INTEGRATED APPROACH FOR IRRIGATION SCHEDULING IN A COMMAND AREA

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **"INTEGRATED APPROACH FOR IRRIGATION SCHEDULING IN A COMMAND AREA"** in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Water Resources Development, submitted in Water Resources Development and Management Department , Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2006 to June 2007, under the supervision and guidance of Dr. S. K. Mishra and Dr. Sanjay Kumar Jain.

The matter embodied in this Dissertation has not been submitted by me for the award of any other degree.

Date : June.29., 2007

Place : Roorkee

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This is to certify that the above declaration made by the candidate is correct to the best of our knowledge.

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ABSTRACT

The success of an irrigation system depends on efficient water management. The scarcity of available land and water resources, which is outcome of the growing population, has necessitated its proper planning and management. Inadequate and uneven distribution of available water resources results in frequent crop failures and shortage of fodder and drinking water. Hydrologists have made attempts to make predictions of water availability to overcome the problems created due to temporal and spatial variations in precipitations.

Irrigation scheduling is defined as the process of determining *when to irrigate* and *how much water to apply.* Irrigation scheduling is a systematic method by which a producer can decide when to irrigate and how much water to apply with goal to supply sufficient water to the plants with minimum loss to deep percolation or runoff. With smart irrigation scheduling, crops yields will not be limited by water stress from drought, and the waste of water and energy. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. Through proper Irrigation scheduling, it should be possible to apply only the water which the crop needs in addition to unavoidable seepage and runoff losses and leaching requirements.

Irrigation management requires huge volume of data pertaining to hydrological, hydro-geological, meteorological, soil, agronomic and cropping pattern parameters. Regular monitoring and performance evaluation of command areas is needed to improve water management practices and achieve an increase in overall efficiency. With the availability of remote sensing and GIS tools, it is now possible to gather instant observations over large areas and to integrate and manage multi-disciplinary data.

This study primarily is carried out for assessment of crop acreage, crop water requirements and irrigation need for carrying out irrigation scheduling in the Left Bank Canal (LBC) command area of Ghatprabha project, Karnataka state in southern India. In this study IRS 1C/1D LISS III multi-temporal digital remote sensing data has been used to find the actual cropping pattern in the command area. The data of Rabi season has been used, as the satellite data of Kharif season was not available. Geographical Information System (GIS) has been used to store, analyse, and retrieve multidisciplinary data.

Crop coefficients (Kc) for the major crops in the LBC along with potential evapotranspiration, estimated from point meteorological observations, are used to find the actual evapotranspiration. CROPWAT software, a decision support system developed by Food and Agricultural Organisation (FAO) was employed to compute reference evapotranspiration using Penman-Monteith method; crop water requirement and irrigation need to develop irrigation schedules under various management and water supply schemes.

Results indicated that reference evapotranspiration is higher during the months of March, April and May. The crop water requirement is 427.97 mm for Wheat, Maize, Sorghum, 434.08 mm for Fodder/Pulses and it is 1175.15 mm for sugarcane .The total net irrigation water requirement is 96454.03 ha-m in the Ghataprabha Left Bank Canal command.

A sensitivity analysis has been conducted upon to study the effect of the most effective factors namely irrigation efficiency and the shift of planting date on the field water supply. These governing factors were found to have significant influence on the computed field water supply, the judicious consideration of either or both of them can lead to augmentation of irrigation output with reduced water supply.

Key words: IRS 1C/1D, Remote sensing, Ghataprabha command area, Crop Water Requirement, Irrigation Scheduling, CROPWAT

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LIST OF ABBREVIATIONS

CCT	: Computer Compatible Tape
CGWB	: Central Ground Water Board
CWR	: Crop Water Requirement
ERDAS	: Earth Resources Data Analysis System
ETc	: Crop Evapotranspiration
ET_o	: Reference Crop Evapotranspiration
FAO	: Food and Agricultural Organisation
FC	: Field Capacity
FCC	: False Colour Composite
FIR	: Field Irrigation Requirement
GCPs	: Ground Control Points
GERI	: Gujarat Engineering Research Institute
GIR	: Gross Irrigation Requirement
GIS	: Geographical Information System
GPS	: Global Positioning System
Ha	: Hectares
Ha-m	: Hectare meter
IDRS	: Integrated Digital Reference Scheme
IRS	: Indian Remote Sensing Satellite
ISODATA	: Iterative Self Organising Data Analysis Technique
ISRO	: Indian Space Research Organisation
Km	: Kilometer
l/s	: liters per second
LAI	: Leaf Area Index
LBC	: Left Bank Canal
LISS	: Linear Imaging Self Scanning
MCM	: Million Cubic Meters
NDVI	: Normalised Difference Vegetation Index
NIR	: Net Irrigation Requirement

RAM	: Readily Available Moisture
SAR	: Synthetic Aperture Radar
SAVI	: Soil Adjusted Vegetation Index
SMD	: Soil Moisture Deficit
SOI	: Survey of India
TAM	: Total Available Moisture
TM	: Thematic Mapper
WALMI	: Water and Land Management Institute
WP	: Wilting Point

LIST OF SYMBOLS

γ	: Psychometric Constant
Δ	: Slope Vapour Pressure Curve
ETc	: Crop Evapotranspiration
ET_0	: Reference Crop Evapotranspiration
e_a	: Actual Vapour Pressure
e_s	: Saturation Vapour Pressure
e_s-e_a	: Saturation Vapour Pressure Déficit
G	: Soil Heat Flux Density
K_c	: Crop Coefficient
P	: Rainfall
Pe	: Effective rainfall
Rn	: Net radiation
T	: Air Temperature at 2 M Height
U2	: Wind Speed at 2 M Height
η_a	: Water Application Efficiency
η_c	: Water Conveyance Efficiency
η_s	: Water Storage Efficiency
θ_{FC}	: Water Content At Field Capacity
θ_{WP}	: Water Content At Wilting Point
Z_r	: Rooting Depth

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Irrigation is of paramount importance in development of agriculture. India has a unique agro-climate permitting the cultivation of variety of crops adapted to tropical, subtropical, temperate, semi arid and arid environments. Thus, Indian society is mainly agrarian with about 75% of the people depending on agriculture. In India about 68% of total sown area of the country is drought prone. Irrigation development has a major factor in increasing agricultural production. India made great strides in irrigation development since independence and has one of the largest irrigation networks in the world. Notwithstanding the impressive program made in creating the irrigation potential since 1950, the productivity of irrigated areas has remained low, ranging from 20 to 30 % (Planning Commission, GOI, 1985). All these areas suffer from inadequate and unreliable water supply, wide gaps between created and utilized irrigation potentials, temporal imbalance of water demands and supplies, excessive seepage losses, and rise of groundwater table leading to environmental problems of waterlogging and salinity.

The scarcity of available land and water resources, which is the outcome of growing population, has necessitated its proper planning and management. Inadequate and uneven distribution of available water resources results in frequent crop failures and shortage of fodder and drinking water. Hydrologists have made attempts to make predictions of water availability to overcome the problems created due to temporal and spatial variations in precipitations. Field research by agricultural scientists has shown that high crop yields are attainable even when water supplies are limited, if irrigation scheduling is based on an understanding of crop water needs and responses in a given environment [CBIP, 1991].

A command is the area bounded within the irrigation boundary of a project, which can be economically irrigated without considering the limitation of the quantity of available water. Irrigation projects (systems) in India are classified according to source of water (surface water or groundwater) and according to the size of culturable command area (CCA). Major projects (more than 10,000 ha of CCA) and medium projects between 2000 to 10,000 ha of CCA) generally have river storage or diversion as the source of irrigation water whereas minor irrigation projects (less than 2000 ha of CCA) are based on water lifting from river or shallow/deep aquifers. Usually, a command area in developing countries like India has a large number of subsistence holdings (unlike large commercial farms in developed countries) due to fragmentation of land holdings having occurred over centuries of traditional agricultural practices. There are marginal farmers (with plot holdings less than 2 ha), small farmers (with plot holding in between 2 to 10 ha), and large farmers (with plot holding more than 10 ha) with marginal farmers covering 24% of area, small farmers covering 53% of area, and large farmers covering 23% of area [Singh, 1985]. Because of small land holdings and the linking and preference of each farmer, spatial heterogeneity within the command area prevails in terms of cropping pattern, agronomic practices, irrigation practices, water availability and utilization, support services etc.

Irrigation provides supplemental water to meet the crop water requirements besides natural rainfall. An efficient canal network (conveyance system) is scattered to cater irrigation to the crops, in the command area. The canals are fed from the reservoirs or from the weirs, the structures meant to collect and store water in rainy days. Hydraulic design for canals are based on the peak flow rate required to meet the crop water requirement. For the design of a water conveyance system, it is necessary to assess the water requirement of the crop intended to be grown in the command. In irrigation system, water allocations are based on assumptions about the irrigated area, crop types, and the near surface meteorological conditions that determine crop water requirements. For optimizing yield vis-à-vis the available water resource, it is essential to assess when the crops need water, so that they are not irrigated arbitrarily and in meantime creating scope for irrigation scheduling. Irrigation scheduling is the primary decision tool to maximize irrigation efficiency by applying the exact amount of water needed to replenish the soil moisture to the desired level and it will in turn raise yields, saves water and energy.

1.2 NEED OF IRRIGATION SCHEDULING

Irrigation is vital for sustaining food production and to stabilize agricultural production especially in arid and semi arid areas. The efficiency of water in agricultural production is, however, low. Only 40 to 60% of the water is effectively used by the crop, the remaining water is lost in the system, in the farm and on the field, either through evaporation, through runoff to the drainage system, or by percolation into the groundwater. Poor management of irrigation water is one of the principal reasons for this low water use efficiency in irrigation. The major irrigation projects in India are reported to perform at low overall efficiency of 30 to 35% [Mohile, 2000a]. The inadequate and often unreliable water deliveries in the main system cause farmers to face regular shortages in water supply, resulting in reduced yields and incomes as well as in much smaller areas being irrigated than originally planned. An array of environmental problems are linked to ineffective water use, such as waterlogging, leaching of agro-chemicals and consequent groundwater pollution, as well as soil and groundwater salinization resulting from inappropriate water applications. For efficient use of available water resource it is recognized that irrigations must be scheduled.

Irrigation scheduling forms the sole means for optimizing agricultural production and for conserving water and is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crop water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply. Irrigation scheduling depends on soil type, crop, atmospheric, irrigation system and operational factors.

Appropriate irrigation scheduling should lead to improvements in yields and incomes, result in water saving and, in turn, increases the availability of water resources and should have a positive impact on the quality of soil and groundwater.

1.3 REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM

Vastness of the command areas, time and manpower constraints in data collection and seasonal changes in the information require fast inventory of agricultural areas. For the formulation and implementation of a water distribution plan, detailed information on spatial variation of existing cropping pattern, soil characteristics, surface topography, groundwater conditions etc. is a perquisite. Up to date information of major land use, acreage, and distribution of crops is a basic need in agriculture throughout the world. These data are essential for efficient management of agriculture resources and sustainability. These data and information need to be analysed, stored and retrieved efficiently in a user-friendly environment. Manual (Traditional) methods of storing, handling and updating irrigation data in the form of field/village maps and reports are relatively slow process, usually unsystematic, require high cost and occupies larger space for data management. In all these circumstances, remote sensing technique and GIS tools are assuming as viable alternative or at least a dependable support system in our conventional way of survey, investigation, planning, monitoring, modeling and decision making process. Planning for future growth is greatly enhanced based on the information on the present extent, location, and productivity of land used for different purposes is needed for analysis.

Remote sensing is the science and art of acquiring information about objects from measurements made at a distance without any physical contact with the objects. It is a cost-time-effective promising technique which has been used to provide regular information on agriculture and hydrological conditions of the land surface for vast areas and have also played vital role in developing and monitoring water management plans. The usefulness of remote sensing technique to obtain information on land use irrigated area, biomass development, crop type, crop yield, crop water requirements, salinity, and water logging etc. has been recognized in various investigations. Information on these parameters is potentially useful in water distribution planning, performance diagnosis and impact assessment. Bastiaanssen et al. (2000) have presented the utility of remote sensing deliverables for various applications (Table 1.1).

Table 1.1: Utility of remote sensing for water management [Bastiaanssen et al. 2000]

Remote Sensing deliverables	Water use/ productivity	Performance diagnosis	Strategic planning	Water rights	Operations	Impact assessment
Land use	√		√			
Irrigated area	√	√	√	√	√	√
Crop type	√	√		√	√	√
Crop yield	√	√	√			√
Daily ET		√			√	
Seasonal ET	√	√		√		√
Crop stress		√			√	
Salinity		√				√
Historical data		√	√	√		√

Data available from sensors on-board, the constellation of IRS satellites which are currently in orbit around the earth can be made use of to extract information on the area under irrigation, types of crop growth and their conditions, crop acreage and crop productivity. Each IRS satellite has a revisit period of 5 to 24 days covering every part of Indian landscape with spatial ground resolution of 5.8m to 23m [Chakraborti, 1998]. With these space based technological capabilities in place and ground segment preparedness in analysing these data in user interactive digital image processing system (DIP) and Geographic Information System (GIS) has been made operational in the country in the irrigation sector [Chakraborti]. GIS can be effectively used to integrate varieties of data, both textual and thematic ones in determining the variability of agricultural and hydraulic performances, and in visualizing the irrigation network configuration.

Indian Remote Sensing satellite (IRS-1C), launched in 1997, opens new possibilities of crop survey, which is required in analysing agriculture as a system. To evaluate requirement of water for crop the cropping pattern must be known. The best way to monitor changes over the year is to compare multi-date remotely sensed data demarcate the change through visual or digital analysis. Vegetation has a unique response in the different channels. The vegetation indices like Normalised Difference Vegetation

Index (NDVI), Ratio Vegetation Index (RVI) quantify the greenness and vigour. NDVI is the first successful vegetation indices based on band ratioing.

If NDVI < 0, healthy vegetation is predictable.

If NDVI > 0, water bodies are predictable

If NDVI = 0, soil may be predictable

Vegetation indices are redundant in information content and should be used judicially. Healthy green vegetation normally has the highest positive NDVI value, while surfaces without vegetation such as bare, soil, rock, water, snow, ice or clouds, usually have a low NDVI value that is near zero or slightly negative, stressed vegetation or vegetation with small leaf always have positive but reduced NDVI values.

1.4 OBJECTIVES AND SCOPE OF STUDY

The foremost objective of the study is

i. To classify the major crops in Ghataprabha command and to obtain area under each crop using multi-temporal satellite data.
ii. To evaluate the Crop Water Requirements using CROPWAT and GIS.
iii. To evaluate Irrigation needs.
iv. Irrigation scheduling for the existing cropping pattern using CROPWAT model.
v. To analyse for different irrigation scenarios with varying cropping pattern.

1.6 ORGANISATION OF THE DISSERTATION

The present thesis work is concerned with the study of various irrigation parameters involved in irrigation scheduling of Ghataprabha LBC command area (Karnataka State) in southern India.

The chapters have been organised in such a manner that the required information has been stepwise drawn to meet the objectives of the study.

Chapter 2 : Discusses about the literature review.

Chapter 3 : Description about the study area.

Chapter 4 : Deals with the material and methodology adopted.

Chapter 5 : Presents the analysis and results followed by discussions.

Chapter 6 : Conclusions and recommendations of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Irrigation scheduling is defined as the process of determining *when to irrigate* and *how much water to apply*. The goal of an effective scheduling program is to supply the plants with sufficient water while minimizing loss due to deep percolation or runoff. Irrigation scheduling is integral part of water distribution planning in the command area of irrigation project. While analyzing irrigation development during the project life, it is important to consider likely water deficit condition, resulting in yield reduction, and plan for irrigation scheduling to mange water deficits at micro field and project level. It requires good knowledge of the crop water requirements and of the soil water characteristics that determine when to irrigate, while the suitability of the irrigation method determines the accuracy of how much water to apply. An integrated approach of Remote Sensing and GIS environment along with the CROPWAT software is helpful for carrying out irrigation scheduling in a canal command area in a more scientific manner.

2.2 CROPPING PATTERN

Crop planning aims to evolve a cropping pattern, which maximizes the socio-economic benefits of irrigation. Cropping pattern means the proportion of area under different crops at a particular period of time. Irrigation water allocation is based on information about the irrigated area, crop types, and near-surface meteorological conditions that determine the crop water demands. Any change in cropping pattern means a change in the portion of area under different crop. Up-to-date and reliable information on cropping patterns in an area can be of invaluable help in taking up remedial measures. Remote sensing has amply shown great potential in agricultural mapping and monitoring changes in cropping patterns due to its advantages over traditional methods in terms of cost effectiveness and timeliness in the availability of information over larger areas [Murthy et al., 1996]. Canal operation schedule is based on the cropping pattern and crop water demand. Correct evaluation of economic, social and ecological factors (rainfall, temperature, soil etc) are necessary to make the crop planning realistic. A cropping pattern often comprises of many crops which differ in terms of sowing date and phenology. Temporal evolution of amount and colour of foliage is a useful feature for crop discrimination, so multi-temporal sequences of satellite images can be used to measure spectral reflectance at different growth stages. Menenti (2000) describes a procedure to discriminate crops by increasing the number of attributes using spectral reflectance of multi-temporal data. Bastiaanssen (1998) has worked out an average accuracy of 86% for crop identification using remote sensing data.

2.3 WATER REQUIREMENTS/ WATER DEMAND

For efficient use of water resources it is recognized that irrigation must be scheduled based on irrigation water demand which varies with the crop water requirement which is in turn varying according to the crop growth stages. Irrigation scheduling is based on query: When to, How often and How much. Irrigate when the crop needs water to meet its evapotranspiration demand, and often enough to prevent the plants suffering from water stress. Irrigate as much as plants demand. Evapotranspiration is low at early stages and maximum at heading stage that demands more frequency of irrigation towards flowering (IRRI, 2005). In a water distribution system water allocation is made according to the designed crop water requirement which is based on crop season, crop calendar and cropping pattern. Hence, the precise assessment of crop water requirements becomes very essential for efficient planning and management of irrigation project.

Crop Water Requirement

Crop Water Requirement also called as Evapotranspiration or Consumptive use have been defined as "the depth of water needed to meet the water loss through evapotranspiration (ETc) of a disease free crop, growing in large fields under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1997). The FAO approach estimates the crop water requirement as:

$ETc = K_c * ETo$

Where, ETc = crop evapotranspiration, K_c = crop co-efficient and ET_0 = reference crop evapotranspiration.

Crop water requirements are normally expressed by rate of evaporation (ET), in mm/day, mm/month, or mm/season. These mainly depend on the climate, crop type, and the growth stage. The effect of various climatic factors is shown in Table 2.1

Table 2.1: Effect of major climatic factors on Crop Water Requirement

Climatic Factors	Crop Water Requirement	
	High	**Low**
Sunshine	sunny (no clouds)	cloudy (no sun)
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Wind speed	windy	little wind

Reference Crop Evapotranspiration

Reference Crop Evapotranspiration (ET_0) represents the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos, 1984). The concept of the reference crop evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices.

A number of methods are available for estimation of reference crop evapotranspiration namely Blaney-criddle, Radiation, Hargreaves method, Penman method, Pan Evaporation method, Penman-Monteith method, Thornthwaite method etc. Primarily the choice of method must be based on the type of climatic data available and on the accuracy required in determining water needs. Climatic data needed for different methods are:

Method	Temperature	Humidity	Wind	Sunshine	Radiation	Evaporation
Blaney-Ciriddle	*	0	0	0		
Radiation	*	0	0	*	(*)	
Penman	*	*	*	*	(*)	
Pan evaporation		0	0			*
Penman-Monteith	*	*	*	*	0	

* Measured data;   0 estimated data;   (*) if available, but not essential

The analysis of the performance of the various calculation methods reveal that FAO (56) Penman-Monteith method is a method with strong likelihood of more correctly predicting ET_0 in a wide range of locations and climates than other earlier methods introduced in FAO Irrigation and Drainage Paper No. 24. The modified Penman method offers the results with minimum possible error of ± 10 percent in summer, and upto 20 percent under low evaporative conditions. The Pan method with possible error of 15 percent, depending on the location of the pan. The radiation method, in extreme conditions, involves a possible error upto 20 percent in summer. The Blany-Criddle method should only be applied for periods of one month or longer; in humid, windy, mid-latitude winter condition an over, and under prediction of upto 25 percent has been noted.

Crop Coefficient

The crop coefficient K_c is the ratio of potential evapotranspiration for a given crop to the evapotranspiration of a reference crop. It represents an integration of effects of four primary characteristics that adjust the crop from reference grass namely crop height, albedo, canopy resistance and evaporation from soil, especially from exposed soil. The factors determining the crop coefficient are crop type, climate, crop growth stage and soil evaporation [Allen, 1998]. The empirically determined crop coefficient can be used to relate ET_o to ET crop as

$$ETc = K_c * ET_0$$

The total crop growth period is divided into four stages [FAO Training Manual No. 3]:

1. The initial stage: is the period from sowing or transplanting until the crop covers about 10% of the ground.
2. The crop development stage: this period starts at the end of the initial stage and lasts until the full ground cover has been reached (about 70-80%).
3. The mid-season stage: this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain setting.
4. The late season stage: this period starts at the end of the mid-season stage and lasts until the last day of harvest; it includes ripening.

Net Irrigation Requirement (NIR)

The net irrigation water requirement is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or ground water contribution or other gain in soil moisture that is required consumptively for crop production (Michael, 2002). It is amount of irrigation water to bring soil moisture level in the effective root zone to field capacity. Neglecting carry over soil moisture or ground water contribution, NIR is computed as.

$$NIR = ETc - Pe$$

Where, ET_c = crop evapotranspiration in mm, Pe = effective rainfall in mm.

The Net Irrigation Requirements (NIR) has to be adjusted for conveyance loss.

Effective Rainfall (Pe)

All the rainfall in a region is never completely utilized; a part of it may be lost by surface runoff, deep percolation or evaporation. The effective rainfall is that portion of the rain falling during the growing period of crops, which is available to meet the water requirement of crops. There are different methodologies available to estimate the effective rainfall based on the fixed percentage, dependable rain, and empirical formula and by the evapotranspiration/precipitation ratio method (USDA, 1969). The U.S. Department of Agriculture, Soil Conservation Service has developed tables relating the effective rainfall of the mean monthly rainfall and mean monthly consumptive use of the crops.

Field Irrigation Requirement (FIR)

It is the amount of water required to be applied to the field. This irrigation water requirement includes the losses due to seepage from the field distribution channels and deep percolation below crop root zone. It also includes runoff losses at the tail end of border and furrows in case of long fields (Michael, 2002). The losses in water application depend on the type of soil, grade (slope) of the field and method of irrigation [Tripathi, 2000e]. FIR is computed as:

$FIR = NIR / \eta_a$

Where, η_a = water application efficiency.

Gross Irrigation Requirement (GIR)

GIR is the field irrigation requirement plus losses in the conveyance system due to seepage, evaporation, etc. This can be determined at outlet head or canal head depending upon the purpose of determination [Tripathi, 2000e]. It is the total amount of water applied through irrigation. GIR is computed as:

$GIR = FIR / \eta_c$

Where, η_c = water conveyance efficiency of canal.

2.4 WATER DELIVERY AND DISTRIBUTION SYSTEM

Aim of Delivery and Distribution Planning

Due to lack of proper planning in distribution and delivery system the whole project will be badly affected. While planning an irrigation system the following aspects are to be kept in mind to achieve them as far as possible.

i) Adequacy: Delivery of water as per crop requirement.

ii) Efficiency: Maximum possible saving of irrigation.

iii) Reliability: Confirmation of uniform water as per the design irrigation schedule.

iv) Equity: Proportionate distribution of water as per the land holding size but not necessarily is the equality.

Delivery and Distribution Schedule

Although water delivery and distribution involves complex technical institutional and investment questions, the potential pay-off from improving irrigation system is large. The delivery system of irrigation water is to be properly managed and scheduled for the proper distribution of water.

1) Warabandi system

The Warabandi system practiced in Haryana, Punjab and Rajasthan is a system of delivery of water in rotation amongst cultivators sharing water from a canal outlet. The system is designed to distribute available water as equitably and reliably as possible. It is known as Osrabandi in Uttar Pradesh. The share of water of an irrigator is in proportion to the area of his landholding in the command outlet. A predetermined quantity of water is provided to each irrigator once a week. Because the farmer is assured of a pre-determined amount of water, he arranges his cropping accordingly and is able to maximize the return of water and rainfall by careful irrigation. The duration of water supply allowed per unit area of the irrigated land under the command of the outlet is determined by dividing the number of minutes in a week by the area of land to be irrigated. Allowances are made for the watercourse filling time and the conveyance losses in the watercourse. The warabandi system was designed to spread available water over as large an area as possible from run-of-the-river diversions to take advantage of the seasonal snowmelt runoff prior to the onset of the monsoon, although natural variations in flow have since been augmented by storage structures.

2) Shejpali System

The Shejpali and Block systems practiced in western and central India is a demand based water distribution system operated in the States of Gujarat, Maharashtra, Karnataka and parts of Madhya Pradesh. Under this system, estimates of expected water availability are made and applications are invited from farmers seeking information on the crop to be grown and the area to be irrigated under each crop. Sanctions are provided to farmers by the State Irrigation Department to grow particular crops and the farmer is thus authorised to draw water to suit his perceived needs. Water is then sanctioned taking into account the total demand and the water availability. A schedule, called Shejpali, giving turns to different irrigators in the sanctioned crop area of the outlet is prepared for each rotation. In the block system, a long-term agreement for the supply of water for 6 to 12 years is made, especially in case of perennial crops. A system called "Rigid Shejpali" has been introduced recently. In this system, definite duration for the supply of water to a particular field area is recorded on the passbooks issued to farmers of the sanctioned area. In principle, the shejpali system is compatible with agro-ecological conditions and works for so long as the full area demanded by farmers is sanctioned and supplied. Canal procedures are therefore 'demand-driven'.

3) Zonal System

This system has been introduced in the Lower Bhavani Project in Tamil Nadu. In this system the command area is divided into two halves. Water is made available continuously to one half of the area for one season, which extends over a period of 4 months in a year. The other half gets irrigation water sufficient for wet crops in the next year. This way each half gets irrigation supplies for wet and dry crops in alternate years. This system of irrigation with dry and wet crop seasons is known as year to year rotation.

4) Localized System

This system is practised in most of the irrigation projects in southern and northeastern states as well as in the states of West Bengal, Orissa, Bihar and Jammu and Kashmir, where paddy is the main crop. Under this system, irrigation below the canal outlet proceeds from one field to another through surface flooding. The localized system of irrigation is presently followed in most of the command areas in India. There is no control over the quantity of water applied in this system. The fertility of the higher fields gets progressively reduced.

2.5 IRRIGATION EFFICIENCY

Water is lost in irrigation during various processes. There are two aspects involved in water use efficiency. One concerns the input i.e. application of irrigation water with minimum losses occurring due to various kinds of processes and the other concerns the output i.e. the crop yield. The losses in storage, conveyance and application depending upon the engineering structures, regulation and application can be minimised by adequate planning of the irrigation system, efficient operation of the system, adequate land preparation and proper irrigation method. The objective of efficiency concept is to show where improvements can be made to reduce these losses and achieve an efficient use of water available for irrigation. Irrigation efficiencies are expressed in different ways. Some of them are given below

a) Water Conveyance Efficiency

It is defined as the ratio of quantity of irrigation water supplied to the field (Wf) to the quantity of water diverted into the canal from off-take point of project head works (river or reservoir). It takes into account the water losses which occur during conveyance from point of diversion into the canal to the fields.

$\eta_c = Wf / Wr * 100$

b) Water Application Efficiency

It is defined as the ratio of quantity of irrigation water stored in the root zone of the plants of the soil (Ws) to the quantity of irrigation water supplied to the field (Wf).

η_a =Wf / Wr *100

c) Water Storage Efficiency

It is defined as ratio of the quantity of irrigation water stored in the root zone during irrigation (Ws) to the quantity of irrigation water needed in the root zone for irrigation (Wn).

η_s = Ws / Wn * 100

2.6 IRRIGATION SCHEDULING

The principle of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. For maximum flexibility, the irrigators should have control of the irrigation interval, water application flow rate and duration. Through proper irrigation scheduling, it should be possible to apply only the water which the crop needs in addition to unavoidable seepage and runoff losses and leaching requirements. The amount of water required for irrigation varies from day to day and is influenced by the factors like soil type, effective root depth, crop maturity, soil-moisture content and evapotranspiration.

1) Soil Moisture Content

Soil moisture content (water content) refers to the capacity of soil to retain water available to plants for their growth (Allen 1998), which depends upon the texture of soil, structure, depth and soil stratification etc. The soil will drain until field capacity after heavy rainfall or irrigation. Field capacity is the amount of water that a well drained soil should hold against gravitational forces, or the amount of water remaining when to replace only the depleted PAW within the effective root zone. The rate of development of root zone depth depends on the crop subject to the influence of soil-moisture and nutrients. The effective root zone for wheat is developed by almost 1cm/day for the first 90 days, and negligible growth occurs afterwards [Singh, 1994].

3) Crop Maturity

The water uptake rate of crop varies with the stage of growth of crops. The growth of crop is divided into four stages namely initial, crop development, mid-season stage and late season stage. The consumptive use is at or near maximum during the mid-season as it includes flowering and grain setting or yield formation. Water shortage at mid-season stage will have pronounced negative effect on the crop yield. The least sensitive to water shortages is the late season stage which includes ripening and harvest. The amount of water applied and the frequency of irrigation must be adjusted to the actual consumptive use of crop, water holding capacity of the soil and depth of the rooting.

COMMON IRRIGATION SCHEDULING APPROACHES

1. Irrigating on fixed intervals or following a simple calendar, i.e., when a water turn occurs or according to a predetermined schedule by the Govt. agencies.
2. Irrigating when one's neighbour irrigates.
3. Observations of visual plant stress indicators.
4. Measuring (or estimating) soil water by use of instruments or sampling techniques such as feel, gravimetric, electrical resistance (gypsum) blocks, tensiometers or neutron probes.
5. By following a soil water budget based on weather data and/or pan evaporation.
6. Some combination of the above.

Various methods and tools have been developed when crops require water and how much irrigation water needs to be applied. These include the various soil and plant monitoring methods as well as the more common soil water balance and scheduling simulation models. The use of various scheduling tools depends on the input requirements related to data type: weather, soil and crop, as well as to the frequency of data collection. Estimates of evapotranspiration and crop water requirements play an important role in many of the available models and various water stress criteria. Different techniques available for irrigation scheduling are shown in Table 2.2.

ADVANTAGES OF IRRIGATION SCHEDULING

Irrigation scheduling offers several advantages:

1. It enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yields.
2. It reduces the farmer's cost of water and labour through less irrigation, thereby making maximum use of soil moisture storage.
3. It lowers fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum.
4. It increases net returns by increasing crop yields and crop quality.
5. It minimises water-logging problems by reducing the drainage requirements.
6. It assists in controlling root zone salinity problems through controlled leaching.
7. It results in additional returns by using the "saved" water to irrigate non-cash crops that otherwise would not be irrigated during water-short periods.

PROBLEMS WITH IRRIGATION SCHEDULING

In developing countries, approximately 80% of the total water used is required for agricultural purposes. Domestic and industrial needs are relatively low. Demand for water is expected to increase in all sectors which will require considerable improvements in efficiency. Despite numerous methods available for irrigation scheduling, the overall use of scheduling methodology is very limited due to some of the constraints such as flexibility, water pricing, cost of scheduling etc., as discussed below.

a) Flexibility

Flexibility in irrigation scheduling is essential. Irrigation scheduling becomes redundant if water is not available when required or if supplied on a rigid schedule

Table 2.2: DIFFERENT TECHNIQUES AVAILABLE FOR IRRIGATION SCHEDULING

Method	Measured parameter	Equipment needed	Irrigation criterion	Advantages	Disadvantages
Hand feel and appearance of soil.	Soil moisture content by feel.	Hand probe.	Soil moisture content.	Easy to use; simple; can improve accuracy with experience.	Low accuracies; field work involved to take samples.
Gravimetric soil moisture sample.	Soil moisture content by taking samples.	Auger, caps, oven.	Soil moisture content.	High accuracy.	Labour intensive including field work; time gap between sampling and results.
Tensio-meters.	Soil moisture tension.	Tensiometers including vacuum gauge.	Soil moisture tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labor to read; needs maintenance; breaks at tensions above 0.7 atm.
Electrical resistance blocks.	Electric resistance of soil moisture.	Resistance blocks AC bridge (meter).	Soil moisture tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Water budget approach.	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall, depending on model used to predict ET.	Weather station or available weather information.	Estimation of moisture content.	No field work required; flexible; can forecast irrigation needs in the future; with same equipment can schedule many fields.	Needs calibration and periodic adjustments, since it is only an estimate; calculations cumbersome without computer.
Modified atmometer.	Reference ET.	Atmometer gauge.	Estimate of moisture content.	Easy to use, direct reading of reference ET.	Needs calibration; it is only an estimation.

without due consideration to varying crop water requirements. This is common in older irrigation projects where water is delivered to farmers on a predetermined schedule. Lack of flexibility can be caused by system limitations.

b) Water Pricing

Irrigation systems have traditionally been built, operated and maintained by the public departments with minimal charge for services. It is estimated that in developing countries, the average government revenue from irrigation is only 10-20 % of the full cost delivery (Postel, 1990). The same is true in the developed world where water is allocated to irrigation districts at costs which do not reflect real market values (Ives, 1993). This promotes inefficient water management practices. By contrast, when prices reflect scarcity, then farmers will use water productively and more efficiently.

c) Cost of Scheduling

Irrigation scheduling methods can be costly and time consuming. Unless properly monitored and maintained, they are unreliable. Economic benefits through irrigation can be minimal for low value crops. The farmers practice proper irrigation without using sophisticated instruments and limited decision-making skills and this will continue until any new technology developed provides perceived benefits with minimal cost or demand for time. If the benefits are not evident, the acceptance and use of such technology will be limited unless highly subsidized.

d) Education

The degree of acceptance of irrigation scheduling technology depends directly on the literacy levels of the farming community. It is unfortunate that most of the traditional irrigation systems are located in areas where educational standards are low. Thus, it is essential that reliable information is developed and disseminated in a very simplified manner understandable to the trainers and end-users.

2.7 REMOTE SENSING AND GIS

Use of remote sensing data gives low-cost synoptic view in multi-spectral data at a repetitive coverage over large areas. The primary differences between remote sensing instruments are in their spatial, temporal, spectral, and radiometric resolutions. Optimising one type of resolution generally involves some sacrifice in other types of resolution, *e.g.*, the Indian Remote Sensing Satellite (IRS) 1C/1D (Linear Imaging Self Scanning) LISS III, Landsat Thematic Mapper (TM) has a much better spatial resolution than the IRS 1C/1D (Wide Field Sensor) WiFS and NOAA/AVHRR (23.5m/30 m versus 188m and 1 km pixel size respectively); however, the AVHRR can provide daily coverage for a given point and WiFS data has a revisit period of 3 days, whereas the LISS and TM can only provide bi-weekly coverage.

Vegetation Indices

A range of spectral vegetation indices have been developed by various authors for various applications that reduce multi band observations to a single numerical index. The index is typically a sum, difference, ratio, or other linear combination of reflectance factor or radiance observations from two or more wavelength intervals. Some of the vegetation indices [Jensen, 1986] are given in Table 2.3.

Table 2.3 Some Vegetation Indices

S. No	Name	Ratio
1.	Simple Subtraction	IR – R
2.	Simple Division	IR / R
3.	Normalized Difference Vegetation Index, NDVI	$\frac{IR - R}{IR + R}$

Note: IR = Infrared reflectance, R = Red reflectance

High absorption of incident sunlight in visible red portion and strong reflectance in near infrared portion of the electromagnetic spectrum by photo synthetically active tissue in plants is distinctive from that of soil and water, the other two predominant landscape features. Thus vegetation indices developed from spectral observations in these two wavelength regions have correlated highly with the plant stand parameters.

More specifically, vegetation indices have been considered a measure of vegetation density or cover. Tucker (1979) described that different vegetation covers can be distinguished according to their unique spectral behavior in relation to the ground features. Visible radiation in red is absorbed by chlorophyll, while in the near infrared region strongly reflected by leaves because of cellular structures. An ideal vegetation index as defined by Jackson *et al.* (1983) should be particularly sensitive to vegetation covers, insensitive to soil brightness, insensitive to soil color, little affected by atmospheric effects and solar illumination geometry and sensor viewing conditions. The commonly used vegetation indices for agricultural application are Normalised Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI) and Leaf Area Index (LAI).

Normalised Difference Vegetation Index (NDVI)

Normalised Difference Vegetation Index (NDVI) gives the information on vegetation cover defined as the ratio of difference in red and near infrared reflectance to their sum. Index values can range from -1.0 to 1.0, but vegetation values typically range from 0.1 to 0.7. In general, higher values of NDVI indicate greater vigor and density of vegetation whereas the clouds and snow will cause index values near zero, making it appear that the vegetation is less green (Tucker, 1979).

NDVI permits good prediction of agriculture crops (Tucker and Sellers, 1986; Bullock, 1992). The success of NDVI as a descriptor of vegetation variation in spite of atmospheric effects and radiometric degradation in red and near infrared bands (Kaufman, 1984 and Holben *et al.*, 1990) resides in the normalisation it permits. Normalisation reduces the effect of sensor calibration degradation by approximately 6 per cent of the overall index value (Kaufman and Holben, 1993).

Soil-Adjusted Vegetation Index (SAVI)

The SAVI has been introduced by Huete (1988) to minimise the effects of soil background on the quantification of greenness by incorporating a soil adjustment factor (L) in the basic NDVI form. The Value of L is taken as 0.5 for annual field crops.

Leaf Area Index (LAI)

LAI was proposed by Watson (1947) as a quantitative measure of the amount of live green leaf material present in the canopy per unit ground surface. It is defined as half the total green leaf area (one-sided area for broad leaves) per unit ground surface (Chen and Black, 1992).

VEGETATION INDICES DERIVED FROM LISS III IMAGERY

LISS stands for Linear Imaging Self-Scanning Sensor, operating in four spectral bands, three in the visible and near-infrared regions and one in the reflected-infrared region. It provides a ground resolution of 23.5 m except in the infrared band which has a coarse resolution of 70.5 m. The various indices can be derived like Simple Ratio (SR), Normalised Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI) and Weighted Difference Vegetation Index (WDVI).

CLASSIFICATION TECHNIQUES

It is possible to analyse remotely sensed data of the earth and extract useful information. One of the most often methods of information extraction is multispectral classification. Most of the information extraction techniques rely on analysis of the spectral reflectance properties of such imagery and employ special algorithms designed to perform various types of spectral analysis [Jensen, 1986].

Multispectral classification is the process of sorting pixels into finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criterion.

This process is also referred to as image segmentation. Multispectral classification may be performed using either of the following two main generic approaches.

Supervised Classification

In a supervised classification the identity and location of some of the land cover types, such as urban, agriculture, and forest are known a priori through a combination of fieldwork, scientific reports, revenue statistics, aerial photographs, maps, and personal experience. The analyst attempts to locate specific areas in the remotely sensed data that represent homogeneous examples of these known land cover types. These are commonly referred to as training sites because the spectral characteristics of these known areas are used to train the classification algorithm. Multivariate statistical parameters are calculated for each training site. Every pixel within and outside these training sites is then evaluated to the class of which it has the highest likelihood of being a member. The image data are classified using any of the algorithm namely minimum (Euclidean) distance to mean, minimum (Mahalanobis) distance to mean, parallelepiped or box and maximum likelihood. Maximum likelihood classifier provides better accuracy. Steps to be followed in this classification technique has been given in the flow chart (Figure 2.1) [Jensen, 1986].

Unsupervised Classification

In the unsupervised classification, the identities of land cover types to be specified, as classes within a scene are not generally known a priori because lack of ground truth or surface features within a scene are not well defined. The computer is required to cluster pixel data into different spectral classes according to some statistically determined criteria. It is then the analyst's responsibility to label these clusters. Procedure for unsupervised classification is given in Figure 2.2 [Jensen, 1986]. Iterative Self-Organising Data Analysis Technique (ISODATA) classifier is a widely used classifier and available in ERDAS IMAGINE. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster

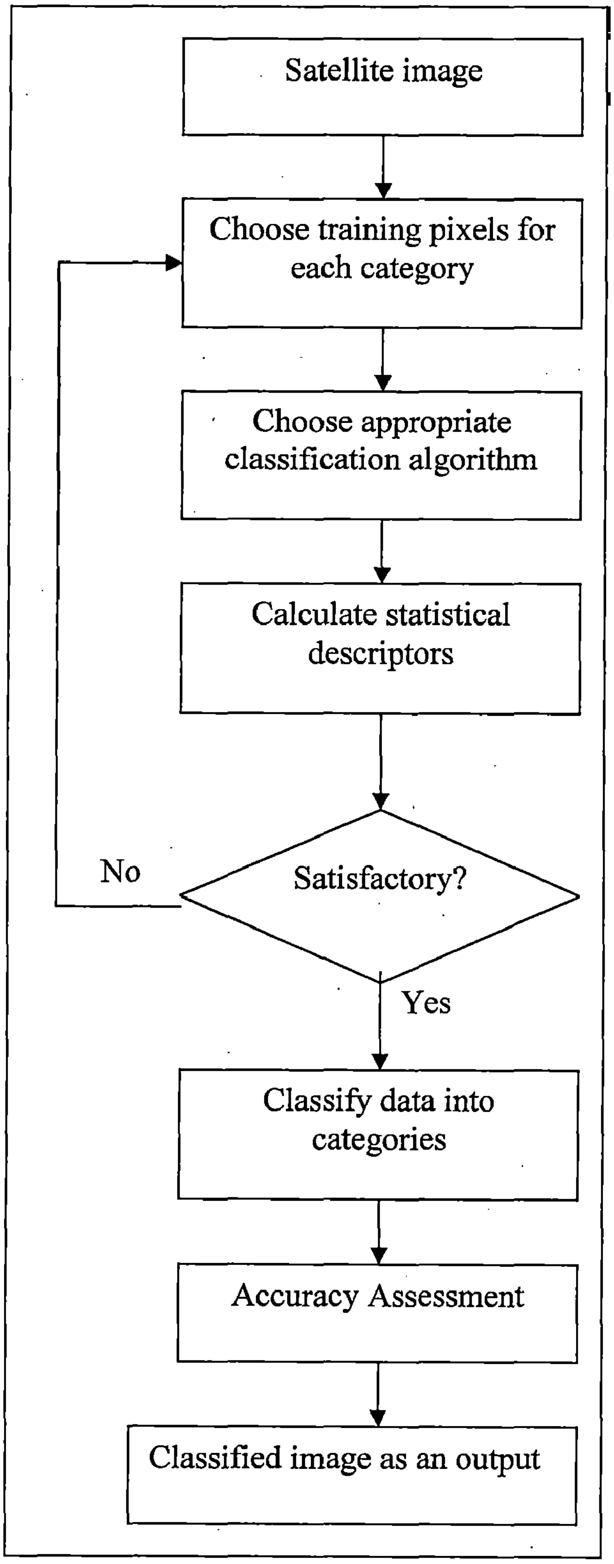


Fig 2.1: Supervised Classification

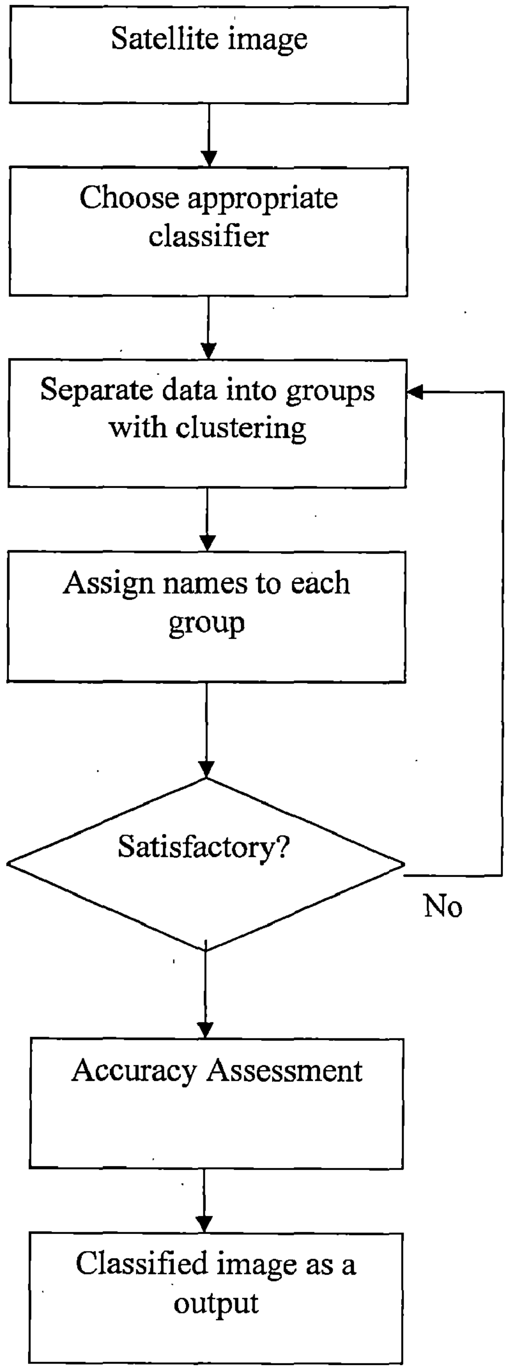


Fig 2.2: Unsupervised Classification

means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. Previous reports states that Combination of unsupervised and supervised classification gives better classification accuracy [Thiruvengadachari, 1996].

Accuracy Assessment

Accuracy assessment allows to evaluate a classified image file (thematic raster layer). In classifying an image, the spectral response of a pixel, representing a fixed area on the ground defined by resolution of the sensor, is used to assign it to one of a number of classes using various classification techniques. Accuracy assessment of a classified map derived from remotely sensed data is a critical and final step in the classification process. Accuracy serves as the basis for the analysis of errors that may creep in during the classification process [Arora and Ghosh, 1986]. One of the most common ways of representing the classification accuracy is by defining it with the help of confusion or an error matrix. The error matrix can be used to generate various statistics that characterise the accuracy of classification technique. The goal is to quantitatively determine how effectively pixels were grouped into the correct land cove classes. To achieve an accurate classification, a number of factors such as classification scheme, classification algorithm, training and testing sample size, number of spectral bands and others must be considered [Arora and Ghosh, 1986].

2.8 MODELS FOR IRRIGATION SCHEDULING

The accurate determination of an irrigation schedule is a time consuming and complicated process. The introduction of computer programs has however, made it easier to schedule the irrigation water supply exactly according to the crop water requirements. The various computer models are available which help in irrigation scheduling, like CROPWAT for windows (Clarke et al., 1998), ORYZA2000 (Bouman et al., 2001), GISAREG (Fortes et al., 2005) and Surface Energy Balance Algorithm for Land (SEBAL) (Waterwatch, 1998). All models are aiming at meeting the crop demand with the available water to get maximum production. The model is able to generate irrigation scheduling alternatives that are evaluated from the relative yield loss produced, when crop evapotranspiration is below its potential level [Oweis et al.,2003; Zairi et al., 2003; Liu et al., 2000; and Campos et al.,2003 (In: Fortes et al., 2005)].

The CROPWAT model was originally developed by Food and Agriculture Organisation of United Nation in 1990 to calculate crop water requirements and for planning and managing irrigation projects. The input data of the CROPWAT model include crop, meteorology, and soil. The meteorology data include: (1) maximum and minimum temperature; (2) wind speed; (3) sunshine hours; (4) relative humidity; (5) rainfall. Procedures for calculation of crop water requirements and irrigation demands are mainly based on methodologies presented in FAO Irrigation and Drainage Paper Nos. 24, 33 and 56. The program is meant as a practical tool to help both Irrigation Engineer and Irrigation Agronomist to carry out standard calculations for design and management of irrigation schemes. It also helps in the development of recommendations for improved irrigation practices and planning of irrigation schedules under varying water supply conditions. CROPWAT version 5.7 facilitates the linkage to the CLIMWAT program, a climatic data base of 3261 stations of 144 countries worldwide in Asia, Africa, Near East, South Europe, Middle and South America. CROPWAT version 7 has been converted to WINDOWS platform for easy data entry and analysis. Presently, CROPWAT 4 WINDOWS 4.2 version is available and is being used in this study.

2.9 APPLICATIONS

There are number of studies carried out in the field of crop area assessment and irrigation water management. A brief review of some relevant studies reported in literature is summarized as follows:

Tripathi et al. (1981) determined the effectiveness of infrared thermometry to detect plant water stress for scheduling irrigation of wheat. There results revealed that a canopy temperature variability value upto 0.6 ^{0}C in wheat represents well watered condition and under shallow water table conditions at canopy temperature variability of 0.7 ^{0}C could be assigned to warn stress.

Morten et al. (1984) carried out a study on irrigated crop inventory by using classified satellite image data. Mixed unsupervised / supervised classification of band 5, band 7 LANDSAT multi-spectral scanner image data was used for determining area of crop land under irrigation in an arid region of the state of New South Wales in Australia. Classification using two analysis systems was described. One was a dial-in bureau service, which supports the ORSER software package and the other a Dipix Aries II interactive image analysis system. Results obtained agreed to within 1 to 5 percent with information provided by field studies. Density slicing using a vegetation index was also described, but with an accuracy of approximately 8 percent. A rough cost-effectiveness analysis was made with irrigated crop inventory studies of other investigators.

Nageswar Rao et al. (1987) carried out a study on use of remotely sensed data for different cropping patterns specific to India. The LANDSAT MSS data in the form of false color composite (FCC) was used for this study. The rice crop was identified with an accuracy of 90 to 94% from cropping pattern having less than 50% of cropped area under rice and rest of the area under multiple crops was identified with an accuracy of 75%. It was observed that besides higher spatial resolution, acquisition of data at the critical crop windows (the periods of minimum overlap of greenness of rice with other crops) is necessary to reach high accuracy for multiple cropping patterns. Cropping seasons of rice in India are kharif (June-September sown crop), Rabi (October-December sown crop) and summer (February-May sown crop). Rice yields are less in the uplands, which are mostly dependent on monsoon rainfall.

Premlatha et al. (1994) estimated crop acreage before harvest. Synthetic Aperture Radar (SAR) data from the European Remote sensing satellite (ERS) acquired in July, October and November 1992, covering the Kharif season of the region was used separately and in combination to identify the major crops of Guntur district, Andhra Pradesh. Satellite remote sensing is an important means of providing accurate, reliable and timely information on acreage and production of major food grain and oil seed crop ever since the launch of Indian Remote sensing satellite (IRS-1A) in 1998. However due to persistent cloud cover during Kharif season pre-harvest production forecasting has been found to be an alternate to for crop inventory because of its all weather and all time capability. This study was an attempt to explore the advantage of multi-temporal SAR data for crop identification and area estimation.

Patnaik et al. (1995) carried out a study crop discrimination using simulated IRS–1C LISS-III data produced using visible and NIR channel from SPOT and middle infrared (MIR) channel from TM over a previously investigated test site, characeterised by multiple crops and small fields, in Sabarkantha district (Gujarat). The seperability amongst dominant kharif season crops, namely, cotton, groundnut, maize, pigeon pea, between crops and various natural vegetation classes was investigated using Jefreys Matusita (J M) distance, a pair-wise inter-class seperability measure. The study highlighted the capability of simulated LISS-III data to be useful in identifying and labeling small fields and the 4-band data set to significantly improve the seperability amongst various crop and vegetation over two 3-band sets and B 345.

Hari Prasad et al. (1996) conducted a study on irrigation command area inventory and assessment of water requirement using IRS-1B satellite data. The study revealed that satellite data provided information of crop area and thereby net irrigation water requirement of crops. IRS-1B LISS II geocoded False Color composite (FCC) images pertaining to October 3, 1992 for kharif season and March 6, 1993 for Rabi season are used in this study. Moreover, FCC images, digital data in the form of Computer Compatible Tape (CCT) of IRS-1B satellite acquired on December 19, 1992 was also used selectively for Rabi crop classification and acreage estimation. Canal alignment and command area boundary map, canal water supply, tube well water supply statistics, pan evaporation and other metrological data were also used. This water requirement when analyzed with canal and tube well water supplies for crops, show large scale-deficiencies in the irrigation command area.

Thiruvengadachari (1996) carried out studies on assessing irrigation performance of ice based Bhakra project. It was an attempt to use the package of satellite remote sensing applications to assess agricultural system performance of rice-based irrigation system.

Multi year satellite data have been analysed to provide disaggregated information on the irrigated area, cropping pattern and rice productivity.

Dutta et al. (1998) carried out a study on the wheat crop classification using multi date IRS LISS-I data of four bands. Months of November, January, March and April were used for the study of temporal behavior of crops. Multi-temporal data acquired at different growth stages increase the dimensionality information content and have advantage over single data for crop classification. The objective of this study was to elect suitable single date and combination of multi-date data for the wheat crop classification in Nalanda district of Bihar state where pulses and other crops are also growing in Rabi season. Dates are chosen during the crop cycle corresponding to seedling maximum tilling, booting, dough and maturity stage of wheat crop. The IRS-1B LISS-1 data provide a spatial resolution of 72 m having four bands of spectral range of 0.45-0.52μm, 0.52-0.59 μm, 0.62-0.68 μm, 0.77-0.86 μm with a repeat cycle of 22 days. Ground truth was done in the month of February 1995. Majority of sample area within the district was visited for ground truth and the detailed information about the crop like growth stage, ground cover etc. was collected during field visit. Amongst the single date data February data was found to be better for wheat classification in comparison to November, January, March and April data. Wheat classification accuracy achieved was 94.54 percent.

Mathur et al. (1998) used a different approach to integrate the remotely sensed data and spatial/non-spatial data generated over the year under crop acreage and production estimation project (CAPE) through GIS for their easy retrieval and comparison. A program in DBASE was also developed to calculate crop acreage using non-spatial attribute imported from GIS. This study was undertaken in three South Western districts of Punjab namely Firozpur, Faridkot and Muktasar and covering 9933 km square geographical area. IRS 1B LISS-I satellite data for March 13, 1996 was used for the study.

Durga Rao et al. (2001) carried out studies on irrigation water requirements and supply analysis in Dehradun region using remote sensing and GIS. This paper focused on analysing the irrigation water supply and demand of different crops under three major canals for Kharif and Rabi seasons. Crop acreage maps of Rabi and Kharif seasons were prepared using Landsat-TM5 digital data by applying different image processing and classification techniques. Crop water and irrigation water requirements of different crops were computed using CROPWAT computer program. Canal discharges were compared with the irrigation water planning and management and found to be more than the irrigation water requirements in many months, indicating the need of revising the irrigation water management.

Gallego (2004) carried out a study on remote sensing and land cover area estimation. The study gives an overview of different ways to use satellite images for land cover area estimation. The operational use of remote sensing was easier with cheaper Land Sat Thematic Mapper images and computing, but many administrations are reluctant to integrate remote sensing in the production of area spastics.

Mausel et al. (2004) studied change detection techniques. Timely and accurate change detection of earth's surface feature is extremely important for understanding relationship and interaction between human and natural phenomena in order to promote better decision making. Remote sensing data are primary source extensively used for change detection in recent decades. Many change detection techniques have been developed.

Kuo, et al. (2005) carried out a study for estimation of irrigation water requirements for ChiaNan Irrigation Association, Taiwan. The field experiments were performed at HsuehChia Experimental station from 1993 to 2001 for estimation of reference and actual crop evapotranspiration, derived from crop coefficient, and collected requirements input data for the CROPWAT irrigation management model to estimate the irrigation water requirements of paddy and upland crops. Based on the field experiments and water management data, the CROPWAT model simulated the on-farm water balance for the first and second paddy crops.

A case study from Rampa Forest Eastern Ghats Andhra Pradesh was carried out in September 99. In this study IRS-P3 WiFs data of Feb 98, March 98, April 98 and May 98 has been taken for analysis of vegetation indices. The linear combination of albedo or bidirectional reflectance, which depends on radiation properties of the surface, can be effectively utilized for discriminating different vegetation types. NDVI is sensitive to the presence of green vegetation (Sellers 1985) and has been successfully used in numerous regional and global applications for studying the state of vegetation (Prince and Tucker, 1986; Townshed and Justice, 1986).

Using remote sensing and GIS, a study of monitoring of Mahi Right Bank Canal Command, Gujarat, was carried out by Gujarat Engineering Research Institute (GERI), Vadodara; Space Application Center, ISRO, Ahmedabad; Water and Land Management Institute (WALMI), Anand; and Narmada and Water Resources Department, Gandhinagar in December 1999. In the first phase the work was carried out for Mahi Right Bank Canal Command. Land use/ land cover change was monitored using visual interpretation of LISS-III geocoded imageries. Crop inventory analysis and performance evaluation was carried out using processing of digital image data and GIS.

CHAPTER 3

STUDY AREA

3.1 GENERAL

The river Ghataprabha is one of the important tributaries of Krishna River. The river Krishna also called as Krishnaveni is the second largest river in Peninsular India. The river rises in the Mahadev range of the Western Ghats near Mahableshwar at an altitude of about 1337 m above mean sea level about 64 km from the Arabian sea. It flows 1440 km through the states of Maharashtra, Karnataka and Andhra Pradesh before flowing into Bay of Bengal. Krishna is the fourth largest river basin in the country, roughly triangular in shape with its base along the Western Ghats and apex at Vijaywada. Ghataprabha River originates in the Sahyadri range of Western Ghat near Amboli in Maharashtra and enters Karnataka near Daddi in Hukheri taluk in Belgaun district and flows eastward for a distance of about 283 km through Belgaum and Bijapur districts before it confluence with the Krishna River near Almatti. It has a total catchment area of 8829 sq.km and discharges an average of 5380 MCM of water annually. It has substantial surface water resource with dependable yield. Its annual yield is estimated to be 121 TMC feet (near Dhupdal Weir) at 75% dependability. The concept of harnessing the potential of Ghataprabha River for the Ghataprabha Valley Development Schemes dates back to year 1852. The salient features of Ghataprabha project are given in Annexure I.

3.2 LOCATION

The study area also called command, chosen for the present work is Ghataprabha LBC command area (Fig 3.1). It extends from 15^0 45' N to 16^0 40' N latitude and from 74^0 15' E to 76^0 00' E longitude falling in survey of India (SOI) toposheets 47L and 47P. The SOI toposheet for the command area is shown in Fig 3.2. The study area is bounded by the Krishna River in the north, Maharashtra State to the west, the confluence of Krishna River and Malaprabha River in the east and the water divide or the basin boundary between Ghataprabha and Malaprapha Rivers in the south. The area is well

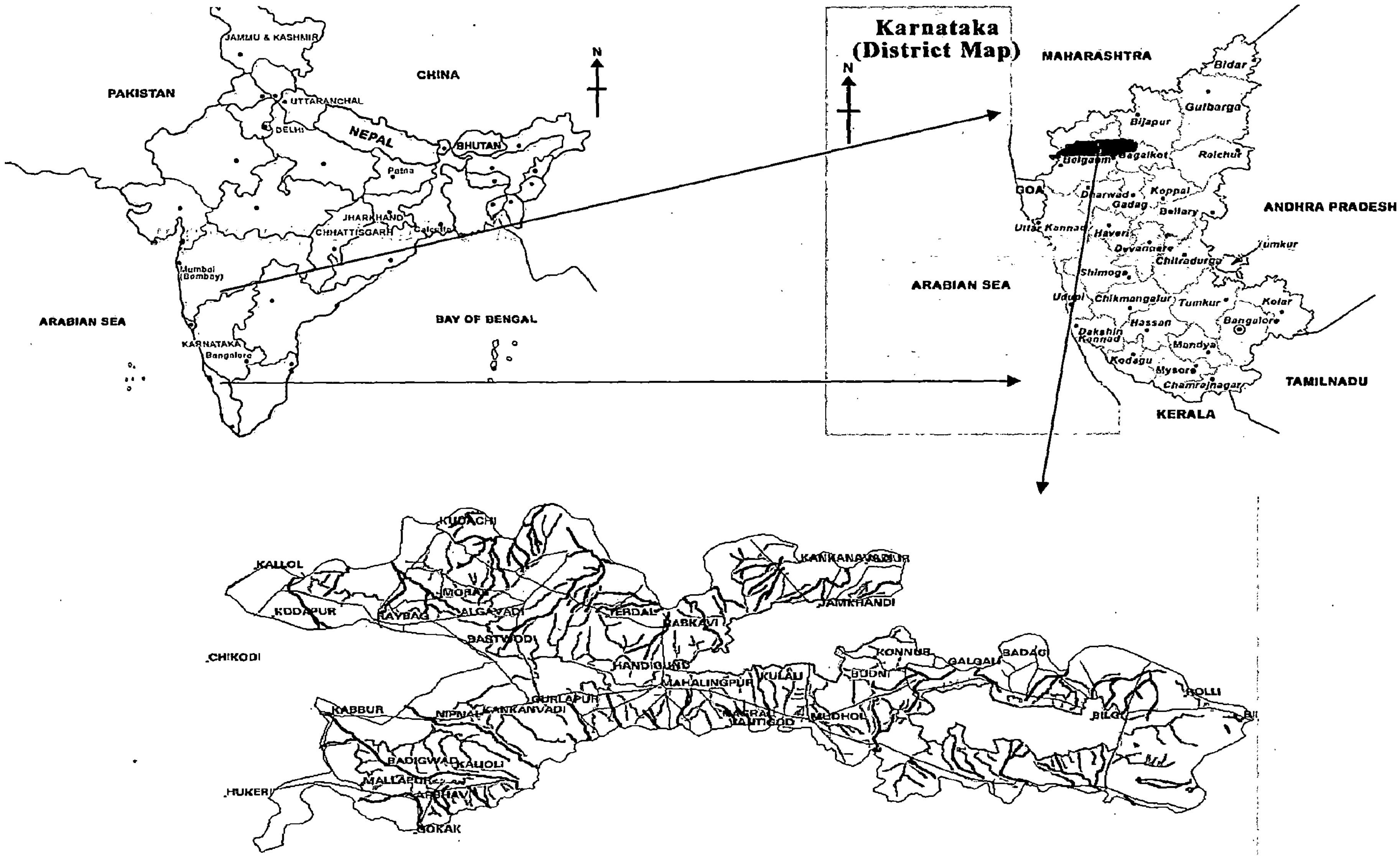


Figure 3.1: Location of the study area

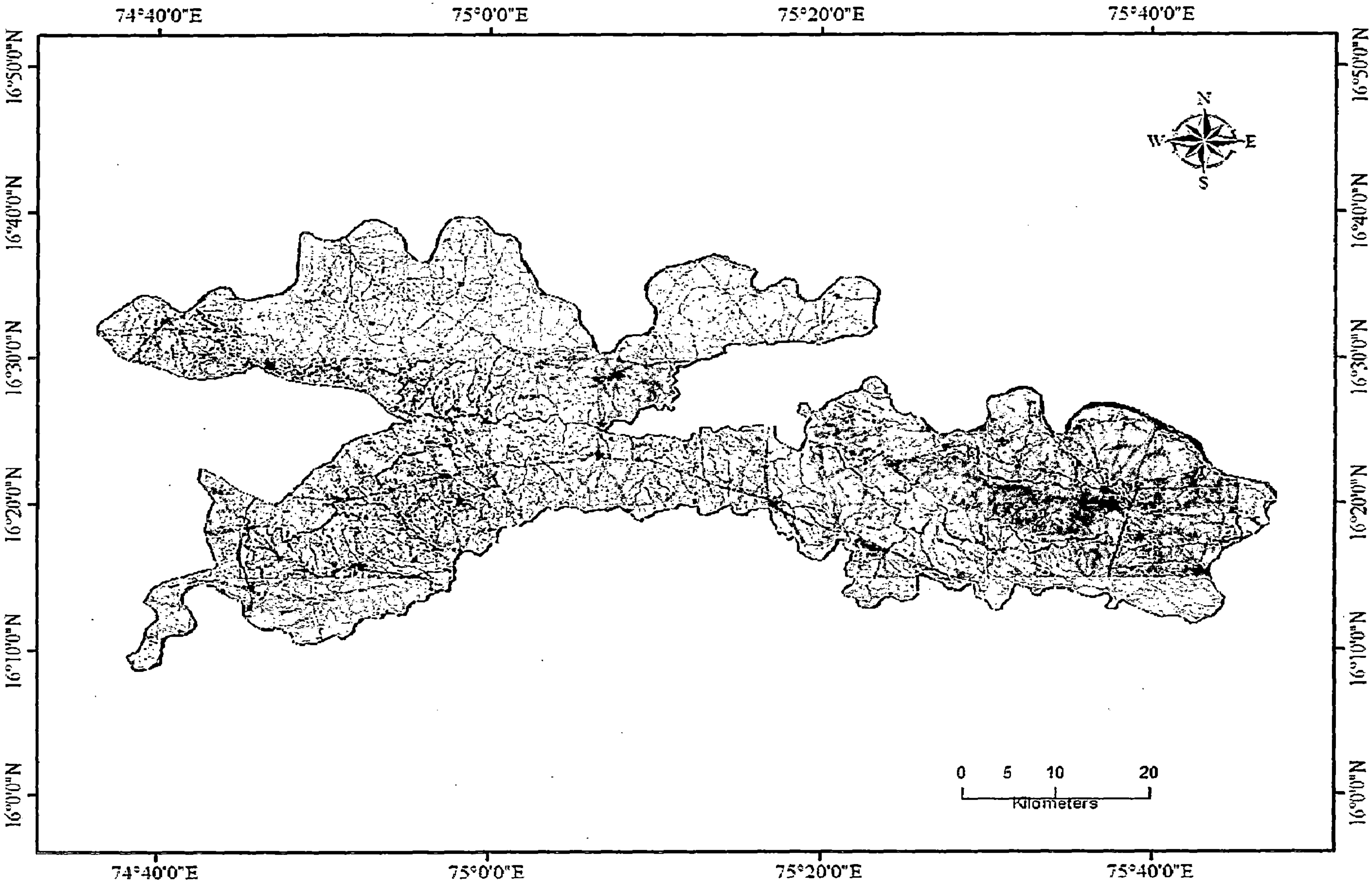


Figure 3.2: Survey of India Toposheets for the study area

connected by road and rail to other parts of state. The interior parts of the command are well connected to both the district headquarters at Belgaum and Bijapur by all weather roads. In the command area there are two hilly areas, which are not part of the command area. These have non-agriculture land use and are not covered in the study area.

3.3 PHYSIOGRAPHY AND DRAINAGE

The topography of the study area is undulating, with tablelands and flat-topped hillocks typical of trap and quartzite country. The general topographic elevation varies from 520 to 890 m above MSL. The elevation shows a gradual fall from west to east from rugged topography in the west to almost flat country in the Bagalkot plains. The general slope of the ground is toward the Ghataprabha River in the southern part and toward Krishna River in the north. The surface water divide between Krishna and Ghataprabha rivers almost follows the Ghataprabha left bank main canal upto Bilgi. The highest topographic elevation in the area is near Ukkad village in Belgaum, having a height of 895 m above MSL. A number of isolated hillocks dot the landscape in the west as seen around Hidkal Dam, Gokak, Chikodi, Raibag and Jamkhandi. Toward east, isolated quartzite hillocks are also seen near Bilgi and south of Bagalkot towns. The limestone country around Bagalkot presents an almost flat terrain.

The command area and its environs essentially form part of the Krishna River basin of northern Karnataka and is drained by Krishna River and its tributary, Ghataprabha. A small portion toward the eastern part of the basin is drained by the Malaprabha River which also joins the Krishna River near Sangam in Bagalkot taluk and comes under the proposed Sangam Branch Canal of the Ghataprabha Right Bank Canal. The Krishna River, which is one of the major rivers of Karnataka, rises near Mahabaleshvar in Maharashtra and enters Belgaum District near Kagwad in Athani taluk. After flowing for a distance of about 150 km through Belgaum and Bijapur districts, it enters Raichur near Amalwadgi in Bijapur District.

Along with the important perennial rivers Markandeya and Hiranyakeshi, there are minor streams like Hirehalla, Kanvihalla, Yadwadhalla, Mallapurhalla etc. which join the Ghataprabha River. The drainage pattern, in general, is dendritic and trells type, typical of black cotton soil and trap country.

3.4 CLIMATE AND RAINFALL

The climate of command is tropical monsoon marked by hot summer and a mild winter. The summer temperature reaches more than 40^0C during the months of April and May while in winter the temperature often falls below 10^0 C in the months of December and January. The relative humidity varies seasonally with values less than 30% during non-monsoon to about 85% during monsoon months.

The command area forms part of semi-arid tract and receive rainfall by south-west monsoon season. The annual rainfall is about 650 mm, out of which 65 % occurs during south-west monsoon in months of June to September. The rainfall from the north-east monsoon is nearly 20% and rest is received during the pre-monsoon period. There exists a wide variation of rainfall both spatially and temporally in the area with the coefficient of variation around 34% and 55.30% for south-west monsoon period and north-east monsoon respectively and for the annual rainfall around 27.50 %.

3.5 SOILS

In the Ghataprabha command area, the disintegration of basic rocks which are relatively rich in bases and iron have resulted in the formation of soils rich in clay . The topography has played a more dominant role than climate and vegetation in the formation of soils. Shallow and light textured soils are generally seen on the ridges and ridge slopes, medium textured soils of moderate depth on gently sloping mid-uplands and very deep heavy- textured soils on level to nearly level low-lying areas along the banks of streams.

3.6 GEOLOGY

The geological formations met within the command area are (i) Deccan traps of the tertiary age covering parts of Gokak, Hukkeri, Chikodi, Raybag, Mudhol and Jamkhandi taluks, (ii) Sedimentary formation known as ' kaladagi group' comprising of limestone, shale and quartzite. They are seen predominantly in Gokak, Mudhol, Jamkhandi, Bilgi and Bagalkot taluks.

3.7 AGRICULTURE

There are two major cropping seasons mainly Kharif, which starts from July and ends in October and Rabi from November to February/March. The major crops grown in the command area are paddy, sugarcane, ragi, bajra, jowar, maize, pulses, groundnut, cotton and oilseeds. In the non command area, the Kharif season depends on rainfall and minor irrigation structures like tanks and wells and during Rabi season, it is predominantly well irrigation. In the canal command area, irrigation water is generally given through canals by June end or July first week. Depending upon the availability of water in the reservoir, sometimes water is made available to the farmers till April. The cropping pattern followed in the command area is 40% Kharif, 40% Rabi and 20 % biseasonal (CGWB, 1997). The period of crops of Rabi season are given in Table 3.1

Table 3.1: Crop calendar

Crops (Rabi Season)	Probable sowing date	Probable harvesting date
Maize, Sorghum, Wheat	Last week of Oct.-1st week of Nov.	1st fortnight of March
Sugar cane	1st week of July	
Fodder/Pulses	Last week of Oct.-1st week of Nov.	1st fortnight of March

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 MATERIALS

Satellite Data

The satellite data of IRS 1C/1D LISS III required for the study was procured from NRSA, Hyderabad. The path and Row of the data used are 96-61 and 97-61. IRS 1D LISS III scenes index of the Ghatbrbha command area is shown in Figure 4.1. This data which has been processed for derivation of landuse/landcover, crop inventory and crop acreage. The data of Kharif could not be obtained, as cloud free data was not available for this season. The data of Rabi season starting from October month is used for this study. The details of the satellite coverage of the command area obtained by using Integrated Digital Reference Scheme (IDRS) software are given in Table 4.1. The technical specification of IRS sensor is given in Annexure II.

Table 4.1: Specifications of the Satellite data

SATELLITE	SENSOR	PATH/ROW	DATE
IRS 1D	LISS III	96-61	22 Nov., 2000
IRS 1D	LISS III	96-61	11 Jan., 2001
IRS 1D	LISS III	96-61	05 Feb., 2001
IRS 1D	LISS III	96-61	02 Mar., 2001
IRS 1D	LISS III	96-61	21 Apr., 2001
IRS 1C	LISS III	97-61	15 Nov., 2001
IRS 1D	LISS III	97-61	08 Jan., 2001
IRS 1C	LISS III	97-61	19 Feb., 2001
IRS 1D	LISS III	97-61	24 Mar., 2001
IRS 1D	LISS III	97-61	18 Apr., 2001

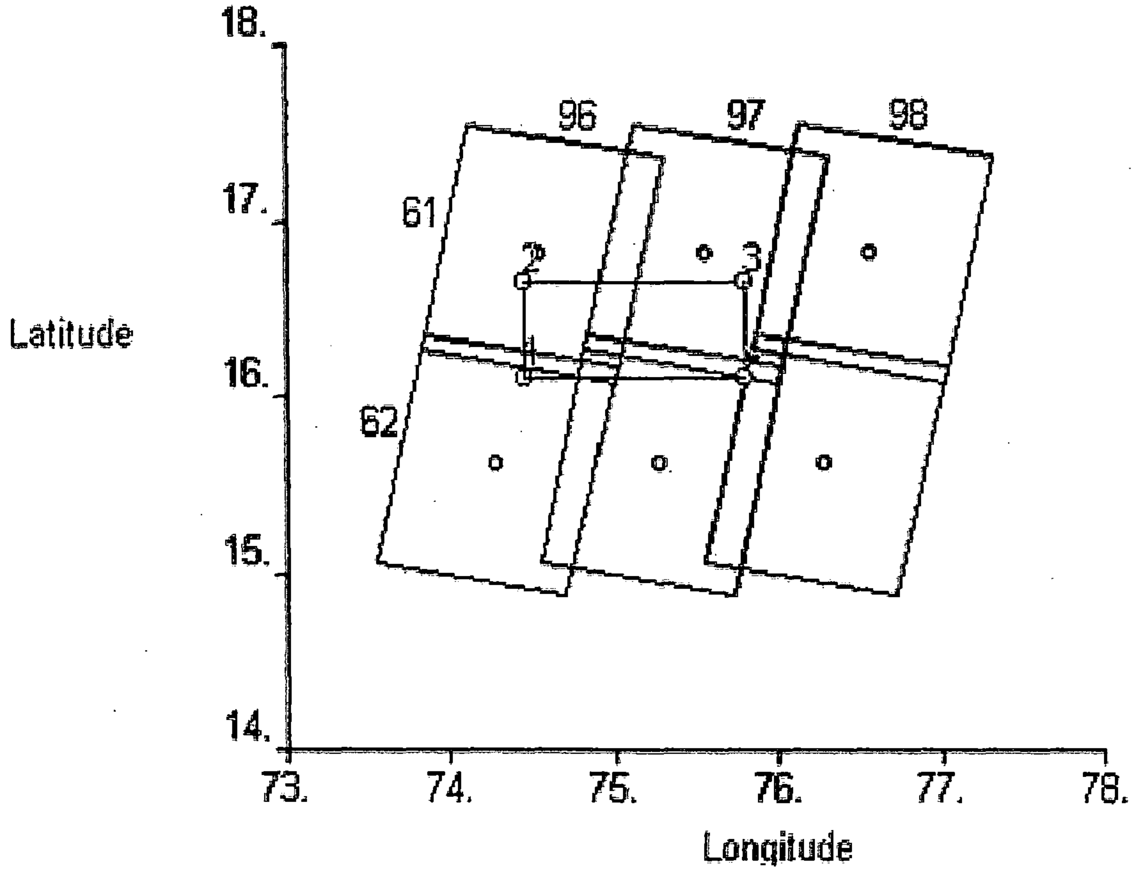


Figure 4.1: IRS 1D LISS III scenes index map covering the Ghataprabha Command

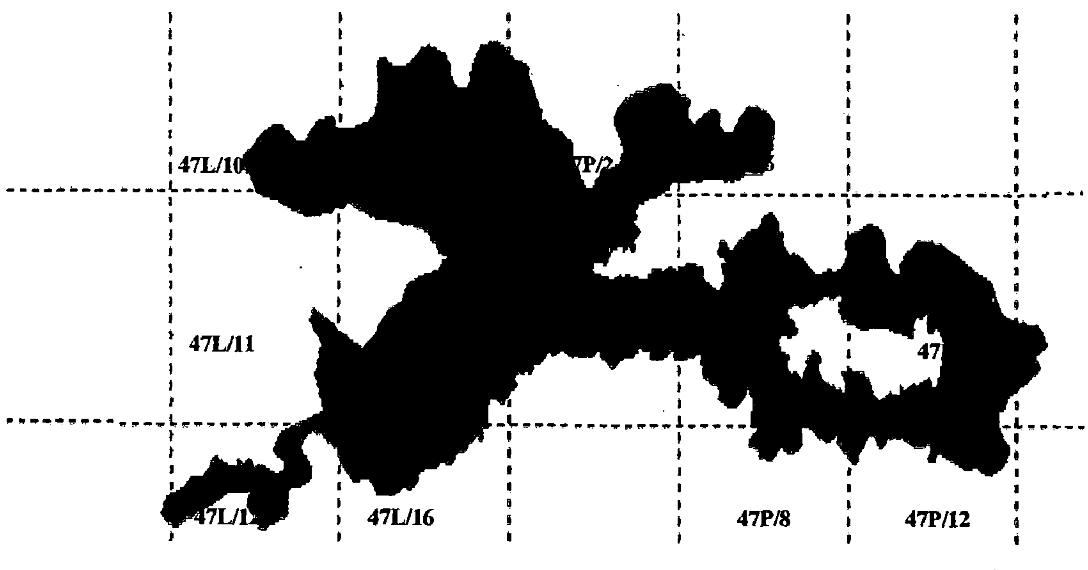


Figure 4.2: Index map of Survey of India covering the Ghataprabha Command

Topographic Data

The Survey of India (SOI) toposheets at a scale of 1:50,000 have been used to obtain topographical data of the command area. The toposheets which covered the study area are 47L-10/11/12/14/15/16 and 47P-2/3/6/7/8/11/12/15. The index map of the SOI topographic maps is shown in Figure 4.2.

Meteorological data

The climatic data like rainfall, maximum and minimum temperature, maximum and minimum relative humidity, wind speed, sunshine records on daily basis for the years 1993, 1994, 1995, 1996 and 1997 of the meteorological station located at Hidkal dam site in Hukeri taluk of Belgaum district are used for the study. The maximum and minimum temperature and relative humidity at the Hidkal dam site observatory are given in the Figures 4.3 and 4.4.

Figure 4.3: Maximum and Minimum Temperature trend at Hidkal Dam site (1993-1997)

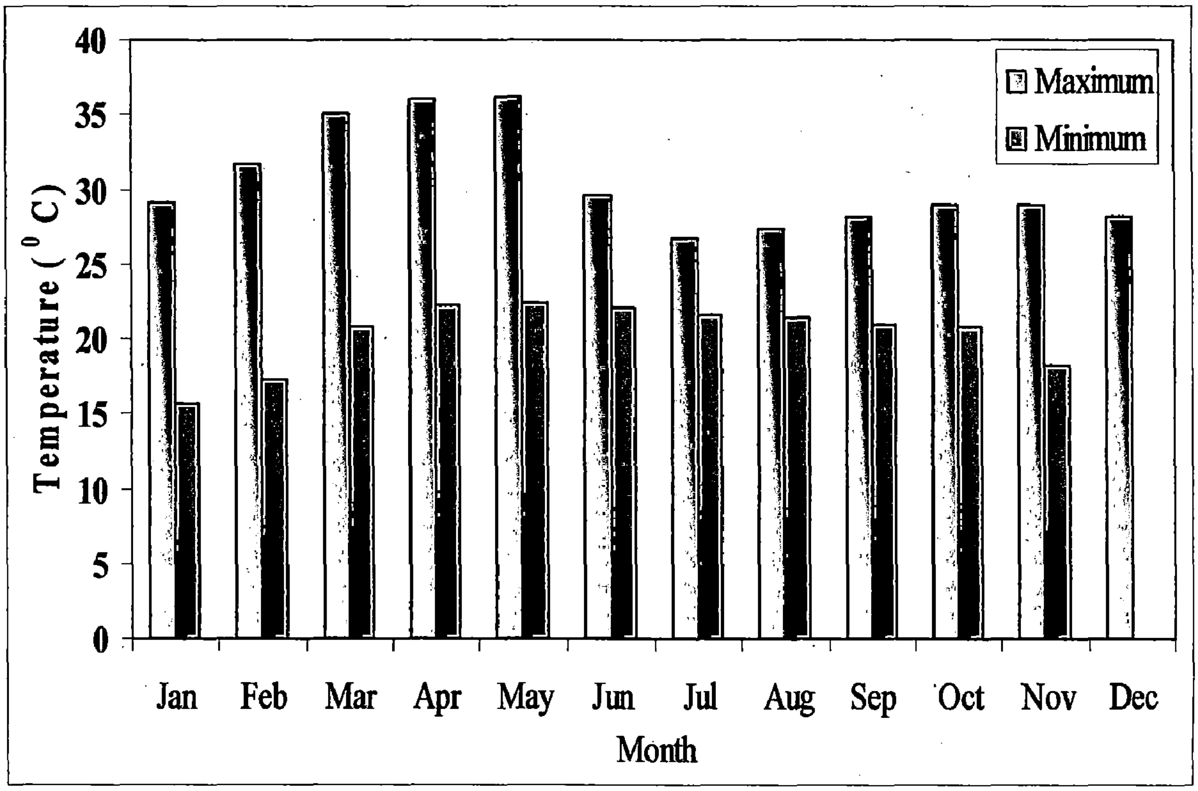
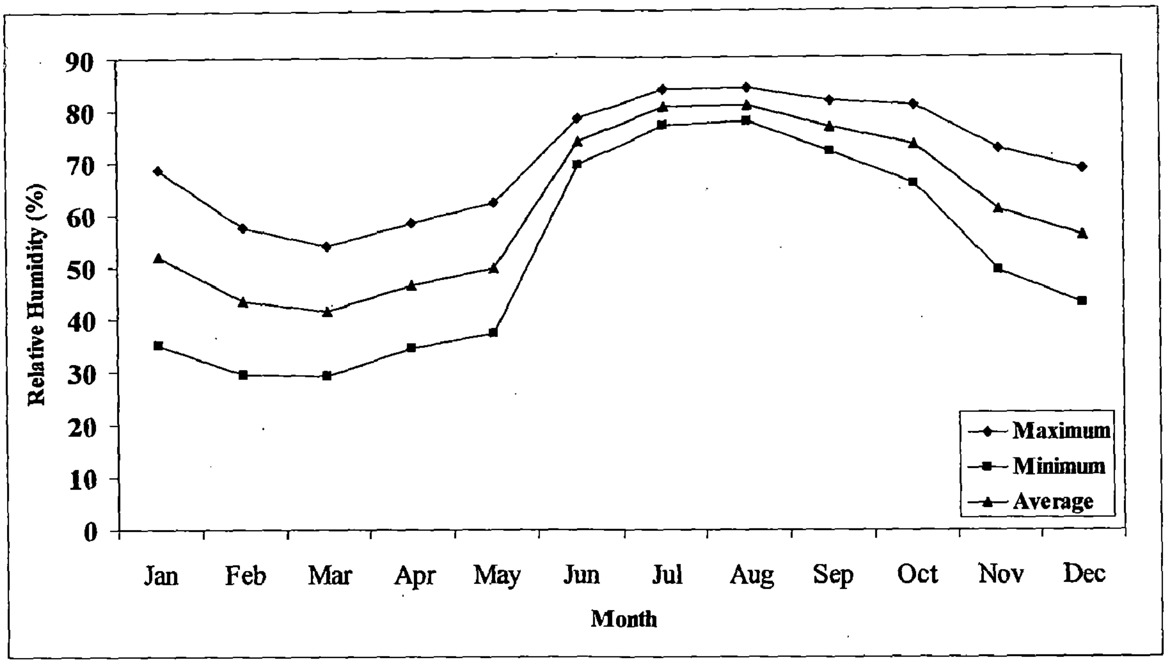


Figure 4.4: Relative Humidity at Hidkal Dam site (1993-1997)



Agricultural Data

The revenue land use statistics is given in Table 4.2. Notably, the statistics given below is not confined to only existing command area.

Table 4.2: Revenue land use statistics

S.No.	Crops	Crop acreage					
		1998-99		1999-2000		2000-2001	
		ha	%	ha	%	ha	%
	Kharif						
1	Hy.Maize	46613	47	51595	61	46903	58
2	Hy.Jawar	1655	2	1554	2	1444	2
3	Bajara	1956	2	1781	2	1737	2
4	Sunflower	6453	7	6389	7	5274	6
5	Soyabean	13610	14	14826	17	13874	16
6	Groundnut	2857	3	2355	3	1623	2
7	Pulses	1949	2	2375	3	1845	2
8	Sugarcane	21534	22	2914	3	7241	8
9	Others	1549	2	1469	2	1584	2
	Total	98176		85258		81525	

S.No.	Crops	Crop acreage					
		1998-99		1999-2000		2000-2001	
		ha	%	ha	%	ha	%
	Kharif						
1	Hy. Maize	19217	27	4654	8	19809	29
2	R. Jawar	14420	20	11988	21	12778	18
3	sunflower	6654	9	7838	14	5290	8
4	Wheat	19154	27	16866	30	18978	27
5	Local_jawar	0	0	300	1	0	0
6	Pulses	3409	5	11915	21	1625	2
7	Groundnut	0	0	150	0	0	0
8	Safflower	199	0	1631	3	0	0
9	Sesamum	48	0	107	0	0	0
10	Others	2921	4	859	2	1914	3
11	Soyabean	331	0	0	0	0	0
12	Sugarcane	4220	6	0	0	8977	13
	Total	70573		56308		69371	
	Biseason						
1	Cotton	3880		8240		4028	

4.2 SOFTWARE USED

Integrated Digital Referencing Scheme

An Integrated Digital Referencing Scheme (IDRS) software package converts the user's area of interest (place, polygon, mapsheet etc.) into path and Row numbers of the required satellite. IDRS has been used to find the Path and Row of satellite covering the Ghataprabha Command area.

ERDAS Imagine 8.5

ERDAS Imagine [Annexure III], an image processing and GIS software has been used for satellite image processing and georeferencing. It has been used for the preparation of thematic maps like command area map, canal network, major road network, rivers and settlements and computing statistics of the command area.

CROPWAT

The CROPWAT for windows software developed by FAO has been used for estimation of reference crop evapotranspiration (ET_o), Crop Water Requirement (CWR), irrigation requirement and in turn for irrigation scheduling.

4.3 METHODOLOGY

To meet out the objectives enumerated in Chapter 1, the database has been generated in GIS. The present study relies on data from remote sensing combined with ground observations and data collected in the field. All sources of information are integrated through GIS for further analysis. Figure 4.5 shows the base map of Ghataprabha command area prepared using Survey of India toposheets at a scale of 1:50,000.The methods are divided into three sections:

(i) Extraction of required information from the satellite data i.e. crop classification and acreage estimation.

(ii) Computation of reference evapotranspiration and crop water requirements from climatic data and computation of irrigation water needs.

(iii) Irrigation scheduling.

The methodology followed is sketched in Figure 4.6. The methodology consists of five parts: collection of data, image processing to extract spatial data, estimation of Crop Water Requirement, estimation of water demand and irrigation scheduling in the command area.

IRS measures the reflected radiance in four spectral channels between 0.45 to 0.86μm, allowing for recognition of crop types based on spectral signature and time. On five of the six overpass dates during Rabi 2000-2001, fully or predominantly cloud free satellite images of seasonal agricultural progress are obtained. In Kharif no cloud free data is obtained and therefore in this study only Rabi season has been considered.

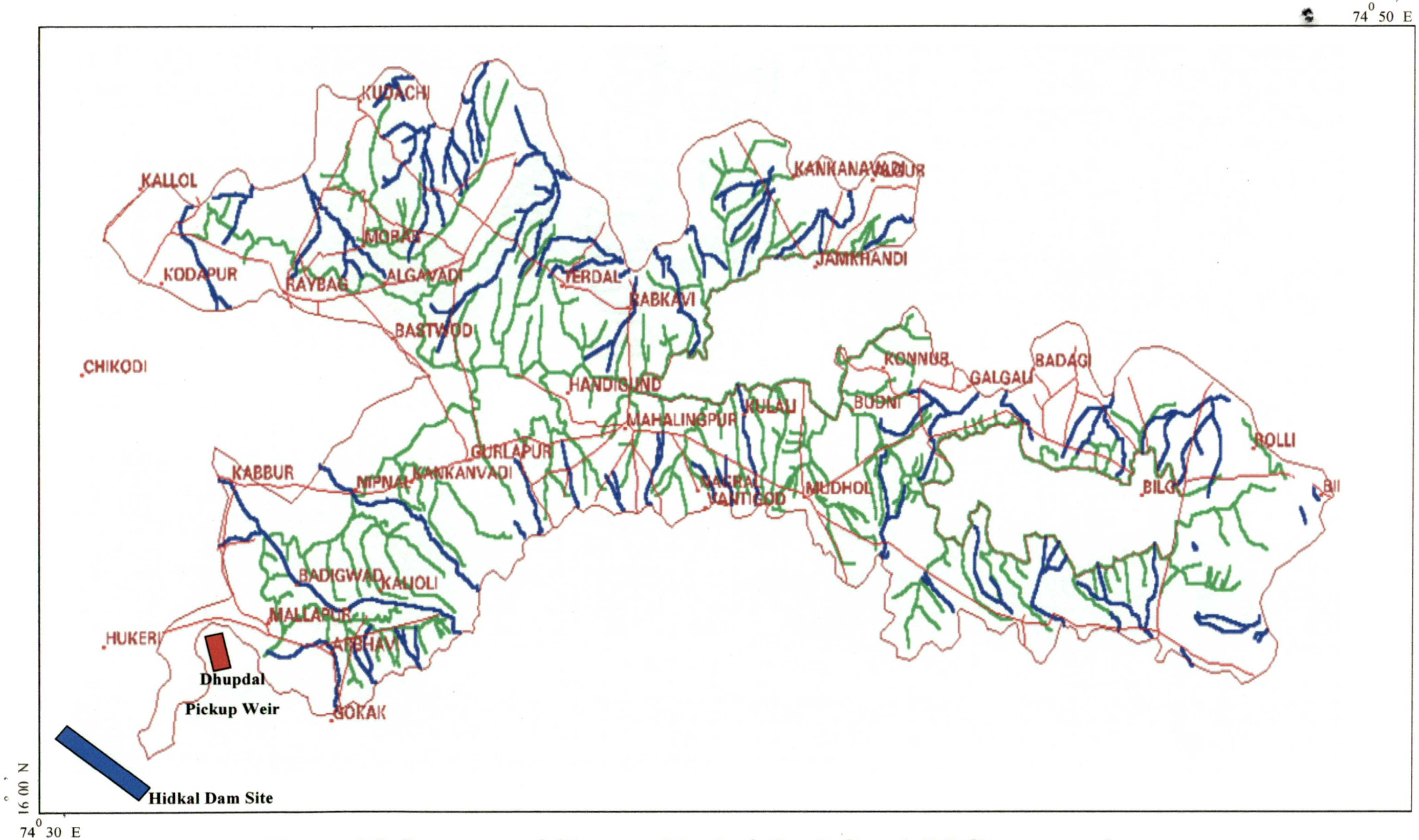


Figure 4.5: Base map of Ghataprabha Left Bank Canal (LBC) command

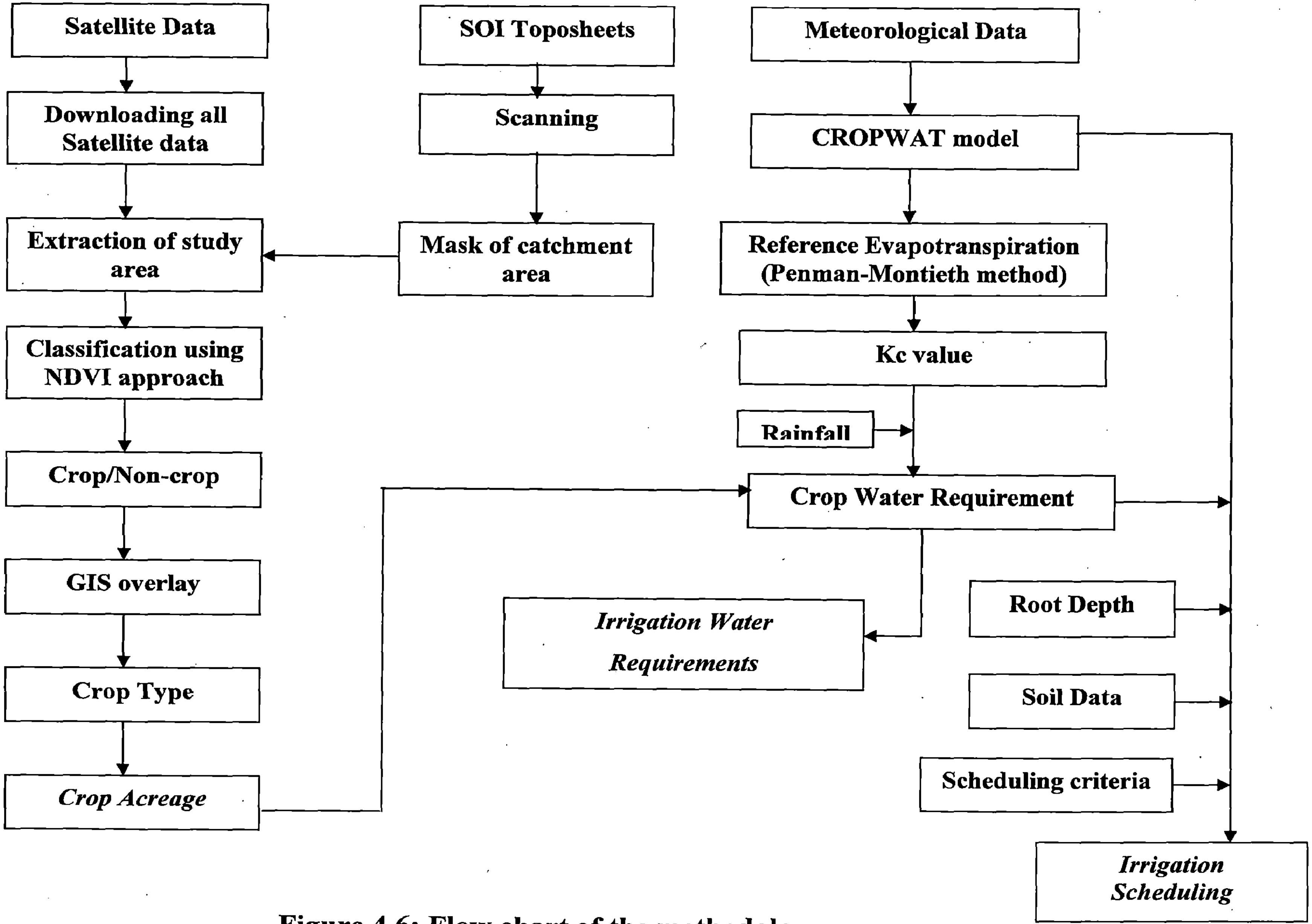


Figure 4.6: Flow chart of the methodology

4.3.1 IMAGE PROCESSING

ERDAS IMAGINE has been used for processing all satellite images. The false color composite composite (FCC) of months November 2000, January to April 2001 are shown in Figures 4.7 to 4.11

4.3.1.1 RECTIFICATION AND GEOREFERNCING

In rectification and Georeferencing of the multi temporal data of high-resolution satellite from LISS-III onboard IRS 1C/1D, one image is georeferenced with the help of Ground Control Points (GCPs) from the Survey of India maps at 1:50,000 through image to map registration moreover other date images are georeferenced with respect to already rectified image. For rectification of one image, GCPs are selected well distributed over the area. In image to image rectification, Photo control points are taken. These are much easier to select due to similar appearance on the images. As well, the images have much more details than a topographic map. The river bend, hill top, road intersections, centre of embankments, canal intersections, bridges, rail-road intersections etc. are selected as GCPs for both image to map and image to image rectification. The projection system adopted here is Polyconic with Indian (India, Nepal) as datum. The georeferenced images were then resampled to 24 m pixel size using nearest neighbour technique and the two georeferenced scenes from path row(96/61 and 97/67) were mosaicked. After that, study area has been extracted from mosaicked image for further processing.

4.3.1.2 CROP ACREAGE ESTIMATION

Rationing is considered to be a relatively rapid means of identifying land use/ cover features. Sometimes differences in the brightness values from identical surface materials are caused by topographic slope and aspect, shadows or seasonal changes in sun light illumination angle and intensity [Jenson, 1996]. To minimize the effects of the environmental factors, ratio may also provide unique information not available in any single band that is useful for discriminating soils and vegetation. Ratio technique is accomplished by dividing the data base brightness values in one spectral band by the data base brightness values in second spectral band for each pixel. The ratio images have two

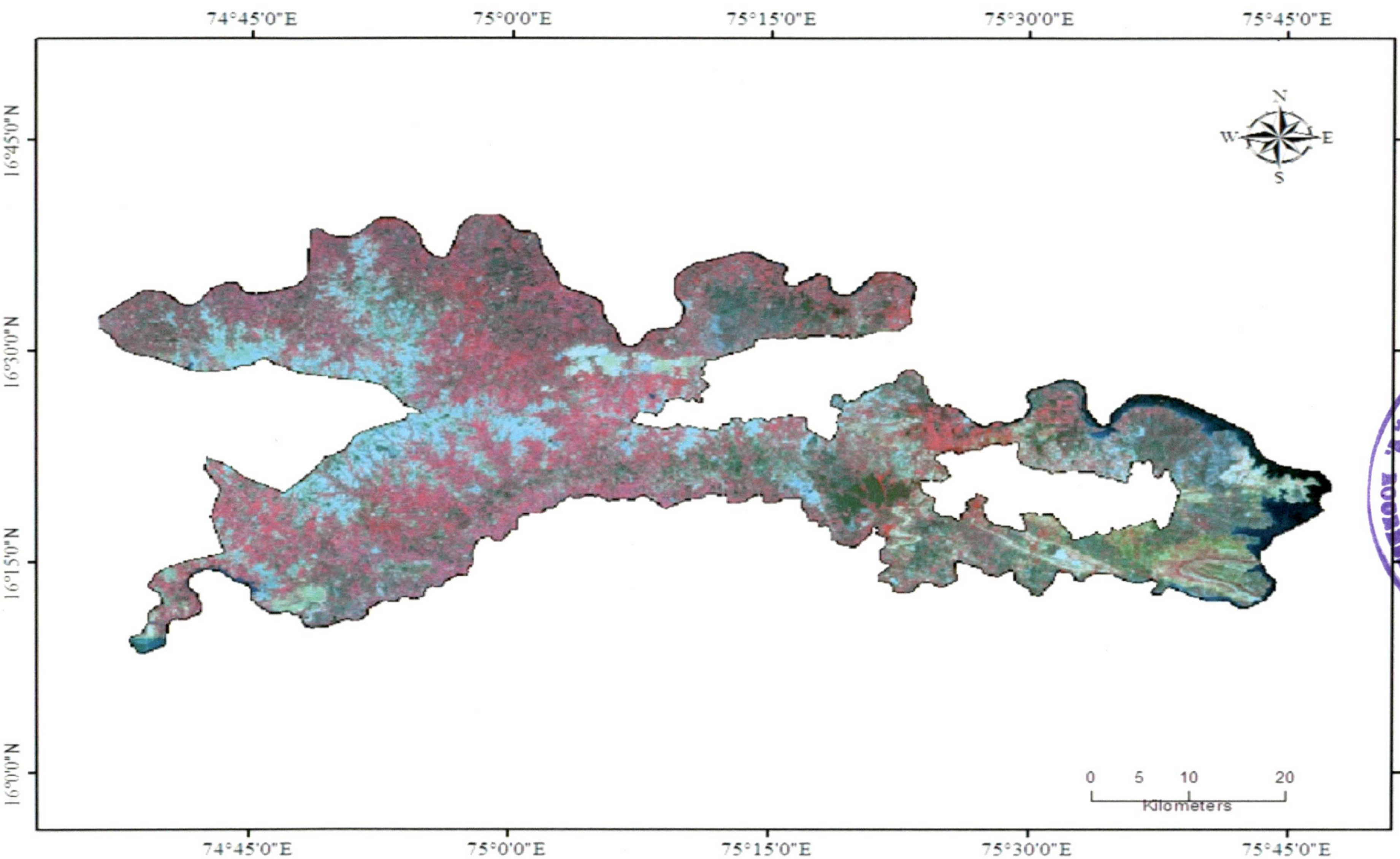


Figure 4.7: False Colour Composite of IRS 1D LISS III data of November 2000

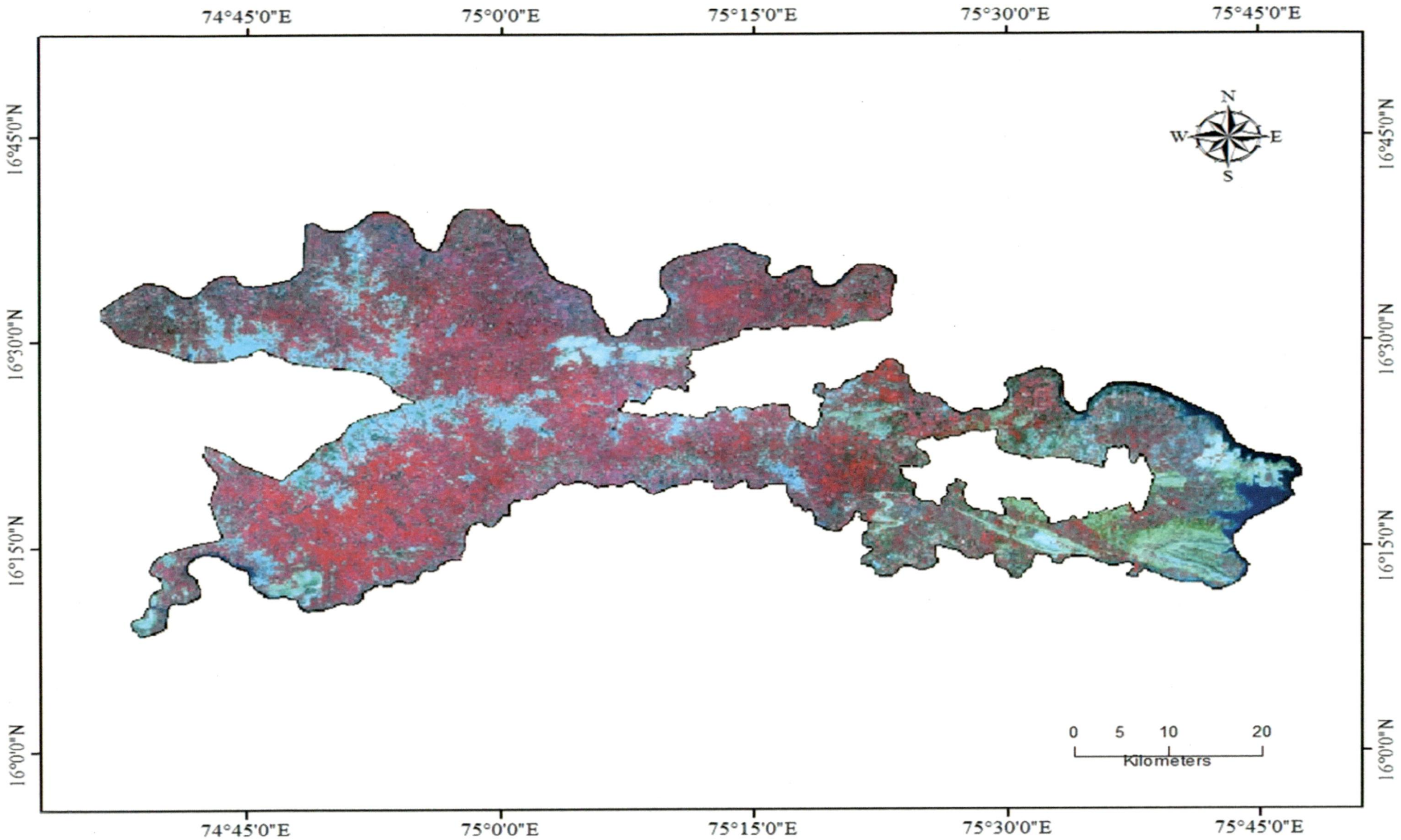


Figure 4.8: False Colour Composite of IRS 1D LISS III data of January 2001

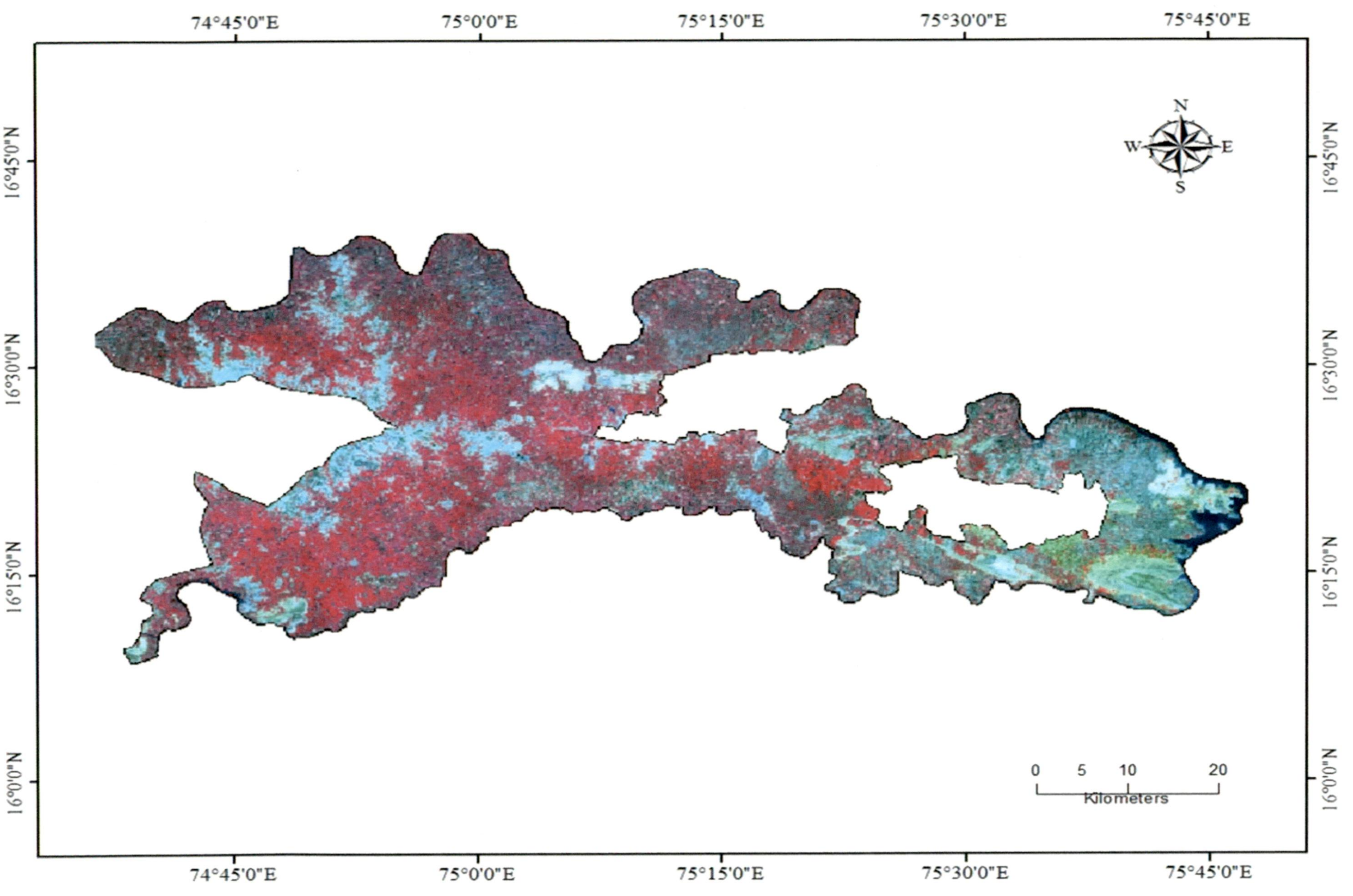


Figure 4.9: False Colour Composite of IRS 1D LISS III data of February 2001

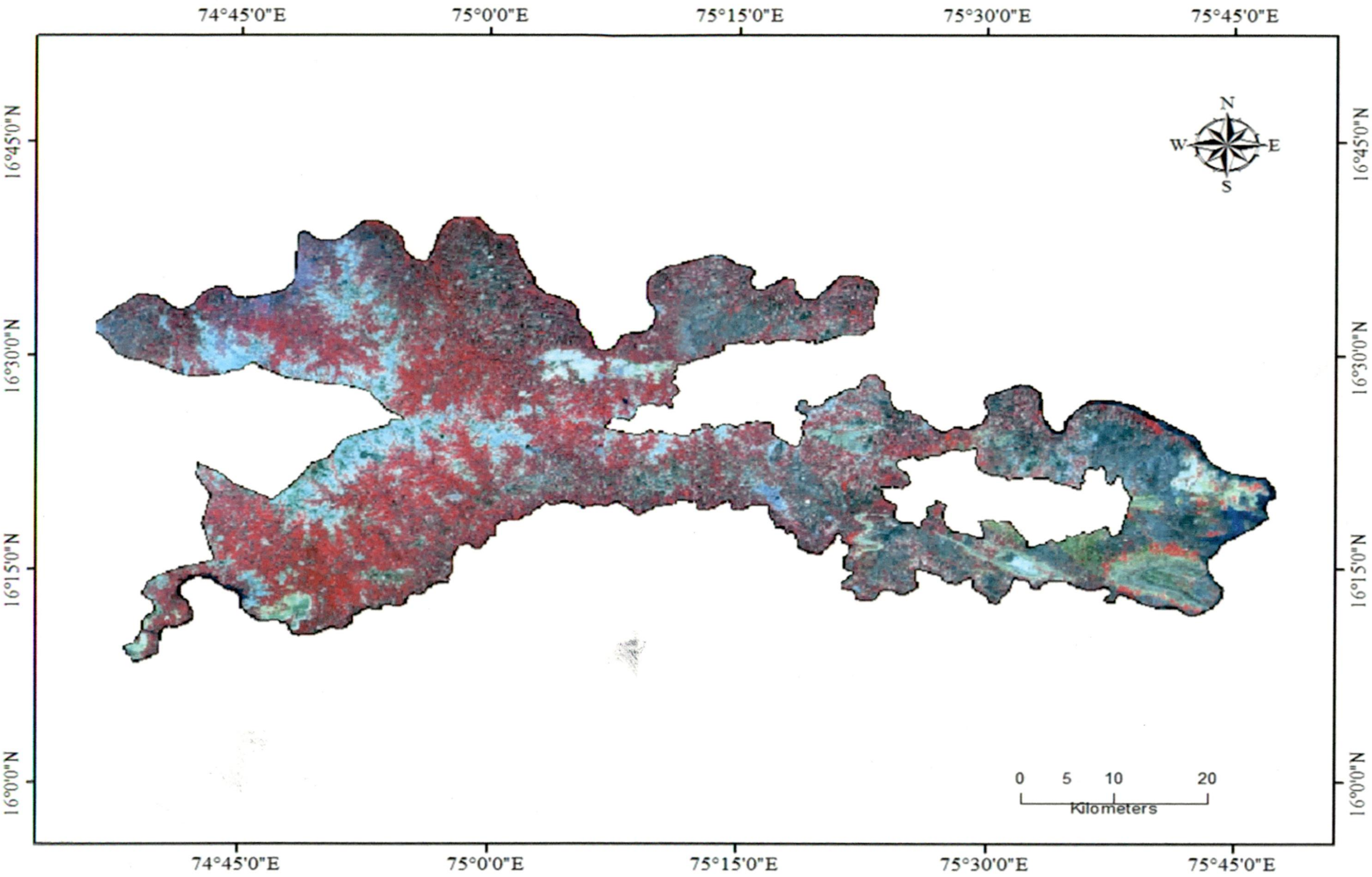


Figure 4.10: False Colour Composite of IRS 1D LISS III data of March 2001

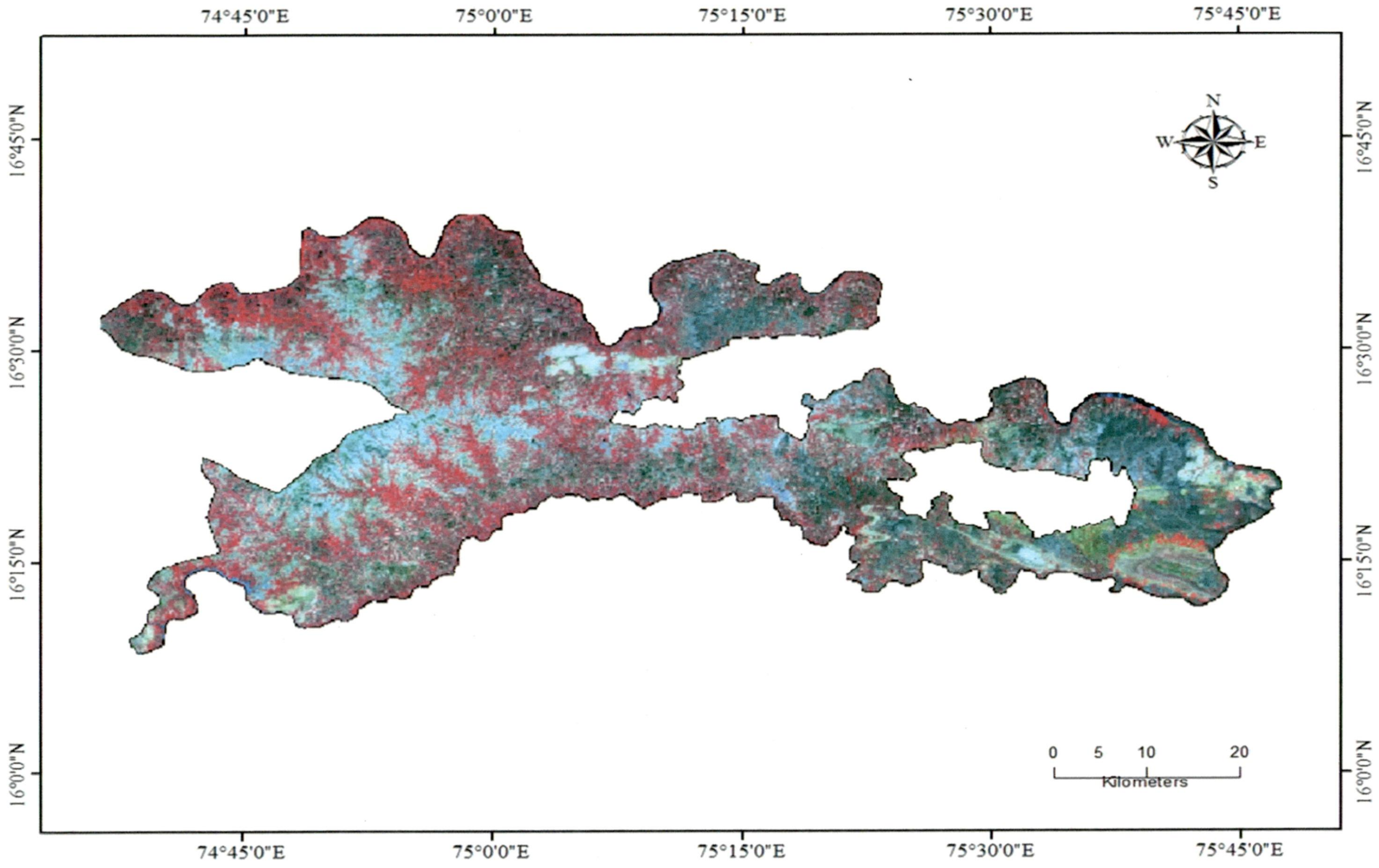


Figure 4.11: False Colour Composite of IRS 1D LISS III data of April 2001

important properties. First, strong differences in the intensities of the spectral response curves of different features may be emphasized in ratioed images. Second, ratios can suppress the topographic effects and normalized differences in irradiance when using multi date images (Singh, 1989). In this study spectral index Normalised Difference Vegetation Index (NDVI) approach and unsupervised classification have been adopted for the estimation of the crop area under different period.

4.3.1.3 Computation of Normalised Difference Vegetation Index

The most common Normalised Difference Vegetation Index (NDVI) suggested by Tucker (1979) is used for estimation of vegetative cover. The NDVI is defined as the ratio of difference between the near infrared and red reflectance to their sum.

$$NDVI = \frac{(NIR - R)}{(NIR + IR)} \qquad \text{-----------------} \; 4.1$$

Where, R and NIR are reflectance in red and near-infrared wave length regions. The value of NDVI index can range from -1.0 to +1.0. Vegetated surfaces tend to have positive values, bare soil may have near zero, and open water features have negative values

A model was prepared using Model Maker of ERDAS IMAGINE to compute the NDVI images for all the scenes. The model is given in Annexure IV. Now the output image contains the NDVI for the whole image and the threshold value for the vegetation has to be decided. For, this purpose, the whole image is examined and the threshold value for all the images is obtained. The NDVI thresholds are obtained by browsing the NDVI images along with the multi-spectral data. The lowest NDVI value in the image for which, the theme is crop is selected as a threshold. The crop and non-crop classes are interpreted based on their standard signature in the multi-spectral data. The threshold NDVI values are given in Table 4.3.

Table 4.3: Normalised Difference Vegetation Index (NDVI) thresholds

Month	Nov 00	Jan 01	Feb 01	Mar 01	April 01
NDVI Threshold value	0.341189	0.287009	0.254247	0.195191	0.268367

Visual approach has been used for digitization of various themes namely canal network, major roads, and rivers, and major cities and overlaid on satellite data. The classified outputs are shown from Fig 4.12 to 4.16 for the months of November 2000, January 2001, February 20001, March 2001 and April 20001 respectively.

4.3.1.4 Multi-spectral Classification of NDVI Images and GIS Overlay

The multi-spectral classification is most widely used technique for land use and land cover mapping. The NDVI stacked images of all the dates are classified using unsupervised classification. Unsupervised classification is based on Iterative Self Organising Data Analysis Technique (ISODATA) clustering method. It is an iterative method. The classified maps are recoded to obtain two themes namely crop and non-crop. The number of clustering is based on the number of classes. The more number of classes helps in post classification stage to interpret the features more visually in feature space image. The land use maps obtained applying the NDVI technique is used for GIS overlay analysis. The images of January to April are overlaid to obtain the Rabi cropping pattern. The statistics of the overlay map are used for computing crop water requirement.

The crops in February or both in February and March are assigned the short duration crop or fodder class. If no crop is identified in January or January-February, the area is classified as fallow. When there is crop in January to April or February to April, the crop is classified as sugarcane. When crop exists in January or January, February or January to March the area is classified as other crop i.e. sorghum (Jowar), maize and wheat.

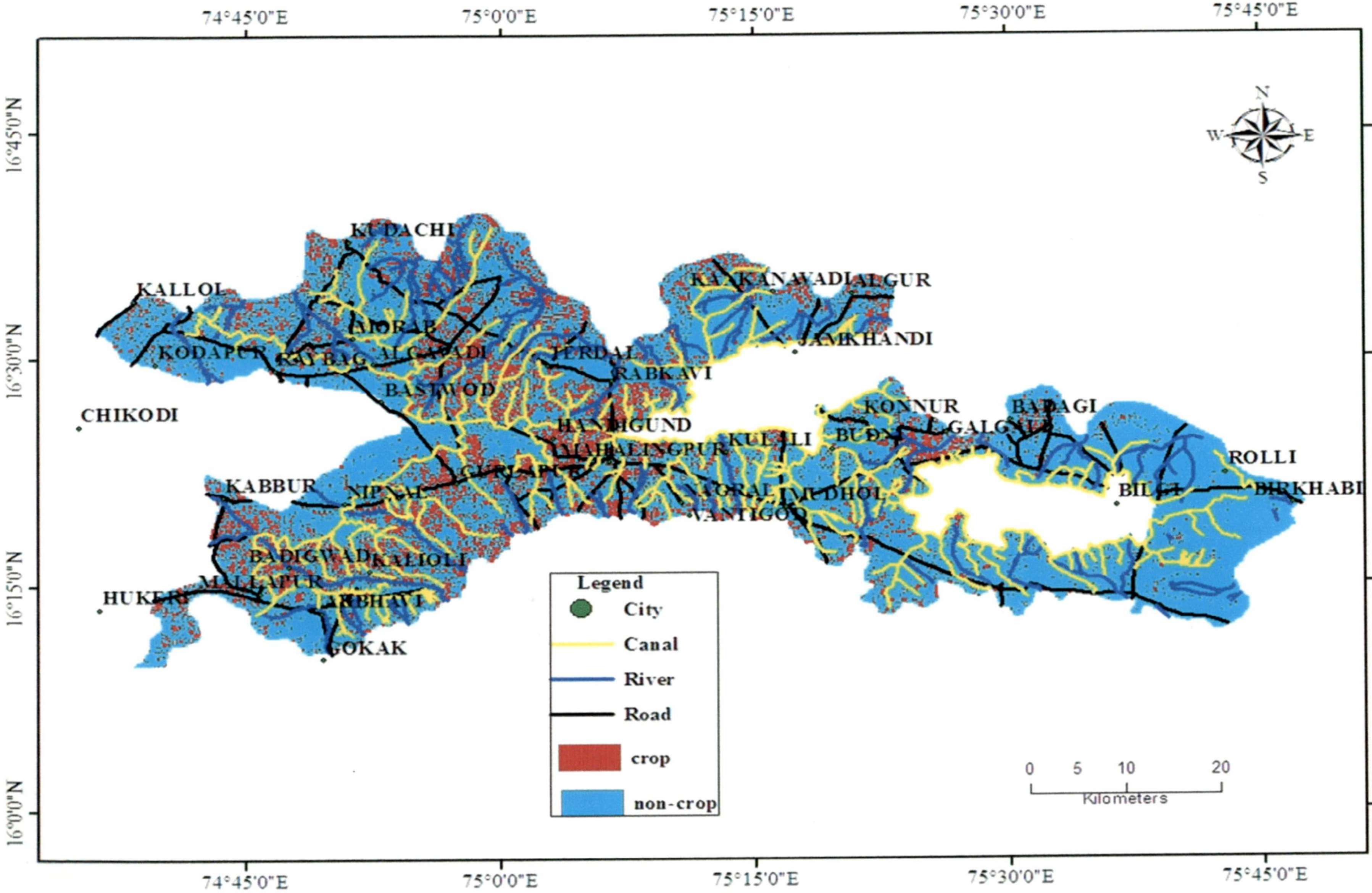


Figure 4.12: Crop classification using NDVI approach for November 2000

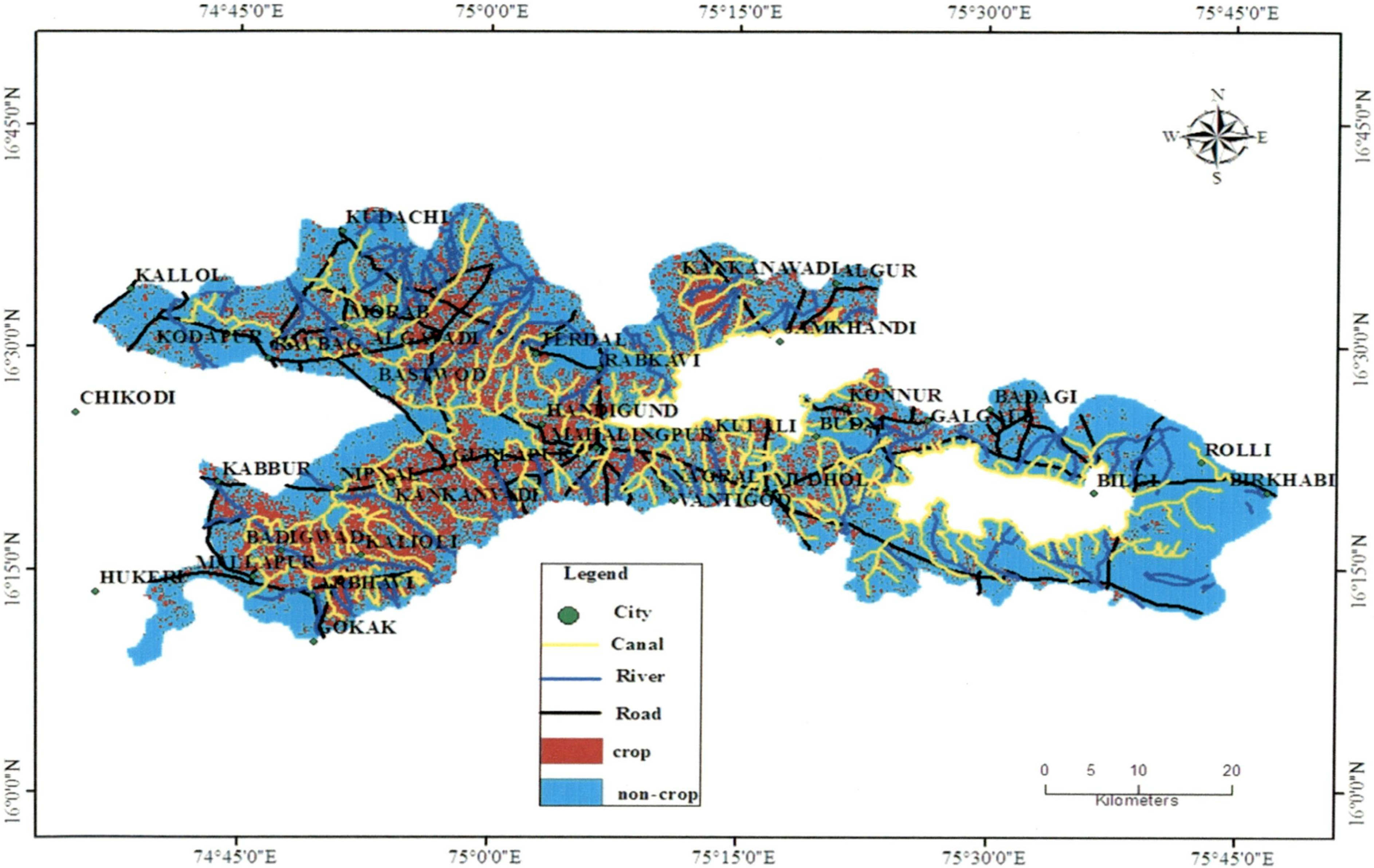


Figure 4.13: Crop classification using NDVI approach for January 2001

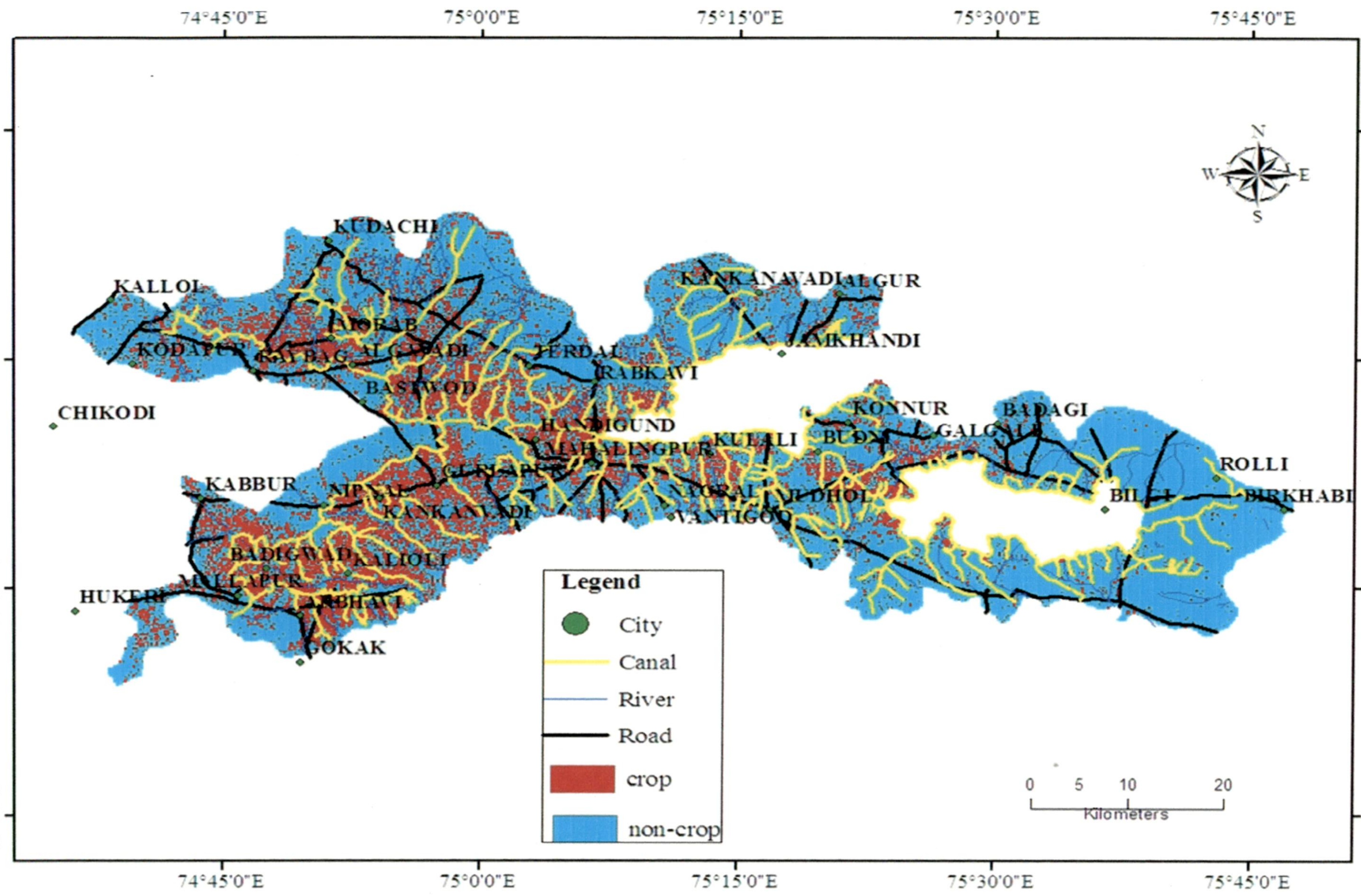


Figure 4.14: Crop classification using NDVI approach for February 2001

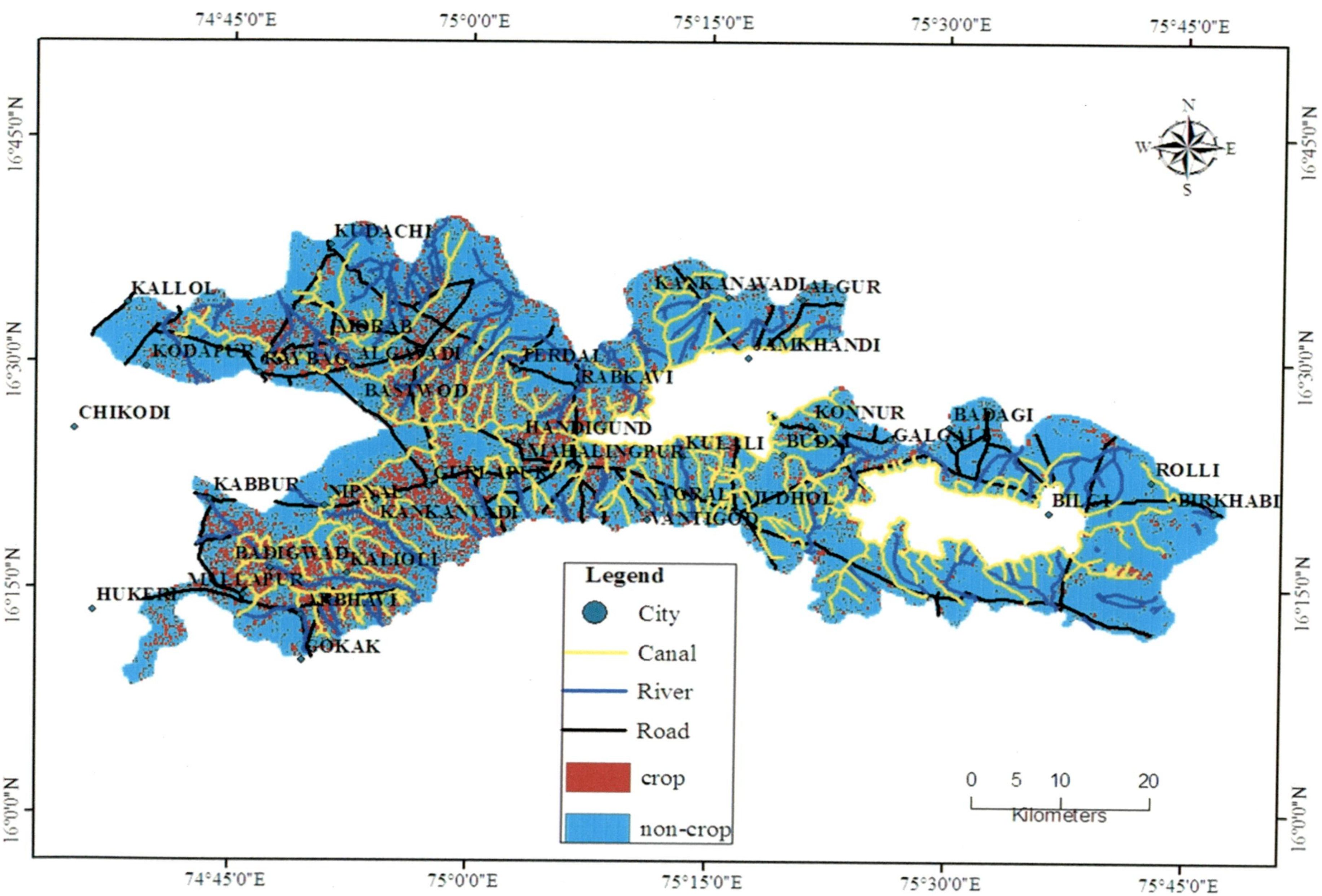


Figure 4.15: Crop classification using NDVI approach for March 2001

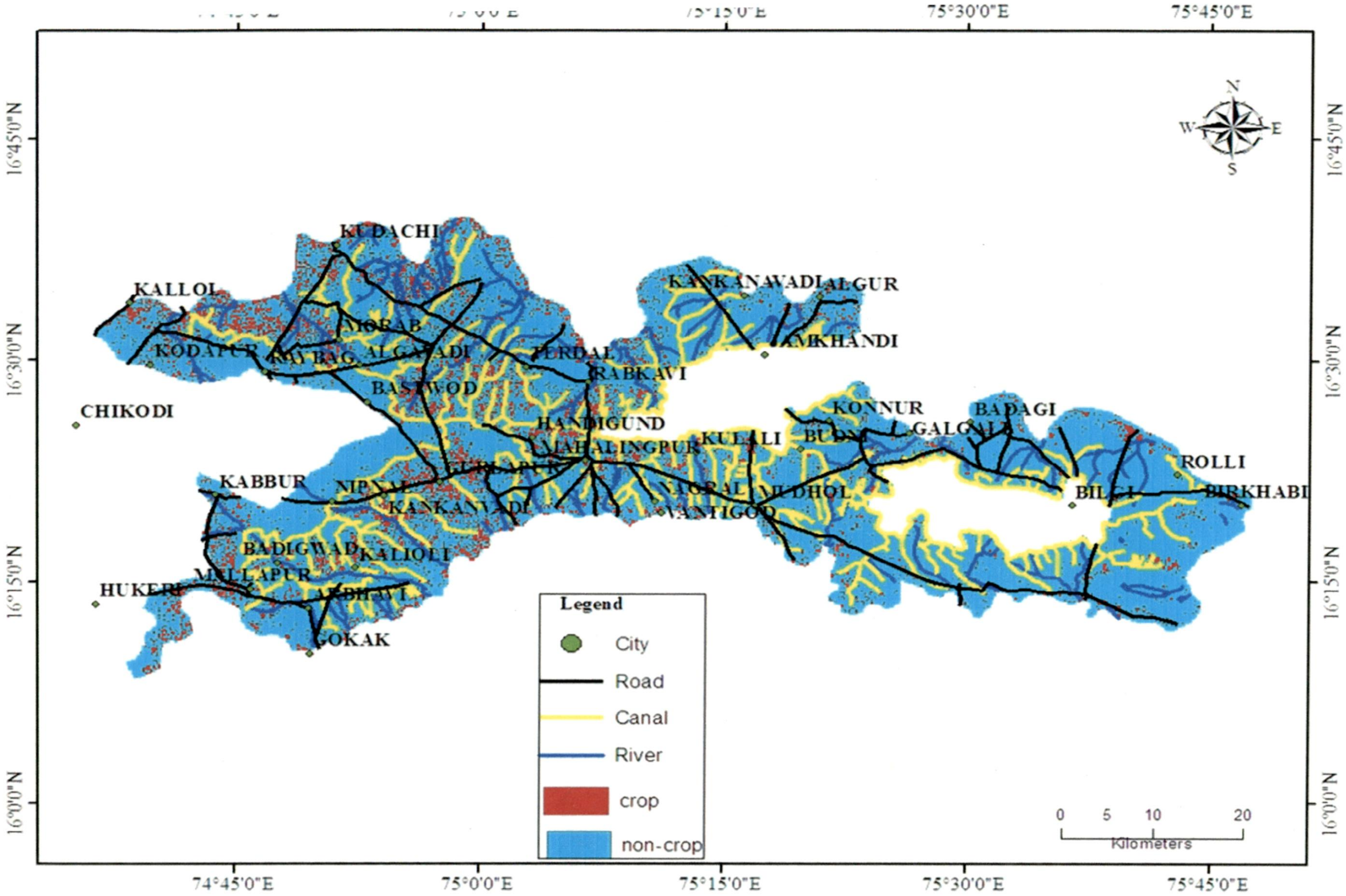


Figure 4.16: Crop classification using NDVI approach for April 2001

4.3.2 COMPUTATION OF REFERENCE EVAPOTRANSPIRATION, CROP WATER REQUIREMENT AND IRRIGATION WATER NEED

4.3.2.1 Reference Evapotranspiration

A number of methods are available in the literature for the estimation of reference evapotranspiration (ET_o) which includes Modified Penman method, Penman-Montheith method, Hargreave method, Blaney Criddle method etc. Notably, the FAO Penman-Monteith-56 (1998) method has been recommended as the sole standard method of correctly predicting (ET_o) in a wide range of locations and has provision for application in data-short situations. The CROPWAT model for windows is being used for computing reference crop evapotranspiration of the study area. This model uses Penman-Monteith method for computing reference crop evapotranspiration. Daily reference evapotranspiration depends on several factors such as maximum and minimum temperature during the day, maximum and minimum relative humidity, solar radiation, average wind speed, latitude and longitude of place. The basic equation governing the estimation of reference evapotranspiration (ET_o) is stated as:

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma \frac{900}{T + 273} * u_2 * (e_s - e_a)}{\Delta + \gamma(1 + 0.34 * u_2)} \qquad \text{----------------- 4.2}$$

Where,

ET_o - reference evapotranspiration in mm/day,

Rn - net radiation at the crop surface in $MJ/m^2/day$,

G - soil heat flux density in $MJ/m^2/day$,

T - mean daily air temperature at 2 m height in ^{0} C,

U2 - wind speed at 2 m height in m/sec,

e_s - saturation vapour pressure in kPa,

e_a - actual vapour pressure in kPa,

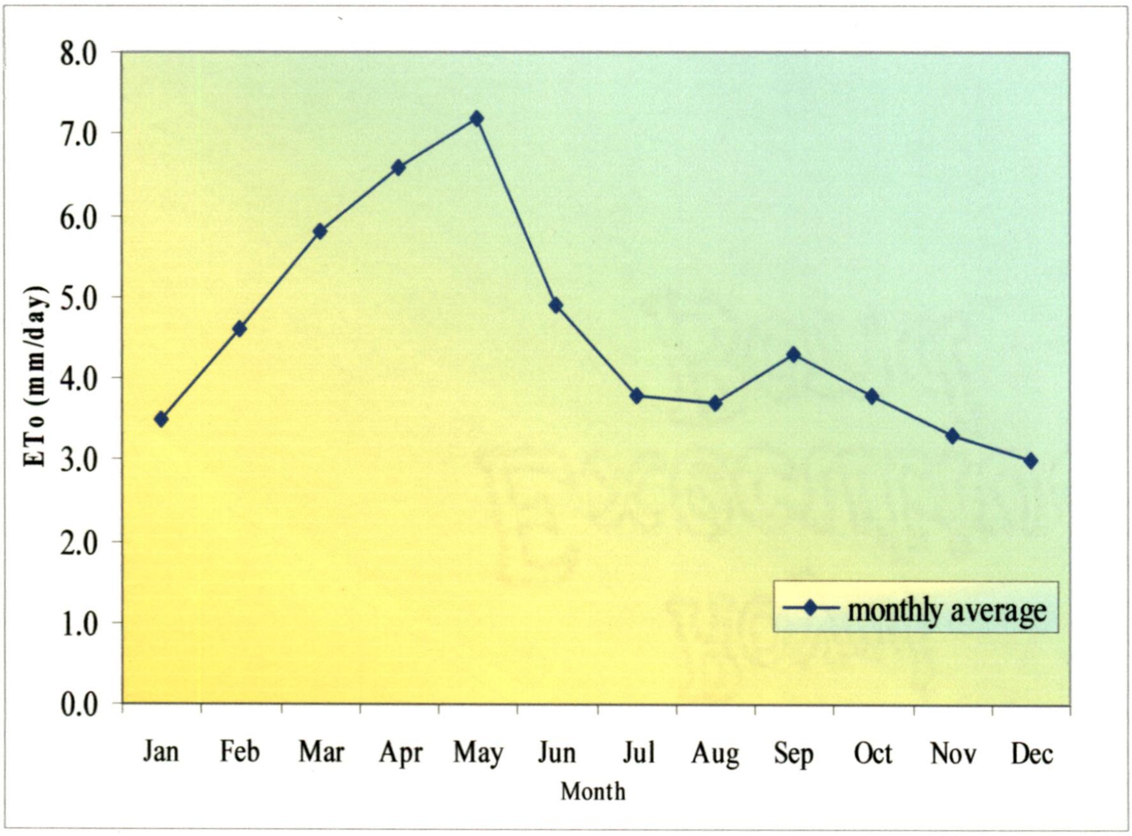
e_s-e_a - saturation vapour pressure deficit in kpa,

Δ - slope vapour pressure curve in kPa/^{0}C,

γ - psychrometric constant in kPa/^{0}C.

In the present study the meteorological data on temperature, humidity, wind, and radiation of the station located at Hidkal dam site was used to compute reference evapotranspiration. The variation of the reference evapotranspiration of the study area is shown in the Figure 4.17. The computed maximum ET_o was 7.2 mm/day during the month of May and minimum was 3.0 mm/day during month of December.

Figure 4.17: Reference Evapotranspiration in the Ghataprabha Command



4.3.2.2 Crop Water Requirements

Crop Water Requirement also called *Evapotranspiration* has been defined as "the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease free crop, growing in large fields under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1997).

In the present study crop water requirement is estimated by the CROPWAT model whereby the effect of the various weather conditions incorporated into ET_0 and the crop characteristics into the crop coefficient. The model determines the crop factor; Kc values for required time step. The values in the initial and midseason stages are constant while in the development and late season stage are calculated by linear interpolation. The crop water requirement is given as

$$ET = Kc * ETo \qquad \text{------------(4.3)}$$

Where, ET = crop evapotranspiration in mm/day,

Kc = crop coefficient,

ET_0 = reference crop evapotranspiration in mm/day.

The values of Kc for different crops during the growth stage are given in Table 4.4.

Table 4.4: Crop period and Kc values for different stages of crop in the study area.

Name of Crop	Total Days	Days of different stages				Kc values of different stages			
		Initial	Dev	Mid	Late	Kc initial	Kc development	Kc mid	Kc end
Wheat, Maize, Sorghum	120	15	30	47	28	0.49	0.49-1.1	1.1	1.1-0.69
Fodder/ Pulses	120	15	30	47	28	0.48	0.98-1.05	1.05	1.05-0.98
Sugarcane	334	31	59	183	61	0.40	0.4-1.25	1.25	1.25-0.75

4.3.2.3 IRRIGATION WATER NEED

The irrigation water need of a certain crop is the difference between the crop water requirement and that part of the rainfall which can be used by the crop (the effective rainfall).

Crop Water Requirement - Effective rainfall = Irrigation Water Need ------------(4.4)

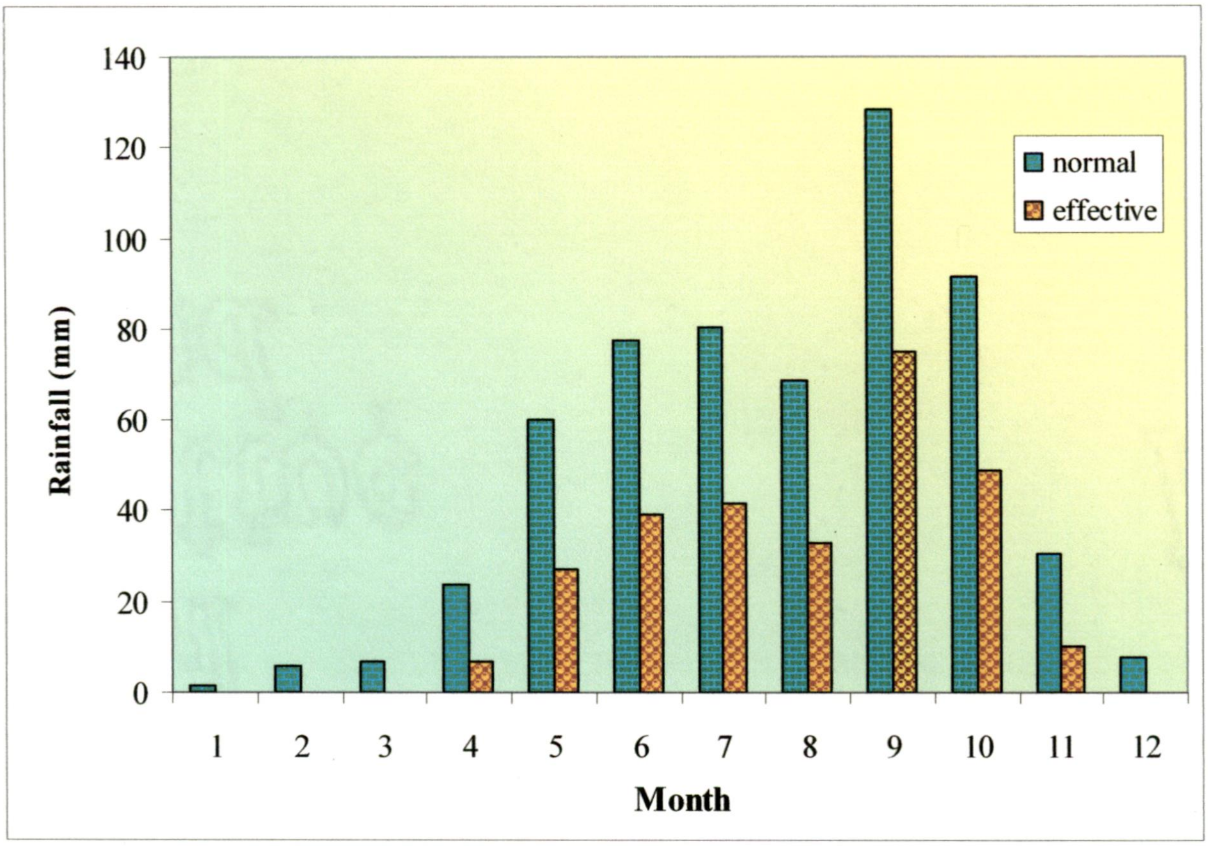
0Since there are no records of the effective rainfall, it is necessary to estimate the portion of total rainfall that can be effective so as to account for losses due to surface runoff and deep percolation. The effective rainfall formula used in obtaining water requirement of various crops is obtained by using the following relationship (Clarke et al. 1998):

$Pe = 0.7P - 15$ if $P \geq 50$ mm --------------------------- (4.5)

$Pe = 0.5P - 5$ if $P \leq 50$ mm ----------------------------(4.6)

Where, P = rainfall in mm, Pe = effective rainfall or precipitation in mm/month. The normal of monthly rainfall based on data from 1961-90 and the computed effective rainfall using formula are shown in Figure 4.18

Figure 4.18: Normal of monthly rainfall and computed effective rainfall (1961-1990)



Field Irrigation Requirement

The field irrigation requirement depends on several factors including basin size, soil type, size of irrigation stream, the skill of farmers and so on. The broad range of irrigation efficiencies depending upon soil type as suggested by ICAR (1980) are given in Table 4.5.

Table 4.5: Irrigation Efficiency under different soil types in Karnataka state

S. No	Soil Class	Irrigation Efficiency (%)
1	Sandy	60
2	Sandy loam	65
3	Loam	70
4	Clay loam	75
5	Heavy clay	80

Source: ICAR, 1980; (see Ramachandra T.V. et al., 2005)

The soil type is Ghataprabha command area is mainly clay loam and therefore, we have assumed the field irrigation efficiency as 75%. The consecutive steps involved in calculation procedure followed for crop water requirement and irrigation water need to supplement rainfall are given in Figure 4.19.

4.3.3 IRRIGATION SCHEDULING

The over and under irrigation of any arable crop has been known to adversely affect the plant growth and ultimately, the crop yield. The over-watering can cause unwanted vegetative growth, loss of valuable water to water table and runoff, leaching of nutrients, plant disease such as root rot whereas under-watering lead to loss in market value through yield reduction and reduction in quality of crops. Thus, to get the better output from an irrigation system, schedule for irrigation must be prepared. While preparing field irrigation schedule, the depth of flow, irrigation interval and duration of irrigation should be considered.

The CROPWAT model has been used for planning of irrigation schedules under varying water supply conditions. The calculations of the scheduling program is based on a soil water balance, where the soil moisture status is determined based on a daily accounting of all incoming and outgoing water (evaporation, rain , irrigation) in the root zone of the soil profile.

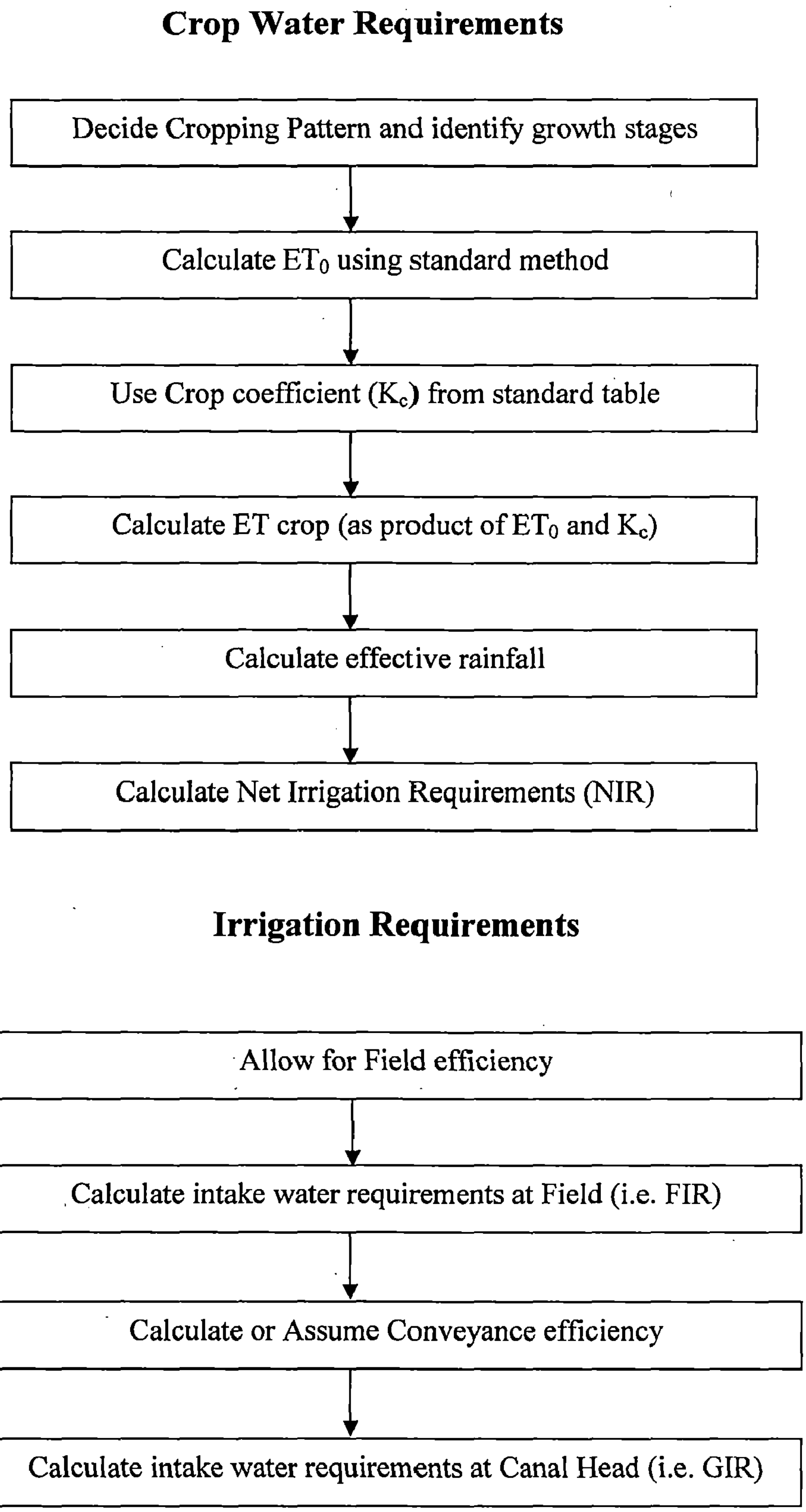


Figure 4.19: Flowchart for Crop Water Requirement and Irrigation Water Requirement

The CROPWAT model requires soil data and irrigation scheduling criteria in addition to the already computed crop water requirement calculations, as from climatic data (ET_0) and crop data (Kc, length of growth stages) representing uptake of water from the root zone by the crop and effective rainfall, which is calculated from normal rainfall for estimation of irrigation needs.

Soil Data

The model requires soil data for information on soil parameters namely Total Available Moisture (TAM), initial soil moisture depletion, maximum rooting depth and maximum infiltration rate which are required for irrigation scheduling.

The Total Available Moisture (TAM) is defined as the difference in soil moisture content between the field capacity and wilting point. It represents the ultimate amount of water available to crop and depends on texture and organic content of the soil expressed in mm/m. Indicative values for different texture class [Hansen et al, 1980] are given in Table 4.6. It is expressed as (FAO Irrigation and Drainage Paper NO. 56, 1998)

$$TAW = 1000\,(\theta_{FC} - \theta_{WP}) * Z_r \qquad (4.7)$$

Where,

TAW/TAM - total available soil water/moisture in the root zone [mm],

θ_{FC} - water content at field capacity, [$m^3\ m^{-3}$]

θ_{WP} - water content at wilting point [$m^3\ m^{-3}$]

Z_r - rooting depth [m]

The rooting depth of the crop is necessary as it used to estimate the Readily Available Water which is defined as the depth of soil water which can be used effectively by the crop. To avoid crop stress, the calculated soil moisture deficit should not fall below the readily available moisture. Readily Available Moisture (RAM) is expressed as:

$$RAM = TAM * P \qquad (4.8)$$

Where,

P is the deletion factor.

In the Ghataprabha command area the soil is mainly clay loam, and therefore, we have assumed the available water as 180mm/m.

Table 4.6: Indicative values for different soil texture class

Soil Texture	Saturated hydraulic conductivity	Apparent Specific Gravity	Field Capacity	Permanent Wilting point	Available Water	
	(mm/h)		*(% by vol)*	*(% by vol)*	*% by vol*	*mm/m*
Sandy	50 (25-250)	1.65 (1.55-1.8)	15 (10-20)	7 (3-10)	8 (6-10)	80 (70-100)
Sandy loam	25 (12-75)	1.5 (1.4-1.6)	21 (15-27)	9 (6-12)	12 (9-15)	120 (90-150)
Loam	12 (8-20)	1.4 (1.35-1.5)	31 (25-36)	14 (11-17)	17 (14-20)	170 (140-190)
Clay loam	8 (3-5)	1.35 (1.3-1.4)	36 (31-42)	18 (15-20)	18 (16-22)	180 (170-220)
Silty clay	3 (0.25-5)	1.3 (1.25-1.35)	40 (35-46)	20 (17-22)	20 (18-23)	210 (180-230)
Clay	5 (1-10)	1.25 (1.2-1.3)	44 (39-49)	21 (19-24)	23 (20-25)	230 (200-250)

Source: Soil and Water Conservation Engineering, Fourth edition

Scheduling Criteria

The irrigation scheduling criteria facilitate the selection among several options for calculations related to Timing options i.e. when irrigation is to be applied, and Application options i.e. how much water is to be given per irrigation turn (eg. 60 mm every 10 days or irrigate to return the soil back to field capacity when all the readily available moisture is used). Once the criteria are set, the model calculates the irrigation dates and the amount of irrigation water. The scheduling criteria used for the present work is shown in Table 4.7. The irrigation scheduling program cannot be addressed directly, but it is reached after completion of the crop water requirement calculations. The model calculates the crop water requirements.

Table 4.7: Scheduling criteria input data

<table>
<tr><th>Criteria</th><th>Calculation method adopted</th></tr>
<tr><td rowspan="2">Reference Evapotranspiration as per Penman-Monteith</td><td>ET_0 distribution model : Fit a curve to monthly averages</td></tr>
<tr><td>Angstrom's Coefficients (default) values:
a= 0.25
b=0.5</td></tr>
<tr><td rowspan="2">Rainfall</td><td>Rainfall distribution model: fit to curve to monthly averages</td></tr>
<tr><td>Aggregate interpolated daily rainfall into individual storm every 7 days</td></tr>
<tr><td>Effective rainfall</td><td>Empirical formula : Clarke et.al,1998</td></tr>
<tr><td rowspan="3">Scheduling</td><td>Application timing: irrigate when a specified % of TAM depletion occurs (taken 100%)</td></tr>
<tr><td>Application depth: refill to a specified % of RAM (100%)</td></tr>
<tr><td>Start of scheduling: planting date of crop
Wheat, Maize Sorghum- 1 Nov
Fodder/Pulses- 1 Nov
Sugarcane – 1 July</td></tr>
</table>

For the crop water requirements and irrigation scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values. The model does in two steps firstly the rainfall from month to month is smoothed into continuous curve using polynomial curve (other smoothing methods are also available like linear interpolation between monthly values). Secondly the model assumes that the monthly rainfall separate rainstorms, one every 7 days (the number of rainstorms is user defined). The effective rainfall has been computed using Clarke et al. 1998 method.

The actual evapotranspiration will be equal to the calculated crop water requirement as long as soil moisture content has not reached the critical level as given by allowable depletion (p). Beyond this level actual crop evapotranspiration will be reduced proportionally to soil moisture depletion. Values for total available moisture in the soil for the crop during the growing season is calculated as field capacity minus the wilting point times the current rooting depth of the crop. The readily available moisture value is calculated as TAM * P (eq. 4.8). To avoid the crop stress, the calculated soil moisture should not fall below readily available moisture.

The ratio of actual crop ET to the maximum crop ET is useful for indicating crop stress. The user defined irrigation schedule should be 100% for an unstressed crop, if less than 100%, the crop is under stress, thus review of scheduling criteria (application timing, application depth and start of scheduling) is required. Repeat the calculations of RAM until the crop is unstressed i.e. ratio of actual crop ET to maximum crop ET is more than 100%. The timing and application of irrigation are incorporated in the calculations. The computational procedure for crop water requirement and irrigation scheduling is depicted in flow chart (Figure 4.20).

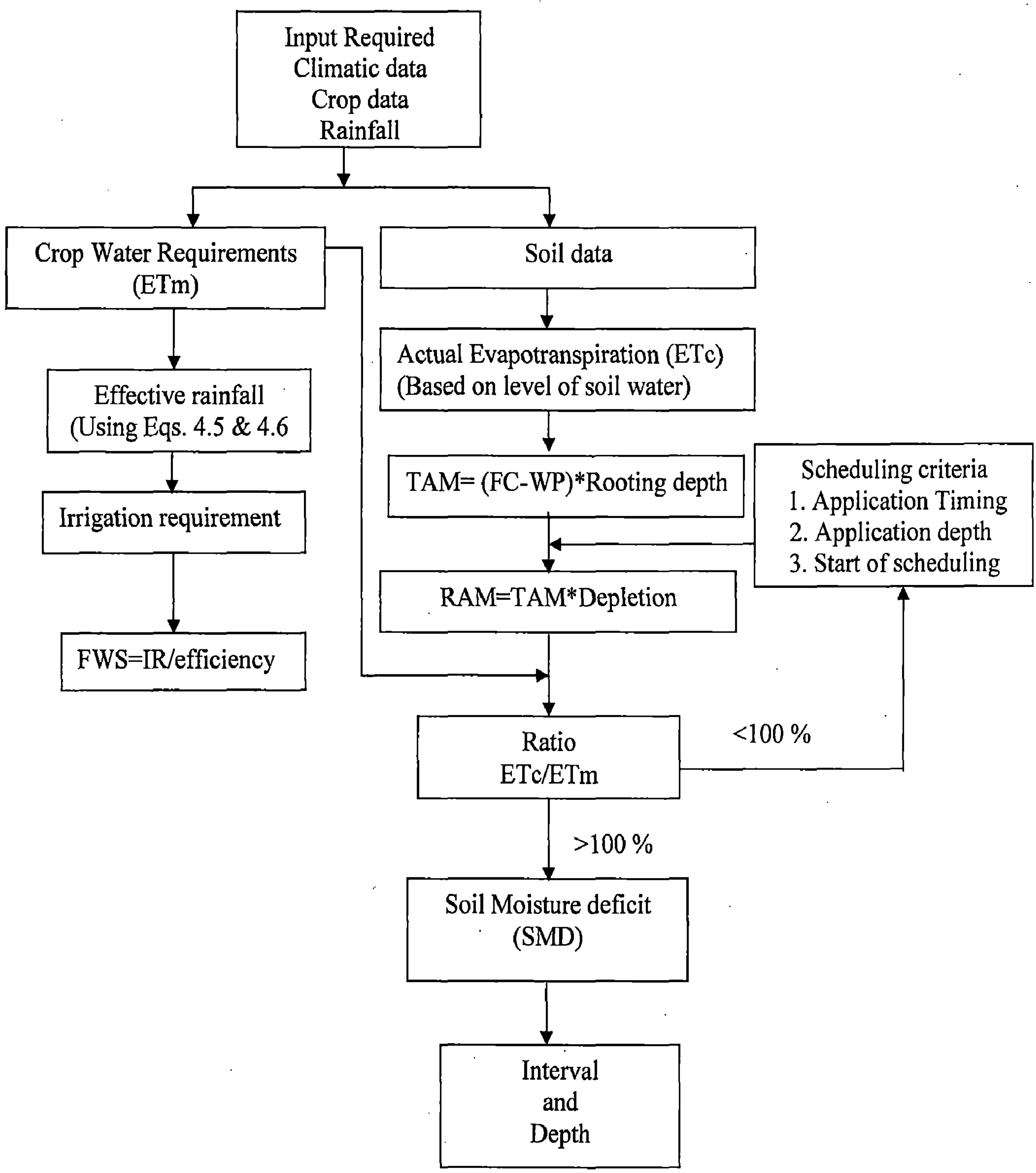


Figure 4.20: Flow chart for CWR and Irrigation scheduling for CROPWAT model

CHAPTER 5

ANALYSIS AND RESULTS

The present study was undertaken in Ghataprabha LBC command area in the Karnataka state in order to schedule the estimated irrigation water. The appropriate scheduling of irrigation water will ultimately lead to better water management actions that aim at effective and efficient utilization of land and water resources. In this chapter various irrigation parameters namely crop area, reference evapotranspiration, crop water requirement and irrigation requirement which sequentially are responsible for irrigation scheduling are discussed.

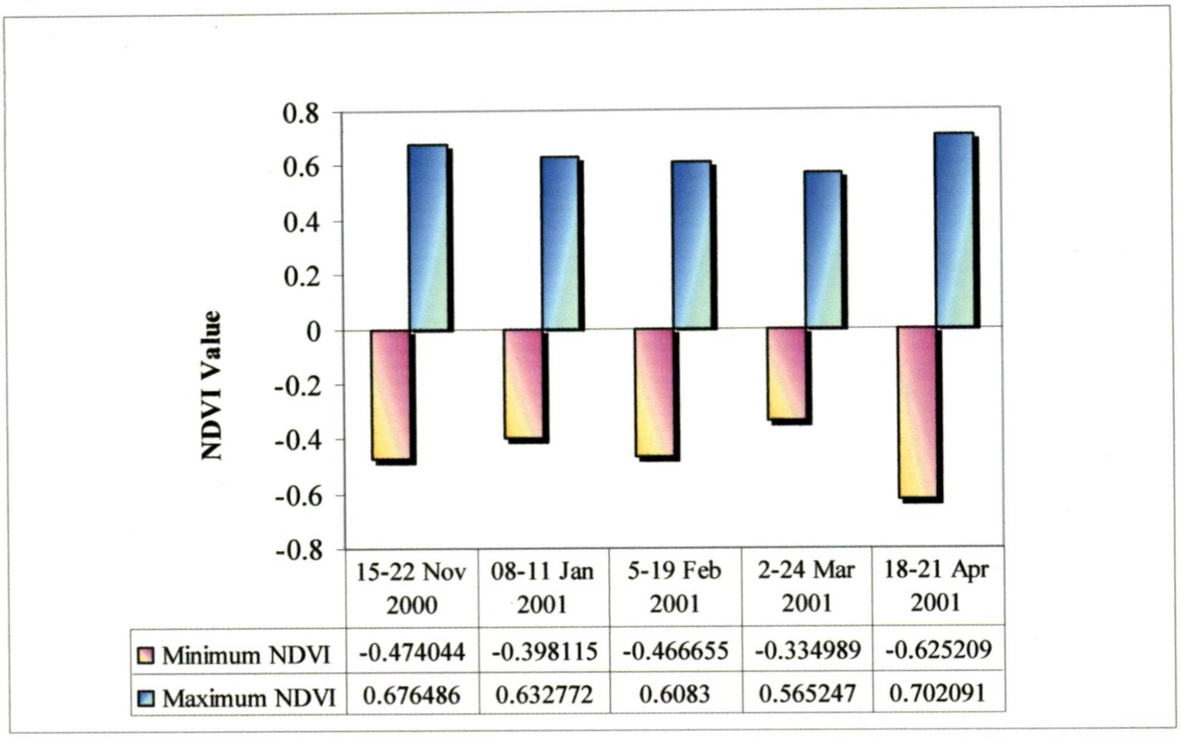
5.1 CROP ACREAGE

In the present study, spectral indices Normalised Difference Vegetation Index (NDVI) approach has been adopted for the estimation of the crop area. The crop area has been estimated for different months. The total area of the Ghatprabhha command as estimated in GIS comes out to be 296987 ha. The command area falls under the two districts of Belgaum and Bagalkot of Karnataka state.

5.1.1 CROP AREA ESTIMATION

Crop discrimination and acreage estimation using remotely sensed data is based upon the fact that each crop has a unique spectral signature. Typical spectral reflectance of a crop shows absorption due to pigments in visible region and high reflectance in the near infrared region because of internal cellular structure of the leaves. The NDVI has been generated for each image which represents the stress of the vegetation. From the statistics of the images the minimum and maximum NDVI values of each image are extracted and values are shown in Figure 5.1.

Figure 5.1: NDVI of the temporal satellite images of the Ghataprabha Command



As seen from Figure 5.1 all the temporal images of the command area have negative and positive value, reflecting the water bodies with negative values as well as greenness having positive values. Initially, the classification of the area into crop and non-crop has been made for different months using the NDVI and crop area has been estimated for these months. The crop area in different months using NDVI approach is shown in Table 5.1.

Table 5.1: Crop area using Normalised Difference Vegetation Index approach

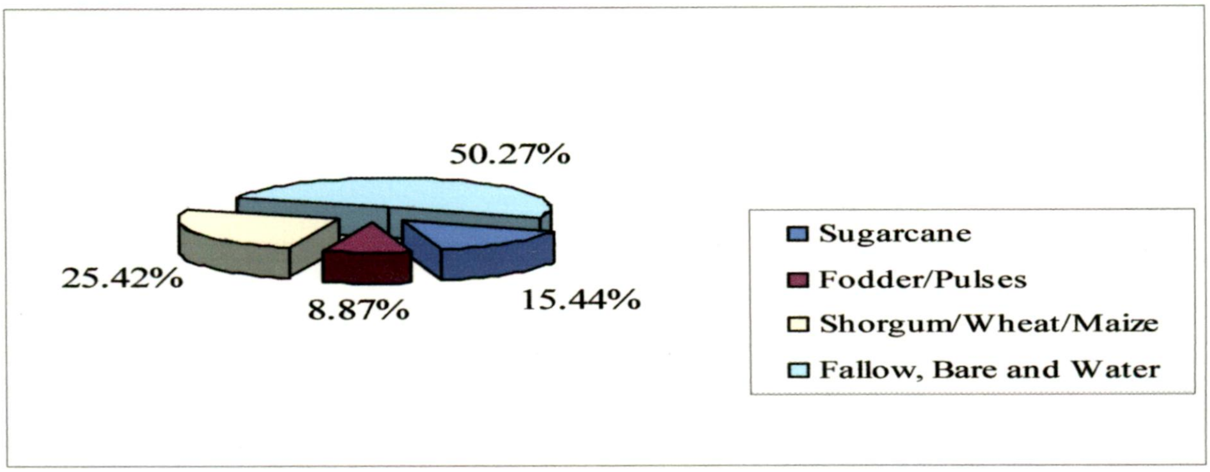
Month	**Nov. 2000**	**Jan. 2001**	**Feb. 2001**	**Mar. 2001**	**Apr. 2001**
Crop Area using NDVI (ha)	70768	85603	87509	63006	46141

Further to estimate the area under each crop, four months data i.e. January, February, March and April data have been taken. From the crop calender we know that the Fodder and or pulses exist in the months of February and March. Therefore the crop which is available in the months of February and February/March represents Fodder. Similarly if the crop is there in the field in January, January/February and January/February/March then the crop is Sorghum, Maize, Wheat. If the crop is available in the field in February/March/April or in all the four months then the crop is sugarcane. By using the above criteria the entire Rabi season has been classified into different crops as given in Table 5.2 and shown through pie chart in Figure 5.2. The classified output for Rabi season is shown Figure 5.3. The major crops identified in the study area during the Rabi season are wheat, maize, sorghum, fodder, pulses along with sugarcane, the perennial cash crop.

Table 5.2: Crop area under different crops in the Ghataprabha Command

Land Use in Rabi Season	Area (ha)	Total Area (Percentage)
Maize/Wheat/Sorghum	75881	25.42
Fodder	26476	8.87
Sugarcane	46101	15.44
Fallow, Bare & Water Bodies	150080	50.27
Gross Command Area	298538	
Total Crop Area	148457	

Figure 5.2: Pie chart showing crop area under different crops in the Ghataprabha command



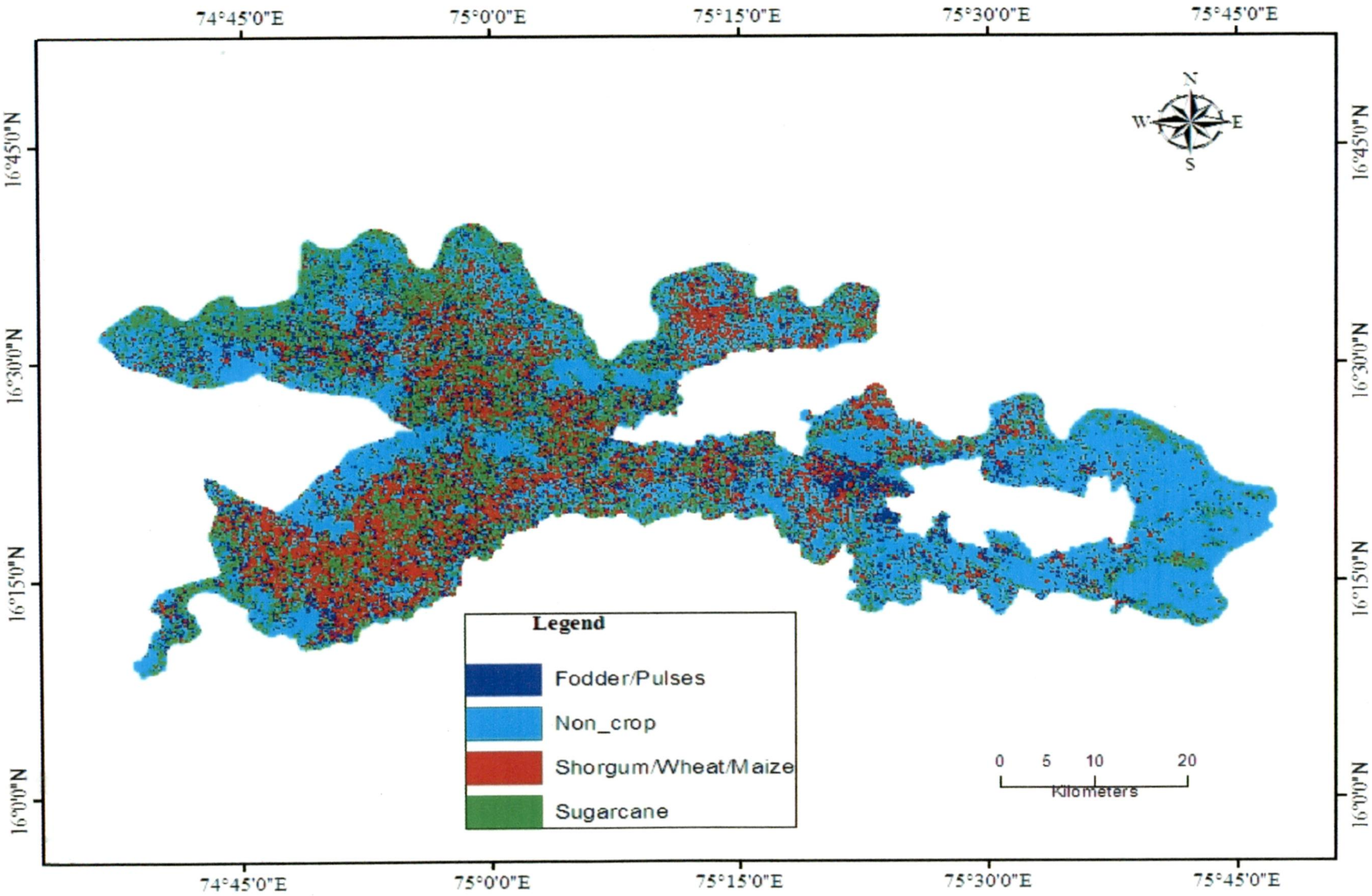


Figure 5.3: Classification of crops during Rabi season

5.2 REFERENCE EVAPOTRANSPIRATION

Reference Evapotranspiration (ET_0) has been estimated by using CROPWAT model, a program developed by Food and Agriculture Organisation (FAO). The Penman Monteith method was used to compute Reference Evapotranspiration (ET_0) using various climatic parameters namely maximum and minimum temperature, maximum and minimum relative humidity, sunshine hours, average wind speed as input parameters. The reference evapotranspiration has been estimated as given in Table 5.3 following the procedure of CROPWAT model [Annexure V]. It indicates that in month of March, April and May the reference evapotranspiration is very high which is because of high temperature, low relative humidity, more wind velocity and more sunshine hours.

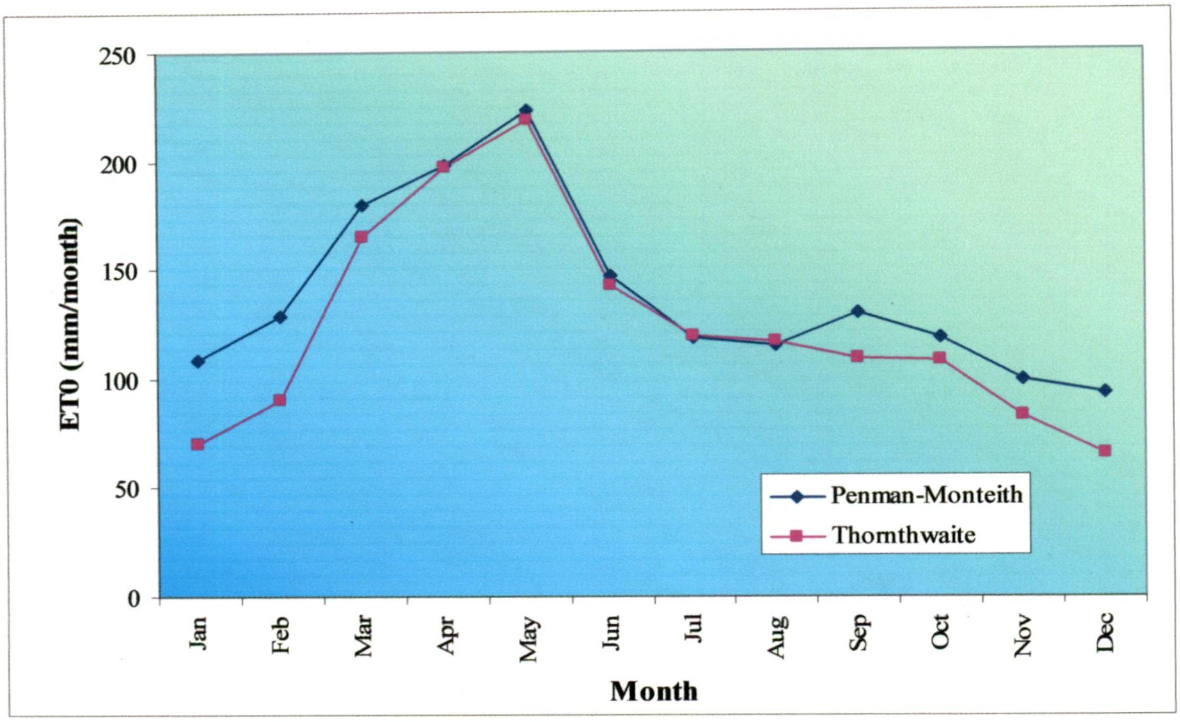
Table 5.3: Reference Evapotranspiration (ET_0) on monthly basis

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	3.5	4.6	5.8	6.6	7.2	4.9	3.8	3.7	4.3	3.8	3.3	3.0

The estimation of reference evaoptranspiration by Thornthwaite (1948) method was also carried out. For this purpose, a computer program has been written in MS Excel. The drawback of this method is that it takes into account temperature data only which is not a good indication for the energy available for evapotranspiration. Figure 5.4 shows the comparison of estimated ET_0 values by Penman-Monteith and Thornthwaite methods. It is revealed from the figure that the values of ET_0 estimated by Thornthwaite method are lower than those estimated by Penman-Monteith method except for the month of July.

In this study the values of reference evaoptranspiration computed from Penman Monteith method has been used for further calculations as it includes maximum climatic parameters. This reference evapotranspiration is the basis for calculating crop water requirement, which in turn is the basis for computing irrigation water requirement and irrigation scheduling.

Figure 5.4: Comparison of ET_0 for the Ghataprabha command area



5.3 CROP WATER REQUIREMENT

The reference evapotranspiration (ET_o) is multiplied with crop coefficient to obtain crop water requirement for the existing cropping pattern in the Ghataprabha command area. The crop growing season has been divided into four stages namely initial stage, crop development stage, mid season stage and late season stage and by knowing the crop calendar information collected from Agricultural department, Govt. of Karnataka and the period of each stage for Rabi season, the crop coefficient values are distributed to monthly values. Using these K_c values crop water requirement is calculated by using the following equation

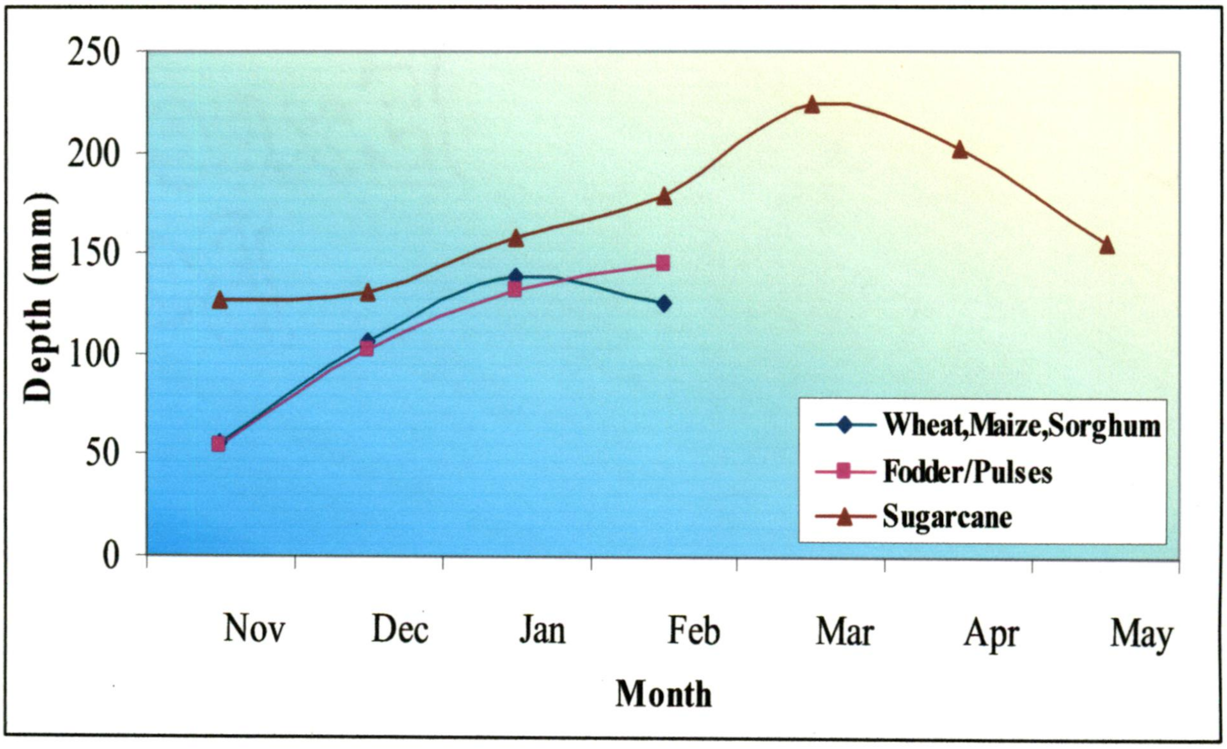
$$ET = Kc \times ETo \qquad \text{.......................} (5.1)$$

The estimated monthly crop water requirement for different crops in the Ghataprabha command is given in Table 5.4 following the computational procedure presented in Annexure VI. The crop water requirements of the various crops are shown graphically in Figure 5.5. It is clear from Figure 5.5 that the crop required different amounts of water at various stages during its growing period.

Table 5.4: Crop Water Requirement for different crops

Days	ET_o (mm/month)	Crop Water Requirement (mm)		
		Sorghum, Maize, Wheat	Fodder	Sugarcane
November	99	56.28	54.72	127.302
December	93	106.63	101.89	130.212
January	108.5	138.89	132.58	157.815
February	128.8	126.17	144.89	178.243
March	179.8			223.563
April	198			202.526
May	223.2			155.491

Figure 5.5: Monthly crop water requirements of various crops



The crop water requirement for the total crop period i.e. starting from November 1st to February 28th (120 days) of Sorghum, Maize, Wheat is 427.97 mm, for Fodder/Pulses is 434.08 mm. The crop water requirement for the Sugarcane is 1175.15 mm during this season. The maximum crop water requirement for wheat, maize, sorghum is 138.89 mm in the month of January, for Fodder /pulses is 148.89 mm in the month of February and in month of March for the sugarcane is 223.563 mm. The crop water requirement of sugarcane has been found to be the highest of all crops.

5.4 IRRIGATION WATER REQUIREMENT

Net irrigation requirement (NIR), Field Irrigation Requirement (FIR), and Gross Irrigation Requirement (GIR) and total volume of water required for different crops in different months were calculated, and these are discussed below.

Net Irrigation Requirement

The net irrigation water requirement/demand under the present study was estimated using CROPWAT model which computes the crop water requirement and the effective rainfall. In the present study, the net irrigation water requirement has been computed on monthly basis. The monthly irrigation requirement for each crop has been obtained by deducting the effective rainfall from crop water requirement. The effective rainfall has been computed using the empirical formula given by Clarke, 1998 [Chapter 4].

Further, the monthly net irrigation requirements (mm/ha) are multiplied with the satellite data derived crop acreage (ha) to arrive at the total net irrigation requirements of various crops in the Ghataprabha command area (ha-m) under the left bank canal. The details of these are given in Table 5.5.

The net irrigation requirement of Maize, Wheat, Sorghum is 32316.96 ha-m, for Fodder/Pulses it is 11437.63 ha-m and for sugarcane it is 52699.44 ha-m. The total net irrigation water requirement for the command comes out to be 96454.03 ha-m and in terms of depth it is 649.71 mm (96454.03/148458*1000) for the Ghataprabha command.

Table 5.5: Monthly Net Irrigation Requirements of crops in Ghataprabha command

Date	NIR for Wheat, Maize, Sorghum		NIR for Fodder/Pulses		NIR for Sugarcane		NIR for Command Area
	(mm/ha)	For 75881 ha area (ha-m)	(mm/ha)	For 26476 ha area (ha-m)	(mm/ha)	For 46101 ha area (ha-m)	(ha-m)
1	2	3	4	5	6	7	8
Nov 00	54.2	4112.75	52.64	1393.70	121.02	5579.14	11085.59
Dec 00	106.63	8091.19	101.89	2697.64	129.14	5953.48	16742.31
Jan 01	138.89	10539.11	132.58	3510.19	157.84	7276.58	21325.88
Feb 01	126.17	9573.91	144.89	3836.11	178.84	8244.70	21654.72
Mar 01	--	--	--	--	224.87	10366.73	10366.73
Apr 01	--	--	--	--	201.58	9293.04	9293.04
May 01	--	--	--	--	129.84	5985.75	5985.75

Field Irrigation and Gross Irrigation Requirement

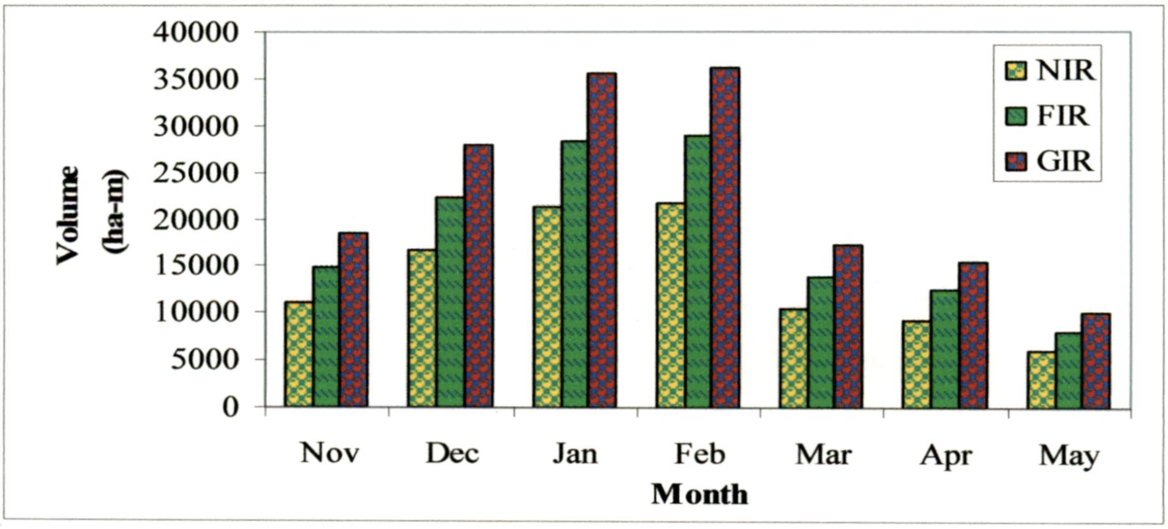
Based on the soil types, field losses are assumed as 25% of the net irrigation requirements. The Field Irrigation Requirement (FIR) on monthly basis has been computed by dividing the net irrigation requirement by 0.75. For the computation of Gross Irrigation Requirement (GIR) of crops the total conveyance losses of canal are assumed as 20 % of the field irrigation requirements. Thus, GIR is computed by dividing FIR by 0.8. The water allowance (continuous flow requirement) at the canal head has been computed to facilitate the water supply schedule for the command area, required for effective release pattern both in planning stage as well as for the existing cropping pattern. The monthly water supply i.e. NIR, FIR, GIR and water allowances in terms of volume for the Ghataprabha command area is shown in Table 5.6.

Table 5.6: Monthly water requirements in terms of volume

Month	NIR	FIR	GIR	Water Allowance (Canal Head)
	(ha-m)	(ha-m)	(ha-m)	(metre ^{3}/sec)
1	2	3 = (col 2/0.75)	4 = (col 3/0.80)	5 = col 4/days*24*3600
November -00	11085.59	14780.79	18475.98	71.28
December -00	16742.31	22323.09	27903.86	104.18
January-01	21325.88	28434.51	35543.14	132.70
Feburuary-01	21654.72	28872.96	36091.19	149.19
March-01	10366.73	13822.31	17277.89	64.51
April-01	9293.04	12390.72	15488.40	59.75
May-01	5985.75	7981.01	9976.26	37.25

The monthly irrigation water requirements for the Ghataprabha command area are shown graphically in Figure 5.6. It can be clearly seen that the irrigation requirements are higher in the months of December, January and February in comparison to other months.

Figure 5.6: Monthly irrigation water requirement in the Ghataprabha command



5.5. IRRIGATION SCHEDULING

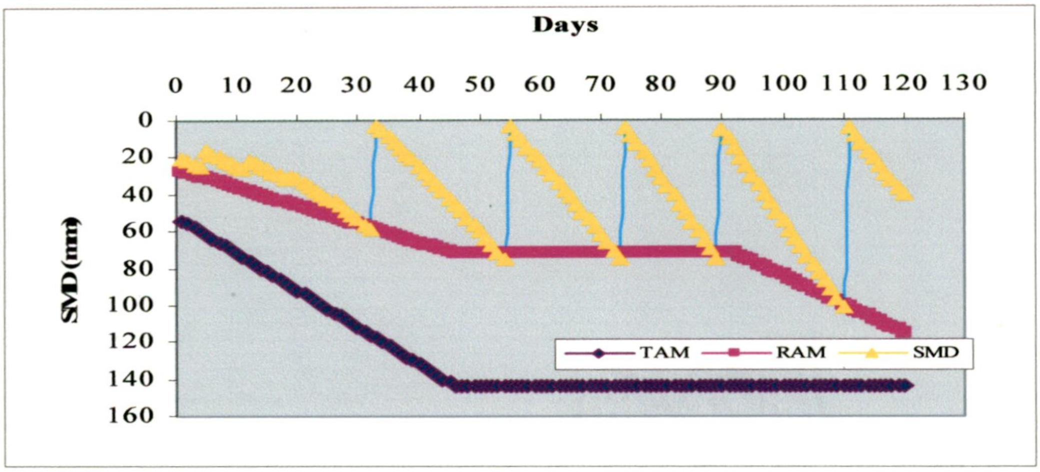
In the present study irrigation scheduling has been done using the CROPWAT model which has used the information provided on crop water requirement, rainfall, soil data and rooting depth. The calculation of the scheduling is based on a soil water balance, where the soil moisture status is determined on a daily basis accounting of all incoming and outgoing (rainfall, irrigation and evaporation) water in the root zone of soil profile. Irrigation water is applied whenever the critical soil moisture level is reached and readily available soil moisture is depleted, defined as 100% RAM for optimal irrigation, where no restrictions are set on timing and availability of water supply. For successful growth and effective utilization of water from the soil, the readily available soil-moisture must be at 50 % level for optimum limit.

The computational results are shown in Table 5.7, following the procedure presented in the Annexure VII. It can be revealed from the table that first irrigation water for wheat, maize, sorghum is required after an interval of 31 days with an amount of 59.1 mm while irrigation water for fodder/pulses and sugarcane require after an interval of 27 days with an amount of 47.2 mm and 142 days with an amount of 175.9 mm. It can also be noted that irrigation water requirement of crops is low during the early crop establishment as looking at the irrigation intervals. For the perennial crop sugarcane, during the monsoon season (July-September) although crop water requirements is high, but due to heavy rains in the region, supplementary irrigation is not required. This is not the case with all of the sugarcane growing regions and throughout the monsoon season. Sometimes prolonged dry spells may persist; that is the time when irrigation must be managed to fulfill the crop water requirements.

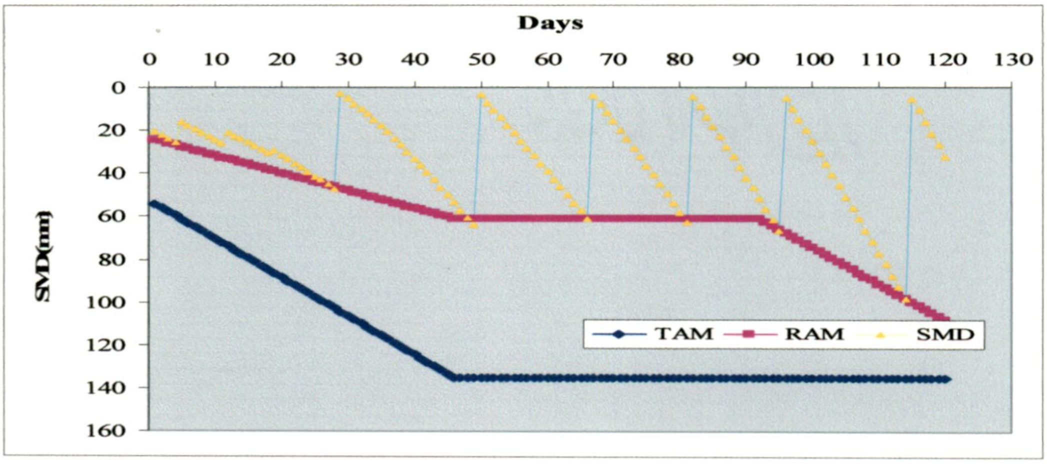
Table 5.7: Irrigation schedules for the major crops in the study area

S.No	Crop	Irrigations	Irrigation Interval	Irrigation required	Total irrigation requirement
			(Days)	(mm)	(mm)
1	Wheat, Maize, Sorghum	1st	31	59.1	384.7
		2nd	22	75.2	
		3rd	19	74.9	
		4th	16	74.8	
		5th	21	100.7	
2	Fodder/Pulses	1st	27	47.2	398.7
		2nd	21	63.8	
		3rd	15	62.4	
		4th	14	66.2	
		5th	19	98	
3	Sugarcane	1st	142	175.9	1068.5
		2nd	43	176.8	
		3rd	34	178.7	
		4th	27	176.9	
		5th	25	180.7	
		6th	29	179.5	

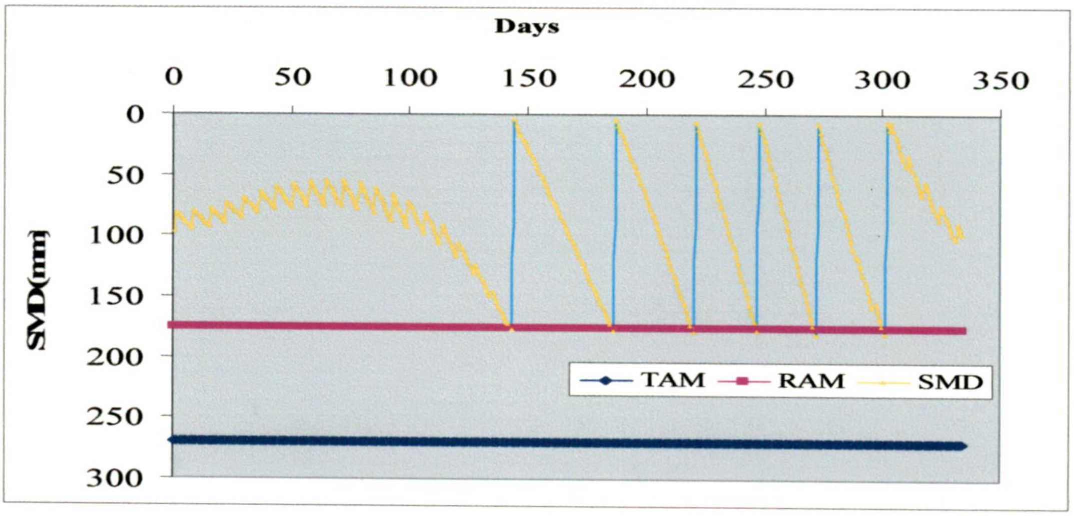
Figure 5.7 shows the irrigation scheduling graphs depicting the daily soil moisture balance throughout the growing season for the various crops in the Ghataprabha command area which is very useful in utilizing the moisture changes throughout the season. It is clear from the graphs that the day when soil moisture depletion is 100% of RAM, the irrigation is needed to meet out the deficit so the crops remain stress free and the yield is not affected. Thus, planning or irrigation scheduling can prove to be helpful for the timing and quantity of water application, leading to judicious use of water resources for contribution in the growth of crops and results in higher crop yield with the



(a) Wheat, Maize, Sorghum



(b) Fodder/Pulses



(c) Sugarcane

Figure 5.7: Irrigation scheduling graphs for major crops in Ghataprabha command

minimum losses.

5.6 SENSITIVITY ANALYSIS

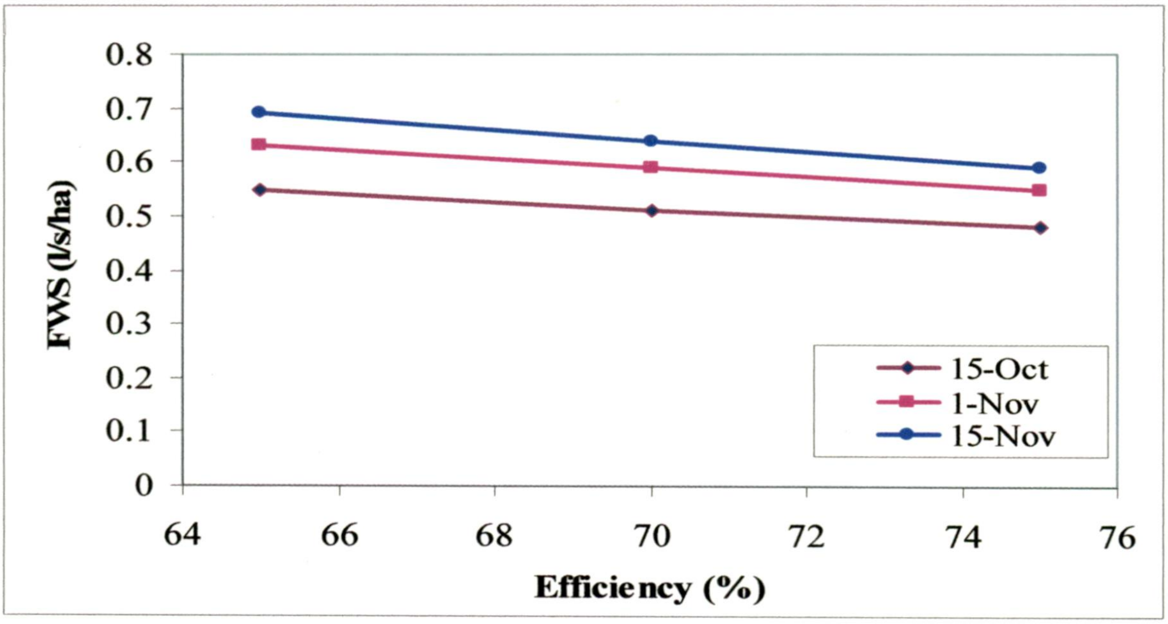
Sensitivity analysis is carried out to study, how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. In the present study, the field water supply was taken as an indicator for investing the effect of the governing factors for improving irrigation scheduling with minimum water supply. A sensitivity analysis was carried out for the governing factors (1) irrigation efficiency and (2) shift in planting date. The results of sensitivity analysis are shown in Table 5.8. It is clearly seen from the table that the average field water supply (FWS) for crops decreases with increase in irrigation efficiency. The trend is almost exponential in nature as seen from Figure 5.8. It follows that FWS is directly dependent upon the net irrigation requirement and efficiency, greater is the efficiency of irrigation, smaller will be conveyance losses and lesser will be the field water supply and vice versa.

Table 5.8: Sensitivity analysis for optimal Field water supply for Rabi season

S.No	Planting Date	Irrigation efficiency	average Field Water Supply (FWS)	
			for Wheat, Maize, Sorghum	for Fodder/Pulses
		(%)	(l/s/ha)	(l/s/ha)
1	*2*	*3*	*4*	*5*
1	15-Oct	65	0.55	0.56
2	1-Nov	65	0.63	0.64
3	15-Nov	65	0.69	0.7
4	15-Oct	70	0.51	0.52
5	1-Nov	70	0.59	0.6
6	15-Nov	70	0.64	0.65
7	15-Oct	75	0.48	0.49
8	1-Nov	75	0.55	0.56
9	15-Nov	75	0.59	0.6

It is also observed that with shifting the planting date from 1 November to 15 October of the crops in the command, the FWS also decreases while, when it is shifted to 15 November, the FWS increases. Furthermore, the evapotranspitration is relatively higher in the month of October than in the month of November but the FWS shows the decaying rate. Since both the factors play a significant role in computation of field water supply it is worth that any or both of these parameters can be considered for ameliorating the irrigation schedule for optimum water supply in the command.

Figure 5.8: Field Water Supply trends in the Ghataprabha command



CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Scientific irrigation scheduling is a tool used to improve irrigation water management. When used properly, it indicates when to irrigate, how much water to apply, and how to apply water to satisfy crop water requirements and avoid plant moisture stress. When carefully used, irrigation scheduling saves water, energy, labour, and fertilizer, and in many cases improves crop yields and crop quality. When water supplies are tight and deliveries are made at much reduced rates, irrigation scheduling can help users to stretch available water for greatest benefit on irrigated crops.

In the present study, integrated approach of remote sensing and GIS along with CROPWAT software has used to meet out the objective in more scientific manner. The study used the multi temporal satellite data of IRS-1C/1D LISS III for digital image processing for the Ghataprabha command area for Rabi season of 2000-01. The NDVI and multi spectral approaches were used for crop area estimation. The collective information through satellite remote sensing and ground data proved to be efficient in identification of the major crops in the area. The results from FAO 56 Penman-Monteith were used in investigation for further application in the CROPWAT model to calculate the crop water requirements, irrigation requirements and scheduling of irrigation in the command area.

The conclusions drawn from the study are:

i. Mapping the extent of various crops is very important in command area studies which may be helpful in irrigation water management, cropping pattern planning etc.

ii. For identification of crops, multi temporal remote sensing data are used in conjunction with the crop calendar of the region. The main crops cultivated in this region are Wheat, Maize, Sorghum, Fodder, Pulses and Sugarcane. Sugarcane is the dominant crop covering 31.05 % of the crop area during Rabi season.

iii. The classification of satellite data for identification of crops has been improved significantly by using Normalised Difference Vegetation Index (synthetically generated images) along with raw data.

iv. A command wise statistics of the study area under different crops is generated for the identified crops. Geographical Information System (GIS) has proved to be efficient in creating thematic database for the Command area.

v. CROPWAT a decision support system developed by FAO has been used to compute reference evapotranspiration, crop water requirements and irrigation water requirement; to develop irrigation schedules under various management conditions in the study area.

vi. The climatic factors play an important role in estimation of reference evapotranspiration (ET_0), which is used in irrigation planning, design, and scheduling and for other water adequacy studies. The ET_0 is higher from the month of March to May and ranges from 5.83 mm/d to 7.19 mm/d.

vii. The crop water requirement of Wheat, Maize, and Sorghum is 427.97 mm and for Fodder/Pulses it is 434.08 mm. The sugarcane requires 1175.15 mm of water which is found to be highest of all the crops in Ghataprabha Left Bank Canal command. The total net irrigation requirement is 96454.03 ha-m in the Ghataprapha LBC command.

viii. The total irrigation requirement for the Wheat, Maize, Sorghum is 384.7 mm with five irrigations. The fodder/Pulses require 398.7 mm with five irrigations while the perennial crop, sugarcane needs 1068.5 mm with six supplementary irrigations.

ix. Sensitivity analysis indicated field water supply to decrease with increase in irrigation efficiency almost exponentially. It has also been revealed that rate of decay of field water supply increased significantly as date of plantation shifted from November 1st to October 15th. Since irrigation efficiency and shifting of dates of plantation showed a significant influence on the field water supply, both of them can be considered for ameliorating the irrigation schedule for optimum water supply.

6.2 RECOMMENDATIONS

The present study has utilised only multi spectral, multi temporal IRS LISS III images and associated Normalised Difference Vegetation Index and unsupervised classification approach for crop area estimation and crop classification. The study can be improved with more numbers of multi-temporal and multi-sensor images like LANDSAT ETM, ASTER. With the advancement in remote sensing and processing techniques, it is possible to deduce other important information about the command area on the actual crop evapotranspiration and link the same to the modelling scheme.

The higher resolution data from satellite like CARTOSAT 1 (2.5 m spatial resolution) and CARTOSAT 2 (1.0 m spatial resolution) can be used up to water course level for data base preparation and spatial analysis of irrigation parameters. Global Positioning System (GPS) survey can be utilised for the ground truth collection etc.

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SALIENT FEATURES OF GHATAPRABHA PROJECT

VIEW OF RAJA LAKHAMGOWDA DAM (HIDKAL DAM) SPILLWAY SECTION AND POWER HOUSE

The river Ghataprabha is a tributary of Krishna and rises in western ghat 'sahyadri' ranges near Amboli in Maharashtra and enters in Karnataka near Daddi in Hukkeri taluk in Belgaum district and joins Krishna near sangam in Bagalkot taluks of Bagalkot district. Command area is bounded by the Krishna River in the north, Maharashtra state to the west, the confluence of Krishna River and Malaprabha River in the east.

The GLBC have six branch canal and 90 distributaries, major and minor. The canal system was completed in 1974-75. The net command area is 1, 61,871 ha. Annual yield estimated to be 121 TMC (near Dupdal weir) at 75% dependability. Average annual rainfall: 690 mm. 65% from SW monsoon and 20% NE monsoon and rest premonsoon. Tropical type climate with hot summer and cold winter. Summer temp reaches more than 40 deg. during April/May and winter fall below 10 degree- December/January.

DETAILS OF HIDKAL DAM

Ghataprabha (Hidkal Dam)	: Latitude 16^{0} 9' 16"
Masonry dam	: Longitude 74 deg. 34' 0"
M S Dam Length	: 149.35 m.
Total length	: 10,183 m.
Height	: 53.34 m.
FRL (RL)	: 2175 ft
Storage capacity	: 51.16 MCFT
Irrigation	: 31,000 ha in Belgaum and Bagalkot District
LEFT Bank Canal	: Dhupdal Weir with Head discharge Capacity of 1500 cusecs to irrigate area 1, 85,085 ha
Work started	: 1948-49
Work completed	: 1976-77

SPECIFICATION OF THE IRS DATA IMAGE

The Indian Remote Sensing IRS-1C and 1D satellites supply high-resolution optical satellite imagery. Both the 1C and 1D satellites carry three sensors. The panchromatic sensor collects a single band of imagery with 5.8-meter resolution. The LISS-III multispectral sensor has a resolution of 23.5 meters and collects 4 bands of image data in the visible, near infrared and short-wave infrared portions of the electromagnetic spectrum. The specifications of IRS Optical Sensors: LISS III and LISS IV are given as below

Sensor	Spectral bands (µm)	Spatial resolution (m)	Swath (km)	Quantization (bits)	SNR*	SWR** @ Nyquist frequency
LISS-III	Green : 0.52-0.59	23.5	141	7	>128	>0.40
	Red : 0.62-0.68	23.5	141	7	>128	>0.40
	NIR : 0.77-0.86	23.5	141	7	>128	>0.35
	SWIR	70.0	148	7	>128	>0.30
LISS-IV	Green : 0.52-0.59	5.8	23	10		
	Red : 0.62-0.68	5.8	23	10		
	NIR : 0.77-0.86	5.8	23	10		

SNR (signal to noise ratio) is the ratio between a signal (meaningful information) and the background noise.

SWR (standing wave ratio) is the ratio of the amplitude of a partial standing wave at an antinode (maximum) to the amplitude at an adjacent node (minimum)

REMOTE SENSING APPLICATIONS FOR DIFFERENT SPECTRAL BANDS

Some of the representative applications for different spectral bands available from existing satellites.

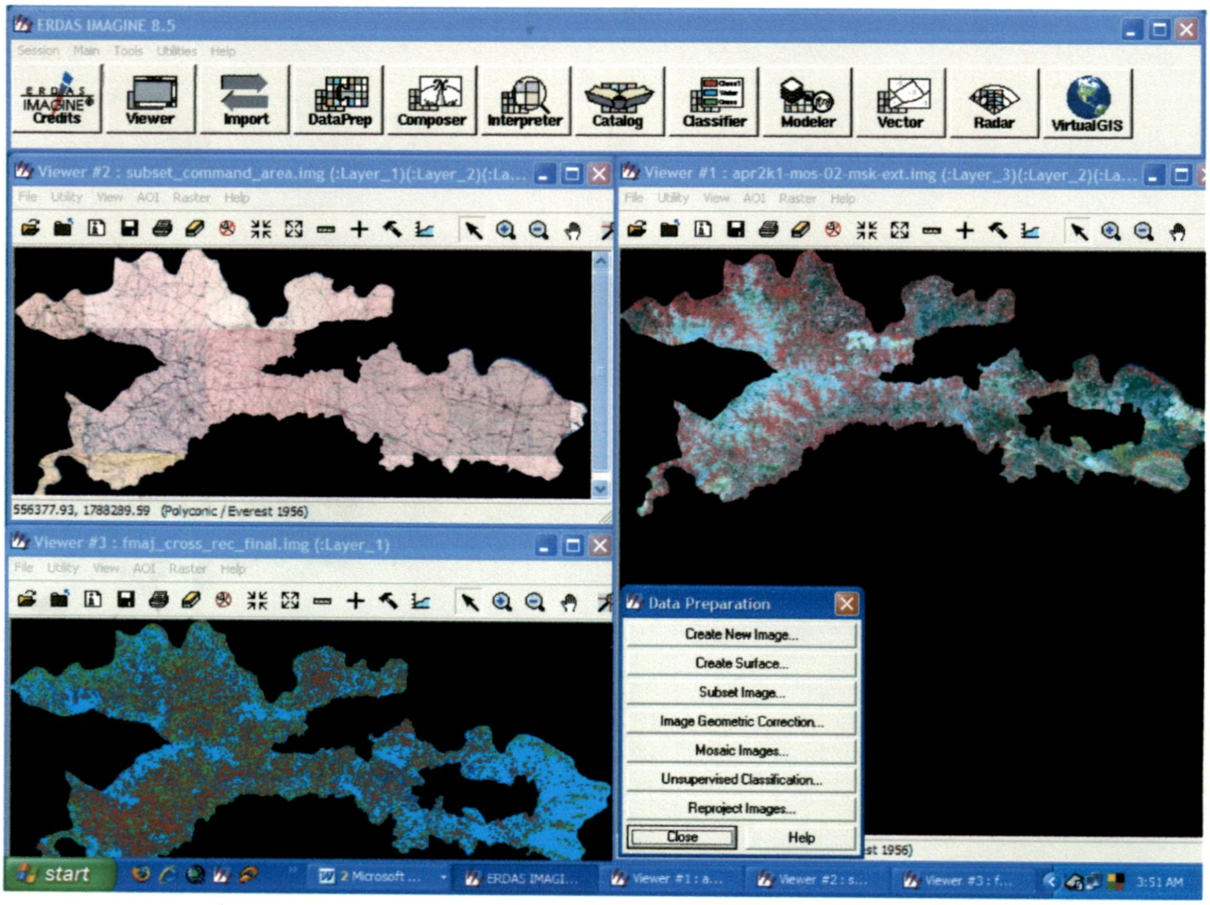
Spectral Band (m)		Applications
Blue	(0.45-0.50)	Water penetration, land use, vegetation chts, sediment.
Green	(0.50-0.60)	Green reflectance of healthy vegetation.
Red	(0.60-0.70)	Vegetation discrimination because of red chlorophyll absorption.
Panchromatic	(0.50-0.75)	Mapping, land use, stereo pairs.
Reflective Infrared	(0.75-0.90)	Biomass, crop identification, soil-crop, land water boundaries.
Mid-infrared	(1.5-1.75)	Plant turgidity, droughts, clouds, snow ice discrimination.
Mid-infrared	(2.0-2.35)	Geology, rock formations.
Thermal infrared	(10-12.5)	Relative temperature, thermal discharges, vegetation classification, moisture studies, thermal inertia.
Microwave-short wave	(0.1-5 cm)	Snow cover, depth, vegetation water content
Microwave –long wave	(5-24 cm)	Melting snow, soil moisture, water, water-land boundaries, penetrate vegetation

ERDAS IMAGINE 8.5

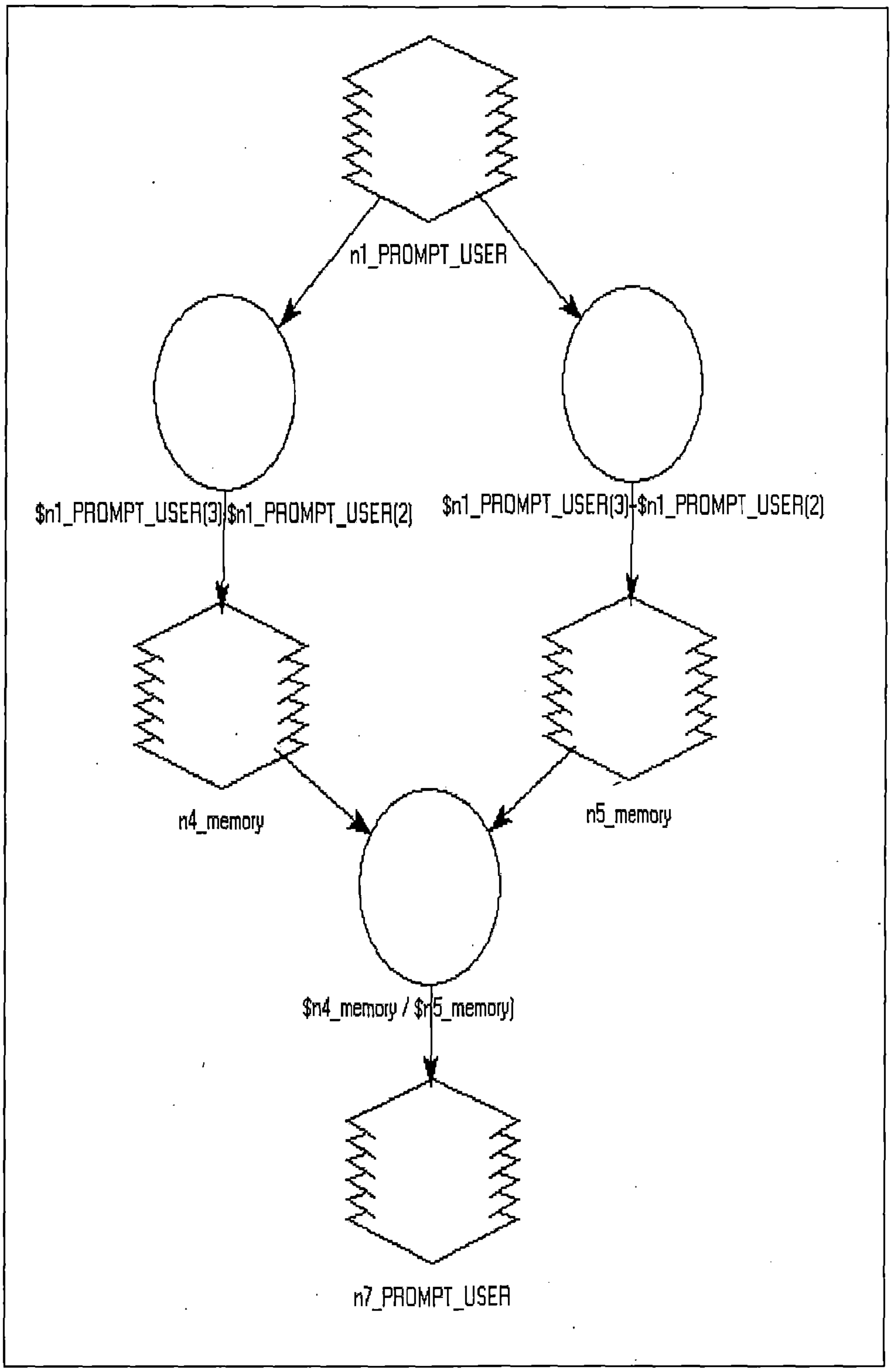
(A Comprehensive Toolbox)

Imagery is far more than pictures of the earth's surface. It is a valuable source of data that captures actual events at specific times and places in the world so that you can study how the earth changes over time. ERDAS IMAGINE gives you the tools to manipulate and understand this data.

ERDAS IMAGINE is a broad collection of software tools designed specially for image processing and GIS package. This package has many advanced features for Image processing. Erdas Modeller allows us to make our own algorithms for image analysis. For image classification user friendly classification techniques like fuzzy classification are incorporated in this package. The main window in ERDAS IMAGINE 8.5 is shown as below



Model for Normalised Difference Vegetation Index



****

Climate and ETo (grass) Data

CropWat 4 Windows Ver 4.2

****

Country : India　　　　Station : Hidkal

Altitude: 625 meter(s) above M.S.L.

Latitude: 16.90 Deg. (North)　Longitude: 74.34 Deg. (East)

Month	Max Temp	MiniTemp	Humidity	Wind Spd.	SunShine	Solar Rad.	ETo
	(deg.C)	(deg.C)	(%)	(Km/d)	(Hours)	(MJ/m2/d)	(mm/d)
January	29.1	15.7	51.9	73.9	9.0	18.7	3.47
February	31.7	17.2	43.4	103.2	10.0	21.8	4.63
March	35.1	20.7	41.5	132.0	9.7	23.3	5.83
April	36.0	22.2	46.3	165.6	9.6	24.3	6.59
May	36.1	22.3	49.7	213.6	10.1	25.0	7.19
June	29.5	22.0	73.8	307.2	6.3	19.1	4.94
July	26.8	21.7	80.4	314.4	4.3	16.1	3.85
August	27.3	21.5	80.8	276.0	3.6	15.0	3.66
September	28.1	21.0	76.8	220.8	6.9	19.4	4.34
October	28.9	20.8	73.3	98.4	7.4	18.7	3.85
November	28.9	18.3	60.9	62.4	7.7	17.3	3.29
December	28.1	15.9	55.7	62.4	7.9	16.7	3.01
Average	30.5	19.9	61.2	169.2	7.7	19.6	4.55

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

a = 0.25　　b = 0.5

****

F:\Dam-Hidkal

CROP WATER REQUIREMENTS

Crop **Wheat,Maize,Sorghum** CropWat 4 Windows Ver 4.2
Planting date 1/11
Calculation time step 30 Days
Irrigation Efficiency 75%

Date	ETo	Area	Crop Kc	ETm	Total Rain	Effect. Rain	Net Irrigation Req.	Field Water Supply
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	(l/s/ha)
1/11	98.47	100	0.57	56.26	29.02	2.09	54.17	0.28
1/12	99.92	100	1.03	102.87	1.06	0	102.87	0.53
31/12	120.43	100	1.1	132.47	0	0	132.47	0.68
30/1	152.3	100	0.9	136.34	0	0	136.38	0.7
Total	471.12			427.97	30.08	2.09	425.89	[0.55]

Crop **Fodder/Pulses**
Planting date 1/11
Calculation time step 30 Days
Irrigation Efficiency 75%

Date	ETo	Area	Crop Kc	ETm	Total Rain	Effect. Rain	Net Irrigation Req.	Field Water Supply
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	(l/s/ha)
1/11	98.47	100	0.56	54.75	29.02	2.09	52.66	0.27
1/12	99.92	100	0.98	98.33	1.06	0	98.33	0.51
31/12	120.43	100	1.05	126.45	0	0	126.45	0.65
30/1	152.3	100	1.02	154.59	0	0	154.59	0.8
Total	471.12			434.08	30.08	2.09	432.03	[0.56]

Crop **Sugarcane**
Planting date 1/7
Calculation time step 30 Days
Irrigation Efficiency 75%

Date	ETo	Area	Crop Kc	ETm	Total Rain	Effect. Rain	Net Irrigation Req.	Field Water Supply
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	(l/s/ha)
1/7	144.56	100	0.4	57.83	70.56	32.44	25.38	0.13
31/7	126.21	100	0.61	76.23	85.18	41.1	35.14	0.18
30/8	111.35	100	1.04	115.48	108.39	66.67	48.81	0.25
29/9	102.01	100	1.25	127.51	97.24	50.01	77.49	0.4
29/10	98.53	100	1.25	123.16	35.24	4	119.16	0.61
28/11	99.65	100	1.25	124.56	1.63	0	124.56	0.64
28/12	116.97	100	1.25	146.21	0	0	146.21	0.75
27/1	149.48	100	1.25	186.85	0	0	186.85	0.96
26/2	172.34	100	1.25	215.43	0.5	0	215.43	1.11
28/3	181.84	100	1.15	208.47	16.88	0.48	207.99	1.07
27/4	178.56	100	0.9	161.18	59.39	20.07	141.11	0.73
27/5	23	100	0.76	17.53	9.82	5.26	12.27	0.47
Total	1504.49			1560.43	484.82	220.03	1340.4	[0.62]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
D:\CROPWAT\HIDKAL.TXT

ANNEXURE-VII

****

Irrigation Scheduling Report

CropWat 4 Windows Ver 4.2

****

* Crop Data:

Crop # 1 Wheat,Maize,Sorghum
Planting c 1/11

* Soil Data:

Soil description Heavy
Initial soil moisture depletion 35%

* Irrigation Scheduling Criteria:

- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 100% of readily available soil moisture.
- Start of Scheduling: 1/11

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Effective Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interval (Days)	Net Irrigation (mm)	Lost Irrigation (mm)	User Adjustment (mm)
5/11	62	31	10.5	10.5	1.6	100.00%	16.5				
12/11	76	38	6.4	6.4	1.6	100.00%	21.3				
19/11	90	45	3.1	3.1	1.9	100.00%	30.1				
26/11	104	52	1.4	1.4	2.3	100.00%	43.6				
2/12	116	58	0	0	2.8	100.00%	59.1	31	59.1	0	
3/12	118	59	0.7	0	2.8	100.00%	2.8				
24/12	144	72	0	0	3.7	100.00%	75.2	22	75.2	0	
12/1	144	72	0	0	4.3	100.00%	74.9	19	74.9	0	
28/1	144	72	0	0	5	100.00%	74.8	16	74.8	0	
18/2	144	99.8	0	0	4.4	100.00%	100.7	21	100.7	0	
Total			22.2	21.5	427.9	100.00%			384.7	0	0

* Yield Reduction:

Estimated 0.00%
Estimated 0.00%
Estimated 0.00%
Estimated 0.00%
Estimated 0.00%

* These estimates may be used as guidelines and not as actual figures.

----

* Legend:

TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].

* Notes:

Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To genera each 7 days of distributed rainfall are
accumulated as one storm.
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was taken into account in the calculations.

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Irrigation Scheduling Report

CropWat 4 Windows Ver 4.2

* Crop Data:

Crop Fodder/Pulses
Planting date 1/11

* Soil Data:

Soil description Heavy
Initial soil moisture depletio 35%

* Irrigation Scheduling Criteria:

- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 100% of readily available soil moisture.
- Start of Scheduling: 1/11

Date	TAM	RAM	Total Rain	Effective Rain	ETc	ETc/ETm	SMD	Interval	Net Irrigation	Lost Irrigation	User Adjustment
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)	(mm)	(Days)	(mm)	(mm)	(mm)
5/11	61.2	27.5	10.5	10.5	1.6	100.00%	16.3				
12/11	73.8	33.2	6.4	6.4	1.6	100.00%	20.9				
19/11	86.4	38.9	3.1	3.1	1.8	100.00%	29.4				
26/11	99	44.5	1.4	1.4	2.3	100.00%	42.5				
28/11	102.6	46.2	0	0	2.4	100.00%	47.2	27	47.2	0	
3/12	111.6	50.2	0.7	0.7	2.7	100.00%	12.2				
19/12	135	60.8	0	0	3.5	100.00%	63.8	21	63.8	0	
5/1	135	60.8	0	0	3.8	100.00%	61.1	17	61.1	0	
20/1	135	60.8	0	0	4.4	100.00%	62.4	15	62.4	0	
3/2	135	65.8	0	0	4.9	100.00%	66.2	14	66.2	0	
22/2	135	97.9	0	0	5.3	100.00%	98	19	98	0	
Total			22.2	22.2	434.1	100.00%			398.7	0	0

* Yield Reduction:

Estimate 0.00%
Estimate 0.00%
Estimate 0.00%
Estimate 0.00%
Estimate 0.00%

* These estimates may be used as guidelines and not as actual figures.

* Legend:

TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].

* Notes:

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Monthly Rainfall is distributed using polynomial curve fitting.
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was taken into account in the calculations.

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Irrigation Scheduling Report

* Crop Data:

Crop # 1 Sugarcane
Planting date 1/7

* Soil Data:

Soil description Heavy
Initial soil moisture depletion 35%

* Irrigation Scheduling Criteria:

- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 100% of readily available soil moisture.
- Start of Scheduling: 1/7

Date	TAM	RAM	Total Rain	Effective Rain	ETc	ETc/ETm	SMD	Interval	Net Irrigation	Lost Irrigation	User Adjustment
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)	(mm)	(Days)	(mm)	(mm)	(mm)
2/7	270	175.5	16.3	16.3	2	100.00%	82.3				
9/7	270	175.5	16.2	16.2	2	100.00%	80.1				
16/7	270	175.5	16.4	16.4	1.9	100.00%	77.4				
23/7	270	175.5	16.8	16.8	1.9	100.00%	73.8				
30/7	270	175.5	17.6	17.6	1.8	100.00%	69				
6/8	270	175.5	18.7	18.7	2.1	100.00%	64				
13/8	270	175.5	20.1	20.1	2.5	100.00%	60.3				
20/8	270	175.5	21.5	21.5	2.8	100.00%	57.5				
27/8	270	175.5	23.1	23.1	3.1	100.00%	55.4				
3/9	270	175.5	24.5	24.5	3.4	100.00%	54.1				
10/9	270	175.5	25.6	25	3.7	100.00%	54.3				
17/9	270	175.5	26.2	25	4	100.00%	56.4				
24/9	270	175.5	26.3	25	4.3	100.00%	60.4				
1/10	270	175.5	25.6	25	4.4	100.00%	66				
8/10	270	175.5	24	24	4.3	100.00%	72.2				
15/10	270	175.5	21.7	21.7	4.2	100.00%	80.3				
22/10	270	175.5	18.5	18.5	4.2	100.00%	91.2				
29/10	270	175.5	14.7	14.7	4.1	100.00%	105.6				
5/11	270	175.5	10.5	10.5	4.1	100.00%	124				
12/11	270	175.5	6.4	6.4	4.1	100.00%	146.2				
19/11	270	175.5	3.1	3.1	4.1	100.00%	171.8				
20/11	270	175.5	0	0	4.1	100.00%	175.9	142	175.9	0	
26/11	270	175.5	1.4	1.4	4.1	100.00%	23.2				
3/12	270	175.5	0.7	0.7	4.1	100.00%	51.2				
2/1	270	175.5	0	0	4.4	100.00%	176.8	43	176.8	0	
5/2	270	175.5	0	0	6	100.00%	178.7	34	178.7	0	
4/3	270	175.5	0	0	7	100.00%	176.9	27	176.9	0	
26/3	270	175.5	1.4	1.4	7.5	100.00%	158.3				
29/3	270	175.5	0	0	7.5	100.00%	180.7	25	180.7	0	
2/4	270	175.5	1.7	1.7	7.4	100.00%	28.1				
9/4	270	175.5	3.5	3.5	7.1	100.00%	75.2				
16/4	270	175.5	6.1	6.1	6.8	100.00%	117.4				
23/4	270	175.5	8.9	8.9	6.4	100.00%	154.4				
27/4	270	175.5	0	0	6.2	100.00%	179.5	29	179.5	0	
30/4	270	175.5	11.6	11.6	6	100.00%	6.7				
7/5	270	175.5	13.8	13.8	5.6	100.00%	33.5				
14/5	270	175.5	15.6	15.6	5.2	100.00%	55.8				
21/5	270	175.5	16.7	16.7	4.8	100.00%	74.1				
28/5	270	175.5	17.3	17.3	4.4	100.00%	88.9				
Total			492.4	488.8	1560.4	100.00%			1068.5	0	0

* Yield Reduction:

Estimated 0.00%
Estimated 0.00%
Estimated 0.00%
Estimated 0.00%
Estimated 0.00%

* These estimates may be used as guidelines and not as actual figures.

* Legend:

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