered to reference database and resample to 30mx30m pixel. Similar exercise was carried out for digitally geo-referencing other dataset too. Furthermore, since four IRS-1A LISS-II scenes cover the command area, in order to have a full coverage of the command, the individual LISS-II scenes were geo-referenced to the reference database and then a mosaic of the digital data was made.

Map Finalization

The ultimate delineation of waterlogged areas from space borne multi spectral data was accomplished through on - the - screen visual interpretation of satellite data on a Silicon Graphics workstation using ERDAS/IMAGE software version 8.4. To begin with the IRS-1D LISS-III data of October 1999 was displayed onto colour monitor of the Silicon Graphics workstation and a blank vector layer was overlaid onto the image. The areas, which were delineated as waterlogged during preliminary visual interpretation, were then located in the image. Boundaries of waterlogged areas were then drawn in the vector layer, which was already superimposed over satellite image, vis-à-vis field observations, and relief information from topographical maps and ground water table data from Command Area Authority, Mahanadi Stagte-1 and Central Ground Water Board (CGWB), Ministry of Water Resources, Government of India. Due care was, however, taken to avoid inclusion of water bodies in the waterlogged areas. The waterlogged areas, thus delineated, were basically, seasonally or temporarily waterlogged and were used as a reference for mapping of waterlogged areas from pre-monsoon period satellite data. Similar exercise was carried out for delineation of perennially waterlogged areas from Landsat-TM data of May 2000. The areas, which exhibited, waterlogging conditions during both the periods' i.e. pre- and post- monsoon, were categorized as permanently/perennially waterlogged while those experiencing waterlogging condition only during post-monsoon period were categorized as seasonally/temporarily waterlogged. Similar approach was followed for delineating waterlogged areas and salt-affected soils from historical period data too.

For delineating salt-affected soils, soil samples collected during field visits were analyzed in the laboratory for pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP), and based on these parameters were classified to portray the nature and magnitude of the problem.

Map Compilation and Area Estimation

As mentioned earlier, the waterlogged areas were digitized on the colour monitor of the using ERDAS/IMAGE version 8.4, and the vector coverage was generated and its topology built. Corrections were then carried out wherever necessary. Final coverage was unioned with the block boundary coverage to generate unique polygons having block as well as waterlogged class-identification (ID). This process helped in generating class as well as doab-area statistics. The maps, thus generated, were composed and printed; and the spatial extent of each category of salt-affected soils and waterlogged areas was then computed.

Change Detection

For monitoring the spatial extent and distribution of waterlogged areas, and salt-affected soils IRS-ID LISS-III data of October 1999, and Landsat TM data of May 2000 were used as a reference. Areas subject to waterlogging and soil salinity during period were then delineated from corresponding period satellite data following aforesaid approach. Subsequently, the change in the spatial distribution of waterlogged areas and salt-affected soils during the periods 1988-89, 1998-99 and 1999-2000 was estimated/calculated.

5.3.2. Regional Remote Sensing Service Centre (RRSSC, 2001)

Regional Remote Sensing Service Centre, Jodhpur has carried out a study on "Assessment and monitoring of waterlogging and soil salinity/alkalinity in Kosi command area using remote sensing".

The methodology consists of following steps (Figure 5).

1. Preparation of various masks
2. Digital database creation
3. Demarcation of waterlogged areas
4. Identification of salt affected areas
5. Ground truth acquisition and finalisation of results
6. Demarcation of critical areas in terms of depth of water and their correlation with waterlogging areas due to surface ponding

Preparation of Various Masks

For the extraction of study area and inclusion of other cultural details, masks for various features were prepared/created. The masks prepared are, study area, canal transport network including road and rail, rivers, districts etc. The methodology adopted for generation of different layers is as follows:

- Thematic manuscript preparation: The theme maps are traced from respective sources, viz. SOI toposheets, maps obtained from canal authorities etc. and scanned to be put in the computer. Using the UTM projection, coverage for study area was prepared with following parameters:

  Bounds $25^0 15'$ to $26^0 45'$ N latitude, $85^0 45'$ to $87^0 45'$ E longitude

- Coverage editing: The coverage thus prepared was edited for the cartographic errors incorporated during tracing or scanning. All the dangle errors, sliver polygons were removed in this process.
- Attribute coding verification: Attribute values were filed to all the polygons and arcs of different coverage. These are also verified to check for any errors.

Digital Database Creation

Digital database creation involves the procedure to remove non-systematic distortions, orient the image in N-S direction and registration of all images with respect to each other.

Geo referencing of Image

To orient the image in north south direction and to remove non-systematic distortions Survey of India toposheets were used. Ground control points, which were common on both image and map, were selected. Second order transformation model was used which removes all the errors of scale, rotation, translation and warping. The points were selected in such a way that they were well distributed over the area and the residual error was less than one pixel. The image was oriented in north direction with this procedure. Rabi season satellite data was initially used for geo referencing the image.

Registration of Images

Once the Rabi image is oriented in North direction the other date images, viz., Kharif and summer were registered with Rabi image. Ground control points, which are common on both images, are selected and second order transformation is used. The roots mean error between points is less than half pixel in this case. The images are registered with respect to each other. Now the database is ready for further analysis.

Demarcation of Waterlogged Areas

For the demarcation of waterlogged areas data pertaining to all the three seasons are used. Following steps are carried out:

Study of FCC

On the computer terminal three bands of satellite data are loaded. Red colour is given to Infrared band; green colour to red band and blue colour is given to green band of satellite data. This showed the area in false colour composite where the entire red colour represents various types of vegetation. Water is represented by dark blue or black colour. Colour of shallow water slightly changes from dark blue to light blue. Analysis of spectral response curve of water is done to understand its behaviour in various conditions. The prominent waterlogged areas are marked after ground truth.

Demarcation of waterlogged area

Logical procedure or methodology as shown in Figure 6 is used for identification of three season-waterlogged area from three seasons FCC. Waterlogged areas are classified using respective season scenes. The area where standing water is seen on the satellite data is demarcated as waterlogged area.

Using the sequence of steps as shown in Figure 6, different stages of waterlogging are obtained. After individual season analysis, the output is aggregated together. Overlapping areas are demarcated as different category. If waterlogging is found in Kharif and Rabi data then the area is marked as waterlogging in two seasons. When waterlogging is found on same parcel of land in all the three season, then that parcel is demarcated as waterlogged throughout. Following logic as shown in Table 2 is applied to identify different stages of waterlogging.

Table 2 : Logical rules for demarcation of different stages of waterlogged areas.

Analysis of kharif data	Analysis of rabi data	Analysis of summer data	Result
Water	Land	Land	Waterlogging in kharif or land not available for cultivation in kharif
Water	Water	Land	Waterlogging in Kharif and Rabi or land not available for cultivation in Kharif as well as in Rabi season
Water	Water	Water	Waterlogging in all the season or land not available for cultivation throughout
Land	Water	Land	Land not available in rabi only

Collection of Ground Information

The waterlogged areas were finalised after visiting some representative part of the study area. Major patches of waterlogging are checked on the ground and verified for their stages during different season.

5.3.3 National Institute of Hydrology

A study for muktsar district, Punjab was carried out using IRS LISSIII data. For image processing Earth Resources Data Analysis System (ERDAS) IMAGINE 8.6 and for GIS purpose such as digitization etc. Integrated Land and Information System (ILWIS) have been used.

CREATION OF DATA BASE

Preparation of base map

The base map of the study area has been prepared from topographical map. This map was then converted to digital form in ILWIS software. The projection is polyconic with central meridian 76^0 30' 00' and false easting 50000 m, geoid Everest and datum Indian (India, Nepal). As the satellite data processing was carried out in ERDAS system, therefore the base map was imported to ERDAS.

Processing of remote sensing data

In this study, digital analysis of four IRS 1C-LISS III scenes were carried out for identifying the waterlogged area. The following steps were used in the analysis:

Import and Visualisation

The data of IRS-1C satellite LISS-III sensor for four dates were loaded on the computer from the CD-ROM and was imported in the ERDAS 8.6 system. Initially, a False Colour Composite (FCC) of 3, 2 and 1 Bands combination was prepared and visualised. Each individual band was also visualised one by one.

The four images were registered with the base map. For carrying out the registration, some clearly identifiable Ground Control Points (GCPs) like crossing of rivers, canals, sharp turns in the rivers, bridges, road/ canal intersections etc.were located on both the image and base map. A polynomial transformation of first order was performed and re sampling was done using the nearest neighbour interpolation method. After completing the geo referencing data covering the study area was extracted for further analysis.

WATERLOGGED AREA ASSESSMENT

In this study waterlogging areas have been mapped for pre and post monsoon season for the year 2000-2001. For pre monsoon March 2000 and for post monsoon September 2000 data have been considered. The other two dates i.e. Feb. 2001 and November 2000 have also been considered.

Though spectral signatures of water are quite distinct from other land uses like vegetation, built-up area and soil surface, yet identification of water pixels at the water/soil interface was found to be difficult. Deep-water bodies have quite distinct and clear representation in the imagery. However, shallow water/turbid water can be mistaken for soil signature mix with water pixels.

Secondly, it may also be possible that a pixel, only at the soil/water interface, may represent mixed conditions (some part as water and other part as soil). Just by looking at the tone and colour of a pixel it is difficult to recognise the difference between suspended sediment and shallow water, since it is basically the same material with the same reflection properties. Therefore, very shallow water will have the same colour and brightness as very turbid (high concentration of suspended sediment) water.

There are many possible methods for identifying water versus non-water areas using satellite data have been applied. Initially supervised and unsupervised classification approaches did not produce very satisfactory results. Other data transformations and image processing methods have also been tried and discussed below.

Density Slicing of Single Band

In many studies Landsat data (TM and MSS), IRS or SPOT have been used to determine the extent of water bodies/waterlogging using simple classification procedures, usually with an infrared band. These studies have relied on the water bodies having a unique spectral response in this range of Electro Magnetic Radiation (EMR) when compared to the surrounding landscape. The infrared band classification gives a much better representation in the water related features than do the visible bands. The range of the density slicing determined from the water training areas covers almost the entire range of the data in each visible band. Each of the visible bands displays a unimodel histogram with no indication of a separate group of data for water pixel. The infra red bands display a bi-model histogram with a darker mode consisting mostly of water pixels. The density slicing ranges for infra red band starts at near zero, meaning that water pixels are the darkest in the image.

Then method based on water index approach has been applied and it is explained as follows.

NDWI Approach

The Normalised Difference Water Index (NDWI) is calculated as follows:

$$\mathrm{NDWI} = \frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \qquad (2)$$

When equation (2) is used to process a multi spectral satellite image that contains a reflected visible green band and an NIR band, water features have positive values; while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI is then from zero to one. Multiplying equation (2) by a scale factor (e.g. 255) enhances the resultant image for visual interpretation. Now in the output obtained water related features were identified.

In the present study, modelling technique was used to identify the water pixels using data of different bands. After, analysing the spectral reflectance of water pixels in all the images, an algorithm was developed and used to identify water pixels using data of different bands. The algorithm matches the signatures of a pixel with that of water and then identifies whether a pixel represents water or not. In addition, it also checks for the NDWI (Eq. 2), which is created as a separate image. The algorithm checks for the following condition for each pixel. If the condition is satisfied, then the pixel is recorded as water, otherwise not.

"If the DN value of NIR band of a pixel is less than the DN value of the Red band and the Green band, and the NDWI is ≥ threshold value, then it is classified as water/waterlogged, otherwise not".

Tasseled Cap Transformation

There are numerous methods available for enhancing spectral information content of satellite data. The Tasseled cap transform compressed the total information into three bands: greenness, brightness and wetness. Besides expressing a large amount of image variability within three bands, tasseled cap bands could be directly related to physical scene characteristics.

A Tasseled cap transformation to data from the Landsat TM has been given (Crist and Cicone, 1984). The coefficients for wetness functions are:

TM Band	1	2	3	4	5	6	7
	0.1509	0.1793	0.3299	0.3406	0.306	-0.7112	-0.4572

One of the main reasons for supporting the use of the Tasseled-Cap Transformation method against, for example, the principal component technique is that the coefficients of the transformation are defined a priori. This method was applied on IRS LISS III, taking the above coefficients, as these are not available for LISSIII data. The above wetness function was applied and threshold value of 0.0 to 53.62 for March and 0.0 to 61.2 for September and 0 to 49.82 for

Feb. have been taken for water features. Similarly threshold values for waterlogged area for the month of March is taken as 53.62 to 61.3, for September values are taken as 61.2 to 68.0 and for Feb. the values are 49.82 to 52.3.

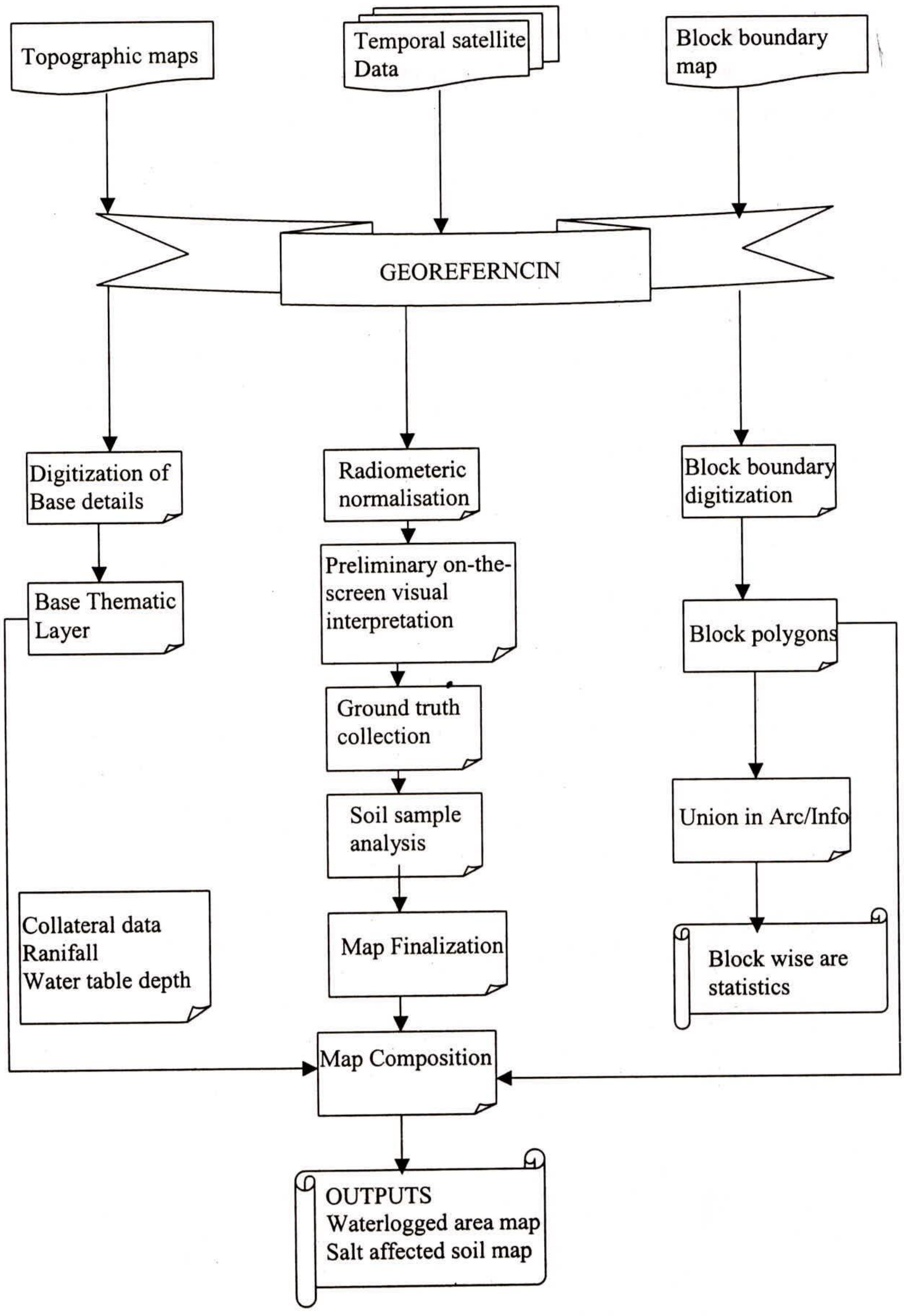

Figure 4: Schematic diagram of the

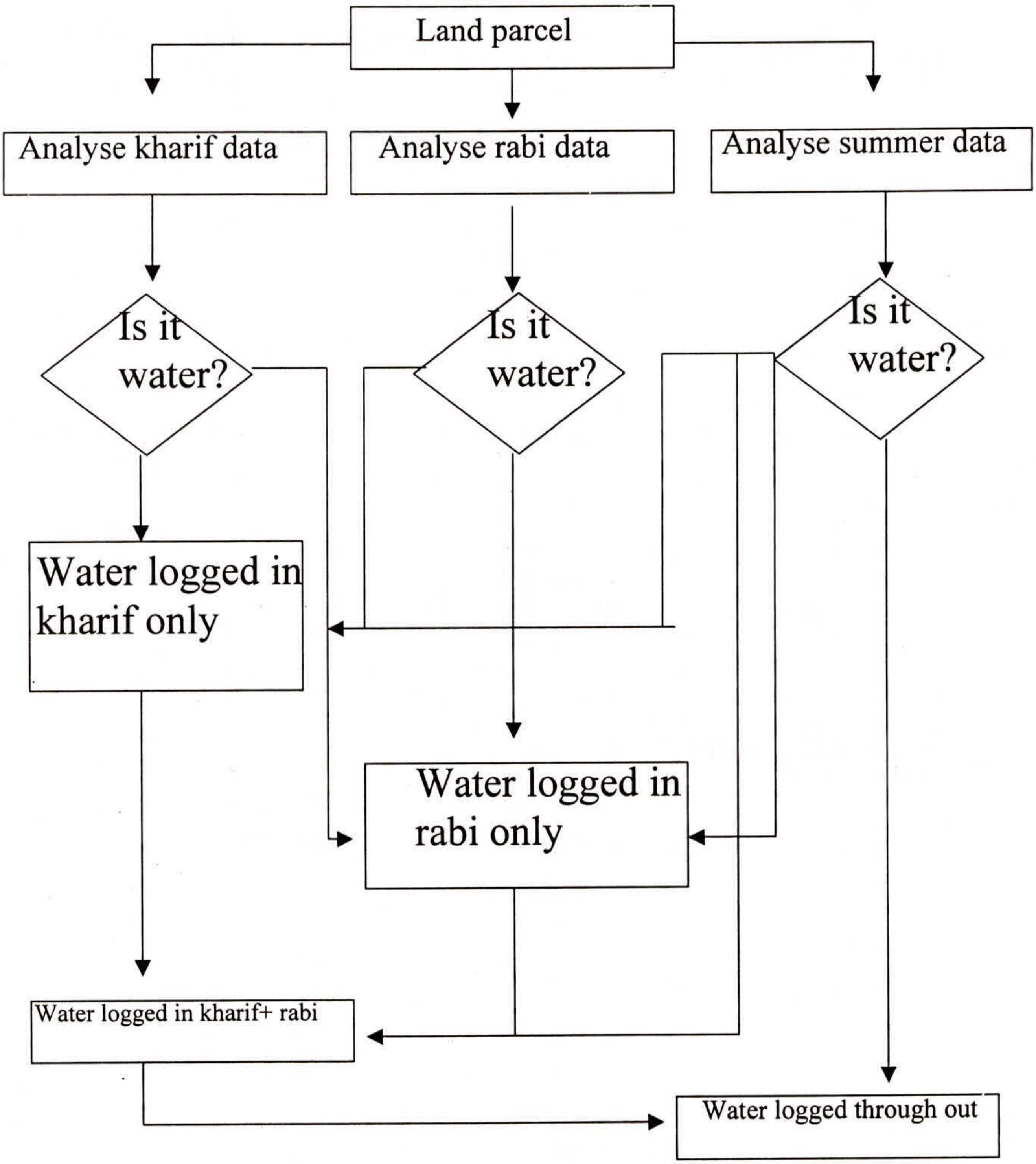

Figure 5: Flowchart depicting methodology for demarcation of waterlogged areas

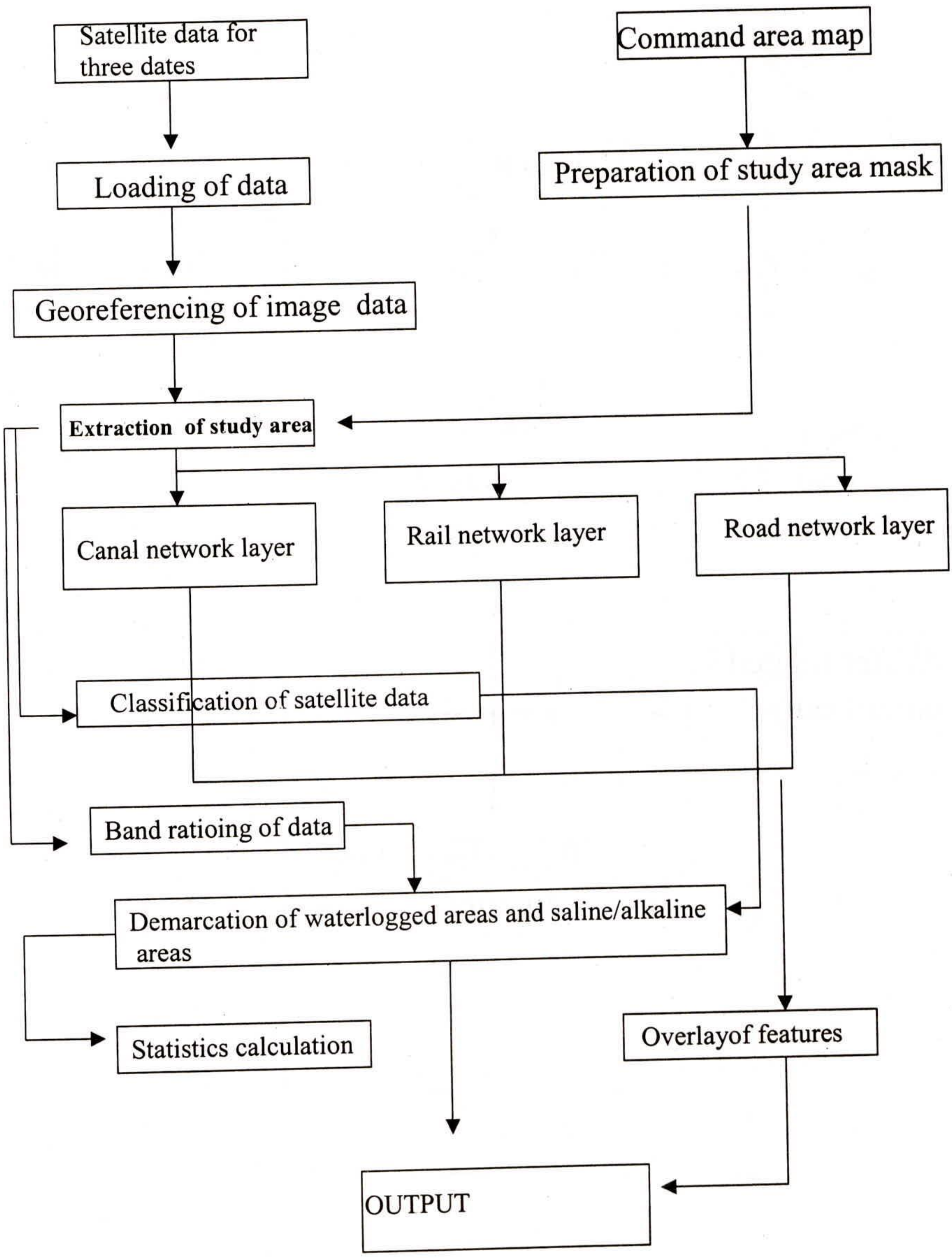

Figure 6: Flowchart depicting methodology for waterlogged and salt affected areas

CHAPTER 5

CONLCUDING REMARKS

Waterlogging has been increasing in many of the developing countries. Water is a scarce resource in these areas and loss of productivity caused by overuse and misuse of water has to be checked. In the command areas, waterlogging has been found to be associated with local depressions and lower elements of the slope with fine textured soils having poor surface and subsurface drainage. Furthermore, temporal variations in the extent and spatial distribution of waterlogged areas are associated with the hydrological conditions of the terrain, which, in turn are, governed, by the quantum, duration and spatial distribution of rainfall, inflow in the canals. The probable causes of waterlogging include large number of factors such as ground water recharge, surface irrigation, cropping patterns, soil characteristics, seepage from field channels and distributaries, poor land development, lack of proper drainage and lack of a comprehensive land use policy. Timely and reliable information about the extent of waterlogging, and on extent of salt affected areas in time domain is pre-requisite for optimum land utilization.

A number of remedial measures can be taken for prevention of waterlogging, such as, conjunctive use of the surface and the groundwater, canal lining, surface drainage, horizontal drainage, subsurface drainage, bio drainage, water management, and adoption of suitable cropping pattern.

Conventional methods have been used for waterlogging studies on the basis of ground water depth etc. Application of geophysical methods such as ground penetrating radar (GPR) and infrared thermography to assess waterlogging has become possible as data handling has become more and more accurate.

Satellite remote sensing coupled with Geographical Information System (GIS) has a powerful role in monitoring and mapping of surface waterlogged and drainage congested areas. Advantages of the information acquired by satellite remote sensing are of synoptic coverage, repetitive and the easiness to compare the data before, during and after monsoons. Two techniques for interpretation of satellite data are in use viz. visual interpretation and digital image processing.

Visual interpretation of an image is an important way of extracting information from remotely sensed data. The chain of processes in visual interpretation of the features in an image begins with detection using tone/colour, size, shape, texture, pattern, location, association, resolution and other features. The presence of high soil moisture and shallow standing water is indicated by bluish tone in FCC. The perennial vegetation could be identified from its characteristics pink or red colour. A systematic on screen visual interpretation of space borne multi spectral data enables generation of information on the nature, extent, spatial distribution and temporal behaviour of waterlogged area and salt affected soils.

Computer-aided analysis of digital data has the added advantage of examining a large quantity of data and objectively classifying it quickly according to guidelines established by pattern recognition algorithms and by analyst. Computer-aided analysis of spectral data based on pattern recognition technique either utilizes unsupervised (Clustering) method of classification or the supervised (training sample) method of classification. Methods such as band ratioing provide additional information. The NDVI and NDWI provide extent and health of vegetation and water characteristics.

The methodologies adopted by NRSA, RRSSC, Jodhpur and National Institute of Hydrology has been discussed. The methodologies involve transformation of spectral reflectance of water related features for classification of waterlogged areas. These methods are required to be tested on command areas in different hydrological regions.

REFERNCES

Anjanevalu, 1972 In, Varshney. R.S (1992), "Necessity of demarcating water logging and drainage limits", Proceeding of 5th International Drainage Workshop, Lahore, Pakistan, ICID – CID, WASRI, Vol 11, 1.7-1.17).

Agarwal, C.S. and P.K.Garg, 2000, Text book on Remote Sensing in natural resource monitoring and management, Wheeler Publishing, A division of A.H. Wheeler & Co. Ltd.

Anonymous, 1991, "Water logging, soil salinity and alkalinity", Ministry of water Resources, Govt. of India, New Delhi.

Arora, A.N. and Goyal, Rohit (2002). Environmental and Socio-Economical Impacts of Waterlogging in Hanumangarh and Shri Ganganagar Districts. Nature Environment and Pollution Technology, 1 (3), pp. 307-316.

Arora, A.N. and Goyal, Rohit (2003). Conceptual Groundwater Modeling using GIS. GIS India 2003, National Conference on GIS/GPS/RS/Digital Photogrammetry and CAD, Jaipur.

Bahadur P, 1996, "Strategy to take effective, preventive measures to check and manage potential problem areas in the irrigation Commands, role of Conjunctive use of surface and ground water to deal with such problems with case studies", proceeding of National Workshop on "Reclamation of waterlogged Saline and Alkaline Lands and Prevention there of, New Delhi.

Bhatt V.B.(1994), 'Problem of waterlogging and its reclamation through integrated remote sensing techniques', in R.K. Gurjar, 'Irrigational environment', Print well, Jaipur, pp. 151-157.

Bowander, B and C. Ravi, 1984, "water logging from irrigation projects", An environmental management problem, Centre for Energy and Technology, Administrative staff college of Inida, Hyderabad.

Chatterjee C., Rakesh Kumar and P. Mani (2003) Delineation of surface waterlogged areas in parts of Bihar using IRS-1C LISS-III data. Photonirvachak- J. Ind. Soc. Remote Sensing, 31(1), 57-65.

Choubey V.K. (1997), 'Detection and delineation of waterlogging by remote sensing techniques', Jou. of Ind. Soc. Of R. S., Vol. 25 (2), pp. 123-135.

Choubey V.K. (1994), 'Assessment of waterlogged area in IGNP stage-1 by remote sensing techniques', National Institute of Hydrology, Roorkee, 30p.

Dhawan, B.D., 1993, Indian water resources development for irrigation: Issues, critiques and reviews, New Delhi: Commonwealth publishers.

Desai, C. C, Aggarwal J.R, Subrimaniyans, 1991, "water logging, soil salinity and alkalinity", Ministry of Water Resources, Gov. of India, New Delhi.

Dwivedi R.S. (1994) 'Study of salinity and waterlogging in Uttar Pradesh (India) using remote sensing data, Land degradation and Rehabilation, Vo. 5, 191-199.

Dwivedi R.S. and K. Sreenivas (2002) 'The vegetation and waterlogging dynamics as derived from spaceborne multi temporal data' International J. of R. S., vol. 23 (8), pp. 1589-1599.

Dwivedi R.S., K. Sreenivas, K.V. Ramana (1999) 'Inventory of salt-affected soils and waterlogged areas: a remote sensing approach', International J. of R. S., vol. 23 (14), pp. 2729-2740.

Dwivedi R.S. and K. Sreenivas (1998) 'Image transforms as tool for the study of soil salinity and alkalinity dynamics, International J. of R. S., vol. 19 (4), pp. 605-619

FAO/UNESCO (1973) In: Sinha, A. K. (1993). " Crop and water management under shallow water table condition", proceeding: A capsule course on basics of subsurface drainage extension, held at IARI, May 31- June 6, 1993.

Farmji, K.K. (1974),"Review of waterlogging and drainage problems and their solution in India", ICID Bulletin, 36-40.

Government of India, 1994, Guidelines for watershed development, Ministry of Rural areas and employment, New Delhi, Department of Wasteland development, GOI.

Government of India, 1999b, Water Resources Development Plan of India: Policy and issues, New Delhi, National commission for integrated Water Resources Plan, Ministry of Water Resources, GOI

Gupta S.K. (2002), 'A century of subsurface drainage research in India', Irrigation and drainage Systems, 16(1): 69-84.

Jensen, John R. *Introductory Digital Image Processing: A Remote Sensing Perspective.* 2nd edition. Upper Saddle River, NJ: Prentice-Hall, 1996.

Joshi P.K. (1994), 'Effect of surface irrigation on land degradation- problems and strategies', in R.K. Gurjar, 'Irrigational environment', Printwell, Jaipur, pp. 38-48.

Kuntz, H. (1974) , Progress in Drainage, ICID Bulletin, (P24 – P26).

McFeeters, S.K., (1996). The use of Normalised Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7), 1425-1432.

Meijerink, A.M.J, H.A.M.Brouwer, C.M.Mannaerts, C.R.Valenzuela, 1994, Introduction to the use of Geographic Information Systems for practical hydrology, UNESCO IHP-IV 2.3, Publication Number 23.

MOWR (Ministry of Water Resources), 1991, Report of the working group on problem identification in irrigated areas with suggested remedial measures, Ministry of Water P.esources, Government of India, New Delhi.

National Commıssionon Agriculture (1976). In: WAPCOS/I MTP(1988). Handbook for drainage of irrigated areas in India, Technical report no 5.

Navalawala, B.N., Waterlogging and its related issue in India. In :Irrigation drainage, international and national perspectives Edited by Rakesh Hooza, S.N.Mundra and Sewa Ram, Agro Tech Publishing Asademy, Udaipur, 2000.

Penning-Rowsell E.C., D.J. Parker, D.M. Harding (1986), 'Flood and drainage', Risks and Harzards series-2, Allen and Unwin, London, 199p.

RRSSC, 2002, Assessment and monitoring of waterlogging and soil salinity/alkalinity in Kosi command area (Bihar) using remote sensing techniques, RRSSCJ/PR/2002/4,

Rao, KV GK, 1996, "Drainage of waterlogged saline soils of India", Proceeding of National workshop on Reclamation of waterlogged saline and Alkaline lands and prevention thereof Gov. of India Ministry of Water Resource New Delhi.

Sabins, Floyd F. *Remote Sensing: Principles and Interpretation.* 3rd edition. New York: Freeman, 1997.

Saeed M.M, Ashraf M., Bruen M. (2002), 'Diagnostic analysis of farmers' skimming well technologies in the Indus Basin of Pakistan', Irrigation and Drainage Systems, 16(2): 139-160.

Saksena K.K. (1994),'waterlogging and salt problem, in command areas- causes and remedies', in R.K. Gurjar, 'Irrigational environment', Printwell, Jaipur, pp 11-15.

Smedema L.K., Walter J.O. (1998), 'Needs and prospects for improved drainage in developing countries', Irrigation and drainage systems 12(4): 359-369.

Smedema L.K., Walter J.O. (1998), 'The state of land drainage in the world', In :Irrigation drainage, international and national perspectives Edited by Rakesh Hooza, S.N.Mundra and Sewa Ram, Agro Tech Publishing Asademy, Udaipur, 2000.

Shah, Mihir, Banerji, D., Vijayshankar, PS and Ambasta, P, 1998, India's Drylands: Tribal societies and development thorugh Environmental Regeneration, New Delhi: Oxford University Press.

Sharma R.C., G.P. Bhargava (1988) 'Landsat imagery for mapping saline soils and wet lands in north-west India', International J. of R. S., vol. 9 (1), pp. 39-44.

Sewa Ram, 1996, "Environmental Concerns in irrigation like water logging soil and water salinity and Alkalinity: Their norms and diagnostic methodology for efficient water utilization and sustainability", Proceeding of National Workshop on Reclamation of waterlogged saline and Alkaline lands and prevention thereof.

Sharma L.N. (1994), 'Negative impact of irrigation', in R.K. Gurjar, 'Irrigational environment', Print well, Jaipur, pp. 31-37.

Tanwar B.S 1986 Waterlogging and Salinization in India- Remedial measures, proceedings-workshop waterlogging and soil salinity in irrigated agriculture, CBIP/CSSRI New Delhi, PP 1-99.

WAPCOS, IMTP (1988). Handbnook for drainage of irrigated areas in India. Technical report no. 5, Irrigation Management and Training Project.

Yadav, J.S.P, 1973, Progress Report. "All India Coordinated Project for research on water management and salinity" P. 158.

Vaidyanathan, A., 1999, water resources management: institution and irrigation development in India, New Delhi, Oxford University Press

WAPCOS (2001), Study of waterlogging in seven canal commands, Water and Power Consultancy Services (India) Limited, November, 2001.

World Bank, 1998, India water management sector review, irrigation sector, New Delhi, The World Bank

World Bank, 1991b, India irrigation sector review, Vol. 2, Washington, The World Bank

World Bank, 1994, Harayana water resources consolidation projects: Staff Appraisal project, New Delhi, The World Bank

DIRECTOR : Dr.K. D. Sharma

STUDY GROUP

Dr. Sanjay K. Jain, Scientist 'E1'

Mr. D. S. Rathore, Scientist 'E1'

Dr. Sudhir Kumar, Scientist 'E1'