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REMOTE SENSING AND GIS APPLICATIONS IN ZONATION OF WATERLOGGING IN IRRIGATION COMMAND

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PREFACE

Water in irrigation command areas is essential for successful agriculture. It is the cause of many associated problems such as waterlogging and salinity. Development of waterlogging in irrigation commands are experienced world over. To assess waterlogging in command areas, multispectral and multi temporal remote sensing data are very useful. Remote sensing technique is cost and time effective. The satellite data thus provide a quick and more reliable delineation of the water-logged areas and standing water. Whereas, the ground data provide the information below the surface but because the data is sparse and thus do not provide the detailed information. Therefore both the data remote sensing as well as ground water data are required to be suprimposed together to extract maximum possible information. In the present study waterlogging zoning have been carried out in Rohtak and Jajjhar district, Haryana state that falls in western Yamuna canal command area. For this study satellite data of the years 1996-97 and 2000 have been used. A field visit of the study area was also carried out to collect groundtruth information and field data. Also ground water level data of the last ten years have been collected from state departments and used in the present study. A DEM of the study area was also prepared to see the effect of topography.

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ABSTRACT

Waterlogging is one of the major land degradation processes that restrict the economic and efficient utilization of soil and land resources in command areas. The natural land physiography, climate and geomorphology play important roles in the developments of these problems, independently or in combination. The application of excess irrigation and recharge from irrigation distribution network causes gradual rise of ground water table and creates waterlogging. The excess soil moisture (waterlogging conditions) affects crop growth because of deficient aeration. Reliable and accurate mapping of areas affected by these processes with their location and extent can be extremely useful in chalking out suitable water management strategies and also to undertake remedial measures to prevent their advancement.

To asses waterlogging in command areas, multispectral and multi temporal imagery are very useful. Remote sensing technique is cost and time effective. The satellite data thus provide a quick and more reliable delineation of the water-logged areas and standing water. Keeping this in view, in the present study waterlogging area zonation was carried for a part of command area falling in Rohtak and Jhajjhar districts. For this study, IRS LISS III data of pre and post monsoon season have been used. Survey of India toposheets has been used to see the topography of the area. Ground water level has been collected and condition of ground water level was depicted. On the basis of results of remote sensing data, DEM and ground water data seasonal and permanent waterlogged area have been delineated and the results obtained have been discussed.

1.0 INTRODUCTION

1.1 GENERAL

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 Kharif crop cultivation 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 implications of a canal irrigation project such as climatic changes, pollution of surface and groundwater, waterlogging, soil salinity, health hazards etc. Several examples are available to show that 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, water logging and salinity threaten works. 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).

Likewise overexploitation of groundwater results into mining of the groundwater reservoir and permanent lowering of the water table regime thereby adversely damaging the environment. The local open wells go dry, the regeneration in adjacent natural drainage is either reduced or the same becomes influent. This seriously effects the social life of the local inhabitants and the cattle life, as much as other commitments on the otherwise affluent drainage system.

There are no universally accepted criteria to declare a land waterlogged. Different states have followed different norms (Report working group, 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 water logging. The working group (1991) set up to identify areas suffering from waterlogging and salinity estimated that an area of 2.46 Mha has been waterlogged and the CWC estimated 1.61 Mha was affected by waterlogging mostly due to rise in water table.

The working group on Problem Identification in Irrigated Areas of Ministry of Water Resources (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) suggested 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 can be different approaches to express the water table depth below soil surface such as:

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

Depth of water table post monsoon (Oct/Nov)

Average water table depth over a season or year

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

Whereas the 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 depth and successful crop production of kharif crops. Equally important is an optimal low water table at post monsoon keeping in view timely plantation and successful crop production of rabi crops.

Keeping in view these considerations, the following norms are 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 areas

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.

The area affected by waterlogging in different irrigation commands as reported by the working group indicated that nearly 11 percent of the area has been affected by waterlogging. Area irrigated by water harnessed through Major and Medium Irrigation projects are estimated to be 26 Mha. On this basis also it works out that an area of about 2.9 Mha may be affected by the problem of waterlogging as a result of rise in the water table.

Large tracts of lands are threatened by waterlogging and rise in salinity levels in southwestern Punjab and the adjoining areas in south Haryana. In these regions large areas are underlain with poor quality ground water which continues to rise largely due to limited exploitation of this ground water and inadequate natural and artificial drainage. Waterlogging and secondary salinization has already manifested in significant areas. Sutlej and Yamuna rivers form the western and eastern parts of these areas with the Ghagger draining through the basin and becoming ephemeral in Rajasthan.

Haryana with its location between the Himalayan mountains on the north-east and the Thar desert on the south west bestows mainly inland drainage conditions or an extensive closed basin (Anonymous, 91). A topographical depression exists in the centre with its axis passing through Delhi-Rohtak-Hisar and Sirsa on the regional scale and ground water moves towards this depression. The central part of Harayana forms a saucer type of depression. Both surface and ground water flows towards this depression, resulting in problems of rising water table, water-logging, flooding after heavy rainfall and soil salinization.

1.2 CAUSES OF WATERLOGGING (Bhatt 1994):

Waterlogging condition develops due to excessive rainfall and poor surface drainage in areas. This may increase infiltration and thus causes rise in the water table. Excessive irrigation will increase seepage of the water in to the ground and thus abating the waterlogging. Subsoil flow from higher elevation can also cause waterlogging.

The waterlogging is caused due to inadequacy of the drainage. This may arise due to clogging of the natural drains by silts and aquatic vegetation and will require cleaning. Any natural or artificial barrier in the ground water flow can cause the waterlogging such as grouting of the foundation of the reservoirs.

Depressions and flat areas with impermeable strata at shallow depths overlain with pervious strata also get waterlogged. The rise in the water table can accentuated by the subsoil characteristics for certain areas. For example in Indira Gandhi canal in the Western Rajasthan, the waterlogging condition is created due to the impermeable subsurface soils. In the non irrigated and less irrigated areas, this condition does not exists (Sharma 1994, Choubey 1994).

1.3 REMEDIES

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

Conjunctive use of the surface and the groundwater: It is stated that in case of the good groundwater quality for the irrigation, the conjunctive use of the surface and the groundwater can be done. This acts as vertical drainage of the excess water. After the draft in the groundwater, the aquifer is replenished by the seepage etc. A part of the water again recharges the groundwater and another part is evaporated and transpired.

Canal lining: The areas where the groundwater quality is poor, the canal lining can be used. In Punjab and Harayana, increase in crop acreage and the cropping intensity have been recorded in appraisal studies of the canal lining.

Horizontal drainage: The horizontal drainage can be as surface and subsurface.

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

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

Floods: Floods can cause waterlogging in the areas with drainage congestion, low lying area and areas with low infiltration capacities. Floods will cause waterlogging in such areas and will cause loss of income to the farmers in the years of floods.
Resource opportunities: The waterlogging can be seen as a resource opportunity and various measures namely fisheries, cultivation of reeds, fertilizers e.g. blue-green algae, lotus farming can be taken up.

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 effect drainage through evapotranspiration.

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

1.4 OBJECTIVES

In the present study, the objective is to study the waterlogging in a part of irrigation command using remote sensing data. For this purpose IRS LISS III data of different dates will be used. The analysis is proposed to be carried out on ERDAS IMAGINE software. Besides using remote sensing data, Survey of India toposheets and ground water depth data were also used. A field visit was made to know the field condition and to collect the field information.

2.0 REVIEW OF LITERATURE

The irrigated areas in arid and semi-arid tracts generally develop the problem of watertable rise resulting in waterlogging and soil salinisation. In India where there has been progressive increase in area under irrigation from 22.6 m ha in 1950-51 to more than 80.8 m ha in 1990-91, the salinity and waterlogging problems are growing with equally rapid speed. Causing partial or complete crop failures, the twin problems of salinity and waterlogging reduce the benefits of irrigation potential created at a huge cost. There has been no accurate estimate of the areas affected by these problems. Framji (1984) reported that nearly 3.5 m ha area in India is waterlogged, a recent study (Bowander and Ravi, 1984) has put the figure of waterlogged areas in India at 10.0 m ha and the menace is increasing every day. Large areas of land even in newly commissioned irrigation projects like sarda Sahayak (State: Uttar Pradesh), Sri Ram Sagar (Andhra Pradesh), Indira Gandhi Canal Project (Rajasthan) and Tungbhadra (Karnataka) are going out of cultivation because of waterlogging and soil salinity problems. A Working Group of Ministry of Water Resources, Govt. of India had placed the reconciled figures of the extent of waterlogging and soil salinity to 2.50 mha in the country (Ann. 1991).

Several approaches exist for identification of waterlogged area mapping. A field research may serve precise data about intensity and area extent of waterlogging, but this approach is very expensive and time consuming for repetitive study of large areas. Also hydrologic simulation models of water flow in a landscape may provide good information on the extent of saturation and flooding areas (Ferance et al. 1994, Macmillan, 1994). In such models very precise input data (topographic, soil, precipitation, etc.) are required, which may be difficult to obtain for large areas. On the other hand these models can provide timely soil moisture information without necessity of field visit (Schmugge, 1980). Unique feature of remote sensing methods is the capability to record the data about a state of a landscape over large area in short time occasion. The desired information is consequently derived from these "synthetic" landscape data.

A property used for discrimination of water from other landscape objects is an overall decrease of reflectance (due to high transparency or absorption) of water in visible, NIR and MIR wavelengths. For soil moisture determination general inverse relationship between soil moisture content and soil reflectance is used. Spectral indices are widely used for emphasising of individual properties of objects. Group of indices sensitive for changes of soil moisture content uses either the measure of overall reflectance or a contrast of reflectance decreases in different bands.

Use of optical remote sensing methods for soil moisture content determination is limited only for thin surface layer of bare soil that controls soil reflectance. Moreover, measurement of soil moisture by remote sensing methods is influenced by other variables including soil composition, physical structure and observation conditions (Jackson et al. 1978). Foody, 1991 has stated that cultivation practices may produce significant variations in a soil moisture, with over 10 per cent difference between top and bottom of a ridged soil. Therefore expression of soil moisture and its measurement by remote sensing methods have to be taken carefully.

Provision of adequate sub-surface drainage measures has been recognized as the basis for any long term success in tackling the problems of waterlogging and soil salinity. Feasibility studies of sub-surface drainage in India were started as early as in 1925 at Chakanwali (Punjab, now in Pakistan) and in 1928 in Maharashtra. However, serious, though sporadic, attempts at drainage experiments were started in late sixties (Yadav, 1973, Pandey and Gupta, 1981 and Holsambre et al. 1982). Despite these experimental successes, the progress of drainage works in the country has been mearge and unsystematic. Lack of technical data, information and expertise, non-availability of funds, socio economic constraints and lack of proper organisational network were the major factors responsible for the slow progress. Recently concerted efforts through pilot projects have been made at Central Soil Salinity Research Institute (CSSRI), Karnal and other research and development organisations in the country to evaluate the drainage requirement of waterlogged saline soils in India. The Indo Canadian Rajasthan Agricultural Drainage Research Project is the largest project in progress in the country where the feasibility of subsurface drainage in reclaiming waterlogged saline soils of the Chambal Command is researched in all its aspects and aimed at providing subsurface drainage in about 20,000 ha. The features and results of drainage feasibility studies undertaken in the country have been reviewed.

FAO/UNESCO (1973) defined waterlogged areas as those where soils are saturated with water temporarily or soils having permanent ground water tables not far from soilsurface. Kuntze (ICID Bulletin, 1974) limits the depth of watertable to 1.3 m, while Framji (ICID Bulletin, 1974) defines waterlogged area as "land made useless by saturation with water. Where the watertable is within 1.5 m relative to the ground level, the lands are recognized as being fully damaged while with watertable 1.5 m to 3.0 m below ground, they are likely to get partially damaged". Anjaneyulu (1972) takes this desirable limit as 1.8 m. National Commission on Agriculture (1976) has defined an area as waterlogged when the watertable rises to an extent that the soil pores in the root zone of a crop become saturated resulting in the restriction of the normal circulation of air, decline in the level of oxygen and increase in the level of carbon dioxide. WAPCOS/IMTP (1988) also recommended adoption of the above definition.

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 and drainage pattern is used to map them visually. Tone 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 areal extent is 143 sq. km. Fifteen points are checked in the field through depth measurements in the dug wells and soil auger bores. The water table depth varies from 1 to 2.5 m. The scale of mapping is 1:250000.

Choubey (1994) has studied the waterlogging in the IGNP stage-1 in Rajasthan. The Landsat TM FCC of March 1990 at 1:250000 scale 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 comprise 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. The E.C. value is more than 8000 micro Siemens cm at 25 C. The value reduces to less than 2000 in other areas. 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 are respectively 39, 4, 0.8 and 1.6 of the total command of 5250 sq. km. The figures are based on survey by Command Area Development Authority in 1991 (Choubey 1994).

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 scrub land. 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 band 4 digital numbers (DN). The waterlogged and the susceptible area delineated are respectively 49 to 93 sq. km. and 144 sq. km.

Diwvedi and others (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 black soil texture is heavy (sandy clay to clay). The red and reddish- yellow soils are shallow to deep. The geology is granite- gneissic complex, sandstone, lime stone 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 in 13 km^2 area. The cause of waterlogging is storage of the water in the depressions. The presence of clay pan/ bed rock 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.

There is a long list of the irrigation command areas effected by the waterlogging problem in India. 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). In Euphrates vally, syria; lower Rafadain plain, Iraq, 50% irrigated land has waterlogging and salinity problem (UNEP 1989).

3.0 THE STUDY AREA AND THE DATA USED

3.1 THE STUDY AREA

3.1.1 General

The study area chosen for the present work is Rohtak and Jhajjhar districts falling in Western Yamuna canal command area. The location of the study area is shown in Figure 3.1. The extent of the study area is 3852 km^2. On the basis of local topography and the distribution of sandy and calcareous sierozemic soils, Haryana can be divided into three broad sub-divisions: (a) Eastern Haryana Plains (northern east districts including Rohtak), (b) Western Haryana Plains and (c) Southern Haryana plains (almost all of the southern and southern-east districts). The soils of this plain are river borne sand, silt and clay. The soil of the eastern districts of this state is very fertile.

3.1.2 Canal and drainage

The Delhi and Butana branches, of the Western Yamuna canal; and Jawahar Lal Nehru lift canal traverse the area. Diversion drains no 8, main drains no 8 and the Najafgarh drain is the main drain. Both the main drains no 8 and the Najafgarh drains are joined near the village Bhindwas (Jhajjhar distt.). The Jhajjhar district receives surface runoff from Rajasthan through the Sahibi and other river from the south. The surface runoff in the command area is received from the north in the Rohtak district. The area of northern catchment is reduced as part of the surface runoff is diverted in to the yamuna through the diversion drain no. 8.

The total catchment area, of which the Rohtak is a part, touches the Lower Shivalik in the north rivers (Chautang, Rakshi, Nai Nallah, Main drain no 8 and diversion drain no 8) and Aravalli Hills in the south (Sahibi and other rivers). A diversion drain takes off from northern river system, for diverting runoff to Yamuna from upstream of Gohana (Distt. Sonipat). Thus, catchment downstream of Gohana only contributes to the main drain no. 8 thereafter. The drain gets water from Isapur Kheri drain and Chappra drain.

Prior to 1960, there used to be extensive flooding in Rohtak. The Rohtak city was flooded in 1960 for nearly two months. Jhajjhar disticts was also flooded in 1960, 1963, 1964 and 1967 due to flood water from Sahibi river. With drainage measures taken such construction of diversion drain no 8 and many drains in Rohtak, the situation is now better. The main drain no 8 and Sahibi flood water drains through the Najafgarh drain. The Main drain no 8 and Najafgarh drains join at Surethi (Chowdhary 1983).

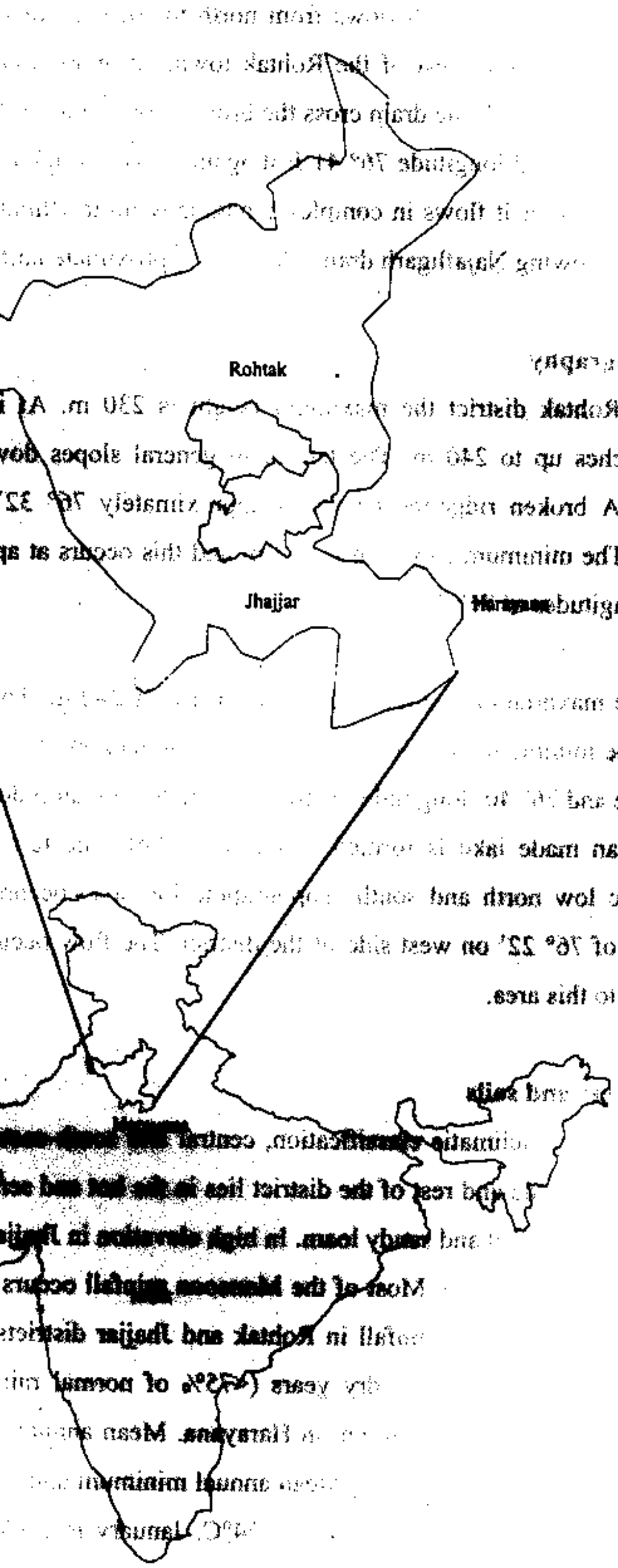

Fig.3.1 Study area

The main drain no. 8 flows from north to south at approximately 76° 31' alignment. The drain passes from west of the Rohtak town. At approximately latitudes of 28° 52' and longitudes of 76° 32' E the drain cross the broken north-south ridgeline to west of the ridge. At latitude 28° 42' and longitude 76° 41'E it again crosses to the east of the ridge in the Jhajjhar district. There after it flows in complex topography up to Bhindwas lake. From this point the west to east flowing Najafhgarh drain takes off (approximate latitude line 28° 32').

3.1.3 Topography

In Rohtak district the maximum height is 230 m. At isolated points the maximum height reaches up to 240 m. The terrain in general slopes downwards from north to south direction. A broken ridgeline passes at approximately 76° 32' E longitude in north south direction. The minimum elevation is 214 m and this occurs at approximately latitudes of 28° 37' and longitudes of 76° 25'.

The maximum elevation in Jhajjhar district is 240 m. This occurs in south west in the district. The minimum elevation is 212 m. The topographic low occurs on approximately 28° 33' latitude and 76° 40' longitude. At topographic low on latitudes of 28° 32' and longitudes of 76° 34' man made iake is formed (Bhindwas lake). The terrain slopes downwards to this topographic low north and south. Topographic low also occurs at latitudes of 28° 38' and longitudes of 76° 22' on west side of the district. The flow occurs from the southern areas of the district to this area.

3.1.3. Climate and soils

As per agroclimatic classification, central and south-eastern area of the district lies in the hot and dry zone and rest of the district lies in the hot and semi arid zone. Broadly, soils in the study area are sand and sandy loam. In high elevation in Jhajjar district (south western area) has sandy soil (Puri 1983). Most of the Monsoon rainfall occurs in months July to September (nearly 80%). The yearly rainfall in Rohtak and Jhajjar districts were analysed for the years 1996 to 1999. Rohtak has 27 dry years (<75% of normal rainfall) during 81 years (1900-1981). This is one of the maximum in Harayana. Mean annual potential Evaporatranspiration rate is 1600- 1650 mm. In Rohtak, Mean annual minimum and maximum temperatures are 17° and 32°C. Annual mean temperatures is 24°C. January is coldest month (mean temperature 13°C) and June is the hotest month (mean temperature 34°C). (Kangle 1983).

3.2 DATA AVAILABILITY

In this study Survey of India (SOI) topographic maps and satellite remotely sensed data have been used. The topographic maps at a scale of 1:50,000 with nos. 53 C/8 and 12 and 53 D/1,5,6,7,9,10, 11, 13,14 and 15 have been used. The maps were surveyed in the years 1965-66, 1968-70 and 1972-73.

Satellite remotely sensed data of the Indian Remote Sensing satellite (IRS) Linear Imaging Self Scanning (LISS)-3 sensor were used for the dates 26th Nov. 1996, 2nd Mar 1997, 14th Apr. 2000 and 6th Oct. 2000. The study area is covered by single scene with path and row nos. 95- 51. In this data, two visible and two near infrared bands with spectral ranges of 0.52-0.59, 0.62- 0.68, 0.77-0.86 and 1.55- 1.70 are available. The sensor has a spatial resolution of 24 m (bands 2-4) and 71 m (band 5) and radiometric resolution of 128 gray levels (7 bits). This data has been procured from NRSA, Hyderabad.

Beside topographical and satellite data, field data such as rainfall and ground water level data have also been collected and used. The rainfall data of the years 1996-1999 and ground water data of the years 1989-1999 have been collected.

4.0 METHODOLOGY

In this study image processing of satellite data have been carried out to map the water logged area. Ground water level data have been used to see the ground water situation in the area. Finally utilizing these two informations alongwith the topographic information, seasonal and permanent water logged area have been delineated. For image processing Earth Resources Data Analysis System (ERDAS) IMAGINE and for GIS purpose such as digitization etc. Integrated Land and Information System (ILWIS) have been used.

4.1 PREPARATION OF BASE MAP

The base map of the study area has been prepared from Survey of India, toposheets at a scale of 1: 50,000. This map was then converted to digital form using ILWIS software. This base map is shown in Figure 4.1. The projection is polyconic with central meridian 76^0 30' 00' and false easting 50000 m, geoid Everest and datum Indian (India, Nepal). Digitization, which is the most time consuming part of the analysis, was carried into parts. Then the digitized map was corrected for many types of errors such as proper joining of the streams, proper overlaying of the segments etc. As the satellite data processing was carried out in ERDAS system, therefore the base map was imported to ERDAS IMAGINE for further use.

4.2 PROCESSING OF REMOTE SENSING DATA

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

4.2.1. Import and Visualisation

The data of IRS-1C satellite LISS-III sensor for these years 1996-97 and 2000 were received from NRSA on the CD-ROM media. The data were loaded on the computer from the CD-ROM and was imported in the ERDAS system. Initially, a false colour composite (FCC) of was prepared and visualised. Then, each individual band was visualised one by one.

4.2.2 Geometric registration

While using the temporal satellite data of the same area, it is required to register the images to base map. For registering one image, GCPs are directly taken from SOI toposheets using tablet digitizer in ILWIS software. Image and base map GCPs thus generated were imported to ERDAS to rectify the image. For carrying out the registration, some clearly identifiable Ground Control Points (GCPs) like crossing of rivers, canals, road/ canal intersections sharp turns in the rivers,

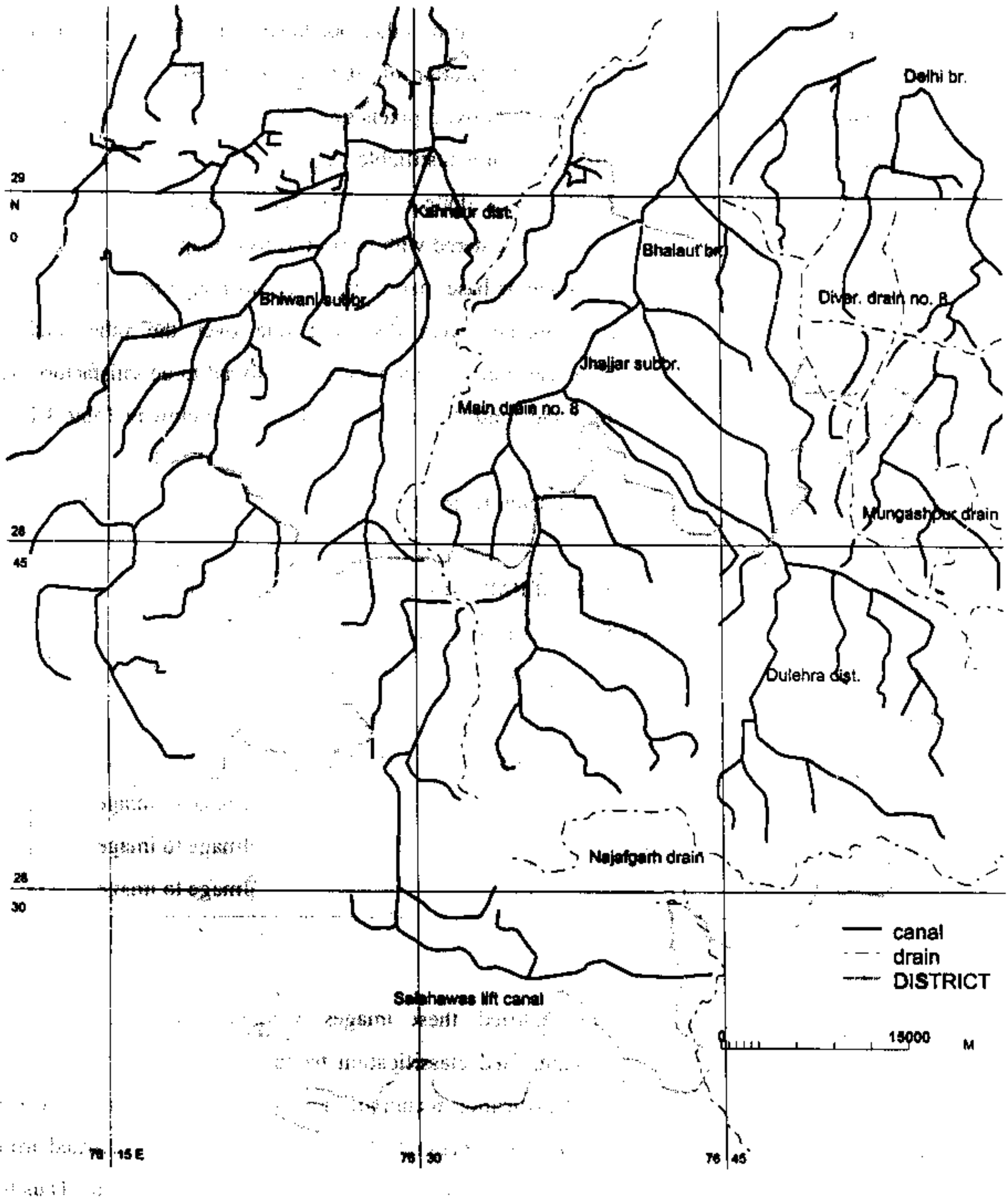

Fig.4.1 Canals and drains

bridges etc. were located on both the images. Now looking at the statistics, some points, which generated big errors, were deleted and replaced by other points so as to obtain the satisfactory registration. The positional accuracy in digitization of GCP was nearly 0.5 mm. This will be translated to 125 m as ground distance (approx. 5 pixels of LISS-3 sensor data). The accuracy obtained for base map to image rectification is justifiable. A polynomial transformation of first order was performed and resampling was done using the nearest neighbour interpolation method. In this manner, one image was registered with respect to base map. Other images were rectified by treating first rectified image as base map using image to image rectification. After completing this process, different images were displayed one over the other and the superimposition was compared. The registration of the images was found to be satisfactory. The registration accuracy, number of ground control points selected is given below in Table 4.1.

Table 4.1 Preprocessing details of the satellite images

Data	Number of GCP	RMS error in pixels of size 24 m	Bands corrected for banding using FFT	Rectification
LISS-3 April 2000	72	5.8	1 and 4	Base map to image
LISS-3 March 1997	49	.64	-	Image to image
LISS-3 October 2000	45	.67	4	Image to image
LISS-3 Nov 1996	50	.77	-	Image to image

4.2.3. Classification

After all the images were rectified, these images were classified using both the techniques i.e. unsupervised and supervised classification techniques. Initially the data was classified using the unsupervised classification technique. From this classification first hand knowledge of different classes have been obtained. The image was again classified using supervised technique. The unsupervised classification has given large area as urban. Thus the area that are classified as urban in the unsupervised classification and fallow in supervised classification is reclassified as 'bare/ fallow/forest/ scrub'. Since, the mapping is done for mainly water and waterlogged areas, the forest are also merged with bare/ fallow/ scrub class to make class 'bare/ fallow/ scrub/ forest.

Based on information collected from farmers and standard cropping pattern for the crops, the crop calendar is given in Table 4.2. The agriculture statistics for Rohtak district is collected for period 1996 to 2000 (Appendix 1).

Table 4.2 Crop calendar

Crops Calendar	
Kharif	
Rice	Aug.- Middle of Nov.
Jowar	July- Nov.
Bajra	Jun.- Oct.
Rabi	
Wheat	Dec.- end of Mar.
Mustard	Oct.- Mar.
Others	
Cotton	Jun. and Jul.- Mar. and Apr.
Sugarcane	Dec.- Dec. (harvesting Dec.-Mar.)

4.3 OVERLAY: PRE AND POST MONSOON CLASSIFICATION

In this study two dates (pre and post monsoon) data have been taken for the years 1996-97 and 2000. These classified data of pre and post monsoon season were overlaid over each other to see the changes that occurred in the year.

The criteria for map overlay operation are given in the table 4.3. According to this criterion the pre and post images were overlaid and reclassified in different classes. For example 'water' class is assigned 'perennial water' class if the pixel has water class in pre monsoon image and in the post monsoon image even if it has non water class.

Table 4.3 Map overlay criteria for pre and post land use maps

Pre monsoon / Post monsoon	Water	Other	unclassified
Water	Perennial water	Seasonal water	unclassified
Waterlogged	Unclassified Water/ waterlogged	waterlogged	unclassified
Other	unclassified	other	unclassified

After applying above criteria, classified output for the years 1996-97 and 2000 were obtained. These outputs were again overlaid to find out the permanent waterlogged areas. This overlaying operation was carried out using the criteria given in Table 4.4.

Table 4.4 Map overlay criteria for maps year 1996-97 and 2000

2000 1996-97	Perennial Water	Seasonal water	waterlogged	Unclassified water/ waterlogged	Other	Unclassified
Perennial Water	Water	Flood inundation	Flood inundation	Unclassified water/ waterlogged	Flood inundation	Unclassified
Seasonal Water	New Waterbody	Seasonal water	Seasonal flood inundation	Unclassified water/ waterlogged	Seasonal flood inundation	Unclassified
Waterlogged	New Waterbody	New seasonal water	Waterlogged	Unclassified water/ waterlogged	Wet year waterlogged	Unclassified
Unclassified water/ waterlogged	Unclassified water/ waterlogged	Unclassified water/ waterlogged	Unclassified water/ waterlogged	Unclassified water/ waterlogged	Unclassified	Unclassified
Other	New waterbody	New seasonal water	New waterlogged	Unclassified	Other	Unclassified
Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified

The permanent water is the class having standing water in all years i.e. 1996-97 and 2000. Permanent waterlogged areas are those classified as waterlogged in years 1996-97 and 2000. The flood-inundation classes namely flood inundation: standing water, flood inundation: seasonal water and flood inundation: waterlogged have respectively standing water, seasonal water and waterlogged land use in 1996-97 overlaid map and bare/ fallow/ scrub/ forest or agriculture or urban class in 2000 overlaid land use map. Whereas recent water, seasonal water and waterlogged classes have respectively standing water, seasonal water and waterlogged land use in 2000 overlaid map and bare/ fallow/ scrub/ forest or agriculture or urban class in 1996-97 overlaid land use map.

4.4 DIGITAL ELEVATION MODEL

The digital elevation model (DEM) was prepared from the topographic contours and spot height depicted on the SOI topographic maps. The contours and spot heights are digitized in ILWIS 2.2. The contour map of the study area is shown in Figure 4.2. This map contains both the vector entities i.e. segment and points. Before interpolation to get the DEM, these two entities have to convert into one type. Therefore the contours were converted to the point map by using a sampling intervals of 4000 m. It means at a interval of 4000 m, the segments or contours of a particular value was given point value. Then these point data were merged to get a point map. The interpolation is done using the merged point data applying Kriging technique. The interpolation parameters used in the interpolation are given in Table 4.5. Total number of points used in the interpolation is 1253. The size of pixel in the output map has been kept as 1000 m. The maps were averaged using 3X3 filter to remove the noise or small patches. The resulted DEM is interpolated using bilinear interpolation to 4.0 magnification (250 m pixel size) in the raster image densification. The DEM of the study area is shown in Figure 4.3. This DEM was used to obtain the RL of the groundwater wells. The point data is displayed over the DEM and the DEM value at the groundwater well location was noted down. These values were given as input in to the groundwater well points map attribute table.

4.5 GROUNDWATER MAPS

The groundwater maps were prepared using the groundwater well data for 138 stations. In the groundwater well data, the depth of the groundwater table is available from field for June and October from 1996 to 2000 (For year 2000 only June 2000 data were available). The RL of groundwater wells was obtained from DEM as described above. The groundwater table height at each well site was obtained by subtracting the water table depth from the RL of the

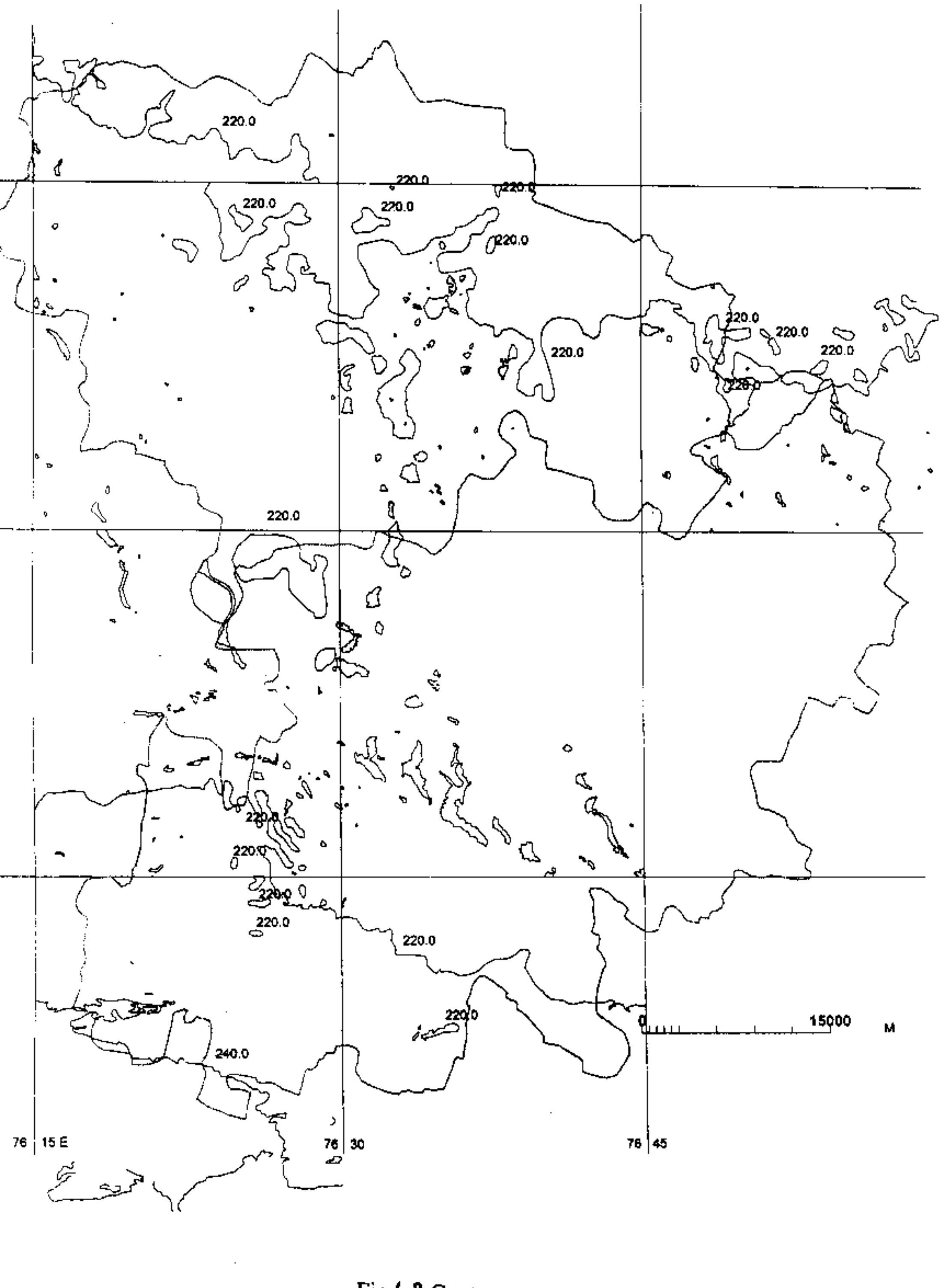

Fig.4.2 Contours

groundwater well. The kriging interpolation with spherical model was applied. The interpolation parameters are given in the Table 4.5. The interpolation was done at 1000 m pixel size. The maps are averaged using 3X3 filter to remove noise. The resulted DEM is interpolated using bilinear interpolation to 4 times magnification (250 m pixel size) in the raster densification. The groundwater table map is subtracted from the DEM to obtain the groundwater depth map. The resultant map is smoothed using 3 X 3 average filter. The ground water table maps for the year 1996 and 1999 are shown in Figures 4.4 and 4.5 respectively, while ground water depth for the years 1996 and 1999 are shown in Figures 4.6 and 4.7 receptively for both the months i.e. June and October. The ground water table and depth map for the year 2000 is shown in Figure 4.8.

Table 4.5 Interpolation parameters for DEM and groundwater table maps

Interpolation parameter	DEM	Groundwater table
Model	Spherical	Spherical
Nugget	7	3
Sill	54	13
Range in m	30000	30000
Radius in m	30000	30000
Maximum points	16	16
Averaging of duplicate points at distance in m	0.1	1000

4.6 FIELD VISIT

A field visit of the study area has been made during the month of Feb. 2001 (13/2/2001 to 15/2/2001). During the field visit, crop information was collected from farmers, the soil samples are taken at depth up to 2.10 m. The crop statistics was collected from agriculture department. The canal and drainage index map is collected from Irrigation department. The description of sites in given below:

Bohr: At the village Bohr on the west of the canal, data are collected from three fields. One field is located closer to the canal. Here during the canal construction, soil had been borrowed, thus lowering the field elevation. This field remains inundated during the monsoon season. The rabi yield is also poor due to high water table. Water table is observed at the depths of 1.1 and

1.65 m in the other fields. Thus, as per 2.0 m water table criteria of water logging, large area is waterlogged in the canal vicinity here. Standing water area in few borrow pits is also observed.
Hoshadarpur Kheri: The site is located on the east of the village. It is a salt affected field with patchy crop growth. Large area on east of this village was flooded in 1996. this site was selected based on satellite image interpretation (November 1996). The water table is not observed up to 2.1m depth. This may be due to decline in the water table in recent years. Again the area is undulating, more sites may be required to be observed to see the ground water table status. As per topographic maps, the inundated area as shown in the satellite image is located in valley. There are many hillocks seen on the topographic map nearby this area. The undulating nature of the topography is not revealed in the topographic map due to large contour interval (20 m). A distant area south of the site is also indicated as liable to inundation on the topographic map. It was confirmed from the villagers that the large area on east of the village was flooded in 1996.

In general, the valley areas have low relief 214 to 216 m. Being depression area, adequate drainage is not available. Further investigations are needed regarding soils, infiltration, water table, topography etc. in this region.
Beri: The sites 1 and 2 are located on North of the Beri- Dujana road, nearly 3-4 km from Beri. The first field is closer from Beri than the second field. Large area is inundated during monsoon in this area. No water table is observed up to 2.1 m depth. Although the farmer has said that water table is nearly 1 m deep. Since this site is away from canal and occurrence of deficit rainfall in recent years, the water table has declined. In the year of excess rainfall, the water table may rise again. Only rabi crop is grown since wetness in kharif areas near canal where sufficient standing water is available in monsoon, both rabi and kharif crops are grown.

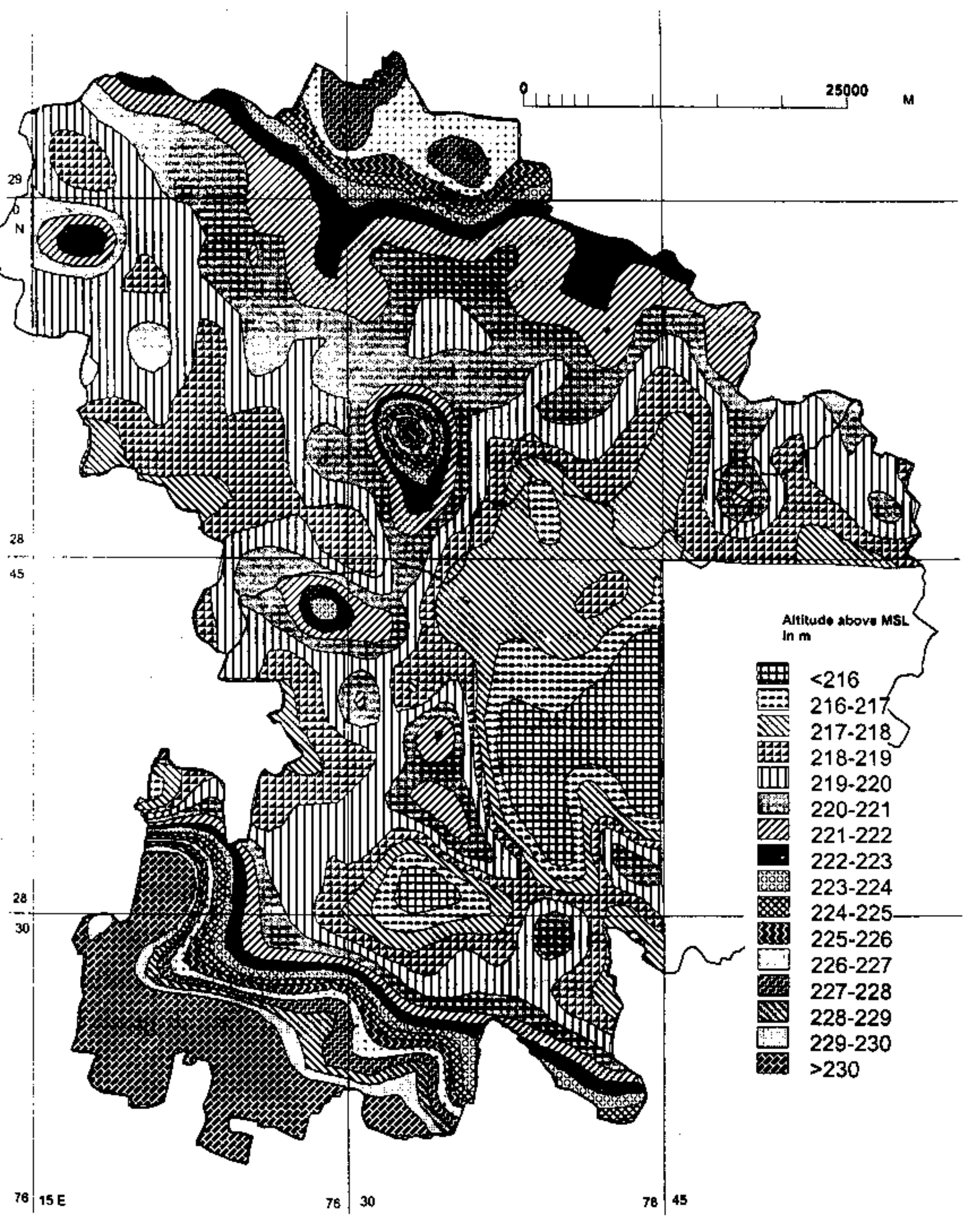

Fig.4.3 Topography

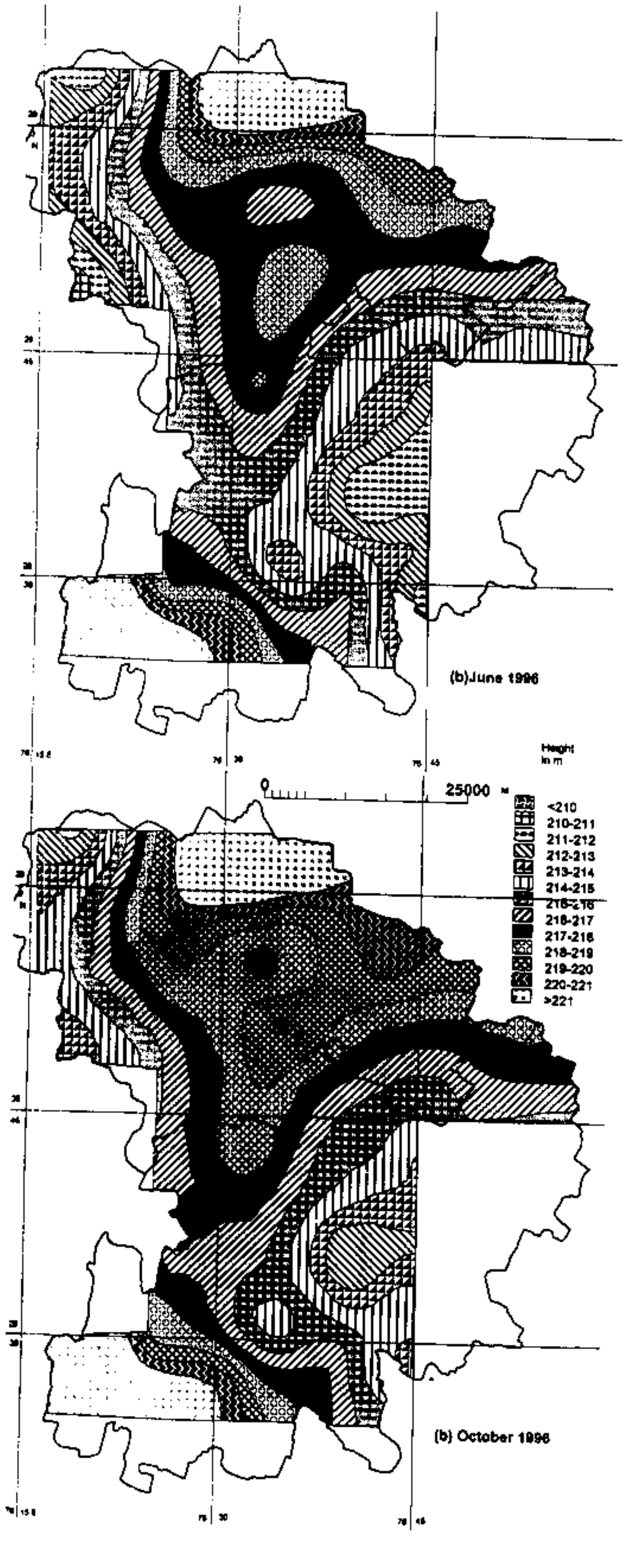

Fig.4.4Groundwater table 1996

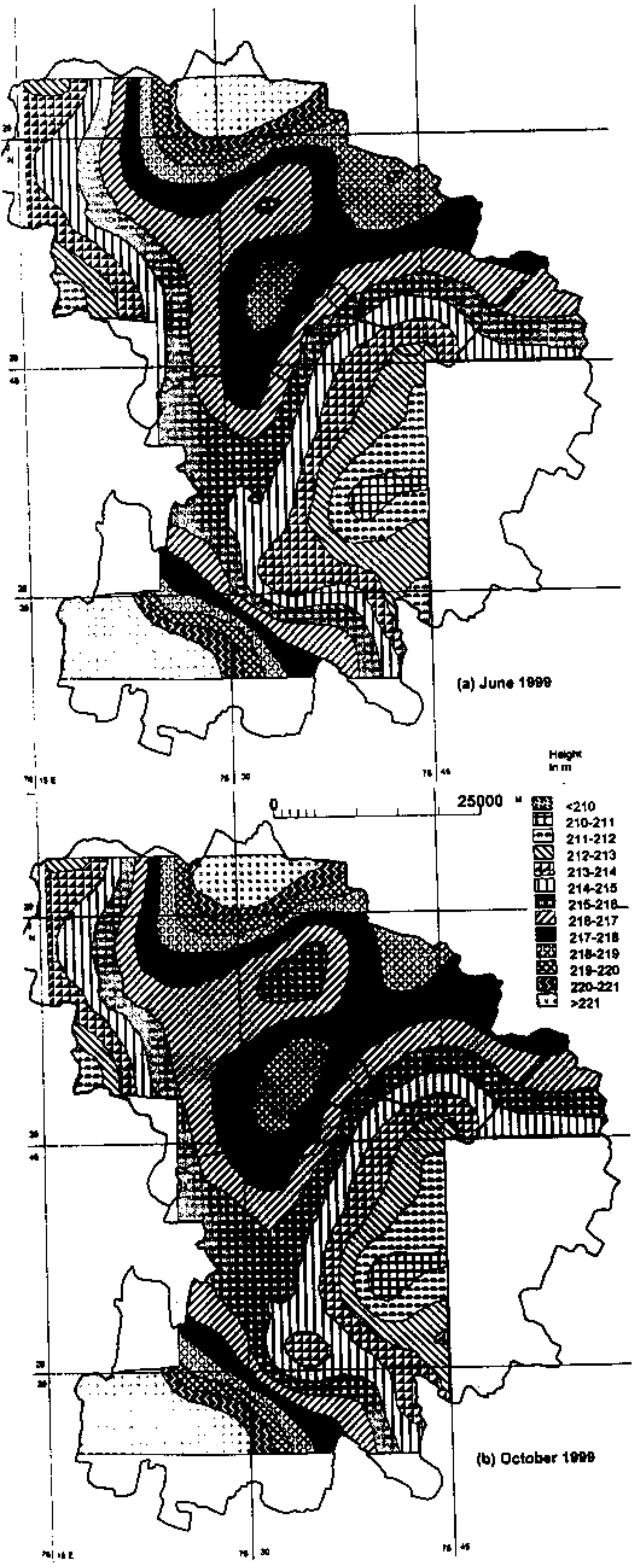

Fig.4.5 Groundwater table 1999

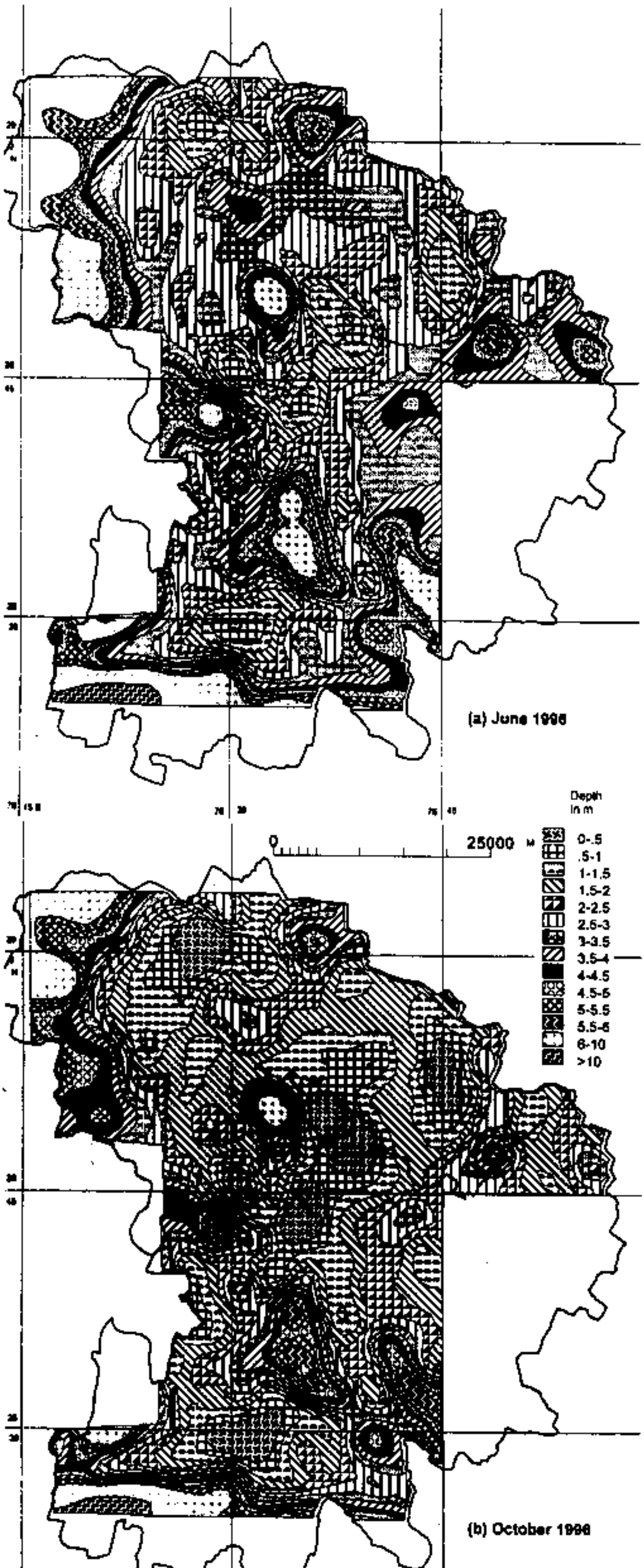

Fig.4.6 Groundwater depth 1996

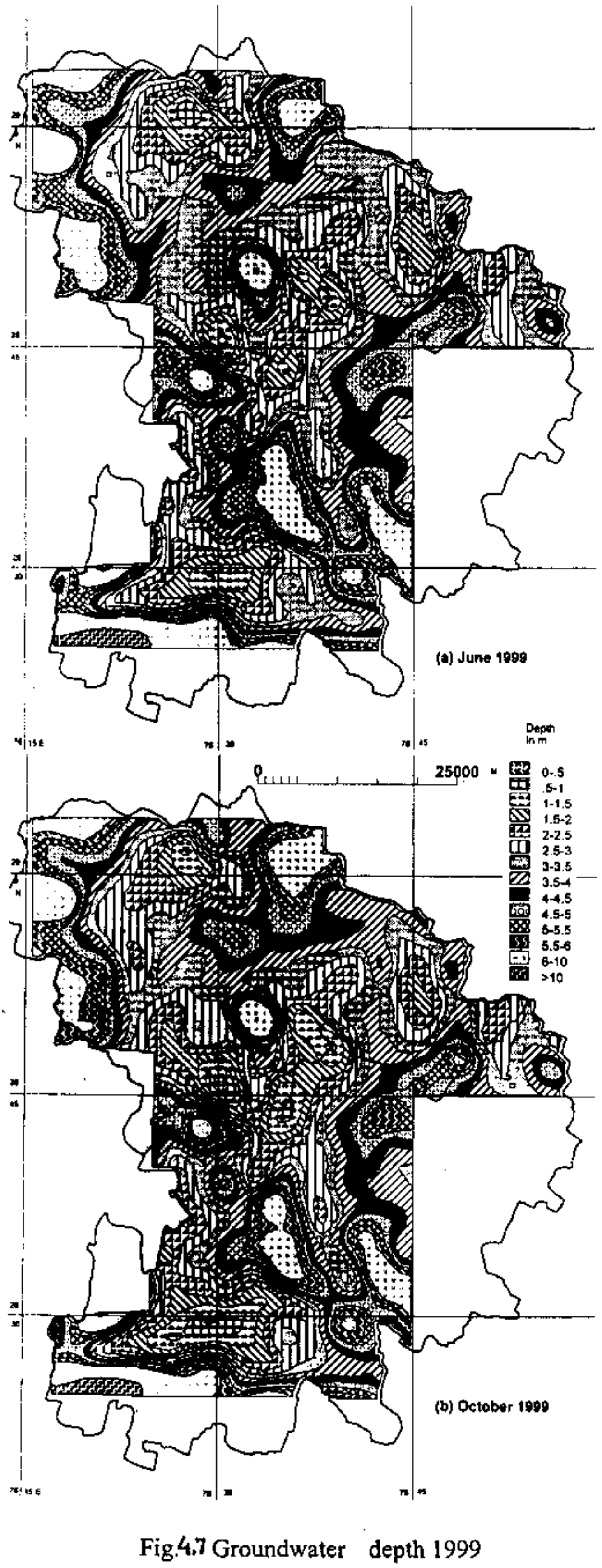

Fig.4.7 Groundwater depth 1999

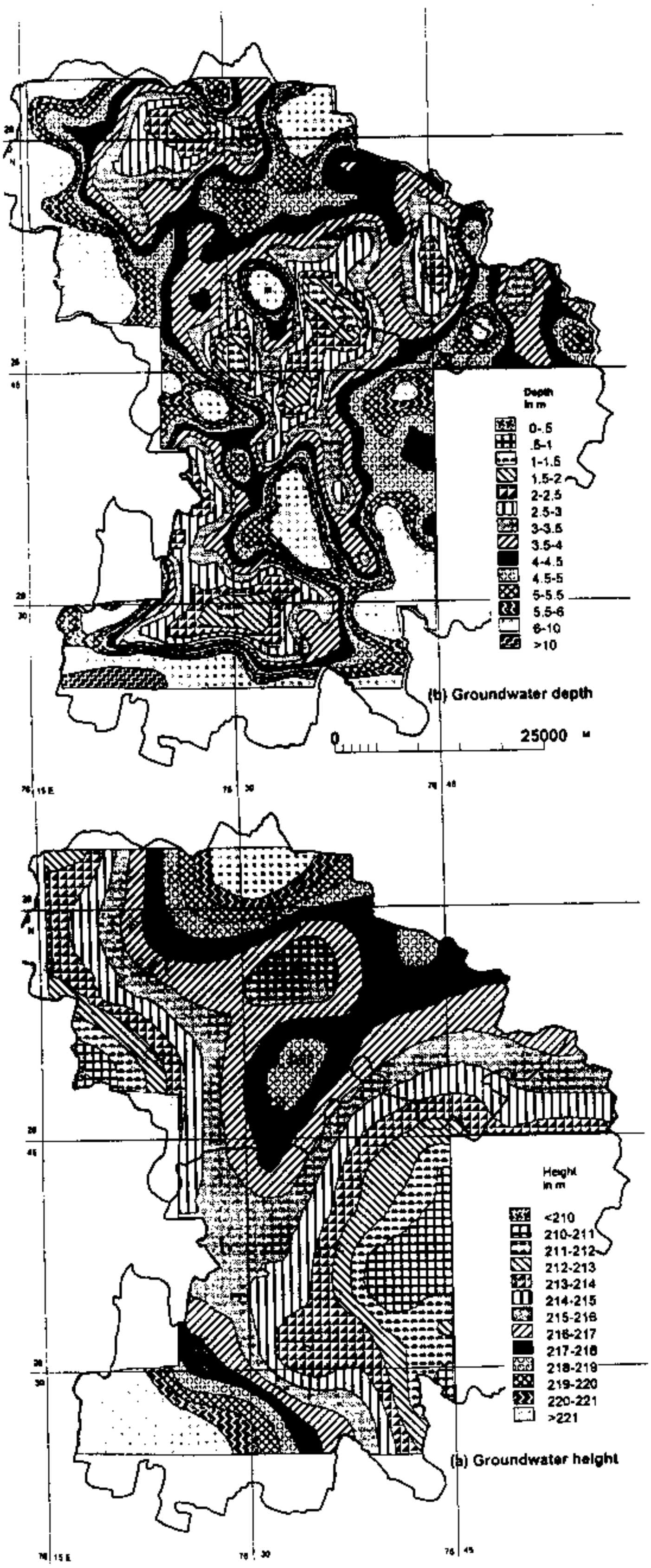

Fig.4.8 Groundwater table and depth June 2000

5.0 ANALYSIS AND RESULTS

5.1 SATELLITE DATA

Based on the satellite data/ field data an appraisal of waterlogged area has been made in Rohtak and Jhajjhar districts for the Western Yamuna canal command. From the landuse map prepared for all the years, the area covered under waterlogging has been computed. The water-logged area is about 2 to 2.5% and the water and waterlogged area is given in Table 5.1. The waterlogged area map is given in Fig. 5.1.

Table 5.1 Waterlogged area statistics

Class name	Jhajjhar		Rohtak		Total	
	ha	%	ha	%	ha	%
Water	35	0.02	22	0.01	56	0.01
New Waterbody	77	0.04	101	0.06	179	0.05
Flood inundation	230	0.11	279	0.17	510	0.13
Seasonal water	48	0.02	77	0.05	125	0.03
New seasonal water	599	0.27	810	0.48	1408	0.37
Seasonal flood inundation	704	0.32	1562	0.94	2266	0.59
Waterlogged	325	0.15	234	0.14	559	0.15
New waterlogged	2676	1.23	3154	1.89	5831	1.51
Wet year waterlogged	4153	1.91	4024	2.41	8179	2.12
Unclassified water/ waterlogged	106	0.05	153	0.09	260	0.07
Other land use	205050	94.06	149355	89.43	354499	92.05
Unclassified	3991	1.83	7236	4.33	11230	2.92
Total	217993		167008		385101	

The Table 5.1 shows that the total waterlogged area is more in Rohtak district both in percentage and value (Rohtak 6.24% 10417 ha, Jhajjhar 4.11% 8952 ha). The total waterlogged area is obtained by subtracting area of other land use and unclassified areas from total area. The unclassified waterlogged area is included in this statistics. The lower waterlogging in Jhajjhar may be due to more aeolian physiography, higher slope, less canal network and low discharges in canal in Jhajjhar district than Rohtak. Thus, factors those abate waterlogging are

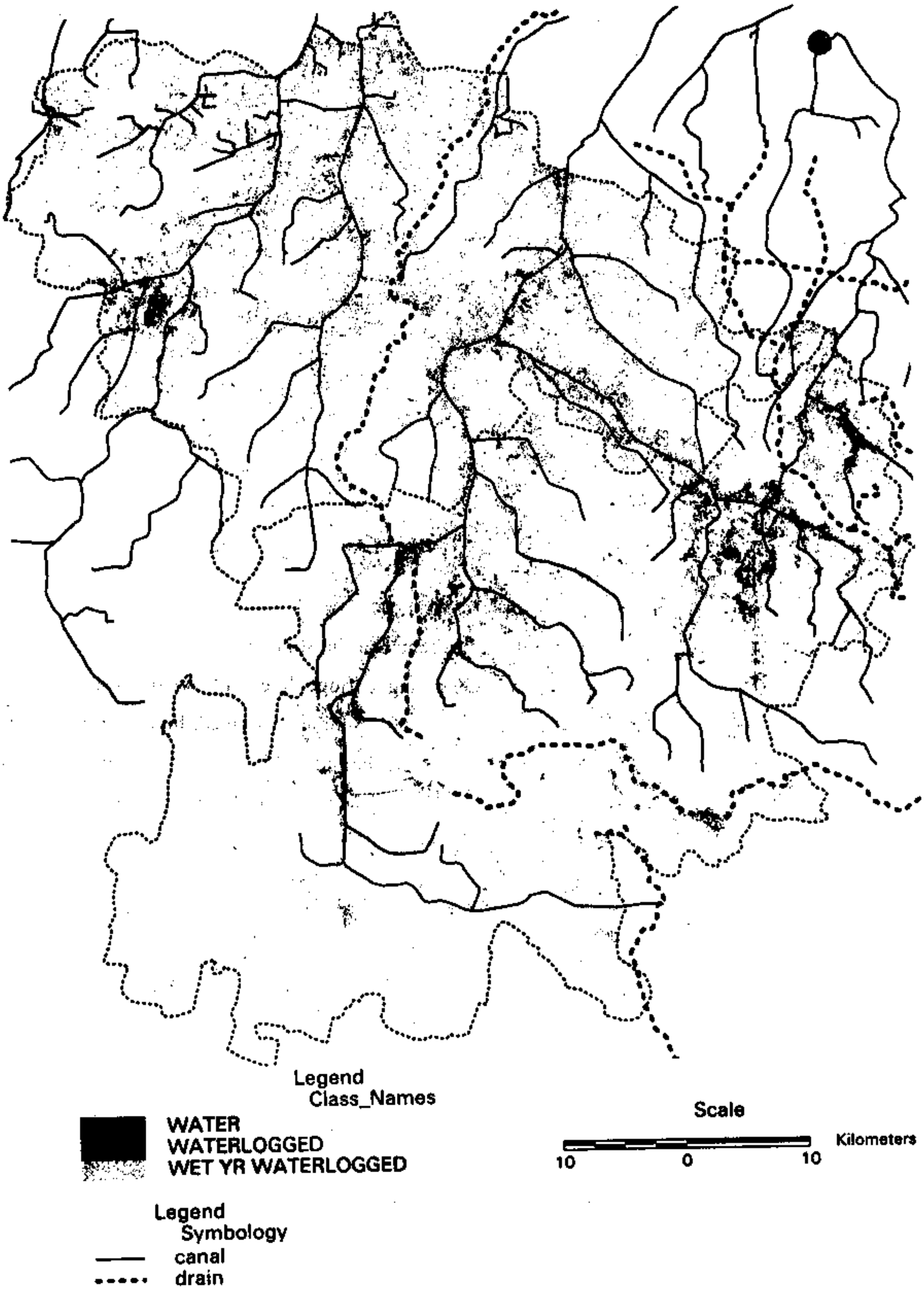

Fig. 5.1 Waterlogged area map

less prevalent in Jhajjhar district than Rohtak district. The flooding due to rainfall is also high in Rohtak (Rohtak 1.10% 1841 ha, Jhajjhar 0.43% 934 ha). The flood area is obtained by summing the areas under flood and seasonal flood inundation. The higher flooding is caused due to more depression areas, alluvial soils (as compared to aeolian soils in Jhajjhar district) in Rohtak. Similarly wet year waterlogging is also more in Rohtak district. The deficient year waterlogging extent is nearly same in two district (Rohtak 2.12% 3542 ha, Jhajjhar 1.43% 3108 ha). The waterlogged area is obtained by summing areas under waterlogged, new waterlogged, and unclassified water/ waterlogged classes. Similarly the waterbody extent, deficient year, is also not different is the districts (Rohtak 0.60% 1010 ha, Jhajjhar 0.35% 758 ha). The waterbody extent is obtained by summing water, new water, seasonal water, and new seasonal water classes.

5.2 TOPOGRAPHY

To consider the topography, a DEM was prepared and discussed in the last chapter. In general, the southern part has higher elevation than the northern part. Isolated hillocks and higher elevation grounds are also visible across the study area. In general there is a north- south oriented broken ridge line running along the centre of the study area. At latitudes 28° 45' and longitudes 76° 45', there appears to be running a ridge line with south-west- north east orientation between longitudes 76° 37' and 76° 50'. Similarly oriented, higher ground (with a valley running in the middle) also exists at the latitude 28° 30' and longitude 76° 40'. Depressions exist in the south centre of SOI toposheet 53 D/5, Centre of toposheet 53 D/6, south east and east central area of the toposheet 53 D/10.

The surface flow directions revealed from the topographic maps/ DEM are, in the northern part with south and south-west flow directions, in the southern part, north and north-east flow directions.

5.3 GROUNDWATER TABLE

In general the change in ground water depth is not much. However in the year 1996 and 1999 post monsoon date more changes are revealed. This may be due to higher recharging in year 1996. Similar to the surface water flow directions, the groundwater flow directions are revealed from the groundwater table maps.

The groundwater depth map provides entirely different information. Since it combines digital elevation model (topography) and groundwater well depths, the valleys/ depressions are only obtained as waterlogged areas in this map. Due to sparse groundwater well distribution, local variations may not be depicted on the groundwater table and depth maps.

Statistics for the water table depths are computed and are given in Table 5.2 to 5.5 for the two districts for all the years for June and October. These tables indicates reduction in the waterlogged area map (with water table depth < 2.0 m) from 1996 to 1999. As the 1996 was a wet year and therefore this indicates on regional scale that recharge from the rainfall may have large effect on the groundwater balance and thereby waterlogging.

Table 5.2 Area in Rohtak district for different groundwater depth ranges during June

GW depth (Upper bound)	Years									
	1996		1997		1998		1999		2000	
	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	area in ha
0.50	0.02	38	0.38	619	0.44	713	0.00	0	0.00	0
1.00	1.37	2244	1.87	3044	1.49	2438	0.64	1050	0.00	0
1.50	4.03	6581	3.19	5206	4.07	6638	1.72	2813	0.92	1494
2.00	6.15	10044	6.92	11288	6.64	10838	4.61	7531	2.19	3575
2.50	12.88	21025	14.35	23425	10.37	16931	8.36	13650	4.59	7488
3.00	22.90	37369	16.53	26981	19.06	31100	12.73	20781	8.41	13725
3.50	16.36	26706	16.58	27050	19.48	31788	21.26	34700	12.61	20575
4.00	7.88	12856	12.67	20669	11.38	18569	14.59	23813	16.66	27188

Table 5.3 Area in Rohtak district for different groundwater depth ranges during October

GW depth (Upper bound)	Years							
	1996		1997		1998		1999	
	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	Area ha
0.50	6.36	10375	3.62	5906	9.23	15056	0.24	388
1.00	8.92	14563	7.09	11563	8.24	13450	0.68	1106
1.50	16.28	26569	8.30	13538	15.74	25688	2.45	3994
2.00	21.23	34650	15.60	25456	17.47	28513	4.51	7356
2.50	10.83	17675	18.57	30300	12.73	20781	10.06	16413
3.00	8.32	13581	12.45	20313	8.73	14250	14.14	23069
3.50	4.94	8063	7.87	12844	5.88	9600	14.55	23738
4.00	4.37	7125	5.33	8694	3.98	6488	15.53	25344

Table 5.4 Area in Jhajjhar district for different groundwater depth ranges during June

GW depth (Upper bound)	Years									
	1996		1997		1998		1999		2000	
	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	Area in ha
0.50	0.75	1225	0.89	1444	0.84	1369	0.73	1188	0.68	1106
1.00	2.02	3294	1.66	2700	1.61	2625	0.16	256	0.13	206
1.50	2.84	4625	3.98	6481	3.40	5531	2.00	3256	0.66	1069
2.00	5.43	8844	7.26	11819	6.27	10213	3.90	6344	3.04	4950
2.50	8.99	14631	10.31	16788	8.91	14500	6.23	10144	5.77	9388
3.00	10.05	16363	9.94	16181	10.11	16450	10.29	16744	7.86	12794
3.50	12.84	20906	12.15	19781	10.67	17375	11.08	18044	8.79	14306
4.00	10.57	17206	11.33	18438	12.09	19681	10.72	17444	9.63	15675

Table 5.5 Area in Jhajjhar district for different groundwater depth ranges during October

GW depth (Upper bound)	Years							
	1996		1997		1998		1999	
	Area %	Area ha	Area %	Area ha	Area %	Area ha	Area %	Area ha
0.50	6.26	10194	3.92	6381	4.13	6731	0.87	1419
1.00	5.52	8994	3.98	6475	6.04	9831	1.67	2725
1.50	9.46	15400	7.33	11925	8.01	13044	3.88	6319
2.00	11.96	19469	10.27	16713	9.32	15169	5.94	9663
2.50	13.25	21563	10.95	17825	11.01	17925	7.63	12425
3.00	8.84	14388	11.71	19056	11.34	18463	9.59	15613
3.50	7.41	12069	10.64	17319	9.56	15569	8.87	14444
4.00	5.42	8825	7.36	11975	6.60	10738	10.98	17869

5.4 DISCUSSION

The waterlogged and water spread area maps were prepared using IRS LISS III data for the years 1996-97 and year 2000. These maps were compared with the DEM prepared from Survey of India toposheets and water table/ depth maps prepared from point data.

In general the water and waterlogged areas do not exist corresponding to the topographic higher elevations e.g. north and south west areas. The south western area (the area is located in Jhajjar district) has higher ground slope and there is almost no waterlogged area in such high elevation zones. However in some other areas though the elevation is high even then the waterlogging is observed e.g. in the mid west of SOI toposheets 53 D/5. In this area, the Butana branch passes and this canal carries high discharge and hence chances of waterlogging is more due recharge. The waterlogged area has increased from 1996 to the year 2000 here.

Contrary to this in eastern part of the SOI toposheet 53 D/10 very less area is under water or waterlogged even though the area is at lower elevation. The reason for this is that the area traversed by canals carrying relatively low discharge.

Similarly, while comparing the groundwater depth map and satellite derived water logged area maps there are very few mismatches. In general the zone of shallow ground water shows the area as waterlogged. However in some of the area of deep ground water the waterlogging was observed. For example, in the south west in toposheet 53 D/ 10, high depth to water table are shown, where as large water/ waterlogged areas is indicated in satellite data derived maps. However this is relatively very small area.

There has been increase in area covered by kharif paddy cultivation from 1996 onwards. During the field visit, as informed by the farmers, that large areas near Bhalaut canal remains inundated up to October. The areas have sufficient inundation depths for paddy cultivation. There is large crop areas located around Bhalaut and Bhutana canals that showed dark red signature in the satellite data. The crop extent is more pronounced in Meham (Butana canal), south- central of Rohtak and north- central of Jhajjar (Bhalaut canal) and around Bahadurgarh (Bhalaut canal). In Meham, the crop extent is more than other areas. These areas have in general a flat topography. As such no ground truth has been carried out during the kharif season, thus exact information on the location of the paddy area is not available. Based on the information provided by the farmers, the dark red signature in the satellite data has been considered under paddy. This area has been classified as crop, not the waterlogged area in this study. This type area is having shallow ground water.

Dark signature was also observed in pre monsoon season around canals in April 2000 satellite image. Since there was no ground truth during that period, the area could not be interpreted with certainty. However, during February visit large scale cultivation of wheat was observed in this area. As per practice in India, the crop residue is burned in the fields after the mechanized cultivation at many places. The dark signature observed during this period may be due to this reason. Therefore the classes with dark signature in the satellite data of this period are reclassified as fallow class. A small patch of wet area observed in the west of JNL feeder canal (Bohar village) during field visit in February month. Thus large wet areas is unlikely during pre monsoon seasons. This also supports the interpretation of dark areas in April 2000 image as fallow.

Therefore we can say that the causes of the waterlogging may be blocking of surface drain by the canals (canals are contour canals and are in fills), flat topography, canal seepage, recharge due to rainfall in the rainfall excess years and movement of groundwater from groundwater highs, borrowing of the soil for canal construction etc. The location of borrow pit near Bohar and Rohtak along the Bhalaut and JLN feeder canal has been observed in satellite image as well as during ground truth. There are areas where soil was borrowed from agriculture land (still under cultivation), and from abandoned pits.

Some of the recent areas have appeared as standing water/ waterlogged in satellite image of 2000. Since the satellite image did not have same date during Kharif, the paddy area could not be compared from satellite image. However, crop statistics of Rohtak indicates that the paddy area has increased. The exact cause of this recent area appearing as standing water could not be ascertained. However, one of the cause for this could be new borrow pits carrying increase in waterlogging.

The approach so taken has been found to be successful for preliminary analysis. The geographical location, of waterlogged areas as seen from remote sensing analysis and geostatistical methods is seen to be almost identical. However, the resolution available in remote sensing data is of a much higher order (23m * 23m) compared to the 0.5 km grid cell size in geostatistical analysis. The interpolation was made using sparse network of ground water data.

6.0 CONCLUSIONS

In the study, waterlogged and stagnation water have been delineated using remote sensing and other ancillary information. From this study, it is inferred that using remote sensing data, first hand knowledge of water logging area can be obtained. To confirm the results obtained from image processing, other data such as topography and ground water level information are very much required. Groundwater maps and satellite derived waterlogged maps may be used to zeroing in to sub areas for further investigation. Waterlogged area was verified in the field through ground truth at few sites through observation and information from local people. From this field visit it was observed that a possible cause of waterlogging could be barrow pits.

The total waterlogged area have been obtained separately for Rohtak and Jhajjar districts and the area under this class is 6.24 % (10417 ha) and 4.17% (8952 ha) of the total area. The total area under waterlogging and standing water comes out to be 3.51% (5865 ha) and 2.33% (5087 ha). In some of the areas, waterlogging has provided additional water required for some of the crops and it can be seen from the increase in paddy crops in years following the excess rainfall year of 1996. The marginal areas, where there is not enough inundation depth/ duration for paddy cultivation, or where depth is excessive requires some relief.

The number of observation wells is small and not sufficient to give smaller waterlogged areas e.g. area north east of Rohtak are seen as waterlogged (<2.0 m watertable) during field visit, but this area is not depicted as waterlogged in the groundwater well derived map. The remote sensing technique, reveals physiographic/ soil/ hydrological differences in area and thus is useful for carrying out further investigations in the areas where in typical investigation sites may be selected based on above differences.

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APPENDIX I

AGRICULTURE IN ROHTAK

Area V. Yield and Production

A=Area ('000 Hect.)	Y=Av. Yield (kg/Hect)	P=Production ('000 Tonnes)

Crop	State Av. Yield for 1998-99		1996-97	1997-98	1998-1999	1999-2000	2000-2001
Rice	2239	A	11	17	28	28	
		Y	1913	1815	1910	943	
		P	21	31	53	26	
Jowar	194	A	33	20	28	24	
		Y	300	250	300	250	
		P	10	5	8	6	
Bajra	1009	A	13	19	19	17	
		Y	1015	1135	1104	850	
		P	13	22	21	14	
Kh Pulses	839	A	7	5	2	2	
		Y	908	950	1000	1000	
		P	6	5	2	2	
Sugarcane	5504	A	18	14	12	13	
		Y	4990	4607	4800	4165	
		P	89	64	58	52	
Cotton	255	A	13	13	13	12	
		Y	258	262	209	298	
		P	20	20	16	21	
Wheat	3621	A	71	74	86	92	
		Y	3605	3306	3700	[illegible]	
		P	255	245	318	363	
Gram	826	A	6	7	5	8	
		Y	1030	691	650	669	
		P	5	5	3	[illegible]	
Barley	2778	A	1.7	2	2	2	
		Y	[illegible]	[illegible]	[illegible]	[illegible]	
		P	5	5	4	2	
Rabi oil seed (Mustard)	1241	A	22	17	12	10	
		Y	1263	407	1070	974	
		P	28	9	13	10	
Fertilizer Consumption (in MT)		N	13291	15751	21436	24070	
		P	6432	6070	6839	3664	
		K	43	9	5	56	
Consumption Kg/hect.			92	104	137	151	
Seed distributed (in Q's.)		Bajra	260	280	807	707	
		Paddy	560	510	642	576	
		Cotton	1690	1700	1273	846	
		Arhar	640	600	238	195	
		Wheat	7160	7480	8690	10632	
		Barley	218	190	186	167	
		Gram	290	210	180	164	
		Mustard	330	255	205	157	
Biogas			35	47	75	68	
Small Saving (in lakhs)			157	217	290	389	
Quality Control Sample Drawn		Seed	127	119	147	113	
		Fert.	162	146	146	173	
		Pest.	72	81	100	98	
Rain fall (mm)			424	656	588	305	

Classifications of area 1999-2000	
No. of Villages	147
Total Geography Area	167311
Cultivable Area	146208
Cultivated area	138801
Cropped Area	244058
Area Sown More than once	105257
Crop Intensity	150-160
Vegetable Area	1400
Fruits Plant	520
Irrigated by canal	90870
Irrigated by T.Well	24900
Total	115770
[illegible]	
Tractor	9144
Seed drill	6842
Seed cum Fert. Drill	1717
Threshers	7390
Disc. Harrow	8788
Hand Sprayers	6113
Duster	90
Sprinkler Sets	12
T/Well	22413
Diesel	20544
Electric	1869
Sale Points (Coop. / Pvt. / Total)	
Seed 8 / 131 / 139	
Fert. 77 / 176 / 253	
Pest. 10 / 113 / 123	
Agri. Officers	6
Ext. Workers	54
Mini Bank	63

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