FINAL REPORT

Development of Integrated Irrigation Information System(IIIS) for a part of Nagarjuna Sagar Command Area, Andhra Pradesh using Remote Sensing ,GIS, GPS and Field Studies

(Under INCID Programme)

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CONTENTS

Sl.No.	DESCRIPTION	Page no
	UNIT – 1 INTRODUCTION	
1.1	General	1
1.2	Remote sensing in agriculture: present scenario	3
1.3	Crop acreage and production estimation	3
1.4	Important remote sensing application projects in agriculture	5
1.5	Geographical information systems in agriculture	6
1.5.1	The data base	7
1.5.2	Opportunities	8
1.5.3	Chalaenges	9
1.6	The major out puts of integrated irrigation information system (iiis)	11
1.7	End users	12
	UNIT – 2 OBJECTIVES AND METHODOLOGY	
2.1	General	13
2.2	Methodology	14
2.2.1	Acquisition and derivation of baseline data	16
2.2.2	Types of data products as per project design	16
2.2.3	Data sources and collections	18
2.3	Creation of GIS and MIS digital database	19
2.4	Development of crop yield prediction model	19
2.5	Determination of API and FII	21
2.6	Net primary productivity (NPP)	22
2.7	Land suitability model	22
2.8	Design and development of IIIS	23
2.9	Validation of IIIS model	25
	UNIT – 3 STUDY AREA DESCRIPTION	
3.1	Description of Krishna river basin	26
3.2	Nagarjuna Sagar project	26
3.3	General features of the command area of Nagarjuna Sagar project reservoir	27
3.3.1	Canal system	28

3.4	Study area profile: Addanki branch canal	28
3.5	Administrative setup	28
3.6	Environmental resources in the study area	29
3.6.1	Population	29
3.6.2	Climate	29
3.6.3	Temperature	30
3.6.4	Rainfall	30
3.6.5	Physiography	30
3.6.6	Drainage	30
3.6.7	Geology	31
3.6.8	Geomorphology	31
3.6.9	Geo hydrology	31
3.6.10	Geo technical characteristics and natural hazards	32
3.6.11	Soils	32
3.6.12	Land utilization	32
3.6.13	Land holding agriculture	32
3.7	Non environmental resources in the study area	33
3.7.1	Road network	33
3.7.2	Railway network	33
3.7.3	List of banks in the study area	33
	UNIT – 4 DATA SOURCES AND DATA USED	34
4.1	Data sources	34
4.2	Collection of data	35
4.2.1	Satellite data	35
4.2.2	Collateral data	42
4.2.3	Agricultural data	42
4.2.4	Meteorological data	42
	Unit –5 Generation Of Database	47
5.1	General	47
5.2	Spatial data from SOI Toposheets	47
5.3	Spatial data from satellite data and processing	48

5.3.1	Geo-coding and geo referencing	48
5.3.2	Digital image enhancement of liss iii data	49
5.3.3	Hard copy generation	49
5.4	Generation of thematic maps from satellite data	50
5.5	Spatial database generation and organization	50
5.5.1	Flow of operation in spatial database generation	51
5.6	Spatial data generation from Toposheets	52
5.6.1	Base map	52
5.6.2	Drainage map	54
5.6.3	Road network map	57
5.6.4	Mandal reference map	58
5.6.5	Village reference map	59
5.6.6	Contour map	60
5.6.7	Physiography map	61
5.6.8	Slope map	62
5.6.9	Watershed map	64
5.6.10	Digital elevation model	67
5.7	Spatial data generated from satellite data and other data sets	68
5.7.1	Remote sensing technology for visual image interpretation	69
5.7.2	Generation of thematic layers	70
5.7.3	Land use / land cover map	70
5.7.3.1	Basic concepts of land use	71
5.7.3.2	Aims of classification	72
5.7.3.3	Land use / land cover classification	72
5.7.3.4	Objectives of land use / land cover map	73
5.7.3.5	Remote sensing as related to land use	74
5.7.3.6	Application of remote sensing techniques for lu/ lc	76
5.7.3.7	Methodology for lu/lc mapping	76
5.7.3.8	Land use / land cover description of study area	78
5.7.4	Wastelands map	82
5.7.5	Geomorphology map	82

5.7.6	Ground water potential map	83
5.7.7	Ground water table map	84
5.7.8	Soil map	85
	UNIT – 6 CROP YIELD PREDICTION MODELS	
6.1	Development of crop yield prediction model (CYPM)	90
6.2	Collection of ground truth	90
6.3	Reconnaissance survey	90
6.4	Preparation of base map	91
6.5	Planning logistics	91
6.6	Field visit for ground truth data collection	92
6.7	Identification of optimum period for selection of satellite data	93
6.8	Selection of methods for crop acreage and yield estimation	94
6.8.1	Total enumeration approach	94
6.8.2	Digital data processing and analysis	94
6.8.3	Geometric correction	95
6.8.4	Fusion product	95
6.9	Yield estimation	95
6.9.1	Spectral yield models	96
6.9.2	Regression models	96
6.9.3	Crop growth profile based model	96
6.10	Time series models	97
6.10.1	Trend analysis for yield modelling	97
6.11	Vegetation indices	97
6.11.1	Ratio vegetation index (RVI)	98
6.11.2	Normalized difference vegetation index (NDVI)	98
6.11.3	Other vegetation indices	99
6.12	Importance of ndvi in crop yield prediction	99
6.13	Development of relationships between vegetation indices and yields	99
6.14	Methodology adopted for ndvi based classification	100
6.15	Crop yield prediction analysis from ndvi data for yield prediction	101
6.16	Results	102

6.17	Acreage estimation	102
6.18	Discussions	115
6.19	Recommendations	115
6.20	Multiple regression model development	116
6.21	NDVI prediction using land and management parameters	117
6.22	Integreted yield prediction model	118
6.23	Yield prediction with other vegetation indices	127
6.24	Normalised diference vegetation index (NDVI)	128
6.25	NDVI as yield prediction parameter	130
6.26	Using single date image for yield prediction	132
6.27	Model performance	133
6.28	Summary and conclusions	133
	UNIT – 7 NET PRIMARY PRODUCTIVITY	
7.1	Estimating NPP	138
7.2	Overview of the NPP project	138
7.3	In-depth	138
7.4	Scope	139
7.5	Status	139
7.6	Estimation of NPP for grasslands	140
7.6.1	Brief literature review	140
7.7	Methods and algorithms for estimating NPP	142
7.8	NPP boreal forest	146
7.9	NPP tropical forest	147
7.9.1	Summary	147
7.9.2	For such studies, we have the following recommendations	148
7.10	NPP cropland	150
7.11	NPP and the global carbon cycle	150
7.11.1	Introduction	150
7.12	NPP database dictionary	151
7.13	Modis daily photosynthesis (PSN) and annual net primary	152
7.14	Theoretical background	153

7.14.1	Estimating NPP from APAR	153
7.14.2	Relating APAR and surface reflectance	154
7.15	Algorithm overview	155
7.16	Daily estimation of GPP	156
7.17	Annual estimation of NPP	158
7.18	Bplut parameterization	158
	UNIT- 8 AGRICULTURAL PRODUCTIVITY INDEX	
8.1	Introduction	159
8.2	Productivity of land	160
8.3	Productivity of labour	161
8.4	Productivity of capital	163
8.5	Approaches to the measurement of agricultural productivity index	164
8.6	Money value index	165
8.7	Developing 'crop yield index's the basis of productivity measurement.	167
8.8	Measurement of agricultural productivity	169
8.9	Agricultural efficiency	170
	UNIT 9. LAND SUITABILITY MODEL	
9.1	General	171
9.2	Significance of the study	172
9.3	The problem to be investigated	172
9.4	Principles of land evaluation	173
9.4.1	Principles of the land evaluation	174
9.5	Land classification	176
9.6	Land capability	178
9.6.1	Basis of land capability classification	180
9.6.2	Utility of land capability classes	180
9.6.3	Level of land capability	180
9.6.4	Land capability classification	181
9.7	Irrigation	181
9.7.1	Importance of irrigation	181

9.7.2	Infiltration under various irrigation regimes	182
9.7.3	Irrigation methods	182
9.7.4	Irrigation scheduling	185
9.7.5	Monitoring soil needs information on the following aspects	185
9.7.6	Irrigation efficiency	186
9.7.7	Methodology of optimal irrigation management	187
9.8	Materials and methodology	188
9.8.1	General	188
9.8.2	Data sources	188
9.9	Collection of data	189
9.9.1	Satellite data	189
9.9.2	Collateral data	190
9.10	Generation of data base	190
9.11	Spatial data from Toposheets	190
9.12	Spatial data from satellite data and processing	191
9.12.1	Geo-coding and geo-referencing	191
9.12.2	Digital image enhancement of liss iii data	192
9.12.3	Hardcopy generation	192
9.12.4	Generation of thematic maps from satellite data	193
9.12.5	Attribute Data	193
9.12.6	Development of land suitability model	193
9.13	Soil & Water quality analysis	202
9.13.1	General	202
9.13.2	Soil and water parameters analyzed	202
9.14	Soils	203
9.15	Farming situation in ongole division	203
9.16	Constraints for soil and water quality in ongole division	204
9.17	Existing and suggested crop plan in mandals of ongole division	204
9.18	Results and discussions	205
9.19	Physical, chemical and physico-chemical characteristics of the soil samples	205

9.19.1	Soil reaction (ph)	205
9.19.2	Electrical conductivity (dsm"1)	205
9.19.3	Organic carbon {%)	205
9.19.4	Calcium carbonate (%)	205
9.19.5	Cation exchange capacity and exchangeable cations	206
9.19.6	Mechanical composition	206
9.19.7	Macronutrients-available nitrogen	206
9.19.8	Available phosphorus	206
9.19.9	Available potassium	206
9.19.10	Secondary nutrients	207
9.19.11	Micronutrients-available iron	207
9.19.12	Available zinc	207
9.19.13	Available copper	207
9.20	Quality of ground water of addanki branch canal	207
9.20.1	Electrical conductivity (dsm"1)	207
9.20.2	Water reaction (ph)	207
9.20.3	Sodium absorption ratio (SAR)	208
9.20.4	Residual sodium carbonate (RSC)	208
9.20.5	Classification of ground waters	208
9.20.6	Different cationic compositions	209
9.20.7	Different anionic compositions	209
9.20.8	Fluorides	209
9.20.9	Nitrates	209
9.20.10	Micronutrients	210
9.20.11	Ionic ratios	210
9.20.12	Correlation studies	210
9.20.13	Correlation with in water parameters	210
9.21	Overall soil fertility status and ground water quality	211
9.23	Surveying and analysis	212
9.23.1	Soil and water quality	212
9.23.2	Irrigation management	213

9.23.3	Flood or furrow irrigation	214
9.23.4	Sprinkler irrigation	215
9.23.5	Chemigation and fertigation	215
9.23.6	Directions of future development	216
	References	

1. INTRODUCTION

1.1 GENERAL

The land use/land cover has been dramatically changing in Asian countries in the last few decades due to the population pressure. Generally, the forested lands have been converted into agricultural lands, as well as the productivity has been improved because of more irrigation, use of chemical fertilizer, mechanization and so on. There is, however, increasing concern about some of the irrigation potential created but not brought into the functional system, lower operating efficiency, lesser crop productivity etc. Improvement in agricultural productivity has become a necessity due to the limitations in expansion of cultivated acreage and ever increasing food demand. A large number of irrigation projects have been commissioned in India in the post-independence era for improving food production and economic development. These irrigated croplands though limited to about 30 percent of the gross cropped area in India, contribute more than 50 percent of the total agricultural production. However, optimistic forecasting of production can not be expected, because there are limits of suitable cropland, limitations of productivity and shortage of water resources. Monitoring, estimating and forecasting crop production are quite important for the management of food demand and supply balance at local level, regional level and World wide. According to the FAO (Food and Agricultural Organization) statistics, the crop production has increased corresponding to the population increase in the last 40 years. This means, scientific management of irrigation croplands through integrated systems approach is the only way to make our agriculture productive and competitive.

National agricultural production, on a sustainable basis, depends on the judicious use and management of natural resources like soil, water, animal resources and crop/plant genetic resources. With an acceptable technological input under prevailing socio-economic infrastructure. In order to achieve an economically sound society, environmentally benign development and judicious utilization of natural resources, it is necessary that a comprehensive Integrated Irrigation Information System (IIIS) be developed to provide systematic and periodic information and its status to the planners, decision-makers and developmental agencies. These resources need proper evaluation that can be done through interactive interpretation in a relational database system. Also, digitizing socio-economic database along with biophysical factors is important to objectively monitor and evaluate the current and future agricultural growth and development. Many agencies have developed various information systems, which include databases on different resources. Space Application Centre (SAC) has developed Natural Resources Information System (NRIS). This database of NRIS covers information on various soil types and water bodies of the entire country. It includes both the spatial and non-spatial databases. Department of Science and Technology (DST) has developed a Natural Resources Data Management System (NRDMS) with the aim of developing and demonstrating the use of spatial decision support for integrated planning and management of resources for micro level planning. Under NRDMS, also developed a user-friendly Geographic Information System (GIS) package viz. Geo-Referenced Area Management (GRAM) for entry, storage, manipulation, analysis and display of spatial data on a low cost computer configuration.

Keeping this trend and importance of such systems for proper and effective irrigation management, it is proposed to develop an Integrated Irrigation Systems Information, the prime objective of this proposed project. Such systems have always been considered as an effective way of increasing agricultural production. The IIIS resulting after the efficient integration of temporal, spectral and spatial stake holders for high resolution data which is important for accurate mapping of agricultural areas which helps the affective management of resources for optimum crop yield.

Remote Sensing has shown great potential in agricultural mapping and monitoring due to its advantages over traditional procedures in terms of cost and time effectiveness in the availability of information over larger areas. In agriculture, Remote Sensing has been employed to the development of precision farming for the better crop production and environmental protection. Hence, it is proposed to use remote sensing data for the mapping of natural resources. Nevertheless, the surface reflectance spectra over a wide range of objects and conditions should be identified and interpreted into meaningful outputs prior to decision-making and applications. Satellite Remote sensing images, such as IRS- LISS, PAN and WIFS are proposed to use in developing a deterministic model for the estimation of crop yield of the project area, which is a part of IIIS. In this model, an attempt will also be made using GIS, as a tool to help the decision making process for enhancing the efficiency of the system to integrate satellite-derived crop information, yield prediction model, water use efficiency, and other components of management discussed in the previous para. A model study area is selected from the part of Nagarjuna Sagar command area to develop IIIS. The methodology adopted for this IIIS may be applied on other command areas under similar environs.

1.2 REMOTE SENSING IN AGRICULTURE: PRESENT SCENARIO

Remote sensing techniques play an important role in crop identification, acreage and production estimation, disease and stress detection, soil and water resources characterization and also by providing required inputs for the following: generation of land and water resources developmental plans, bringing479additional land into cultivation through mapping and reclaiming wastelands, increasing the irrigation potential through ground-water prospects mapping; crop-yield and crop-weather models, integrated pest management, command area management, watershed management, agro meteorological services, precision farming, etc. Remote sensing applications to agriculture have grown to a stage where such inputs are being used for number of policy level decisions related to food security, poverty alleviation and sustainable development in the country. Decision on buffer stock of food grains could be based on pre-harvest crop acreage and production estimation while the ground water prospects maps serve as the major source of information in ensuring drinking water and other needs in rainfed and less favored areas. Nation wide wasteland, land use, land cover and soil mapping has helped in expanding and intensification of agricultural activities and also in identifying the land capability classes and crop suitability indices.

1.3 CROP ACREAGE AND PRODUCTION ESTIMATION

In India the use of space-borne remote sensing data for crop acreage estimation and production forecasting was experimented in early 1980s in selected districts for wheat, rice and groundnut. The promising and encouraging results of this initial study led to an attempt to estimate state-level wheat acreage using Land sat MSS data for Haryana and Punjab in

1985-86. The results were encouraging and the project, namely, 'Crop Acreage and Production Estimation' (CAPE) was launched covering wheat, rice, groundnut and *Rabi* sorghum in selected major growing states/districts. Since availability of optical data is a concern in monsoon seasons, the use of data from active sensors, such as SAR of RADARSAT was operationally used for Khariff rice in 12 districts of Karnataka. The microwave data, which has all weather capabilities, has shown that the rice crop can be discriminated at better than 90% accuracy, which can aid in early detection with multiple forecasting. Apart from using the single-date high-resolution satellite data to provide crop acreage estimates at district-level under CAPE, the multi date WiFS data (coarse resolution and high receptivity) is used to explore the possibility of making national-level forecasts. The procedure uses a national-level sampling frame and coarse sample segment grids to make multiple forecasts as well asinter-seasonal crop growth differences using multiyear WiFS data .A comprehensive software package called 'CAPEWORKS/CAPEMAN' has been developed enabling end-to-end analysis culminating ingeneration of production statistics. The remote sensing techniques have also been deployed in assessing the horticultural crops. For example, acreage estimation of mango and banana plantations in Krishna district of AP and Thiruchirapalli district in Tamilnadu respectively has also been successfully carried out with an accuracy of 94% in a joint venture with the Indian Institute of Horticultural Research. Mapping of sugarcane has been carried out to aid various users and cooperative sugar mills in accurately estimating the acreage. This is also done at cadastral level enabling the government to identify those beneficiaries (farmers) who are not paying the tax. Efforts made on estimating the onion acreage in Nasik district, Maharashtra yielded results to an accuracy of 75% because of smaller field size, peculiar leaf structure, continuous cultivation and spectral mixing with other crops. From the experience gained on implementation of CAPE project and also to meet the requirements of timeliness, accuracy and coverage of crops, an integrated concept of Forecasting Agricultural output using Space, Agro meteorology and Land based observation (FASAL) has been evolved. A National Crop Forecasting Centre is being established by the Department of Agriculture and Cooperation, Govt. of India to execute the project. (As remote sensing, weather and field observation provide complementary & supplementary information for making crop forecasts, FASAL proposes an approach which integrates in pulses from these three types of observation on to make forecasts of desired coverage, accuracy and timeliness). The concept of FASAL thus strengthens the current capabilities of early crop season estimation from econometric and weather-based techniques with remote sensing mid-season assessments that can be supplemented with multi-temporal coarse resolution data based analysis. In the later half of crop growth period, direct contribution of remote sensing in the form of acreage estimates and yield forecasts is available. However, in this case also, the addition of more extensive field information and weather inputs would increase the forecast accuracy. India is also planning for some exclusive satellites to provide data specific to agriculture.

1.4 IMPORTANT REMOTE SENSING APPLICATION PROJECTS IN AGRICULTURE

- Crop Acreage and Production Estimation (CAPE) State Departments of Agriculture/ Ministry of Agriculture
- Cotton Acreage and Condition Assessment (CACA) Ministry of Textiles.
- Forecasting of Agricultural output based on Satellite, Agrometerorology and Land based observation (FASAL) State Department of Agriculture
- Nation wide mapping of soil resources on1:250000 scale Ministry of Agriculture
- Mapping of saline/alkaline soils of India Central and State Agricultural Departments.
- National wasteland mapping on 1:1 Million scale/1:50,000 scale Wasteland Development Department / District Au thorities
- Nationwide mapping of land use/land cover for agroclimatic zones on 1:2, 50,000 scale Planning commission
- National Agricultural Drought Assessment and Management Systems (NADAMS) Department of Agriculture and Co-operation, State Agricultural Departments and District Authorities.
- Forest covers mapping for the entire country Department of Forest, Forest Survey of India, State Forest Departments.

- National drinking water technology mission on 1:2,50,000 scale Ministry of Rural Development, Ground Water Department
- Satellite monitoring of command areas for crops, salinity/alkalinity and waterlogged Areas Central Water Commission / State Command Area Development Authorities.
- Integrated Mission for Sustainable Development (IMSD) Planning Commission, Ministries of Rural Development, Agriculture, Environment and Forests, State governments. (Venkataratnam, 2001) 481

1.5 GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN AGRICULTURE

Integration of the land and water resources and identification of the constraints/ecological problems at the micro level will help in identifying the location specific solutions through the effective use of remote sensing based resource information combined with other socio-economic data using GIS. This is being done by survey of resources at different scales using traditional and remote sensing techniques, collection of collateral information like slope, topography etc, preparation of a set of resource maps (hydro geomorphology, soils, land use / cover, surface water/drainage/watershed etc.) and generation of action plan maps giving site specific recommendations for development and management of agriculture, ground water recharge, fuel and fodder as well as for soil conservation / reclamation and afforestation. In one of the experiments at NRSA, sustainable action plan for upper Machkund Watershed falling in tribal areas of Visakhapatnam district, Andhra Pradesh has been generated through GIS techniques. GRAM ++ is an indigenously developed Geographical Information System (GIS) software package for storage, analysis and retrieval of geographic information relevant to the task of local level planning (GRAM++ - Geo-referenced Area Management Package a Tool for Local Level Planning, Natural Resources Data Management System, Department of Science & Technology, and Government of India). The package has been put to use in a variety of applications like watershed management, waste land reclamation, land capability analysis, soil erosion assessment, energy budgeting, location/ allocation of facilities, and Hazard zonation studies. These applications have been conducted and functionalities tested by Karnataka State Council for Science and Technology, Bangalore; Technology Informatics

Design Endeavour, Bangalore, National Atlas and Thematic Mapping Organization, Calcutta, National Water Development Agency, New Delhi and several other universities and R&D institutions. Under NNRMS, Dept. of Space, a Natural Resources Information System (NRIS) is being developed for policy makers to ensure the optimum utilization of natural resource information. This information system will enable to update existing natural resource information and integrate with socioeconomic data. GIS forms the core of NRIS for data storage, retrieval, data integration and analysis. It will also be linked with other existing information systems at district/state level to provide an efficient and powerful tool for management of resources. NNRMS (2000) has prepared a document on the node design and standards to be adopted under NRIS for all themes like soil, land use, water, geomorphology, socioeconomic data, infrastructure facilities, etc.Thus, the potential of the GIS is vast to improve the resource management for enhancing the productivity on a sustainable basis in an eco-friendly manner. This involves collection and formatting large database with co-operation from line departments/institutions for deriving the maximum benefits out of this technology. Précising farming is an emerging concept in modem agriculture. It is a micro management system to arrive at improved agricultural and land management decisions that result from using information delivered by geospatial technologies. In other words it is "Digital Agriculture" involving very large scale farm level mapping, comprehensive data base creation on required resources generated through space based inputs and field observations and making a detailed plan of work for maximizing the yield and reducing the custom inputs using the decision support system.

1.5.1 THE DATA BASE

- Crop characteristics like, stage of the crop, crop health, nutrient requirement, etc;
- Detailed soil layer with physical and chemical properties, depth, texture, nutrient status, salinity and toxicity, soil temperature, productivity potential, etc.,
- Microclimate data (seasonal and daily) about the canopy temperature, wind direction and speed, humidity etc.
- Surface and sub surface drainage conditions;

- Irrigation facilities, water availability, and other planning inputs of interest. With the advent of differential Global Positioning System (GPS) with high accuracy, there are possibilities of automating the farm operations like tillage, planting, fertilizer applications, pesticide/herbicide spraying, irrigation, harvesting and other mechanized cultural operations. High resolution Digital Elevation Models (DEM) may also form a component of the database, which provides the appropriate description of the topography to support soil moisture and fertility models for decision making.482 Precision farming enables micro-management concepts that include the ability to appropriately manage every field operation at each location in the field, if it is technically and economically advantageous to manage at that level. The concept of precision farming is picking up very fast in developed countries due to large farm holdings and fully mechanized agricultural operations. With the present day technological developments and further availability of higher resolution multi spectral sensor data, there is scope for adopting precision farming for cultivation of high value / Commercial / fruits / flowers/ vegetables etc. in developing countries including India. The application of remote sensing and GIS techniques in the management of agricultural resource are increasing rapidly due to improvement in space borne remote sensing satellites in terms of spatial, spectral, temporal and radiometric resolutions. Many of conventional approaches of handling multi thematic information to arrive at optimal solutions are being computerized using GIS utilities. Keeping in view the development in satellite, computer and communications technologies, the following opportunities and challenges exist in the application of remote sensing GIS and precision farming technologies in India.

1.5.2 OPPORTUNITIES

- Prioritization of macro/micro watersheds for implementation and impact assessment of watershed projects at national, state, district, taluk and hobli levels.

- Forecasting of outbreak of pests and diseases based on soil water status and plant stress indicators in crops such as paddy, wheat, sugarcane, cotton, chilli, & pigeonpea, etc.
- Development of decision support system for precise management of resources at farm level at least in commercial / fruit / flower crops to begin with.
- Airborne SAR data utilization for identification of *Khariff* crops and development of procedures for canopy backscatter models for identification and yield prediction.
- Soil mapping at cadastral scale using high resolution spatial, spectral and radiometric resolutions.
- Quantification of soil loss.
- Detection of water logging due to rising ground water table.
- Delineation of salt-affected soils in black soil and sandy regions.
- Soil moisture estimation and mapping using micro wave/optical/thermal remote sensing techniques in surface and root zone depth.
- Land surface temperature estimation using thermal and microwave remote sensing techniques.
- Hyper spectral studies on soils to establish quantitative relationship between spectral reflectance and soil properties.
- Development of digital techniques for a variety of applications using GIS techniques. For e.g., soil suitability to crops, land capability classification and land irrigability assessment etc.
- Preparatory activities towards hyper spectral data utilization for understanding the plant processes and development of spectral response models for stress detection.
- Improved yield models by integration of biophysical simulation and regional level crop models.

1.5.3 CHALLENGES

The application of Remote Sensing, GIS and precision farming techniques in the management of agricultural resources are increasing rapidly due to improvements in space science supported by computer and communication technologies. The following challenges need to be addressed in the application of these technologies.

- Identification of crops and estimation of area and production of short duration crops grown in fragmented land holdings, in particular during *Khariff* season.
- Forecasting of droughts/floods.
- Detection of crop stress due to nutrients, pests and diseases and quantification of their effects on crop yield.
- Automation of land evaluation procedures for a variety of applications using GIS techniques.
- Information on sub-surface soil horizons.
- Extending precision farming database to smaller farm size and / or diverse crops/cropping systems.
- Developing decision support systems for management of biotic and abiotic stresses at the farm level.
- More accurate yield models 483
- Estimation of depth of water in reservoirs and quality assessment of ground water.
- Better than 1m contours for watershed development plan at the micro level.
- Use of remote sensing and precision farming technologies in intercropping/multiple cropping situations.
- Identifying ways and means of reducing the cost of RS, GIS and precision farming technologies and time gap in collection, interpretation and dissemination of data to enable their usage on a large scale. A successful example in this direction is that of hand-held radiometer developed by Optometry Engineers Hyderabad in collaboration with space application center, ISRO Ahmedabad for standardizing the spectral signature insitu for inter pressing the RS Data.
- Convincing evidence to prove the utility and economic viability of these technologies so as to mobilize support for R & D work.
- Human resource development to hasten the process of large scale use of unexplained and cutting edge technologies that have tremendous scope and potential. Agriculture,

the dynamic system governed by several biotic and abiotic factors, needs to be sustained, as it is the major player in Indian economy. Though we are self sufficient in food grain production, there are several gray areas which need to be improved for achieving ever-green revolution. There is a need to transform low-yielding food production systems in to high yielding ones through the convergences of agrotech (mainly production related), biotech (productivity related) with space technology (RS and GIS)Launching of satellites like IKONOS-II Quick Bird-2, TES and planned indigenous earth observation mission, namely Resourcesat-1 Cartosat-1 and Cartosat - 2, Orbriew-3, SPOT-5 and Advance Land Observation Satellite (ALOS) may enable generating detailed and more specific information on land and water resources. To facilitate deriving information on crops during the *Khariff* season, India has proposed to launch a dedicated microwave mission *viz.*, Radar Imaging Satellite (RISAT) with a c-band SAR. Generation of DEM with fine resolution is another important requirement for watershed development. Translation of remote sensing data, GIS techniques and precision farming database information in to implement able schemes at the field level and absorption of technology at the grass root level by the actual beneficiaries still remains a greater challenge. These technologies should infiltrate in to agricultural sector at micro level for greater and sustainable benefits.

1.6 THE MAJOR OUT PUTS OF INTEGRATED IRRIGATION INFORMATION SYSTEM (IIIS)

a. Irrigation planning: In many irrigation systems it is necessary to adjust the area to be planted as well as the crops to the available water resources. Climatic variations or market conditions may strongly influence the planted area. Adjusting the demand to available water supply is a complex exercise, particularly when the cropping pattern is made up of many crops. IIIS greatly facilitates this process and a reasonable optimization can be made before starting the irrigation season.

a. Irrigation scheduling: This module aims at providing, under different hypotheses of operation, the schedule (regulation, opening and closing of gates) and the operating flow in the irrigation network. The three methods of operation are: proportional supply, fixed rotation and semi-demand (on-request). Some indicative values of depths and intervals to apply for all possible planting periods will also be provided.

C.Control of Maintenance Activities: Apart from being a mechanism to control the performance of the staff, an activity report constitutes a valuable source of information, particularly showing where maintenance and repairs have been executed for comparison to the maintenance/rehabilitation plans. If properly set up, compilation of the data registered on different (daily, weekly, monthly) activity reports permits periodical reviews of the time and money spent on the different types of management activities of the project.

1.7 END USERS

Government of Andhra Pradesh emphasized the importance of linkage of various river systems, which is the only solution to tide over the severe water shortage in different parts of the country. Addressing a press conference, Chief Minister of Andhra Pradesh said several areas in Assam, West Bengal and Bihar were resulting in floods, the southern states were facing acute drought situation. He said that the two rivers Ganga and Cauvery are linked; the problem of excess or less water will be solved (Deccan Chronicle, September 23, 2002).To solve such problems, and to link various appropriate river systems, the proposed IIIS will be used by many organisations related to water and its management of the other command areas of analogous environmental settings

Many organizations like state and central ground water departments, Irrigation department (major and minor) can utilize the outcome of this project for the planning of the irrigation system. This project will also provide scope and methodology for carrying out such studies for other basins in India. The planning of irrigation information system will be highly useful to the development of natural resources as unplanned utilization leads to the environmental degradation for which the existing work is expected to be useful for planners, environmentalists and State Govt. policy makers. At the end of this project, "ready to use irrigation database" for Krishna basin shall be created and maintained on Internet by NIC - JNTU for the appropriate end users.

2. OBJECTIVES AND METHODOLOGY

2.1 GENERAL

The present study is aimed at supporting the Govt. of Andhra Pradesh in planning, coordinating and developing interventions in the irrigation sector of Nagarjuna Sagar command area. The expected output of the project is an "Integrated Irrigation Information System (IIIS): a computer base model" using Remote Sensing GIS, GPS and field studies.

The specific objectives and INCID approved of this project are

1. To examine and analyse the spatial information related to present practices of irrigation in Addanki branch Canal command area. The existing spatial data will be obtained from Concerned Government organisations.

2. To generate GIS and MIS digital database for the study area: Addanki Branch Canal of Nagarjunasagar command area, namely,

a) Spatial database consisting of thematic data derived from IRS ID PAN + LISS III merged Products and topographic data from SOI toposheets,

b) Attribute database consisting of collateral data acquired from various organisations and The data collected through field studies.

3. To develop models;

i) Crop yield prediction

ii) Agricultural Productivity Index (API) and Farmers Involvement Index (FII). The FII will be computed considering detailed questionnaire designed to obtain all the relevant information through field survey.

iii) Net Primary Productivity (NPP) using NDVI and PAR

iv) Land suitability based on land characteristics

With the integration of spatial database and attribute database with their topological relationships.

A. To develop a model, named as, **Integrated Irrigation Information System (IIIS)** for the study area by designing two main modules:

- Project Data Module
- Irrigation Management Module

B. To validate this IIIS model with the help of other feeder channels with in Nagarjunasagar command area

2.2 METHODOLOGY

The development of IIIS for Addanki Branch Canal command area of Nagarjunasagar reservoir is based on a step-by-step approach. The major activities to be carried out for the development of IIIS are given below:

1. Acquisition and derivation of Baseline data
2. Field surveys and creation field database
3. Creation of GIS and MIS database for model development
4. Crop yield Prediction Model Development
5. Determination of API and FII.
6. Net Primary Productivity (NPP) computations.
7. Land Suitability Model Development
8. Design and Development of IIIS.
9. Validation of IIIS model

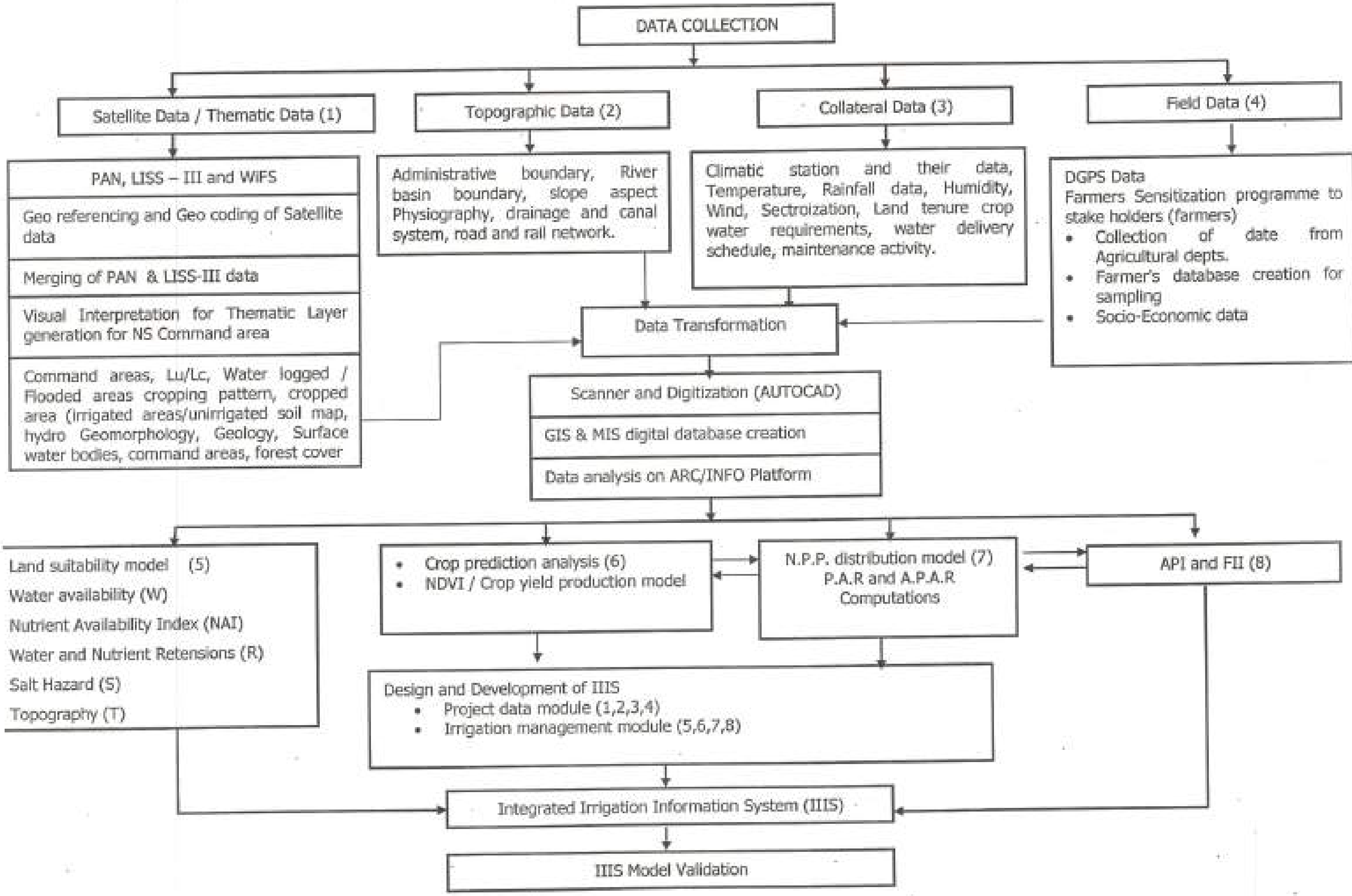


Fig 2. Flow chart showing the step-by-step process of IIIS Model development.

2.2.1 ACQUISITION AND DERIVATION OF BASELINE DATA

The base line data consists of:

- Topographic data
- Land use / land cover data
- Cropped and irrigated area data
- Soils data
- Ground water level data
- Water quality and other environmental data
- Geological and Geomorphological data
- Land ownership data
- Socio-economic data
- Surface water sources data
- Data related to command areas

2.2.2 TYPES OF DATA PRODUCTS AS PER PROJECT DESIGN

Data types with their relevance in the Digital database for IIIS are classified based on the source of acquisition and creation. For the preparation of the base line digital data base all the data products are categorized as

i) Topographical data to be derived from SOI toposheets

ii) Thematic data to be derived from satellite sensing (IRS ID, PAN + LISS III)

iii) Collateral data to be derived from related organisations

Iv) Field data to be derived from Field Survey.

a. Topographical data

Comprises of all the topographical details available on SOI 1:50,000 topo maps. The important topographical data layers are:

- Road, rail network
- Water bodies
- Forest boundaries

- Administrative boundaries
- Drainage
- Settlements
- Forest areas
- Scrubs/waste lands
- Bridges crossing etc.

b. Thematic data

Thematic data to be derived from IRS ID LISS III + PAN data mainly comprises of the following themes:

- Land use / land cover and crop classification
- Water logged or flooded area
- Cropped area maps (Irrigated and un irrigated areas)
- Soil maps
- Hydrogeomorphological maps (Groundwater status)
- Geology and Geomorphology
- Surface water bodies
- Data related to command areas

c. Collateral Data:

The Collateral Data consists of climatic stations and their data, temperature, rainfall, humidity, wind, sectorization, land tenure, crop water requirements, water delivery schedule and current maintenance activities, will be collected from various organizations like local irrigation departments, India Meteorological Department (IMD) etc.

d. Field Data

The Field Data consists of data measured by DGPS; farmer's database through a standard questionnaire and socio-economic data will be collected through the intensive field survey. During this field survey, the views of the Water User Association (WUA) duly constituted by Govt. of A.P will be given due considerations in the computation of FII.

2.2.3 DATA SOURCES AND COLLECTIONS

It is proposed to use multi-band, multi-date satellite data to derive the above thematic data and the field surveys to derive elevation data and collateral data. The details of sources of all the required data products, which are used as input for the IIIS, are:

Type of Data	Source of Data
1. Satellite data IRS-LISS III/c -ID	National Remote Sensing Agency (NRSA), Hyderabad
2. 1:2,50,000 Topo maps 1:50,000 Topo maps 1:25,000 Topo maps Planimetric and height data	Survey of India (SOI) and published data
3. Ground water data Maps Depths to water level data maps Irrigation related data and Collateral data	Field survey and APPCB Field data and state ground water board State Irrigation Department. India meteorological Dept.
4. Field Data	Through DGPS, Questionnaire during field survey, Water User Association (WUA)

2.2.4 FIELD SURVEYS AND FIELD DATABASE

Sampling procedure for selection of the farmers

The questionnaire will be designed to get the attribute database of farmers and their grievances. The selection of farmers will be done based on a stratified random sampling and the yield variability. Once the number of farmers in a particular reach is selected, the further selection is totally based on random sampling so as to see that the farmers selected are having their land evenly located within a reach. Members of WUA will be consulted in selecting the numbers and composition of farmers for the detailed field survey. Apart from this, the team will be comprising of 4 scientists, two having irrigation water resources background and other two with agricultural background. During the interview, question on farmer's personal view and wishes will be noted. The data items will be used as input for base line data base generation in GIS platform. The existing maps and data collected related to the bench marks provided by the irrigation department and all planimetric control covering the area will be collected during the field survey. In addition to this, the socioeconomic data along with demographic details will also be collected during the field survey. The instrument that is proposed to use during the field survey is DGPS for determining heights and survey of contours for mapping with the help of GIS software for DTM modelling

2.3 CREATION OF GIS AND MIS DIGITAL DATABASE

The four kinds of required data products and thematic coverages of the study area derived from the interpretation of satellite images (Three season's data), the data layers derived from SOI toposheets will be made ready for GIS modelling by means of conversion process and transformation of the data compatible to ARC/INFO GIS software. The acquisition or derivation of these data products consists of collection of existing maps, analysis of satellite data using visual and digital techniques, analysis of collateral data and measurement of elevation data and the field data. These types of data products are then converted into digital mode for the creation of GIS database. The collateral and field data will be converted into the maps showing the spatial distribution of each one of the components which intern will be used for modeling process.

2.4 DEVELOPMENT OF CROP YIELD PREDICTION MODEL

Radiometric normalization will be done to remove inherent noise in multi –temporal IRS images. Linear transformation will be done for radiometric correction. After performing geometric correction, radiometric normalization and making for assigning null value to non vegetation areas of images, NDVI values will be calculated by using field boundary vector file as ROI (region of interest). Geometrically rectified multidate satellite data is sequentially analysed with maximum likelihood classifier algorithm supported with ground truth / field database collected during field visit. Various crops are identified and extracted sequentially at different stages of the classification process. Crop land suitability will be generated using DEM based on information of land altitude and slope gradient. Drainage model will be generated using DEM and river network information. By using this model, each pixel can be identified where is the catchment of the fixed and where to flow to the down stream. NPP is estimated using NDVI and PAR data.

Crop production analysis will be made using administrative boundary, statistics of agricultural production and population, land cover data, crop land suitability, drainage model. The data required for crop production or crop yield prediction model.

- Digital Elevation Model (DEM)
- River Network
- Administrative Boundaries
- Agricultural Production
- Population data
- Land cover data
- NDVI data
- PAR data

This multidate (three seasons data) and multiband satellite data is also transformed to NDVI using the following formula:

NDVI = (NIR – VR)/(NIR + VR)

NDVI represents the integral effect of various factors that influence crop production and is well accepted in India and elsewhere for crop yield forecast and agricultural drought monitoring.

All digital coverage will be used for assessing modelling parameters like slope, aspect, elevation, age of the plantation, type, relative humidity, annual cumulative rainfall, average daily temperature, average daily sunshine hours, soil depth, rock cover percentage of the field and Leaf Area Index (LAI) are computed.

The ground reported yield will also be interpolated using the weighted average interpolation technique to generate a yield map. The ground report yield map is then cross checked with the satellite driven yield to prove the validity of yield model and estimate the error of interpolation. Ground report travel time of flow is also interpolated to get a general picture of canal condition the moisture stress, the fertilizer application adequacy to find out the effect on yield and involvement of farmers in various extension works.

2.5 DETERMINATION OF API AND FII

Two types of indices namely Agricultural Productivity Index (API) to study the effect of inputs on productivity and Farmers Involvement index (FII) to study the farmers participation in the irrigation activities will be computed on the basis of water availability per unit area besides the role of Water User Associations. The API will be derived as below

API = W (wl) + F (w2) + S (w3) + P (w4)

W = water availability (moisture stress)

Where, F= fertilizer application adequacy

S =seeds quality

P = pesticides usage

W1 to w_4 = respective weightages

The FII will be calculated by taking into consideration the awareness, response and involvement in irrigation related works. The weightages for various factors will be calculated applying Boolean logic. The importance of these indices will be useful to the review of the farmers status and responsiveness in yield prediction. Socio-economic factors such as farmers awareness, response and involvement in various works and waves on the various Govt. Agencies are spatialised by performing a cluster analysis using theissen polygon method.

To obtain all the relevant information, will be designed for the irrigation officials, agricultural authorities and the farmers. The questionnaire to the irrigation authorities will cover questions related to irrigation water management, canal conditions, interaction with the farmers and the agricultural officials. The questionnaire prepared to the agricultural authorities covers questions related to the crops to be grown in the study area, their interaction with the farmers and the irrigation officials, type of agricultural extension and other miscellaneous information regarding the soil fertility conditions in the study area. The

Questionnaire will be prepared for farmers based on farmers awareness, information related to their identification the details regarding the inputs and the production in the current season, farmers response to irrigation, status of agricultural works, farmers views on irrigation department and farmers views on agricultural department using this field database, the following spatial maps will be generated.

i) Farmers awareness to the various programmes

ii) Match between water delivery schedule and agricultural production and operation.

iii) Farmers involvement in irrigation scheduling

iv) Status of agricultural works

v) Farmers views on responsiveness on the Dept. of Irrigation.

The clustering analysis adopted for this study enable the zonation of the project area into zones of farmer's level of involvement.

2.6 NET PRIMARY PRODUCTIVITY (NPP)

NPP will be estimated with a method proposed by Hirakoba (1998) based on production efficiency approach. NPP is estimated using Photosynthetically Active Radiation (PAR) and NDVI. The distribution of agricultural land can be seen in the land use / land cover map. The NPP on the agricultural land of the command area will be estimated with the dataset consist of PAR, NDVI, from which the per capita productivity will be analysed. The efficiency index (E), which is the ratio of radiation energy changed into the organic substances can also be taken into consideration for the model. The radiation energy in wavelength which a plant can use for the photosynthesis is called PAR absorbed by the canopy of the plant and can be estimated using NDVI. Solar radiation absorbed by a plant is named APAR (absorbed PAR) and can be calculated from the data set of PAR and NDVI.

2.7 LAND SUITABILITY MODEL

The Land characteristics like Water availability (W), Nutrient Availability Index (NAI), Water and Nutrient Retentions (R), Salt hazard (S) and Topography (T) are considered as thematic layers in the GIS. The water availability (W) is based on the amount of annual rainfall and availability of irrigation and W can be generated using spatial analysis of rainfall and irrigated areas.

The Nutrient Availability Index (NAI) is based on the method given by Radcliffe et al (1982) and is given by

NAI = N x P x K x ph.

The spatial information for each one of these parameters can be obtained from soil map. The water and nutrient retentions will be estimated from the soil texture and particle size. Higher clay content results in high retention of water and available nutrients. The soil salinity is an important edaphic constraint in the region. The soil salinity map will be prepared and used to derive factor rating. The diagnostic factor of topography (T) is a combination of land form and slope gradient. The information on landform and slope can be extracted from satellite imagery and toposheets.

Each of these five qualities with associated attribute data are digitally encoded in a GIS database and used to generate five thematic layers. The land evaluation or land suitability model will be developed using the formula:

Land suitability = W x NAI x R x S x T.

These five layers are then spatially overlaid to produce a resultant polygon layers. Finally, a land suitability map will be derived using this model.

The distribution of the agriculture productivity in terms of five parametric layers, namely: Water availability (W), Nutrient Availability Index (NAI), water and Nutrient Retention (R), Salt hazard (S) and topography (T) are the land characteristics considered as a thematic layers in the GIS. The W-factor is generated from the spatial analysis of annual rainfall and irrigated data. The nutrient availability index can be computed based on the method developed by Radcliffe et al (1982).

2.8 DESIGN AND DEVELOPMENT OF IIIS

It is realized, however, that the irrigation potential created is not being fully utilized and gap exists between the potential created and potential utilized because of lack of proper coordination. Keeping this scenario, an attempt is made to improve the productivity of the land for agricultural produce by developing an Integrated Irrigation Information System (IIIS) model for Addanki Branch Canal command area of Nagarjunasagar reservoir, Krishna basin of Andhra Pradesh. This system – IIIS includes the module to forecast the growth of agricultural productivity, crop production data based on administrative zones on GIS platform. Remedial measures to improve the crop acre age and to minimize the land access problems based on land surveys, crop suitability, crop scheduling, DEM models, drainage models, river network analysis model etc.

The agricultural production is considered to be a part of Net Primary Production (NPP) on the agricultural land. The NPP can be estimated using Photo synthetically Active Radiation (PAR) and Normalised Difference Vegetation Index (NDVI) that can be derived from three seasons satellite based radiance data. The distribution of agricultural land can be seen in the land use/land cover map derived from satellite data. By integrating the result of the agricultural NPP with the statistics of crop production, the conversion efficiency of agricultural production from agricultural NPP will be made. All these components will be included in the IIIS model which will intern be used to compute the per capita productivity. Hence the IIIS (Integrated Irrigation Information system) will be structured in two major modules:

a. Project Data Module

b. Irrigation Management Module.

In the **Project Data** (project data files) module, the user can input new data, modify or delete existing records, re-arrange data or issue a report. These data are not supposed to change very often and they are the information basis of the system. The following four sub-modules are utilized to store "basic" data of the irrigation system such as:

i) Thematic Data

ii) Topographical Data

iii) Collateral Data

iv) Field Data including Questionnaire

The **Irrigation Management Module** consists of 4 sub modules and they are:

i) GIS and MIS digital database creation

ii) Land suitability model

iii) NDVI / DEM / Crop yield prediction model and crop production analysis

iv) NPP, API, FII, PAR models

2.9 VALIDATION OF IIIS MODEL

The IIIS model developed for the Addanki branch canal command area of Nagarjuna Sagar reservoir is then validated by applying this model on the other feeder channels within the NS command area. The evolved and validated model resulted out of this project may be potential enough to be utilized in elsewhere of various command areas under similar environmental settings.

3. STUDY AREA DESCRIPTION

3.1 DESCRIPTION OF KRISHNA RIVER BASIN

From the time of Atareya Brahman (2000 B.C) through the regions of the Satbahanas, Chalukyas, Vijayanagaras down to the Nizam shahis and present day, the Krishna flows through the passage of time in the vibrant youthful company of Bhima and Tungabhadra .Spatially, the Krishna originating in the dizzy heights of Sahyadri (western ghats) at Rahabadeswar passes through the Nallamalai gorge (near Atmakur) at the base of the Srisailam temples through the shrives of the Nagarjuna Konda and strides into the wide coastal plains and fan out into a delta before ending its journey into the Bay of Bengal. The total length of Krishna river is 1400 Km, basin area is 257923 Sq Km. and annual average discharge 67675 (million cubic waters). Yet it has a rather poor water wealth because of fairly low rainfall in the basin (Pune 661mm, Kurnool 607mm and Machilipatnam 1070mm).

3.2 NAGARJUNASAGAR PROJECT

Nagarjunasagar project is one of the most important major water resources scheme in the country catering to irrigation of vast command area apart from flood control and power generation Project whereas the Krishna Delta System is the on down stream side of the project. The dam site of the project is located at Nandikonda village of Nalgonda district in Andhra Pradesh with latitude 16 34′ 24″ N and longitude 79 18′ 47″ E. Nagarjunasagar dam, constructed in 1969 across the River Krishna, is the one of the largest and highest straight gravity masonry dam in the world. The catchment area of the River Krishna at Nagarjunasagar dam is 2, 07,120 km2. The project has a gross storage capacity of 11560.05 MCM (408.24 TMC). Out of the 22653.44MCM (800 TMC) allocated to Andhra Pradesh by KWDT, Nagarjunasagar project is allocated 7475.65 MCM (264 TMC) with an additional amount of 481.39 MCM (17 TMC) towards evaporation losses. Figure 3.1 shows Nagarjunasagar project.

3.3 GENERAL FEATURES OF THE COMMAND AREA OF NAGARJUNA SAGAR PROJECT RESERVOIR

The rainfall of the command area varies considerably over two monsoon seasons. The first spell of rain (South - West monsoon) in the Khariff season occurs during the period of June to September and the second (North - East monsoon) in the Rabi season from October to December. Nearly 70 percent of the annual rainfall in the Left Bank command and 55 percent in the Right Bank command occurs in the Khariff season. The Rabi season rainfall amounts to about 20 percent of the annual rainfall in the Left Bank command and about 30 percent in the Right Bank command. The annual rainfall of the command area ranges from 680 mm to 1110 mm. The temperatures range from a low of about 15°C in December to about 45°C in May. Relative humidity ranges from about 30 percent to about 80 percent with a mean of about 60 percent. Evaporation ranges from about 145 mm in November and December to about 350 mm in May.

3.3.1 Canal System

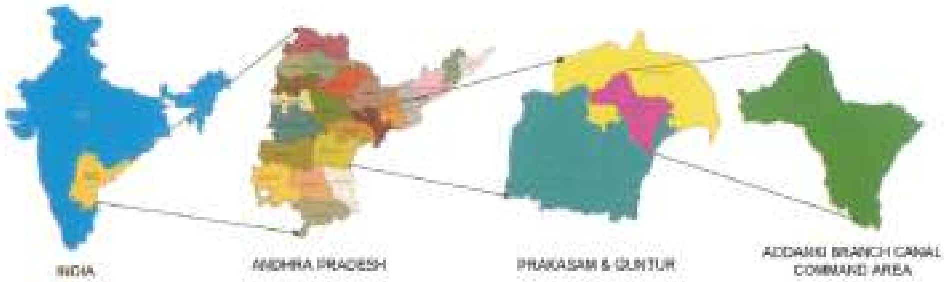
Following are the Canal Systems of the Nagarjunasagar Reservoir:

1. Nagarjunasagar Right canal (Jawahar Canal)

2. Nagarjunasagar Left Canal (Lal Bahadur Canal)

3.4 STUDY AREA PROFILE: ADDANKI BRANCH CANAL

The Addanki branch canal is one of the major branch canal of Nagarjuna Sagar right branch canal (Jawahar canal) as per Government records the total aerial extent under Addanki branch canal command area is 6, 69,655 acres (2, 71,000 hectares). The Addanki branch canal command area is located in the Eastern part of the state and it is covered 25 mandals part of Prakasam and Guntur districts in the state of Andhra Pradesh. Location map is shown by figure.3.2



3.5 ADMINISTRATIVE SETUP

Addanki Branch canal command area is present covered in part of Guntur and Prakasam districts. The study area is bounded on the North by vogaruvagu, East by Kommamur canal, and South by Gundlakamma River and West by Nagarjunasagar Right bank canal. The total geographical area is 6, 69,655 acres (2, 71,000 hectares). Topographical index map shown by figure.3.3.

SurveyofIndiatoposheetscovered56p/11,56p/12,56p/15,56p/16,57m/9,57/m13,57m/14,65d/4,65d/8,66a/1,66a/2and66a/5 on 1:50,000 scale Addanki branch canal command area coveringnearly25mandalsofAndhraPradesh,inPrakasamdistrictSathamagaluru,Ballikuruva,Addanki,Martur,Yaddanapudi,Parchuru,Chirala,Karamchedu,Inkollu,Vetapalem,janakavarampangaluru,Korisapadu,Maddipadu,Nagaluppalapadu,Chinaganjam another 10 mandals are covererdinGunturdistrictthesemandalsareBollapalle,Ipuru,Nekarikallu,Vinukonda,Savalayapu,Rompicherla,Narasaraopet,Chilakaluripet,Peddanandipadu,Kakumanu.

3.6 ENVIRONMENTAL RESOURCES IN THE STUDY AREA

3.6.1 Population

The study area has a total population of 2,342,803. It has a density of 242 persons per square kilometer, (Prakasam and Guntur Districts 2001). In these twenty five mandals there are nearly 450 villages covered, the population is 90% rural and 10% is urban population.

3.6.2 Climate

The study area is characterized by tropical climate with hot summers as well as cold winters are characterized by tropical climate with hot summers as well as cold winters. The study area receives an average annual rainfall of 1045 mm and 75 percent of the rainfall is received through the south-west monsoon period and remaining one-fourth is received through north-east monsoon. The study area is generally hot during summer and cold in winter, while the period from April to June is the hottest touching temperature of 43oC or even more. The meteorological data is presented in Annexure-II. Situated nearly distance from the Sea Coast, the climatic condition is humid.

3.6.3 Temperature

The temperature fluctuations are high in this study area. The normal mean minimum temperature is 19°C and mean maximum is 43°C. At times the temperature plummets to as low as 12°C during winter and soars to as high as 45°C during the peak summer.

3.6.4 Rainfall

The normal rainfall in the study area is 890mm, of which about 90% comes from the southwest monsoon during the latter part of June to the end of October. The study area normal average rainfall during 2006 till the end of March 2006 is 530.4mm. The rainfall is received through the south-west monsoon period and remaining one-fourth is received through north-east monsoon.

3.6.5 Physiography

The study area is characterized by an undulating terrain with erosional landforms like inselbergs, and ridges noticed amidst vast area of dissected pediment and Pediplain but the major part is flat terrain with fertile soils. The highest elevation in the study area is 420m above msl, which is Vinukonda, while the lowest point is 90m above msl which is at South West of Dharmavaram.

3.6.6 Drainage

The main rivers draining in the study area is Krishna and its tributaries. Gundlakamma River and Vogaruvagu. The overall drainage pattern is sub-dendritic, while locally rectilinear and trellis patterns are noticed. The drainage pattern is Coarse textured in the areas of metamorphic rocks and fine textured in the areas of barren sheet rock areas which is mostly in the Western parts of the study area.

3.6.7 Geology

The minerals obtained in the study area are Limestone, Lime kankar, Napa slabs, and copper lead. Granite, Road metal, Slate, Quartz, Gravel, silica sand, iron ore in Ongole, Addanki, & maddipadu e.t.c .There is copper mines in Ipur. Colour Granite is predominantly available in Ballikurava region of the study area. The lime stone is basically available in the South West region of the study area and of one of the types of metamorphic rocks with undulating topography. All the above rocks are profusely intruded by K-rich grey granite, syeno- granite and monzogranite of lower Proterozoic age Grey granite is characterized predominantly by K-feldspar. The contact between granites is gradational. The soil types in the study area are in general fertile broadly classified as black cotton, red loamy and sandy Loamy .The percentage of the Black cotton area is 70%, Red loamy is 24%, and sandy loamy is about 6%.

3.6.8 Geomorphology

Mostly the South west central part of the study area is composed of granitic rocks represented by a pediment-Pediplain along with some central parts of the study area complex with inselbergs and residual hills standing out prominently besides the linear ridges made of dolerites.

3.6.9 Geo Hydrology

The study area dominantly comprises lime stones and granitic and gneisses among which the major is metamorphic lime stone which has a high permeability for infiltration of water into the ground water table. The ground water in these rocks is fracture controlled, occurring only along the major fractures. In the southern and northern parts of the study area the rivers are located which indicate the coarse textured drainage pattern. Part of the Study area is prominent zone composed of Barren sheet rocky areas which has a poor ground water potential with low permeability and yield.

3.6.10 Geotechnical Characteristics and Natural Hazards

The rock type, of the major part of the study area , have a good permeability, high bearing capacity and compressive strength (1000-2000 kg/cm2) and very good foundation characteristics. As the study area is near to the coast natural hazards are common with Cyclonic effects like heavy rains and high speed winds causing lot of damage to the crops and the human habitat.

3.6.11 Soils

The soil types in the study area are in general fertile broadly classified as black cotton, red loamy and sandy Loamy .The percentage of the Black cotton area is 70%, Red loamy is 24%, and sandy loamy is about 6%.

1.5.17. Land utilization:

The major part of the study area is arable irrigated land with patches of un irrigated land seen in the less percentage, as the soil is fertile and the water is sufficient enough probably owing to the presence of the Nagarjuna sagar Right bank canal in the West, Kommamur canal in the east Gundlakamma river in the southern part and Vogaruvagu in the northern part of the study area. The western parts have patches of the forestland and scrubland. Prominent wastelands are seen in the some parts of the study area. The total geographical area is 2, 71,000 hectares, net cropped area is 6, 69,655.58 acres and net irrigated area is 3, 81,177.811 hectares.

1.5.18. Land holding agriculture

Agriculture is the backbone of the study area economy and about 85% of the working population depends on agriculture. The major crops grown are paddy, groundnut, chillies, sugarcane and sunflower, tobacco, maize, pulses e.t.c.

3.7 NON ENVIRONMENTAL RESOURCES IN THE STUDY AREA

3.7.1 Road network

NH-5 is the main National Highway passing through the study area along with State highways. All the important places in the Study area are well connected by network of different roads. The mandals & mandal headquarters in the study area are well connected by bus communication. State transport buses are being operated to different places in the Study Area.

3.7.2 Railway network

The South central railway main line passes through the major stations like Narasaraopet, Vinukonda, of the study area.

3.7.3 List of Banks in the study area

S. No.	Name of the Bank	No. of branches
1	State Bank of Hyderabad	8
2	Andhra Bank	25
3	Syndicate Bank	10
4	State Bank of India	22
5	Indian Overseas Bank	13
6	Vijaya Bank	9
7	Canara Bank	10
8	Indian Bank	10
9	Dena Bank	3
10	Union Bank of India	8
11	Corporation Bank	4
12	Punjab National Bank	4
13	Central Bank of India	10
14	Bank of India	9
15	Bank of Maharashtra	2
16	Oriental Bank of Commerce	3
	TOTAL	150

Source: National Beauro of Economic and Statistics, Hyderabad

4. DATA SOURCES AND DATA USED

Based on the source of acquisition of data, nature of data and its use in the present study, the data products are classified into four types namely, topographical data, thematic data, field data and collateral data.

4.1. DATA SOURCES

A heightened awareness of water resources problems has developed over the past several decades and this has spurred a need for reliable geospatial data to enable better understanding of water related problems and their impacts on environment. Crop yield models have also undergone changes and these have created new requirements for geospatial data. In view of critical role, digital data plays in any kind of spatial modeling and analysis. Emphasis is given to new information gathering initiations for remotely sensed data and to advancements in integrating data from different sources with GIS. The availability of appropriate and adequate crop yield data, and other related data derived from collateral data and other field survey are important concerns. GIS and crop yield models function with a broad spectrum of geospatial data that are used for spatial analysis and modeling of crop yields. These data generally come in different formats and from various sources and measurements. The examination and organization of data into a useful form produces information content, which is compatible to GIS and which enables appropriate analysis and modeling of crop yield prediction.

In the present study, four different sources are used to collect the required data products. The four sources are remote sensing satellite systems, survey of India toposheets, related government and private agencies for existing data products and field surveys for collection of primary data products. In transforming this raw data to data compatible to GIS, care is taken for appropriate level of data precision and accuracy. The data types, important features and corresponding data sources used in the present study are listed in table 3.1.

Table 3.1. Data type, important features and sources of acquisition

S.No	Primary Map	Reference Map
1	Base	SOI-Toposheet & Satellite Data
2	Drainage	SOI-Toposheet & Satellite Data
3	Road network	SOI-Toposheet & Satellite Data
4	Mandal reference map	SOI-Toposheets & cadastral maps
5	Village reference map	SOI-Toposheets & cadastral maps
6	Land use/Land Cover	SOI-Toposheets & Satellite Data
7	Soil Map (Type, Depth, Drainage, AWC, Particle Size & Erosion)	Soil, SOI-Toposheet & Satellite Data

4.2. COLLECTION OF DATA

The following types of data have been used in the present investigation

- Satellite data
- Collateral data
- Crop characteristics and agricultural data
- Meteorological data

4.2.1. Satellite data

Remotely sensed data from IRS-1C/1D and IRS P6 LISS III data in the form of false colour composite (FCC) prints and computer compatible tapes (CCT's) pertaining to the study areas are used in the study. The entire study area is covered by three scenes of IRS-1C/1D and IRS P6 LISS III data. The satellite data sets are used in the experiment are given below in table.3.2.

Table: 3.2. Satellite data sets used in the study area

Year	Satellite	Sensor	Date of Pass
1996	IRS IC	LISS III	12 Feb 1996
1997	IRS IC	LISS III	12 Feb 1997
1998	IRS IC	LISS III	16 Dec 1998
1999	IRS IC	LISS III	17 Nov 1999
2000	IRS IC	LISS III	10 Dec 2000
2001	IRS ID	LISS III	9 Dec 2001
2002	IRS ID	LISS III	27 Nov 2002
2003	IRS ID	LISS III	4 March 2003
2004	IRS P6	LISS III	19 March 2004
2005	IRS P6	LISS III	27 Dec 2005
2006	IRS P6	LISS III	20 Jan 2006

The raw satellite images are presented in Fig 3.1. To 3.11 for the cropping season of 1996 to 2006. The satellite data for the all seasons are completely cloud free and the data sets were used for generation of spectral indices from individual fields in the study area, for paddy condition assessment and acreage estimation.

Figure 3.1 shows satellite image year of 1996

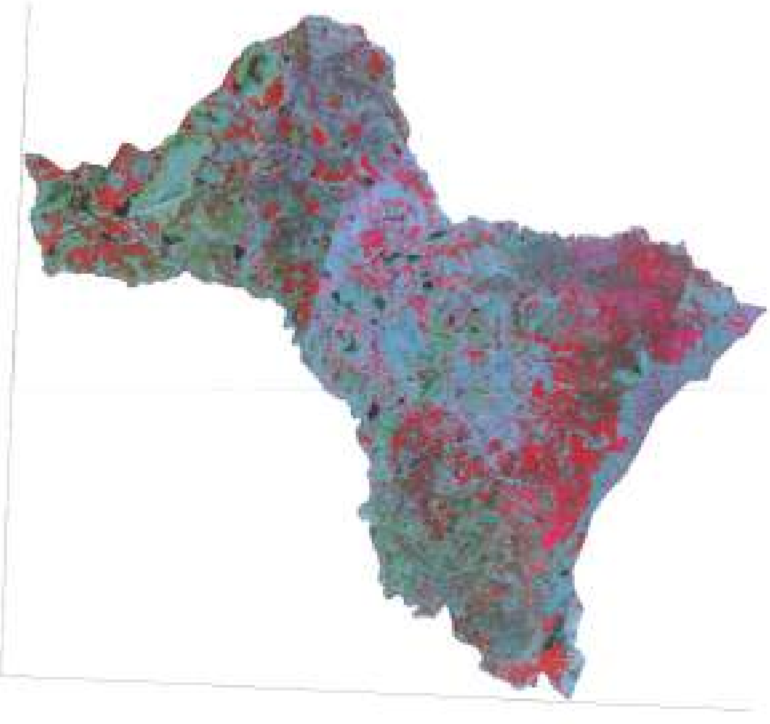


Figure 3.2 shows satellite image year of 1997

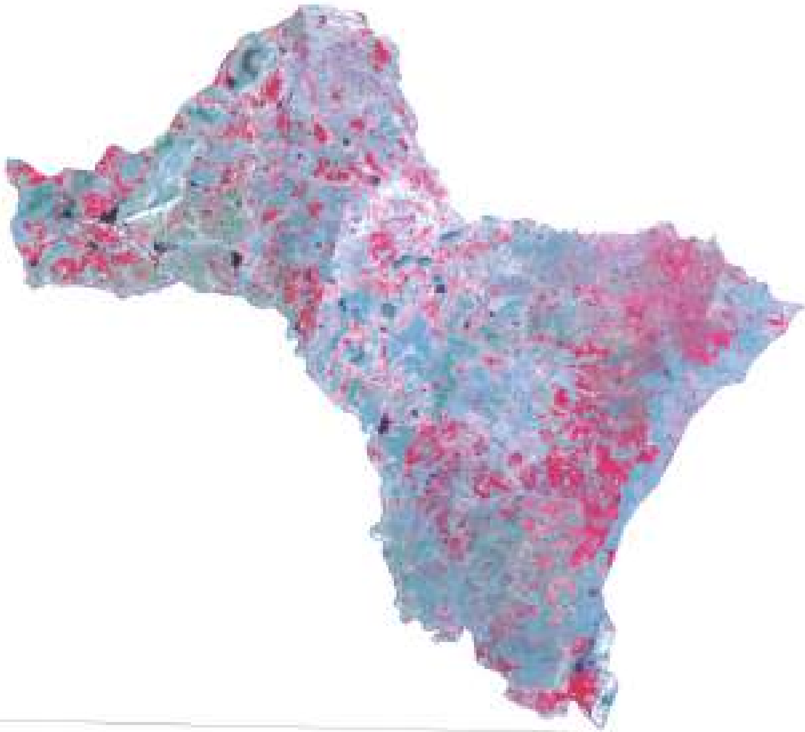


Figure 3.3 shows satellite image year of 1998

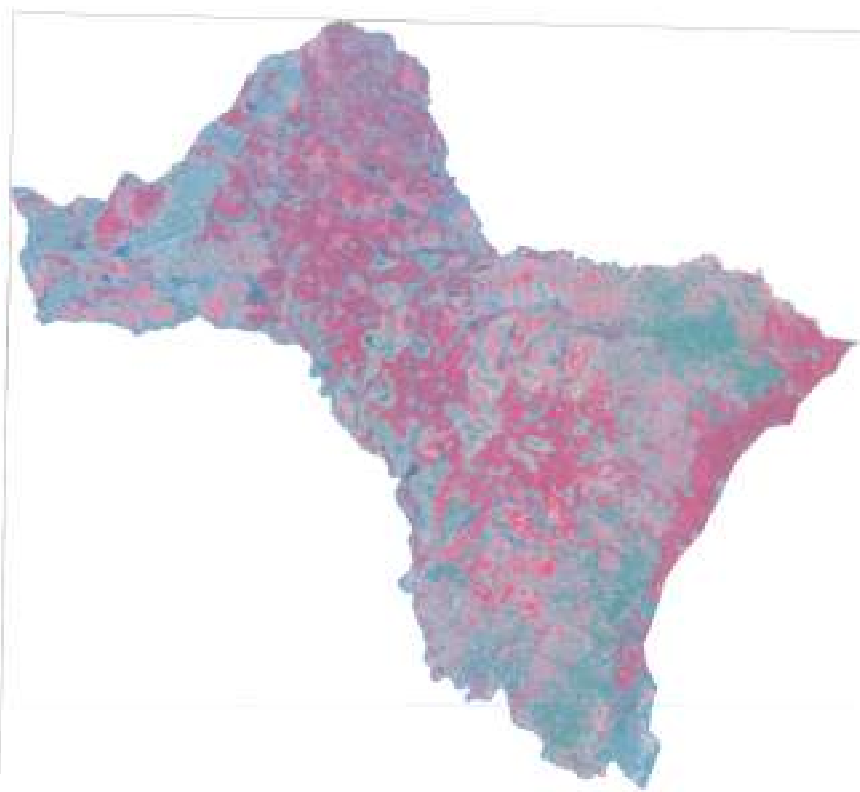


Figure 3.4 shows satellite image year of 1999

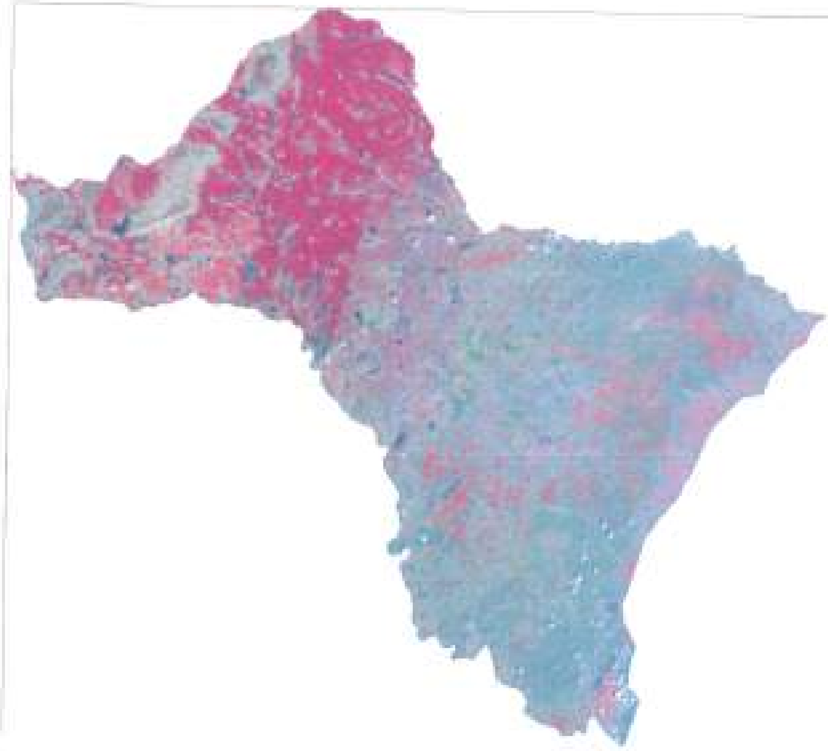


Figure 3.5 shows satellite image year of 2000

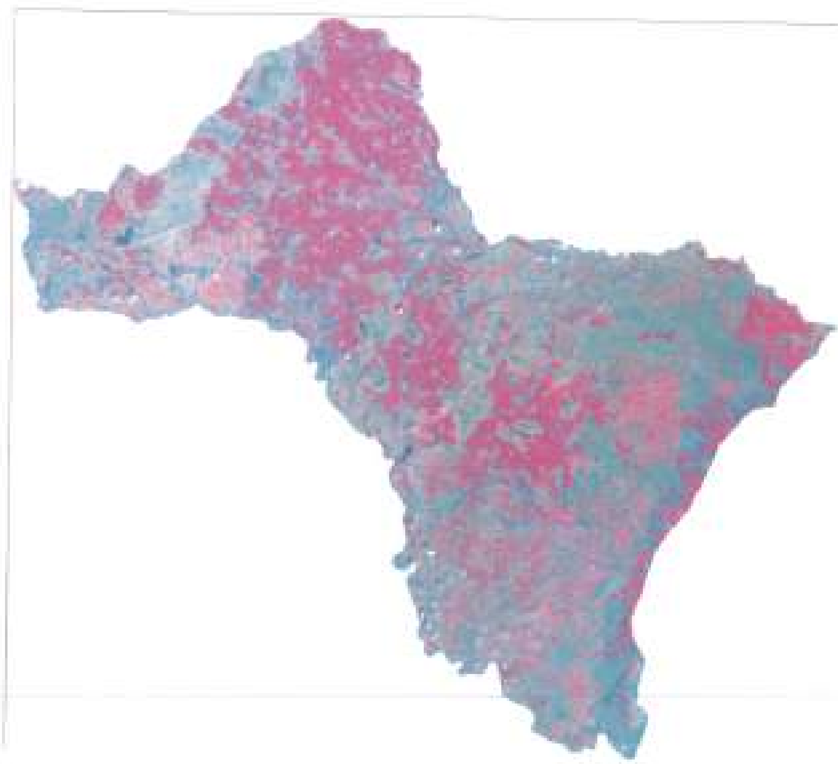


Figure 3.6 shows satellite image year of 2001

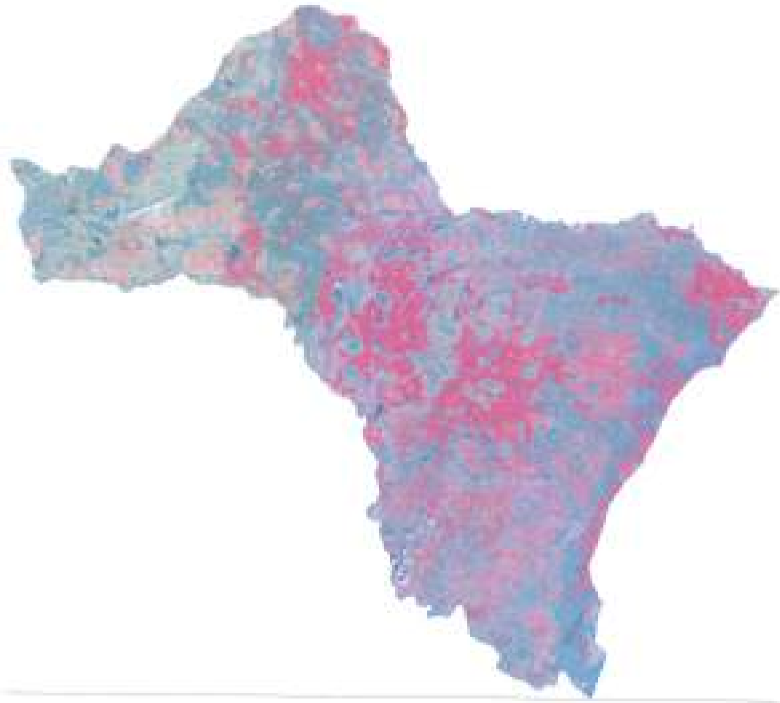


Figure 3.7 shows satellite image year of 2002

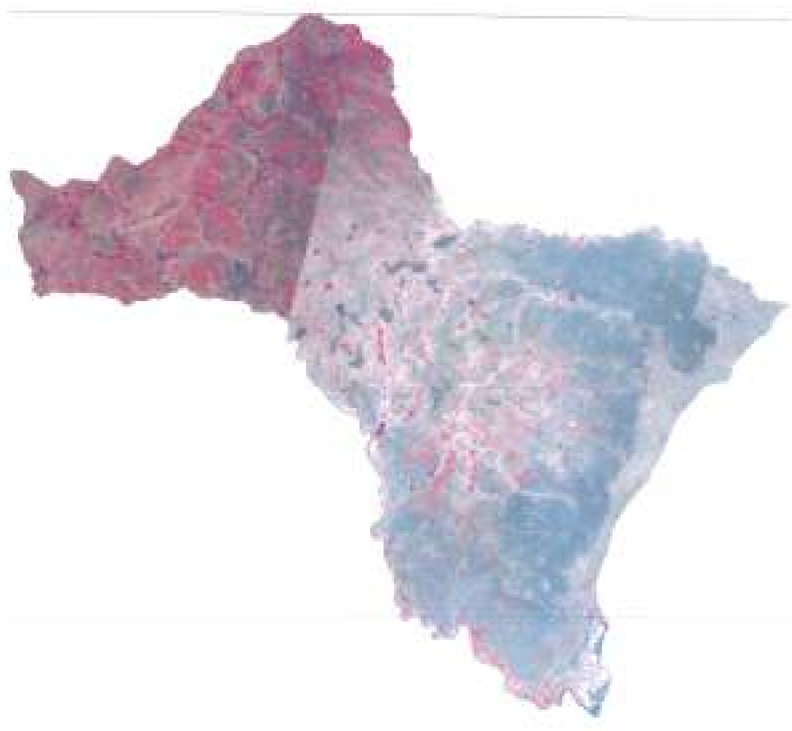


Figure 3.8 shows satellite image year of 2003

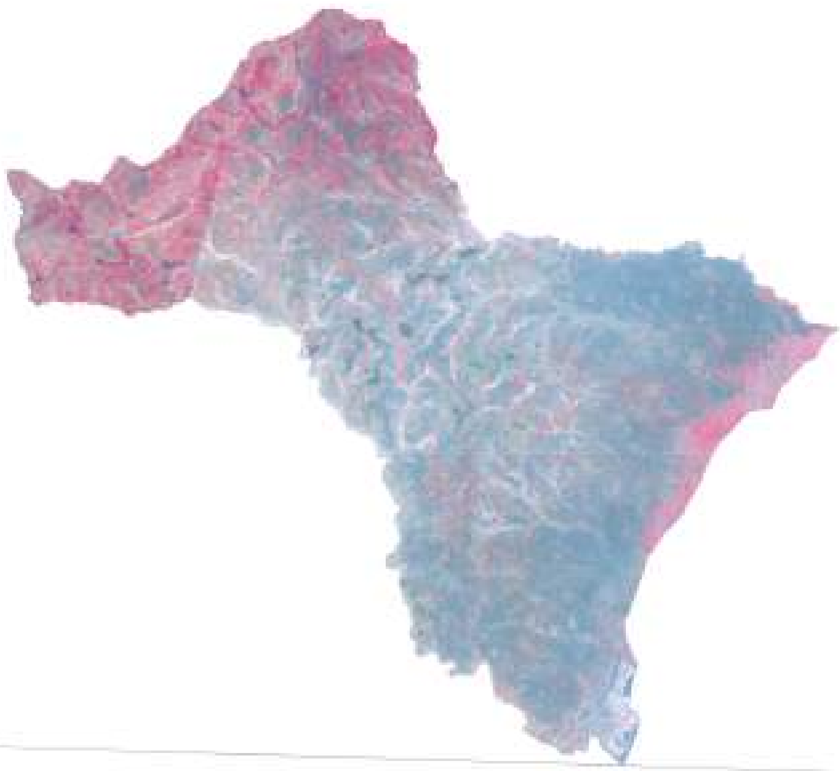


Figure 3.9 shows satellite image year of 2004

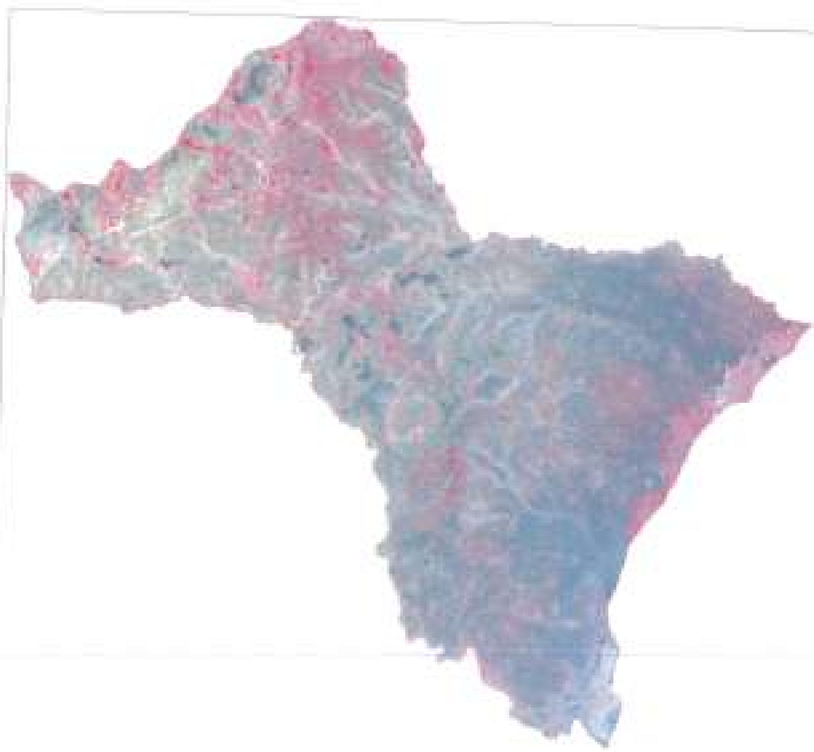


Figure 3.10 shows satellite image year of 2005

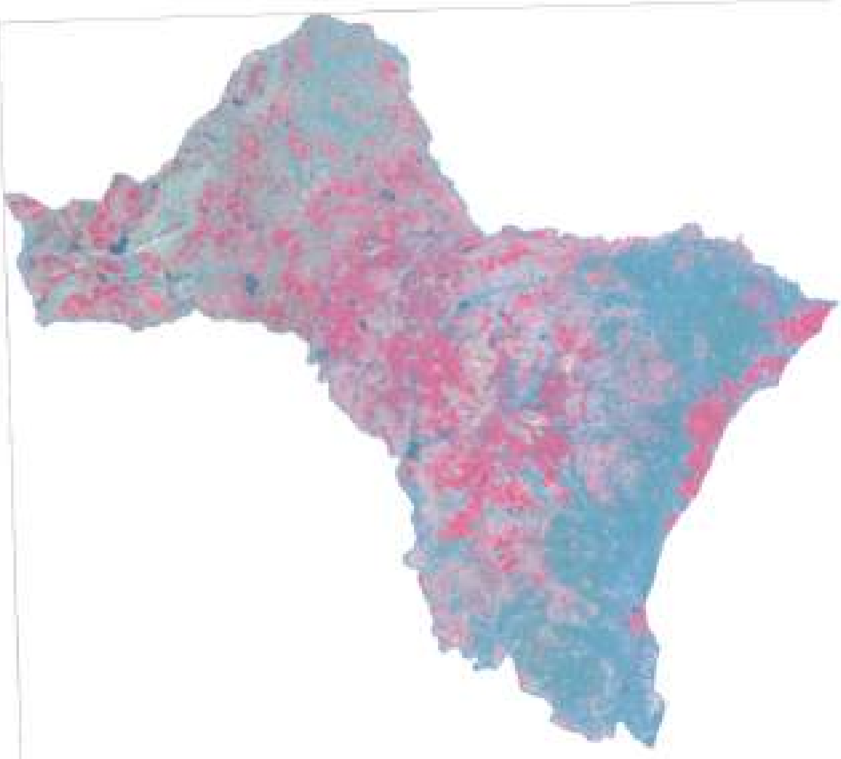
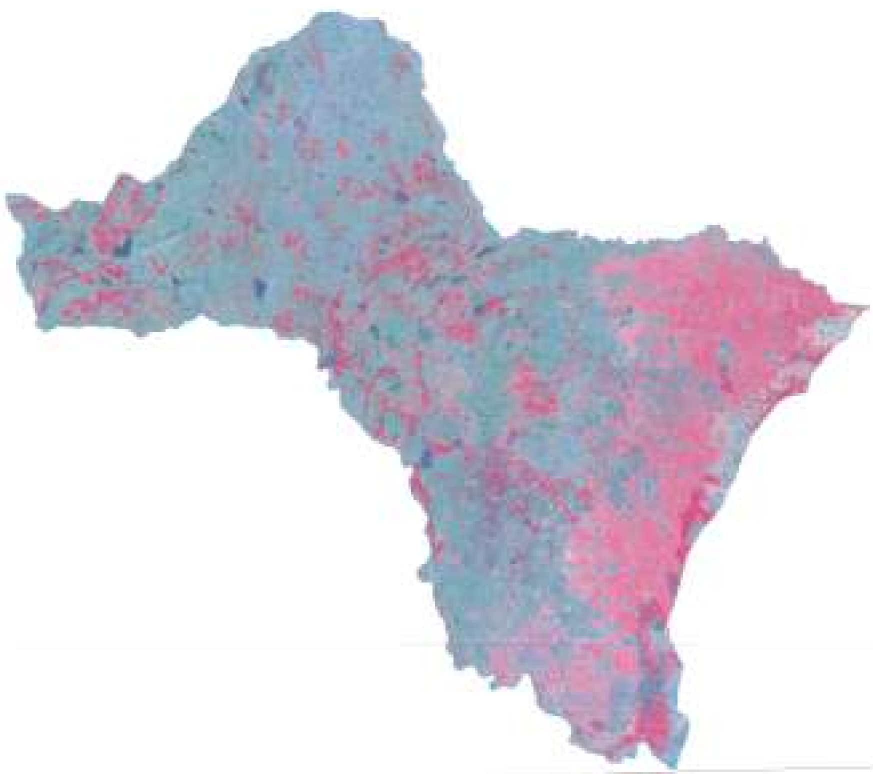


Figure 3.11 shows satellite image year of 2006



4.2.2. Collateral data

Collateral data used in the study includes topographical and thematic maps of the study area. The topographical maps are required for preparation of base maps. The thematic maps of land use/cover maps, agro-climatic zone maps, soil type maps and irrigation maps. The topographical maps were collected from survey of India, soil type maps from NBSSLUP and other maps such as land use/cover, agro climatic maps, irrigation maps from NATMO, Kolkatta.

4.2.3. Agricultural data

Information on the crop characteristics of paddy and other crops were collected from Department of Agriculture, Directorate of ICAR, Govt. of Andhra Pradesh, officials during preparatory activities. The data includes cropping pattern, planting and harvesting periods, crop area statistics and crop calendars of various crops in the study area. The crop calendars are useful in determining maximum vegetative period for acquisition of satellite data. These calendars are also provides information on other crops and their probable growth periods. It has observed that sometimes the sowing operations are delayed due to late onset of monsoons or delayed release of water into canals. Therefore, the peak vegetative period may shift from year to year, thus there is a need to develop a crop calendar for deciding the acquisition of remote sensing data.

4.2.4. Meteorological data

The meteorological data was collected from IMD station as well as the data recorded by Ongole and Nellore officials in the study area. The data includes maximum and minimum temperature, rainfall distribution, relative humidity, sunshine hours, which are useful in development of relationship between meteorological parameters and crop yield. The historical meteorological data is presented in Annexure-VI. Table 3.3 shows temperature and table 3.4 shows rainfall data.

Table 3.3 shows temperature data

		MEAN				MEAN				MEAN	
YEAR	MONTH	MAX.	MIN.	YEAR	MONTH	MAX.	MIN.	YEAR	MONTH	MAX.	MIN.
1996	JANUARY	30.0	17.2	1997	JANUARY	27.4	15.5	1998	JANUARY	30.4	17.7
1996	FEBRUARY	31.9	18.7	1997	FEBRUARY	32.4	16.1	1998	FEBRUARY	32.6	19.5
1996	MARCH	36.8	21.1	1997	MARCH	36.0	20.3	1998	MARCH	36.1	22,5
1996	APRIL	37.0	23.0	1997	APRIL	35.9	22.3	1998	APRIL	39.4	25.3
1996	MAY	40.7	26.7	1997	MAY	39.1	25.9	1998	MAY	40.4	27.6
1996	JUNE	35.6	24.8	1997	JUNE	36.7	24.5	1998	JUNE	37.0	25.8
1996	JULY	31.9	23.0	1997	JULY	32.0	22.8	1998	JULY	32.7	23.6
1996	AUGUST	29.6	22.0	1997	AUGUST	30.7	22.1	1998	AUGUST	30.2	22.8
1996	SEPTEMBER	30.7	22.3	1997	SEPTEMBER	31.3	22.2	1998	SEPTEMBER	30.4	22.8
1996	OCTOBER	29.7	20.5	1997	OCTOBER	31.1	20.8	1998	OCTOBER	30.1	21.4
1996	NOVEMBER	29.7	17.5	1997	NOVEMBER	29.9	20.6	1998	NOVEMBER	29.6	18.5
1996	DECEMBER	28.2	14.9	1997	DECEMBER	28.7	19.2	1998	DECEMBER	28.7	12.8

		MEAN				MEAN				MEAN	
YEAR	MONTH	MAX.	MIN.	YEAR	MONTH	MAX.	MIN.	YEAR	MONTH	MAX.	MIN.
1999	JANUARY	29.2	14.0	2000	JANUARY	30.4	15.6	2001	JANUARY	29.8	16.0
1999	FEBRUARY	32.2	18.6	2000	FEBRUARY	31.4	19.2	2001	FEBRUARY	34.5	17.7
1999	MARCH	36.7	21.6	2000	MARCH	35.7	20.1	2001	MARCH	35.4	22.1
1999	APRIL	39.9	24.7	2000	APRIL	39.8	24.7	2001	APRIL	36.9	24.7
1999	MAY	37.6	25.1	2000	MAY	37.6	25.2	2001	MAY	40.4	27.1
1999	JUNE	33.3	23.2	2000	JUNE	31.6	22.9	2001	JUNE	33.1	23.4
1999	JULY	31.3	22.4	2000	JULY	30.0	22.3	2001	JULY	31.9	22.7
1999	AUGUST	30.1	21.9	2000	AUGUST	29.7	22.2	2001	AUGUST	29.4	22.1
1999	SEPTEMBER	30.2	21.7	2000	SEPTEMBER	31.0	21.7	2001	SEPTEMBER	32.0	22.7
1999	OCTOBER	31.1	20.3	2000	OCTOBER	33.0	20.4	2001	OCTOBER	30.4	20.5
1999	NOVEMBER	30.9	16.6	2000	NOVEMBER	31.2	17.2	2001	NOVEMBER	30.6	18.7
1999	DECEMBER	29	14.2	2000	DECEMBER	29.5	13.3	2001	DECEMBER	29.4	14.5

		MEAN				MEAN				MEAN	
YEAR	MONTH	MAX.	MIN .	YEAR	MONTH	MAX.	MIN .	YEA R	MONTH	MAX.	MIN .
2002	JANUARY	30.5	20.7	2003	JANUARY	30.9	19.4	2004	JANUARY	30.8	19.3
2002	FEBRUARY	32.7	21.0	2003	FEBRUARY	32.8	21.8	2004	FEBRUARY	32.8	20.7
2002	MARCH	35.1	23.8	2003	MARCH	33.9	23.8	2004	MARCH	35.6	23.2
2002	APRIL	36.9	26.2	2003	APRIL	36.8	26.2	2004	APRIL	37.6	26.7
2002	MAY	40.7	29.0	2003	MAY	41.3	29.3	2004	MAY	36.9	27.1
2002	JUNE	37.1	26.8	2003	JUNE	39.9	28.1	2004	JUNE	38.1	28.0
2002	JULY	37.4	28.0	2003	JULY	34.1	25.7	2004	JULY	35.3	26.4
2002	AUGUST	34.9	25.3	2003	AUGUST	34.1	26.0	2004	AUGUST	36.4	28.0
2002	SEPTEMBE R	37.4	26.1	2003	SEPTEMBE R	35.6	26.0	2004	SEPTEMBE R	34.5	25.8
2002	OCTOBER	32.9	24.3	2003	OCTOBER	32.8	24.7	2004	OCTOBER	32.5	24.9
2002	NOVEMBER	32.0	21.3	2003	NOVEMBER	32.9	22.5	2004	NOVEMBE R	31.5	22.1
2002	DECEMBER	32.0	19.7	2003	DECEMBER	30.7	19.8	2004	DECEMBE R	31.9	19.9

		MEAN				MEAN	
YEAR	MONTH	MAX.	MIN.	YEAR	MONTH	MAX.	MIN.
2005	JANUARY	31.6	21.1	2006	JANUARY	30.4	14.0
2005	FEBRUARY	33.8	21.7	2006	FEBRUARY	33.6	18.6
2005	MARCH	35.1	24.3	2006	MARCH	34.2	20.6
2005	APRIL	37.0	26.7	2006	APRIL	37.9	23.6
2005	MAY	39.9	27.8	2006	MAY	38.4	25.6
2005	JUNE	40.5	30.4	2006	JUNE	34.0	24.6
2005	JULY	35.7	26.8	2006	JULY	31.8	23.4
2005	AUGUST	36.1	27.1	2006	AUGUST	30.0	22.6
2005	SEPTEMBER	34.0	26.0	2006	SEPTEMBER	31.4	22.9
2005	OCTOBER	31.2	25.2	2006	OCTOBER	31.0	21.2
2005	NOVEMBER	31.4	22.2	2006	NOVEMBER	29.4	19.2
2005	DECEMBER	30.9	20.8	2006	DECEMBER	29.7	15.2

Table 3.4 shows rainfall data

YEAR	MONTH	RAINFALL	YEAR	MONTH	RAINFALL
1996	JANUARY	0.0	1997	JANUARY	56.1
1996	FEBRUARY	0.4	1997	FEBRUARY	0.0
1996	MARCH	0.0	1997	MARCH	12.3
1996	APRIL	58.8	1997	APRIL	59.6
1996	MAY	9.7	1997	MAY	19.7
1996	JUNE	76.3	1997	JUNE	25.4
1996	JULY	192.8	1997	JULY	181.5
1996	AUGUST	334.8	1997	AUGUST	167.2
1996	SEPTEMBER	138.9	1997	SEPTEMBER	73.8
1996	OCTOBER	102.6	1997	OCTOBER	95.2
1996	NOVEMBER	57.8	1997	NOVEMBER	33.6
1996	DECEMBER	0.0	1997	DECEMBER	40.6
YEAR	MONTH	RAINFALL	YEAR	MONTH	RAINFALL
1998	JANUARY	0.0	1999	JANUARY	0.0
1998	FEBRUARY	0.0	1999	FEBRUARY	1.8
1998	MARCH	0.4	1999	MARCH	0.0
1998	APRIL	5.5	1999	APRIL	8.9
1998	MAY	17.7	1999	MAY	87.6
1998	JUNE	43.7	1999	JUNE	38.2
1998	JULY	221.7	1999	JULY	149.9
1998	AUGUST	265.7	1999	AUGUST	121.8
1998	SEPTEMBER	141.5	1999	SEPTEMBER	124.3
1998	OCTOBER	239.6	1999	OCTOBER	32.0
1998	NOVEMBER	6.4	1999	NOVEMBER	0.0
1998	DECEMBER	0.0	1999	DECEMBER	0.0
YEAR	MONTH	RAINFALL	YEAR	MONTH	RAINFALL
2000	JANUARY	0.0	2001	JANUARY	32.5
2000	FEBRUARY	80.7	2001	FEBRUARY	0.0
2000	MARCH	0.7	2001	MARCH	0.0
2000	APRIL	12.9	2001	APRIL	65.4
2000	MAY	64.9	2001	MAY	10.3
2000	JUNE	215.7	2001	JUNE	56.8
2000	JULY	126.0	2001	JULY	30.9
2000	AUGUST	469.0	2001	AUGUST	96.4
2000	SEPTEMBER	51.0	2001	SEPTEMBER	95.4
2000	OCTOBER	21.8	2001	OCTOBER	274.4
2000	NOVEMBER	1.8	2001	NOVEMBER	116.5
2000	DECEMBER	1.0	2001	DECEMBER	11.4

YEAR	MONTH	RAINFALL	YEAR	MONTH	RAINFALL
2002	JANUARY	32.8	2003	JANUARY	6.4
2002	FEBRUARY	0.0	2003	FEBRUARY	0.0
2002	MARCH	0.0	2003	MARCH	42.6
2002	APRIL	3.2	2003	APRIL	0.0
2002	MAY	34.7	2003	MAY	0.0
2002	JUNE	38.9	2003	JUNE	81.3
2002	JULY	49.5	2003	JULY	138.8
2002	AUGUST	75.2	2003	AUGUST	105.4
2002	SEPTEMBER	34.0	2003	SEPTEMBER	121.6
2002	OCTOBER	211.4	2003	OCTOBER	222.5
2002	NOVEMBER	113.4	2003	NOVEMBER	19.6
2002	DECEMBER	0.0	2003	DECEMBER	58.4

YEAR	MONTH	RAINFALL	YEAR	MONTH	RAINFALL
2004	JANUARY	30.4	2005	JANUARY	0.0
2004	FEBRUARY	0.0	2005	FEBRUARY	5.4
2004	MARCH	1.6	2005	MARCH	0.1
2004	APRIL	2.1	2005	APRIL	0.0
2004	MAY	184.7	2005	MAY	18.8
2004	JUNE	13.2	2005	JUNE	9.9
2004	JULY	15.4	2005	JULY	78.9
2004	AUGUST	13.8	2005	AUGUST	105.7
2004	SEPTEMBER	153.8	2005	SEPTEMBER	184.6
2004	OCTOBER	126.1	2005	OCTOBER	389.5
2004	NOVEMBER	48.4	2005	NOVEMBER	68.7
2004	DECEMBER	0.0	2005	DECEMBER	10.1

YEAR	MONTH	RAINFALL
2006	JANUARY	0.0
2006	FEBRUARY	0.0
2006	MARCH	41.8
2006	APRIL	67.9
2006	MAY	100.3
2006	JUNE	83.8
2006	JULY	192.7
2006	AUGUST	228.1
2006	SEPTEMBER	206.1
2006	OCTOBER	15.7
2006	NOVEMBER	52.2
2006	DECEMBER	0.0

5. GENERATION OF DATABASE

5.1 GENERAL

The generation of data base needs the source information comprising non spatial data and a spatial data. The spatial data is comprised of land use/land cover, drainage, base details and soil maps etc. The non-spatial or attribute data is composed of climatic parameters, crop pattern etc. In this chapter, the steps involved in deriving all these data products, the sources of data acquisition and the ways of transforming these data products suitable to GIS software are discussed.

This work has been accomplished with the use of the capacity of Geographical Information System (GIS) as a tool for remote sensing data processing and analysis. This chapter introduces spatial data issues involving data collection strategies, the use of cartographic and remote sensing products as sources of digital data and digital characteristics of spatial databases. Data collection issues include the choice of spatial model for discretizing geographic properties, for example, necrotizing the real world by objects with clearly defined boundaries, defining regions such as polygons with assumed internal homogeneity. These spatial models are transformed into various data structures such as the raster or vector formats. In this chapter the methods of generation of spatial database and analysis is presented.

5.2 SPATIAL DATA FROM SOI TOPOSHEETS

Creating a GIS spatial database is a complex operation, and is heart of the entire work; it involves data capture, verification and structuring processes. Because raw geographical data are available in many different analogue and digital forms such as toposheets, aerial photographs, satellite imageries and tables. Out of all these sources, the source of toposheet is of much concern to natural resource scientist and an environmentalist. In the present study, the thematic maps generated from toposheet are, base map, drainage map and Road network map. These paper based maps are then converted to digital mode using scanning and automated digitization process. These maps are prepared to a certain scale and show the attributes of entities by different symbols or colouring. The location of entities on the earth's surface is then specified by means of an agreed co-ordinate system. It is mandatory that all spatial data in a GIS are located with respect to a frame of reference. For most GIS, the common frame of reference co-ordinate system is that of plane, orthogonal Cartesian co-ordinates oriented conventionally north-south and east-west. This entire process is called georeferencing. The same procedure is also applied on remote sensing data before it is used to prepare thematic maps from satellite data.

5.3 SPATIAL DATA FROM SATELLITE DATA AND PROCESSING

The step-by-step procedure for preparing the spatial data derived from remote sensing satellite data for the entire study area is discussed as below:

Satellite data processing using image processing software

- Geoprocessing and Georefencing
- Digital enhancement
- Generation of hard copy
- Generation of thematic maps: Land use / land cover and soil map.

5.3.1 Geo-coding and Geo-referencing

The following standard techniques have been adopted for georeferencing of LISS III data covering the study area. ERDAS image processing software has been used for this work. 1:50,000 scale toposheets are scanned and raster file for study area is created. These are geo-referenced based on the longitudinal & latitudinal co-ordinates. After geo-referencing all the maps are edge-matched and a digital mosaic is prepared which depicts the continuity of the study area. The LISS III data obtained from National Remote Sensing Agency (NRSA) is processed for initial corrections like drop outs, stripping and earth rotations etc. Sufficient numbers of well distributed ground control points are selected both on the maps and corresponding imagery. Care is taken to satisfy the condition on density of GCPs for image registration. Georeferencing is carried out using ERDAS image processing software. The geo-referenced image is further mosaicked and then feature matching is carried out. At the end of this process the digital data which is free from all distortions is available for digital image enhancement, classification for land use/land cover map preparation with the help of visual image analysis techniques.

5.3.2 Digital image enhancement of LISS III data

Image enhancement deals with the individual values of the pixels in the image. The goal of spectral enhancement is to make certain features more visible in an image by bringing out more contrast. Initial display of LISS III data through ERDAS software revealed that the features like minor roads and streams are not clear/visible as the contrast of the imageries very dull because of the raw data values fall within a narrow range. Therefore, an attempt is made to apply linear contrast stretch technique in order to improve the contrast of the image, which can be capable of expanding the dynamic range of radiometric resolution of LISS III digital data. To perform this technique, Look up Tables (LUT) is created that convert the range of data values to the maximum range of the display device. Based on these LUT's an enhanced image is produced.

5.3.3 Hardcopy generation

In order to derive spatial thematic data, a hardcopy of satellite image is generated through the following steps:

- Acquisition of satellite data from NRSA, Balanagar, Hyderabad and toposheets from Survey of India, Hyderabad.
- Geo-coding and geo-referencing of LISS III digital data by extracting the Ground Control Points (GCPs) from SOI toposheets and GPS Points
- Digital image enhancement and application of correction models for making the digital data free from errors and distortions both radiometry and geometry of the satellite data.

- Satellite Image in FCC mode and is used for visual interpretation to extract the thematic data by applying both pre-visual interpretation, ground truthing and post visual interpretation techniques.
- A satellite hardcopy is generated for subsequent analysis.

5.4 GENERATION OF THEMATIC MAPS FROM SATELLITE DATA

The thematic maps namely, land use/land cover and soil are generated from satellite digital hardcopy. The standard basic elements and key elements for visual interpretation are applied on this satellite hardcopy digital image so as to extract the entropy or information extent in accordance with the above thematic maps. At the end of the interpretation process the above thematic maps in the form of paper based maps are ready for subsequent scanning and automated digitization and then created a digital database for GIS data analysis and modeling. The entire procedure is discussed in detail in the following.

5.4 SPATIAL DATABASE GENERATION AND ORGANIZATION

Mapping of different themes is carried out using the data derived from remote sensing data analysis, supported with ground truth studies on GIS platform. Spatial elements of GIS database, which depends upon the end use and defines the spatial data sets that will populate the database. The spatial elements are application specific and are mainly made of maps obtained from different sources. The spatial elements are categorized into primary elements, which are the ones that are digitized and / or entered into the database, and derived elements, those that are derived from the primary elements based upon GIS operation. To perform this study the spatial database is created with the help of scanning with automated digitization and GIS software. Thematic layers are generated for the study area using the data obtained from Survey of India toposheet, satellite digital data and ground observations. The step by step procedure for creating the spatial database is discussed in the following paragraphs.

5.4.1 Flow of Operations in Spatial Database generation

Based on the design, the steps of database creation are worked out and a procedure lay down. The procedure for the spatial database creation adopted in general for preparation of all themes is described below:

Creating Spatial Frame work : The spatial framework of the GIS database can be organized in the GIS by specifying the registration points for the total database and specifying the registration points for the total database and specifying the coordinate system of the database. Registration points for the total area are entered through key - board.

Master Template Creation: A master template is created as a reference layer and consisting of the boundary, drainage and base map features etc. This template is then used for the component themes digitization.

Thematic Map Manuscript Preparation: Based on the spatial domain, the different themes oriented information is transferred from the base map to a transparent sheet. Spatial data manuscripts are consisting features that are to be digitized. And the instructions like, registration point locations and identifiers, features codes as per the defined codes, feature boundaries, tolerance specifications and other relevant digitization / scanning instructions to be followed.

Digitization of Features: The features of the spatial data set are then digitized / scanned using the GIS package. The digitization / scanning is done for each map sheet of the spatial reference. The master registration reference points are used for the digitization. Each theme prepared, digitization is done as a component into a copy of the master template layer.

Coverage Editing: The digitized coverage is processed for digitization errors such as dangles, constituting the overshoots or undershoots and labels for polygons. And finally the coverage is processed for topology creation using GIS in ARC / Info workstation.

Attribute Coding Verification: The attribute codes for the different categories need to be then verified and additional attributes – feature name, description etc. are added into the feature database. After these operations the thematic coverage are ready for GIS analysis.

5.5 SPATIAL DATA GENERATED FROM TOPOSHEETS

The spatial databases from toposheets of Survey of India (SOI) relevant for this study are

- Base map
- Drainage map
- Road network map
- Mandal reference map
- Village reference map
- Contour map
- Physiography map
- Slope map
- Watershed map
- Digital Elevation Model (DEM)

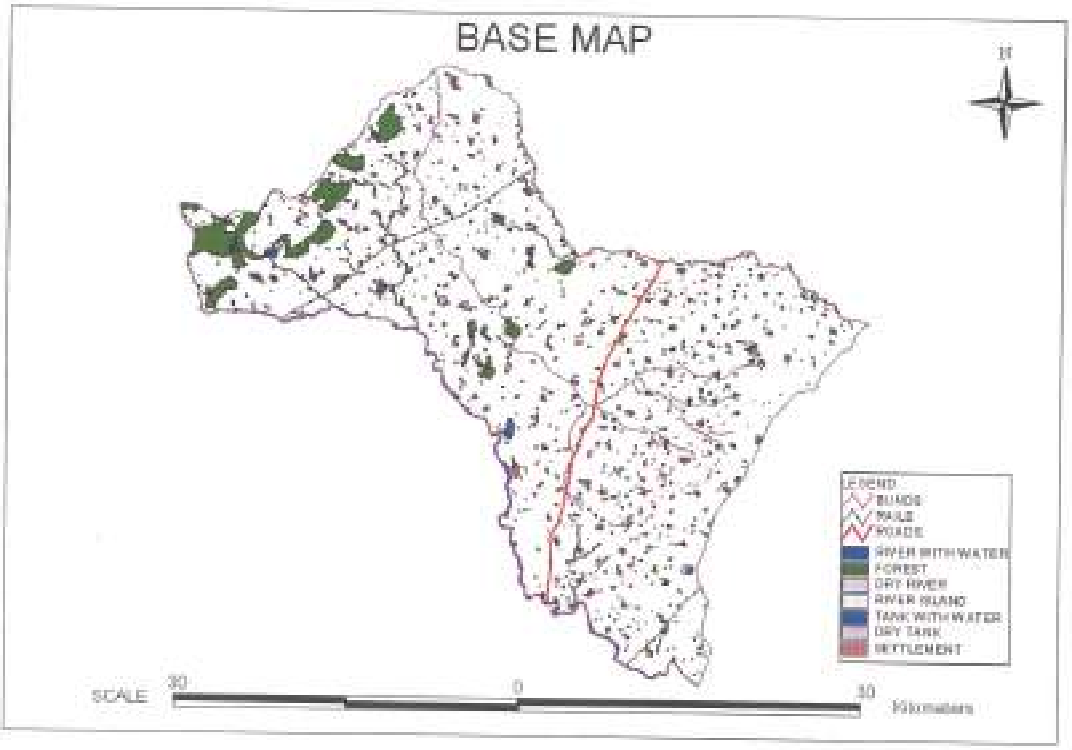
5.5.1 Base Map

Maps are representation of features on the surface of the earth drawn to a scale. A topographic map is a representation of the shape, size, position and relation of the physical features of an area. A base map consists of various features like the road network, settlements, water bodies, canals, railway track, vegetation etc. which are delineated from the toposheet. The map thus drawn is scanned and digitized to get a digital output. A map which depicts the outline structure of the district is called as base map. The base map is prepared using Survey of India (SOI) toposheets (56P/12, 56P/15, 56P/16, 57M/9, 57M/13, 57M/14, 65D/4, 65D/8, 66A/1, 66A/2, 66A/5) on 1:50000 scale and updated with the help of satellite imagery. The information content of this map is used as a baseline data to finalize all the other physical features of maps. The features included in the base map in general are district boundary, taluk/ block/mandal boundary, rivers / water bodies, district /

mandal headquarters, major settlements, major roads, railways and other towns. The characteristic features of the study area are:

- Major Roads
- Major settlements
- Rivers
- Water bodies
- Railway line
- Forest areas

Since the toposheets are very old and prepared long back, the major roads, railways and the other settlements which are recently developed are updated using satellite image and existing maps. The major settlements in the present study area are Bollapalle, Ipur,Nakarikallu,Vinukonda,Savalayapuram,Rompicherla,Narasaraopaet,Chilakaluripet,Pedanandipadu,Kakumanu,Santhamaguluru,ballikuruva,addanki,martur,Yaddanapudi,Parchuru,Chirala,karamchedu,Inkollu,Vetepalem,Janakavarampanguluru,Korisapadu,Maddipadu,Nagullup palapadu and Chinaganjam. The major water bodies represented in the base map include Gundlakamma River and Vogaruvagu. The south central railway line passes through the study area along with the NH-5.which connect different places. The base map of study area has shown in figure 5.1.

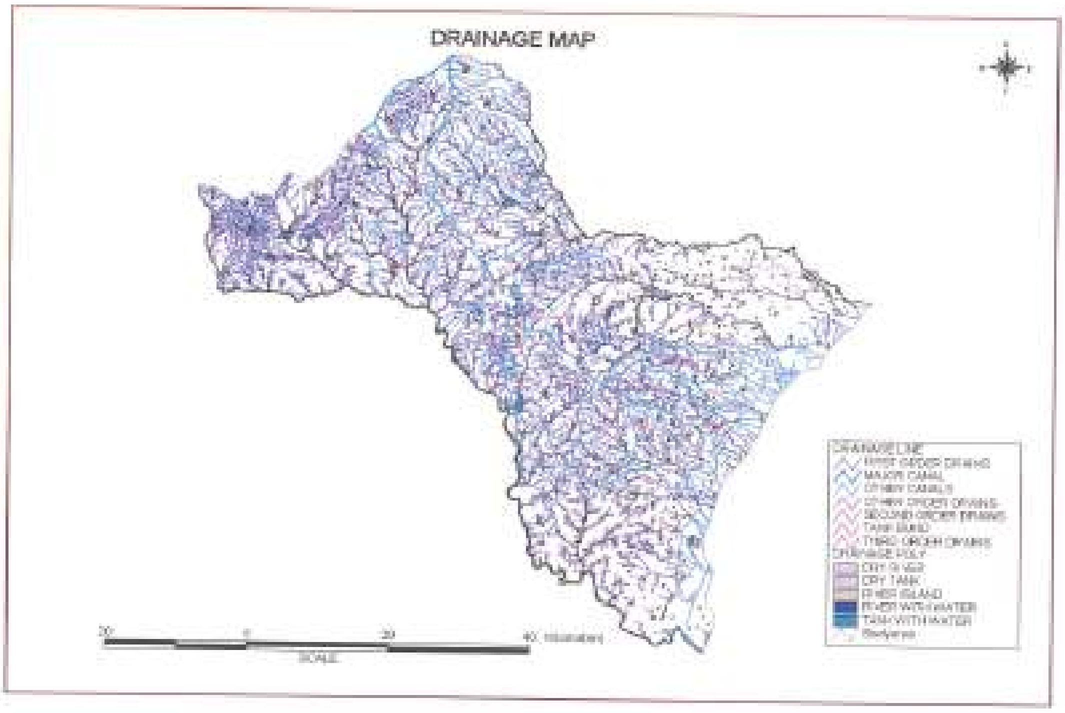


5.5.2 Drainage Map

This map consists of all water bodies, rivers, tributaries, perennial & ephemeral streams, reservoirs, tanks, ponds and the entire drainage network from first order originating in the area to the last order joining the rivers, tributaries and tanks based on topography. Understanding the importance of drainage depends on the purpose and the objective of the project. For the present study purpose the following factors have to be understood and extracted from the study of the drainage pattern. Drainage network helps in delineation of watersheds. Drainage density and type of drainage gives information related to runoff, infiltration relief and permeability.

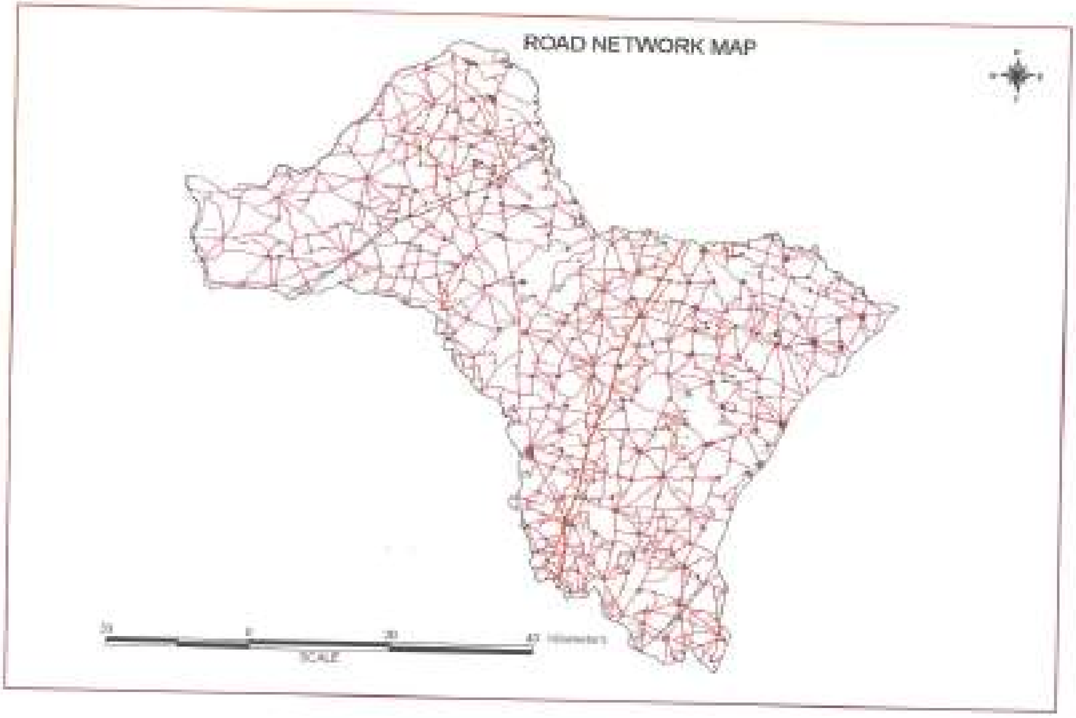
Table 5.1. Shows Drainage Density Based Criteria Proposed by smith and strahler.

Drainage Density	Texture	Runoff	Infiltration	Relief	Stratum
< 5.0	Coarse (High)	High	Low	High	High Impermeable
5.0 - 13.7	Medium	Medium	Medium	Medium	Medium Permeable
13.7 - 155.3	Ultra fine (Low)	Low	High	Low	Good Permeable



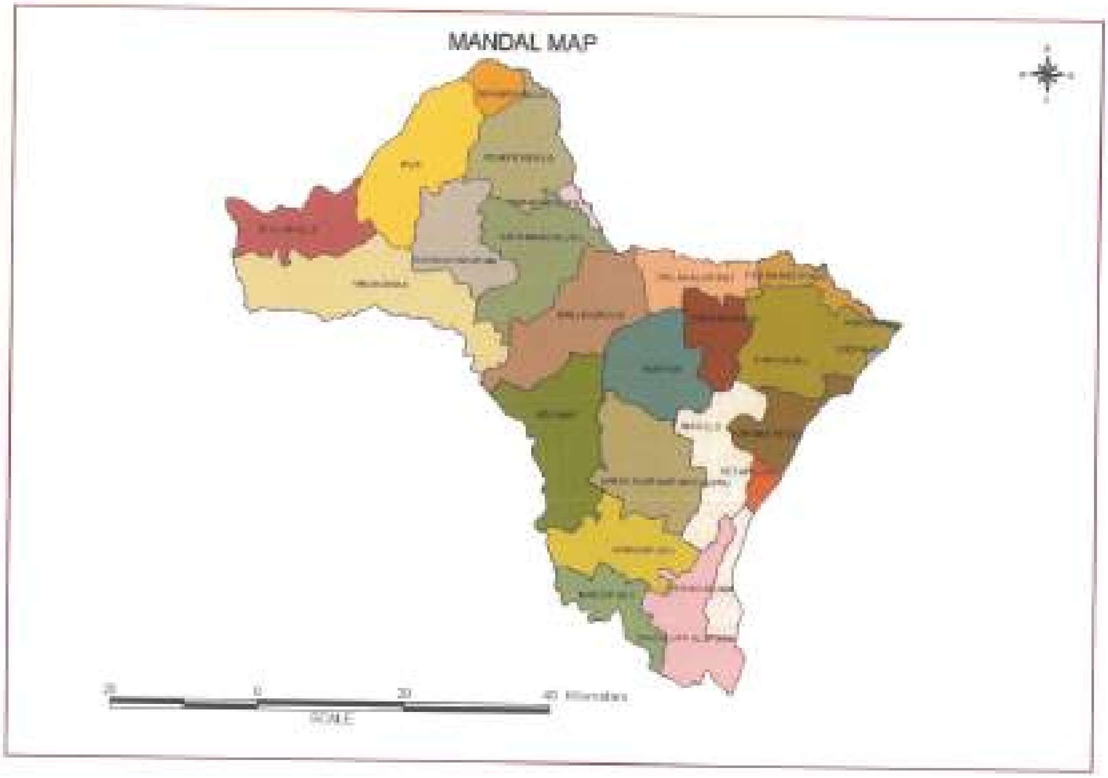
5.5.3 Road Network Map

The major and all the minor roads connecting different places of the study area are were delineated from the toposheet and a road network map was prepared. The road network map was used for the selection of shortest route during the field work for the collection of Agriculture information from farmers. Transport network interpreted using IRS-1D PAN Data when compared with 1:50,000 scale SOI map delineated about 80% of roads as depicted on map. It was possible to delineate major roads and connecting of around 10 m width in the highly congested urban areas. Railway stations and marshalling yards, main bus complexes and main road junctions were clearly identified on PAN data. Monuments like could be delineated by virtue of their unique shapes and well defined patterns observed on PAN data. Recreational facilities and parks are very clearly depicted by PAN data. Other features like road/rail bridges, brick kilns, field bunds, rows of trees in orchards could be delineated precisely using the data. Thus, the results of the data conclude that, improved spatial resolution of the PAN offers scope to map and urban features on 1: 50,000 scale. The road network map of study area has shown in figure 5.3.



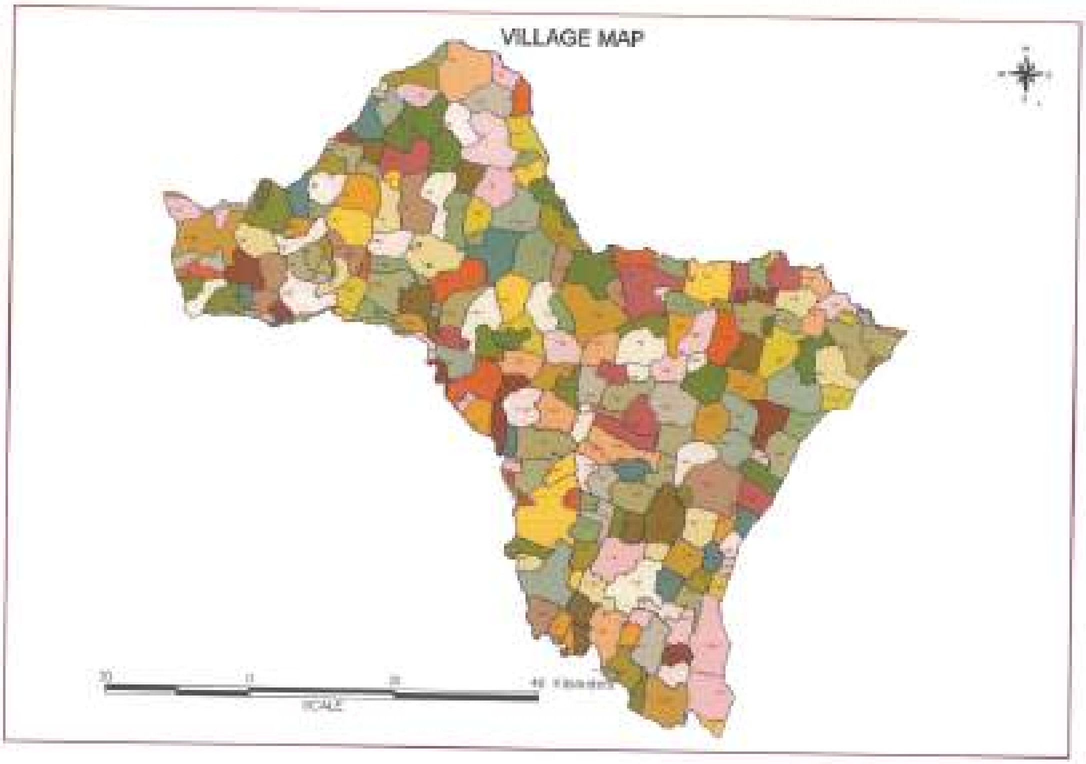
5.5.4 Mandal reference map

The mandal reference map prepared from survey of India toposheets (1:25,000 scale) and village maps the map shows the all mandal head quarters and locations of all the revenue villages in the district. The boundary of the mandals has taken from SOI toposheets. The map also contains mandal boundaries as shown in the source map. There are 25 mandals & 450 villages in the parts of Prakasam and Guntur Districts. The mandals are Bollapalle, Ipur, Nakarikallu, Vinukonda, Savalyapuram, Rompicherla, Narasaraopet, Chilakaluripet, Pedanandipadu, Kakumanu, Sathamagaluru, Ballikurava, Addanki, Martur, Yeddanapudi, Parchur, Chirala, Karamchedu, Inkollu, Vetapalem, Janakavarampangaluru, Korisapadu, Maddipadu, Naguluppalapadu, and Chinaganjam. The mandal reference map of study area has shown in figure 5.4.



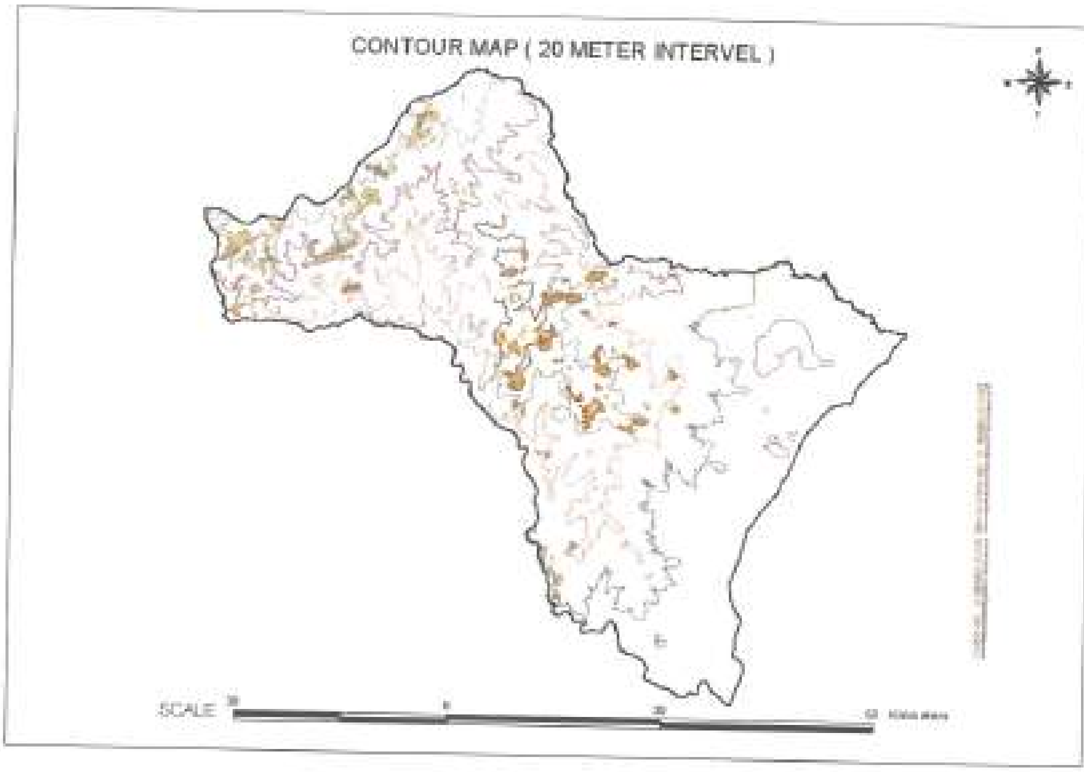
5.5.5 Village Reference map

The village reference map shows the locations of all the revenue villages in the district. The boundary of the district taken from SOI toposheets. The map also contains Mandal boundaries as shown in the source map. There are 450 villages & 25 mandals in the parts of Prakasam and Guntur Districts. A.P. Pollution Control Board supplied this data. The village reference map is used for location - reference purpose of particular crops and cropping pattern and Agricultural research stations, Religious, Historic places, Tourist places, Handlooms, Tribal areas etc. The village reference map of study area has shown in figure 5.5.



5.5.6 Contour map

Contour is a line joining the points of equal elevation. Contour interval used while preparing this map is 20 m. Spot heights are also included in this map. Elevation of the study area varies from 338 to 639 m. above mean sea level (MSL). The maximum of 639 m. height exists in the village and the minimum in village. This map is used in the preparation of slope map. The contour map of study area has shown in figure 5.6.



5.5.7 Physiography map

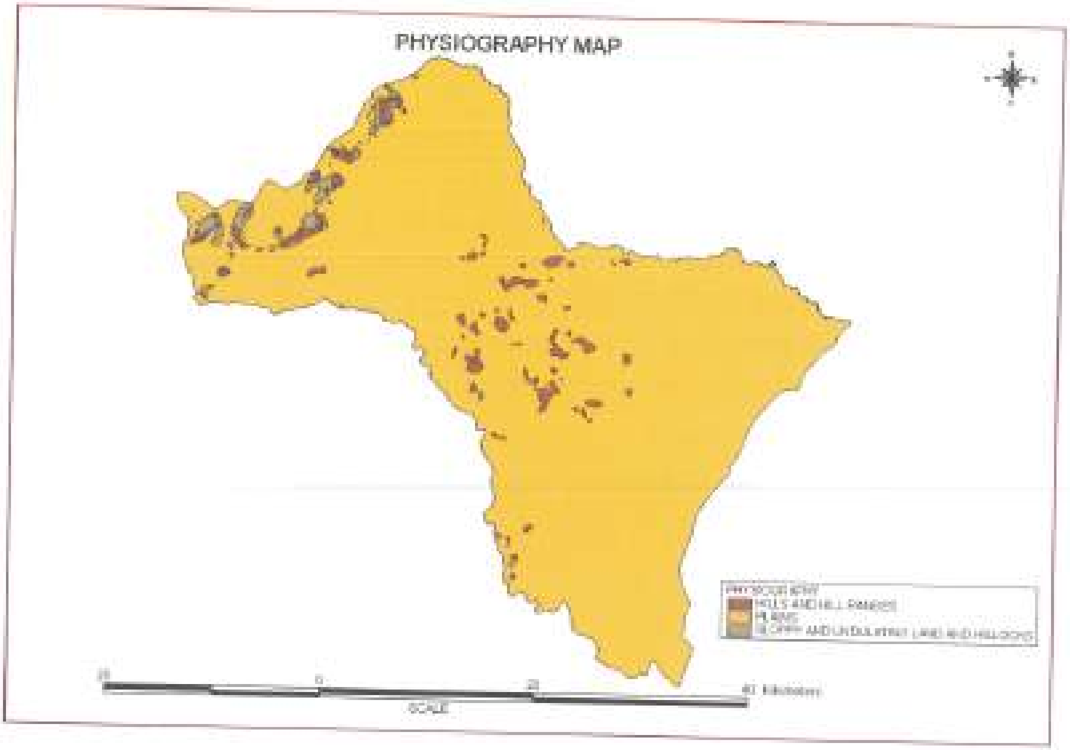
The purpose of Physiography layer is to understand disposition and distribution of barriers of winds. The Physiography is prepared using the contours derived from Survey of India topo sheets. According to the guidelines of Central Pollution Control Board (CPCB), three Physiography categories are demarcated in the map as under:

High - Hills and hill ranges with steep slopes generally high hills of more than 200m with slopes of at least 1:4.5 and all those hills that pose a constraint for construction activities.

Medium - Moderate slope areas including undulating land and hillocks.

Low- Gentle slope areas including plains

The high slope areas not only pose physical constrains for developmental activities as barriers for monsoon winds. The plains occupy the major part of the project area, which indicates nearly level, gently sloping and very gently sloping terrain. The next major unit is the undulating terrain indicating moderately and strongly sloping terrain, which indicates the steep and very steep sloping along with the residual hills. These landforms indicate the granite rocks. The schematic representation of Physiography map shown in the map. The highest elevation in the study area is 420m above msl, which is while the lowest point is 90m above msl which is at SW of Dharmavaram. The Physiography map of the study area shown in figure 5.7.



5.5.8 Slope map

Slope of land has a great influence on the soil and water loss from the area and thereby influence the land use capability. The slope percentage determines the erosion susceptibility of the soil depending upon the nature and helps in placing the lands in suitable capability classes.

The classification and methodology is followed from the guidelines of All India Soil and Land Use Survey on slope categories vides Soil Survey Manual (IARI 1971). The slope is classified based on the percentage of slope. A land with 5m of vertical drop over a horizontal distance of 100m has 5% slopes. Accordingly, 10m or 20m vertical drop for every 100m of horizontal distance is 10% or 20% slope respectively. The vertical drop is measured from the contour intervals and the horizontal distance in between the contours is measured from the contour map by multiplying the map distance with the scale factor.

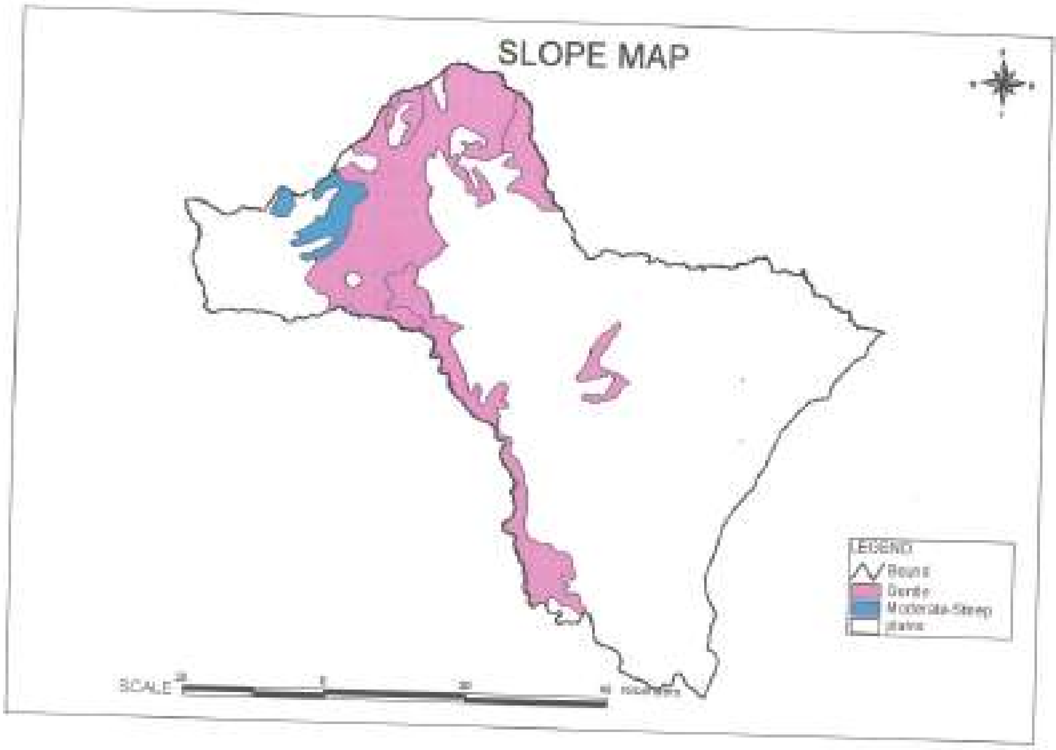
Slope classification adopted

Serial No.	Slope Category	Slope Range (in %)
1	Nearly Level	0 - 1
2	Very Gently Sloping	1 – 3
3	Gently Sloping	3 – 5
4	Strongly Sloping	5 – 10
5	Moderately Sloping	10 – 15
6	Moderately Steep to Steep Sloping	15 – 35
7	Very Steep Sloping	> 35

In the preparation of slope map GIS is used for editing the digitized work, especially to dissolve units. This map is overlaid with village map to know the sloping categories of each village. The slope map of the study area shown in figure 5.8.

The seven categories of slope are merged in to three categories as given below.

Serial No.	Slope Category	Slope Range (in %)	Slope category	Slope Range (in %)
1	Nearly Level	0 - 1	Nearly Level	0 - 1
2	Very Gently Sloping	1 – 3	Sloping Ground	1-10
3	Gently Sloping	3 – 5		
4	Moderately Sloping	5 – 10		
5	Strongly Sloping	10 – 15	Steep Slope	>10
6	Moderately Steep to Steep Sloping	15 – 35		
7	Very Steep Sloping	> 35		



5.5.9 Watershed map

Watersheds are the optimal hydrologic units for planning and implementation of various development programs. Watershed is defined as a "Natural Hydrologic entity that cover a specific area expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point." From this generalized definition it emerges that the size of a watershed is governed by the size of the stream or river in question or the point of interception of the water course like a dam, barrage etc. Obviously no political or administrative boundaries govern a watershed.

The size of the watershed could be some lakhs of hectares or if a small stream is chosen the same could be of a few hundred hectares. To avoid this ambiguity and to suggest a stage where land development could be of viable size a hierarchical approach was suggested by the Ministry of Agriculture (MOA), Govt. of India, in 1990. According to Central Water and Power Commission (CWPC), the country was distinctly delineated into 6 Water Resources Regions (WRR).

Region 1: Rivers falling into Arabian Sea, excluding Indus system.

Region 2: The Indus basin in India.

Region 3: Rivers falling into the Bay of Bengal, other than the Ganga and the Brahmaputra systems.

Region 4: The Ganga system.

Region 5: The Brahmaputra system.

Region 6: Rajasthan.

Number of Hydrologic Units at Different Stages of Delineation of our Country

Water Resources Regions	-	6
Basins	-	35
Catchments	-	112+
Subcatchments	-	500+
Watersheds	-	3237+

Watershed Codification

Water Resources Regions are assigned Arabic numbers 1, 2, 3....

Basins are assigned letters as A, B, C....

Catchments are assigned Arabic numbers 1, 2, 3....

Subcatchments are assigned letters as A, B, C....

Watersheds are assigned Arabic numbers 1, 2, 3....

Thus, watersheds will have the codes like 1A1A1, 2B2A3, 3A5C4.

It has been suggested that the watersheds could be further divided into sub-watersheds, micro-watersheds and nano-watersheds. The watershed atlas provided map sheets of 1:1 million scale indicating the codifications up to watersheds only.

The size at each stage could be on an average as follows:

Water Resource Region	:	5.0 la sq.km (+)
Basin	:	0.50 la sq.km (+)
Catchment	:	0.05 la sq.km (+)
Sub-Catchment	:	0.005 la sq.km (+)

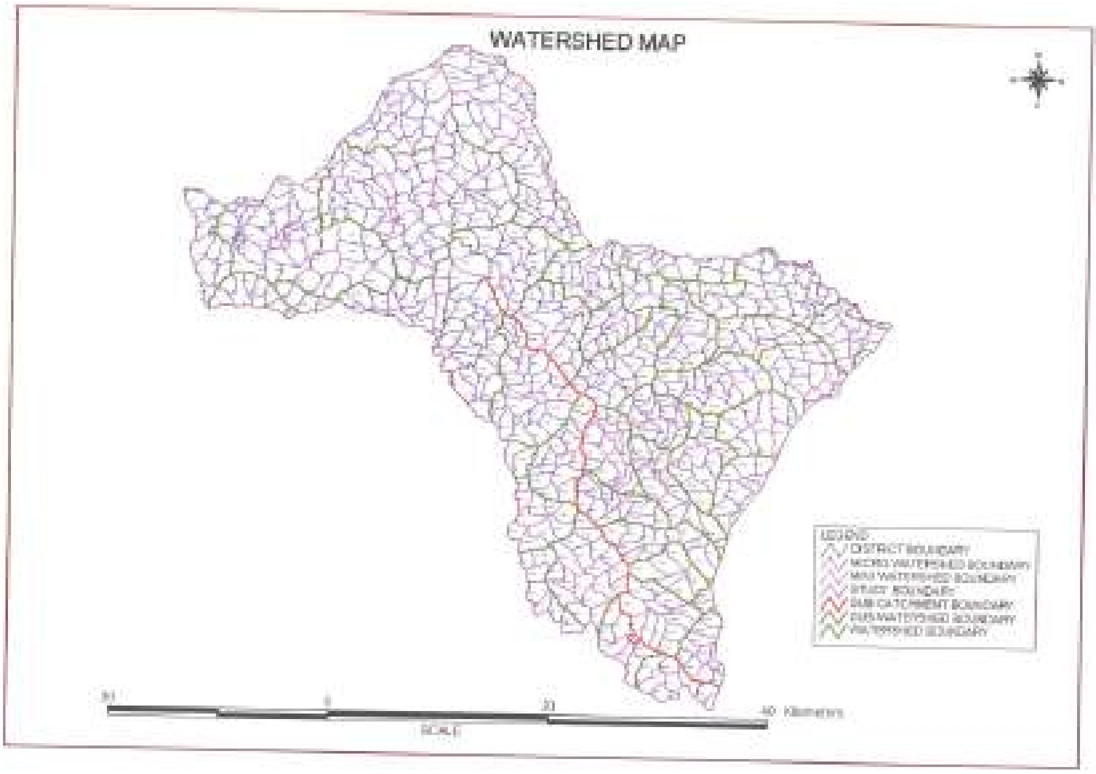
Nano-watershed	:	A few hectares of land

An alphanumerical system of codification has been suggested by the MOA under this system:

Water resources regions are assigned numbers 1,2,3,4,5 & 6

Basins	-	A, B, C.......
Catchments	-	1, 2, 3.........
Sub-catchments	-	A, B, C.......
Watersheds	-	1, 2, 3..........

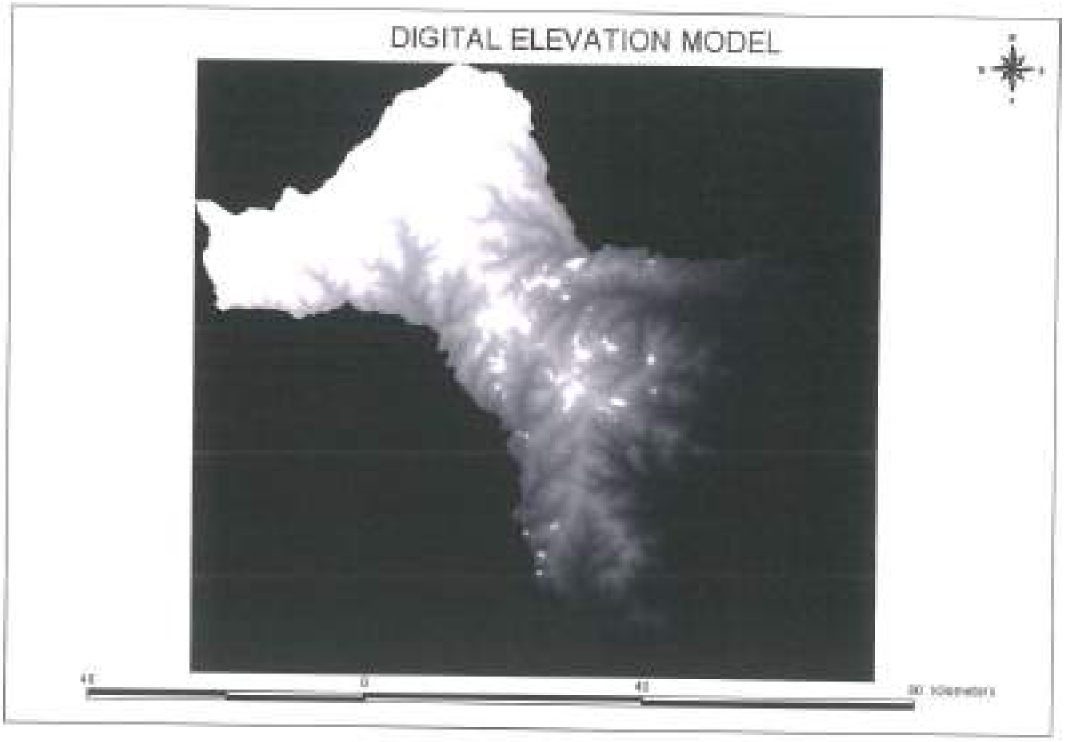
The watershed map is prepared in accordance with the National Watershed Atlas (1990). India is divided into 6 regions out of which the present study area comes under Region-4 i.e. the river flowing into Bay of Bengal. The study area watershed map shown in plate 4.3. The total area occupied by this region is 1130.48 lakh. Present study area falls under basin-C i.e. between Cauvery and Krishna basin which has a total area of 14,606 hectares. The total catchment is divided as 3 and 4 which includes Pennar (5740 ha) and Pennar Krishna (2426 ha). The 3 catchment is further divided into A, B, C, D etc sub-catchments. The sub-catchment-A i.e. Lower Pennar 536 ha consists of the present study area and occupies the 1(Right Bank Pennar) and 2 (Left Bank Pennar) watersheds. The 4 catchment is further divided into A, B, C, and D etc sub-catchments. The sub-catchment-A i.e. Maneru 479 ha consists of the present study area and occupies the 1(Bungale) and 2(Upputeru) watersheds. For a detailed study the 4C3A1, 4C3A2 and 4C4A1 watersheds are further divided into sub-watersheds (4C3A1a etc.), mini-watersheds (4C3A1a1 etc.) and micro-watersheds (4C3A1a1a etc.). The watershed map of the study area shows in figure 5.9.



5.5.10 Digital Elevation model

Differential GPS uses position corrections to attain greater accuracy. It does this by the use of a reference station. The reference station (or base station) may be a ground based facility or a geosynchronous satellite, in either case it is a station whose position is a known point. When a station knows what its precise location is it can compare that position with the signals from the GPS satellites and thus find the SA error. These corrections can then be immediately transmitted to mobile GPS receivers (real time DGPS), or the receiver positions can be corrected at a later time (post processing).

The use of DGPS can greatly increase positional accuracy (in general, the better it is the more expensive it is). Some surveying systems can give sub centimeter readings. There are a lot of different differential providers that supply real time and post processing corrections, many are private companies. The availability of these services varies greatly depending on what part of the country you are in. The DEM map of the study area shown in figure 5.10.

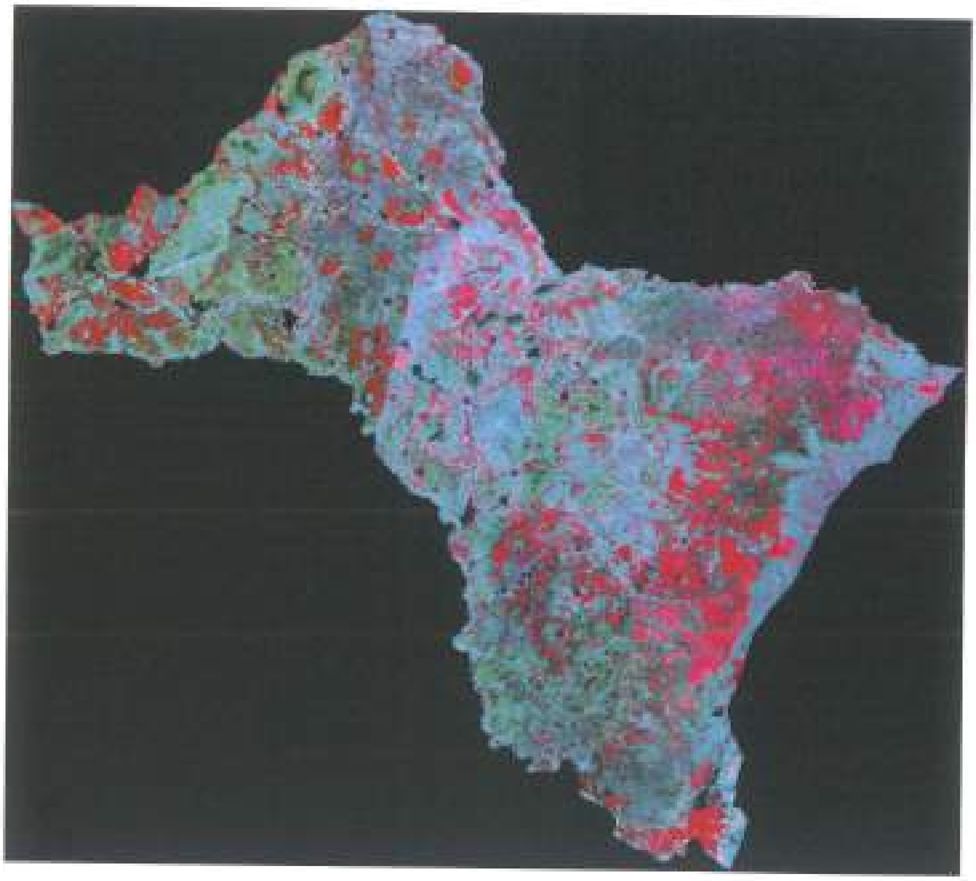


5.6 SPATIAL DATA GENERATED FROM SATELLITE DATA AND OTHER DATASETS

Before satellite images can provide meaningful measurements to user, the raw, unbiased reflectance values received by the satellite sensors require considerable mathematical processing. Manipulations are required both to register the grid of pixels to specific locations on the Earth's surface and to transform the data into useful information. Understanding the various algorithms operating on the raw data is usually beyond the ability of non specialists, and the resulting spatial data must be accepted on faith. Frequently the result of this manipulation is classified data in which pixel values indicate classes of an attribute (e.g., nominal data such as vegetation type or land use classes) rather than interval or ratio data classification algorithms and techniques are among the most highly disputed in the discipline (Estes, 1995). Methods for statistically estimating the error resulting from the classification of satellite images have been developed and do provide some quality assurance (Burrough, 1998).

5.6.1 Remote Sensing Technology for Visual Image Interpretation

The procedure consists of a set of image elements or characteristics like colour / tone, texture, pattern ,size, shape and so on, which help in the recognition or interpretation of various land use /land cover features systematically on the enhanced satellite imagery during the classification of features (Lillesand, 2000) (Table 4.4). The land use/ Land cover classification system used in this project is the system which is pioneered by United States Geological Survey (USGS) and is modified by National Remote Sensing Agency(NRSA) according to Indian conditions. A preliminary image classification key is prepared for the fussed pictorial data and is used during interpretation process. Using the image interpretation key, preliminary interpretation of satellite imagery is carried out by transferring the features from base map on to the transparency. This transparency with base line data features is then overlaid on the satellite imagery. Then the features of LU/LC are extracted and transferred from the satellite pictorial data. The doubtful areas (due to similar spectral response and spectral signature) identified during the preliminary image classification are listed out before ground verification. After finalizing the ground traverse plan the doubtful areas are physically verified and field observation about terrain condition and land use pattern are noted. Based on the ground information collected, corrections and modifications of miss classified land use/land cover details and doubtful areas are carried out on enhanced imageries for final land use/land cover classification. The final land use/land cover classes are separated by assigning standard colors with respect to each one of the land use/land cover classes. The study area satellite images are shown in figure 4.11. Figure 4.11. Shows satellite imagery of the study area



5.6.2 Generation of Thematic Layers

Based on the physical characteristics of the study area, their sources, method of derivation of maps (IMSD Technical Guidelines, NRSA, 1995), suitability and environmental sensitivity, the following maps are generated.

- Land use / Land cover map
- Waste lands map
- Geomorphology map
- Ground water potential map
- Ground water table map
- Soil map

5.6.3 Land Use / Land Cover Map

Land use refers to man's activities and various uses, which are carried on land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformation. Although land use is generally inferred based on the cover, yet both the terms land use and land cover are closely related and interchangeable. Information on the rate and kind of change in the use of land resources is essential to the proper planning, management and regulation of the use of such resources.

Knowledge about the existing land use and trends of change is essential if the nation is to tackle the problems associated with the haphazard and uncontrolled growth. A systematic framework is needed for updating the land use and land cover maps that will be timely, relatively inexpensive and appropriate for different needs at national and state level. The rapidly developing technology of remote sensing offers an efficient and timely approach to the mapping and collection of basic land use and land cover data over large area. The satellite imageries are potentially more amenable to digital processing because the remote sensor output can be obtained in digital format. Land use data are needed in the analysis of environmental processes and problems that must be understood if living conditions and standards are to be improved or maintained at current levels.

5.6.3.1 Basic Concepts of Land Use

Clawson has given nine major ideas or concepts about land. These are:

1. Location or the relation of a specific parcel of land to the poles, the equator, and the major oceans and landmasses. There is also relationship between various tracts of land, as well as a political location.
2. Activity on the land, for what purpose this piece of land or tract is used.
3. Natural qualities of land, including its surface and subsurface characteristics and its vegetative cover.
4. Improvements to and on the land. This is closely related to the activity.
5. Intensity of land use or amount of activity per unit area.
6. Land tenure, i.e. who owns the land, which uses it.
7. Land prices, land market activity and credit as applied to land.
8. Interrelations between activities on the land and other economic and social activities.
9. Interrelations in the use between different tracts of land.

5.6.3.2 Aims of Classification

1. The major aim of land use classification system is to provide a framework as broad as possible and would cover all the possible types of land use within the country that could be mapped within certain limitations.
2. The second objective is to see the applicability of IRS-IC LISS-III satellite data for delineating various land use, land cover categories through computer analysis as well as visual interpretation techniques.
3. The third objective is to provide a standardized land use, land cover classification system, which can be used with the satellite imagery available in India, at present.

5.6.3.3 Land Use / Land Cover Classification

The USGS devised a land use and land cover classification system for use with remote sensing data in the mid-1970. The basic concepts and structure of this system are still valid today. The USGS classification system was devised according to the following criteria:

i) The minimum level of interpretation accuracy using remotely sensed data should be at least 85%

ii) The accuracy of interpretation for the several categories should be about equal

iii) Repeatable results should be obtainable from one interpreter to another

iv) The classification system should be applicable over extensive areas

v) The categorization should permit land use to be inferred from the land cover types

vi) The classification system should be suitable for use with remote sensing data obtained at different times of the year

vii) Categories should be divisible into more detailed subcategories that can be obtained from large scale imagery or ground survey

viii) Aggregation of categories must be possible

ix) Comparison with future land use and land cover should be possible

x) Multiple uses of land should be recognized

USGS specified the classification, which is principally of interest to users who desire information on a nation wide, inter state, or statewide basis. Levels III and IV can be

.utilized to provide information at a resolution appropriate for regional or local planning and management activities.

5.6.3.4 Objectives of Land Use / Land Cover Map

The main objectives of land use map are,

1) The land use map will be utilized as a basic database, which provides the information for allocating new land use practices.
2) It will incorporate demographic, economic and environmental impact, which has occurred in an area.
3) Not only will the information indicate where intensive development has already taken place and where there is open land suitable for future expansion, but it will also make it possible to determine special areas, such as prime agricultural lands.
4) Land use/ land cover map will serve as a basis for monitoring land use change.
5) The land use map will serve as a base in the integrated overall planning of agricultural and industrial development of the region.

Land use refers to man's activities and various uses, which are carried on land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformation. Although land use is generally inferred based on the cover, yet both the terms land use and land cover are closely related and interchangeable. Information on the rate and kind of change in the use of land resources is essential to the proper planning, management and regulation of the use of such resources. Knowledge about the existing land use and trends of change is essential if the nation is to tackle the problems associated with the haphazard and uncontrolled growth. A systematic framework is needed for updating the land use and land cover maps that will be timely, relatively inexpensive and appropriate for different needs at national and state level. The rapidly developing technology of remote sensing offers an efficient and timely approach to the mapping and collection of basic land use and land cover data over large area. The satellite imageries are potentially more amenable to digital processing because the remote sensor output can be obtained in digital format. Land use data are needed in the analysis of environmental processes and problems that must be understood if living conditions and standards are to be improved or maintained at current levels.

S.No.	Level I	Level II
1.	Urban or built-up land	11 Residential 12 Commercial and service 13 Industrial 14 Transportation, communications and utilities 15 Industrial and commercial complexes 16 Mixed urban or built-up land 17 Other urban or built-up land
2.	Agricultural land	21 Cropland and pasture 22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas 23 Other agricultural land
3.	Rangeland	31 Herbaceous rangeland 32 Shrub and brush rangeland 33 Mixed rangeland
4.	Forest land	41 Deciduous forest land 42 evergreen forest land 43 Mixed forest land
5.	Water	51 Streams and canals 52 Lakes 53 Reservoirs 54 Bays and estuaries
6.	Wetland	61 forested wetland 62 Nonforested wetland
7.	Barren land	71 Dry salt flats 72 beaches 73 Sandy areas other than beaches 74 Bare exposed rock 75 Strip mines, quarries and gravel pits 76 Transitional areas 77 Mixed barren land
8.	Tundra	81 Scrub and bush tundra 82 herbaceous tundra 83 Bare ground tundra 84 Wet tundra 85 Mixed tundra
9.	Perennial snow or ice	91 Perennial snowfields 92 Glaciers

(Source: Lillesand, 2000)

Table 4.4. USGS Land Use / Land Cover Classification System

5.6.3.5 Remote sensing as related to Land Use

Land is the most important natural endowment on which all the man's activities are based. The interaction between man and land (Soil), vegetation, water and other resources culminates in the development of land use. A sequential development of land use with time results in different land utilization patterns and trends. Growing population and increased human activities are exerting pressure on limited land resources. This is evident by the decrease in per-captia available cultivable land from 0.48 ha. In 1951 to 0.22 ha. In 1991 the unprecedented demand on land for agriculture, urban and industrial, mining besides for forests and pastures (apart from land degradation and erosion) calls for an optimum utilization of land. This requires timely and up to date information about the spatial distribution, location, extent, type of different land use and its spatial pattern of changes over a period of time for scientific land use planning and management.

Ever since the remotely sensed data are available (Since the launch of ERTS-1 in 1972), the mapping of land use/land cover has gained importance. Earlier to this, the land use details have been collected by village officers and the surveys lacked. The spatial representation, reliability are time consuming. By the time the detail are compiled and reaches the planner, the data become obsolete. Remotely sensed data, due to its synoptic, unbiased, repetitive coverage provides reliable information on spatial distribution of land use. Further, this is the only source for the inaccessible areas. Organization like Central Arid Zone Research Institute (CAZRI) in Jodhpur, National Remote Sensing Agency (NRSA) in Hyderabad, Space Application Center (SAC) in Ahmedabad, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) in Nagpur, All India Soil and Land Use Survey (AIS&LUS) in New Delhi and other state remote sensing centers have been engaged in land use mapping using remotely sensed data. NRSA has carried out land use surveys in some parts of the country using MSS, TM Pavam Terra and recently SPOT and IRS data. Wasteland mapping of the entire country on 1:1 M scale was completed using 1980-82 MSS false colour composites based on which around 53.3 million ha, (16.2%) of the total geographical area of the country was categorized as wastelands under eight different categories. Presently land use/land cover mapping of all the states and union territories is being carried out on 1:250,000 scale, based on IRS 1C, LISS-III image on 1:50,000 scale, besides other collateral data as available in the form of maps, charts, census records, reports, and Survey of India topographical maps.

Some of the characteristics of remote sensing which are related to land use may be inferred from the criteria given by Anderson. These important characteristics are: The interpretation from one interpreter to another will vary greatly for certain types of interpretation where insufficient guidelines or poorly constructed and defined classes are used. Terrain appearance and the size of similar features change from place to place and the level of available detail may therefore change for similar imagery scales. Terrain appearance varies from season to season. Land use cannot be read directly from imagery. What can be obtained from the imagery is dependent on scale. Land cover must be used to infer land use.

5.6.3.6 Application of Remote sensing techniques for land use/land cover

Remote sensing techniques provide reliable, accurate baseline information for land use mapping. Generalized delineation of land use classification for large area and spatial distribution of land use categories is possible by satellite imagery as it provides synoptic view. Satellite Remote sensing techniques are helpful to study changes at regular intervals. Rapid small scale land use mapping for state and national series on 1:1,000,000 and 1:250,000 is possible by satellite remote sensing techniques. Satellite remote sensing provides data in different bands of the electromagnetic spectrum. Also we can have the coverage of the same area on different dates. We can combine data in different bands to produce a color composite. Land use mapping both by visual interpretation and computer aided interpretation is possible by satellite remote sensing technique.

5.6.3.7 Methodology for land use/land cover mapping

Flowchart showing the methodology adopted for land use/land cover mapping is given in Figure 1. For analysis and interpretation two types of data are needed:

1. Basic data 2. Ground data

1. **Basic data includes:**

    (a) Satellite data of LISS-III

    (b) Toposheets

    (c) Local knowledge

    (d) Area map on any scale to transfer details

    (e) Reports and other literature of the study area

2. **Ground data:** Ground data is very much essential to verify and to increase the accuracy of the interpreted classes and also to minimize the field work.

3. **Data analysis:** For analysis and interpretation of satellite data, the study can be divided into three parts:

    A. Preliminary work

    B. Field work

    C. Post field work

A. Preliminary work includes:

    i. to see the limitation of satellite data

    ii. to lay down the criteria for land use classification to be adopted

    iii. to fix the size of mapping units, which depends upon the scale

    iv. interpretation of different land use/land cover classes

    v. demarcation of doubtful areas

    vi. preparation of field land use/land cover map

B. Field work:

    i. Type of ground data to be collected

    ii. Selection of sample area for final classification

    iii. Checking of doubtful areas

    iv. Change in land use/ land cover due to wrong identification, fresh development, nomenclature.

v. General verification

C. Post field work:

i. reinterpretation or analysis or correction of doubtful areas

ii. transfer of details on base map

iii. marginal information

iv. preparation of final land use/land cover map

5.6.3.8 Land use/land cover description of Study area:

Present land use/land cover map showing the spatial distribution of various categories and their areal extent is vital for the present study. The spatial distributions of various land uses are interpreted based IRS-ID, LISS III data. The different land use/ land cover classes existing in the area over space and time are briefly discussed here in their dimension. The land use \ land cover map of study area has shown in figure 4.12. The wastelands map of the study area shown in figure 4.13.

Table 4.5. Land Use / Land Cover classification

Settlements

It is defined as an area of human habitation developed due to non agricultural use and that which has a cover of buildings, transport, and communication, utilities in association with water, vegetation and vacant lands. Settlements appears as dark bluish green in the core and bluish on the periphery on satellite imagery. It may be either big or small in size, irregular in shape with coarse or mottled texture. The total settlements area in the present study is about 1126 Ha, which includes some parts of Nellore urban area, etc.

Agriculture Area

It is defined as the land primarily used for farming and for production of food, fiber, commercial and horticultural crops. It include land under crops (irrigated and unirrigated), fallow and plantations etc.

Crop land

It is evident from the study of the two season's data that most of the double cropped area is seen under canal command or ground water irrigation area. The cropping intensity is high in these areas because of the physical factors like flat terrain, good alluvial soils, good rainfall and assured irrigation from delta canals of Somasila reservoir. Most of the double cropped area was found in both banks of Gundlakamma River and area is estimated to be 15,305 ha. Single crop area found to be 11,215 ha.

Fallow lands

Fallow land is described as agricultural land which is taken up for cultivation but is temporarily allowed to rest, un cropped for one or more seasons, but not less than one year. These lands are particularly those which are seen devoid of crops at the time, when imagine taken up for both seasons. The area under this category is estimated as 11 ha.

Plantations

It is described as an area under agricultural tree crops, planted adopting certain agricultural management techniques. It includes coconut, arecant, citrus, orchards and other horticultural nurseries. This mostly confined to the beach ridges, sandy areas and along river courses. Plantation can be seen very prominently on the imagery with a dark red to red tone, regular in shape, sharp edges and coarse to medium texture. Their size varies from small to medium. The area under this category forms 759 ha.

Scrub forest

It is an area bearing an association predominately of trees and other vegetation types capable of producing timber and other forest produce. The scrub forest describes as a forest where the vegetative density is less than 20% of the canopy cover. It is the result of both biotech and abiotic influences. Scrub is a stunted tree or bush/ shrub. Most of the low lying hills are in degraded conditions consisting of mixed dry deciduous types of species and it appears as light green colour in satellite image. In the present study scrub forest identified as 1084 ha.

Marshy/ Swamp Lands

Marshy land is that which is permanently or periodically inundated by water and is characterized by vegetation which includes grasses and weeds. This category of land is estimated to be 224 ha.

Land with Scrub

It is the land, which has an undulating topography with thin soil cover and scattered trees/ scrubs. These lands are being used for grazing and are ideal sites for plantations. 3210 ha.

Water Bodies

The water bodies are identified based on their tone, regular to irregular shape & smooth to mottled texture on the satellite imagery. Surface water spread of the tank or lake varies from season to season. The major river present in the study area includes the Gundlakamma River. It appears as long, narrow to wide feature on the imagery with an irregular shape and a smooth texture. The water bodies mainly tanks in the study area occupied 3,146 ha and dry river and tanks estimated to be 2,143 ha.

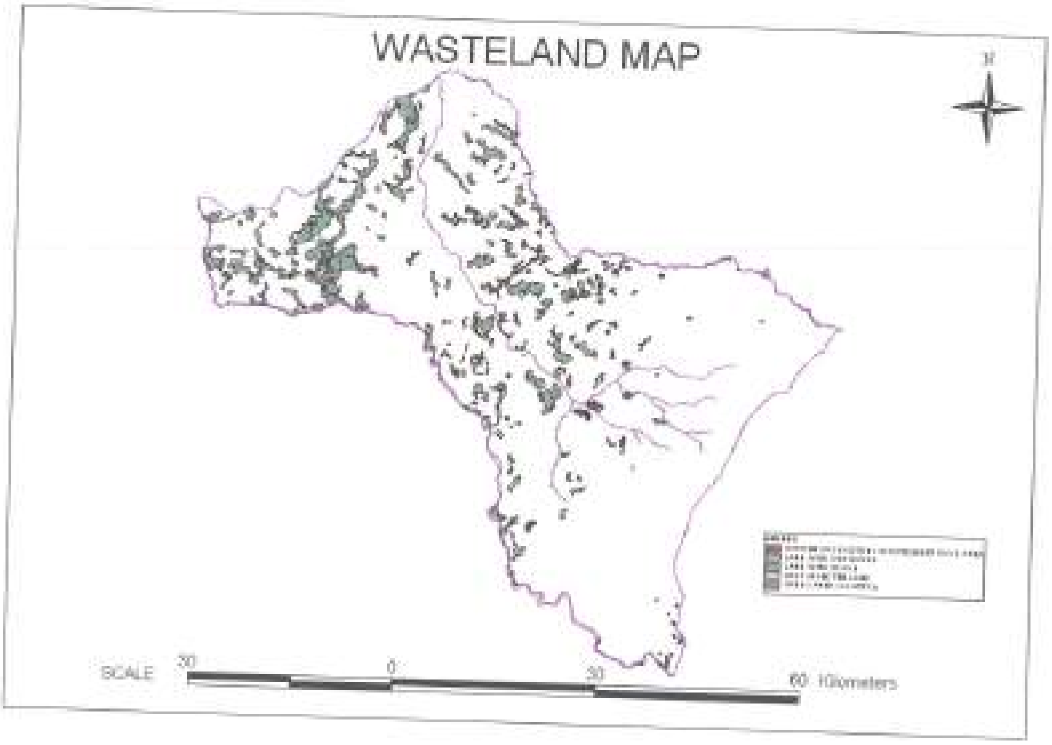
Sandy Area

These are the areas which have stabilized accumulations of sand in situ or transported in coastal or riverine areas. The sand area occurs in the form of sand dunes, beaches, channel islands etc. The sand area appears in satellite image as white colour and area estimated as 970 Ha.

Waterlogged Areas

Waterlogged land is that land where the water is at/ or near the surface and water stands for most of the year, such lands usually occupy topographically low lying areas. The area is estimated as 20 Ha.

5.6.4 Wastelands map



5.6.5 Geomorphology map

Geomorphography is defined as part of geomorphology dealing with the description of Earth's surface features / landforms. The linkage between the physiographic units and geomorphic units are necessary to relate the landforms and soils. Geomorphology map is prepared by visual interpretation of high-resolution satellite imagery with the help of Survey of India Topographic maps and ground truth. Lithology, drainage and contour maps are considered while preparing the geomorphology map. The earth's surface can be classified into different geomorphic units/land forms based on their physiographic expression, origin, material content and climatic conditions, etc. Technical guidelines of National Remote Sensing Agency are taken into consideration in the classification of geomorphic units. In the study area, the following eight geomorphic units are delineated from the satellite imagery. The geomorphology map of the study area shown in figure 4.14.

PPS : Pediplain Shallow Weathered

VFS : Valley Fill Shallow

PD : Pediment

PIC : Pediment-Inselberg Complex

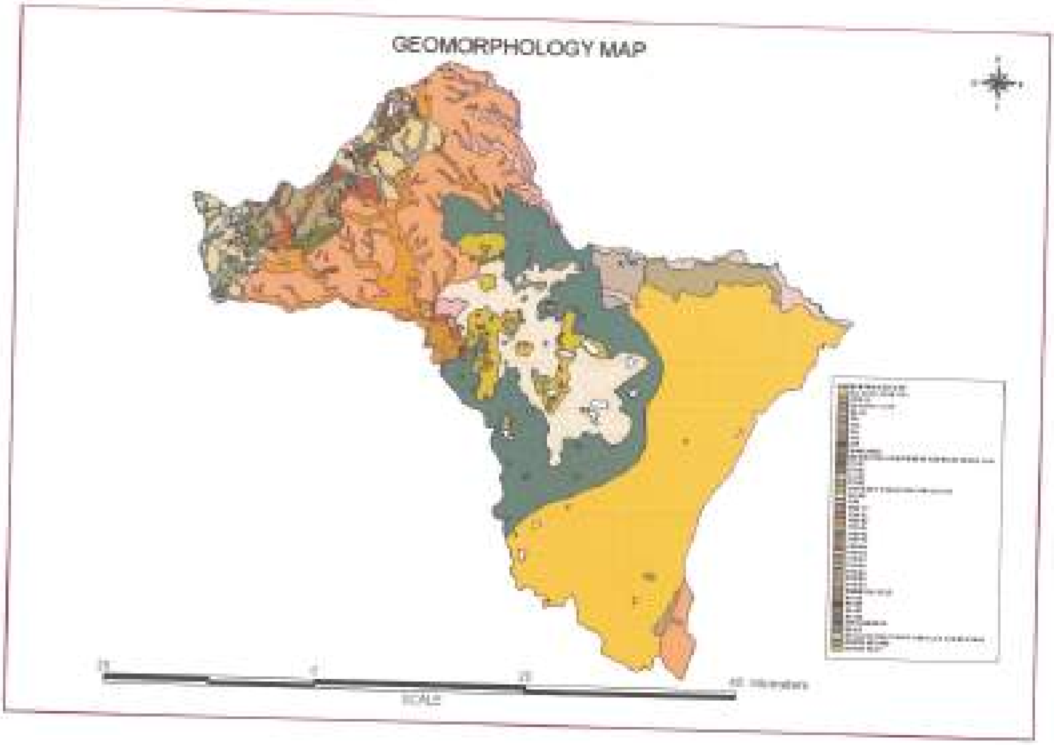
I : Inselberg

DR : Dyke Ridge

RH : Residual Hill

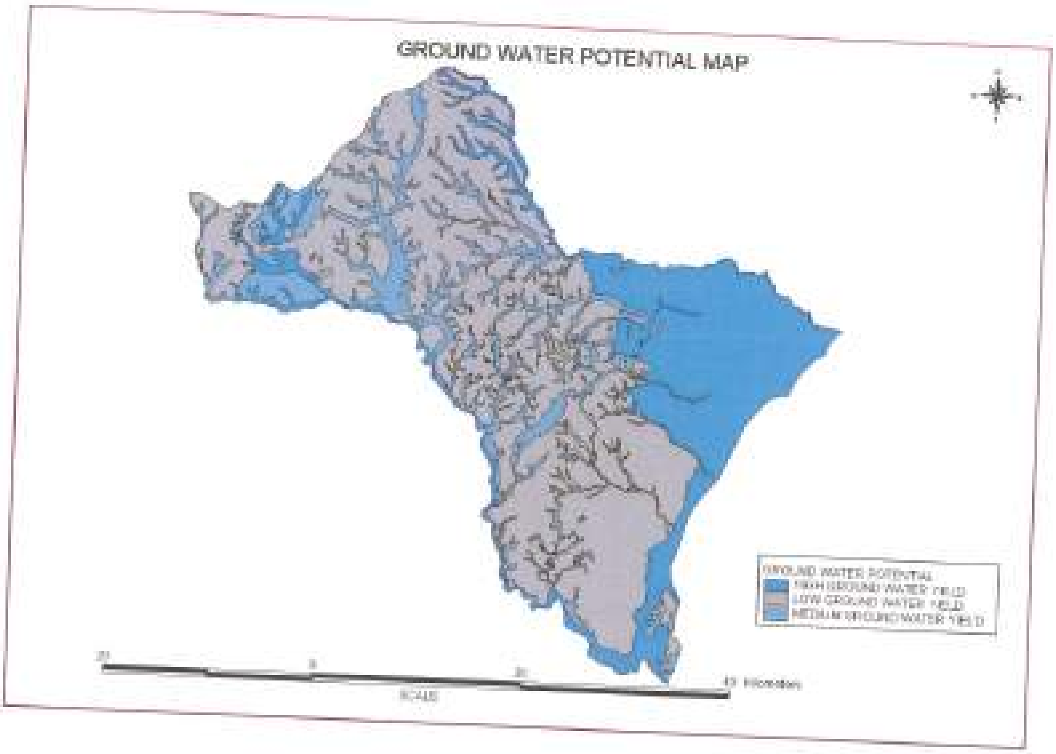
DH : Denudational Hill

Maps Derived from Hydrogeomorphology and Ground water Data



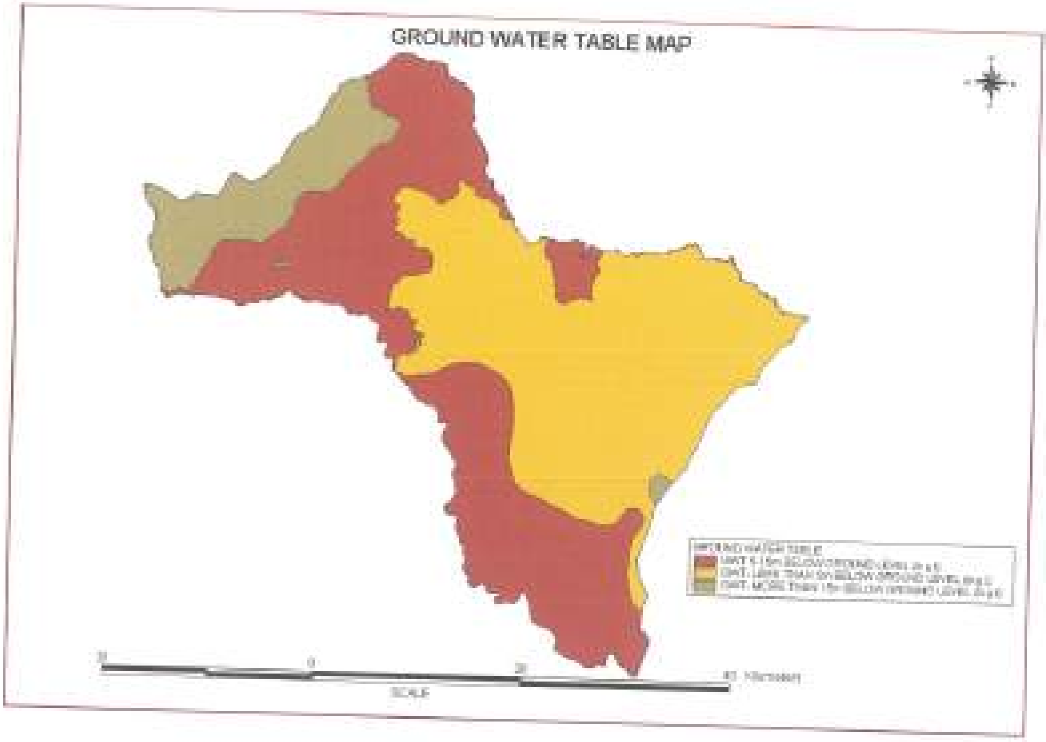
5.6.6 Ground water potential map

The ground water potential map is prepared based on the analysis of various themes such as geomorphology, land use / land cover, lineament, intersection points, drainage pattern, lithological evidences by using converging evidence concept, besides the collateral data obtained from State Ground Water Board with necessary field checks. The ground water potential map reveals the available quantum of ground water. This map is delineated into three zones High, Medium, and Low potential areas / zones as per CPCB guide lines. The high potential areas represent areas with adequate ground water resources, low potential zone represent areas where ground water is not available and the medium potential zone represent areas where excessive with drawls may lead to ground water depletion. In the project area, the geomorphic unit Pediplain with moderate weathering (PPM) indicate high ground water potential which is observed along the Gundlakamma River and areas surrounding major tanks such as. Pediplain with shallow weathering (PPS) indicating medium ground water potential which is observed in major part of the study area. The other geomorphic units such as pediments, inselbergs and residual hills indicate low ground water potential. The ground water potential map of the study area shown in figure 4.15.



5.6.7 Ground water table map

This map is prepared based on information from the Central and State Ground Water Departments, besides necessary ground checks. During fieldwork, information about the depths of water levels are obtained from the residents and used in preparation of this map. The ground water table map of the study area shown in figure 4.16.



5.6.8 Soil Map

Soil is a major component of land system which provides a medium for plant growth. The potentials and limitations of a soil for sustained use under agriculture, horticulture, silvipasture and forestry as well as its response to irrigation and other management practices are controlled by its inherent qualities and characteristics. The quality of the soil is a function of its morphological, morophometric, physical and chemical characteristics. These characteristics are expressed a taxonomic class as depicted on soil map with locational reference. Soil mapping of the region is intended to serve as a crucial input for preparing an integrated plan for sustainable development of the area. Soil surveys provide desired information on nature, location, extent and physio-chemical characteristics along with their spatial distribution. Earlier, soil surveys have been carried out using topographic maps and cadastral maps as data base. The development of aerial photo interpretation technique in late sixties in India substantially augmented the efficacy of soil mapping programme. The launch of first satellite of Landsat series during 1972 and subsequently earth observation satellites opened a new vista in this endeavor. By virtue of fairly large area coverage in discrete bonds of the electromagnetic spectrum at a regular interval besides amenability of such data to digital analysis on image processing/analysis systems, the space borne data have been founded to provide timely, reliable and cost-effective information on natural resources including soils. Conventional soil mapping through intensive field traversing is tedious, slow and subjective. Application of remote sensing for soil mapping helps to overcome these shortcomings encountered in traditional system.

The properties and ultimate use of soils are affected to a great extent by climatic parameters. In addition, these parameters also govern the crop growth. Hence they have been included as soil properties, namely soil temperature at various categorical levels in soil taxonomy (U.S. Dept. of Agriculture, 1951).

The specific objectives of the soil mapping are:

1. Identification, characterization and classification of the soils of the area.
2. Generation of derivative maps
3. Land evaluation for food/cash and horticultural crops.

Methodology:

The approach followed for delineating soil scape boundaries is as follows:

Preliminary visual interpretation:

For preparing soil resources map, a collective approach comprising mono scopic visual interpretation of IRS –1B, LISS-III geocoded false colour composite (FCC) picture on 1:50,000 scale and adequate field verification along with the collateral data namely topographic maps and published soil survey reports and maps was adopted. Topographic information taken from SOI toposheets on 1:50,000 scale was superimposed onto FCC prints of LISS-III data. An image interpretation key in terms of lithology, Physiography, contour information, land use, erosion status and IRS image characteristics namely colour, texture, shape, pattern, association etc. was developed in order to correlate them with the distribution of soils. Sample strips were randomly selected for further field verification.

Ground Truth Collection:

Field visits were made to study soil profile characteristics and to correlate the interpretation units with the soils of the study area. Intensive profile examinations were carried out in the sample strips. Soil samples were collected from representative profiles for analysis in the laboratory. Random observations were however also made outside the sample strips in order to account for variation in soil therein.

Post Field Interpretation:

The soil profile data along with their taxonomic classification were incorporated into image interpretation units. Based on observations in the field, soil boundaries drawn during preliminary visual interpretation were modified and a legend shoeing soil series and associations was prepared. Subsequently the soil scape boundaries were transferred onto base maps prepared from Survey of India toposheet at 1:50,000 scale. The soil map is shown in Plate 4.17.

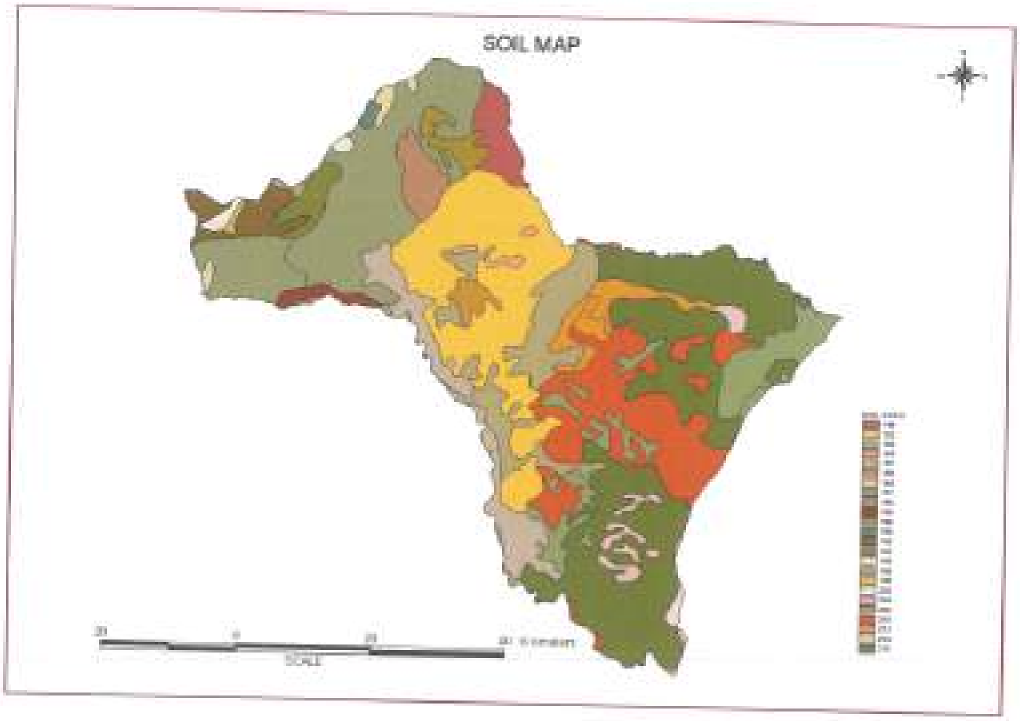


Table 4.6. Shows soil units with 3 tier symbol, description & soil taxonomy

Soil Code	Description	Soil Taxonomy
100	Moderately deep, moderately well drained, cracking clay, calcareous soils with very high AWC, on undulating lands with moderately deep, moderately well drained, calcareous, clay soils.	Fine, montmorillontic, (calcareous), Leptic Haplusterts. Fine mixed, (calcareous), Typic Ustropepts.
172	Very deep, well drained, clayey soils with medium AWC, on undulating lands, moderately eroded; associated with: Deep, well drained, clayey soils.	Fine, mixed, Typic Rhodustalfs Fine, mixed, Typic Haplustalfs
175	Shallow, somewhat excessively drained, gravelly clay soils with very low AWC, on hills & ridges, severely eroded; associated with: Rock outcrops	Clayey-skeletal, mixed, Lithic Listic Haplocambids. Rock lands
176	Moderately deep, moderately well drained, cracking clay, calcareous soils with very high AWC, on undulating lands, moderately eroded; associated with: Deep, well drained, clayey, calcareous soils.	Fine, montomorillonitic, (Calcareous), Ustertic Haplocambids Fine, mixed, (calcareous), Ustic Haplocambids.
177	Moderately deep, moderately well drained, cracking clay, calcareous soils with very high AWC, on gently sloping lands, slightly eroded; associated with: Deep, moderately well drained, cracking clay soils.	Fine, montmorillonitic, (calcareous), Ustertic Haplocambids. Fine, mixed, Aridic Haplocambids.
181	Shallow, somewhat excessively drained, gravelly loam soils with very low AWC, on hills and ridges, with stony surface, very severely eroded; associated with : Rock outcrops	Loamy-skeletal, mixed, (Paralithic) Ustorthents Rock lands
182	Moderately deep, well drained, gravelly loam, calcareous soils with very low AWC, on gently sloping lands, moderately eroded; associated with: Moderately shallow, well drained, gravelly clay soils.	Loamy-Skeletal, mixed, (calcareous), Typic Ustropepts Clayey-Skeletal, mixed, Typic Rhodustalfs.
185	Shallow, well drained, gravelly clay soils with very low AWC, on rolling lands, severely eroded; associated with: Shallow well drained, gravelly clay soils.	Clayey-skeletal, mixed, Lithic Ustropepts Clayey-Skeletal, mixed, Lithic Rhodustalfs
186	Shallow, somewhat excessively drained, gravelly clay soils with very low AWC, on hills and ridges, severely eroded; associated with: Rock outcrops	Clayey-Skeletal, mixed, Lithic Ustropepts Rock lands
190	Very deep, imperfectly drained, cracking clay, calcareous soils with very high AWC, on gently sloping lands, slightly eroded; associated with: Very deep, moderately well drained, cracking clay, calcareous soils.	Very fine, montmorillonitic, (calcareous), Typic Haplusterts Fine, montmorillonitic, (Calcareous), Vertic Ustropepts.
192	Very deep, moderately well drained, cracking clay, calcareous soils with very high AWC, on undulating lands, moderately eroded; associated with: Deep moderately will drained cracking clay soils	Very fine, montmorillontic, (calcareous), Aridic Haplusterts. Fine, montomorillonitic, (calcareous), Ustertic Hamplocambids.
195	Rock outcrops on hills and ridges; associated with: Very shallow, excessively drained, gravelly loam soils with very low AWC, very severely eroded.	Rock lands Loamy-Skeletal, mixed, Lithic Ustorthents
196	Rock outcrops on hills and ridges; associated with: Shallow excessively drained, gravelly loam soils with very low AWC, very severely eroded.	Rock lands Loamy-Skeletal, mixed, Lithic Ustropepts
209	Deep, well drained, loamy soils with high AWC, on undulating lands, moderately eroded; associated with: Very deep, well drained, clayey soils	Fine, mixed, Typic Ustropepts.
210	Deep, well drained, clayey soils with high AWC, on very gently sloping plains, slightly eroded; associated with: Very deep, well drained, clayey soils.	Fine, mixed, Typic Ustropepts. Fine, mixed, Typic Haplustalfs
211	Deep, well drained, clayey soils with high AWC, on very gently sloping plains, slightly eroded; associated with: Deep, poorly drained, clayey soils.	Fine, mixed, Typic Ustropepts Fine, mixed, Aeric Tropaquepsts
212	Deep, well drained, clayey soils with high AWC, on undulating lands, moderately eroded; associated with: Moderately deep, well drained, gravelly clay soils with low AWC.	Fine, mixed, Typic Ustropepts Clayey-Skeletal, mixed, Typic Ustropepts
213	Very deep, moderately well drained, clayey soils with high AWC, on salt pans, surface salt encrustations, strongly saline, slightly flooded; associated with: Deep imperfectly drained,	Fine, mixed, Typic Ustropepts Fine, mixed, Aquic Ustropepts

	clayey soils.	
214	Deep, moderately well drained, clayey soils with high AWC, on lowlands, slightly flooded; associated with very deep, well drained, stratified loamy soils.	Fine, mixed, Typic Ustropepts Fine loamy, mixed, Fluventic Ustropepts.
216	Deep, imperfectly drained, cracking clay soils with very high AWC, on swamps and marshes, very shallow water table, strongly saline, slightly flooded; associated with: Deep, imperfectly drained, clayey soils.	Fine, montmorillonitic, Typic Haplusterts. Fine, mixed, Aquic Ustropepts.
223	Deep, imperfectly drained, cracking clay,calcarious soils with very high AWC , on lowlands, shallow water table ; associated with : Deep , imperfectly drained , cracking clay, calcareous soils	Fine, montomorillonitic,(calcareous) , chromatic Haplusterts Fine,montmorillontitic,(calcareous),Vertic Ustropepts
231	Deep, well drained, gravelly clay soils with surface crusting and low AWC , on gently sloping plains, slightly eroded; associated with: very deep, well drained, clayey soils with high AWC	Clayey skeletal, kaolinitic,typic Haplustalfs Fine, kaolinitic,Typic Ustropepts
232	Very deep, well drained, clayey soils with surface crusting and medium AWC, on gently sloping plains, slightly eroded; associated with: Very deep, well drained, gravelly clay soils with low AWC.	Fine , kaolintic, Typic Haplustsfs Clayey skeletal, kaolintic, Typic Haplustalfs
238	Deep, well drained, gravelly clay soils with surface crusting and low AWC , on gently sloping plains, moderately eroded; associated with: very deep, well drained , clayey soils.	Clayey skeletal, mixed Typic Rhodustalfs Fine , mixed, Rhodic paleustalfs

6. MODELS DEVELOPMENT

6.1 DEVELOPMENT OF CROP YIELD PREDICTION MODEL (CYPM)

The present study in ground data activity, digital data analysis and crop acreage, crop yield and production estimates. After collection of historical data from Addanki branch canal command area and Department of Agriculture, Govt. of Andhra Pradesh, the work plan is prepared. The Ground truth work carried out on near real time basis and digital analysis is carried out after getting the digital data. The yield estimation was carried out using satellite based spectral data, historical yield data and climatic variables. The estimates of paddy acreages and yields are evaluated for accuracy and finally, the production estimation of paddy was attempted.

The methodology includes collection of field/ground truth information, identification of optimum period for satellite data selection, selection of image analysis techniques, and selection of methods for crop acreage and production estimates and crop yield prediction.

6.2 COLLECTION OF GROUND TRUTH

Ground truth data collection has an important bearing in most remote sensing applications (Dozier and Strahler. 1983). Its role in crop production forecasting includes crop identification, condition assessment and yield forecasting, the three main aspects of crop production forecasting. Crop discrimination and acreage estimation based on the maximum likelihood decision rule, requires ground truth data to train the classifier. Collection of ground truth data involves gathering information on land-cover types, their spatial extent, and condition, geographical coordinates of the location. In crop related applications, ground truth data collection is necessarily done synchronous or near synchronous to the time of satellite data acquisition in order to maintain the corresponding relations between remote sensing and field observations.

6.3 RECONNAISSANCE SURVEY

Reconnaissance survey is essentially a preliminary field survey, which is done to obtain a general idea of study area. The feasibility of using remote sensing data, the logistics that would be involved, while planning field survey for data collection, etc., are ascertained during reconnaissance. Using inputs from the reconnaissance survey, available satellite data is interpreted, visually/digitally in order to explore the feasibility of crop discrimination, its acreage estimation for condition assessment. Collateral data (e.g., historical crop statistics, local cropping pattern, crop calendar) in conjunction with existing satellite data, can be used to determine the most appropriate time for data acquisition (both RS and field). Once feasibility of crop identification and period of data acquisition are established, actual planning for ground truth data collection may be initiated based on the study of the archived remote sensing data, potential ground truth sites are marked on the base map.

6.4 PREPARATION OF BASE MAP

Base maps for ground truth planning contain administrative boundaries (e.g. state, district, mandal, and village), along with major features like towns\mandal head quarters\villages, reservoirs, lakes, highways, railways etc., which may be identifiable on satellite imagery. The base map is prepared on tracing film/paper usually at 1:50,000 scale, so that they can be used for visual interpretation of the study area by superimposing the map on FCC prints of the study area at corresponding scale. A Proforma for collecting crop related information should also be prepared for field data collection. A typical Proforma for ground truth data collection is given in table 3.5. A sketch showing the ground truth sites can be drawn on the reverse of the Proforma.

6.5 PLANNING LOGISTICS

The extent of the area to be covered for data collection will determine the duration to complete it. Feedback from the reconnaissance and local information can help in planning a good field survey. It becomes necessary to have a clear picture of the location and distribution of paddy crop in the study area. This is best achieved by marking all selected crop signatures on maps at on 1:50,000/25,000 scale. Selected sites are then scrutinized for accessibility (easy approach and traverse within the site) and where approach may be difficult, alternative site may be selected for ground truth collection. It is often required to cover large areas in a short time, the best approach is, and take the help from local officials and form small teams and divide the study area into as many smaller areas. In general, route planning is done in such a manner that the maximum area is covered with a minimum of 'dead-run'. In the present study the help of officials of Ongole irrigation department engineers and agriculture department officials, has taken for ground truth collection during in-situ seasons of 2004, 2005 and 2006.

Table 3.5: Typical Proforma for ground truth data collection

DISTRICT	GUNTUR / PRAKSAM	MANDAL		Date Collected	

Crop Code	1. Paddy	2. Cotton	3. Tobacco	4. Sugar Cane	5. Chillies
	6.Ground Nut	7. Cerals	8. Sun Flower	9.	10. Others
Soil Color	B. Black Cotton	R. Red	W. White	Br. Brown	M. Mixed
Soil Type	1. Sandy Clay	2. Sandy Clay Loamy	3. Sandy Loamy	4. Loamy Sand	5. Clay Loam
Water Source	1a. Sw. Canal 1b. Sw. Tank	2a. Gw. O. Well 2b. Gw. B. Well 2c. Gw. T. Well	USW + GW 3a. Canal + Well 3b. Tank+ Well	4a. RW (Sw.) 4b. RW (Ne.)	5a. Springs 5b. Filter Points

S.No	Date of Crop	Crop Type	Soil Type	Water	MAP NO.	Village	Yield Bags per Ac	GPS Coordinates		Crop Economics	
								Lat.	Long.	Exp. Per Acre	Return Per Acre
1.											
2.											
3.											
4.											
5.											
6.											

6.6 FIELD VISIT FOR GROUND TRUTH DATA COLLECTION

Ground truth data collection for crop related studies could include information on crop type; percent canopy cover, spatial extent, phenological stage, planting date, expected date of harvest, availability of irrigation and incidence of pests and diseases. The areas from where data has been collected, need to be located accurately on satellite images hence, their spatial extent and geographical coordinates need to be recorded during data collection preferably on map tracings. The minimum mapable field size, which is the combined group of contiguous adjacent fields of the same crop, is of more significance than the size of individual fields. Therefore, a global positioning system (GPS) receiver can help in the accurate recording of extent and location of a site. During data collection for the complete enumeration approach, it is necessary to ascertain that the entire range of spectral variability in the area gets represented and the sites should be uniformly distributed. Proximity of ground truth sites, to unambiguously identifiable ground control points is desirable, though not always possible. When accuracy assessment is undertaken, wall-to-wall ground truth data collection is usually done involving the collection of field-by-field information on various land cover classes. A cadastral map of the study area can be used for the collection of field-wise information.

Field information collected needs to be compiled probably for future use. For any region which has been traditionally under a particular crop, the year-to-year changes in the cropped area needs to be recorded and in case of paddy, the rationing of crop during next paddy season is obviously noted down. The crop sites, which are more or less invariant in type and extent, can be used in the supervised maximum likelihood classification every paddy season, without having to visit the site each time.

6.7 IDENTIFICATION OF OPTIMUM PERIOD FOR SELECTION OF SATELLITE DATA

The most important step in the selection of satellite data is the identification of suitable cloud free satellite data sets, when the crop is significantly manifested on the satellite data. The crop calendar of the study area is useful in determining the optimum period for acquisition of satellite data, which coincides with peak vegetative growth. Crop calendar also provides information on presence of other crops present in the study area at a given time and their probable growth stages, thus paving way for digital classification of satellite data. The crop calendar for the study area as obtained from reports of department of agriculture; Govt. of A.P.

The optimum acquisition period for selection of satellite data may shift from year to year based on the sowing/planting schedule. Besides different mandals may have different growing periods for the same crop. An example would be the tobacco growing season in Karnataka is entirely different from Andhra Pradesh.

6.8 SELECTION OF METHODS FOR CROP ACREAGE AND YIELD ESTIMATION

In traditional methods, the crop acreage estimation is obtained through enumeration made by the land revenue officials using complete enumeration and sampling approaches. However, these estimates are likely to have human errors and are available only after harvest of the crop. However, remote sensing techniques can be used for crop acreage estimation either visual interpretation or by digital image processing even before the harvest of crops. The limitations of visual interpretation techniques are highly subjective in nature, because of difficulty in the detection of minor changes in the radiance values of different crop/vegetation types. The advantage of digital image processing is less subjective, because of possibility to detect minute subtle changes in the radiance values of land cover types including crops. With availability of image processing systems and efficient software, digital techniques for crop area estimation in very large areas, requires less time and man-power compared to visual interpretation techniques. Therefore, digital techniques are adopted for crop acreage estimation, crop condition assessment and yield forecasting in this study which are discussed below.

6.8.1 Total enumeration approach

In this approach, the administrative boundary of the study area (district/mandal/village) is overlaid on the image to extract all pixels belonging to the study area. The classification of multispectral data, pixel by pixel is carried out using available classification algorithms, such as maximum likelihood classifier. In this procedure, crop map showing spatial distribution of different crops could also be generated, in addition to paddy in the study area. In the present study, the administrative boundary layer approach was used for acreage estimation of paddy crop at command area level as well as mandal level.

6.8.2 Digital data processing and analysis

Digital data pertaining to the study area in the form of digital raw data's are processed and analyzed in Centre for Environment, IST, J.N.T.University, Kukatpally, Hyderabad.

6.8.3. Geometric correction

After loading the data, the quality of the satellite data was checked. The contrast in FCC image of IRS was improved by histogram stretching of raw data bands. Geometric corrections in the digital data are carried out by registering the digital data with topographical maps of survey of India through ground control points already identified and by developing map to image co-ordinates transformation equation. The data is resampling using transformation equation developed and village boundaries are digitized on to the data.

6.8.4. Fusion product

A combination of NIR, red and green bands coded in RGB filters, respectively to generate a False Colour Composite (FCC), where in vegetation appears as red/magenta. This is known as standard FCC and useful for interpretation of various land use/cover features. Fusion of an RGB colour image on an input file with black and white intensity image and resultant image is an RGB colour image with the spatial resolutions of intensity image i.e., finer resolution for improving the detection capabilities of small size objects on land surface. This image is known as fusion/merged product and Intensity-Hue-Saturation (IHS) model is used for its generation. In the IHS model, the Red, Green and Blue image channels were converted to Intensity, Hue and Saturation channels and inversion of these channels into RGB is the merged data product. The IRS LISS-III data having 23.6 meters spatial resolution was fused with IRS panchromatic data (5.8 meters resolution) and the out put image is FCC with spatial resolution of panchromatic data. This merged FCC is used in wall-to-wall ground truth collection and estimation of paddy acreage at mandal level.

6.9 YIELD ESTIMATION

The various possibilities of crop yield estimations using remotely sensed data and other collateral data for yield modeling are discussed in this chapter. Yield models are developed by relating various vegetation indices (VI) derived from spectral data with the measured grain yield (or raw paddy yields) from selected sample areas. Vegetation indices are indicative of plant biomass or LAI or physiological processes like photosynthesis and evapotranspiration. In the present study various vegetation indices like RVI, VIN, NDVI, TVI and SAVI were related to paddy yields in order to evaluate their suitability towards paddy crop yield modeling using the following types of models.

6.9.1 Spectral yield models

Spectral data from a crop is an integrated manifestation of the effect of the crop growth stage, condition and environment. Absorption in red region and high spectral reflectance in the near-infra red region are characteristics of vegetation. The radiance measured in red and NIR regions and their ratio. Normalized difference, linear combinations etc., defined vegetation indices (VI) are indicators of vigour and thus can be related to yield. The methodology used for deriving the relationship between yield-spectral indexes for paddy crop is showing. Two common approaches used for yield model development are 1) Regression models 2) Crop Growth Profile based models are discussed below.

6.9.2 Regression models

In this approach, spectral data or VIs are related to the crop yields measured, which is basically a statistical approach. The spectral VI's of the crop at a particular stage (normally peak vegetative growth/maximum LAI) are related to its yield through regression techniques. Measurement of VI made from remotely sensed data acquired at crop stages other than peak vegetative growth stage generally do not relate well to yield and should be avoided. The occurrence of peak vegetative stage even for the same crop may differ in different regions based on existing agro-climatic conditions and cultural practices. The local crop calendars and in-situ crop sowing information may be used to decide the date of remote sensing data acquisition.

6.9.3 Crop growth profile based model

Growth and decay of crop canopy can be characterized by temporal plot of spectral indices. A mathematical function fitted to this temporal spectral pattern is known as spectral crop growth profile. The peak of this profile corresponds to peak vegetative cover of the crop. Crop growth profile can also be used to derive information on the crop stage for a given remote sensing acquisition date, normalization for data acquired at stages other than peak vegetative stage, crop vigour and crop identification. Since, yield is not directly obtainable from remote sensing data; an assumption based on functional form is used for such relations. Normally, a linear relation is assumed for yield-spectral index data sets. In order, to achieve consistency of relations in time and space, the exercise of generating VI should be repeated for three or more years. The analysis for the development of a model should be done on multi-year data sets.

6.10 TIME SERIES MODELS

The variation of crop yield in an area during different years is checked using historical data. The analysis of these data to develop a model is mainly done using two methods: (1) Trend analysis and (2) Auto Regressive Integrated Moving Average (ARIMA) as demonstrated by Box and Jenkins (1976).

6.10.1 Trend analysis for yield modeling

In regression analysis, external variables such as rainfall, temperature etc., are considered as explanatory independent variables to "explain" the variation in dependent variable such as yield. Substituting time as an independent variable in a regression equation leads to the concept of trend line. One can use linear or non-linear trend relationships with time. Time is not a causal or explanatory variable in the conventional sense, nevertheless, an increasing trend for example, with high RP^{2P} value may imply that the underlying technology improvement variable can be used along with other external variables such as rainfall, temperature, etc. in a multiple regression equation, showing non-linear trend (Makridakis and Wheelwright, 1978). In the present study, regression and trend analysis models were used for prediction of yields of paddy in Addanki branch canal command area.

6.11 VEGETATION INDICES

Based on this concept, many vegetation indices (VIs) have been developed that have specific features concerning the range of vegetation cover. VIs has been used since the LandSAT satellite became operational. The vegetation indices provide information on the state of vegetation on the land surface. vegetation is the result of a complex relation between land and land use, and provides thus a means of monitoring and estimating changes over time (Dadhwall & Ray 2000, de Wit & Boogaard, 2001, Gielen & de Wit 2001). The commonly used VIs includes.

6.11.1 Ratio Vegetation Index (RVI)

This is the simplest form of ratio-based vegetation indices calculated through the use of infrared and the Red band of the electromagnetic spectrum. It is calculated as follows;

RVI=IR/R

Where:

RVI = Ratio Vegetation Index

IR = Infrared band of the electromagnetic spectrum

R = Red band of the electromagnetic spectrum.

This VIs seems to be more affected by the noise present in the image due to atmospheric condition (Gielen & de Wit, 2001).

6.11.2 Normalized Difference Vegetation Index (NDVI)

This vegetation index is a ratio based VI calculated by the difference of the infrared and red bands as ratio to their sum. Thus:

NDVI = IR-R/IR+R

Where:

NDVI = Normalized Difference Vegetation Index

IR = Infrared band of the electromagnetic spectrum

R = Red band of the electromagnetic spectrum.

Through this normalisation, the values are scaled between −1 and +1.

RVI and NDVI are related to vegetation amount until saturation at full canopy cover and are therefore related to the biophysically active radiation, efficiencies and productivity (Rondeaux et al. 1996).

6.11.3 Other vegetation indices

Other vegetation indices that take into account the soil effect on vegetation reflectance, especially at low vegetation levels, have been developed. These indices assume a linear relationship between near infrared and the visible reflectance from bare soil. These VIs provide better results than NDVI at low vegetation cover because they eliminate the soil background effect. These VIs include Perpendicular Vegetation Index (PVI), Weighted Difference Vegetation Index (WDVI), Soil Adjusted Vegetation Index (SAVI), Transformed Soil Adjusted Vegetation Index (TSAVI) and the more recently introduced Modified SAVI (MSAVI) (de Wit & Boogaard 2001, Huete 1988, Qi et al. 1994, Rondeaux et al. 1996).

6.12 IMPORTANCE OF NDVI IN CROP YIELD PREDICTION

Out of all VIs, the Normalised Difference Vegetation Index (NDVI) stands out and is regarded as an all-purpose index. This VI is the most widely used and well-understood vegetation index (de Wit & Boogaard 2001). It is simple to calculate, has the best dynamic range and has the best sensitivity to changes in vegetation cover (Gielen & de Wit 2001). It has been found to correlate better with yield than other vegetation indices and thus continues to be used as a vegetation/biomass indicator using remotely sensed data (Andrew et al. 2000, Mohd et al. 1994, Singh et al. 2002).

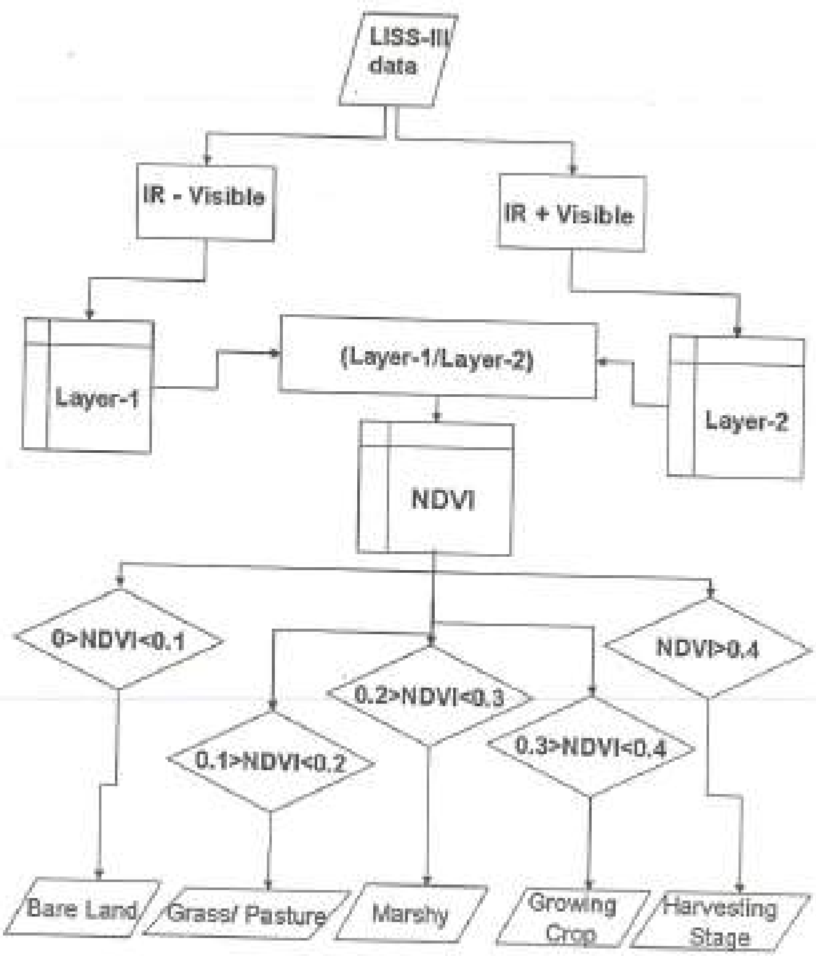
6.13 DEVELOPMENT OF RELATIONSHIPS BETWEEN VEGETATION INDICES AND YIELDS

The classified image is further processed to generate a binary mask, which is having '1' for each of the pixels belonging to paddy, and zero for other land use/ cover types. Thus, the crop mask is superimposed on original four-band data for generation of VI's belonging to the crop of interest for further analysis. Computation of spectral vegetation indices involves ratio (NIR/Red) or Normalized Difference Vegetation Index = (IR-red)/(IR+red) e.g. for IRS data Digital Number or Radiance Value of Band#4 and Band#3 pertaining to the crop of interest was used. In the first instance, the regression equation was developed using VI values and yields obtained from individual fields in the study area. These relations were further used in the development of production estimates.

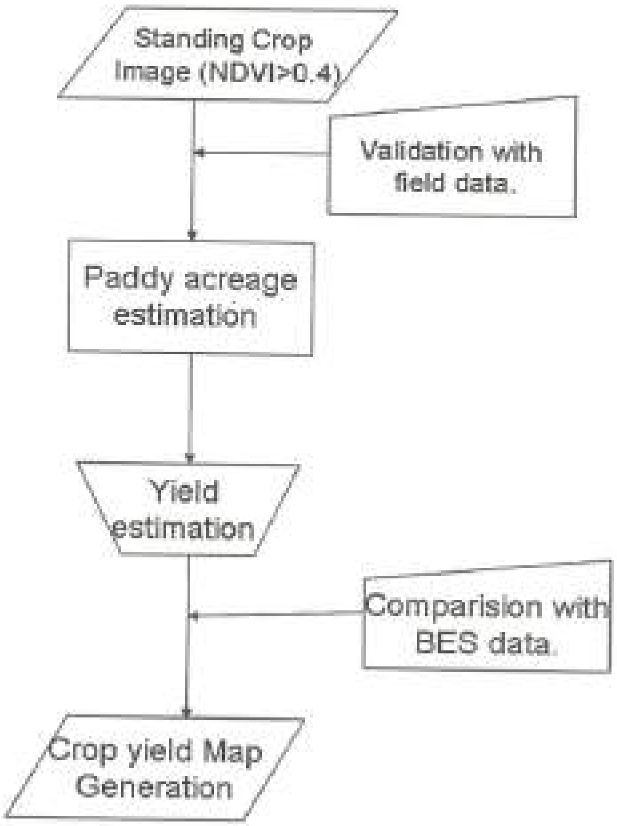
The development of model is done using multi-year data sets and the steps are as follows:

- Year-wise scatter plot of yield Vs spectral-index is prepared at command area level and tested for the functional form of the relation, outliers and natural groupings within the data set.
- Functional form of the relation (normally linear) is established and the outliers are screened out on the basis of statistical criteria. Further, analysis is performed on the data sets pertaining to all the years.
- The equations are examined for the stability of slopes and intercepts through statistical significance test. Similarity of high regression coefficients for different years indicates a good relation to develop a possible spectral yield model.
- Data sets of the years giving similar regression coefficients are pooled and regression analysis is performed again.
- The spectral yield model is updated by pooling the successive year's data on yield and spectral indices using the above steps.

6.14 METHODOLOGY ADOPTED FOR NDVI BASED CLASSIFICATION



6.15 CROP YIELD PREDICTION ANALYSIS FROM NDVI DATA FOR YIELD PREDICTION



6.16 RESULTS

The eleven data sets of satellite data were available to assess the crop growth and condition in the study area during paddy growing season of 1996 to 2006. The data was used for delineation of various agricultural land use / land cover classes in the study area. The mango orchards, which are permanent in nature, have shown significant changes in the spectral values after fall of leaves and as the new leaves are emerging. The cotton present in the study area along Gundlakamma River has distinctly different spectral reflectance and can be observed from 1996 to 2006 onwards.

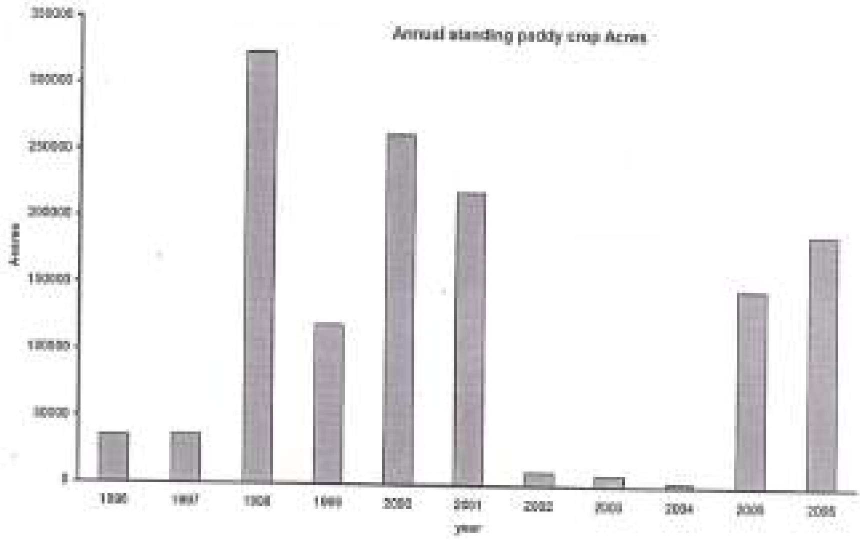
6.17 ACREAGE ESTIMATION

The acreage estimation of paddy crop was carried out on boundary mask approach in the study area of Addanki branch canal command area parts of Prakasam and Guntur districts, Andhra Pradesh. The training areas were generated for all classes in the study area based on ground truth information collected during field checks on near real time basis. The spectral signatures were generated for paddy crop at different ages, mango, banana and other land use classes in a spatial domain. Spectral separability analysis revealed that paddy crop has higher DN values as shown and is separable from other vegetation classes in the study area. Several factors such as soils, agricultural inputs, fertilizers and climate influence spectral signatures. The spectral reflectance is the manifestation of all these factors signifying the vegetation vigour.Then the supervised maximum livelihood classifier was employed for classification/categorization for further acreage estimation. The NDVI data sets of Addanki branch canal command area are shown in fig.6.2 to 6.23 for the seasons of 1996 to 2006, respectively and the acreage estimates of paddy obtained using remote sensing data and bureau of Economic and Statistics are presented in table.6.1. And figure 6.1 shows annual standing paddy crop diagram.

Table: 6.1 Paddy acreage estimation using RS data and BES, Govt. of AP

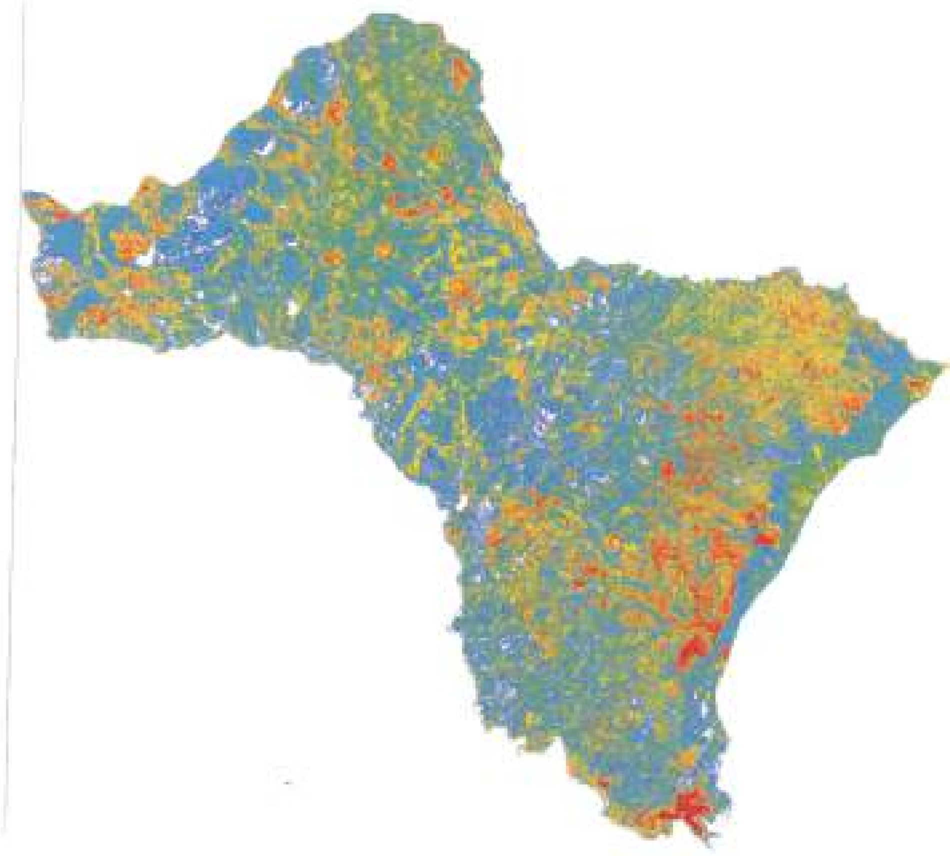
Year	Area in Acres	
	Remote sensing	BES Estimate
1996	932213.7	932200.1
1997	954324.1	954324.1
1998	8504598	8504595
1999	3142928	3142920
2000	6914326	6914340
2001	5763442	5863442
2002	265155.4	265125.3
2003	225093.9	225090.2
2004	74387.95	74348.21
2005	3873935	3872926.5
2006	4968918	4968920.3

Figure 6.1 shows annual standing paddy crop diagram.

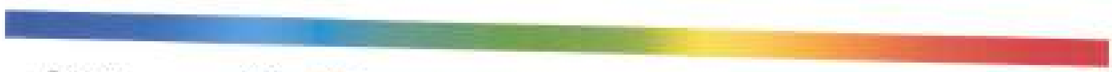


The relative deviations between remote sensing estimates with Bureau of Economic Statistics estimates are varying with in the limits of plus or minus 5 percent, which is statistically acceptable. The changes in acreages between 1996 to 2006 cropping seasons is related to socio-economic factors such as remunerative prices to paddy output and alternate crops in the study area. The forest areas and other crops in the study area were masked with digital masks.

Figure 6.2 shows NDVI image of 1996



Legend for NDVI image



0- 0.1 Bare Land	0.1 – 0.2 Grass /Pasture	0.2 – 0.3 Marsh y	0.3 – 0.4	>0.4

Figure 6.3 shows paddy image of 1996

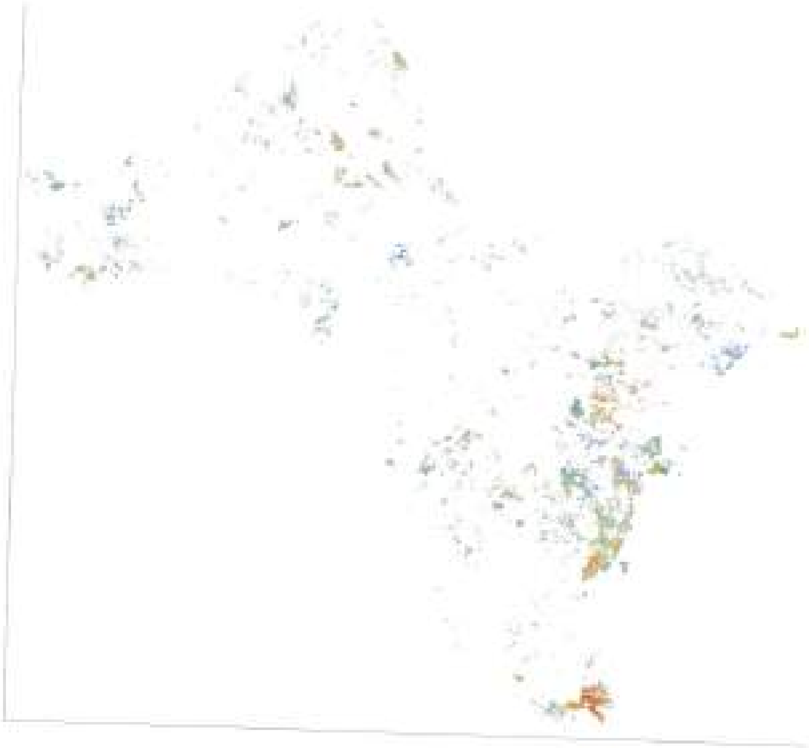


Figure 6.4 shows NDVI image of 1997

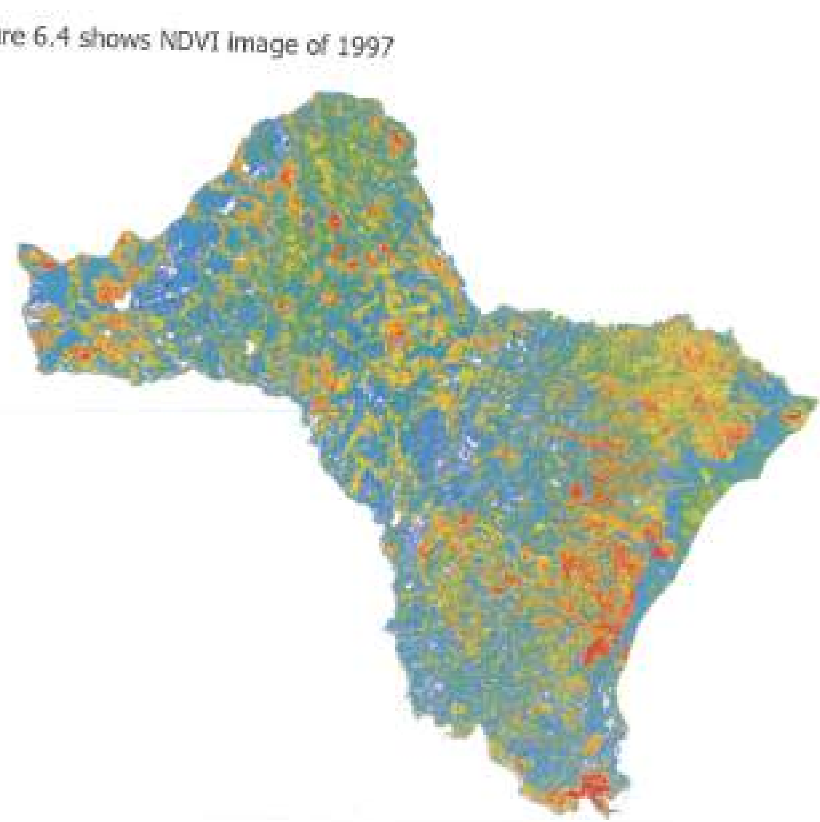


Figure 6.5 shows paddy image of 1997

Figure 6.6 shows NDVI image of 1998

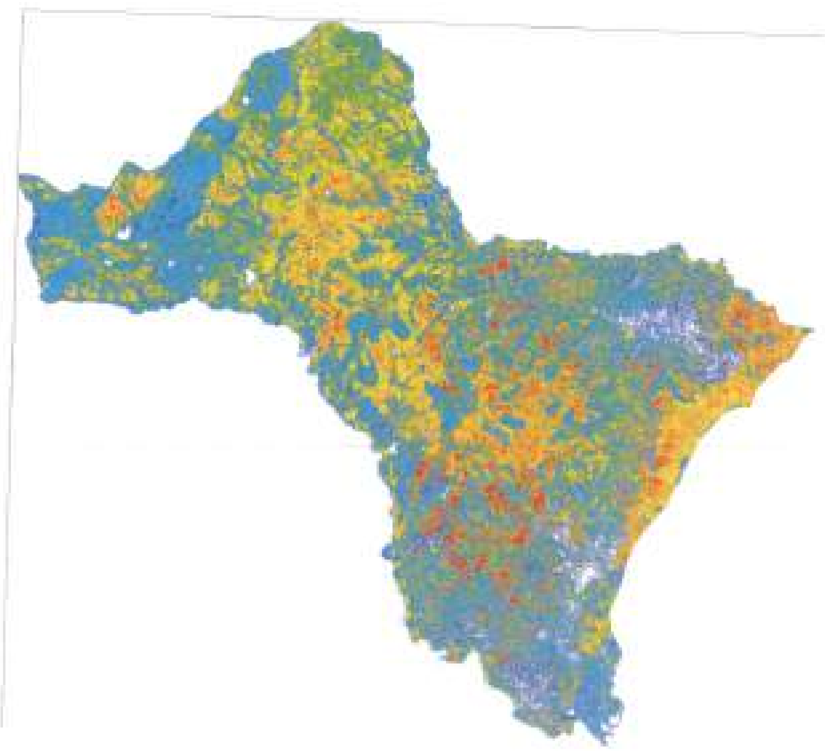


Figure 6.7 shows paddy image of 1998

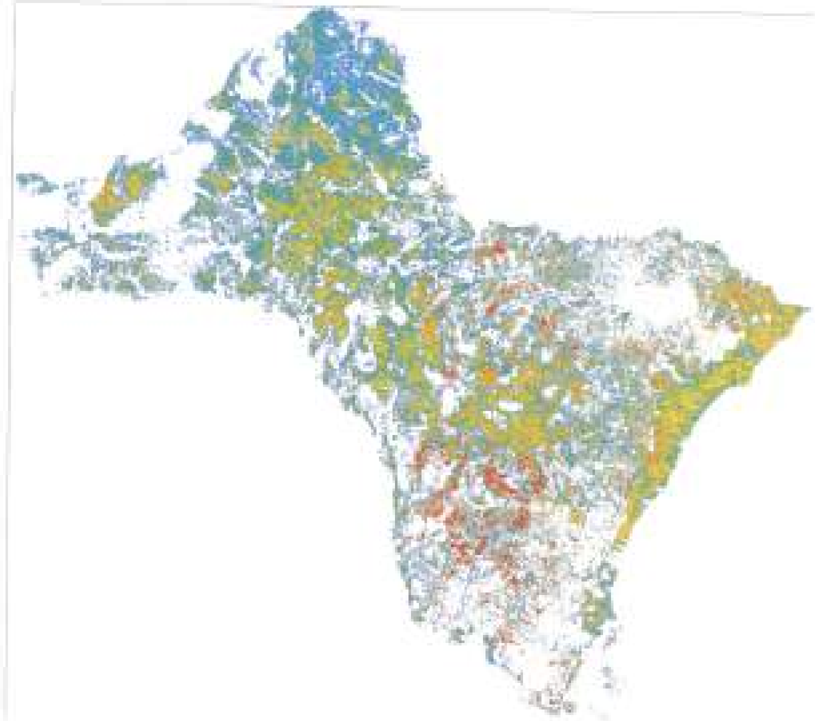


Figure 6.8 shows NDVI image of 1999

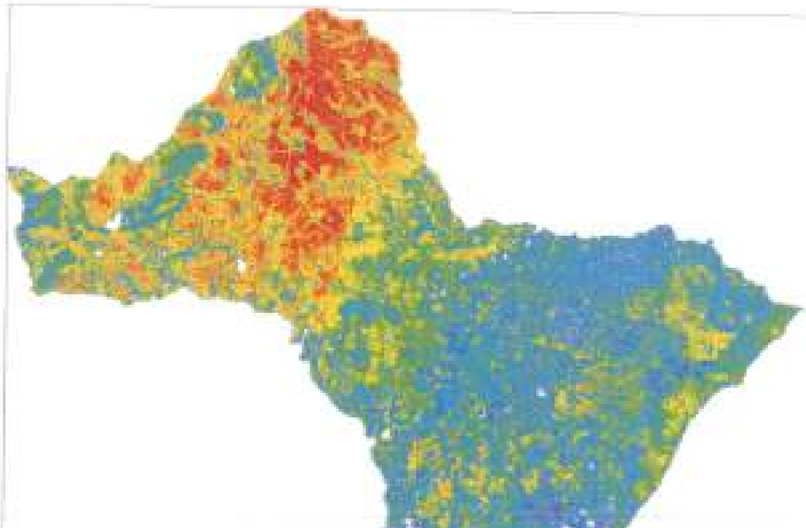


Figure 6.9 shows paddy image of 1999

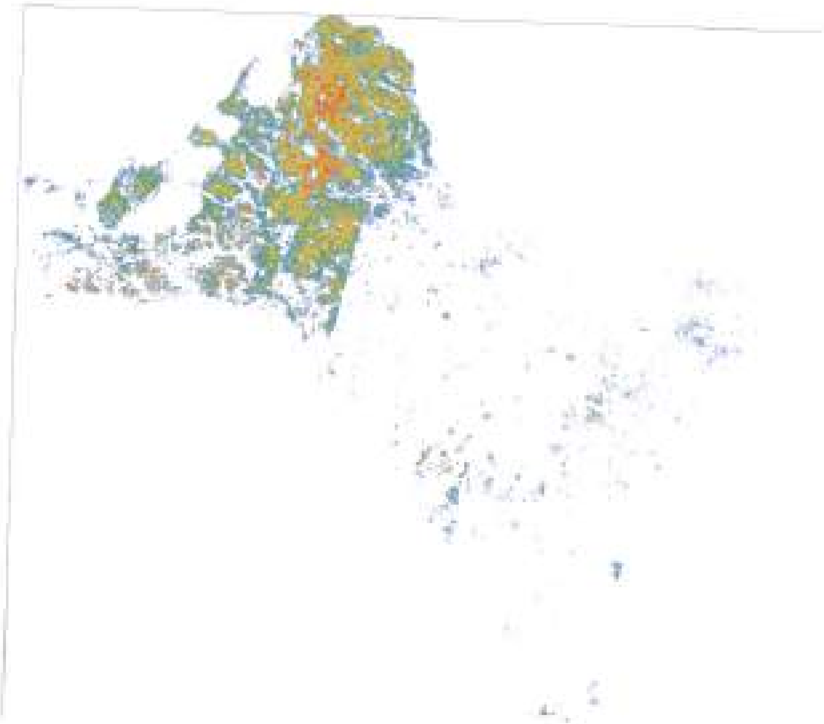


Figure 6.10 shows NDVI image of 2000

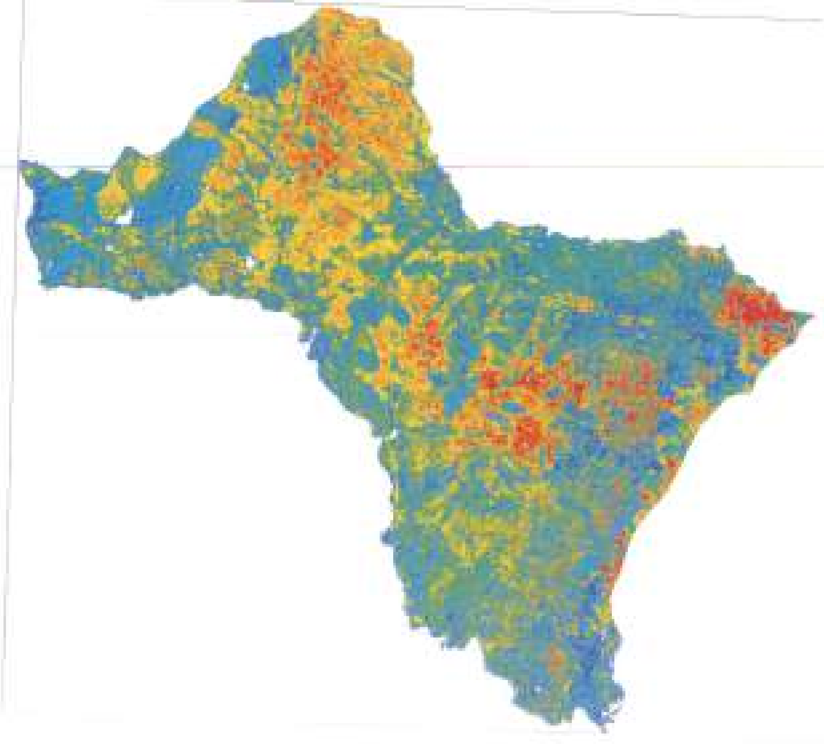


Figure 6.11 shows paddy image of 2000

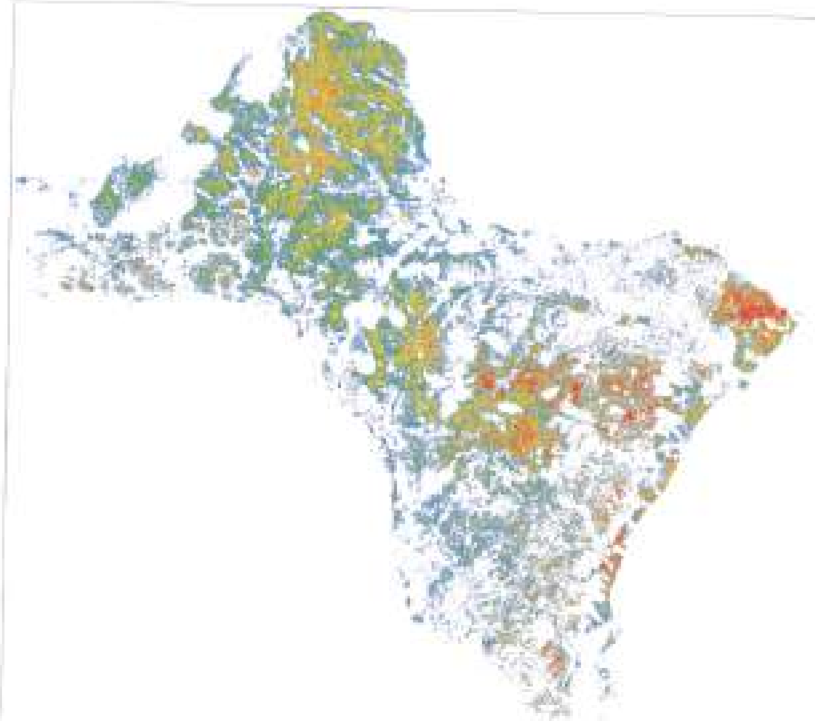


Figure 6.12 shows NDVI image of 2001

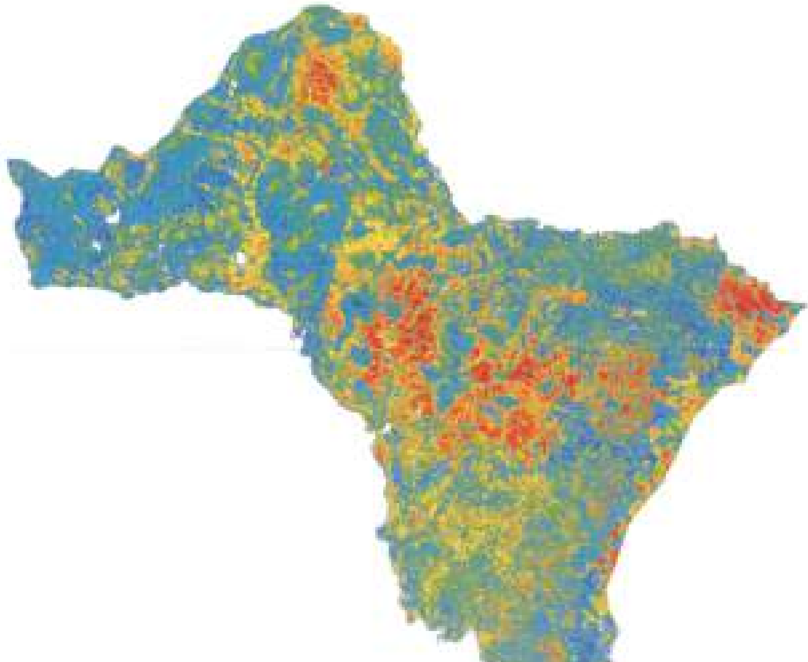


Figure 6.13 shows paddy image of 2001

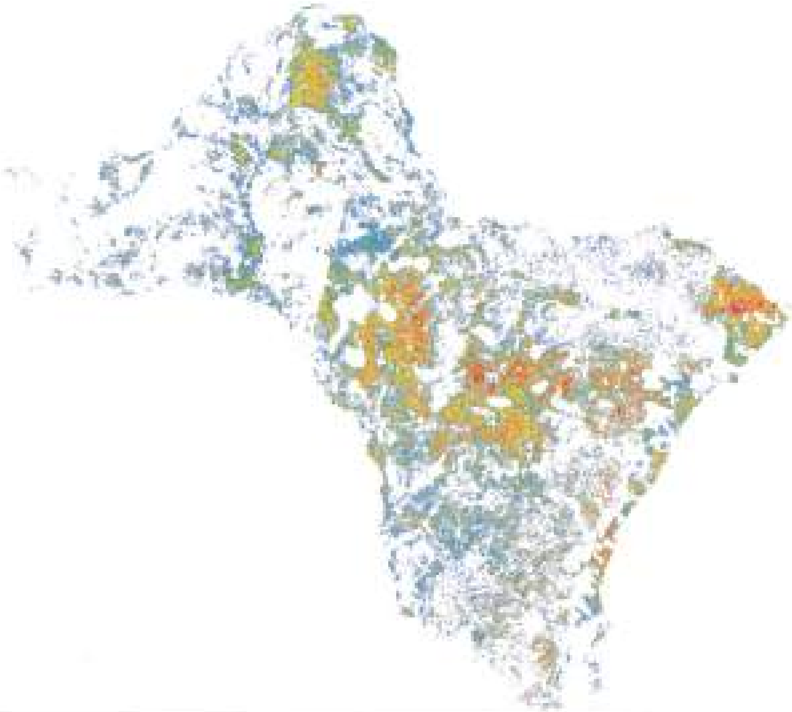


Figure 6.14 shows NDVI image of 2002

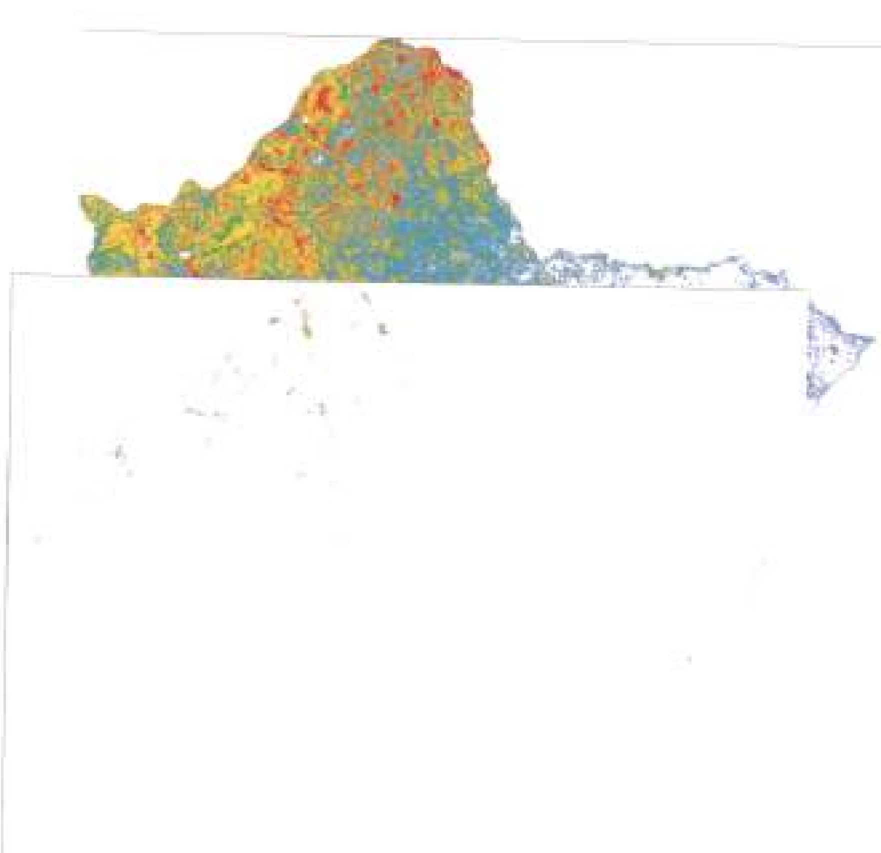


Figure 6.15 shows paddy image of 2002

Figure 6.16 shows NDVI image of 2003

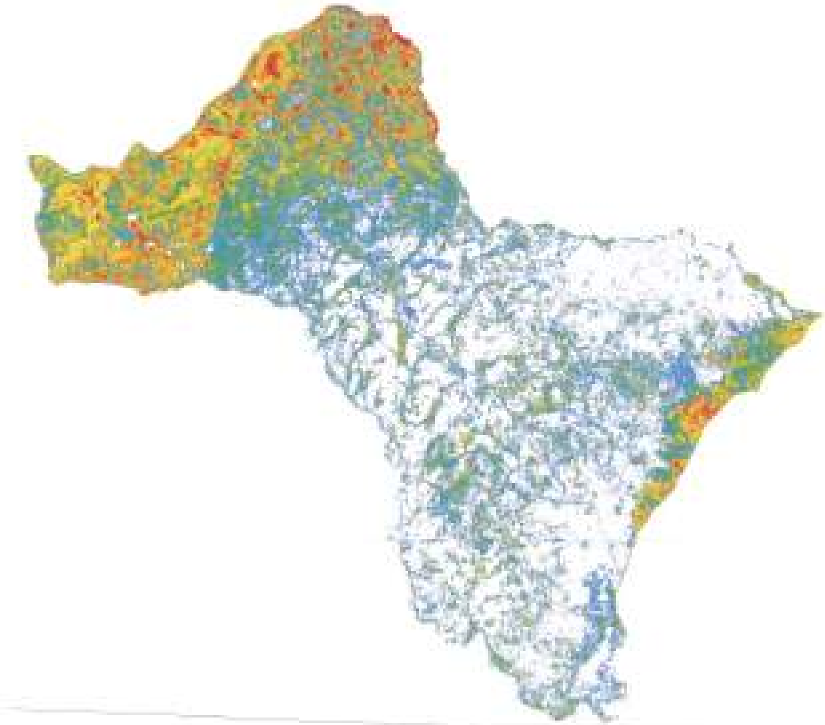


Figure 6.17 shows paddy image of 2003

Figure 6.18 shows NDVI image of 2004

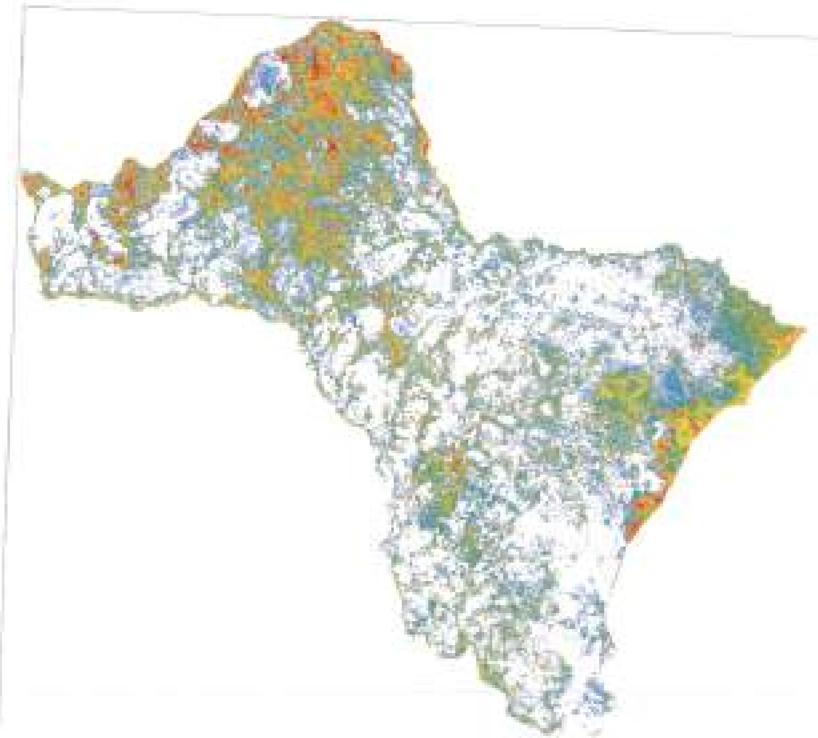


Figure 6.19 shows paddy image of 2004

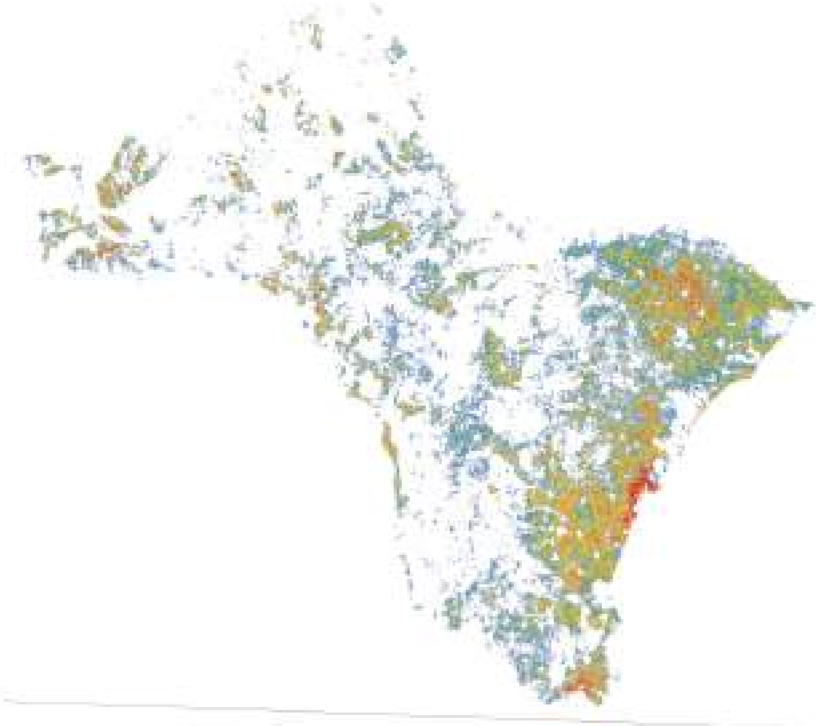


Figure 6.20 shows NDVI image of 2005

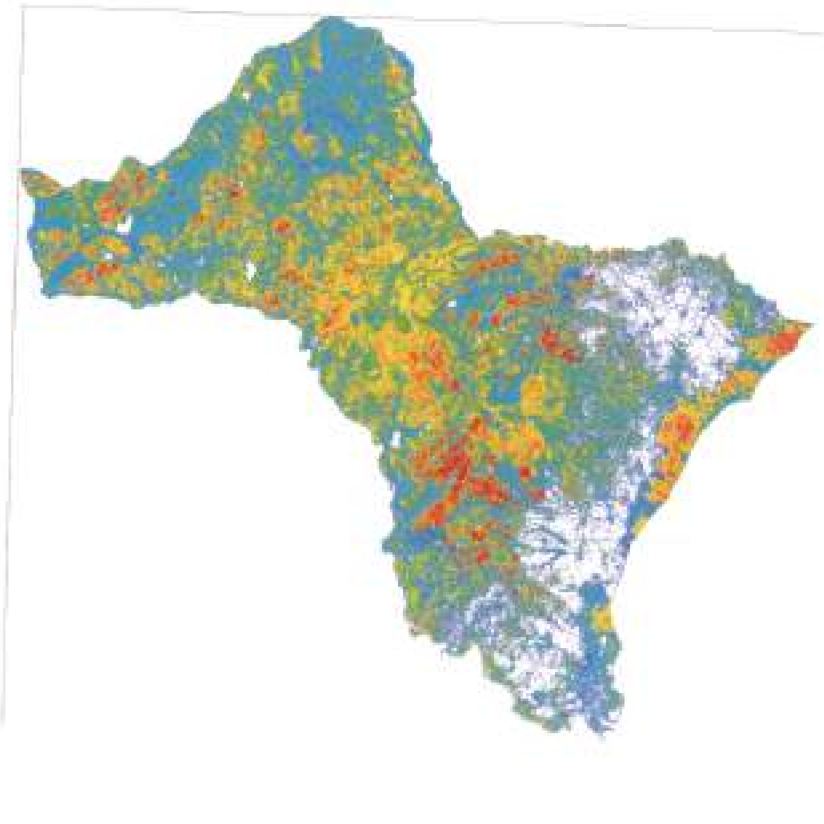


Figure 6.21 shows paddy image of 2005

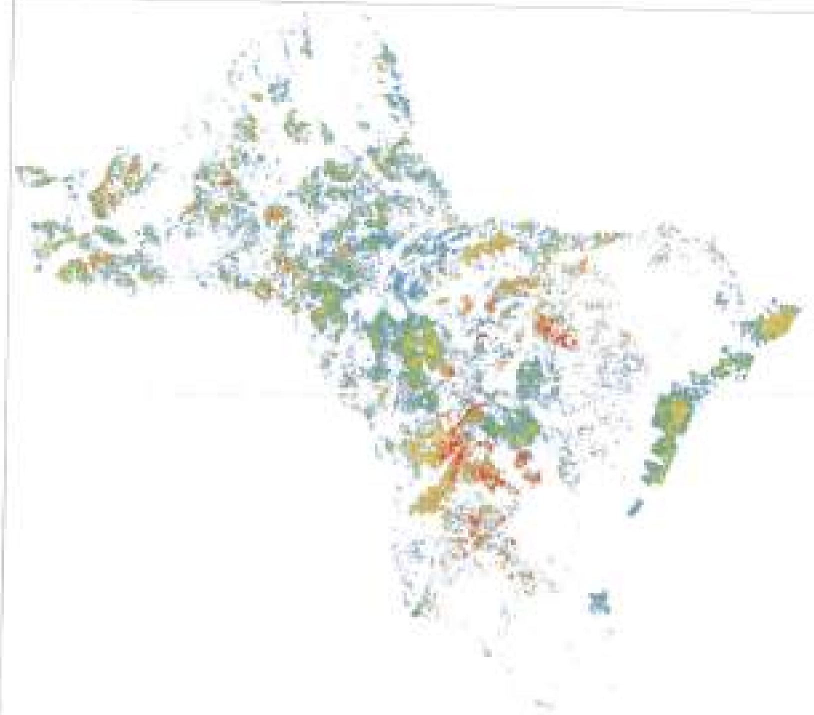


Figure 6.22 shows NDVI image of 2006

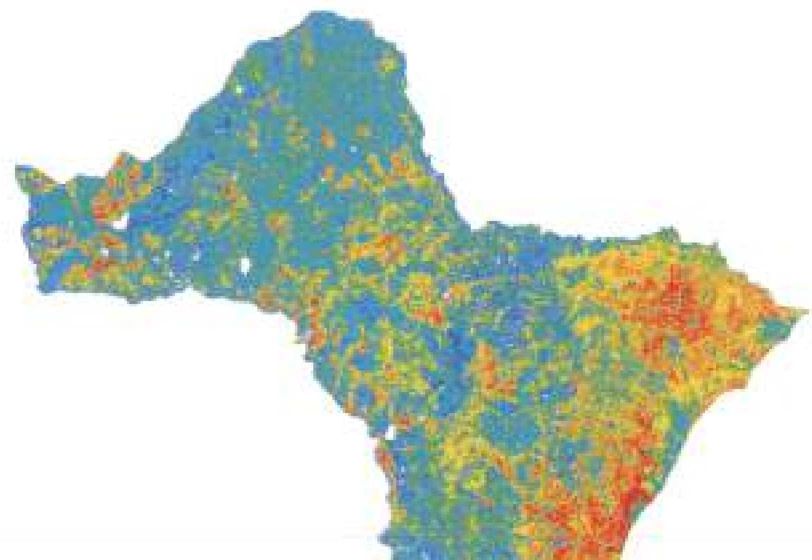


Figure 6.23 shows paddy image of 2006

6.18 DISCUSSIONS

Through integration of remotely sensed data, land factors and management aspects, an assessment of field level yield prediction has been executed. It is shown that a combination of NDVI, land and management parameters can improve field level yield prediction above use of NDVI alone. It is found that the availability of water, the weeding method, the number of fertiliser applications, soil type and the date of transplanting explain yield variability. The date of transplanting and the soil type are found to relate to the NDVI variability at field level. These points are observed under below.

1. From our study we concluded December month is the ideal period to estimate the crop yield through remote sensing (NDVI).
2. In Nagarjuna sagar commend area max rainfall occurred during the north east monsoon (September and October) due to due to cyclonic activity in Bay of Bengal December month is ideal period.

6.19 RECOMMENDATIONS

This study has developed a yield prediction model for field level. The data used in this study was provided by farmers through interviews. As such there might be a lot of anomalies in the reported data that has to be verified before final conclusions are drawn on its accuracy and applicability. There is need for further research to find more factors that can explain yield variability at field level and improve the model. Based on this the following recommendations are drawn:

- There is a need for further investigation on the factors that contribute to yield variability at field level. Factors such as soil type used in this study were at higher level and more generalised, developed from 1:50,000 maps. As such, it could not provide detailed variation that may occur at field level. There is need for detailed study on the soil characteristics at field level and include factors like pH, texture for specific areas / fields which have a significant effect on water holding capacity, nutrient availability and yield.

- This study observed that there is no relationship between N: P: K and yield and N: P: K and NDVI. However, all the farmers applied fertiliser at different times, different rates and types. Therefore, it is proposed that an in depth study on fertiliser use efficiency is required to establish fertiliser utilisation, losses and the gaps existing at field level.
- The water being used for irrigation is mainly canal water, which is released into the paddy fields. There is need to assess the quality of water, canal water recharge and specific canal water depth for the area, which may have impact on water availability and yield.
- In the analysis, it has been shown that other vegetation indices (including those that take into account soil influences) have not performed better than the NDVI. Nevertheless, these have been claimed to perform much better than VIs that do not take into account soil influences on reflectance. In view of this it is suggested that there is need to find and establish specific soil reflectance in the area and apply the actual soil reflectance when dealing with soil adjusted VIs rather than using the generally applied factor of 0.5 for all the soils and at any vegetation density.
- The study did not consider the previous land management practices, which may have a residual effect on crop growth and production. Zinc is normally applied at two-year intervals and this has not been considered. If some farmers applied Zinc in the previous season or prior to the season is in question. However, it is important to assess this and incorporate into the model if found to be significant.

6.20 MULTIPLE REGRESSION MODEL DEVELOPMENT

The relationships and effects of land and management aspects on yield and NDVI. Some land and management parameters had a significant effect on yield and NDVI. This is explored and established a yield prediction model based on NDVI and significant land and management parameters. Stepwise forward multiple linear regression was applied to build the model. This selected only those parameters that strongly and significantly explained yield variability. Stepwise forward regression adds variables to a regression model for the purpose of identifying a useful subset of predictors. Repeated 'trial and error' attempts were done to identify interactions between parameters and to explore unexpected sign of coefficients. Hundred and ninety samples were randomly selected from the yield data and reserved for model testing. Multiple regressions were then applied to the remaining set of data. All the regression models were weighted by a quality weighing factor as explained to standardise the data.

6.21 NDVI PREDICTION USING LAND AND MANAGEMENT PARAMETERS

All the significant variables were entered into the stepwise multiple regression to select the best subset that explains the field level NDVI variability. Through repeated trial and error, 3 variables were selected as predictors explaining 21.0% of NDVI variability. The purpose of this was to identify which parameters can explain the NDVI variability to avoid auto correlation when building the final model. The regression equation is:

NDVI max = 0.4603 – 0.002 (DOTJ) + 0.0435(Soil code_n1) + 0.0437(Soil code_n2)

Where:

NDVI max = Predicted field level maximum NDVI

DOTJ = date of transplanting

Soil code_n1= if rice is grown on soil sub-group E

Soil code_n2= if rice is grown on soil sub-group B

The model suggests a negative effect on NDVI with delayed planting and that high NDVI values will be obtained if rice is grown in soil code_N1 and N2. Table 5.1 shows the coefficients, t values and p-values for each predictor in the model. The date of transplanting cross-relates between NDVI and yield data.

Table 5.1 shows coefficients and p-values for NDVI prediction model.

Constant = 0.4603	R2 adj = 21.0%		
Predictor	Coefficient	T	P
Date of transplanting	-0.0020	-2.7	0.1

If Soil sub group E	0.0435	2.1	0.05
If Soil sub group B2	0.0437	2.0	0.56

6.22 INTEGRATED YIELD PREDICTION MODEL

The final stage was to build an integrated yield prediction model based on NDVI, land and management factors. First, was to establish a yield prediction model without NDVI for later comparison. All the management and land variables that were significant were entered into the multiple regressions. The best selected predictors explained 38.1% of the yield variability in the area. The regression equation is given below:

Yield = 6046 + 1142(Soil code_n1) + 962(WS_NS) -1370 (APP_2)

Where:

Yield = yield (kg/ha) predicted by land and management factors

Soil code_n1= Soil sub-group E

WS_NS = If there is no water shortage

APP_2 = If fertiliser is applied only twice

The results suggest that if land and mangement factors are considered for yield prediction, 38.1% of the yield variability will be explained by the model. Table 5.2 shows the coefficients, t-values and probability level of the predictors.

Table 5.2 shows yield prediction model using land and management factors.

Constant = 6046	R2 adj = 21.0%		
Predictor	Coefficient	T	p
If Soil sub group E	1142	2.7	0.01
If no water shortage	962	3.2	0.001
If fertiliser is applied only twice	-1370	-2.4	0.02

The final yield prediction model was done by entering NDVI values and all the significant variables that were not related to NDVI prediction into a stepwise multiple regression to select the best subset that explains significantly yield variability at field level. The model selected four variables, explaining 45.8% of the variability. These four predictors provided better results than any other combination. The model is defined by:

Yield = 3027 + 7751(NDVImax) + 1030(WS_NS) – 648(WM2_H) – 1126(APP_2)

Where:

Yield = Predicted yield (kg/ha)

NDVI max = field level NDVI aggregated by maximum

WS_NS = if there is no water shortage

WM2_H = second weeding if done by hand weeding

APP_2 = if fertiliser is applied only twice instead of three or more

Table 5.3 shows the results of the model.

Table 5.3 Yield prediction model using NDVI, management and Land.

Constant = 3027	R2 adj = 45.08%		
Predictor	Coefficient	T	p
NDVI	7751	2.9	0.01
If no water shortage	1030	3.8	0.00
If second weeding is done by hand	-648	-2.3	0.02
If fertiliser is applied only twice	-1126	-2.0	0.06

Figure 5.1 shows a scatter diagram of the relationship between predicted yield from the independent data against reported yield and all the data against reported yield. Fitted with a regression line of all the samples. The line explains 12.4% of the yield variability ($p = 0.01$) with a regression equation Ypred = 5891 + 0.24(reported yield). Table 5.4 shows the results of the predicted yields from the hundred and ninety randomly selected samples.

Figure 5.1 shows a scatter diagram of the relationship between predicted yield and reported yield

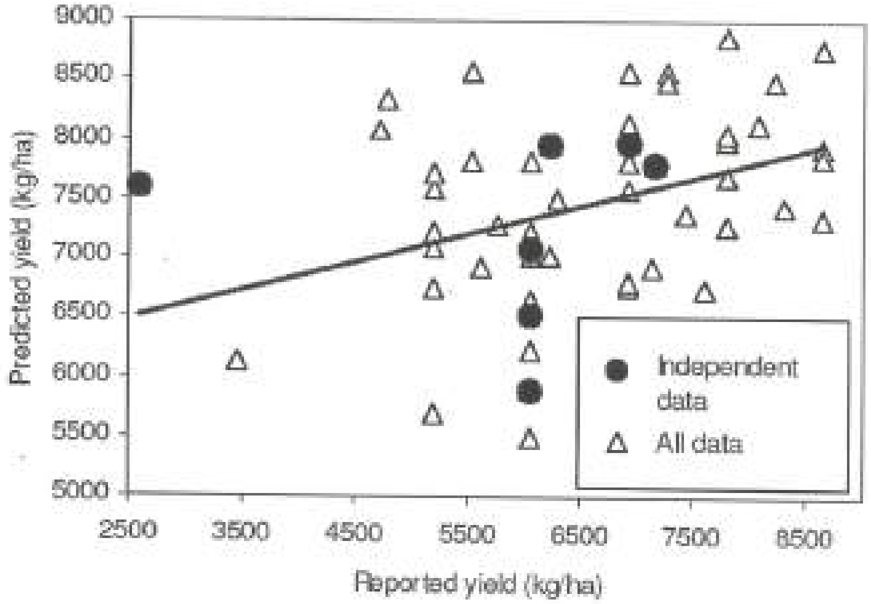


Table 5.4 shows test results of the integrated model.

LONGITUDE	LATITUDE	NDVI	Reported yield (Yr) (Kg/Ha)	Reported yield (Yp)(Kg/Ha)	Difference (Yr-Yp) (Kg/Ha)	% Difference ((Yr-Yp)/ Yr) * 100
79.79286	16.137498	0.40112993	6918.5696	7000	81.430399	1.176983
79.89929	16.127116	0.40119761	6918.9119	6500	-418.9119	-6.054592
79.83076	16.231204	0.40127388	6919.2976	7200	280.70242	4.056805
79.84504	16.093371	0.40127388	6919.2976	6900	-19.29758	-0.278895
79.79182	16.11232	0.40136054	6919.7357	6800	-119.7357	-1.730351
79.87722	16.101158	0.40136054	6919.7357	7100	180.26426	2.605074
79.94861	16.071048	0.40136054	6919.7357	7300	380.26426	5.495358
79.74666	16.114916	0.40145984	6920.2377	7200	279.76232	4.042669
79.78767	16.117511	0.40157479	6920.8185	6800	-120.8185	-1.745726
80.06437	15.962027	0.40157479	6920.8185	6900	-20.81855	-0.30081

79.78741	16.121924	0.4025974	6925.9788	7000	74.021188	1.068747
79.83102	16.236396	0.40277779	6926.8878	7100	173.11225	2.499135
79.73965	16.086362	0.40277779	6926.8878	7200	273.11225	3.942784
79.81882	16.239251	0.40579709	6942.0408	6600	-342.0408	-4.927093
80.06412	15.950606	0.40645161	6945.3108	6700	-245.3108	-3.532035
79.87515	16.086622	0.4074074	6950.0765	6800	-150.0765	-2.15935
79.83154	16.236396	0.40939596	6959.956	6900	-59.95597	-0.861442
79.89903	16.131528	0.4108527	6967.1629	7000	32.837139	0.471313
79.84893	16.071048	0.41605839	6992.7097	7200	207.29029	2.964377
79.87359	16.097784	0.41605839	6992.7097	7100	107.29029	1.534316
80.24011	15.886751	0.62616825	7822.1517	7300	-522.1517	-6.675295
80.27463	16.015759	0.62831861	7829.1077	7300	-529.1077	-6.758212
80.24737	15.88078	0.6339286	7847.1433	7400	-447.1433	-5.698167
80.27255	16.030554	0.63451779	7849.0283	7500	-349.0283	-4.446771
80.16483	15.689994	0.63876653	7862.5692	7300	-562.5692	-7.15503
80.25464	16.006673	0.64035088	7867.5956	6500	-1367.596	-17.38264
80.25257	16.029256	0.64824122	7892.4439	6600	-1292.444	-16.37571
80.3756	15.998627	0.65644169	7917.9505	7100	-817.9505	-10.33033
80.24504	15.877406	0.66371679	7940.3134	7200	-740.3134	-9.323479
80.16665	15.689734	0.66666669	7949.3114	7400	-549.3114	-6.910175
80.23517	15.883636	0.67099565	7962.444	7100	-862.444	-10.8314
80.25308	16.029256	0.68224299	7996.1725	6900	-1096.172	-13.70871
79.94705	16.061184	0.41333333	6979.3766	6400	-579.3766	-8.301266
79.98702	15.986427	0.41843972	7004.2897	6500	-504.2897	-7.199726
79.91252	16.135941	0.42068964	7015.1702	6600	-415.1702	-5.918178
79.92862	16.056512	0.42465752	7034.2178	6700	-334.2178	-4.751314
80.06308	15.964363	0.42635658	7042.3196	6800	-242.3196	-3.440907
79.88761	16.099082	0.42857143	7052.8327	6900	-152.8327	-2.166968

79.91019	16.132567	0.43055555	7062.2045	7000	-62.20447	-0.880808
79.83076	16.084286	0.4326241	7071.9292	7200	128.0708	1.810974
79.92239	16.067673	0.43478259	7082.0273	7100	17.972677	0.253779
79.82738	16.07598	0.44776121	7141.7082	7300	158.29177	2.216441
80.28994	15.988244	0.61165047	7774.5552	7400	-374.5552	-4.817706
80.25049	15.874031	0.61320752	7779.7138	7500	-279.7138	-3.595425
80.2427	16.002001	0.6195122	7800.4684	7400	-400.4684	-5.133902
80.23881	15.884934	0.6195122	7800.4684	7300	-500.4684	-6.415876
80.24348	15.878704	0.62037039	7803.2771	6800	-1003.277	-12.85713
79.92161	16.136979	0.44217688	7116.2441	6900	-216.2441	-3.038739
79.87567	16.089218	0.44262296	7118.29	6600	-518.29	-7.281102
79.83335	16.2216	0.44360903	7122.8051	6700	-422.8051	-5.935936
79.92602	16.062222	0.4437086	7123.2605	6800	-323.2605	-4.538097
80.06126	15.945155	0.44999999	7151.8278	6900	-251.8278	-3.521167
79.92031	16.137758	0.45323741	7166.3728	7000	-166.3728	-2.321576
79.93485	16.061443	0.45323741	7166.3728	7200	33.627231	0.469236
79.88709	16.098562	0.45833334	7189.0583	7300	110.94167	1.543202
79.9878	15.988763	0.45833334	7189.0583	7400	210.94167	2.934204
80.1586	15.701675	0.592233	7709.0979	7500	-209.0979	-2.712353
80.2588	15.990839	0.59770113	7727.7459	7000	-727.7459	-9.417311
80.2466	15.870657	0.59798998	7728.7262	7100	-628.7262	-8.134926
80.16172	15.706866	0.60185188	7741.7876	7200	-541.7876	-6.998224
80.24789	15.881819	0.60194176	7742.0906	7400	-342.0906	-4.418582
80.16301	15.790708	0.60194176	7742.0906	6500	-1242.091	-16.04335
80.24815	15.885972	0.60396039	7748.8835	6600	-1148.884	-14.82644
80.27229	15.991359	0.60576922	7754.9512	6700	-1054.951	-13.60358
79.93589	16.060665	0.46206897	7205.5286	6900	-305.5286	-4.240197
79.83491	16.089477	0.46478873	7217.4364	6800	-417.4364	-5.783721

79.91849	16.146584	0.46666667	7225.6178	6600	-625.6178	-8.65833
80.05944	15.948789	0.46753246	7229.3787	6500	-729.3787	-10.08909
79.87592	16.095967	0.46875	7234.6557	7000	-234.6557	-3.243495
79.92265	16.065337	0.46969697	7238.7506	7200	-38.75056	-0.535321
80.00441	15.992916	0.47222221	7249.6299	7300	50.370108	0.694796
79.91642	16.050801	0.47619048	7266.6091	7400	133.39087	1.835669
79.91019	16.134124	0.47887325	7278.0081	7500	221.99191	3.050174
79.87748	16.095707	0.47928995	7279.7729	6500	-779.7729	-10.7115
79.83076	16.086622	0.48299319	7295.3897	6600	-695.3897	-9.531906
79.92706	16.057809	0.48344371	7297.2814	6500	-797.2814	-10.92573
80.28475	16.036524	0.57541901	7650.6594	6600	-1050.659	-13.73293
80.24919	15.873253	0.58163267	7672.4521	6700	-972.4521	-12.67459
80.366	16.016797	0.58282208	7676.5971	6800	-876.5971	-11.41908
80.24452	15.880261	0.58585858	7687.1407	6900	-787.1407	-10.23971
80.27125	16.016797	0.58762884	7693.2624	7000	-693.2624	-9.011292
80.25231	15.875329	0.58999997	7701.4331	7200	-501.4331	-6.510906
80.38183	16.014461	0.58999997	7701.4331	7300	-401.4331	-5.212446
80.07009	15.955538	0.59210527	7708.6603	7500	-208.6603	-2.706829
80.06593	15.961248	0.48427674	7300.7746	7400	99.225374	1.359107
79.99715	15.993695	0.4852941	7305.0326	6700	-605.0326	-8.282409
79.92317	16.145545	0.48993289	7324.3352	6800	-524.3352	-7.158809
79.94809	16.067414	0.49275362	7335.9834	6600	-735.9834	-10.03251
80.00078	15.991099	0.49668875	7352.1226	6900	-452.1226	-6.149552
79.83465	16.085324	0.5	7365.6044	6600	-765.6044	-10.39432
80.06178	15.946193	0.5029586	7377.575	6800	-577.575	-7.828792
79.90707	16.135162	0.50318474	7378.487	7200	-178.487	-2.41902
79.94264	16.059886	0.50354612	7379.9437	7100	-279.9437	-3.793304
79.87541	16.089477	0.50413221	7382.304	7300	-82.30397	-1.114882

80.23491	15.871695	0.56122446	7599.9799	7500	-99.97991	-1.315529
80.0706	15.952942	0.56129032	7600.218	7400	-200.218	-2.634372
80.17132	15.703751	0.56345177	7608.0164	7300	-308.0164	-4.048577
80.37534	16.018614	0.56382978	7609.3772	7200	-409.3772	-5.379904
80.29176	16.010048	0.56424582	7610.8738	7100	-510.8738	-6.712419
80.14303	15.788632	0.56701028	7620.7904	6900	-720.7904	-9.45821
80.37119	16.011865	0.5714286	7636.5397	6600	-1036.54	-13.57342
80.2466	15.884934	0.57291669	7641.8166	6500	-1141.817	-14.94169
80.37093	16.017056	0.57317072	7642.7161	6600	-1042.716	-13.64327
80.06775	15.954499	0.57419354	7646.3336	6700	-946.3336	-12.37631
79.87541	16.102196	0.50335568	7379.1762	6800	-579.1762	-7.848793
79.94783	16.070269	0.50993377	7405.5204	6600	-805.5204	-10.8773
79.9159	16.058329	0.5138889	7421.1969	7200	-221.1969	-2.98061
79.90681	16.13023	0.51677853	7432.5742	7100	-332.5742	-4.474549
80.06152	15.957355	0.51807231	7437.6475	7400	-37.64751	-0.506175
79.92524	16.056252	0.5182482	7438.3363	7500	61.663729	0.828999
79.83673	16.092333	0.52054793	7447.32	7400	-47.32004	-0.635397
80.00675	15.988503	0.52201259	7453.021	7300	-153.021	-2.053141
79.93433	16.069231	0.52447551	7462.5716	7200	-262.5716	-3.518514
79.93978	16.056252	0.52941179	7481.5789	7100	-381.5789	-5.100246
80.0623	15.948789	0.5316456	7490.1221	6500	-990.1221	-13.21904
80.38079	16.016018	0.53846157	7515.9695	6600	-915.9695	-12.18698
80.15626	15.787074	0.54000002	7521.7584	6700	-821.7584	-10.92508
80.38131	16.015499	0.54140127	7527.0166	6800	-727.0166	-9.658762
80.24218	15.870657	0.54444444	7538.3896	6900	-638.3896	-8.468514
80.25828	16.035227	0.54871798	7554.2537	7000	-554.2537	-7.336975
80.37171	16.018873	0.55029583	7560.0798	7100	-460.0798	-6.085647
80.25049	15.879742	0.55319148	7570.7284	7400	-170.7284	-2.255112

80.25386	16.017576	0.55555558	7579.381	7500	-79.38095	-1.047328
80.38261	16.007971	0.50602412	7389.9042	6900	-489.9042	-6.629371
80.07398	15.945155	0.5131579	7418.3087	6800	-618.3087	-8.334901
80.1599	15.782921	0.51351351	7419.7142	6800	-619.7142	-8.352265
80.25646	15.881819	0.51412427	7422.1261	7200	-222.1261	-2.992755
80.17833	15.706607	0.51677853	7432.5742	7400	-32.57417	-0.438262
80.26503	16.010048	0.51724136	7434.3905	7500	65.609462	0.882513
80.38313	16.006673	0.52662724	7470.8788	7400	-70.87879	-0.948734
80.25724	16.012384	0.52873564	7478.9858	7300	-178.9858	-2.393183
80.24789	15.884934	0.53439152	7500.5748	7500	-0.57479	-0.007663
79.87411	16.095967	0.53600001	7506.6728	7400	-106.6728	-1.42104
79.92992	16.054175	0.53623188	7507.5503	7400	-107.5503	-1.432562
79.81155	16.214851	0.53658539	7508.8875	7100	-408.8875	-5.445381
79.83465	16.093631	0.53741497	7512.022	7300	-212.022	-2.822436
79.92005	16.066375	0.54362416	7535.3303	6500	-1035.33	-13.73968
80.00156	15.984869	0.54430377	7537.8653	6500	-1037.865	-13.76869
79.88267	16.102975	0.54666668	7546.6544	6900	-646.6544	-8.568756
79.8427	16.217707	0.5471698	7548.5209	6800	-748.5209	-9.916127
80.06126	15.956576	0.54838711	7553.0299	6600	-953.0299	-12.61785
79.83258	16.23977	0.55000001	7558.9888	7200	-358.9888	-4.749164
79.99689	15.995252	0.55555558	7579.381	7500	-79.38095	-1.047328
79.83881	16.089997	0.55704701	7584.8206	7300	-284.8206	-3.75514
80.15782	15.785517	0.47058824	7242.597	7200	-42.59702	-0.588146
80.23569	15.884674	0.47428572	7258.4769	6900	-358.4769	-4.938734
80.25023	15.886231	0.49112427	7329.2632	6800	-529.2632	-7.221233
80.244	15.869359	0.49411765	7341.5923	6600	-741.5923	-10.10125
80.08021	15.95372	0.50318474	7378.487	6500	-878.487	-11.90606
79.88267	16.10012	0.56284153	7605.8177	7300	-305.8177	-4.02084

80.07216	15.950346	0.56291389	7606.0786	7100	-506.0786	-6.653607
80.00234	15.986427	0.56578946	7616.417	7400	-216.417	-2.841455
79.84296	16.080652	0.57446808	7647.3035	7500	-147.3035	-1.926215
80.07398	15.944376	0.57499999	7649.1813	6500	-1149.181	-15.02359
79.82349	16.217187	0.57664233	7654.9684	6700	-954.9684	-12.47514
80.00649	15.992397	0.57763976	7658.4749	6800	-858.4749	-11.20948
79.9904	15.994474	0.58940399	7699.3825	6600	-1099.382	-14.27884
80.25464	15.885453	0.44134077	7112.4039	6900	-212.4039	-2.986386
80.23491	15.887529	0.45251396	7163.1315	6600	-563.1315	-7.861527
80.24452	15.8813	0.45882353	7191.2272	7500	308.77281	4.293743
80.36366	15.999925	0.46052632	7198.7433	7300	101.25672	1.406589
80.08255	15.943597	0.46206897	7205.5286	7200	-5.528603	-0.076727
80.06723	15.957355	0.59006214	7701.6469	6900	-801.6469	-10.40877
79.82583	16.085065	0.59154928	7706.7541	6800	-906.7541	-11.76571
79.94341	16.06949	0.59210527	7708.6603	6600	-1108.66	-14.38201
79.88241	16.102456	0.59440559	7716.5276	7200	-516.5276	-6.693783
79.77807	16.095707	0.59722221	7726.1194	6900	-826.1194	-10.69255
79.78014	16.109465	0.60000002	7735.5349	6800	-935.5349	-12.09399
79.99896	15.987465	0.6025641	7744.1873	6700	-1044.187	-13.4835
79.91849	16.06975	0.60264903	7744.4732	6600	-1144.473	-14.77794
79.82141	16.22757	0.60273975	7744.7786	6500	-1244.779	-16.07249
79.82323	16.087401	0.60839158	7763.7157	7500	-263.7157	-3.396772
79.77599	16.124001	0.62162161	7807.3653	7400	-407.3653	-5.217705
79.93718	16.070009	0.625	7818.3626	7300	-518.3626	-6.630066
79.87852	16.09389	0.62962961	7833.3368	7200	-633.3368	-8.085147
79.81025	16.216668	0.63636363	7854.9221	6500	-1354.922	-17.24934
79.93874	16.065337	0.63870966	7862.3886	6600	-1262.389	-16.05604
80.24088	15.871176	0.40243903	6925.1805	6700	-225.1805	-3.251619

80.38054	16.00252	0.40277779	6926.8878	6900	-26.88775	-0.388165
79.81233	16.215111	0.65306121	7907.4747	6500	-1407.475	-17.79929
80.06178	15.959431	0.65445024	7911.7857	7200	-711.7857	-8.996524
79.78248	16.11232	0.65562916	7915.4374	7400	-515.4374	-6.5118
79.81025	16.21537	0.6630435	7938.2541	7100	-838.2541	-10.55968
80.00961	15.989542	0.66451615	7942.7556	7200	-742.7556	-9.351359
79.81155	16.217187	0.67195767	7965.3509	6500	-1465.351	-18.39656
79.78274	16.113099	0.67532468	7975.4923	6600	-1375.492	-17.24649
80.13939	15.792006	0.40106952	6918.264	6700	-218.264	-3.154896
80.16457	15.705828	0.40112993	6918.5696	6800	-118.5696	-1.713788
79.90837	16.132047	0.68527919	8005.1822	6900	-1105.182	-13.80583
79.87852	16.099601	0.69633508	8037.6556	7400	-637.6556	-7.933353
79.81285	16.21563	0.70297033	8056.898	7500	-556.898	-6.912065

6.23 YIELD PREDICTION WITH OTHER VEGETATION INDICES

Other vegetation indices were calculated to test if they can have better prediction ability than NDVI. This Vegetation Indices includes Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI2), Infra-red Percentage Vegetation Index (IPVI), Difference Vegetation Index (DVI) and the Ratio Vegetation Index (RVI) (see appendix 4 for details). Test for correlation between the Vegetation Indices was significant ($p = 0.00$). Table 5.5 shows the R2 adj for the fitted logarithmic regression line for the different VIs versus yield. It shows that RVI explains slightly more of the yield variability than any of the Vegetation Indices and DVI explains the least.

Table 5.5 shows prediction ability of different VIs

	NDVI	SAVI	MSAVI	IPVI	DVI	RVI
R2 adj	25.0	26.2	25.9	26.8	22.7	26.9

Testing yield predicted using these VI based models resulted in very little improvement in the yield prediction ability at field level. Table 5.6 shows the R2adj for different VI based models. It shows that IPVI based model explains slightly more than the other VI based models. With the exceptional of DVI based model, the difference is less than 1% in all cases).

Table 5.6 shows R2 adj for different VI based models.

	NDVI	SAVI	MSAVI	IPVI	DVI	RVI
R2 adj %	45.7	46.0	45.9	46.4	43.7	46.3

From these results, the use of NDVI, which is the most commonly, used VI, remains valid.

6.24 NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

Recently, there has been mounting evidence that remotely sensed data may become as successful, if not more successful, at estimating forest functioning (such as photosynthesis or evapotranspiration) than forest structure, especially in a regional context (Tucker and Sellers 1986).

Remotely sensing of the Near Infra-Red (NIR) and Red (R) wavelengths of the electromagnetic spectrum has been shown to have potential for estimating forest functioning and LAI (Peterson and Running 1989, Price and Bausch 1995). In the NIR region of the spectrum, within-leaf scattering is high and the radiation from the canopy is therefore generally high. However, in the R component of the spectrum pigment absorption is high resulting in a low radiation reflection. Consequently, LAI is usually positively related to an increase in the difference between NIR and R radiation. This relationship has been shown to hold generally over a number of different biomes.

The NDVI is one of the most common vegetation indices derived from remotely sensed data and is computed by the product of the ratio of two electromagnetic wavelengths (near infrared - red)/(near infrared + red). Maps showing the vegetation of Africa (Tucker *et al.* 1985), North America (Goward *et al.* 1985) and the entire world (Justice *et al.* 1985) have been produced.

Sellers (1985, 1987) derived an important relationship between LAI, Absorbed Photo-synthetically Active Radiation (APAR) to NDVI. Research found that under specified canopy properties APAR was linearly related to NDVI and curvilinear related to LAI. Sellers therefore showed that:

NDVI = f (APAR) = f (LAI)

As a result, if a canopy has a known structure, light scattering or absorbing properties, any one particular measure of the canopy can be used interchangeably with the other with only some minor algebraic manipulation of formulae. The major problem with these types of relationships is the underlying assumption that the vegetation is not water, temperature or nutrient limited. In the case of annual crop cycles, where the crops are well fertilised, irrigated and produced in the ideal growing seasons, this assumption is valid. However in regions of natural, mixed age forests, the perennial vegetation can be routinely water stressed and is usually temperature limited at some time throughout the year. There is, however, uncertainty in the effect on the NDVI of temporal changes of different vegetation species, especially natural vegetation which is routinely water and nutrient stressed. This is particularly the case over Australian forests where extensive shadowing which is common in most images is caused by complex topography superimposed with a variety of natural and human disturbance regimes leading to an array of structural and floristic pattern. The high degree of speciation and intraspecific variation in the genus Eucalyptus complicates the situation as does the canopy geometry of the genus with generally vertical leaves and a wide range in leaf form with a range from juvenile leaves to old, insect damaged leaves commonly present on a single tree (Lees and Ritman 1991).

Many of the variations caused by differences in canopy closure, under storey location and background reflectance at local scales may be minimized in favor of large scale variations such as regional climate and altitudinal patterns due to AVHRR data integrating over a significantly larger field of view than other remote sensing satellites (Peterson and Running 1989). Over natural vegetation, an AVHRR pixel will typically cover a land facet, or in dissected topography, a cantena of edaphic/physiographic conditions (Malingreau 1986).

6.25 NDVI AS YIELD PREDICTION PARAMETER

Through integration of remotely sensed data, land factors and management aspects, an assessment of field level yield prediction has been executed. It is shown that a combination of NDVI, land and management parameters can improve field level yield prediction above use of NDVI alone. It is found that the availability of water, the weeding method, the number of fertiliser applications, soil type and the date of transplanting explain yield variability. The date of transplanting and the soil type are found to relate to the NDVI variability at field level.

This study established that there is a significant positive relationship between remotely sensed Normalised Difference Vegetation Index and field level yield, where production is at the mercy of many factors acting on the crop. This clearly shows the potential of using NDVI for yield prediction at field level. Among all the NDVI parameters, only maximum NDVI was retained as significant variable for field level yield prediction in the stepwise multiple regression, explaining the yield variability suggesting that maximum NDVI is the best parameter for yield prediction. Groten and Ilboudo (1996) also found similar results where only the maximum NDVI was retained after running multiple regressions with many NDVI parameters in millet yield estimation. However, the prediction ability is low, suggesting that if only NDVIs are used for field level yield prediction, a lot of additional factors explaining yield variability are not covered. NDVI explains the yield variability caused by date of transplanting and soil. It does not reflect other production factors like availability of water and other management factors. Water shortage had a significant impact on yield but not on NDVI. These suggest that the problem was not severe enough to be registered by NDVI. This gives the impression that temporal water shortage is, in the first instance, not reflected by lower vegetation cover. The use of land and management parameters alone has shown that 38.1% of the yield variability can be explained. The combination of NDVI, land and management factors together improved the model to an explanatory power of 45.8%. This shows that use of NDVI alone, as done in many studies, can be improved if land and management factors are also considered, especially at field level where parameters vary from field to field, as opposed to regional or national level, where these factors are generalised. Despite the fact that this study used interview data of the previous season, relying on farmers ability to remember exactly when an operation was done and how or how much fertilisers and other management practices were done, the results agree with studies done before. Muthy *et al.* (1994) reported correlations (r = 0.44 – 0.85) between NDVIs and yield in irrigated rice in command areas under Bhadra project and reported a yield prediction model that explained 75% of the yield variability. Mohd *et al.* (1994) found correlation of 0.85 between NDVI and yield when he conducted a study based on 2 x 2 m area and collected spectral data with a hand held radiometer. All these findings indicate that there is correlation between remotely sensed spectral data and yield. The differences in the correlations and explaining ability of yield variability is due to the level of application and the quality of data being used to investigate the relationships and to derive models. Muthy *et al.* (1994) used yield estimates from CCE, which are fairly accurate and used time composited NDVI. Mohd *et al.* (1994) used yield from highly controlled research plots. This study used data collected through interviews. From the results of this study, it is evident that the quality of data may have a significant effect on the degree of the relationships between remotely sensed NDVI and yield. The results of this study also agree with studies done with other crops. Rajak *et al.* (2002) found that maximum NDVI was linearly related to yield for various crops in Punjab and Haryana states and grown during Rabi 2000 – 2001. They reported that the yield was poorly correlated to NDVI. Ray *et al.* (2002) reported correlations of 0.60 between NDVI and wheat yield in Jajandhsr – Punjab.

6.26 USING SINGLE DATE IMAGE FOR YIELD PREDICTION

This study has demonstrated that, with a single date image, field level yield can be predicted up to 45.8%. This agrees with the range of 6% - 83% as reported by Parihar and Dadhwal (2002) and Dadhwall and Ray (2000) of explained yield variability when single date image based models for various crops including rice are used in some states of India. However, the reported variability by the two authors was at state level with a lot of generalisations and using district level yield estimates. The results of this study shows that, even at field level, despite the great variability in planting date, and other factors, single date images can provide useful information of the crops and yield status. The timing of the image to be used for yield estimation is important. Though Gielen *et al.* (2001) explained that there is good correlation between NDVI and yield but using NDVI as an end-of season yield estimator gives unsatisfactory results because of the problems of choosing the best time of the image to use, Muthy *et al.* (1994) found that vegetation indices calculated from images taken at panicle initiation and heading stages have high correlation with yield, therefore, they can best be used for yield prediction. The findings of Muthy *et al.* (1994) agree with the findings of this study. However, it is difficult to have a single date image representing one phenological stage at field level because of the differences in planting dates and the varieties used, resulting in wide differences in crop phenological stages. To improve the predictability of yield, Muthy *et al.* (1994) and Gat *et al.* (2000) proposed the use of time composited multi-date images for yield prediction covering panicle initiation and heading stages and considering maximum NDVI which normally occurs at heading stage in rice. It is difficult, especially in most tropical environments, to get a series of images due to clouds or other logistical problems. In this case a single date image, as demonstrated in this study, still provides good information to predict end-of-season yield as long as it is within the time when there is maximum vegetation (between panicle initiation and heading stage) and other production factors are taken into account. It should be noted that plant ultimate growth is affected by its growth history and all the environmental parameters, therefore, remote sensed data and other data are required to develop a functional relationship between plant condition and yield at field level. The use of data acquired from space-borne sensors will help to reduce the need for the laborious ground based measurements and enhance the timeliness of information on crop condition and food situation. However, it should be realised that the predicted yield at any stage of plant growth account for all the factors that affect the crop from planting date to the time of prediction. This is then projected to the final yield. As such predicted yield reflects potential yield of the crop with the prevailing conditions. Factors such as drought, floods, pests and diseases happening after the prediction may significantly reduce the yields.

6.27 MODEL PERFORMANCE

This study has also shown that the use of other vegetation indices to predict yield or using models based on other VIs, did not offer any significant improvement in explaining the yield variability. Even linear transformations and combinations of NDVIs and other vegetation indices in different forms did not improve the model's prediction ability. This suggests that use of NDVI for crop development and growth monitoring and for yield estimation is valid as reported by many authors. Gat et al. (2000) also noted the correlations between VIs and linear transformed VIs could not perform any better than the original VIs and he proposed to use the original VIs without any transformation. Testing the model with independent samples drawn randomly from the data has shown that the predicted yield fall within the other yields when all the samples are used. With a regression line explaining 12.4% of the variability.

6.28 SUMMARY AND CONCLUSIONS

Paddy is an important food crop playing a pivotal role in agrarian economy of the country influencing the socio-economic status of small and marginal farmers. India's requirement of paddy for 2025 AD has been projected at 1625 million tonnes and thus, there is a need to raise the productivity levels and hence, more scientific research on paddy is essential. Information on crop acreages, condition assessment and production enables the planners and managers to adopt measures to meet shortages and implement suitable measures for increasing the crop production. Satellite remote sensing, GIS and GPS has emerged as a potential tool and efficient technology for inventorying and monitoring of natural resources especially the crops, soils, irrigation management and drought monitoring. The remote sensing techniques are very effective in estimation of expansion and prediction of potential crop yields for specific crops over large areas both in terms of cost effectiveness and timeliness over traditional method of area and production estimation.

The spectral response of the paddy crop is influenced by leaf area, percent canopy cover, growth stage, chlorophyll content and soil/moisture background etc., The Remote Sensing techniques are expected to contribute for paddy crop are identification and acreage estimation of the crop, condition assessment and yield forecasting. Hence, the present investigation on "Development of Crop yield prediction model (CYPM) for a part of Nagarjuna sagar command area" was carried out in the following.

To develop Crop yield prediction Model (CYPM) with the integration of spatial database and attribute database with their topological relationships.

The spectral indices, such as Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Vegetation Index Number (VIN), Transformed Vegetation Index (TVI) and Soil Adjusted Vegetation Index (SAVI) are computed and applied for paddy crop in this study area. The analysis of satellite data involves registration of raw satellite data with the SOI map base, generation of training areas, spectral indices and signatures, spectral separability analysis, classification and estimation of crop acreage. The condition of crop is assessed using temporal VI's and relationships between spectral indices and crop growth variables like plant population, paddy girth and plant height is developed.

The salient conclusions drawn on the present investigation titled are summarized below: "Development of Crop yield prediction model (CYPM) for a part of Nagarjuna sagar command area"

- Satellite remote sensing is found to be useful for pre-harvest paddy crop acreage estimation and condition monitoring necessary for taking corrective measures if any during rest of the crop growth period.
- The spectral reflectance curves obtained for paddy crop from satellite data are useful for identification and delineation of the crop, when the paddy crop is at 100, 120 and

150 DAP. The paddy crop is not separable at 50 and 75 DAP in the study area as the soil background is dominating in the pixel information.

- The paddy crop identification, acreage estimation and condition monitoring can be attempted using satellite data obtainable from May to September months. The acreage estimation could be carried out using satellite data sets from May to September and where as during initial stages of crop growth up to April, the soil background is dominating and during October-November period, the crop is reaching pre-ripening stage. The estimated acreages of paddy crop in Addanki branch canal command area using satellite data during paddy growing seasons of 1996 to 2006 were found to be 932213.7, 954324.1, 8504598, 3142928, 6914326, 5763442, 265155.4, 225093.9, 74387.95, 3873935, 4968918 acres.
- Acres, respectively with a relative deviations of –4.68, 3.20, -0.62 for these years in comparison with Beauro of Economic and Statistics estimations.
- The generation of fused product by integrating the spatial resolution of LISS-III sensor data of Indian remote sensing Satellites (1C/1D) for Addanki branch canal command area, have increased the capabilities for identification of individual paddy fields. The area estimation was carried out for the all villages during the paddy crop season of 1996 to 2006.
- Vegetation indices are quantitative measurement of the vigour of crop, which show better sensitivity to crop growth parameters. The indices such as Ratio Vegetation Index (RVI), Vegetation Index Number (VIN), Normalized Difference Vegetation Index (NDVI), Transformed Vegetation Index (TVI), and Soil Adjusted Vegetation Index (SAVI) were studied to evaluate their suitability towards paddy production estimation using the satellite data sets obtained at different crop growth stages along with ground information for crop seasons of 1996 to 2006. The results revealed that NDVI is most suitable for prediction of paddy yields during grand growth period for the years of 1996 to 2006, respectively.
- NDVI is a quantitative measurement of vigour of crop, which denotes the biomass and crop health status, which are related to yields of paddy crop. The NDVI profile

of paddy crop is plotted against time for the paddy seasons of 1996 to 2006. The results showed a strong relationship between NDVI and yields of individual paddy fields. The yield prediction is carried out using yield data from the years of 1996 through 2006 using the methodology envisaged in trend analysis and the predicted yields are having relative deviation of 5.10 and 8.25 percent with yields reported from Addanki branch canal command area of 1996 to 2006. The reported regression coefficient is 0.84 and SEE is 2.70 tonnes per acre indicating that the yield prediction/forecast of the paddy crop is possible using satellite data in conjunction with the data on historical crop yields.

- The production forecast was made using the acreage estimates obtained from satellite remote sensing data and yield predictions from trend analysis. The production estimate is reported with a relative deviation of -7.24 and 6.08 percent respectively for the paddy seasons of 1996 and 2006.
- It was found that there is a poor correlation between NDVI and number of internodes, paddy girth and plant height. However, the relation between individual paddy weight and plant population and NDVI is positively correlated with 'r' values of 0.764 and 0.83 respectively. The study suggested that only paddy weight and plant population is significantly influencing the spectral information.
- The accuracy assessment had shown that the crop classification accuracy for the area estimation was 93.74%, 93.01% and 91.61% respectively for the paddy growing seasons of 1996 to 2006 in the study area. The estimated kappa coefficient was 0.911, 0.916 and 0.894 respectively for the seasons of 1996 to 2006 respectively.
- The remote sensing data is not only advantageous but also economically cost effective in paddy area estimation and condition assessment and not influenced by human bias.
- More work needs to be done for deriving Agro-Spectral-Yield relations of paddy crop by creation of large data bases over years and validating these relationships using meteorological, crop, soil and water management practices in different agro-climatic zones.

- Multi-date satellite data sets with higher spatial resolutions (2.5 to 1.0 meter PAN and 5.0 meter LISS) are needed to study paddy crop growth dynamics vis-à-vis crop stresses.

7. NET PRIMARY PRODUCTIVITY

Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time. NPP refers to a rate process, i.e., the amount of vegetable matter produced (net primary production) per day, week, or year.

However, the terms net primary productivity and net primary production are sometimes used rather liberally and interchangeably, and some scientists still tend to confuse productivity with standing biomass or standing crop. NPP is a fundamental ecological variable, not only because it measures the energy input to the biosphere and terrestrial carbon dioxide assimilation, but also because of its significance in indicating the condition of the land surface area and status of a wide range of ecological processes

7.1 ESTIMATING NPP

There are many ways to estimate terrestrial NPP from field measurements that depend on the type of plants and available measurements. Methods are discussed in connection with the biomes included in the NPP Database. Some of the methodology reviews were carried out as part of the NCEAS (National Center for Ecological Analysis and Synthesis) Working Groups on "Development of a Consistent Worldwide Net Primary Production (NPP) Database" between December 1997 and October 1998.

7.2 OVERVIEW OF THE NPP PROJECT

The ORNL DAAC Net Primary Production (NPP) Database contains field measurements of biomass and estimated NPP for terrestrial sites worldwide, compiled from published literature and other extant data sources. It includes intensively studied and well-documented field study sites, together with more extensive collections of worldwide data. Compilation of these data was sponsored by the Terrestrial Ecology Program of NASA's Office of Earth Science.

7.3 IN-DEPTH

The NPP Database contains data for 65 intensive study sites. The majority of these sites are grasslands, the remainder being located in tropical forest, boreal forest, and tundra. Some combination of above-ground annual peak live biomass data and/or seasonal biomass dynamics data is available for all sites. Many sites also have data on below-ground biomass and/or turnover. A number of previously compiled multi-site, multi-biome data sets of georeferenced NPP estimates are also provided

7.4 SCOPE

The Oak Ridge DAAC NPP Database contains documented field measurements of NPP for global terrestrial sites compiled from published literature and other extant data sources. The NPP Database contains biomass dynamics, climate, and site-characteristics data georeferenced to each intensive site. A major goal of the data compilation is to use consistent and standard well-documented methods to estimate NPP from the field data. Other important components of the database include investigator contact information and a list of key references (some with summaries) for each site. As far as possible, the original principal investigator or his/her successor has been contacted to review the data and documentation.

7.5 STATUS

The NPP Database contains detailed data for numerous intensive study sites. The majority of these sites are grasslands, the remainder being located in tropical forest, boreal forest, and tundra. Some combination of above-ground annual peak live biomass data and/or seasonal biomass dynamics data are available for all sites. Many sites also have data on below-ground biomass and/or turnover. Climate and other data (soils, etc.) are available for all sites in varying degrees of detail. Estimates of net primary productivity are included.

There are over 450 site-year-treatment combinations of biomass/NPP measurements and an average of 30 years of monthly climate data for each site. The sites have been grouped in vegetation land-cover classes based upon Bailey ecoregions, and have also been mapped with respect to Holdridge Life-Zones, Matthews vegetation classes, Olson World Ecosystem Complexes, and the University of Maryland Global Land Cover map.

A number of previously compiled multi-site, multi-biome data sets of georeferenced NPP estimates are also provided: these include lists of original references, to allow users to consult literature providing more detailed site information. We encourage your User Comments concerning questionable data values, incomplete metadata, the general format and organization, or suggestions for additional sources of NPP data that could be added for grasslands, forests or other biomes

7.6 ESTIMATION OF NPP FOR GRASSLANDS

The Oak Ridge DAAC Net Primary Production (NPP) Database includes field measurements from grassland study sites worldwide. The following brief review and discussion is intended to explain the complexity of NPP estimates derived from grassland measurements. There is no single answer to the question, "What is the productivity of the ecosystem at study site A?"; rather there may be range of estimates of NPP, depending upon what data were actually collected and how these data are processed. Although some of these methods for determining NPP for grasslands may be applicable to other vegetation types (e.g., semi-deserts, tundra, or some crops), methods for forests, in particular, are significantly different. Since the field measurements were collected by research workers using a variety of methods, secondary users of these data such as the modelling community are encouraged to consult the general scientific literature as well as the published study site descriptions in order to more fully understand the data from each site.

7.6.1 BRIEF LITERATURE REVIEW

Net primary production, sensu stricto, is the total photosynthetic gain (less respiratory losses) of vegetation per unit ground area. For a given period, this is equal to the change in plant mass plus any losses due to death and decomposition, measured for both above ground and below ground plant parts. Earlier estimates of grassland NPP were based on peak standing dry matter only, and the studies of the International Biological Programme (IBP) in the late 1960s and early 1970s were based mainly on above-ground biomass changes, with few estimates of below-ground production. Peak above-ground live biomass (or in some cases, the difference between maximum and minimum biomass) has been used as an estimate of net primary production - usually where only one or two measurements per year are available. Sometimes a conversion factor has been applied to take into account the estimated turnover and the estimated ratio of above-ground to below-ground dry matter.

The "IBP Standard Method" of Milner and Hughes (1968) assumes that where live biomass increases between successive samples, production equals this increase; where biomass decreases or remains the same, production is assumed to be zero. Annual production is then obtained by summing the estimates for each sample interval. Essentially, this method was used for the IBP synthesis by Singh and Joshi (1979), in particular for their estimates of below-ground production. A modified method was used for above-ground production, determined by a decision matrix (Singh et al., 1975). In cases where increments in live biomass coincided with increases in standing dead matter, the latter were added to the monthly production.

The limitations of the above methods are discussed in detail by Long et al. (1989) and Long et al. (1992). In particular, the peak biomass method and variations on the IBP method underestimate production by not accounting for simultaneous growth and death. This may be significant in temperate grasslands with a long growing season, and is particularly a problem in tropical grasslands where the growing season may extend over much of the year. Some limited overestimation may occur by not accounting for periods of negative NPP (due to stress, or translocation between above and below ground plant parts) but underestimation of root turnover is probably the largest source of error. Long et al. (1989) estimated NPP for three terrestrial tropical grassland sites by summing monthly changes in live biomass plus losses due to death and decomposition for above and below ground vegetation. Monthly losses were determined as the change in dead matter plus the estimated disappearance of dead matter through decomposition. Dead matter disapperance was calculated each month as the product of relative decomposition rate and mean amount of dead matter.

Although some correlation between estimates obtained using different methods has been reported (Singh et al., 1975), the degree of underestimation may be strongly site-specific (Linthurst and Reimold, 1978; Long and Mason, 1983). Where sufficient data are available for a given grassland site, it may be possible to estimate NPP according to the different methods for the purposes of comparison. This may involve entry of data into algorithms or a spreadsheet containing these algorithms.

7.7 METHODS AND ALGORITHMS FOR ESTIMATING NPP

Annual NPP may be calculated for a given year (Jan-Dec) or for any appropriate 12-month growing cycle, depending on latitude (Northern or Southern hemisphere growing season) and environmental or management factors which determine this cycle. For example, annual burning during a short dry season is an important "scheduling" factor in many humid savannas. Note that the length of the growing season varies widely, from as little as 3 months in extreme continental or semi-arid conditions to as much as 12 months in some humid tropical regions. Dry weight of each above-ground category is determined at intervals of one month or less (preferably) within a specified number of randomly located quadrats or in a randomized block design of quadrats. Dry weight is determined by clipping standing biomass to ground level and collecting the litter (fallen dead matter) from the area of each quadrat. Clipped material is sorted into live leaves and standing dead matter, and stems are sorted likewise, paying attention to removal of dead sheaths from live stems. Below-ground plant matter is sampled by removing soil cores from the center of each quadrat, to a depth determined by trial sampling to retrieve at least 80% of below-ground matter (usually 15-30 cm). Where the soil structure or hardness does not permit the use of corers (gouges) or augers, soil pits may be dug to specified dimensions. Soil samples are washed over a 2 mm sieve, because the ability to pass through a 2 mm mesh is generally taken as the arbitrary division between recognizable dead matter and particulate organic matter. Larger roots may be removed and weighed separately from fine roots (less than about 1 mm diameter). Fine roots may be sub-sampled before separation into live and dead matter on the basis of tissue necrosis, using vital staining such as tetrazolium salts where visual discrimination is difficult. All sorted plant matter is washed and dried to constant weight at 90-95 degrees Celsius. Below-ground sampling is time-consuming and can be expensive, so data is often of poor quality or absent altogether.

Decomposition or disappearance of dead matter may be determined using "paired plots" or litter bags (Weigert and Evans, 1964; Long et al., 1989). The paired plots technique involves measuring dead matter present at the start and end of a sampling interval, whereas the latter comprises the use of (typically) 2 mm nylon mesh bags. Bags of dead above-ground matter are placed at the ground surface, and dead below-ground matter is buried in the soil. Bags are recovered at the end of the sample interval, and the loss of material determined and expressed as a relative decomposition rate.

Statistical procedures exist for determining the optimum number and size of quadrats for sampling within desired tolerances. However, it is generally not practicable to maximise the number of quadrats so as to obtain a statistically significant difference in biomass between consecutive samples (Long et al., 1992).

Methods for calculating NPP are summarized below (refer to the Directory of Terms and Definitions for further details):

1a. Peak Biomass Method A

ANPP = max {AGbiomass}

7.7.1 ASSUMPTIONS

- any standing dead matter or litter was carried over from previous year, and death in current year is negligible
- live biomass was not carried over from previous year
- below-ground production is ignored, or estimated only as a fraction of above-ground production using a crude root/shoot ratio

7.7.2 CONCLUSION

May be applicable to annual arable crops, but clearly a poor estimate of production for perennial vegetation (i.e. most natural plant communities), especially where below-ground turnover may be significant. May be useful for crude comparisons between seasonal temperate grasslands, but has little meaning for tropical grasslands, and should definitely not be used to compare temperate and tropical grasslands.

1b. Peak biomass method B

ANPP = max {AGTotclip}

7.7.3 ASSUMPTIONS

- Any standing dead matter was formed by death in current year, hence counts as part of this year's plant production
- No standing dead matter has yet fallen as litter or decomposed
- Neither live biomass nor standing dead matter were carried over from previous year
- Below-ground production is ignored, or estimated only as a fraction of above-ground production using a crude root/shoot ratio

7.7.4 CONCLUSION

- As for Method (1a) above; may be a slightly better estimate of NPP where significant death occurs during the growing season.

1c. Max-Min Method

NPP = max {AGbiomass} - min {AGbiomass}

7.7.5 ASSUMPTIONS

- As for Method (1a), but any live biomass carried over from the previous year is excluded

7.7.6 CONCLUSION

- As for Method (1a) above; subtraction of minimum biomass is likely to be a useful correction only under limited conditions.

2a. IBP Standard Method (Milner and Hughes, 1968)

NPP = sum {positive increments in AGbiomass}

7.7.7 ASSUMPTIONS

- Most growth occurs between successive sample intervals, i.e. simultaneous growth and death do not occur
- NPP is never negative during a sample interval
- Below-ground production may be similarly measured, ignored altogether, or estimated only as a fraction of above-ground production using a crude root/shoot ratio

7.7.8 CONCLUSION

- This allows for several distinct phases of growth within a year, but still fails to account for new shoot growth during periods of high mortality, and vice versa. However, for sites where data on biomass dynamics are available (preferably both above and below ground) a more dynamic comparison of net primary production may be possible. Nevertheless, comparisons between temperate grasslands displaying marked seasonal changes in biomass and tropical grasslands (where biomass may not change much despite high turnover) should be avoided.

7.7.9 ASSUMPTIONS

- Simultaneous growth, death and decomposition (i.e. continuous turnover) does not occur
- NPP is never negative during a sample interval
- below-ground production may be similarly measured, ignored altogether, or estimated only as a fraction of above-ground production using a crude root/shoot ratio

7.7.10 CONCLUSION

- As for Method (2a), although the correction for material lost by death during periods of biomass increase will reduce the degree of underestimation of NPP

7.7.11 ASSUMPTIONS

- Measured changes in parameters are statistically significant over each sample interval (in practice, this may be very hard to achieve, since an impractically large number of samples would be required to detect real but modest changes over each sampling interval)
- Decomposition rate is independent of the composition of dead matter (in fact, it will decline exponentially as a function of lignin:N ratio)
- Losses of AGbiomass and AGTotdead by grazing, root exudation, etc. are negligible
- Below-ground production may be similarly measured, or estimated only as a fraction of above-ground production using a crude root/shoot ratio

7.7.12 CONCLUSION

- This is the only method which incorporates all components required for an accurate estimate of NPP (and then only if both above and below-ground production are measured). Although such detailed data are not available for all study sites, it provides a useful benchmark against which to check the possible degree of underestimation using other methods. Where detailed biomass dynamics are available but no data exists on decomposition or disapperance of dead matter, it may be possible to improve on estimates by modelling decomposition using data from other similar sites. However, such applications are outside the scope of this summary.

7.8 NPP BOREAL FOREST

7.8.1 SUMMARY

The three objectives of this study were: (1) to summarize net primary productivity (NPP) and carbon allocation patterns for boreal forests, (2) to examine relationships between climatic and biological variables and NPP, and (3) to examine carbon allocation coefficients for all boreal forests or types of boreal forests that can be used to estimate NPP from easily measured components of NPP.

Twenty-four Class I boreal forest stands (complete NPP budgets) and 45 Class II stands (aboveground NPP - ANPP - budget only) were identified. The geographic distribution of the Class I stands was not uniform; 46% of the stands were from two studies in North America and only one stand was from the important larch forests of Eurasia. Total (above- and below-ground) net primary productivity (NPP) ranged from 52 to 868 gC/m2/yr and averaged 424 gC/m2/yr. ANPP was consistently larger for deciduous than evergreen boreal forests in each of the major boreal regions, especially for boreal forests in Alaska. Ratios of belowground net primary productivity (BNPP) to total net primary productivity (BNPP:TNPP) were consistently larger for evergreen (0.36) than deciduous (0.19) boreal forests. NPP of different-aged stands in age sequence varied from 44 to 77% - a magnitude equal or greater to that of climatic factors or vegetation type.

NPP and ANPP were positively correlated (r2 = 0.66 to 0.68) to mean annual aboveground increment for Class I stands and this empirical relationship explained 81% of the observed variation of ANPP for Class II stands. These robust relationships provide an approach for increasing the number and spatial coverage of boreal forest NPP data needed to evaluate NPP estimates from ecosystem models. Notable deficiencies of boreal forest NPP data were: ground layer vegetation and belowground NPP data, NPP data for boreal forest age sequences, and NPP data for boreal larch ecosystems in Eurasia.

7.9 NPP TROPICAL FOREST

7.9.1 SUMMARY

It is clear that the currently available data on net primary production in tropical forests are extremely limited and that even our best estimates for this biome can only be thought of as rough approximations within wide bounds. Nevertheless, this study has provided a basis for evaluating the quality and utility of the data generated by past studies and of the NPP estimates that have been reported in the literature for tropical forests. Clearly, the most important knowledge gap is with respect to the belowground components of NPP in these ecosystems. In particular, fine root losses are likely to be a substantial proportion of NPP in many tropical forests, and they as yet remain unquantified. It is also clear that there have been many of the previous NPP studies in this biome have involved methodological problems and poor documentation. Henceforward, it is paramount that such studies be carefully designed and reported so as to avoid these pitfalls. A third issue that needs to be addressed is that of sampling bias and the lack of replication in either time or space for NPP studies in these forests. Given the very small and subjectively located plots that are the basis for most of the existing data, it is possible that the existing understanding of NPP processes in tropical forests is highly skewed toward the highest biomass patches (flat sites with large trees, no gaps) and is unrepresentative of the larger forest landscapes.

There is a great need for well-designed field studies of NPP in sites spanning the very broad climatic range that is covered by tropical forests. Of particular importance at this stage will be more studies of old-growth stands of these diverse forest types. While successional and human-impacted tropical forest systems are clearly of great ecological and economic importance, NPP processes in them are highly variable due to successional processes and/or to the varied degrees and qualities of human impacts on them. It thus seems more productive to first concentrate on broadening our base of understanding of the more predictable processes in old-growth stands, which are the basis of many global modeling efforts and which also will be the more interpretable guides to how tropical forest ecosystems are responding to processes of global climatic and atmospheric change.

7.9.2 For such studies, we have the following recommendations:

- Study plots at a site should be replicated, the number and size of these plots should be determined by pre-sampling with respect to the variance in aboveground biomass, and siting should be based on a random or stratified-random design.

- Production should be measured through at least two or three full yearly cycles, to give some bounds on the temporal variance and climatic sensitivity of NPP at each tropical forest site.
- For litterfall, large numbers of collectors should be used, the wood component should be restricted to pieces < 1 cm in diameter, data must come from at least a full year cycle and from biweekly collections, components should be quantified and reported separately, and the statistical uncertainty around the litterfall values should be calculated and reported.
- For aboveground biomass increment, estimates should be based on re-measurement of at least all woody stems in each plot above a reasonable minimum diameter for that forest type (10 cm in most tropical moist and wet forest, smaller diameters in many tropical dry and montane forests), all boles should be measured above buttresses (and this should be reported), data should be given separately for palms, lianas, and hemiepiphytes, and if possible, appropriate allometries should be used for them, and the details of the biomass accounting should be reported.
- A major emphasis should be placed on obtaining reliable estimates for fine root losses, preferably by combining at least two of the best currently available techniques (e.g., minirhizotrons, and sequential coring + decomposition studies), with sampling to at least 1 m depth and with as much replication as logistically possible.
- Ancillary studies by other investigators should be sought, to be carried out concurrently at the same site, to obtain at least rough estimates of little-studied components of NPP (coarse root increments, emission of BVOC's, rhizodeposition, losses to consumers).
- When publishing values for NPP components, core site descriptions should always be provided, including: mean annual temperature, mean annual precipitation (and preferably the annual temperature and rainfall for the year(s) when production was measured); elevation; soil characteristics; forest age and extent of human impact,

and precise site location data (latitude and longitude or more precise GPS data if possible).

7.10 NPP CROPLAND

Net primary productivity (NPP) of agricultural regions, where most of the land is sown with a few well-studied crops, was estimated from crop harvested yield, as recorded in national agricultural statistics. The magnitudes and inter-annual variations in NPP of croplands in the US Mid-West were estimated using crop area and yield data from the US National Agricultural Statistics Service (NASS). Total NPP, including estimates of both above and below-ground components, was calculated from harvested yield data by (1) conversion from reporting units of yield of the crop product, usually in volume, to mass; (2) conversion from fresh weight to dry weight; (3) estimation of above-ground yield using crop harvest indices, defined as the ratio of economic product (e.g. grain) dry weight to plant above-ground dry weight; and (4) estimation of below-ground yield as a function of above-ground biomass.

7.11 NPP AND THE GLOBAL CARBON CYCLE

7.11.1 INTRODUCTION

Photosynthetic carbon fixation comprises a major component of the global carbon cycle. Data on net primary productivity (NPP) may be sparse, but a consistent NPP data set may be used to calibrate, parameterize and evaluate models of terrestrial carbon cycling, as well as for validation of remote sensing data and other applications (identifying trends, investigating biogeochemical processes, etc.). It is also useful to place such data within the context of carbon cycling and carbon storage worldwide. For example:

- How much carbon exists in the biosphere, and where exactly is it stored?
- How much is in fossil fuels (coal, oil, gas), and how large are current fossil-fuel emissions?
- How much is in living biomass (plants/ animals/ humans)?

- How much carbon dioxide is there altogether in the atmosphere, or dissolved in the oceans, and how much is locked up in geological reserves such as carbonates?

A number of tables of data have been reproduced here from selected key references in the literature, showing the estimated contribution of different vegetation types to the global carbon cycle in terms of overall NPP and carbon stocks. Information on fossil fuel carbon stocks and emissions is provided for comparison.

- Viewable ASCII file versions of Amthor's 1998 data (worldnpp1.txt) and Lieth's 1975 data (worldnpp2.txt)
- viewable ASCII file showing world carbon flows, stocks and balances, circa 1990 (Hall and Scurlock, 1993) (worldnpp3.txt)

Some differences between Lieth's 1975 estimates and the recent review by Amthor et al. are summarised in the following graphs (browsable .JPG images):

- Area of selected ecosystems
- Estimated NPP for selected ecosystems

Although extreme dry deserts and ice are included here as ecosystems (or land cover types), differences in accounting make it hard to compare forest types between the two sources. Amthor et al. (1998) drop altogether two of Lieth's (1975) forest categories, account for northern peatlands separately from the remainder of the boreal forest zone, and consider urban and other human-modified land area as a new category. However, their larger area for savannas and desert/semidesert makes up most of this difference.

7.12 NPP DATABASE DICTIONARY

The NPP Database Dictionary defines the common terms, codes, and conventions used in the database. Data in the NPP Database may have been reformatted to achieve consistency in format and definitions of variables. Some of the processing or conversions that are often necessary to have common definitions include: expressing biomass as dry weight, expressing

NPP as carbon equivalents, and distinguishing above-ground, below-ground, and total plant components. Missing numeric values are assigned a code of "-999.9." Since the data were collected by research workers using a variety of methods, secondary users of these data are encouraged to consult the general scientific literature as well as the published study site descriptions in order to more fully understand the data from each site. The NPP Database Dictionary attempts to standardize the terms and abbreviations used by field workers and modellers, but may not include the full range of synonyms used for plant biomass and production parameters. All the terms used throughout the NPP Database are defined, although they sometimes differ from biome to biome. The following list was prepared principally with reference to grasslands.

7.13 MODIS DAILY PHOTOSYNTHESIS (PSN) AND ANNUAL NET PRIMARY PRODUCTION (NPP) PRODUCT INTRODUCTION

Probably the single most fundamental measure of "global change" of practical interest to humankind is change in terrestrial biological productivity. Biological productivity is the source of all the food, fiber and fuel that humans survive on, so defines most fundamentaly the habitability of the Earth. The spatial variability of NPP over the globe is enormous, from about 1000 gC/m_2 for evergreen tropical rain forests to less than 30 gC/m_2 for deserts (Lieth and Whittaker 1975). With increased atmospheric CO_2 and global climate change, NPP over large areas may be changing (Myneni et al 1997a, VEMAP 1995, Melillo et al 1993).Understanding regional variability in carbon cyle processes requires a dramatically more spatially detailed analysis of global land surface processes The PSN (Photosynthesis) and NPP (Net Primary Production) products are designed to provide an accurate, regular measure of the production activity or growth of terrestrial vegetation. These products will have both theoretical and practical utility. The theoretical use is primarily for defining the seasonally dynamic terrestrial surface CO_2 balance for global carbon cycle studies such as answering the "missing sink question" of carbon (Tans et al. 1990). The spatial and seasonal dynamics of CO_2 flux are also of high interest in global climate modeling, because CO_2 is an important greenhouse gas (Keeling et al. 1996, Hunt et al 1996). Currently, global carbon cycle models are being integrated with climate models, towards the goal of integrated Earth Systems Models that will represent the dynamic interaction between the atmosphere, biosphere and oceans. The weekly PSN product is most useful for these theoretical CO_2 flux questions.

The practical utility of these PSN/ NPP products is as a measure of crop yield, range forage and forest production, and other economically and socially significant products of vegetation growth. The value of an unbiased, regular source of crop, range and forest production estimates for global political and economic decision making is immense. These products will be available for all users worldwide. This daily computed PSN more correctly defines terrestrial CO_2 fluxes than simple NDVI correlations currently done to increase understanding on how the seasonal fluxes of net photosynthesis are related to seasonal variations of atmospheric CO_2.

7.14 THEORETICAL BACKGROUND

7.14.1 ESTIMATING NPP FROM APAR

The notion of a conservative ratio between absorbed photosynthetically active radiation (APAR) and net primary production (NPP), was proposed by Monteith (1972;1977). Monteith's original logic suggested that the NPP of well-watered and fertilized annual crop plants was linearly related to the amount of solar energy they absorbed. APAR depends on the geographic and seasonal variability of daylength and potential incident radiation, as modified by cloudcover and aerosols, and on the amount and geometry of displayed leaf material. This logic combined the meteorological constraint of available sunlight reaching a site with the ecological constraint of the amount of leaf-area bsorbing that solar energy, avoiding many complexities of carbon balance theory. Time integrals of APAR have been shown to correlate well with observed NPP, but different relationships are observed for different vegetation types, and for the same vegetation type under different growth conditions (Russell et al., 1989). Other factors influencing NPP, in addition to APAR, include: concentration of photosynthetic enzymes, canopy structure and average PAR flux density, respiration costs for maintenance and growth ,canopy temperature, evaporative demand, soil water availability, and mineral nutrient availability

The challenge of estimating NPP from APAR over a global domain is in accounting for these multiple influences. Although it has been clearly demonstrated that useful empirical relationships between measured NPP and measured APAR can be derived for individual sites or related groups of sites, the objective parameterization of these empirical relationships over the global range of climate and vegetation types is a more difficult problem. Monteith's original formulation included a maximum radiation conversion efficiency (emax) that was attenuated by the influence of other simple environmental factors postulated to reduce growth eficiency. The same basic approach has been used in most other appli cations of the radiation use efficiency concept, with the most significant

differences between approaches being the determination of values for emax and the functional forms for its attenuation. Early applications assumed a universal constant for

emax that would apply across vegetation types, but later studies showed important differences in maximum efficiency between types (Russell et al., 1989). It has been shown that differences in autotrophic respiration costs may account for some of the important differences in emax between vegetation types (Hunt, 1994), which suggests that APAR may be more closely related to the gross primary production (GPP) than to NPP (GPP is the photosynthetic gain before any plant respiration costs have been subtracted).

This approach, using APAR to predict GPP instead of NPP, and later accounting forrespiration costs through other relationships, has been employed in recent studies (Prince and Goward, 1995). Since the relationships of environmental variables, especially temperature, to the processes controlling GPP and those controlling autotrophic respiration have fundamentally different .it seems likely that the empirical parameterization of the influence of temperature on production efficiency would be more robust if the gross production and autotrophic respiration processes were separated.

7.14.2 RELATING APAR AND SURFACE REFLECTANCE

A strong relationship has been shown to exist for vegetated surfaces between the fractional absorption of incident PAR and the surface reflectance of incident radiation (Sellers, 1987; Asrar et al., 1992). A robust predictive theory for this relationship has also been established (Sellers et al., 1992). This relationship makes the radiation conversion efficiency logic an attractive avenue for predicting NPP from remote sensing inputs. It is important to note that the radiation use efficiency logic requires an estimate of APAR, while the usual application of remote sensing data provides an estimate of FPAR, the fraction of incident PAR that is absorbed by the surface (APAR = PAR * FPAR). Measurements or estimates of PAR are therefore required in addition to the remotely sensed FPAR. For studies over small spatial domains with in situ measurement of PAR at the surface, the derivation of APAR from satellite-derived FPAR is straightforward.

NPP algorithm depends on global daily estimates of PAR, ideally at the same spatial resolution as the remote sensing inputs, which is a challenging problem. Various methods have been implemented to address this problem, and we will consider some of them in a later section. For now, we simply note that in spite of the strong theoretical and empirical relationship between remotely sensed surface reflectance and FPAR, accurate estimates of NPP will depend at least as strongly on the quality of the global daily estimates of PAR.

7.15 ALGORITHM OVERVIEW

The details of algorithm implementation, focusing on compute structure, data handling, Processing loads, and quality assurance issues. Section 6 covers algorithm validation efforts. The essence of the core science in the algorithm is an application of the radiation conversion efficiency logic to predictions of daily GPP, using satellite-derived FPAR and independent estimates of PAR and other surface meteorological fields (from the DAO), and the subsequent estimation of maintenance and growth respiration terms that are subtracted from GPP to arrive at annual NPP. The maintenance respiration (MR) and growth respiration (GR) components are derived from allometric relationships linking daily biomass and annual growth of plant tissues to satellite-derived estimates of leaf area index (LAI), same parameters used in the Biome-BGC ecosystem process model

The parameters relating APAR to GPP and the parameters relating LAI to MR, GR are estimated separately for each unique vegetation type in the at-launch land cover product. The GPP parameters are derived empirically from the output of Biome-BGC simulations performed over a gridded global domain using multiple years of gridded global daily meteorological observations. The MR and GR parameters are taken directly from the Biome-

BGC ecophysiological parameter lists, which are organized by plant functional type (White et al., in prep.). See Section 4 for a discussion of the parameterization process for GPP and respiration parameters, operates over the global set of 1km land pixels, using the combination of daily and annual processing just outlined. The discussion of daily and annual processing in the following subsections is with respect to a single 1km land pixel.

7.16 DAILY ESTIMATION OF GPP

For a particular pixel from the global set of 1km land pixels, daily estimated FPAR from MOD15 and daily estimated PAR from DAO are multiplied to produce daily APAR for the pixel. Based on the at-launch land cover product, a set of radiation conversion efficiency parameters are extracted from the biome properties lookup table (BPLUT). There are five such parameters for each vegetation type:

Parameter	Units	Description
Emax	(kgC MJ-1)	the maximum radiation conversion efficiency
TMINstart	(°C)	the daily minimum temperature at which e = emax (for optimal VPD)
TMINfull	(°C)	the daily minimum temperature at which e = 0.0 (at any VPD)
VPDstart	(Pa)	the daylight average vapor pressure deficit at which e = Emax (for optimal TMIN)
VPDfull	(Pa)	the daylight average vapor pressure deficit at which e = 0.0 (at any TMIN)

The two parameters for TMIN and the two parameters for VPD are used to Calculate two scalars that attenuate emax to produce the final e used to predict GPP, The second step of the daily process is to estimate maintenance respiration costs for leaves and fine roots. These estimates are based on a standard exponential function of daily average air temperature scaled by the biomass of leaves and fine roots. We use LAI from MOD15 to estimate leaf mass, based on a specific leaf area (SLA) from the BPLUT. Fine root mass is assumed to be present in a constant ratio to leaf mass.

There are several components of the plant respiration costs that cannot be estimated accurately on each daily timestep, given the constraints of the data available in the MODIS processing stream. One of these is the component of maintenance respiration in woody vegetation types that is due to the live cells of the woody biomass. These cells are present and respiring as a function of temperature throughout the year, even for deciduous types which have no leaves displayed in the winter or drought months. The logic used above to relate fine root mass to leaf area will not work for this component, since it misses respiration occurring when the trees are bare. A better approach is to assume that the amount of live woody tissue is constant through the year, and is related to the annual maximum leaf mass. By sending daily leaf mass as an output from the daily algorithm, this annual maximum can be assessed in the annual time step logic. Because of the non-linear influence of temperature on maintenance respiration, it is also necessary to send an index of daily maintenance respiration potential as an output from the daily algorithm, so that once the live woody tissue mass is known it can be used to estimate annual total live woody maintenance respiration.

Growth respiration is the other component that cannot be estimated accurately at the daily time step, Differencing of LAI between time steps could possibly produce estimates of daily growth, but such a method would be very sensitive to random variation in estimated LAI. Here again we use the annual maximum of leaf mass, together with empirical allometric relationships estimated from literature review, to estimate growth and its associated respiration costs. The daily output of leaf mass described above is used for this purpose. Since some of the maintenance respiration costs and all of the growth respiration Costs have not been accounted for in the daily timestep, the daily output from this algorithm is termed NPP*, to differentiate it from the true daily NPP, which is never Known. Outputs from the daily algorithm, NPP*, daily leaf mass, and an index of daily maintenance respiration.

7.17 ANNUAL ESTIMATION OF NPP

The annual algorithm finishes the estimation of annual NPP by first estimating the live woody tissue maintenance respiration, then estimating the growth respiration costs for leaves, fine roots, and woody tissue. Finally, these components are subtracted from the accumulated daily NPP* to produce the an estimate of annual NPP. The annual maximum leaf mass, as estimated from the output of daily leaf mass, is the primary input for estimates of both live wood maintenance respiration and whole-plant growth respiration. This approach relies on empirical studies relating annual growth of leaves to annual growth of other plant tissues. In addition to the annual maximum leaf mass, an estimate of leaf longevity (the inverse of leaf turnover rate) is required to predict the annual leaf growth for evergreen types. For deciduous types, leaf longevity is assumed to be less than one year, so the total leaf mass must be grown each year. Our logic makes the assumption that no litterfall begins for deciduous types until the maximum annual leaf mass has been attained. In cases where litterfall is happening at the same time as new leaf growth our method would tend to underestimate the total annual growth respiration costs. The same problem applies to evergreen canopies, but with longer leaf lifespan the potential error is smaller.

Growth respiration costs depend only on the amount of tissue grown and the type of tissue. Although our implementation of the annual algorithm leaves open the possibility of having different growth costs for different tissues, our current implementation uses the same growth cost per unit of new carbon in leaves, fine roots, live wood, and deadwood (Larcher, 1995; Thornton, 1998). The annual algorithm uses annual maximum leaf mass and the leaf longevity to assess leaf growth respiration, and then uses empirical coefficients to relate annual leaf growth respiration costs to annual fine root, live wood, and dead wood growth respiration. These parameters are calculated directly from similar parameters used in the Biome-BGC model

7.18 BPLUT PARAMETERIZATION

Parameterization strategy overview: Parameter values for the daily and annual algorithms all come, directly or indirectly, from the terrestrial ecosystem process model Biome-BGC. In the case of the parameters controlling daily estimates of GPP, there is an indirect connection to

Biome-BGC, where daily output from extensive simulations over the global range of vegetation and climate is used to guide the parameter selection through a multivariate optimization procedure. In the case of the parameters for daily leaf and fine root maintenance respiration the parameters come directly from the model's ecophysiological parameter files that define differences between plant functional types. It has been recognized that the relationship between APAR and NPP (or GPP) is not simple or linear, but that it can under certain conditions provide robust empirical estimates. The strongest argument for its application in processing stream is the direct link it provides to remotely sensed surface reflectances. This link permits estimates of NPP that account for observed landcover changes. Earlier arguments for the RUE approach focused on the lack of mechanistic understanding of terrestrial primary production, which prevented robust applications of more process-oriented approaches. Given the strong predictive ability of our mechanistic NPP algorithms, demonstrated in comparisons against measurements at multiple scales and in multiple biomes, it appears that understanding of mechanism is not a serious limitation.

The cost of implementing more mechanistic models in the operational processing stream is, however, an important consideration. The memory and processing requirements for Biome-BGC compared to MOD-17, for example, are on the order of 100:1, a strong argument for the radiation conversion efficiency approach. Validation of the MOD-17 results is an important component of our research efforts, and the large number of dependencies in this level 4 product make that a very challenging process. A direct validation of the MOD-17 results with surface observations will be very difficult, and will have to wait until there is an adequate overlap between MODIS processing and surface data collection (see Section 6). There are important steps that can be taken before then, and our use of the Biome-BGC model results in parameterizing is an integral part of our pre-launch validation planning.

8. AGRICULTURAL PRODUCTIVITY INDEX

8.1 INTRODUCTION

Productivity is not a synonym of 'fertility'. It is generally used to express the power of agriculture in a particular region to produce crops without regard to whether that power is due to the bounty of nature or to the efforts of man. On the other hand, fertility denotes the ability of soil to provide all the essential plant nutrients in available form and in a suitable balance for the plant growth. In recent years many attempts have been made to define the connotation of agricultural productivity and a considerable amount of literature exists on this subject. Agricultural productivity may be defined as the ratio of the index of total agricultural output to the index of total input used in farm production. It is, therefore, a measure of the efficiency with which inputs are utilized in production, other things being equal. According to Dewett, "Productivity expresses the varying relationship between agricultural output and one of the major inputs, like land or labour or capital, other complementary factors remaining the same ...." It may be borne in mind, that productivity is physical rather than a value-concept. The connotation of agricultural productivity engaged the attention of many an economist at the 23rd Annual Conference of the Indian Society of Agricultural Economics.

Some economists suggested, that the yield per acre should be considered to indicate agricultural productivity. A number of objections were raised against this view because it considered only land which is just one factor of production while other factors are also responsible, and that, therefore, it was arbitrary to attribute productivity entirely to land and express it per acre of land. It was suggested, for instance, that productivity could also be measured in terms of per unit of labour and different regions compared on that basis. It was pointed out further, that the average returns per unit of scarce resource does not depict the true picture, therefore, instead of it, the marginal returns per unit of the scarce resource should be considered. This definition appears to be more meaningful than others, but gives rise to a lot of practical difficulties. After a thorough discussion, it was generally agreed that the yield per acre may be considered to represent the agricultural productivity in a particular region, and that other factors of production be considered as the possible causes for the variation while comparing it with the other regions/ Pandit has stated the connotation of productivity in these words, "Productivity is defined in economics as the output per unit of input.... the art of securing an increase in output from the same input or of getting the same output from a smaller input." He further suggests, that increases in productivity, whether in industry or agriculture, is generally the result of a more efficient use of some or of all the factors of production, viz., land, labour and capital. According to Saxon basically, productivity is a physical relationship between output and the input which gives rise to that output.6 Horring defines the term productivity that it is generally used rather broadly to denote the ratio of output to any or all associated inputs, in real term.

There are many different concepts of productivity, and still more ways for computing it. The Chairman of the International Commission on Agricultural Typology, Prof. Kostrowicki, invited different views on this problem by sending a questionnaire to over 100 scholars throughout the world, which embodied the following two questions:

- What methods, of measuring intensity of agriculture should be applied in typological studies of various orders?
- What methods, measures and indices should be used to define land, labour and capital productivity of agriculture in typological studies of various orders?

About fifty geographers from all over the world responded and suggested various approaches to the measurement of agricultural intensity and productivity. The Chairman of the commission while evaluating the different views pointed out, that a special study for testing various methods and techniques to be used in the studies of various scales were needed Productivity of agriculture so far has been looked at from different points of view, such as productivity of land, labour and capital. These are the best known partial productivity measures.

8.2 PRODUCTIVITY OF LAND

Attention may specially be focussed on the productivity of land, because it is the most permanent and fixed among the three conventional categories of inputs (land, labour and capital), and in recent times has assumed special importance with the population explosions.

Land on regional or unit basis expresses yield of crops in terms of output, and from a national point of view, it is desirable to secure the employment of the greatest number of persons. Productivity of land is obviously of primary importance in countries with a high density of population. Where land resources are limited, the principal means of raising production to keep pace with the growth of population and the demand for improved diets is by raising yields per hectare.

Raising the productivity of land, however, does not mean only raising the yields of individual crops. It encompasses the whole output of a farm or country in relation to the total area of farm land, and may be raised also by changing the pattern of production toward more intensive systems of cultivation or towards higher value crops. The productivity of land may be increased by raising multiple crops in a year on the same land as the farmers of Japan, China (Taiwan), or United Arab Republic are doing. It may be increased also by progressively changing land from low-value crops to high-value crops.

Here a distinction must be made between the concepts of measurement of agricultural output in terms of calories (or some other measurement of food values), and in terms of money values. For example, if in a certain region land is shifted from cereals to potatoes the output per hectare in terms of calories, of human food is likely to be increased, but its productivity in terms of money value may be changed up or down according to the relative prices of cereals and potatoes. Again shifting of land from main crop potatoes to early season potatoes or to luxury vegetables may well increase its productivity in money terms, but will almost certainly reduce it in terms of calories. In developing countries with dense and fast-growing populations where food is in short supply, the first need may be to maximize the volume of the total output in terms of calories.

8.3 PRODUCTIVITY OF LABOUR

Whereas, the productivity of land is of primary importance as a determinant of the total level of food and agricultural production, the productivity of labour is mainly important as a determinant of the income of the population engaged in agriculture. The productivity of labour is a somewhat more complex concept than land productivity. It may be simply expressed by the hours of work needed to produce, e.g., a ton of wheat or cotton. But except where mainly monocultural agriculture is practised such measurements have a limited meaning, and more commonly labour productivity is measured by the total agricultural output per unit of labour.

Labour input may be expressed as the total number in the labour force or, in order to take into account the intensity of labour, as the number of man-hours worked in agriculture. Similarly, the total agricultural output may betaken as the gross farm output, or it may be taken as the value added by labour and other factors in agriculture, i.e., the value of fertilizers, pesticides, fuel and other inputs from outside the agricultural sector is subtracted from the value of the output in order to determine the net contribution of agricultural sector. The more refined systems of measurement, in particular value added per man-hour, are of importance chiefly in economically advanced countries where it is intended to compare labour productivity in agriculture with that of other occupations, or where it is necessary for social purposes to compare the incomes and productivity of workers in agriculture with those in other occupation*,. They are of less importance in developing countries where there is commonly an abundance of farm labour, and where farm workers are often seasonally employed or underemployed except at times of peak labour demand, e.g., at harvest.

Labour productivity in agriculture has two important aspects. First, it profoundly affects national prosperity, i.e., the national income; secondly, it principally determines the standard of living of the agricultural population.[9] National prosperity in the economic perspective is largely synonymous with the high output per man-hour. Therefore, if a country intends to increase its prosperity it needs:

(a) to encourage technical assistance and improvements to the labour population, which help to increase productivity in the agricultural economy, and

(b) to stimulate a continual transfer of labour from low productivity to high productivity regions.

So far as raising the farmer's standard of living is concerned, there are two ways : either he may be paid more than the prevailing regional or world prices for a given amount of work, or the steps can be encountered to raise his output, e.g., productivity from the same resources. Output per man can be improved in the agricultural economy :

(i) by giving each farm worker more land and livestock to look-after, and

(ii) by making each unit of land and livestock capable of yielding a bigger output.

8.4 PRODUCTIVITY OF CAPITAL

Productivity measures of capital are particularly complicated to compute and difficult to interpret. This is largely because of both diversity of farms, and the purpose for which capital may be utilized in agricultural production process. It is generally utilized for the purchase of land, for land improvement, land reclamation, drainage, irrigation purposes, livestock purchase, feeds, seeds, fertilizers, agricultural implements and machinery, crop protection chemicals, etc. Measurement of agricultural productivity depends upon conceptually consistent measures of aggregate agricultural output and input. The concept of inputs in productivity studies includes the resources committed to agriculture by the farmers. These inputs are subjected to control by the decisions of the farmers under the framework of government's policies. And these inputs may be classified as labour and tangible capital (including intermediate products which are purchased annually from the non-farm sources, such as fertilizer and processed feed and seed). Land, building, machinery, pesticide, livestock and purchased production services are tangible capital inputs. Choice of inputs mainly determines the increase in agricultural productivity with due regard to the qualities of inputs in a relative sense and the techniques and skills which are utilized in production process.

Stamp while attempting to measure crop productivity per unit area emphasized, that areal differences in productivity are the result partly of natural advantages of soil, and partly of farming efficiency.[11] Farming efficiency refers to the properties and qualities of various inputs, the manner in which they are combined and utilized in production. In the United States, various hypotheses about the causes of increase in agricultural productivity have been advanced. For instance, Henry[12] has mentioned, that it is primarily the result of an unusual abundance of land and natural resources. Loomis and Barton[13] suggest, that real causes of increase in productivity has been 'new knowledge and technical change, and such closely related forces as changing relative prices, increased specialization, increased size of farm operation, changes in institutional structure of education, credit, transportation, processing and the economic activity, etc

8.5 APPROACHES TO THE MEASUREMENT OF AGRICULTURAL PRODUCTIVITY INDEX

THE ASSESSMENT of agricultural productivity has engaged the attention of scholars working in different disciplines like, geography, economics and agricultural sciences for a long time. Many attempts have been made to measure and quantify agricultural productivity in India as well as in other countries of the world.

the relative productivity expressed it in terms of gross output of crops and livestock. We considered the following seven parameters:

(i) the yield per acre of crops,

(ii) the livestock per 10!) acres,

(iii) the gross production or output per 100 acres,

(iv) the proportion of arable land,

(v) the number of persons employed,

(vi) the cost of production expressed in terms of wages and labour costs, rent or interest, and

(vii) prices relative profitability and general economic conditions.

This area is expressed as a proportion of the total cropped area under all the selected crops. Secondly, Ganguli tried to obtain the index number of yield. This is found by dividing the yield per hectare for the entire region as the standard. This yield may be expressed as a percentage and the percentage may be regarded as the index number of yield. Thirdly, the proportion of the area under A and the corresponding index number of yield were multiplied.

There are two advantages which are apparent by using this method, i.e.,

(a) the relative importance of the crop A in that unit of study is assessed (as indicated by the proportion of the cropped area which is under A, and

(b) the yield of the crop A in comparison to the regional standard. The product thus obtained indicates actually an index of the contribution of the crop A to the productivity of the unit considered.

it as a mathematical problem and initiated a system of four coefficients

(a) productivity coefficient,

(b) ranking coefficient,

(c) money value coefficient and

(d) starch equivalent or energy coefficient.

Kendall pointed out, that the productivity coefficient and the ranking coefficient are concerned only with the yield per acre, but are not in any way weighted according to the volume of production. He, therefore, evolved a measure of crop productivity by using index number technique. In this technique the yield of different crops should be expressed in terms of some common units, Kendall pointed out, that there are two common units which can be taken note of: first money value 'as expressed in price' and second energy 'as expressed in starch equivalent.

8.6 MONEY VALUE INDEX

In case of money value index there is one major difficulty, that data for certain crops are not available, for example, there are many vegetables and beans which are grown mostly for the consumption on the farms and their price data are not recorded in contrast to cereal crops whose data are adequate. While determining the money value coefficient, another difficulty arises with regard to the prices—for example, the prices prevailing in the area should be adopted, or those prevailing in the region or in the country as a whole, in addition to the local variations in the prices which depend on circumstances like, proximity to the market or the relative nutritive character of the product. Significant differences in prices per ton between the crops affect the final result heavily in favour of the higher priced commodity. This method, the crop production of each unit area is valued by multiplying the volume of production of a particular crop by the price, and then add the results for the selected number of crops together. The total is divided by. The total acreage in the unit area under the total selected crops. The result gives for each unit area a figure of money value per acre/ hectare under the crops considered. So far as energy coefficient concerned, an index based on nutritional factor ignores local variations because of the absence of data. Kendall, therefore, suggests starch equivalent as the most suitable unit.whilecalculating a coefficient based on starch equivalent it should be decided: (a) whether a gross or net digestible energy figure is to be taken, (b) whether any allowance is to be made for byproducts, such as—wheat and barley straws or the green stalks of maize, jowar, and bajra, and (c) whether any account should be taken of the fact that the energy in certain foods has first to be fed to livestock and then wheat and milk is used for human consumption. The basic question that arises in this technique is whether the gross starch equivalent of the various crops should be considered or the net equivalent. Net energy refers to the amount of energy for work and body building whereas, a gross figure includes the energy employed in the digestive process of the consuming animal and similar non-realisable forms. It should be mentioned here, that the money value coefficient does not take into consideration the value of the by-products of the crops but a similar omission of any allowance or the energy of the by-products in the energy coefficient would have a serious affect. It is surmised, that there is nearly as much starch [1] equivalent in the straw produced on a hectare of land as the grain itself. Therefore, it becomes necessary to estimate the production by weight of by-products to the main products of wheat, barley, oats, beans, peas, etc.

The determination of productivity by the productivity coefficient method involves the use of higher mathematics and the money value coefficient and starch equivalent or energy coefficient posses a practical difficulty. Therefore, Kendall looked for a coefficient which might lead to similar results in productivity and save a good deal of calculations. The method "■ attempts to arrange in sequence any given number of units growing the same range of crops and then assess their agricultural efficiency." Kendall took the acre yields of ten leading crops in each of the forty-eight administrative counties of England for four selected years. The places occupied by each county in respect to the selected crops were then averaged, and thus ranking coefficient of agricultural efficiency of each county was obtained. If a county was at the top of every list, it would have a ranking coefficient of one and if it were at the bottom of every list, it would have a ranking coefficient equal to the number of counties concerned.

8.7 DEVELOPING'CROP YIELD INDEX'S THE BASIS OF PRODUCTIVITY MEASUREMENT.

It expresses the average of the yields of various crops on a farm or in a locality relative to the yields of the same crops on another farm in a second locality and attempted to determine the labour productivity, we considered productivity of labour as the ratio of total output to the total man-hours consumed in the production of that output resulting in output per man-hour. This has been designed with the equation:

$$\Pi = f(P, L)$$

where

Π =productivity of labour,

P= production, and

L=labour utilized.

Method for measuring the agricultural productivity, i.e., to convert the total agricultural production in calories. The caloric intake is a measure of the general health of a person because it determines the amount of heat and energy needed by the human body. The British Medical Association on the basis of exhaustive enquiry, published a table showing a range of desirable caloric intake among adults from 2,100 calories a day for a woman in sedentary occupation to 4,250 calories for a man engaged in active manual work. For children, the desirable intake is calculated as 800 calories a day, for infants under one year and to 3,400 calories for teenage boys.[9]Taking into consideration the age structure of the population, the range of occupation, the weight and height of the people living under climatic conditions of northwestern Europe,' the average is 2,460 calories a day or about 9, 00,000 calories per year, aggregate productivity depends upon conceptually consistent measures of agricultural output and input. The measures of inputs includes all the production factors that depend directly on the decisions of farmers, we considered eight indices of agricultural production which cover various phases of the period extending between the years 2006 and 2008 and measured the efficiency of production in agriculture by using the coefficient of output relative to input. The concept of productivity measurement is difficult to define and even more difficult to quantify. while working out the trends of productivity in agriculture of the state of Kerala (India) has measured productivity on the basis of yield per acre. Enyedi(1964) while describing geographical types of agriculture in Hungary refers to a formula for determining agricultural productivity.

The concept of productivity is based not only on the single relationship between output and input, but rather on the differences between two or more relationships, i.e., differences in the same agricultural region or sub-region as between successive periods (in time), and between similar agricultural regions in different countries or regions during the same period (in space). It may also be possible to make comparisons between the trends of productivity for different products, between different regions of the national economy or between the agricultural regions and the national economy as a whole.

The variables relating to the level of output per acre are selected as follows:

(i) normal level of rainfall,

(ii) percentage of current and old fallows,

(iii) percentage of area under irrigation,

(iv) percentage of literacy,

(v) percentage of population on agriculture,

(vi) intensity of cropping,

(vii) percentage of gross value other than foodgrains and fodder,

(viii) The percentage of area under all crops excluding fodder and foodgrains,

(ix) density of agricultural population per acre, and

(x) percentage of total area under commercial crops including rice.

In order to assess the weighted ranks, the ranking position of a crop is multiplied by the magnitude of it to the total cropped area. For example, an enumeration unit A has rank 5 on the basis of yield for wheat, and wheat occupies 33 per cent of area to the total cropped land; jowar ranks 3 and occupies 16 per cent of the area; rice ranks 4, and occupies 30 per cent of the total cropped land. Thus, the weighted average of ranks for different crops would be: (5x33) + (3x 16) + (4x30) = 333 divided by the sum of the weights as 333/79=4.21. Kendall's 'ranking coefficient' would be worked out as follows: 5+3+4 = 12 divided by the number of crops taken into consideration as: 12/3 - 4.

8.8 MEASUREMENT OF AGRUCULTURAL PRODUCTIVITY

Agricultural productivity can also be measured with respect to all the resources committed to agriculture including all the inputs, like land, labour, building, machinery and fertilizers, etc. These inputs should be aggregated and compared with the gross output of the entire region. He further suggests that productivity studies are more useful when they are made over a period of time. Wherever comparable data are available, different techniques for analyses in different time series can be employed. Productivity comparisons might also be made for different regions or for different crops.

Assessment of productivity with the output per unit of a single input and output per unit of cost of all inputs in the agricultural production. The common purpose of this function is to express input/output relationship between several inputs and one output in the agricultural systems. The function takes the following form:

$$Y = Ax_1^b x_2^c x_3^d x_4^e \ldots\ldots x_n^y$$

where x_1, x_2, x_3, x_4, ... n denote various inputs, like land, labour capital assets and other working expenses. The values of b, c, d,.......y represent elasticities of the respective inputs. Tambad (1965 and 1970) has adopted 'Crop Yield Index' as the basis for measuring agricultural productivity. He explains, that the purpose of this technique is to express the average yield of various crops on a farm or in a region relative to the yield of same crops on an another farm or in a second region. It can be expressed in the equation form as:

n

$$\text{Crop Yield Index} = \frac{\sum_{i=1}^{n} \frac{y_i}{y_{i0}} A_i}{\sum_{i=1}^{n} A_i}$$

Where

i= 1,2, 3, ... n are the number of crops considered in an unit area or year,

Y_i= is the yield per acre of crop i, in a farm area or year,

A_i= is the weightage of crop i. denoted by the area under the crop as a percentage of total cropped, and

Y_{i0}= is the average yield per acre of crop i, at the group of farms or entire region or the base year.

8.9 AGRICULTURAL EFFICIENCY

The productivity on the basis of labour population engaged in agriculture. it can be computed by dividing the gross production in any unit area by the number of man-hours or less precisely by the numbers employed in agriculture. In order to assess the productivity on the basis of population engaged in agriculture it can either be obtained by dividing the total production with the number of workers, or a reverse index be applied where the total number of workers per unit of production is assessed. Standard deviation formula to determine agricultural efficiency in Study area. For this purpose we selected all the twenty-five major crops grown in the study area which were grouped into cereals, pulses, oilseeds and cash crops and specific yields per hectare of cereals, pulses and oilseeds were taken. And in case of money crops, their monetary values were calculated (in Rs.) per hectare by incorporating wholesale market prices. Finally, the standard scores were computed and to give them weightage, these values were multiplied by the acreage figures, i.e., the area of cultivation under the crops. Attempted to compute the index of productivity coefficient following the formula initiated by Enyedi for each district of India with regard to twelve food crops. Accounted agricultural labour productivity differences in developed countries (DCs) and of less developed countries (LDC's) for three different periods. They incorporated the independent variables, like land, labour, livestock, fertilizer, machinery, education and technical manpower,

9. LAND SUITABILITY MODEL

9.1 GENERAL

Land, a finite resource, is shrinking in extent and deteriorating in quality as a result of expanding urbanization, industrialization, varied civic uses and mismanagement of water resource. The current gap between demand and supply of land, fuel, fodder and timber is likely to worsen in near future as a consequence of continuing degradation of land and reduced per capital land availability. Irrigation in a particular situation may degrade the land, if not scheduled and planned properly as per the requirement of crop and soil. Suitability evaluation of land for irrigation is a systematic appraisal of land and their designations by categories or classes on the basis of physical and chemical characteristics (Resler 1979). The characteristics of land that determine its suitability for irrigation are topography, wetness, texture, depths to bed rock, $CaCO_3$, water retention and infiltration rate(Peters 1977). Land evaluation aims at assessing present projection performance level and its production potential for a specific purpose.

Land suitability provides a rational basis to analyse various soil, nutrients and land parameters to arrive at optimum solution to various problems of natural resources. It includes land capability classification, land irrigability assessment, soil suitability for crops, suitability to plantation / trees / aquaculture etc. land evaluation principle is based on matching the requirements of a land for specific use with the characteristics of inherent soil, nutrients retentions, climatic, topographic and other natural resource. The soils of the command areas were mapped following visual interpretation of satellite data with soil profile studies and laboratory analysis of soils, at the level of soil families and their association as per soil taxonomy (Soil Survey Staff, 1992). The land suitability for irrigation was developed by Ministry of Agriculture, Govt., of India (AIS&LUS, 1970).

Remote Sensing has shown great potential in Land suitability model mapping and monitoring due to its advantages over traditional procedures in terms of cost and time effectiveness in the availability of information over larger areas.. Hence, it is proposed to use remote sensing data for the mapping of natural resources. Nevertheless, the surface reflectance spectra over a wide range of objects and conditions should be identified and interpreted into meaningful outputs prior to decision-making and applications. Satellite Remote sensing images, such as IRS- LISS, PAN and WiFS are proposed to use. GIS (Geographic Information System) has become an important tool because it enables to integrate the complex decisions to be taken under milti-variant situations of the resource base and their dynamics. Survey of literature reveals that GIS techniques have been employed for development of land suitability model for Irrigation Management

9.2 SIGNIFICANCE OF THE STUDY

Land Suitability or Evaluation is a tool to be used in planning process and should be feasible in order to meet changing conditions and requirement. The result will assist the planners and decision makers in their selection of land use alternatives so that available resource may be used most beneficially for development and **"A Systematic Approach"** for land suitability pattern shows how man uses the land and how best he can plan its future use. Information on land use permits a better understanding of the land utilization aspects on cropping pattern, fallow land, forest wastelands, surface and ground water, land capability, soil characteristics etc which are very vital for development planning and also for **"Optimal land use Planning"** for sustained efforts and renewed economic returns.

9.3 THE PROBLEM TO BE INVESTIGATED

The problem is a gap between the present situation and better management. To define a problem we have to establish (1) the present situation, (2) judge ways in which it is bad, and (3) identify ways in which it can be made better (Siffins, 1980). The problems investigated are off fallowing types:

- Different people want to use the same land for different purposes. This become very apparent in the rural-urban fringe surrounding an expanding city.
- One use of the land may have adverse affects on other people. For example, when forest clearance causes sedimentation down-stream, or reducing the capacity of water;

- The uses that individuals make of the land may be at odds with the common good. For example when exploitative cropping systems reduce future productivity and add up to place national food security at risk.
- Confusion about land and water rights and obligations. Most societies have traditional customs, often linked to religion or social structure that guide land use.
- The local people should know the advantage and adverse affect of land use plan. They should be aware about losses & benefits of these plans. For example overgrazing will create the soil erosion, bringing good agricultural land under urban sprawl, which is unavoidable will reduce the prime agricultural lands.

9.4 PRINCIPLES OF LAND EVALUATION

Land evaluation is defined as the process of collating and interpreting basic inventories of soil, vegetation, climate, and other aspects of land in order to identify and make a comparison of promising land use alternatives in terms applicable to the objectives of the evaluation. In summary a multidisciplinary approach is recommended and basis to the concept of recognition of the fact that land evaluation is meaningful only in relation to a clearly defined use. The frame work recommends qualitative and quantitative classifications of land for well defined land utilization types under unimproved and improved conditions, by suitability orders, classes, subclasses and units. A single state (physical and socio-economic studies together) approach or a two stage (physical studies followed by socio-economic studies) is allowed for. The frame work is intended to provide an outline of principles and terminology within which local systems of land evaluation may be formulated (FAO-1977).

Land evaluation or Land suitability for a specific purpose is a tool to be used in the planning process and should be flexible in order to meet changing conditions and environment. The result will assist the planner and decision makers in their selection of land use alternatives so that available resources may be used most beneficially for development. The sequence steps in land evaluation.

9.4.1 PRINCIPLES OF THE LAND EVALUATION

- Land suitability assessment is only meaningful with respect to specified kinds of use. This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example an alluvial floodplain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture. The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirement, like soil moisture, rooting depth etc. the qualities of each type of land, such as moisture availability or liability to flooding , are compared with the requirement of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.
- Evaluation requires a comparision of the benefits obtained and the inputs needed on different types of land. Land in itself, without inputs, rarely if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wildness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required inputs, such as labour, fertilizers or road construction, with the goods produced or other benefits obtained.
- A multidisciplinary approach is required. In particular, suitability evaluation always incorporates economic considerations to be a greater or lesser extent. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In a quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. It follows that a tem carrying out an evaluation requires a range of specialists. These will usually include geomorphologists, land use soil surveyors, ecologists, agronomists, foresters, irrigation engineers, experts in livestock management, economists and sociologist. They may need for combining some of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics, remains.
- Evaluation is made in terms relevant to the physical economic and social context of the area concerned. Such factors as the regional climate, levels of living of the

population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable and availability of capital, form the context within which evaluation takes place. It would, for example be unrealistic to say that land was suitable for non mechanized rice cultivation, require large amounts of low costs labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another, and to some extent between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding, and to assist in comparison between different areas, such assumptions should be explicitly stated.

- Suitability refers to use on a sustained basis. The aspect of environment degradation is taken into account when assessing suitability. There might, for example be forms of land use which appear to be highly profitable in the short run but likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability, and cause the land to be classed as not suitable for such purposes. The principle by no means requires that the environment should be preserved in completely unaltered state. Agriculture normally involves clearance of any natural vegetation present and normally soil fertility under arable cropping is higher or lower, depending on management, but rarely at the same level as under the original vegetation. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such assessments taken into consideration in determining suitability.
- Evaluation involves comparison of more than a single kind of use. The comparison could be for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing.

9.5 LAND CLASSIFICATION

Land classification system was evolved in response to the need for the classification of landscape units to help and solve land use and land planning problems. Different environments have different land problems of course and different resources to meet the needs. Land classification itself is not an end – it is a means towards an end. The desired end for which land classification are created is an improved physical and economic environment in which people can live more productive and satisfying lives.

Classification is the easier of the two to define, the placement of individuals together into mutually exclusive groups defined in terms of one or more attributes of the individual. The attributes may be morphological (e.g. Shape, color, chemical composition) of functional (e.g. productivity, suitability, erodability). For a morphological classification, there may be red land and brown land, or steep land and flat land. Examples of a functional interpretation are good land and bad land or erodable land and nonerodable land.

Land an area of the earth's surface, the characteristics of which embrace all reasonable stable or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal population and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of land by man (wageningen meeting on land evaluation, 1972). Jack (1946) reviewed land classification as it relates to the grouping of lands according to their suitability for producing plants of economic importance.

Land therefore involves:

- Climate
- Geology
- Geomorphology
- Soil
- Vegetation
- Population and their effects

Young (1974) lists the following as subjects for classification of lands

a. Agriculture

   i. Cultivation of a specified crop or crops, annual or perennial

   ii. Irrigated agriculture

   iii. Arable farming

   iv. Grazing, or unimproved or improved pastures.

b. Forestry

   i. Logging of natural forests

   ii. Forest plantations

c. Water Resources

   i. Ground water and surface water

   ii. Resource of irrigation

d. Mining

e. Engineering purposes

   i. Transportation purpose in general

   ii. Building foundation

   iii. Urban use

f. Recreation

g. Wildlife conservation (flora and fauna)

h. Special purposes

   i. Military purpose

   ii. Local government administration (e.g. assessment for taxation)

i. Multiple purposes

To this list ma be added many far-reaching subjects such as agricultural adjustment, investment potential and environmental protection.

In land classification an attempt is made to differentiate between morphological and functional classification, and to illustrate both.

A. Morphology

Based on the morphological classifications main categories of land are listed.

Table 9. 1: shows Agricultural land classification

Agricultural Land Classification	Irrigated crop land
	Unirrigated crop land
	Types of crops
	Single cropped area
	Double cropped area
	Triple cropped area
	Agricultural Plantation
	Command Area

B. Functional land classification

It is probably true to say that every country in the world has a functional land resources classification, of one field or another as a planning tool to assess the potentiality for agricultural development.

In India, broad land capability classification based on functions has been divided into 8 classes as given below

1. Very good cultivable land (No special difficulty in farming)
2. Good cultivable land (Protection from erosion)
3. Moderately good cultivable land (Special attention to erosion)
4. Fairly good land (Intensive erosion control when in cultivation)
5. Very well suited for grazing, not arable
6. Well suited for grazing or forests, not arable
7. Suited only for wild life, recreation.

9.6 LAND CAPABILITY

Land capability classification is basically a system of aggregation of soil map unit (from detail map) into a group of soils showing similarities in response to management and similarities in hazards limitation or risk in use.

Land capability classification is an interpretative grouping of soils mainly based on:

- The inherent soil characteristics
- External land features
- Environmental factors that limit the use of land

Information on the first two items are provided by standard detailed soil survey. Scientific survey and classification of soils are the primary requirement for grouping soils according to their capability for uses of varying intensity. Capability grouping is thus another aspect of soil survey work, and is closely related to soil correlation. The taxonomic soil units established after field survey laboratory study and correlation are the ultimate management units which provide specific information about ability of the soil to respond to use, management and plant growth.

The classification soil unit provides information on the nature of parent material colour, texture, structures of the soil type of clay mineral and consistency, permeability, depth of soil, soil reaction and also root distribution along the depth of the profile. Each of the above factors has a definite role to play in behaviour of the soil and its management.

- The parent material gives an idea of potential nutrients status of the soil.
- The soil colour speaks of organic matter content and the state of bleaching and hydration.
- Texture and structure of the soil influence the air water balance in the root zone and movement of water.
- The types of clay mineral modify the exchange capacity of the soil and the condition of maintaining a mapping of plant nutrients.
- Slow permeability of the sub surface layers such as claypan, fregipan indurated, caliche layer etc. can influence root development.
- Root distribution determines the depth of soil material to layers inhibiting root penetration.
- The soil depth control root development and effect moisture retention and
- The soil reaction determines the state of base saturation as also the balance of available plant nutrients.

- Besides the above inherent soil characteristics landscape features like slope and erosion condition may limit the safe and productive use of soil.

9.6.1 BASIS OF LAND CAPABILITY CLASSIFICATION

Land capability classification is based on detailed soil survey on a scale 1:50,000. The classification consists essentially of grouping the various soil mapping units. The soil mapping units is defined as the "portion of the land scape that has similar characteristics and qualities and whose limits are fixed by precise definitions" and it's the unit about which the greatest number of precise statements and predictions can be made.

Soil mapping unit put into a capability unit are sufficiently uniform to:

i. Produce similar kind of cultivated crops and pasture plants with similar management practices.
ii. Require similar conservation treatment and management under the same kind and condition of vegetation cover.
iii. Hence comparable potential productivity.

Use of capability units condense and simplify soil mapping unit information for planning use and management of individual areas of land.

9.6.2 UTILITY OF LAND CAPABILITY CLASSES

Land capability classes are used as a means of introducing the map user to the more detailed information on the soil map. The classes show the location suitability of the soils for agricultural use, the sub classes provide information about the kind of conservation problems. Both classes used together, provide the map user with general information about the limitations and problems involved for broad programme planning. The capability unit indicates soil areas that are alike enough to be suited to the same crop and pasture plants to require similar management.

9.6.3 LEVEL OF LAND CAPABILITY

Land capability system is used in two levels

i. At the lowest level on farmers fields to help plan conservation practices and crop rotation for individual management objectives.

ii. At the national level, the land capability classification is used to group soils to summaries conservation problems and needs for solution on a national level.

9.6.4 LAND CAPABILITY CLASSIFICATION

Land capability gives a direct information regarding the soil potentiality of different areas. Scientific appraisal of the physical characteristics of the land, if inherent soil qualities etc. gives us to delineate problematic and potential arable land responsible to the use of bio-chemical techniques and to various degree of farm management practices.

It should be stressed at this stage that land capability assessment is based on a broader range of characteristics than just pure soil properties. Land capability assessment utilizes information on slope angle, climate, flood and erosion risk, as well as on soil properties. Of course, there is a large degree of interrelation between these type of information and thus to a very large extent soil mapping units are grouped together to form capability units.

9.7 IRRIGATION

It is defined as the artificial application of water to soil to help crop growth and production especially during stress periods and the primary objective of irrigation suitability land classification is to support irrigation project development by characterizing and delineating the lands suitable for sustained irrigated agricultural production under a given project setting. Some important land classification investigation contributions to an irrigation project planning study include assistance in determining: (1) proper land and water uses, (2) farm unit size, (3) establishment of repayment assessments, (4) benefits and costs, (5) land development needs, (6) irrigable area, (7) design of irrigation and drainage systems, (8) appraised value of land, (9) return flow water quality, and (10) irrigation requirements.

9.7.1 IMPORTANCE OF IRRIGATION

Irrigation is the artificial application of water, with good economic return and no damage to land and soil, to supplement the natural sources of water to meet the water requirement of crops. Crops receive water from natural sources in form of precipitation, other atmosphere water, ground water and flood water. Since the amount, frequency and distribution of precipitation which is the principal source of water for crops are unpredictable may be insufficient and untimely and the ground water may be too deep in the soil profile, irrigation becomes necessary for successful crop growing. Irrigation should however be profitable and applied in times of crop need and in proper amount. The excess or under irrigation may damage lands and crop. Irrigation applied earlier to the actual time of crop need results in ineffective irrigation and waste of water, while delayed irrigation may cause water stress to crops and reduce the yield.

Irrigation is the key input in crop production. Full benefit of crop production technologies such as high yielding varieties, fertilizer use, multiple cropping, crop culture and plant protection measures can be derived only when adequate supply of water is assured. On the other hand, optimum benefit from irrigation is obtained only when other crop production inputs are provided and technologies applied.

9.7.2 INFILTRATION UNDER VARIOUS IRRIGATION REGIMES

In filtration (or surface intake) refers to the rate of entry of water into the soil under the action of gravity. It is greatest when the land is dry and takes place either at the start of precipitation or the earliest irrigation application. The rate of infiltration decreases as the top soil gets saturated, and finally gets stabilized at a particular rate depending on particle size/ texture of the soil. The infiltration rate is a measure of how much water a soil can soak up in a given period of time. As should be expected, the more permeable a soil, the greater its infiltration rate. Hence, clay soils are characterized by low infiltration rates and sandy soils by high. The infiltration characteristics of a soil are an important consideration in irrigation. When irrigation is applied in excess of the infiltration rate, water may be wasted (this is often the case where water is charged per hectare, but not on the basis of water used). Besides, the flowing water may cause erosion or may form puddles, from which it evaporates faster.

9.7.3 IRRIGATION METHODS

The principal methods of irrigation and their advantages and disadvantages are described below.

(i) .Surface irrigation or gravity irrigation, whereby water introduced at the head of the field spreads and infiltrates throughout the field through forces of gravity and hydrostatic pressure. In this method, the soil is the medium through which water is *conveyed, distributed,* *and infiltrated.* For this reason, the physical and chemical properties of the soil, and the way the land has to be prepared for irrigation enter the picture prominently. This is the most ancient of all irrigation technologies and it has been estimated that this method serves about 95% of the irrigated land worldwide. This method is mechanically simple, has low energy requirements (as it is based on gravity), and can "be easily adapted to small holdings. Its serious deficiencies are low application efficiency, high conveyance losses and wastage of water, which lead to adverse consequences such as waterlogging and salinization.

(ii) Sprinkle irrigation, whereby sprayed water falls on plants like rain. This system does not depend upon' the soil surface for conveyance and distribution of water. It is hence not necessary to level the land (as required in the case of surface irrigation) and conveyance losses are minimal. Water can be applied at a rate less than that of the soil infiltrability. This allows soil aeration. The disadvantages are the high capital costs, maintenance requirements, and energy costs (for maintaining high pressure). Also, sprinkle irrigation is strongly affected by wind.

(iii) Drip irrigation, whereby water is applied directly to the root zone through a set of polyethylene tubes laid along the ground or buried at a depth of 15 to 30 cm. Water is delivered drop by drop through perforations or emitters in the pipes. The trickling rate is maintained at less than the rate of infiltrability in the soil. The operating pressures are 15 to 45 psi. Under this system, it is not necessary to level the land, and it is not affected by wind. By providing the rooting volume with the requisite amounts of water (and nutrients, which can be added to water), the soil can be kept continuously moist and aerated. As only a portion of the soil surface is wetted, the amount of direct evaporation is reduced. Slightly brackish water (up to 1000 mgl^{-1}) can be used under the method for some crops which are not too sensitive. As the water does not come into direct contact with foliage, it will not cause saline scorching. As the chosen volume of the soil is kept constantly wet, the salts in the brackish water do not have a chance to concentrate and affect the crop. Drip irrigation can be used any where in rugged terrains, in sandy soils of low moisture storage capacity, and arid climates of high evaporative. The capital costs of a drip irrigation system are high. The method needs very rigorous adherence to scheduling and maintenance. In an effort to cope with the extreme scarcity of water, Israelis have developed drip irrigation into a fine art. In the context of rising cost and scarcity of water, and lower costs of plastic tubing, this method is likely to be widely adopted.

(iv)A microprocessor-based, drip irrigation system: suitable for use in developing countries is now commercially available. This device uses low-cost ceramic sensors and operates on a solar cell-charged battery. The device continuously monitors the soil moisture and controls the drip rate so as to maintain the moisture within the desired limits.

(v) Micro sprayer: Micro sprayers have several of the advantages of the drip systems in that the water is applied only to a fraction of the ground surface, high frequency irrigation is possible, and 'fertilizers can be injected, if desired. Besides, they have the following advantages over the drip systems: (i) as micro sprayers have larger nozzle orifices, clogging of emitters is not a serious problem, and it is not necessary to filter the irrigation water; (ii) micro sprayers are operated at pressures of the order of 2 atmospheres, which are much lower than for the drip systems; and (iii) micro sprayers can be scaled down for use in small farms in the developing countries.

Micro sprayers have the following minor disadvantages: (i) as wetting of leaves will be involved, brackish water cannot be used in irrigation; and (ii) since the area wetted is larger than in drip systems, there are some evaporation losses.

(vi) Low-head, bubbler irrigation: *A* closed-conduit irrigation system has the great advantage in that it avoids conveyance losses and maintains uniformity in application. But any such system needs energy to pressurize water for distribution. Low-head, bubbler irrigation has the advantages of a piped system, but requires neither pumps nor nozzles. Even the low head available from a surface ditch may be adequate. In this arrangement, water is simply allowed to bubble out from open, vertical standpipes, 1-3 cm, which rise from buried lateral irrigation tubes. Bubbler systems are particularly suitable for widely spaced crops such as fruit trees and grapevines. Small circular basins can be constructed around the trees for the water to bubble into. Low-volume, high-frequency, partial area irrigation L- possible with the system. The initial cost of the system (about USD 1600 ha^{-1}) is comparable or even lower than other systems. As the system works by gravity, there are no energy costs. It also has a longer life because it is buried. Rawlins (1977) gave a techno-economic analysis of the system.

9.7.4 IRRIGATION SCHEDULING

In the course of irrigation, water is introduced into that part of the soil profile that serves as the root zone of a crop plant. The soil moisture thus produced serve; as a kind of bank providing water to the roots as needed. An ideal irrigate on system is the one wherein the spatial and temporal distribution of water in the soil is just what the crop needs to achieve the highest productivity. The timing and quantity of water application are decided on the basis of monitoring the soil, the plant, and the microclimate.

As the days pass after rains or irrigation, the moisture reserve in the root zone steadily reduces due to evaporation and root extraction. It is critically important to ensure that the soil moisture never goes down to the level of permanent wilting point, lest it adversely affect plant yield. Hence it would be prudent to keep the allowable depletion midway between the field capacity (PC) and the permanent wilting point (FWP). If the field capacity is 20%, and the wilting point 8%, the irrigator should apply water when the field capacity has dropped to 14%.

9.7.5 MONITORING SOIL NEEDS INFORMATION ON THE FOLLOWING ASPECTS:

(I) Rooting depth of the crop: it may be shallow (0.3 - 0.*7* m for vegetables), medium (0.9 - 1.5 m for wheat) or deep (1.0 - 2.0 m for maize, sorghum, and sugar-cane); (ii) potential and actual water contents of the root zone, and field capacity (expressed as fractional volume), on the basis of determination of soil moisture content, moisture tension, and moisture release characteristics of the soil. As soil moisture diminishes, the densitometers record increased tension. This information can be used to estimate when the plants will suffer stress and need application of water. Because of the complexity of the variables involved, laboratory measurement of soil moisture may give misleading results. Soil moisture is best determined in *situ* with a portable neutron moisture meter. Though expensive, it has several positive features: measurement is made *in situ*, it can be made conveniently and instantly, and it gives meaningful results. Moisture tension is determined with a densitometer

(Hillel, 1987, p.37 & 38). An experienced farmer or agronomist can assess the water status of the crop just by direct visual inspection of the foliage. Irrigation scheduling has to take into account the meteorologically imposed evapotranspiration demand. Time-domain reflectometry (TDR) is being increasingly used to determine irrigation scheduling (Topp and Davis, 1985).

9.7.6 IRRIGATION EFFICIENCY

The World Bank estimates that irrigation efficiency (i.e., net amount of water added to the root zone divided by the amount of water drawn from some source) is almost always below 50% (it may be as low as 30%). It is demonstrably possible to achieve an irrigation efficiency of 85 to 90% by proper management practices, particularly conveyance systems. It is therefore cost effective to spend money on improving irrigation efficiency rather than on constructing new irrigation reservoirs. The efficiency of any process is usually taken as the measure of the output obtainable from a given input. In the case of irrigation, this could be defined in financial, physiological, sociological, etc. terms. Thus, irrigation efficiency may be considered the financial return for a particular amount of investment in water supply. This can vary tremendously from year to year and from place to place. Besides, it is not always possible to quantify the long-term sociological benefits of irrigation. In drought-prone situations, where the incidence of drought is not predictable, even a modest contribution to food security arising from assured irrigation can have very profound consequences on the quality of life of the people. The water supply efficiency is estimated in terms of flow at four points: (i) A-Flow at source, (ii) B-Flow at turnout, (iii) C-Flow into the field, and (some water may leave the system through subsurface flow). Project efficiency deals with the relative proportion between flow at source and the amount of water applied to crops. Farm efficiency deals with the proportion of water at the turnout to the amount of water applied to crops. Field efficiency deals with the proportion of water flowing into the field to the amount of water applied to crops.

9.7.7 METHODOLOGY OF OPTIMAL IRRIGATION MANAGEMENT

Problems in the c L ;e of irrigation arise from a fallacy in human thinking — if something is good, more of it should be better. If a certain amount of irrigation raises crop productivity, which it surely does, more irrigation should produce more crops. As Hillel (1987) put it perceptively in his monograph, "The Efficient Use of Water for Irrigation", *Just Enough is Best — no less and certainly no more*. For too long, irrigation has been thought of as simply a water delivery system, and this has had disastrous consequences. None would disagree with the dictum, *just enough is best*. But to determine what is enough is an enormously complicated job.

The following scenario is envisaged for optimizing an irrigation system:

1. Determine the water requirements of the crop to be grown in a particular agroclimatic setting on the basis of the Potential Evapo- transpiration (PET) and empirical crop coefficient (KC) data.
2. Withdrawal of water from the source (river, reservoir or aquifer) in rune with the water requirements, on time-variable and space-variable basis;
3. Delivery of water in tune with the rooting depth of the crop and available water capacity of the soil;
4. Planning the drainage system right at the outset as an integral part of the of the irrigation system. This is absolutely essential in the case of river valleys prone to high water-table conditions. Soil salinity should be monitored continuously in order to alert the farmer about the accumulation of injurious levels of salinity in the root zone of the plant.

9.8 MATERIALS AND METHODOLOGY

9.8.1 GENERAL

Based on the source of acquisition of data, nature of data and its use in the present study, the data products are classified into four types namely, topographical data, thematic data, field data and collateral data.

9.8.2 DATA SOURCES

A heightened awareness of water resources problems has developed over the past several decades and this has spurred a need for reliable geospatial data to enable better understanding of water related problems and their impacts on environment. Crop yield models have also undergone changes and these have created new requirements for geospatial data. In view of critical role, digital data plays in any kind of spatial modeling and analysis. Emphasis is given to new information gathering initiations for remotely sensed data and to advancements in integrating data from different sources with GIS. The availability of appropriate and adequate crop yield data, and other related data derived from collateral data and other field survey are important concerns. GIS and crop yield models function with a broad spectrum of geospatial data that are used for spatial analysis and modeling of crop yields. These data generally come in different formats and from various sources and measurements. The examination and organization of data into a useful form produces information content, which is compatible to GIS and which enables appropriate analysis and modeling of crop yield prediction.

In the present study, four different sources are used to collect the required data products. The four sources are remote sensing satellite systems, survey of India toposheets, related government and private agencies for existing data products and field surveys for collection of primary data products. In transforming this raw data to data compatible to GIS, care is taken for appropriate level of data precision and accuracy. The data types, important features and corresponding data sources used in the present study are listed in table 1.

Table 1. Data type, important features and sources of acquisition

S.No	Primary Map	Reference Map
1	Base	SOI-Toposheet & Satellite Data
2	Drainage	SOI-Toposheet & Satellite Data
3	Road network	SOI-Toposheet & Satellite Data
4	Mandal reference map	SOI-Toposheets & cadastral maps
5	Village reference map	SOI-Toposheets & cadastral maps
6	Land use/Land Cover	SOI-Toposheets & Satellite Data
7	Soil Map (Type, Depth, Drainage, AWC, Particle Size & Erosion)	Soil, SOI-Toposheet & Satellite Data

9.9 COLLECTION OF DATA

The following types of data have been used in the present investigation

- Satellite data
- Collateral data

9.9.1 SATELLITE DATA

Remotely sensed data from IRS-1C/1D and IRS P6 LISS III data in the form of false colour composite (FCC) prints and computer compatible tapes (CCT's) pertaining to the study areas are used in the study. The entire study area is covered by three scenes of IRS-1C/1D and IRS P6 LISS III data.

Table: 2. Satellite data sets used in the study area

Year	Satellite	Sensor	Date of Pass
2005	IRS P6	LISS III	27 Dec 2005
2006	IRS P6	LISS III	20 Jan 2006

The raw satellite images are presented in Fig 11. The satellite data for the all seasons are completely cloud free and the data sets were used for generation of spectral indices from individual fields in the study area.

9.9.2 COLLATERAL DATA

Collateral data used in the study includes topographical and thematic maps of the study area. The topographical maps are required for preparation of base maps. The thematic maps of land use/cover maps, agro-climatic zone maps, soil type maps and irrigation maps. The topographical maps were collected from survey of India, soil type maps (from NBSSLUP) and other maps such as land use/cover, agro climatic maps, irrigation maps (from NATMO), Kolkata.

9.10 GENERATION OF DATA BASE

The generation of data base needs the source information comprising spatial data and non spatial data. The spatial data is comprised of land use/land cover, soil maps. The non-spatial or attribute data is composed of climatic parameters, demography, cropping pattern etc. In this chapter, the steps involved in deriving all these data products, the sources of data acquisition and the ways of transforming these data products suitable to GIS software are discussed.

9.11 SPATIAL DATA FROM TOPOSHEETS

Creating a GIS spatial database is a complex operation, and is heart of the entire work; it involves data capture, verification and structuring processes. Because raw geographical data are available in many different analogue and digital forms such as toposheets, aerial photographs, satellite imageries and tables. Out of all these sources, the source of toposheet is of much concern to natural resource scientist and an environmentalist. In the present study, the thematic maps generated from toposheet are, base map, drainage map and Road network map. These paper based maps are then converted to digital mode using scanning and automated digitization process. These maps are prepared to a certain scale and show the attributes of entities by different symbols or colouring. The location of entities on the earth's surface is then specified by means of an agreed co-ordinate system. It is mandatory that all spatial data in a GIS are located with respect to a frame of reference. For most GIS, the common frame of reference co-ordinate system is that of plane, orthogonal Cartesian co-ordinates oriented conventionally north-south and east-west. This entire process is called georeferencing. The same procedure is also applied on remote sensing data before it is used to prepare thematic maps from satellite data.

9.12 SPATIAL DATA FROM SATELLITE DATA AND PROCESSING

The step-by-step procedure for preparing the spatial data derived from remote sensing satellite data for the entire study area is discussed as below:

Satellite data processing using image processing software

- Geoprocessing and Georefencing
- Digital enhancement
- Generation of hard copy
- Generation of thematic maps: Land use / land cover and soil map.

9.12.1 GEO-CODING AND GEO-REFERENCING

The following standard techniques have been adopted for georeferencing of LISS III data covering the study area. ERDAS image processing software has been used for this work. 1:50,000 scale toposheets are scanned and raster file for study area is created. These are geo-referenced based on the longitudinal & latitudinal co-ordinates. After geo-referencing all the maps are edge-matched and a digital mosaic is prepared which depicts the continuity of the study area. The LISS III data obtained from National Remote Sensing Centre (NRSC) is processed for initial corrections like drop outs, stripping and earth rotations etc. Sufficient numbers of well distributed ground control points are selected both on the maps and corresponding imagery. Care is taken to satisfy the condition on density of GCPs for image registration. Georeferencing is carried out using ERDAS image processing software. The geo-referenced image is further mosaicked and then feature matching is carried out. At the end of this process the digital data which is free from all distortions is available for digital image enhancement, classification for land use/land cover map preparation with the help of visual image analysis techniques.

9.12.2 DIGITAL IMAGE ENHANCEMENT OF LISS III DATA

Image enhancement deals with the individual values of the pixels in the image. The goal of spectral enhancement is to make certain features more visible in an image by bringing out more contrast. Initial display of LISS III data through ERDAS software revealed that the features like minor roads and streams are not clear/visible as the contrast of the imageries very dull because of the raw data values fall within a narrow range. Therefore, an attempt is made to apply linear contrast stretch technique in order to improve the contrast of the image, which can be capable of expanding the dynamic range of radiometric resolution of LISS III digital data. To perform this technique, Look up Tables (LUT) is created that convert the range of data values to the maximum range of the display device. Based on these LUT's an enhanced image is produced.

9.12.3 HARDCOPY GENERATION

In order to derive spatial thematic data, a hardcopy of satellite image is generated through the following steps:

- Acquisition of satellite data from NRSC, Balanagar, Hyderabad and toposheets from Survey of India, Hyderabad.
- Geo-coding and geo-referencing of LISS III digital data by extracting the Ground Control Points (GCPs) from SOI toposheets and GPS Points
- Digital image enhancement and application of correction models for making the digital data free from errors and distortions both radiometry and geometry of the satellite data.
- Satellite Image in FCC mode and is used for visual interpretation to extract the thematic data by applying both pre-visual interpretation, ground truthing and post visual interpretation techniques.
- A satellite hardcopy is generated for subsequent analysis.

9.12.4 GENERATION OF THEMATIC MAPS FROM SATELLITE DATA

The thematic maps namely, land use/land cover and soil are generated from satellite digital hardcopy. The standard basic elements and key elements for visual interpretation are applied on this satellite hardcopy digital image so as to extract the entropy or information extent in accordance with the above thematic maps. At the end of the interpretation process the above thematic maps in the form of paper based maps are ready for subsequent scanning and automated digitization and then created a digital database for GIS data analysis and modeling.

9.12.5 ATTRIBUTE DATA

The attribute data in the present study consists of collateral data, which includes demographic details, soil quality data, water quality data acquired from various Government organizations like Andhra Pradesh Pollution Control Board (APPCB), Central Ground Water Board (CGWB), Bureau of Economics and Statistics (BES) etc.

9.12.6 DEVELOPMENT OF LAND SUITABILITY MODEL

After collection of historical data from Addanki branch canal command area and Department of Agriculture, Govt. of Andhra Pradesh, the work plan is prepared. The Ground truth work carried out on near real time basis and digital analysis is carried out after getting the digital data. The yield estimation was carried out using satellite based spectral data, historical yield data and climatic variables. The development of suitability model is done based on land capability classification and soil site suitability evaluation for crops.

The methodology includes collection of field/ground truth information, identification of optimum period for satellite data selection, selection of image analysis techniques, and selection of methods for crop acreage and production estimates and crop yield prediction.

9.12.7 COLLECTION OF GROUND TRUTH

Ground truth data collection has an important bearing in most remote sensing applications (Dozier and Strahler. 1983). Its role includes land capability, land irrigability, land classification and land identification, condition assessment and suitability prediction. Collection of ground truth data involves soil and water sample collection, gathering information on land-cover types, their spatial extent, and condition, geographical coordinates of the location. In land related applications, ground truth data collection is necessarily done synchronous or near synchronous to the time of satellite data acquisition in order to maintain the corresponding relations between remote sensing and field observations.

9.12.8 RECONNAISSANCE SURVEY

Reconnaissance survey is essentially a preliminary field survey, which is done to obtain a general idea of study area. The feasibility of using remote sensing data, the logistics that would be involved, while planning field survey for data collection, etc., are ascertained during reconnaissance. Using inputs from the reconnaissance survey, available satellite data is interpreted, visually/digitally in order to explore the feasibility of land discrimination, its suitability estimation for condition assessment. Collateral data (e.g., Collection of data from Agricultural depts., Farmer's database creation for sampling, Socio-Economic data collection) in conjunction with satellite data can be used to determine the most appropriate time for data acquisition (both RS and field). Once feasibility of land identification and period of data acquisition are established, actual planning for ground truth data collection may be initiated based on the study of the archived remote sensing data, potential ground truth sites are suggested.

9.12.9 PREPARATION OF BASE MAP

Base maps for ground truth planning contain administrative boundaries (e.g. state, district, mandal, and village), along with major features like towns\mandal head quarters\villages, reservoirs, lakes, highways, railways etc., which may be identifiable on satellite imagery. The base map is prepared on tracing film/paper usually at 1:50,000 scale, so that they can be used for visual interpretation of the study area by superimposing the map on FCC prints of the study area at corresponding scale. A Proforma for collecting land related information should also be prepared for field data collection. A typical Proforma for ground truth data collection is given below.

9.12.10 PROFORMA FOR FARMERS INVOLVEMENT INDEX (FII)

Checklist for field data collection

DATE: Sample No:....................

Name of farmer..

1. GENERAL INFORMATION:

- Field size:
- Form farmer
- GPS measurements
- Ownership
- Soil Type (Local Name)

2. CROP CALENDAR:

- How many crops did you grow last year When

3. PLUGGING:

- When did you start land preparation
- How
- Source of Power
- Number of Plugging

4. PLANTING:

- When did Planting start
- How Seed rate for nursery
- Plant used % Varity
- Plant quality(Good/average/Poor)
- Age at transplanting
- Source of seed
- Seed quality
- Water availability (Water level/shortage).

5. FERTILIZER APPLICATION:

- Number of fertilizer applications
- When How
- Type
- Quantity
- Water level (before and after).
- How long does the water drain after supplying

6. WEEDING:

- When How

7. PESTICIDE APPLICATION:

- When Why
- Severity of damage
- Names of pest/disease
- Control method How

8. YIELD:

- When was it done
- How much did they harvest
- How much did they expect
- Why the difference
- Problems-water shortage

Input availability

Extension

How much was the reduction

9. FARMER SUGGESTIONS.

- What are your plans to increase yield.
- Which types of support do you expert
- Would you like to change the crop
- To which crop\ variety

10. FARMERS VIEWS ON DEPARTMENT OF AURICULAR

9.12.11 FIELD VISIT FOR GROUND TRUTH DATA COLLECTION

Ground truth data collection for crop related studies could include information on crop type; percent canopy cover, spatial extent, phenological stage, planting date, expected date of harvest, availability of irrigation and incidence of pests and diseases. The areas from where data has been collected, need to be located accurately on satellite images hence, their spatial extent and geographical coordinates need to be recorded during data collection preferably on map tracings. The minimum mapable field size, which is the combined group of contiguous adjacent fields of the same crop, is of more significance than the size of individual fields. Therefore, a global positioning system (GPS) receiver can help in the accurate recording of extent and location of a site. During data collection for the complete enumeration approach, it is necessary to ascertain that the entire range of spectral variability in the area gets represented and the sites should be uniformly distributed. Proximity of ground truth sites, to unambiguously identifiable ground control points is desirable, though not always possible. When accuracy assessment is undertaken, wall-to-wall ground truth data collection is usually done involving the collection of field-by-field information on various land cover classes. A cadastral map of the study area can be used for the collection of field-wise information.

9.12.12 METHODS OF SOIL & WATER ANALYSIS

The methods adopted for estimation of soil properties are as follows.

PHYSICAL PROPERTIES

Particle Size Distribution

Particle size distribution of the soils was determined by hydrometer method as described by Gee *et al.* (1986). Textural classes of the soil were interpreted from the textural triangle diagram given for the International System of Particle Sizes.

Bulk Density

Bulk density of soil was determined by the core method on dry weight basis and results were expressed in g cm^{-3} (Blake and Hartge, 1986).

Water Holding Capacity

The water retained by the soil samples at 0.33 and 15 bar tensions was determined by using pressure plate apparatus (Klute, 1986). The moisture retained was expressed in terms of percentage on dry weight basis.

Saturated Hydraulic Conductivity (K_s)

The hydraulic conductivity (K_s) of the undisturbed soil sample was measured by the constant head method as per the procedure outlined by Klute and Dirksen (1986) and results were expressed as cm h^{-1}.

Soil Colour

Munsell's notation of hue, value and chroma were observed for soils in both moist and dry conditions (Soil Survey Staff, 1951).

PHYSICO-CHEMICAL PROPERTIES

Soil Reaction (pH)

The pH of the soil in 1:2.5 soil water suspensions was determined by digital pH meter (Jackson, 1967).

Electrical Conductivity (EC)

The electrical conductivity of the soil was measured in 1:2.5 soil water extract with the help of digital conductivity meter (Jackson, 1967) and the results were expressed in dS m^{-1}.

Cation Exchange Capacity (CEC)

The CEC of the soil samples was determined by the sodium saturation method as described by Chapman (1965) and the results were expressed in c mol (p^+) kg^{-1} soil.

Exchangeable Cations

The exchangeable cations *viz.,* sodium, potassium calcium and magnesium were extracted with neutral normal ammonium acetate method as described by Jackson, (1967) and results were expressed in c mol (p^+) kg^{-1} soil.

Free calcium carbonate

The free calcium carbonate content was determined by rapid titration method as described by Piper (1966).

CHEMICAL PROPERTIES

Organic Carbon

The organic carbon content of the soils was determined by Walkley and Black rapid titration method (1956) and the results were expressed in percentage.

Available Nitrogen

The available nitrogen in the soil and plant was determined by alkaline permanganate method as given by Subbaiah and Asija (1956) with the help of Kelpus nitrogen analyser and the results were expressed in

$kgha^{-1}$.

Available Phosphorus

The available phosphorus content was determined by extracting with 0.03N NH_4F+0.025 N HCl (Bray and Kuntz, 1945) and the phosphorus content was estimated colorimetrically using ascorbic acid method (Olsen, 1954).

Available Potassium

The available potassium content was determined in neutral normal ammonium acetate extract using flame photometer (Jackson, 1967).

Available sulphur

Available sulphur was extracted from the soil using 0.15 per cent calcium chloride solution and sulphur in solution was determined by turbidometry as outlined by Black (1986) using Spectrophotometer (Spectronic 20-D) at 420 nm.

Available Micronutrients

The available micronutrients *viz.*, zinc, iron, manganese and copper were determined in the DTPA extract of soil using Atomic Absorption Spectrophotometer (AAS) as described by Lindsay and Norwell (1978).

Correlation

The correlation analysis was carried out between soil physical, chemical properties and nutrient availability by using standard procedures.

Nutrient status maps

Nutrient status maps for study area are generated by using GIS software's ARC INFO and ARC VIEW.

9.12.3 Collection and processing of soil and plant samples

Soil samples were collected from each horizon of the fifteen profiles. Surface samples numbering forty were also collected randomly from the sites of interest. The samples were air dried, pounded with wooden pestle and were passed through 2 mm sieve. Particles greater than 2mm were considered as gravel. The sieved soil samples were used for determination of mechanical composition, bulk density, and physico-chemical and chemical properties.

Undisturbed samples were collected from each horizon using brass cylinders of 15 cm height and 5 cm diameter for determining hydraulic conductivity and metal cores of 5 cm diameter and 5 cm height for bulk density estimations.

Plant samples collected from identified profile and surface soil sampling fields. Two plant samples were collected to represent each pedon and a total of 30 plant samples of various crops were taken from study area. The samples were air dried for two days afterwards oven dried for one day at $50^{0}C$. The samples are grinded with plant sample grinder to pass throw 40 mesh sieve.

9.12.14 LAND CAPABILITY CLASSIFICATION

The land capability is mainly based on the inherent soil characteristics, external land features and environmental factors. The land capability classes and sub classes were arrived at as per the guidelines in Soil Survey Manual. The criteria used for land capability classification are presented in Appendix I.

9.12.15 LAND EVALUATION

9.12.15.1 Soil-site suitability evaluation for crops

Soil suitability for major crop growing was evaluated based on FAO frame work (1976) for land evaluation. It involved formulation of climatic and soil requirements of crop and ratings of these parameters viz., highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N) for agriculture. Soil-site suitability for some of the major crops was evaluated based on the criteria suggested by Sehgal (1996) and Sys *et al.* (1991). Soil-site suitability characteristics for crops are presented in Appedix II

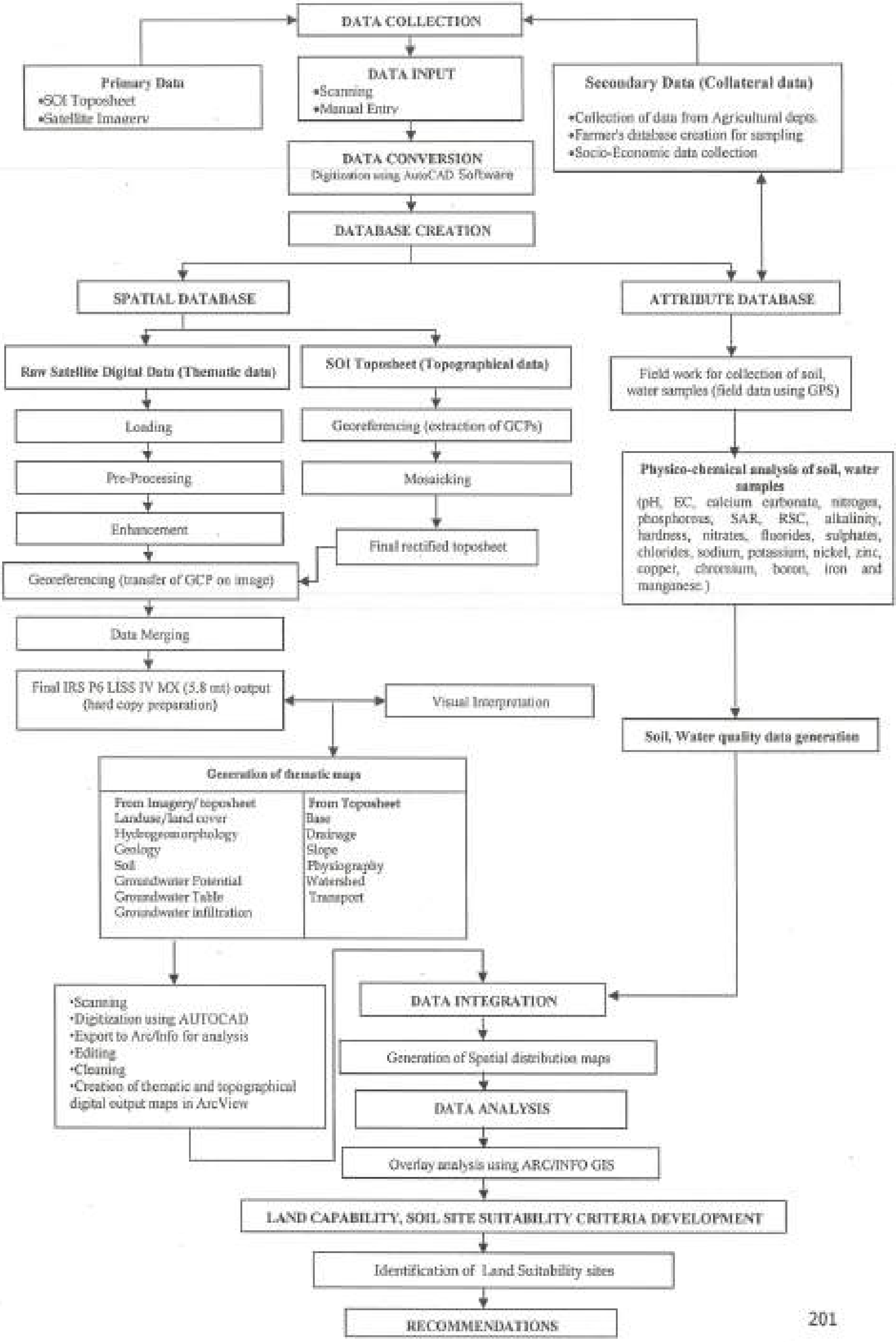
9.12.15.2 Simple and maximum limitation method for land evaluation

In this method land characteristics (or qualities) are compared with the crop requirements and the land class is attributed according to the less favourable characteristics or quality.

The methodology suggests an evaluation of the climatic characteristics in the first place with an ultimate aim of one class level to be introduced in the total evaluation.

The relationship between land classes or suitability classes and limitations are given below.

Limitations			**Suitability class (land class)**		
0	:	No	S1	:	Highly suitable
1	:	Slight	S2	:	Moderately suitable
2	:	Moderate	S3	:	Marginally suitable
3	:	Severe	N1	:	Temporarily Unsuitable
4	:	Very severe	N2	:	Permanently unsuitable


DATA COLLECTION
Primary Data
•SOI Toposheet
•Satellite Imagery
DATA INPUT
•Scanning
•Manual Entry
Secondary Data (Collateral data)
•Collection of data from Agricultural depts.
•Farmer's database creation for sampling
•Socio-Economic data collection
DATA CONVERSION
Digitization using AutoCAD Software
DATABASE CREATION
SPATIAL DATABASE
ATTRIBUTE DATABASE
Raw Satellite Digital Data (Thematic data)
SOI Toposheet (Topographical data)
Field work for collection of soil, water samples (field data using GPS)
Loading
Georeferencing (extraction of GCPs)
Pre-Processing
Mosaicking
Physico-chemical analysis of soil, water samples
(pH, EC, calcium carbonate, nitrogen, phosphorous, SAR, RSC, alkalinity, hardness, nitrates, floorides, sulphates, chlorides, sodium, potassium, nickel, zinc, copper, chromium, boron, iron and manganese.)
Enhancement
Final rectified toposheet
Georeferencing (transfer of GCP on image)
Data Merging
Final IRS P6 LISS IV MX (5.8 mt) output (hard copy preparation)
Visual Interpretation
Soil, Water quality data generation
Generation of thematic maps
From Imagery/ toposheet
Landuse/land cover
Hydrogeomorphology
Geology
Soil
Groundwater Potential
Groundwater Table
Groundwater infiltration
From Toposheet
Base
Drainage
Slope
Physiography
Watershed
Transport
•Scanning
•Digitization using AUTOCAD
•Export to Arc/Info for analysis
•Editing
•Cleaning
•Creation of thematic and topographical digital output maps in ArcView
DATA INTEGRATION
Generation of Spatial distribution maps
DATA ANALYSIS
Overlay analysis using ARC/INFO GIS
LAND CAPABILITY, SOIL SITE SUITABILITY CRITERIA DEVELOPMENT
Identification of Land Suitability sites
RECOMMENDATIONS

9.13 SOIL & WATER QUALITY ANALYSIS

9.13.1 General

To study the Environmental parameters of the Study area Field Survey was carried out during 2007, apart from Ground Truth Checking for the thematic maps Soil and water samples were collected as per the strategy planned. The location information was collected using Garmin GPS.

The soil and water samples were collected form the field and the parameters which were analyzed are Ph, EC Calcium, Nitrogen, Phosphorus, Magnesium, Sulphur, Alkalinity, Carbonate, Bicarbonate, Chloride & Hardness, remaining parameters were analysed at Centre for Environment. Institute of Science and Technology, JNTUH at Kukatpally, Hyderabad.

9.13.2 SOIL AND WATER PARAMETERS ANALYSED:

- General - pH, EC, TDS, THS,
- Cations - Ca, Mg, Na, K, S, CEC, ESP, Fe, Zn, Cu, Mn
- Anions – CO_3,HCO_3, Cl, So_4
- Ratios - SAR, Mg/Ca, Na/Cl,
- Others – RSC, SSP.

Table 1: pH content of soils of study area

S. No	Mandal	No. of samples	SURFACE							SUB-SURFACE					
			PH		Slightly acidic	Normal	Mildly alkaline	Moderately alkaline	Strongly alkaline	pH		Normal	Mildly alkaline	Moderately alkaline	Strongly alkaline
			Range	Mean	No.	No.	No.	No.	No.	Range	Mean	No.	No.	No.	No.
1	Bollapalle	3	6.80-8.50	7.63	-	1	1	1	-	6.80-8.60	7.73	1	1	-	1
2	Ipuru	2	7.90-8.30	8.10	-	-	1	1	-	7.80-8.90	8.35	-	1	-	1
3	Nekarikallu	3	5.70-7.92	6.83	1	1	1	-	-	5.54-8.10	7.06	1	1	1	-
4	Vinukonda	2	7.76-8.30	8.03	-	-	1	1	-	7.68-8.75	8.31	-	1	-	1
5	Savalayapu	2	6.40-8.40	7.40	1	-	-	1	-	7.04-8.46	7.75				
6	Rompicherla	2	8.38-8.48	8.43	-	-	-	2	-	8.42-8.50	8.46	-	-	2	-
7	Narasaraopet	2	7.64-7.74	7.69	-	-	2	-	-	7.97-7.98	7.97	-	2	-	-
8	Chilakaluripet	3	6.90-7.94	7.21	-	2	1	-	-	7.80-8.59	8.29	-	1	1	1
9	Peddanandipadu	2	7.81-8.10	7.99	-	-	1	1	-	8.14-8.35	8.23	-	-	2	-
10	Kakumanu	2	7.90-8.30	8.10	-	-	1	1	-	7.80-8.90	8.35	-	1	-	1
11	Addanki	4	8.10-8.75	8.42	-	-	-	2	2	8.10-8.48	8.32	-	-	4	-
12	Korisapadu	2	7.89-8.16	8.03	-	-	1	1	-	8.12-8.47	8.23	-		2	-
13	J.Panguluru	2	7.87-8.10	7.99	-	-	1	1	-	8.10-8.35	8.23	-	-	2	-
14	Ballikurava	2	8.27-8.32	8.30	-	-	-	2	-	8.42-8.47	8.45	-	-	2	-
15	Santamaguluru	2	8.30-8.46	8.38	-	-	-	2	-	8.55-8.61	8.58	-	-	-	2
16	Martur	4	8.01-8.45	8.25	-	-	-	4	-	8.20-8.62	8.39	-	-	3	1
17	Yeddanapudi	2	7.89-8.09	7.99	-	-	1	1	-	8.36-8.46	8.41	-	-	2	-
18	Chirala	2	7.65-7.74	7.69	-	-	2	-	-	7.95-7.98	7.97	-	2	-	-
19	Vetapalem	3	7.01-8.32	7.48	-	2	1	-	-	7.64-8.94	8.22	-	1	1	1
20	Chinaganjam	3	6.93-7.94	7.21	-	2	1	-	-	7.89-8.59	8.29	-	1	1	1
21	Parchur	2	8.02-8.19	8.11	-	-	-	2	-	8.06-8.22	8.14	-	-	2	-
22	Inkollu	3	7.80-8.02	7.83	-	-	2	1	-	7.98-8.15	8.06	-	1	2	-
23	Karamchedu	2	7.51-7.62	7.57	-	-	2	-	-	8.02-8.06	8.04	-	-	2	-
24	N.G.Padu	3	7.20-9.10	8.12	-	1	-	1	1	7.50-9.70	8.43	-	1	1	1

Table 2 : EC (dsm^{-1}) content of soils of Study area

S. No.	Mandal	No. of samples	SURFACE						SUB-SURFACE					
			EC		Low saline	Medium saline	High saline	Very high	EC		Low saline	Medium saline	High saline	Very high saline
			Range	Mean	No.	No.	No.	No.	Range	Mean	No.	No.	No.	No.
1	Bollapalle	3	0.16-0.37	0.25	2	1	-	-	0.17-0.81	0.44	1	1	1	-
2	Ipuru	2	0.14-0.25	0.19	1	1	-	-	0.09-0.24	0.17	2	-	-	-
3	Nekarikallu	3	0.06-0.78	0.51	1	1	1	-	0.05-0.64	0.43	1	2	-	-
4	Vinukonda	2	0.22-0.44	0.35	1	1	-	-	0.14- 0.32	0.28	1	1	-	-
5	Savalayapu	2	0.29-0.30	0,29	-	2	-	-	0.22-0.31	0.26	1	1	-	-
6	Rompicherla	2	0.14-0.38	0.26	1	1	-	-	0.16-0.18	0.17	2	-	-	-
7	Narasaraopet	2	0.14-0.16	0.15	2	-	-	-	0.16-0,2	0,18	2	-	-	-
8	Chilakaluripet	2	0.15-0.25	0.20	1	1	-	-	0.09-0.24	0.17	2	-	-	-
9	Peddanandipadu	3	0.16-0.37	0.25	2	1	-	-	0.17-0.81	0.44	1	1	1	-
10	Kakumanu	2	0.20-0.40	0.30	1	1	-	-	0.36-0.59	0.48	-	2	-	-
11	Addanki	4	0.21-0.36	0.30	1	3	-	-	0.22-2,84	1.01	1	2	-	1
12	Korisapadu	2	0.33-0.34	0.34	-	2	-	-	0.24-0.32	0.28	1	1	-	-
13	J.Panguluru	2	0.36-0.90	0.63	-	1	1	-	0.32-0.45	0.39	-	2	-	-
14	Ballikurava	2	0.20-0.34	0,27	1	1	-	-	0.16-0.18	0.17	2	-		-
15	Santamaguiurl.	2	0.22-0.40	0.31	1	1	-	-	0.13-0.32	0.25	1	1	-	-
16	Martur	4	0.15-0.51	0.25	3	1	-	-	0.11-0.38	0.21	3	1	-	-
17	Yeddanapudi	2	0.26-1.17	0.72	-	1	1	-	0.20-0.45	0.33	1	1	-	-
18	Chirala	2	0.96-6.06	3.51	-	-	1	1	0.45-6.58	3.52	_	1	-	1
19	Vetapalem	3	0.23-1.45	0.97	1	1	1	-	0.09-1.18	0.51	1	1	1	-
20	Chinaganjam	3	0.25-1.45	0.98	-	1	2-	-	0.32-0.93	0.69	_	1	2	-
21	Parchur	2	0.20-0.40	0.30	1	1	-	-	0.36-0.59	0.48	-	2	-	-
22	Inkollu	3	0.13-0.54	0.29	2	1	-	-	0.11-0.30	0.22	1	2	-	-
23	Karamchedu	2	0.42-1.90	1.16	-	1	1	-	0.40-0.65	0.53	-	2	-	-
24	N.G.Padu	3	0.24-1.73	1.03	1	-	2	-	0.20-1.19	0.85	1	-	2	-

Table 3 : Cation exchange capacity and exchangeable cations (c.mol (p^+) kg $^{-1}$) of Study area

S No.	Mandal	No. of samples	Exchangeable Ca		Exchangeable Mg		Exchangeable Na		Exchangeable K		CEC		ESP	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	3	16.00-56.00	37.33	8.00-16,00	12.00	1.00-6.40	3.47	0.78-1.18	101	26.00-60.00	42.00	3.84-16.00	8.28
2	Ipuru	2	28.00-28.00	28.00	8.00-12.00	10.00	2.00-2.40	2.20	0.36-0.58	0.47	18.00-28.00	23.00	8.57-11.10	9.84
3	Nekarikallu	3	4.00-32.00	16.00	8.00-24.00	16.00	0.40-3.20	1.73	0.26-1.78	1.18	7.60-26.00	17.90	5.30-12.30	8.53
4	Vinukonda	2	60.00-62,00	61.00	6.00-18.00	12.00	2.40-3.40	2,90	0.84-1.66	1.25	52.00-56.00	54.00	4.60-6.07	5.34
5	Savalayapu	3	37.20-54.80	46.58	7.20-14.50	10.54	2.49-5.70	4.09	0.61-1.34	0.96	31.98-49.60	41.17	9.25-16.71	11.28
6	Rompicherla	2	16.00-78.00	52.00	4.00-8.00	6.50	1.00-6.00	3.07	0.32-1.70	1.01	36.00-48.00	42.00	4.44-15.00	11.48
7	Narasaraopet	4	12.00-76.00	48.00	2.00-12.00	6.00	3.00-8.60	5.80	0.48-1.08	0.78	16.00-70.00	35.30	11.05-13.07	12.06
8	Chilakaluripet	3	28.00-28.00	28.00	8.00-12.00	10.00	5.20-8.20	6.7	0.84-1.78	1.22	16.00-70.00	35.30	8.57-11.10	9.84
9	Peddanandipau	2	14.00-28.00	21.00	6.00-8.00	7.00	1.00-2.20	1.60	0.68-0.72	0.70	16.00-20.00	18.00	5.00-13.80	9.40
10	Kakumanu	2	66.00-74.00	70.00	4.00-14.00	9.00	2.80-3.20	3.00	0.42-0.48	0.45	42.00-46.00	44.00	6.67-6.95	6.81
11	Addanki	4	26.00-60.00	48.00	2.00-8.00	5.00	2.20-7.00	4.95	0.84-1.78	1.22	26.00-42.00	34.00	6.88-18.30	14.29
12	Korisapadu	2	64.00-68.00	66.00	8.00-10.00	9.00	2.40-4.80	3.60	0.58-1.44	101	44.00-48.00	46.00	5.45-10.00	7.73
13	J.Panguluru	2	68.00-70.00	69.00	6.00-6.00	6.00	3.80-7.00	5.40	0.48-1.30	0.89	42.00-60.00	51.00	6.33-16.67	11.50
14	Ballikurava	2	44.00-50.00	47.00	18.00-18.00	18.00	3.40-4.20	3.80	0.48-0.58	0.53	26.00-38.00	32.00	11.05-13.07	12.06
15	Santamaguluru	2	54.00-60.00	57.00	8.00-14.00	11.00	4.20-5.20	4.70	0.48-1.08	0.78	32.00-36.00	34.00	13.13-14.45	13.79
16	Martur	4	16.00-78.00	52.00	4.00-8.00	6.50	1.80-3,40	2.80	0.42-1.30	0.78	16.00-56.00	41.50	4.09-21.25	9.20
17	Yeddanapudi	2	68.00-70.00	69.00	4.00-8.00	6.00	3.00-8.60	5.80	1.30-2,56	1.93	56.00-64.00	60.00	5.36-13.44	9.40
•18	Chirala	2	40.00-40.00	40.00	16.00-22.00	14.00	4.40-16.20	10.30	1.58-1.58	1.58	56.00-68.00	62.00	6.47-28.90	17.68
19	Vetapalem	3	4.00-38,00	16.67	2.00-12.00	6.00	1.00-6.00	3.07	0.22-0.26	0.23	16.00-70.00	35.30	13.75-30.00	19.32
20	Chinaganjam	3	6.00-28.00	18.00	4.00-10.00	7.33	1.60-4.80	3.13	0.36-2.56	1.25	20.00-36.00	29.30	4.44-15.00	11.48
21	Parchur	2	70.00-78.00	74.00	14.00-42.00	28.00	3.40-5.60	4.50	0.32-1.70	1.01	72.00-76.00	74.00	4.47-7.78	6.13
22	Inkollu	3	12.00-76.00	48.00	8.00-18.00	12.67	2.00-4.80	3.80	0.22-1.13	0.57	20.00-68.00	50.67	7.06-10.00	8.09
23	Karamchedu	2	60.00-62.00	61.00	6.00-10.00	8,00	5.20-8.20	6.7	0.72-1.58	1.15	36.00-48.00	42.00	10.83-22,78	16.80
24	N.G.Padu	3	24.00-38.00	32.67	4.00-12.00	7.33	1.80-7.40	4.20	0.78-1.38	1.10	16.00-46.00	32.67	3.90-46.20	19.84

Table 4 :Organic carbon content (%) of soils of study area

S. No.	Mandal	No. of samples	SURFACE					SUB-SURFACE				
			Organic Carbon		Low	Medium	High	Organic Carbon		Low	Medium	High
			Range	Mean	No.	No.	No.	Range	Mean	No.	No.	No.
1	Bollapalle	3	0.27-0.44	0.35	3	-	-	0.23-0.38	0.28	3	-	-
2	Ipuru	2	0.18-0.24	0.21	2	-	-	0.09-0.24	0.17	2	-	-
3	Nekarikallu	3	0.16-0.72	0.51	1	2	-	0.09-0.61	0.36	2	1	-
4	Vinukonda	4	0.26-0.62	0.44	1	3	-	0.21-0.47	0.35	3	-	1
5	Savalayapu	2	0.45-1.12	0.77	1	-	1	0.31-0.72	0.52	1	1	-
6	Rompicherla	2	0.30-0.37	0.34	2	-	-	0.33-0.42	0.38-	2	-	-
7	Narasaraopet	2	0.54-0.94	0.74	-	1	1	0.28-0.61	0.45	1	1	-
8	Chilakaluripet	2	0.19-0.64	0.42	1	1	-	0.07-0.42	0.25	2	-	-
9	Peddanandipau	2	0.30-0.37	0.34	2	-	-	0.33-0.42	0.38	2	-	-
10	Kakumanu	2	0.27-0.31	0.29	2	-	-	0.21-0.28	0.25	2	-	-
11	Addanki	4	0.06-0.81	0.43	2	1	1	0.03-0.33	0.25	4	-	
12	Korisapadu	2	0.34-0.60	0.47	1	1	-	0.31-0.33	0.32	2		-
13	J.Panguluru	2	0.17-0.52	0.35	1	1	-	0.36-0.78	0.57	1	1	-
14	Ballikurava	2	0.18-0.49	0.34	2	-	-	0.21-0.39	0.30	2	-	-
15	Santamaguluru	2	0.37-0.76	0.57	1	1	-	0.25-0.45	0.35	2	-	-
16	Martur	4	0.15-0.57	0.37	2	2	-	0.10-0.28	0.18	4	-	-
17	Yeddanapudi	2	0.19-0.64	0.42	1	1	-	0.07-0.42	0.25	2	-	-
18	Chirala	2	0.54-0.94	0.74	-	1	1	0.28-0.61	0.45	1	1	-
19	Vetapalem	3	0.02-0.37	0.22	3	-	-	0.03-0.16	0.09	3	-	-
20	Chinaganjam	3	0.40-0.63	0.53	1	2	-	0.11-0.32	0.22	3	-	-
21	Parchur	2	0.41-0.99	0.70	1	-	1	0.41-0.76	0.59	1	-	1
22	Inkollu	3	0.46-0.97	0.63	2	-	1	0.23-0.49	0.34	3	-	-
23	Karamchedu	2	0.13-0.57	0.35	1	1	-	0.45-0.96	0.71	1	-	1
24	N.G.Padu	3	0.16-0.33	0.26	3	-	-	0.12-0.51	0.29	2	1	-

Table 5: Mechanical composition of soils of Study area

S No.	Mandal	No. of samples	% Sand		% Silt		% Clay		Textural class
			Range	Mean	Range	Mean	Range	Mean	
1	Bollapalle	3	45.70-50.24	48.50	19.70-26.70	22.70	28.60-32.60	30.60	SCL
2	Ipuru	2	82.40-86.44	83.60	7.10-21.00	12.10	8.46-10.40	9.12	LS
3	Nekarikallu	3	93.40-96.30	94.50	1.29-3.10	2.33	2.12-3.46	2.81	S
4	Vinukonda	3	50.90-62.34	56.27	13.40-19.80	16.45	24.60-31.09	27.69	CL
5	Savalayapu	2	51.64-61.64	56.64	11.40-17.40	14.40	26.90-30.60	28.75	SCL
6	Rompicherla	4	30.50-36.40	33.45	41.60-63.64	52.40	13.30-21.60	17.45	LS
7	Narasaraopet	2	32.70-57.10	43.27	7.56-8.72	8.14	25.10-25.40	25.25	CL
8	Chilakaluripet	3	25.10-25.40	25.25	93.40-96.30	94.50	51.30-69.40	60.40	CL
9	Peddanandipau	2	43.40-50.40	46.90	16.20-20.30	18.25	33.50-36.60	35.05	SCL
10	Kakumanu	2	42.40-44.50	43.50	25.10-25.40	25.30	30.40-36.60	33.50	CL
11	Addanki	4	40.10-46.60	42.80	19.70-24.70	22.20	34.60-37.80	35.50	CL
12	Korisapadu	2	35.70-38.70	37.20	15.40-23.40	19.40	40.80-45.60	43.20	CL
13	J.Panguluru	2	37.40-45.60	41.50	25.20-27.60	26.40	29.70-35.60	32.65	CL
14	Ballikurava	2	52.74-60.04	56.49	12.70-17.40	15.05	27.30-29.80	28.55	SCL
15	Santamaguluru	2	51.30-69.40	60.40	9.70-20.70	15.20	20.60-27.90	24.25	SCL
16	Martur	4	39.64-63.64	50.32	9.70-19.70	13.85	36.60-42.50	39.52	sc
17	Yeddanapudi	2	42.40-44.60	43.50	25.10-25.40	25.25	30.50-36.40	33.45	CL
18	Chirala	2	88.10-89.20	88.65	4.30-4.30	4.30	7.56-8.72	8.14	LS
19	Vetapalem	3	93.90-97.90	95.60	1.20-2.01	1.67	1.90-2.90	2.46	S
20	Chinaganjam	3	41.60-63.64	52.40	13.40-27.40	20.26	22.90-30.90	26.90	SCL
21	Parchur	2	28.60-62.80	45.60	10.10-25.00	17.55	24.40-47.20	35.50	CL
22	Inkollu	3	32.70-57.10	43.27	14.80-23.20	18.67	29.00-44.00	35.00	CL
23	Karamchedu	2	36.60-56.60	46.60	13.30-21.60	17.45	30.00-42.00	36.00	CL
24	N.G.Padu	3	39.70-61.50	47.50	11.90-20.20	16.70	27.20-40.30	33.00	SCL

Table 6 : Available Nitrogen content (Kg ha-^{1}) of soils of study area

S No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Nitrogen		Low		Nitrogen		Low	
			Range	Mean	No.	%	Range	Mean	No.	%
1	Bollapalle	3	138-160	152	3	100	144-172	157	3	100
2	Ipuru	2	103-141	122	2	100	131-156	143	2	100
3	Nekarikallu	3	122-232	174	3	100	119-222	164	3	100
4	Vinukonda	4	158-211	184.05	5	100	145-189	168	5	100
5	Savalayapu	3	181-188	184	4	100	163-232	198	3	100
6	Rompicherla	2	207-247	227	5	100	138-160	152	5	100
7	Narasaraopet	3	137-247	187	2	100	166-188	177	2	100
8	Chilakaluripet	2	156-235	195	2	100	116-169	142	2	100
9	Peddanandipau	2	156-178	167	2	100	163-172	167	2	100
10	Kakumanu	2	191-210	200	2	100	188-200	194	2	100
11	Addanki	4	122-210	168	4	100	119-213	165	4	100
12	Korisapadu	2	144-241	192	2	100	144-150	147	2	100
13	J.Panguluru	2	228-229	228	2	100	166-203	185	2	100
14	Ballikurava	2	156-200	178	2	100	153-203	178	2	100
15	Santamaguluru	2	194-206	200	2	100	191-206	198	2	100
16	Martur	4	159-225	191	4	100	166-206	185	4	100
17	Yeddanapudi	2	181-188	184	2	100	166-188	177	2	100
18	Chirala	2	206-247	226	2	100	225-201	213	2	100
19	Vetapalem	3	137-247	187	3	100	62-169	121	3	100
20	Chinaganjam	3	144-194	168	3	100	112-169	145	3	100
21	Parchur	2	163-232	198	2	100	150-219	185	2	100
22	Inkollu	3	169-232	190	3	100	128-175	158	3	100
23	Karamchedu	2	207-247	227	2	100	189-228	208	2	100
24	N.G.Padu	3	87-166	134	3	100	81-159	133	3	100

Table 7 : Available Phosphorus content ($KgP_2O_5ha^{-1}$) of soils of study area

S. No.	Mandal	No. of samples	SURFACE Phosphorus Range	SURFACE Phosphorus Mean	SURFACE Low No.	SURFACE Medium No.	SURFACE High No.	SUB-SURFACE Phosphorus Range	SUB-SURFACE Phosphorus Mean	SUB-SURFACE Medium No.	SUB-SURFACE High No.
1	Bollapalle	3	54.60-89.60	68.09	-	1	2	34.90-85.20	62.50	1	2
2	Ipuru	2	46.60-67.21	56.89	-	1	1	34.04-56.50	45.30	1	1
3	Nekarikallu	3	74.40-144.30	115.60	-	-	3	60.90-137.10	102.20	-	3
4	Vinukonda	2	51.50-76.60	64.05	-	1	1	35.40-38.50	36.90	2	-
5	Savalayapu	2	59.88-93.44	77.07	1	1	40	51.96-78.81	65.39	1	1
6	Rompicherla	2	48.40-85.60	67.00	-	1	1	57.80-74.70	66.10	-	2
7	Narasaraopet	2	38.50-44.80	41.65	-	2	-	28.70-43.00	35.10	2	-
8	Chilakaluripet	2	62.70-91.40	77.05	-	1	1	60.90-137.10	102.20	1	1
9	Peddanandipau	4	67.20-74.40	70.80	1	2	1	41.60-70.80	53.00	2	2
10	Kakumanu	3	19.80-89.60	55.60	-	2	1	51.10-94.90	66.30	2	1
11	Addanki	4	34.90-82.40	64.25	-	1	3	33.20-73.50	53.30	2	2
12	Korisapadu	2	28.90-70.80	49.85	-	1	1	41.20-67.20	54.20	1	1
13	J.Panguluru	2	57.30-57.80	57.55	-	-	2	44.60-67.20	55.90	1	1
14	Ballikurava	2	57.40-117.40	87.40	-	-	2	67.60-94.90	8125	-	2
15	Santamaguluru	2	100.40-105.70	103.05	-	-	2	67.40-70.80	69.10	-	2
16	Martur	4	54.70-100.80	83.78	-	1	3	66.70-85.60	75.50	-	4
17	Yeddanapudi	2	73.50-94.10	83.80	-	-	2	66.90-89.60	78.30	-	2
18	Chirala	2	105.70-131.70	118.70	-	-	2	113.80-120.90	117.40	-	2
19	Vetapalem	3	19.60-89.60	55.60	1	1	2	38.50-87.80	68.90	1	2
20	Chinaganjam	3	78.40-112.40	93.50	-	-	3	41.60-70.80	53.00	2	1
21	Parch ur	2	67.20-74.40	70.80	-	-	2	23.80-67.60	60.70	1	1
22	Inkollu	3	85.20-144.30	115.02	-	-	3	33.60-76.30	54.90	1	2
23	Karamchedu	2	62.70-91.40	77.05	-	-	2	67.60-74.40	71.00	-	2
24	N.G.Padu	3	57.40-87.80	67.80	-	-	3	51.10-94.90	66.30	2	1

Table 8: Available Potassium content (kg k₂o ha ⁻¹) of soils of study area

S. No.	Mandal	No. of samples	SURFACE					SUB-SURFACE				
			Potassium		Low	Medium	High	Potassium		Low	Medium	High
			Range	Mean	No.	No.	No.	Range	Mean	No.	No.	No.
1	Bollapalle	3	940-1344	1120	-	-	3	672-1209	940	-	-	3
2	Ipuru	2	241-362	301.9	-	1	1	201-322	262	-	2	-
3	Nekarikallu	3	161-2150	1397	1	-	2	134-1747	1120	1	-	2
4	Vinukonda	3	443-1123	776.995	-	1	2	372-819	592	-	3	-
5	Savalayapu	2	672-1344	1008		-	2	403-672	537	-	-	2
6	Rompicharla	2	430-430	430	-	-	2	228-336	282		2	-
7	Narasaraopet	2	215-255	235	-	2	-	147-228	188	1	1	-
8	Chilakaluripet	3	210-200	205	1		2	376-1478	842	1	2	-
9	Peddanandipau	2	325-375	350	-	2	-	309-940	624	2	-	-
10	Kakumanu	3	410-430	420	-	3	-	450-480	465	1	2	-
11	Addanki	4	416-1747	977	-	-	4	362-806	594	-	-	4
12	Korisapadu	2	268-940	604	-	1	1	161-940	550	1	-	1
13	J.Panguluru	2	215-806	510	-	1	1	188-537	362	-	1	1
14	Ballikurava	2	201-322	262	-	2	-	188-268	228	-	2	-
15	Santamaguluru	2	268-806	537	-	1	1	215-672	443	-	1	1
16	Martur	4	215-806	436	-	1	3	147-537	288	1	2	1
17	Yeddanapudi	2	806-1478	1142	-	-	2	537-1075	806	-	-	2
18	Chirala	2	1075-1209	1142	-	-	2	940-1075	1008	-	-	2
19	Vetapalem	3	80-1209	479	2	-	1	67-188	107	2	1	-
20	Chinaganjam	3	255-1747	891	-	1	2	376-1478	842	-	-	3
21	Parchur	2	1075-1478	1276	-	-	2	940-134	1142	-	-	2
22	Inkollu	3	134-1478	940	1	-	2	94-940	658	1	-	2
23	Karamchedu	2	389-1075	732	-	-	2	309-940	624	-	1	1
24	N.G.Padu	3	806-1478	1120	-	-	3	537-1075	851	-	-	3

Table 9 : Exchangeable Calcium content (c mol (p+)kg^{-1}) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Calcium		Above critical limit		Calcium		Above critical limit	
			Range	Mean	No.	%	Range	Mean	No.	%
1	Bollapalle	3	12.2-39.2	21.20	3	100	17.4-48.5	35.20	3	100
2	Ipuru	2	21.0-28.0	24.50	2	100	30.0-30.5	30.25	2	100
3	Nekarikallu	3	1.70-28.0	10.90	3	100	5.0-25.0	17.00	3	100
4	Vinukonda	5	27.7-43.1	35.37	5	100	28.3-42.1	35.97	5	100
5	Savalayapu	2	51.0-54.0	52.50	2	100	49.0-49.0	49.00	2	100
6	Rompicherla	4	4.5-48.5	26.5	4	100	11.0-69.0	40.60	4	100
7	Narasaraopet	3	16.6-44.4	30.5	3	100	12.2-39.2	21.20	3	100
8	Chilakaluripet	4	15.4-505	32.5	4	100	3.0-18.0	9.00	4	100
9	Peddanandipau	2	20.0-30.0	25.00	2	100	17.0-28.0	22.50	2	100
10	Kakumanu	2	54.0-55.0	54.50	2	100	52.0-53.0	52.50	2	100
11	Addanki	4	30.0-45.0	38.00	4	100	32.0-43.0	44.50	4	100
12	Korisapadu	2	44.0-57.0	50.50	2	100	44.0-53.0	48.50	2	100
13	J.Panguluru	2	31.0-60.0	45 50	2	100	37.0-49.0	43.00	2	100
14	Ballikurava	2	27.0-38.0	32.50	2	100	30.0-39.0	34.50	2	100
15	Santamaguluru	2	33.0-35.0	34.00	2	100	30.0-32.0	31.00	2	100
16	Martur	4	16.0-47.0	36.00	4	100	16.0-52.0	36.50	4	100
17	Yeddanapudi	2	48.0-49.0	48.50	2	100	48.0-50.0	49.00	2	100
18	Chirala	2	24.0-29.0	26.50	2	100	21.0-27.0	24.00	2	100
19	Vetapalem	3	3.0-18.0	9.00	3	100	3.0-19.0	8.67	3	100
20	Chinaganjam	3	5.0-21.0	14.33	3	100	9.0-21.0	15.66	3	100
21	Parchur	2	52.0-56.0	54.00	2	100	54.0-57.0	55.50	2	100
22	Inkollu	3	11.0-59.0	40.60	3	100	11.0-65.0	42.00	3	100
23	Karamchedu	2	50.0-56.0	53.00	2	100	44.0-57.0	50.50	2	100
24	N.G.Padu	3	20.0-57.0	36.33	3	100	16.0-44.0	29.67	3	100

Table 10 : Available Sulphur content (ppm) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Sulphur		Above critical limit		Sulphur		Above critical limit	
			Range	Mean	No.	%	Range	Mean	No.	%
1	Bollapalle	3	15-60	35	3	100	30-90	55	3	100
2	Ipuru	2	45-45	45	2	100	30-60	45	2	100
3	Nekarikallu	3	45-150	99	3	100	45-132	89	3	100
4	Vinukonda	4	72-107	102	4	100	67-95	81	4	100
5	Savalayapu	4	90-117	103	4	100	102-177	140	4	100
6	Rompicherla	3	60-90	70	3	100	45-45	45	3	100
7	Narasaraopet	3	30-90	55	3	100	45-117	79	3	100
8	Chilakaluripet	2	75-90	82	2	100	75-75	75	2	100
9	Peddanandipadu	2	102-150	126	2	100	90-117	103	2	100
10	Kakumanu	2	90-102	192	2	100	90-117	103	2	100
11	Addanki	4	60-117	95	4	100	75-102	92	4	100
12	Korisapadu	2	90-102	192	2	100	90-90	90	2	100
13	J.Panguluru	2	102-177	140	2	100	102-117	110	2	100
14	Ballikurava	2	60-75	67	2	100	60-60	60	2	100
15	Santamaguluru	2	75-90	82	2	100	75-75	75	2	100
16	Martur	4	60-102	74	4	100	45-90	60	4	100
17	Yeddanapudi	2	75-117	96	2	100	45-60	52	2	100
18	Chirala	2	117-150	133	2	100	75-102	88	2	100
19	Vetapalem	3	60-117	79	3	100	60-90	70	3	100
20	Chinaganjam	3	90-162	118	3	100	75-132	99	3	100
21	Parchur	2	90-117	103	2	100	102-132	117	2	100
22	Inkollu	3	45-117	79	3	100	45-90	65	3	100
23	Karamchedu	2	117-132	125	2	100	90-102	96	2	100
24	N.G.Padu	3	45-117	79	3	100	60-75	70	3	100

Table 11 : Available Iron content (ppm) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Iron		Below critical limit	Above critical limit	Iron		Below critical limit	Above critical limit
			Range	Mean	No.	No.	Range	Mean	No.	No.
1	Bollapalle	3	2.95-6.99	4.86	1	2	2.88-6.72	5.00	1	2
2	Ipuru	2	3.77-3.88	3.83	2	-	3.40-5.69	4.55	1	1
3	Nekarikallu	3	5.51-36.67	25.15	-	3	19.22-36.67	30.67	-	3
4	Vinukonda	2	4.37-4.63	4.50	-	2	30.47-31.94	31.21	2	-
5	Savalayapu	4	7.44-16.64	11.96	2	2	6.22-14.42	10.56	1	3
6	Rompicherla	3	4.10-7.09	6.06	3	-	3.77-3.88	3.83	1	2
7	Narasaraopet	3	3.08-11.83	7.64			3.12-28.54	13.72	3	-
8	Chilakaluripet	2	3.78-4.92	4.35	1	1	3.68-4.79	4.24	1	1
9	Peddanandipadu	2	6.68-18.12	12.40	-	2	6.23-13.84	10.14	-	2
10	Kakumanu	2	3.77-4.61	4.19	1	1	4.17-4.59	4.38	1	1
11	Addanki	4	2.76-4.12	3.48	4	-	2.51-3.83	3.02	4	-
12	Korisapadu	2	3.10-17.82	10.47	1	1	2.70-9.33	6.02	1	1
13	J.Panguluru	2	3.88-10.67	7.23	1	1	4.47-23.02	13.75	1	1
14	Ballikurava	2	4.37-4.63	4.50	1	1	3.74-5.20	4.47	1	1
15	Santamaguluru	2	20.18-21.54	20.86	-	2	17.38-22.19	19.78	-	2
16	Martur	4	4.26-32.42	14.54	1	3	3.08-11.83	7.64	1	3
17	Yeddanapudi	2	3.26-4.95	4.11	1	1	3.05-3.18	3.12	2	-
18	Chirala	2	30.47-31.94	31.21	-	2	12.69-30.5	21.59	-	2
19	Vetapalem	3	9.54-32.83	22.93	-	3	6.95-30.32	20.05	-	3
20	Chinaganjam	3	16.42-25.45	21.31	-	3	11.63-24.98	18.95	-	3
21	Parchur	2	2.02-2.52	2.27	2	-	1.64-2.47	2.05	2	-
22	Inkollu	3	3.12-28.54	13.72	1	2	3.17-23.68	11.80	1	2
23	Karamchedu	2	15.17-18.29	16.73	-	2	7.61-18.43	13.02	-	2
24	N.G.Padu	3	3.81-21.90	11.06	1	2	4.10-7.09	6.06	1	2

Table 12 : Available Zinc content (ppm) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Zinc		Below critical limit	Above critical limit	Zinc		Below critical limit	Above critical limit
			Range	Mean	No.	No.	Range	Mean	No.	No.
1	Bollapalle	3	0.21-0.40	0.27	3	-	0.25-0.36	0.29	3	-
2	Ipuru	2	0.18-0.46	0.32	2	-	0.24-0.33	0.29	2	-
3	Nekarikallu	3	0.43-1.52	0.86	2	1	0.40-0.73	0.56	3	-
4	Vinukonda	3	0.43-0.79	0.61	1	2	0.32-0.54	0.44	3	1
5	Savalayapu	4	0.32-0.46	0.39	3	1	0.56-0.67	0.62	4	-
6	Rompicherla	2	0.11-0.42	0.28	-	2	0.34-1.15	0.75	2	-
7	Narasaraopet	4	0.25-0.36	0.29	3	1	0.21-0.40	0.27	3	1
8	Chilakaluripet	2	0.53-0.54	0.54	2	-	0.33-0.35	0.34	2	-
9	Peddanandipadu	2	0.50-0.63	0.57	2	-	0.41-0.74	0.58	2	-
10	Kakumanu	2	0.27-0.30	0.29	2	-	0.26-0.30	0.28	2	-
11	Addanki	4	0.22-0.46	0.31	4	-	0.20-0.45	0.3	4	-
12	Korisapadu	2	0.32-1.06	0.69	1	1	0.34-0.39	0.37	2	-
13	J.Panguluru	2	0.34-1.15	0.75	1	1	0.29-0.79	0.54	2	-
14	Ballikurava	2	0.22-0.28	0.25	2	-	0.33-0.34	0.34	2	-
15	Santamaguluru	2	0.48-0.53	0.51	2	-	0.48-0.53	0.51	2	-
16	Martur	4	0.35-0.64	0.44	4	-	0.32-0.46	0.39	4	-
17	Yeddanapudi	2	0.44-0.66	0.55	2	-	0.28-0.44	0.36	2	-
18	Chirala	2	0.56-0.67	0.62	2	-	0.42-0.52	0.47	2	-
19	Vetapalem	3	0.71-1.95	1.52	1	2	0.22-1.32	0.73	2	1
20	Chinaganjam	3	0.36-1.05	0.72	2	1	0.19-0.48	0.32	3	-
21	Parchur	2	0.71-0.95	0.83	1	1	0.48-0.53	0.51	2	-
22	Inkollu	3	0.31-0.56	0.41	3	-	0.26-0.42	0.5	3	-
23	Karamchedu	2	1.14-1.67	1.41	-	2	0.55-0.93	0.74	1	1
24	N.G.Padu	3	0.30-0.36	0.32	3	-	0.11-0.42	0.28	3	-

Table 13 : Available Copper content (ppm) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Copper		Below critical limit	Above critical limit	Copper		Below critical limit	Above critical limit
			Range	Mean	No.	No.	Range	Mean	No.	No.
1	Bollapalle	3	0.72-1.5	1.12	-	3	0.99-1.48	1.22	-	3
2	Ipuru	2	0.52-1.09	0.81	-	2	1.08-1.11	1.09	-	2
3	Nekarikallu	3	0.56-2.29	1.62	-	3	0.67-2.04	1.43	-	3
4	Vinukonda	3	1.23-1.92	1.59	-	3	1.21-1.80	1.50	-	3
5	Savalayapu	2	1.30-1.74	1.52	-	2	1.29-1.43	1.36	-	2
6	Rompicherla	3	1.35-2.21	1.72	-	3	2.29-2.92	2.61	-	3
7	Narasaraopet	2	1.14-1.86	1.5	-	2	3.21-3.59	3.4	-	2
8	Chilakaluripet	4	1.08-1.11	1.09	-	4	0.72-1.5	1.12	-	4
9	Peddanandipadu	2	1.15-1.51	1.33	-	2	1.29-1.36	1.33	-	2
10	Kakumanu	2	1.15-1.37	1.26	-	2	1.09-1.36	1.23	-	2
11	Addanki	4	0.82-1.16	0.99	-	4	0.80-1.21	0.97	-	4
12	Korisapadu	2	1.02-1.11	1.07	-	2	1.15-1.92	1.54	-	2
13	J.Panguluru	2	1.25-2.50	1.88	-	2	1.23-2.81	2.02	-	2
14	Ballikurava	2	0.71-1.25	0.98	-	2	0.76-1.28	1.02	-	2
15	Santamaguluru	2	2.30-2.38	2.34	-	2	2.36-2.64	2.50	-	2
16	Martur	4	1.40-2.19	1.69	-	4	1.29-2.13	1.74	-	4
17	Yeddanapudi	2	1.49-1.57	1.53	-	2	1.24-1.33	1.29	-	2
18	Chirala	2	3.21-3.59	3.4	-	2	2.29-2.92	2.61	-	2
19	Vetapalem	3	0.22-0.89	0.57	-	3	0.18-1.45	0.68	-	3
20	Chinaganjam	3	1.42-2.67	2.24	-	3	1.35-2.21	1.72	-	3
21	Parchur	2	1.14-1.86	1.5	-	2	0.91-1.27	1.09	-	2
22	Inkollu	3	1.02-1.42	1.28	-	3	0.96-1.41	1.19	-	3
23	Karamchedu	2	2.27-4.36	3.32	-	2	2.37-3.37	2.87	-	2
24	N.G.Padu	3	1.02-1.83	1.35	-	3	0.89-1.29	1.06	-	3

Table 14 : Available Manganese content (ppm) of soils of Study area

S.No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Manganese		Below critical limit	Above critical limit	Manganese		Below critical limit	Above critical limit
			Range	Mean	No.	No.	Range	Mean	No.	No.
1	Bollapalle	3	19.20-47.40	29.15	-	3	27.50-60.15	39.63	-	3
2	Ipuru	5	15.96-29.91	23.44	1	4	16.01-28.23	21.64	1	4
3	Nekarikallu	2	12.90-21.35	17.13	-	2	22.90-24.80	23.85	-	2
4	Vinukonda	3	10.25-40.55	25.45	-	3	12.40-43.85	26.80	-	3
5	Savalayapu	2	30.60-36.55	33.58	-	2	22.35-30.95	26.65	-	2
6	Rompicherla	2	34.30-73.35	53.83	-	2	41.95-67.30	54.63	-	2
7	Narasaraopet	2	19.70-32.00	25.85	-	2	19.85-33.15	26.50	-	2
8	Chilakaluripet	4	26.65-32.20	29.42	1	3	10.25-40.55	25.45	1	3
9	Peddanandipadu	3	22.90-24.80	23.85	1	2	9.65-11.10	10.37	-	3
10	Kakumanu	4	14.35-17.40	15.87	-	4	10.25-40.55	25.45	-	4
11	Addanki	4	7.90-38.75	21.36	-	4	9.30-25.15	15.71	-	4
12	Korisapadu	2	17.00-33.40	25.20	-	2	19.30-21.50	20.40	-	2
13	J.Panguluru	2	22.80-36.75	29.78	-	2	24.45-27.05	25.75	-	2
14	Ballikurava	2	19.45-20.70	20.07	-	2	14.35-17.40	15.87	-	2
15	Santamaguluru	2	24.65-32.30	28.48	-	2	26.65-32.20	29.42	-	2
16	Martur	4	15.60-33.85	26.86	-	4	16.35-49.45	32.58	-	4
17	Yeddanapudi	2	23.70-34.35	29.03	-	2	18.80-22.50	20.65	-	2
18	Chirala	2	11.55-27.05	19.30	-	2	13.80-18.70	16.25	-	2
19	Vetapalem	3	2.45-6.00	3.68	1	2	0.10-10.65	4.30	1	2
20	Chinaganjam	3	5.85-8.60	6.95	-	3	4.80-6.65	5.83	-	3
21	Parchur	2	9.65-11.10	10.37	-	2	6.65-7.15	6.90	-	2
22	Inkollu	3	4:55-18.80	10.15	-	3	3.75-21.40	10.50	-	3
23	Karamchedu	2	7.25-10.40	8.83	-	2	5.40-5.90	5.65	-	2
24	N.G.Padu	3	21.95-34.9	29.28	-	3	9.55-38.60	24.80	-	3

Table 15 : Calcium Carbonate content of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Calcium carbonate		Weakly calcareous	Strongly calcareous	Cajcium carbonate		Weakly calcareous	Strongly calcareous
			Range	Mean	No.	No.	Range	Mean	No.	No.
1	Bollapalle	3	1.00-8.25	3.08	2	1	0.63-9.75	3.46	2	1
2	Ipuru	2	4.00-7.40	5.70	1	1	3.10-7.80	5.45	1	1
3	Nekarikallu	3	0.83-10.30	4.38	2	1	0.63-9.80	3.47	2	1
4	Vinukonda	4	4.90-8.90	6.53	3	1	5.30-8.89	6.64	1	3
5	Savalayapu	2	12.38-12.50	12.40	2	-	2.38-2.38	2.38	1	1
6	Rompicherla	3	11.25-12.38	11.82	3	-	12.38-12.50	12.40	1	2
7	Narasaraopet	4	7.60-8.30	5.30	2	2	4.00-7.40	5.70	2	2
8	Chilakaluripet	2	8.30-9.00	8.70	-	2	8.50-9.13	8.82	-	2
9	Peddanandipadu	2	1.20-3.63	2.42	2	-	1.00-3.63	2.32	2	-
10	Kakumanu	2	9.80-12.40	11.10	-	2	9.70-12.30	11.00	-	2
11	Addanki	4	1.13-9.50	4.91	3	1	0.38-10.00	6.16	1	3
12	Korisapadu	2	10.00-12.50	11.30		2	10.50-12.00	11.25	-	2
13	J.Panguturu	2	7.80-12.00	9.90		o	7.80-12.25	10.03	-	2
14	Ballikurava	2	10.50-12.70	11.60	-	2	11.25-12.38	11.82	-	2
15	Santamaguluru	2	12.38-12.50	12.40	-	2	12.50-12.63	12.60	-	2
16	Martur	4	0.25-11.25	4.94	2	2	0.63-11.00	5.38	2	2
17	Yeddanapudi	2	8.50-11.20	9.85	-	2	8.80-9.20	9.00	-	2
18	Chirala	2	2.38-2.38	2.38	2	-	3.50-3.50	3.50	2	-
19	Vetapalem	3	1.00-4.13	1.71	3	-	0.38-5.13	1.84	2	1
20	Chinaganjam	3	0.25-1.63	0.85	3	-	0.63-2.25	1.23	2	-
21	Parchur	2	8.80-12.00	10.40	-	2	9.80-11.90	10.90	-	2
22	Inkollu	3	5.30-6.50	3.93	1	2	7.60-8.30	5.30	1	2
23	Karamchedu	2	2.00-5.50	5.80	1	1	4.00-4.50	4.30	2	-
24	N.G.Padu	3	4.50-10.90	5.13	2	1	4.70-10.30	5.00	2	1

Table 16 : Exchangeable Magnesium content (c mol (p+) kg^{-1}) of soils of study area

S. No.	Mandal	No. of samples	SURFACE				SUB-SURFACE			
			Magnesium		Above critical limit		Magnesium		Above critical limit	
			Range	Mean	No.	%	Range	Mean	No.	%
1	Bollapalle	3	8.10-12.00	10.50	3	100	1.90-6.60	4.46	3	100
2	Ipuru	2	3.00-4.00	3.50	2	100	4.00-6.00	5.00	2	100
3	Nekarikallu	3	2.00-20.30	9.80	3	100	2.00-14.00	9.00	3	100
4	Vinukonda	4	5.31-11.22	8.17	4	100	5.95-13.03	9.61	4	100
5	Savalayapu	3	8.00-16.00	12.00	2	100	4.00-9.00	6.80	2	100
6	Rompicherla	2	27.00-30.00	28.50	2	100	5.00-13.00	10.00	2	100
7	Narasaraopet	4	3.00-9.00	6.00	4	100	3.00-4.00	3.50	4	100
8	Chilakaluripet	2	5.00-10.00	7.50	2	100	7.00-12.00	9.50	2	100
9	Peddanandipadu	2	1.00-1.00	1.00	2	100	5.00-8.00	6.50	2	100
10	Kakumanu	2	1.00-3.00	2.00	2	100	2.00-5.00	3.50	2	100
11	Addanki	4	1.00-8.00	3.80	4	100	3.00-9.00	6.50	4	100
12	Korisapadu	2	2.00-7.00	4.50	2	100	2.00-5.00	3.50	2	100
13	J.Panguluru	2	2.00-16.00	9.00	2	100	10.00-15.00	12.50	2	100
14	Ballikurava	2	2.00-5.00	3.50	2	100	2.00-4.00	3.00	2	100
15	Santamaguluru	2	4.00-6.00	5.00	2	100	3.00-9.00	6.00	2	100
16	Martur	4	4.00-9.00	6.80	4	100	2.00-6.00	4.50	4	100
17	Yeddanapudi	2	2.00-9.00	5.50	2	100	6.00-7.00	6.50	2	100
18	Chirala	2	26.00-32.00	29,00	2	100	23.00-42.00	32.50	2	100
19	Vetapalem	3	1.00-7.00	3.30	3	100	2.00-7.00	5.00	3	100
20	Chinaganjam	3	5.00-13.00	10.00	3	100	8.00-15.00	10.60	3	100
21	Parch ur	2	6.00-10.00	8.00	2	100	8.00-16.00	12.00	2	100
22	Inkollu	3	3.00-16.00	7.70	3	100	1.00-18.00	10.00	3	100
23	Karamchedu	2	27.00-30.00	28.50	2	100	19.00-46,00	32.50	2	100
24	N.G.Padu	3	1.00-6.00	4.50	3	100	8.00-10.00	9.06	3	100

Table 17 : Chemical composition of under ground waters of study area

S.No	Mandal	No. of sample	EC (dS/m)		pH		SAR		RSC (me/l)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	16	0.72-8.48	3.94	6.96-7.92	7.40	1.48-8.99	5.58	Nil-5.80	0.42
2	Ipuru	10	0.75-3.76	1.99	7.04-8.15	7.51	1.79-11.19	7.06	Nil-10.40	2.58
3	Nekarikallu	15	0.58-3.54	2.08	7.20-7.86	7.55	0.91-5.58	3.96	Nil-0.20	0.02
4	Vinukonda	13	0.84-3.77	1.39	7.21-8.67	7.95	1.04-11.39	3.71	Nil-10.40	1.03
5	Savalayapu	11	1.83-5.16	2.67	7.08-7.98	7.47	3.21-11.02	7.58	Nil-10.00	3.21
6	Rompicherla	14	0.62-4.16	1.69	7.21-8.82	7.87	1.48-9.64	3.92	Nil-9.00	0.98
7	Narasaraopet	12	0.75-5.12	3.24	7.19-8.79	8.11	1.70-15.6	6.66	Nil-4.40	1.44
8	Chilakaluripet	15	0.97-6.23	2.65	6.53-7.95	7.31	3.49-11.41	6.60	Nil-2.60	0.31
9	Peddanandipadu	10	0.75-3.76	1.99	6.98-8.49	7.76	3.21-11.02	7.58	Nil-10.00	3.21
10	Kakumanu	8	1.22-6.52	2.43	6.53-7.95	7.31	1.28-8.81	4.47	Nil-5.40	1.68
11	Addanki	17	1.39-18.75	3.19	6.96-8.17	7.39	1.92-15.2	4.88	Nil-10.80	1.71
12	Korisapadu	9	1.43-7.35	2.70	7.19-8.79	8.11	2.45-13.25	8.86	Nil-11.60	4.89
13	J.Panguluru	9	0.97-6.23	2.65	7.98-8.83	8.41	2.23-8.0	5.16	Nil-2.00	0.31
14	Ballikurava	11	1.27-4.31	2.44	8.06-8.76	8.45	2.12-12.33	6.87	Nil-12.20	2.92
15	Santamaguiuru	11	1.28-4.72	2.36	7.97-8.72	8.39	1.70-15.6	6.66	Nil-8.00	2.00
16	Martur	11	1.20-4.20	2.38	7.75-8.69	8.31	1.28-8.81	4.47	Nil-4.60	0.75
17	Yeddanapudi	8	1.32-5.78	2.59	8.10-8.75	8.57	3.63-9.52	6.40	Nil-5.40	1.68
18	Chirala	13	1.12-3.35	2.22	6.98-8.49	7.76	3.35-7.39	5.58	Nil-2.60	0.31
19	Vetapalem	17	0.75-5.12	3.24	6.87-8.45	7.75	1.75-9.89	6.26	Nil-0.20	0.02
20	Chinaganjam	10	0.59-18.86	3.96	6.53-7.95	7.31	1.94-8.29	4.57	Nil-0.00	Nil
21	Parchur	12	0.59-5.52	2.43	7.06-8.08	7.64	1.52-8.32	4.42	Nil-2.00	0.23
22	Inkollu	10	1.22-6.52	2.43	7.23-7.89	7.56	3.49-11.41	6.60	Nil-4.40	1.44
23	Karamchedu	12	0.63-6.52	2.38	7.22-8.76	7.74	2.77-7.21	5.11	Nil-Nil	Nil
24	N.G.Padu	21	1.20-17.6	4.39	6.94-8.30	7.57	3.06-25.3	9.57	Nil-13.80	3.36

Table 18 : Classification of ground water of study area

S. No	Mandal	No. of samples	pH			EC (dS/m)				SAR				RSC (me/I)			
			Acidic	Neutral	Alkaline	C1	C2	C3	C4	S1	S2	S3	S4	A1	A2	A3	A4
			<6.5	6.5-7.5	>7.5	0.2-	1.5-3.0	3.0-5.0	5.0-	<10	10-18	18-26	>26	<2.5	2.5-5.0	5-10	>10
1	Bollapalle	16		11	5	3	2	6	5	16	-	-	-	15	-	1	-
2	Ipuru	10	-	7	3	3	6	1	-	9	1	-	-	6	2	1	1
3	Nekarikallu	15	_	5	10	4	9	2	-	15	-	-	-	15	-	-	-
4	Vinukonda	13	-	2	11	11	1	1	-	12	1	-	-	13	-	-	-
5	Savalayapu	11	-	6	5	-	9'	1	1	9	2	-	-	6	2	3	-
6	Rompicherla	14	-	2	12	10	2	2	-	14	-	-	-	13	-	1	-
7	Narasaraopet	15	-	4	11	9	4	2	-	13	2	-	-	14		1	
8	Chilakaluripet	16	-	7	9	4	10	2	-	15	1	-	-	13	2	1	-
9	Peddanandipadu	8	-	2	6	1	6	1	1	7	1	-	-	7	-	1	-
10	Kakumanu	10	-	2	8	5	3	2	-	9	1	-	-	8	-	2	
11	Addanki	17	-	12	5	3	9	4	1	15	2	-	-	14	1	-	2
1?	Korisapadu	9	-	2	7	1	7	-	1	4	5	-	-	3	2	3	1
13	J.Panguluru	9		_	9	4	1	3	1	9	-	-	-	9	-	-	-
14	Ballikurava	11	-	-	11	2	6	3	-	9	2	-	-	7	2	1	1
15	Santamaguluru	11		-	11	3	6	2	-	10	1	-	-	7	3	1	-
16	Martur	11	-	-	11	1	6	4	-	11	-	-	-	9	2	_	-
17	Yeddanapudi	8	-	-	8	2	5	-	1	8	-	-	-	6	2	-	
18	Chirala	13	-	4	9	4	8	1	-	13	-	-	-	12	1	-	-
19	Vetapalem	17	-	6	11	2	4	10	1	17	-	-	-	17	-	-	-
20	Chinaganjam	10		9	1	2	4	3	1	10	-	-	-	10	-	-	-
21	Parchur	12	-	5	7	4	5	2	1	12	-	-	-	12	-	-	-
22	Inkollu	10	-	3	7	2	6	2	-	9	1	-	-	7	3	-	-
23	Karamchedu	12		3	9	2	8	1	1	12	-	-	-	12	-	-	-
24	N.G.Padu	21	-	9	12	1	11	1	8	16	4	1	-	12	2	6	1

Table 19 : Quality ratings of ground water samples of study area

S. No	Mandal	No. of samples	Good		Saline						Alkali					
					Marginally		Saline		High SAR		Marginal		Alkali		High alkali	
			No	%	No	%	No	%	No	%	No	%	No	%	No	%
1	Bollapalle	16	3	18.17	7	43.75	6	37.50	-	-	-	-	-	-	-	-
2	Ipuru	10	3	30.00	4	40.00	-	-	-	-	1	10.00	2	20.00	-	-
3	Nekarikallu	15	5	33.33	10	66.66	-	-	-	-	-	-	-	-	-	-
4	Vinukonda	13	11	84.62	1	9.09	-	-	-	-	-	-	-	-	1	9.091
5	Savalayapu	11	1	9.09	5	45.45	1	9.09	-	-	-	-	1	9.09	3	27.27
6	Rompicherla	14	10	71.42	2	14.29	1	7.14	-	-	-	-	1	7.14	-	-
7	Narasaraopet	12	8	66.66	2	16.66	1	8.33	-	-	1	8.33	-	-	-	-
8	Chilakaluripet	15	5	33.33	8	53.33	-	-	1	-	-	-	1	6.66	-	-
9	Peddanandipadu	8	3	37.50	3	37.5	-	-	-	-	-	-	2	25	-	-
10	Kakumanu	16	12	75.00	2	12.5	1	-	-	-	-	-	1	6.25	-	
11	Addanki	17	8	47.06	5	29.41	1	5.89	-	-	-	-	1	5.89	2	11.76
12	Korisapadu	9	-	-	2	22.22	1	11.11	-	-	1	11.11	-	-	5	55.55
13	J.Panguluru	9	5	55.55	2	22.22	2	22.22	-	-	-	_	-		-	-
14	Ballikurava	11	3	27.27	3	27.27	1	9.09	-	-	-	-	2	18.18	2	18.18
15	Santamagulur	11	2	18.18	4	36.36	2	18.18	-	-	1	9.09	1	9.09	1	9.09
16	Martur	11	5	45.45	4	36.36	1	9.09	-	-	1	9.09	-	-	-	-
17	Yeddanapudi	8	3	37.50	2	25.00	1	33.33	-	-	1	33.33	1	33.33	-	-
18	Chirala	13	4	30.77	9	69.23	-	-	-	-	-	-	-	-	-	-
19	Vetapalem	17	2	11.76	10	58.82	5	29.41	-	-	-	-	-	-	-	-
20	Chinaganjam	10	5	50.00	4	40.00	1	10.00	-	-	-	-	-	-	-	-
21	Parchur	12	5 -	41.67	5	41.67	2	16.67	-	-	-	-	-	-	-	-
22	Inkollu	10	3	30.00	6	60.00	-	-	-	-	1	10.00	-	-	-	-
23	Karamchedu	12	8	66.66	2	16.66	2	16.66	-	-	-	-	-	-	-	-
24	N.G.Padu	21	1	4.77	3	14.28	6	28.57	2	9.52	1	4.76	3	14.29	5	23.81

Table 20 : Different anions compositions in ground water of study area

S. No.	Mandal	No. of samples	Carbonates (me/I)		Bicarbonates		Chlorides (me/I)		Sulphates (me/I)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	16	0.6-4.4	3.47	2.6-14.8	7.94	4.6-68.8	27.90	0.32-3.67	1.75
2	Ipuru	10	0.8-4.4	2.12	2.4-11.4	6.48	5.2-2.2	10.84	0.46-1.54	0.96
3	Nekarikallu	15	0.0-4.0	2.19	2.0-6.6	4.44	3.4-25.0	12.49	0.44-4.28	1.65
4	Vinukonda	13	0.0-1.2	0.56	3.6-12.8	6.34	4.8-22.4	7.38	0.27-1.17	0.47
5	Savalayapu	11	0.0-2.4	1.20	4.8-12.8	9.69	6.8-36.0	14.45	0.54-3.09	1.27
6	Rompicherla	14	0.0-2.0	0.20	3.4-13.2	6.11	4.8-32.8	10.88	0.06-2.53	0.64
7	Narasaraopet	15	0.4-0.6	0.50	2.0-12.8	7.73	5.2-2.2	10.84	0.46-1.54	0.96
8	Chilakaluripet	13	0.8-4.9	2.85	2.4-14.2	5.92	1.8-32.6	14.89	0.31-4.12	1.57
9	Peddanandipadu	10	0.5-4.2	2.35	6.4-11.0	8.13	2.4-166.0	31.42	0.21-7.50	1,83
10	Kakumanu	9	0.2-2.4	1.3	2.8-13.8	6.23	6.2-19.6	14.95	0.39-5.39	1.51
11	Addanki	17	0.0-2.4	0.61	6.8-11.6	8.78	5.2-33.6	12.14	0.29-1.71	0.78
12	Korisapadu	9	0.0-2.0	0.97	5.2-13.6	10.16	5.2-54.0	14.50	0.37-4.60	1.52
13	J.Panguluru	9	0.0-2.4	0.84	4.0-11.8	8.13	5.6-44.8	16.60	0.59-4.12	1.40
14	Ballikurava	11	0.0-2.4	0.95	6.4-14.6	10.22	6.0-27.6	12.97	0.45-2.36	1.18
15	Santamaguluru	11	0.0-2.0	0.33	6.4-11.0	8.13	6.0-32.4	14.36	0.73-3.36	1.59
16	Martur	11	0.0-2.0	0.89	6.0-12.4	8.27	6.4-30.0	13.02	0.76-3.65	1.45
17	Yeddanapudi	8	0.0-2.4	1.43	6.0-11.2	8.10	6.2-19.6	14.95	0.48-4.83	2.13
18	Chirala	13	0.0-2.8	0.85	5.0-8.8	6.83	6.4-19.2	12.83	0.31-4.12	1.57
19	Vetapalem	17	0.0-2.2	0.79	2.0-12.8	7.73	4.8-40.2	21.56	0.54-7.55	2.14
20	Chinaganjam	10	0.0-3.2	0.78	2.0-14.4	6.90	3.6-65.8	20.22	0.39-5.39	1.51
21	Parchur	12	0.0-2.0	0.56	2.8-13.8	6.23	1.8-32.6	14.89	0.32-11.58	2.48
22	Inkollu	10	0.0-2.6	1.18	3.2-12.6	7.53	8.2-28.2	14.26	0.68-2.09	1.45
23	Karamchedu	12	0.0-2.8	1.18	2.4-14.2	5.92	3.8-48.8	15.63	0.21-7.50	1,83
24	N.G.Padu	21	0.0-5.6	2.86	4.6-19.2	8.63	2.4-166.0	31.42	0.31-4.86	1.38

Table 21 : Fluorides, Nitrates and Micro nutrient composition of ground waters of study area

S.No.	Mandal	No. of samples	F (mg l^{-1})		NO_3-N (mg l^{-1})		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	16	0.52-2.42	1.120	8.20-14.40	9.950	0-0.13	0.020	0-3.24	0.230	0-0.02	0.005	0-0.05	0.030
2	Ipuru	10	0.63-1.22	0.890	0-9.18	5.320	0-0.05	0.012	0-0	0.000	0-0	0.000	0-0.03	0.004
3	Nekarikallu	15	0.64-1.28	0.920	6.50-10.20	8.250	0-0.07	0.005	0-0.22	0.220	0-0.08	0.013	0-0.02	0.004
4	Vinukonda	9	0.22-2.82	1.130	0-9.20	5.720	0-0.18	0.070	0-0.02	0.004	0-0.04	0.016	0-0.04	0.014
5	Savalayapu	15	0.54-1.82	1.050	0-10.63	7.850	0-0.37	0.093	0-0.62	0.058	0-0.01	0.003	0-0.05	0.010
6	Rompicherla	12	0.32-2.42	1.160	0-10.42	3.030	0-0.21	0.070	0-0.11	0.030	0-0.16	0.031	0-0.15	0.030
7	Narasaraopet	11	0.18-1.12	0.580	0-9.38	7.380	0-0.35	0.070	0-0.12	0.020	0-0.07	0.010	0-0.03	0.004
8	Chilakaluripet	13	0.78-2.26	1.380	0-6.82	3.960	0.02-0.21	0.120	0-0.08	0.020	0-0.07	0.010	0-0.02	0.005
9	Peddanandipau	11	0.52-1.58	1.010	2.90-9.32	7.320	0.01-0.21	0.090	0-008.	0.030	0-0.02	0.006	0-0.04	0.010
10	Kakumanu	14	0.68-1.54	1.000	7.01-9.46	8.370	0.04-0.24	0.110	0-0.13	0.040	0-0.06	0.012	0-0.03	0.009
11	Addanki	17	0.65-1.25	0.890	8.19-11.21	9.230	0-0.63	0.130	0-0.08	0.013	0-0.07	0.020	0-0.03	0.010
12	Korisapadu	9	0.22-2.82	1.130	0-9.20	5.720	0-0.28	0.110	0-0.02	0.004	0-0.04	0.016	0-0.05	0.014
13	J.Panguluru	9	0.45-1.98	1.040	0-9.80	6.930	0-0.22	0.096	0-0.02	0.003	0-0.09	0.012	0-0.02	0.006
14	Ballikurava	11	0.45-2.08	1.150	2.36-9.68	7.390	0-0.18	0.070	0-0.04	0.011	0-0.03	0.005	0-0.03	0.005
15	Santamaguluru	11	0.05-1.52	0.860	0-10.30	5.850	0-0.19	0.039	0-0.06	0.009	0-0.14	0.013	0-0.04	0.014
16	Martur	11	0.65-1.26	0.890	5.66-10.50	8.300	0-0.31	0.080	0-0.14	0.031	0-0.08	0.016	0-0.03	0.008
17	Yeddanapudi	8	0.54-1.82	1.050	0-9.38	7.380	0-0.37	0.093	0-0.00	0.000	0-0.01	0.003	0-0.05	0.013
18	Chirala	13	0.06-1.08	0.510	0-12.06	8.360	0-0.24	0.058	0-0.12	0.020	0-0.09	0.030	0-0.05	0.011
19	Vetapalem	17	0.18-1.12	0.700	0-10.63	7.850	0-0.42	0.072	0-0.62	0.058	0-0.16	0.024	0-0.05	0.011
20	Chinaganjam	10	0.18-1.12	0.580	0-9.61	8.360	0-0.17	0.055	0-0.29	0.038	0-0.05	0.009	0-0.04	0.004
21	Parchur	12	0.11-1.02	0.630	0-9.57	7.100	0-1.32	0.160	0-0.13	0.033	0-0.16	0.031	0-0.11	0.020
22	Inkollu	10	0.08-0.94	0.640	4.83-10.68	8.300	0-0.21	0.070	0-0.08	0.030	0-0.01	0.006	0.0-0.0	0.000
23	Karamchedu	12	0.06-0.82	0.360	0-10.42	3.030	0-0.32	0.130	0-0.08	0.020	0-0.07	0.010	0-0.05	0.010
24	N.G.Padu	21	0.32-2.42	1.160	1.18-10.50	6.820	0-0.35	0.070	0-0.11	0.030	0-2.74	0.310	0-0.15	0.030

Table 22 : Classification of ground water based on fluorides and nitrates of study area

S.No	Name of mandal	No. of samples	Fluorides (mq I^{-1})			Nitrates (mg I^{-1})		
			Safe	Moderately safe	Unsafe	Safe	Moderately safe	Unsafe
			<1	1-5	>5	<5	5-30	>30
1	Bollapalle	16	10	6		-	16	-
2	Ipuru	10	7	3	-	4	6	-
3	Nekarikallu	15	11	4	-	-	15	-
4	Vinukonda	12	10	2	-	2	10	-
5	Savalayapu	15	14	1	-	3	12	-
6	Rompicherla	19	13	6	-	5	14	-
7	Narasaraopet	10	8	2	-	7	3	-
8	Chilakaluripet	13	4	9	-	6	7	-
9	Peddanandipadu	11	6	5	-	3	8	-
10	Kakumanu	14	8	6	-	-	14	-
11	Addanki	17	12	5	-	-	17	-
12	Korisapadu	9	6	3	-	3	6	-
13	J.Panquluru	9	5	4	-	2	7	
14	Ballikurava	11	5	6	-	3	8	-
15	Santamaguluru	11	8	3	-	4	7	–
16	Martur	11	8	3	–	-	11	
17	Yeddanapudi	8	6	2		1	7	-
18	Chiraia	13	12	1	-	1	12	-
19	Vetapalem	17	15	2	-	2	15	-
20	Chinaganjam	10	8	2	-	1	9	–
21	Parchur	12	11	1	-	2	10	–
22	Inkollu	10	10	-	-	2	8	-
23	Karamchedu	12	12	-	-	8	4	-
24	N.G.Padu	21	11	10	-	6	15	-

Table 23 :Mean values of different Ionic ratios of ground water of study area

S.NO	Mandal	No. of sample	Ca/Mg		Ca/Na		Mg/Na		Ca/SO4		Mg/HCO3	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	16	0.42-2.11	1.00	0.17-3.41	0.85	0.28-4.82	0.99	1.68-11.52	4.95	0.35-3.34	1.08
2	Ipuru	10	0.67-4.67	6.00	0.08-0.92	0.36	0.09-0.76	0.28	0.87-6.96	4.19	0.14-1.11	0.50
3	Nekarikallu	15	1.26-5.33	2.15	0.52-1.85	0.86	0.18-1.23	0.44	1.45-7,73	5.48	0.55-1.54	0.79
4	Vinukonda	10	0.81-3,09	1.87	0.04-0.82	0.54	0,05-1.28	0.54	0.75-8.77	3.51	0.18-1.26	0.65
5	Savalayapu	12	0.69-4.00	2.25	0.24-1.10	0.44	0.22-1.35	0.62	0.49-16.3	5.17	0.08-1.92	0.74
6	Rompicherla	11	0.47-3.67	1.27	0.26-2.96	0.66	0.15-0.59	0.28	0.84-12.20	3.68	0.35-1.23	0.65
7	Narasaraopet	9	0.61-7.50	1.97	0.18-4.29	1.02	0.06-0.92	0.38	1.77-6.82	3.71	0.12-1.50	0.52
8	Chilakaluripet	13	0.21-2.0	1.16	0.04-2.06	0.95	0.17-2.82	0.87	0.77-16.3	8.10	0.18-1.11	0.50
9	Peddanandipadu	11	0.41-2.0	0.39	0.06-1.18	0.41	0.11-1.16	0.45	1.65-5.94	3.51	0.16-1.09	0.56
10	Kakumanu	14	0.33-11.5	2.28	0.19-4.6	0.94	0.09-1.82	0.65	1.34-230	27.03	0.15-1.29	0.64
11	Addanki	17	0.04-23.5	2.89	0.03-1.8	0.80	0,05-1.28	0.54	0,82-21.36	10.27	0.05-1.86	0.59
12	Korisapadu	9	0.23-2.36	0.98	0.04-2.0	0.49	0.12-1,21	0.39	0.95-11.64	3.46	0.15-1.39	0.50
13	J.Panguluru	9	0.33-2.29	1.18	0.07-1.21	0.58	0.17-1.56	0.51	0.24-11.43	4.29	0.19-1.18	0.46
14	Ballikurava	11	0.33-2.77	0.94	0.05-1.53	0.43	0.15-0.79	0.40	0.84-12.20	3.68	0.18-0.92	0.43
15	Santamaguluru	11	0.61-4.25	1.62	0.06-1.64	0.54	0.06-0.92	0.38	0.75-8.77	3.51	0.12-1.50	0.52
16	Martur	11	0.49-3.83	1.35	0.21-2.97	0.86.	0.22-1.35	0.62	1.42-10.0	5.07	0.35-1.23	0.65
17	Yeddanapudi	8	0.27-2.08	0.76	0.05-0.53	0.26	0.17-0.48	0.34	0.25-7.08	2.22	0.25-0.66	0.45
18	Chirala	13	1.07-3.80	2.23	0.04-0.82	0.54	0.15-0.63	0.26	2.33-5.59	4.20	0.19-0.92	0.45
19	Vetapalem	17	0.81-3,09	1.87	0.31-2.83	0.89	0.16-1.54	0.53	0.49-16.3	5.17	0.18-1.26	0.65
20	Chinaganjam	10	0.69-4.00	2.25	0.41-1.38	0.87	0.21-1.69	0.50	3.49-11.4	6.63	0.3-1.89	0,65
21	Parchur	12	0.78-2.80	1.45	0.18-4.29	1.02	0.16-2.70	0.73	0.93-6.94	4.37	0.31-1.30	0.69
22	Inkollu	10	0.61-7.50	1.97	0.24-1.10	0.44	0.15-0.59	0.28	1.77-6.82	3.71	0.21-0.92	0.41
23	Karamchedu	12	0.47-3.67	1.27	0.26-2.96	0.66	0.22-1.88	0.59	0.75-12.59	5.24	0.3-1.57	0.59
24	N.G.Padu	21	0.5-2.31	1.22	0.06-2.51	0.74	0.06-1.84	0.59	0.99-21.13	6.80	0.08-1.92	0.74

Table 24 : Mean values of different Ionic ratios of ground water of study area

S..No.	Mandal	No. of sample	Cl/HCO_3		SCl/HCOa		HCO3/SO_4		HCO3/Cl		Cl/SO4	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Bollapalle	16	0.79-8.70	3.54	0.08-0.46	0.21	2.17-12.78	6.59	0.11-1.26	0.46	8.84-30.32	16.81
2	Ipuru	10	0.69-4.67	1.99	0.10-0.41	0.17	2.43-10.43	7.31	0.21-1.45	0.70	5.51-17.78	11.71
3	Nekarikallu	15	1.57-4.58	2.68	0.14-10.7	0.38	0.93-7.27	4.04	0.22-0.64	0.40	2.45-15.73	9.76
4	Vinukonda	12	0.78-7.30	2.46	0.07-0.62	0.20	2.81-19.44	8.95	0.22-2.04	0.70	4.71-40.69	16.35
5	Savalayapu	8	0.50-4.22	1.31	0.08-0.36	0.16	5.08-24.36	10.85	0.08-1.41	0.69	2.35-56.25	24.88
6	Rompicherla	10	1.57-8.83	3.82	0.09-0,26	0.17	0.35-15.00	6.05	0.08-1.41	0.69	5.17-43.33	20.75
7	Narasaraopet	11	0.79-6,07	3.40	0.03-1.22	0.21	2.38-7.14	4.81	0.27-1.09	0.68	0.25-40.00	12.72
8	Chilakalurpet	13	0.46-1.84	1.12	0.05-0.10	0.07	10.43-20.74	15.10	0.54-2.19	1.00	8.73-23.70	16.47
9	Peddanandipadu	11	0.59-3.40	1.48	0.05-0.45	0.15	2.22-21.48	10.13	0.29-1.71	0.84	4.07-16.32	12.12
10	Kakumanu	14	0.52-5.16	1.82	0.02-0.39	0.11	2.56-63.33	23.11	0.19-1.94	0.81	8.89-86.70	28.13
11	Addanki	17	0.52-2.68	1.31	0.03-0.17	0.08	6.03-31.03	14.40	0.37-1.93	0.95	8.53-30.14	16.69
12	Korisapadu	9	0.50-4.22	1.31	0.05-0.54	0.16	1.84-20.73	11.76	0.24-2.00	1.10	2.88-16.73	10.61
13	J.Panguluru	9	0.31-3.93	1.65	0.08-0.36	0.16	2.77-12.88	8.27	0.25-1.41	0.82	2.69-34.29	12.61
14	Ballikurava	11	0.48-2.58	1.27	0.04-0.20	0.12	5.08-24.36	10.85	0.39-2.09	0.99	6.06-15.58	11.24
15	Santamaguluru	11	0.79-5.07	1.97	0.10-0.56	0.21	1.79-9.74	5.84	0.20-1.27	0.75	3.71-17.80	9.11
16	Martur	11	0.71-12.77	2.51	0.08-0.29	0.17	3.4-12.63	6.81	0.08-1.41	0.69	5.57-48.45	13.82
17	Yeddanapudi	8	0.91-3.75	1.78	0.05-0.55	0.25	1.82-20.00	6.16	0.27-1.09	0.68	2.57-32.50	10.48
18	Chirala	13	1.23-2.53	1.83	0.14-0.42	0.23	2.38-7.14	4.81	0.40-0.81	0.57	4.56-11.90	8.54
19	Vetapalem	17	0.08-6.48	2.64	0.05-0.59	0.27	1.70-19.63	4.87	0.15-12.94	1.08	0.25-40.00	12.72
20	Chinaganjam	10	1.57-8.83	3.82	0.09-0.37	0.20	2.67-11.19	6.01	0.11-0.64	0.38	6.17-38.14	19.28
21	Parchur	12	1.49-8,57	4.48	0.07-2.90	0.44	0.35-15.00	6.05	0.12-0.67	0.30	2.35-56.25	24.88
22	Inkollu	10	0.79-6,07	3.40	0.09-0,26	0.17	3.79-11.34	6.66	0,16-1.26	0.47	5.17-43.33	20.75
23	Karamchedu	12	1.15-15.83	4.19	0.04-1.08	0.23	0.93-25.71	9.61	0.06-0.87	0.39	2.29-140.74	36.39
24	N.G.Padu	21	0.31-34.58	4.50	0.03-1.22	0.21	0.82-31.35	10.57	0.03-3.25	0.70	2.87-97.36	24.79

9.14 SOILS

There are nine types of soils existing in study area, Out of these nine soil types the problematic soils are sandy soils of Chirala, Vetapalem and Kothapatnam, Deltoic calcareous black soils of Parchur, Yeddanapudi, Martur, Inkollu, J.Panguluru, Korisapadu, N.G.Padu, Ongole and Kothapatnam, Saline sodic soils of Chirala, Vetapalem, Chinaganjam, Ongole and Kothapatnam and Swamp and marshy soils of Kothapatnam and Chinaganjam mandals respectively, soil types are represented in Table 25.

9.15 FARMING SITUATION IN ONGOLE DIVISION

In entire Guntur and Prakasam district, there exist eight types of farming situations. In Ongole division seven types of farming situations exist, Out of eight farming situations the FS3 was absent in Ongole division i.e., Heavy soils-irrigated-Tank fed farming situation. FS1 was existing in almost all the mandals of Ongole division i.e., Heavy soils-irrigated-canal type, and it occupies around 60 percent of the total. FS2 was seen in Chimakurthy, Maddipadu, S.N.Padu, Addanki, J.Panguluru and Karamchedu mandals i.e.,

Light soils-irrigated-Canal type and it occupies around 2 percent of the total. FS4 was found in N.G.Padu, Chirala, Vetapalem and Chinaganjam mandals i.e., Light soils-irrigated-Tank fed/wells and Bore wells and it occupies 1 per cent of the total farming situations area. FS5 was seen in N.G.Padu, Chirala, Vetapalem and Chinnaganjam mandals i.e., Sandy soils-Lift irrigation on KWD canal and it occupies about 6 percent of the total area. FS6 was seen in Kothapatnam, N.G.Padu, Chirala, Vetapalem and Chinaganjam mandals i.e., Coastal sands-irrigated-Filter points/Doruvu system and it occupies around 4 percent. FS7 was found in all mandals except Maddipadu, J.Panguluru, Chirala, Vetapalem and Chinaganjam mandals i.e., Heavy soils-Rainfed situation and it occupies around 25 percent. FS8 was seen only in Chimakurthy mandal i.e., Light soils-Rainfed situation and it occupies around 0.5 percent, Farming situation are represented in Table 26.

Table 25: Soils of Study Area

S. No.	Type of Soil	Mandals
1	Red shallow calcarious gravelly loam	Chinaganjam, Kothapatnam, Santamaguluru
2	Red Shallow gravelly clay	Santamaguluru
3	Red Calcareous Clayey soils	Santamaguluru, Ballikurava, Addanki, Chimakurthy
4	Sandy soils	Chirala, Vetapalem, Kothapatnam
5	Red Clayey Soils	Inkollu, Martur, J.Panguluru, Korisapadu, Tangutur
6	Deltoic calcarious black soils	Parchur, Yeddanapudi, Martur, Inkollu, J.Panguluru, Korisapadu, N.G.Padu, Ongole, Kothapatnam
7	Alluvial soils	Vetapalem, Chirala, Chinaganjam,N.G.Padu, Korisapadu
8	Saline sodic soils	Chirala, Vetapalem, Chinaganjam, Ongole, Kothapatnam
9	Swamp & Marshy soils	Kothapatnam, Chinaganjam

Table 26: Farming situation in study area

S.No.	Farming Situation	Mandals
FS1	Heavy soils - Irrigated -Canal	Ongole, Tangutur, Kothapatnam, N.G.Padu, Chimakurthy, Maddipadu, S.N.Padu, Addanki, Korisapadu, J.Panguluru, Ballikurava, Santamaguluru, Martur, Yeddanapudi, Chirala, Vetapalem, Chinaganjam, Parchur, Inkollu and Karamchedu.
FS2	Light soils - Irrigated - Canal	Chimakurthy, Maddipadu, S.N.Padu, Addanki, J.Panguluru and Karamchedu.
FS3	Heavy soils - Irrigated - Tankfed	NIL
FS4	Light soils - Irrigated - Tankfed/Wells and Bore Wells	Chimakurthy, Santamaguluru
FS5	Sandy soils - Lift Irrigation on KWD Canal	N.G.Padu, Chirala, Vetapalem and Chinaganjam.
FS6	Coastal sands - Irrigated -Filter Points/Doruvu system	Kothapatnam, N.G.Padu, Chirala, Chinaganjam and Vetapalem
FS7	Heavy soils - Rainfed	Ongole, Tangutur, Kothapatnam, N.G.Padu, Chimakurthy, S.N.Padu, Addanki, Korisapadu, Ballikurava, Santamaguluru, Martur, Yeddanapudi, Parchur, Inkollu and Karamchedu
FS8	Light soils - Rainfed	Chimakurthy

9.16 CONSTRAINTS FOR SOIL AND WATER QUALITY IN ONGOLE DIVISION

Based on the rating charts as mentioned in tables 3 to 6 and also based on the physical, chemical and physico-chemical properties of soil and waters the constraints for soil and water quality are presented in the Table 27.

9.17 EXISTING AND SUGGESTED CROP PLAN IN MANDALS OF ONGOLE DIVISION

By taking the constraints for soil and water quality in Ongole division and also by considering the existing crops in these mandals an alternate crop plan was suggested. The existing and suggested crops were presented in Table 28.

Table 27 : Constraints for soil and water quality in the study area

S. No.	MANDAL	SOIL	WATER
1.	Bollapalle	-alkaline	-marginally saline water
		-low available	-Na^+ and Cl^- were dominant
		nitrogen	-NO_3 -N content was
		-low organic carbon	moderately safe for irrigation
		-zinc deficiency	
2.	Ipuru	-moderately alkaline	-marginally saline water
		-low organic carbon	-based on RSC these water
		-low available	*are* marginally alkali
		nitrogen	
		-medium K and P	
		-Iron deficiency	
		-zinc deficiency	
3.	Nekarikallu	-medium saline	-EC of ground water is 2.08
		-medium organic	dS m^{-1} (67 per cent of waters
		carbon	are marginally saline)
		-sandy soils	
		-low available N	
		-zinc deficiency	
4.	N.G.Padu	-moderately alkaline	-EC of ground water is 4.39
		-high saline	dS m^{-1}(30 per cent of
		-low organic carbon	samples are saline)
		-low available N	-very high RSC (9.57 me l^{-1})
		-zinc deficiency	-F and NO_3-N were
			moderately safe for irrigation
5.	Vinukonda	-mildly alkaline	- F content was moderately
		-mediujm saline	safe for irrigation
		-medium organic	
		Carbon, deficiency	
		-low available N	
		-iron and zinc	

Contd...

6.	Savalayapu	-moderately alkaline	-EC of ground water is 2.67
		-low organic carbon	dS m^{-1} (45 per cent of
		-low available N	samples are marginally
		-zinc deficiency	saline)
			-NO3-N was moderately safe
			for irrigation
7.	Narasaraopet	-moderately alkaline	- NO3-N was moderately safe
		-low organic carbon	for irrigation
		-strongly calcareous	
		-low available N	
		-zinc deficiency	
8.	Addanki	-moderately alkaline	-EC of ground water was 3.19
		-medium saline	dS m^{-1}(30 per cent of
		-low organic carbon	samples are marginally
		-low available N	saline)
		-iron and zinc	- NO3-N was moderately safe
		deficiency	for irrigation
9.	Korisapadu	-mildly alkaline	-RSC was 4.89 me l^{-1}(56 per
		-medium saline	cent of samples were high
		-low organic carbon	alkali waters)
		-low available N	-NO3-N was moderately safe
		-medium in iron and	for irrigation
		zinc status	
10.	J.Panguluru	-moderately alkaline	- NO3-N was moderately safe
		-medium saline	for irrigation
		-low available N	
		-strongly calcareous	
11.	Ballikurava	-moderately alkaline	-EC of ground water is 2.44
		-low organic carbon	dS m^{-1} (28 per cent of
		-low available N	samples are marginally
		-medium in K	saline)

Contd...

12.	Santamaguluru	-moderately alkaline	-EC of ground water is 2.36
		-strongly calcareous	dS m"¹ (36 per cent of
		-low available N	samples are marginally
		-zinc deficient	saline)
13.	Martur	-moderately alkaline	-NO_3-N ranges between 5-30
		-low organic carbon	mg l"¹ and it is moderately
		-low available N	safe for irrigation
		-zinc deficient	
14.	Yeddanapudi	-moderately alkaline	- NO3-N was moderately safe
		-medium saline	for irrigation"
		-low organic carbon	
		-low available N	
		-zinc deficient	
15.	Chirala	-mildly alkaline	-EC of ground water was 2.22
		-high saline	dS m"¹ (70 percent of
		-loamy sands	samples are marginally
		-low available N	saline)
		-zinc deficient	
16.	Vetapalem	-medium saline	-EC of ground water was 3.24
		-sandy soils	dS m"¹ (59 per cent of
		-low organic carbon	samples are marginally
		-low available N	saline)
		-low Potassium	
17.	Chinaganjam	-High saline	-EC of ground water was 3.96
		-medium organic	dS m"¹ (40 per cent of
		carbon	samples are marginally saline
		-low available N	and 10 per cent are saline)
		-zinc deficient	- NO_3-N ranges between 5-30
			mg !"¹ and ii is moderately
			safe for irrigation

Contd...

18,	Parchur	-moderately alkaline	-EC of ground water was 2.43
		-medium saline	$dS\ m^{-1}$ (42 per cent of
		-strongly calcareous	samples are marginally
		-clay loamy soils	saline)
		-low available N	- NO3-N was moderately safe
		-iron deficient	for irrigation
19,	Inkollu	-mildly alkaline	-EC of ground water was 2.43
		-strongly calcareous	$dS\ m^{-1}$ (60 per cent of
		-low organic carbon	samples are marginally
		-low available N	saline)
		-iron and zinc	
		deficient	
20.	Karamchedu	-mildly alkaline	-EC of ground water was 2.38
		-medium saline	$dS\ m^{-1}$ (16 per cent of
		-low organic carbon	samples are marginally saline
		-low available N	and saline respectively)
21	Chilakaluripet	-moderately alkaline	- NO3-N was moderately safe
		-low organic carbon	for irrigation
		-strongly calcareous	
		-low available N	
		-zinc deficiency	
22	Peddanandipadu	-mildly alkaline	-RSC was 4.89 $me\ l^{-1}$(56 per
		-medium saline	cent of samples were high
		-low organic carbon	alkali waters)
		-low available N	-NO3-N was moderately safe
		-medium in iron and	for irrigation
		zinc status	

Contd...

23	Kakumanu	-mildly alkaline	-EC of ground water was 2.43
		-strongly calcareous	dS m^{-1} (60 per cent of
		-low organic carbon	samples are marginally
		-low available N	saline)
		-iron and zinc	
		deficient	
24	Rompicherla	-moderately alkaline	- NO3-N was moderately safe
		-medium saline	for irrigation
		-low available N	
		-strongly calcareous	

Table 28: Suggested crop plan taking care of the constraints for soil and water quality

S. No.	MANDAL	EXISTING CROPS	SUGGESTED CROPS
1.	Bollapalle	Rice, Black gram, Tobacco	Cotton, Finger millet, Maize,
		and Coriander	Groundnut, Pomegranate,
			Guava, Berand *Casurina*
			cunninghamiana(Saru)
2.	Ipuru	Rice, Jowar, Chillies and	Maize, Cotton, Pearl millet,
		Tobacco	Sesame, Tomato and
			Watermelon
3.	Nekarikallu	Rice, Chillies, Vegetables,	Sorghum, Maize, Pearlmillet,
		Groundnut and Tobacco	Castor, Tomato and Sunflower
4.	N.G.Padu	Rice, Ragi, Tobacco,	Maize, Jowar, Cotton,
		Coriander and Chick pea	Sunflower, Chillies, *Terminalia*
			arjuna (Arjun) and *Acacia*
			nilotica (Desi kikar)
5.	Vinukonda	Rice, Maize, Red gram,	Groundnut, Cotton, Sunflower,
		Chillies and Tobacco	*Acacia farnesiana* (Pjssi babool)
			and *Prosopis juliflora* (Pahari)
6.	Rompicherla	Rice, Vegetables,	Maize, Jowar, Cotton,
		Tobacco, Coriander and	Groundnut, Castor and Mustard
		Chillies	
7.	Narasaraopet	Rice, Vegetables, Castor,	Cotton, Maize, Jowar and
		Tobacco and Coriander	Groundnut
8.	Addanki	Rice, Maize, Red gram	Sorghum, Castor, Chillies,
		and Tobacco	Guava, Pomegranate and Cotton
9.	Korisapadu	Rice, Jowar, Chillies,	Sorghum, Castor, Pomegranate
		Vegetables and Tobacco	Finger millet, Pigeon pea and
			Pongamia pinnata (Papri)

Contd...

10.	J.Panguluru	Rice, Chillies, Vegetables,	Sorghum, Castor, Pomegranate,
		Tobacco and Bengal gram	Groundnut and *Terminalia arjuna*(Arjun)
11.	Ballikurava	Rice, Black gram, Tobacco	Maize, Jowar, Cotton, Pearl
		and Bengal gram	millet and Castor
12.	Santamaguluru	Rice, Black gram, Tobacco	Cotton, Maize, Groundnut,
		and Cotton	Pigeon pea, Tomato and
			Chillies
13.	Martur	Rice, Jowar, Chillies,	Cotton, Groundnut, Maize and
		Tobacco and Pigeon pea	*Acacia nilotica* (Desi kikar)
14.	Yeddanapudi	Rice, Chillies, Tobacco	Jowar, Groundnut, Be*hgal gram
		and Cotton	and Fodder
15.	Chirala	Rice, Maize, Black gram,	Tobacco, Cotton, Coconut and
		Vegetables and Groundnut	Sorghum
16.	Vetapalem	Rice, Ragi, Jowar and	Pearlmillet, Sorghum, Castor,
		Groundnut	Cotton, Berand Vegetables
17.	Chinaganjam	Rice, Ragi, Black gram	Tobacco, Tamarix articulate
		and Chillies	(Pharansh) and Acacia
			farnesiana (Pissi babool)
18.	Parchur	Rice, Chillies, Cotton,	Maize, Jowar and Groundnut
		Tobacco and Vegetables	
19.	Inkollu	Rice, Maize, Chillies,	Sorghum, Groundnut, Castor,
		Vegetables, Fodder and	Sunhemp and Pongamia
		Tobacco	pinnata (Papri)

Contd...

20.	Peddanandipadu	Rice, Ragi, Black gram	Tobacco, Tamarix articulate
		and Chillies	(Pharansh) and Acacia
			farnesiana (Pissi babool)
21.	Savalayapu	Rice, Chillies, Cotton,	Maize, Jowar and Groundnut
		Tobacco and Vegetables	
22.	Kakumanu	Rice, Maize, Chillies,	Sorghum, Groundnut, Castor,
		Vegetables, Fodder and	Sunhemp and Pongamia
		Tobacco	pinnata (Papri)
23.	Karamchedu	Rice, Maize, Black gram	Sorghum, Castor, Sunflower,
		and Chillies	Tobacco and Cotton
24.	Chilakaluripet	Rice, Chillies, Tobacco	Jowar, Groundnut, Be*hgal gram
		and Cotton	and Fodder

9.18 RESULTS AND DISCUSSIONS

The results obtained from the present investigation entitled "Assessment of soil and water quality in Addanki branch canal of Nagarjunasagar command area, Andhra Pradesh," have been discussed under the following headings and sub-headings.

Physical, chemical and physico-chemical characteristics of the soil samples. Quality of ground waters of Ongoie division Correlation between soil parameters and water parameters.

9.19 PHYSICAL, CHEMICAL AND PHYSICO-CHEMICAL CHARACTERISTICS OF THE SOIL SAMPLES

9.19.1 SOIL REACTION (PH)

Out of 75 surface soils tested, about fourteen percent of samples were normal, thirty percent of samples were mildly alkaline and fourty six percent samples were moderately alkaline in their soil reaction as per the prescribed ratings (Anonymous, 1984). On the whole, the soils of Nagarjunasagar command area are moderately alkaline (mean 8.43) in soil reaction. Mildly or moderately alkaline soil reaction could be maintained despite the heavy use of acid producing nitrogenous fertilizers particularly urea, because of presence of free calcium carbonate in these soils which could be neutralizing.

9.19.2 ELECTRICAI CONDUCTIVITY (DSM"1)

Electrical conductivity of surface soils ranged from 0.26 to 1.02 dSrrT1 with a mean value of 0.64 dSm"1. All the soil samples tested were normal in their soluble salt content i.e., < 2 dSm"1

9.19.3 ORGANIC CARBON {%)

Organic carbon content of the surface soil samples ranged from 0.26 to 0.62 percent with a mean value of 0.44 percent. For sub-surface soils the organic carbon ranges from 0.21 to 0.47 percent with a mean of 0.34 per cent.

9.19.4 CALCIUM CARBONATE (%)

In surface soils the calcium carbonate content ranges from 4.9 to 8.9 percent with a mean of 6.53 percent. In sub-surface soils the calcium carbonate content ranges from 5.3 to 8.89 with a mean of 6.64 percent, sub-surface soils were more calcareous than surface soils. 52

percent of surface and 56 percent of sub-surface soils were strongly calcareous and 48 percent of surface, 44 percent of sub-surface soils were weakly calcareous.

9.19.5 CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS

The cation exchange capacity of soils under study ranged from 31.98 to 49.6 with a mean value of 41717 c mol (p+) kg"1 soil. The highest value of cation exchange capacity was recorded in the soils of Parchur mandal (mean 74 c mol (p+) kg"1 soil), while the least value of the same was observed in sols of Kothapatnam mandal (mean 17.9 c mol (p+) kg"1 soil). High CEC of soils of Ongole division might be due to the montmorillonite type of clays, which are having high cation exchange capacity.

9.19.6 MECHANICAL COMPOSITION

The percent sand, silt and clay content varied from 50.9 - 62.34, 13.4-19.8 and 24.6-31.09 respectively. They came under the textural classes loamy sand, sandy clay loam, sandy and clay loam.

9.19.7 MACRONUTRIENTS-AVAILABLE NITROGEN

Available nitrogen content of surface soils anged from 158 to 211 kg ha"1 with a mean value of 184 kg ha"1 and for sub-surface soils it ranged from 145 to 189 kg ha"1 with a mean value of 168 kg ha"1.

9.19.8 AVAILABLE PHOSPHORUS

On the whole 80% of surface and 66% of sub-surface soils are high in available phosphorus and 20% of surface and 34% of sub-surface soils were medium in available phosphorus content as per the ratings proposed by Muhr et al. (1965). Medium and high available phosphorus content could be ascribed to heavy application of phosphatic fertilizers and organic matter, which favoured the solubilisation of fixed phosphorus releasing more quantity to the available pool.

9.19.9 AVAILABLE POTASSIUM

Seventy two percent of surface and sixty per cent of sub-surface soils under study recorded high potassium status, 20% surface and 26% subsurface soils recorded medium potassium status, while remaining 8% of surface and 14% of subsurface soils recorded low potassium status as per the ratings suggested by Muhr et al. (1965). The high available potassium in these soils could be due to greater potassium retention on the exchange complex by the high CEC clays on organic colloids. The higher potassium content of loamy or clayey soils might be attributed to the presence of potassium bearing minerals in heavy textured soils.

The low and medium available potassium content was due to light coarse texture (sandy, loamy sand and sandy loam) of these soils, which can retain less potassium in external position and also because of low CEC.

9.19.10 SECONDARY NUTRIENTS

All the soil samples tested comes under the category of above critical limit range with respect to calcium, magnesium, Sulphur.

9.19.11 MICRONUTRIENTS-AVAILABLE IRON

Sixty four percent of surface and sub-surface samples were above critical limit, while remaining thirty six percent of both the samples were below critical limit.

9.19.1 2 AVAILABLE ZINC

Eighty two percent of surface and ninety six percent of sub-surface samples were below critical limit while remaining 18% of surface and 4% of sub-surface were above critical limit The low available zinc content in these soils might be due to the fact that the farmers do not apply zinc as a fertilizer.

9.19.1 3 AVAILABLE COPPER

Hundred per cent of both the surface and sub-surface samples are above critical limit.

9.20 QUALITY OF GROUND WATER OF ADDANKI BRANCH CANAL

9.20.1 ELECTRICAL CONDUCTIVITY (DSM"1)

The electrical conductivity of all the water samples ranged from 1.02 to 7.06 dSrrf1 with a mean value of 3.42 dSm"1. Highest value of EC was found in case of Chinaganjam manaal (mean 3.96 dSm") waters because of the dominance of sodium ions, while lowest EC was found in Chimakurthy mandal (mean 1.39 dSm"1) waters.

Around 25.6 percent of ground water samples of this division have the EC<1.5 dS m"1 and can be used without any possible risk of soil salinization. Further 46 percent of water samples have EC between 1.5-3.0 dS m"1 and thus can be rated as marginal with regard to their suitability for irrigation and 19.6 percent of waters have EC between 3.0-5.0 dS m"1 and 8.8

percent of water have EG between 5-10 dS m"1 and are usually considered unfit for irrigation.

9.20.2 WATER REACTION (PH)

The pH of all the water samples ranged from 7.28 to 8.40 with a mean value of 7.83. The highest mean value was found in Ballikurava (8.45) and the lowest mean value in Chinaganjam (7.31). According to classification of water based on pH, 65.6 per cent of samples were categorized under alkaline range having pH>7.5 and 34.4 per cent of samples under neutral range having pH between 6.5-7.5.

9.20.3 SODIUM ABSORPTION RATIO (SAR)

The overall SAR of water samples ranged from 2.16 to 10.91 with a mean value of 5.83. The highest SAR was found in N.G.Padu mandal (mean 9.57) and lowest was in Chimakurthy mandai (mean 3.71) waters. The main reason for high SAR in ground waters is their sodium dominating character. On an average 92 per cent of samples were under S1 class (SAR<10), 7.6 per cent samples under S2 class (SAR10-18) and only 0.4 percent of samples were under S3 class (SAR18-26) respectively.

9.20.4 RESIDUAL SODIUM CARBONATE (RSC)

The range of RSC for all the waters of Ongole division are from nil to 6.17 me I"1 with a mean viaue of 1.39 me I"1. The highest RSC value was found in Ballikurava mandal (mean 12.2 me I"1) waters. In higher salinity range the sodium is associated mainly with chloride and sulphate, where as in low to medium salinity waters it is associated with carbonates and bicarbonates. This causes problem of high RSC in these waters. However, irrigation with this water for a long time leads to slight to moderate sodicity in soil.

9.20.5 CLASSIFICATION OF GROUND WATERS

On an average out of 250 samples, 87 samples were good for irrigation (34.8%), 90 samples were marginally saline (36%), 33 samples were saline (13.2%), 2 samples were high SAR saline (0.80%), 7 samples were marginally alkali (2.80%), 12 samples (4.8%) were alkali and 19 samples (7.6%) were high alkali waters. These are rated as per the guide lines given by the All India Co-ordinated Research Project on use of saline water in agriculture, Biennial report (2002-2004).

9.20.6 DIFFERENT CATIONIC COMPOSITIONS

Among the cations the dominant cation was sodium. The highest Na+ content was found in N.G.Padu mandal (25.1 me I"1 mean) and lowest in Chimakurthy mandal (mean 6.83 me I"1) waters. The order of the cations in the Ongole division with descending order are Na+ > Ca2+ > Mg2+ > K+.

9.20.7 DIFFERENT ANIONIC COMPOSITIONS

Among the anions the dominant anion was chloride with highest mean value of 31.42 me I"1 in N.G.Padu mandal and lowest in Chimakurthy(mean 7.83 me I"1) mandal waters. The dominance order of anions in the ground water of Ongole division are as follows CI" > HCO3" > SO4= > CO3=.

9.20.8 FLUORIDES

The overall range of F in ground water of study area ranges from 0.39 to 1.58 mg I"1 with a mean value of 0.89 mg I"1. The highest F was found in Chimakurthy mandal (mean "1.38 mg I"1) and lowest was in Karamchedu (mean 0.36 mg I"1) mandal waters. The data from table 29 show that 70 percent of samples were safe in fluoride content i.e., <1mg I and 30 percent of samples ranges between 1-5 mg I"1 and these are moderately safe for irrigation.

9.20.9 NITRATES

Nitrate is a beneficial element which may be considered important in irrigation water although for drinking purpose it is considered as a pollutant above specified limit of 10 mg I"1. From irrigation point of view the effect of nitrate ion has been found more spectacular than all the other nutrients because irrigated soils are generally deficit in nitrogen . The nitrate-nitrogen range of these water samples ranged from 2.34 to 10.25 mg I"1 with a mean value of 7.19 mg I*1. The highest and lowest values of means were found in Ongole (mean 9.95 mg I"1) and Karamchedu (mean 3.03 mg I"1) mandals respectively. The data from table 29 show that 80.8 per cent of water samples shows that the nitrate-nitrogen ranges between 5-30 mg I"1 and 19.2 per cent of samples shows <5 mg I"1, On an average the nitrate-nitrogen levels of these waters are moderately safe in nitrate-nitrogen content.

9.20.10 MICRONUTRIENTS

The mean values of the four micronutrients were 0.08,0.042, 0.03 and 0.011 ppm for iron, manganese, zinc and copper respectively in study area.

9.20.11 IONIC RATIOS

Ground waters are classified as good quality water and presence of seawater based on the ionic ratios mentioned in table 5. Based on the Ca/Mg ratio 91.2 percent of samples were having traces of seawater and remaining 8.8 percent were good quality water. Based on Ca/Na ratio 61.2 percent of samples were having seawater intrusion and remaining 38.8 percent are good quality water. It is clearly observed that most of the ground water is affected by the intrusion of seawater based on the ionic ratios.

9.20.1 2 CORRELATION STUDIES

Correlation with in soil parameters, the EC of soil had a significant and positive correlation with exchangeable magnesium, available sulphur, available iron and available copper. Soil available iron had a significant and positive correlation with available phosphorus (r=0.4421), available zinc (r=0.3646) and it had a significant and negative correlation with exchangeable calcium (r=-0.6271) and calcium carbonate (r=-0.4757).

9.20.1 3 CORRELATION WITH IN WATER PARAMETERS

Water pH had a positive and significant correlation with RSC (r=0,4548) of waters. EC had a positive and non-significant correlation with SAR (r=0.2591). RSC of water had a positive and non-significant correlation with SAR (r=0.1931). pH had a significant correlation with SAR (r=0.1931). Fluorides of water exhibited a positive and non-significant correlation with RSC (r=0.2248) of water. SAR had a positive and non-significant correlation withEC(r=0.2591). Soil pH had a positive and non-significant correlation with RSC (r=0.3035), Fig.18. it had a negative and non-significant correlation with SAR (r=-0.1549) and EC of water (r-=0.3294)

9.21 OVERALL SOIL FERTILITY STATUS AND GROUND WATER QUALITY

The overall fertility status of soils of Ongole division and the overall quality of ground waters of nagarjunasagar command area are presented in table below. On an average Nitrogen and Zinc are low while Phosphorus, Potassium, Secondary nutrients, Iron, Manganese and Copper were medium to high. Most of the waters comes under marginally saline.

a) Macro nutrients (N P K)	**Mandals**
LHH	Ongole, Kothapatnam, N.G.Padu, Addanki, J.Panguluru, Santamaguluru,
LMH	Tangutur, Chimakurthy, Maddipadu and Korisapadu
LMM	S.N.Padu
LHM	Baliikurava
LHL	Vetapalem
b) Secondary nutrients (Ca, Mg and S)	
All above critical limit	Ongole, Kothapatnam, N.G.Padu, Addanki, J.Panguluru, Santamaguluru, Martur, Yeddanapudi, Chiraia, Chinaganjam, Parchur, Inkollu, Karamchedu, Tangutur, Chimakurthy, Maddipadu, Korisapadu, S.N.Padu, Baliikurava and
c) Micro nutrients	
Available Iron: Medium	Tangutur, Chimakurthy, S.N.Padu, Addanki, Baliikurava, Yeddanapudi and Parchur
Adequate	Ongole
High	Kothapatnam, N.G.Padu, Maddipadu, Korisapadu, J.Panguluru, Santamaguluru, Martur, Chiraia, Vetapalem, Chinaganjam, Inkokllu and
Available Manganese: High	Ongole, Kothapatnam, N.G.Padu, Addanki, J.Panguluru, Santamaguluru, Martur, Yeddanapudi, Chiraia, Chinaganjam, Parchur, Inkollu,
Available Copper: High	Ongole, Kothapatnam, N.G.Padu, Addanki, J.Panguluru, Santamaguluru, Martur, Yeddanapudi, Chiraia, Chinaganjam, Parchur, Inkollu,
Available Zinc :	Ongole, Tangutur, N.G.Padu, S.N.Padu, Addanki, Baliikurava, Martur and
Medium	Chimakurthy, Maddipadu, Korisapadu, J.Panguluru, Santamaguluru,
Adequate	Kothapatnam, Parchur and Karamchedu

9.22 The overall quality of ground waters of Addanki branch canal

Groundwater quality	Mandals
Good	Chimakurthy, S.N.Padu, Addanki, J.Panguluru, Martur, Yeddanapudi and Karamchedu
Marginally saline	Ongote, Tangutur, Kothapatnam, Korisapadu, Maddipadu, Ballikurava, Santamaguluru, Chirala, Vetapalem, [illegible]
Saline	N.G.Padu

9.23 SURVEYING AND ANALYSIS

9.23.1 SOIL AND WATER QUALITY

- A survey was conducted during the months of February and March, 2007 in twenty four mandals using GPS(Global Positioning System) for part of Nagarjunasagar command area of Guntur and Prakasam district to study the "Assessment of soil and water quality
- All the soil samples collected from twenty four mandals representing the command area division of Guntur and Prakasam district were found to be moderately alkaline, low to medium saline and low in organic carbon in both surface and sub-surface samples.
- The available nitrogen content of the soil samples was low, available phosphorus content was medium to high and also high in available potassium in both surface and sub-surface samples.
- The cation exchange capacity and calcium carbonate content of the soils were found to be high indicating a high sorption capacity of the soils. All the selected soil samples varied in their texture from sandy to clay loam.
- Exchangeable calcium was found to be the most dominant exchangeable cation followed by magnesium, sodium and potassium. Exchangeable calcium, magnesium and the available sulphur were found to be above critical limit in both surface and sub-surface soils.

- DTPA extractable iron, manganese and copper were found to be above critical limit where as, zinc was below critical limit in all the mandals. 36 per cent of the water samples collected was found to be marginally saline, 34.8 per cent were good for irrigation. 13.2, 0.8, 2.8, 4.8 and 7.6 per cent of samples were categorized under saline, high SAR saline, marginally alkali, alkali and high alkali waters respectively. The fluoride and nitrate-nitrogen content in these waters was safe and moderately safe respectively.
- Soil pH had a significant and positive correlation with calcium carbonate and exchangeable calcium. Soil EC had a significant and positive correlation with exchangeable magnesium, available sulphur, available iron and available copper.
- Soil organic carbon had a significant positive correlation with available nitrogen and available potassium. Available nitrogen had a significant and positive correlation with exchangeable calcium, available sulphur, available zinc and available copper.
- Available phosphorus had a significant and positive correlation with available potassium, exchangeable magnesium, available iron and available copper.
- pH of water had a positive and significant correlation with RSC of water. Water EC had a negative and significant correlation with RSC of water. RSC of water had a significant and positive correlation with available copper of soil.
- Fluorides of water had a significant and positive correlation with available manganese. An alternate crop plan had suggested by keeping the constraints of soil and water quality and existing crops in view.

9.23.2 IRRIGATION MANAGEMENT

- Determine the relative leaching potential of your particular soil and site. Employ all appropriate BMPs on fields with severe leaching potential. 2.2 Monitor soil moisture by the feel method, tensiometers, resistance blocks, or other acceptable methods before and after each irrigation.
- Schedule irrigation according to crop needs, soil water depletion, and water availability, accounting for precipitation and chemigation. Apply only enough irrigation water to fill the effective crop root zone.

- Evaluate the efficiency of the total irrigation system from the pump or diversion to return flow or tail water. Upgrade irrigation equipment to improve delivery and application efficiency where feasible.
- Monitor irrigation application and uniformity of water applied.
- Time irrigations to individual crop needs to eliminate unnecessary applications. Calculate the date of the final irrigation of the season to ensure the soil profile is largely depleted by crop harvest. Post harvest irrigation should be limited to meet the needs of specific operations only.
- Analyze irrigation water quality periodically, and credit NO3-N in water to crop requirements.
- Avoid intentionally applying excess irrigation to leach salts until the growing crop has taken up fertilizer N. When leaching of soluble salts is necessary to maintain productivity, time leaching to coincide with periods of low residual soil nitrate.
- Contact a qualified professional to help schedule irrigation and determine the application efficiency of your system, if necessary.

9.23.3 FLOOD OR FURROW IRRIGATION

- Maximize efficiency and uniformity on surface irrigated fields by installing surge flow irrigation, decreasing set time, leveling fields, or using tail water recovery systems as appropriate. Producers currently using flood or furrow irrigation on coarse-textured soils should install sprinkler systems when feasible.
- Use alternate furrow irrigation and N fertilizer placement on soils with severe leaching potential to reduce nitrate leaching to groundwater.
- Use fertigation to apply in-season N fertilizer with high efficiency irrigation systems only. Fertigation is strongly discouraged with conventional flood or furrow systems unless tail water recovery systems are employed.
- Line irrigation water delivery ditches to reduce seepage losses. Install pipelines to convey irrigation water where feasible.

9.23.4 SPRINKLER IRRIGATION

- Minimize deep percolation below the crop root zone on sprinkler irrigated fields by applying water according to crop evapotranspiration and soil moisture status.
- Minimize surface runoff and increase uniformity on sprinkler irrigated fields by decreasing application depth or by changing nozzle and pressure configuration, height, or droplet size as appropriate.
- Maintain sufficient surface residue to reduce overland water flow and increase moisture intake rate. Where practical, follow soil conservation practices such as minimum tillage or contour planting to reduce erosion of soil sediments containing nutrients or pesticides.
- Plant grass filter strips on the downhill side of any highly erodible fields to filter nutrients or other chemicals from runoff. Utilize basin tillage on sprinkler irrigated fields with slopes of 3 to 5% to reduce surface runoff.
- Test systems periodically for depth of application, pressure, and uniformity.

9.23.5 CHEMIGATION AND FERTIGATION

- Read the chemical label prior to application. Follow all label instructions and take careful note of the specific chemigation instructions. Chemigators also must follow the rules of the Colorado Chemigation Act.
- Reduce water application rate to ensure no runoff or deep percolation occurs during chemigation sets. Avoid chemigation when additional water is not needed by the crop. Adjust irrigation schedule to account for water applied during chemigation
- Monitor and inspect chemigation equipment and safety devices regularly to determine proper function. Replace all worn or nonfunctional components immediately.
- Upgrade well condition to reduce the possibility of point source contamination at the wellhead. Handle chemicals carefully around the wellhead and chemigation site. Clean up any fertilizer or pesticide spill immediately to avoid well contamination.

9.23.6 DIRECTIONS OF FUTURE DEVELOPMENT

- Irrigation units **in** developing countries have an enormous range — from several thousand hectares in the case of Government-sponsored commercial farms, to less than a hectare in the case of small family units. For instance, high-pressure sprinkle systems are cost effective in the case of large farms, whereas microsprayer or bubbler systems may turn out to be more suitable for family units.
- It is not possible to design a universally applicable system of efficient use of water in irrigation because of the complexity of the variables with regard to soil, water, climate, crop and people, and because of the need to be compatible with other inputs such as seed varieties, fertilizers, tillage, pest control, etc.
- Advances in information technology have made it possible to optimize the various system variables. Efficiency of water delivery needs to be optimized in terms of conveyance of water with minimal losses (say, in closed conduits), capability to provide measured amounts of water calibrated to meet the needs of crops in time and space, while preventing wastage, salinity, and rise in the water table.
- Efficiency of water utilization is to be optimized to low-volume, low-pressure, high-frequency, partial-area irrigation to achieve high crop yields (Hillel, 1987, p. 99).

Appendix - I

EVALUATING LAND CAPABILITY, CRITERIA

In the land suitability classification, different parameters and their implications on soil productivity are discussed. A comprehensive land suitability classification model, based on the limitations of different parameters, has been proposed. These Tables are tentative and more research work is needed to modify or validate these Tables for semi-quantitative evaluation of different soils for their placement in a particular Capability Class.

The following parameters along with their limits may be used for evaluating land capability classification of a soil-unit/series. The soil-unit which qualifies for Class-III, with 2 or more parameters in Class-TV, finally will key out in Class IV, that is in one class higher. Another soil-unit, qualifying for Class-III in one parameter and Class-II or I in all other parameters, is finally classified as Class-III. A uniform application of the criteria results in capability class that correlates well with the field observations.

Soil Texture	Symbol	Clay (%)	Capability Class*
Very fine (clay)	O	>60	III
Fine (clay)	C	35-60	II or III
Moderately fine (sil, cl)	E	35-40	II
Medium fine and Medium (1)	M and L	27-35 & 17-27	II or I
Medium coarse (sl)	R	10-17	I or II
Coarse (ls)	S	<15	III
Very coarse (s)	Z	<10	III

* depending on soil structure; massive soils may qualify for a class higher.

Soil Reaction

Soil reaction (pH) is very important as it controls the availability of most elements for Plant growth. The neutral reaction (pH 6.5-7.5) is the most optimal. The proposed criteria for rating of soil reaction is given as under :

Soil Reaction Rating

Degree/Descriptive term	pH Range	Capability Class
Extremely-acidic	<4.5	VI/VII
V. strongly-acidic	4.5-5.0	V/VI
Strongly-acidic	5.1-5.5	IV/V
Moderately-acidic	5.6-6.0	III
Slightly-acidic	6.1-6.5	II
Neutral	6.6-7.5	I
Slightly-sodic	7.6-8.0	I/II
Moderately-sodic	8.1-8.5	II/III
Strongly-sodic	8.6-9.0	IV/V
Very strongly-sodic	9.1-9.5	V/VI
Extremely-sodic	>9.5	VII

Soil Salinity

Soil salinity adversely affects plant growth. Its effects are more limiting when observed in heavy textured soils, such as Vertisols or in soils with increasing sodium on the exchange complex.

Soil Salinity Class	Symbol	ECe dSm^{-1}	Capability Class
Non-to very slightly-saline	(S-0)	<4	I or II
Slightly-saline	(S-1)	4-8	II
Moderately-saline	(S-2)	8-15	II or III
Strongly-saline	(S-3)	15-25	III or IV
Very strongly-saline	(S-4)	25-50	V

Severely-saline	(S-5)	>50	VI/VII

Gypsum Status

Within limits, the presence of gypsum is useful as it does not allow saline soils to turn sodic and is a source of calcium and sulphur for plant growth. Its presence in higher amounts, by dissolution, affects engineering structures. It also affects plant growth in an indirect manner by making sink-holes, rendering the land uneven and resulting in loss of irrigation water, fine soil and plant nutrients to deeper layer and/or join the groundwater.

Gypsum Class	Symbol	Percent Gypsum	Capability Class
Non-gypsiferous	(G-0)	<0.3	I or II
Slightly-gypsiferous	(G-1)	0.3-2.0	I
Moderately-gypsiferous	(G-2)	2-5	II
Strongly-gypsiferous	(G-3)	5-10	III or IV
Very strongly-gypsiferous	(G-4)	10-25	V or VI
Extremely-gypsiferous	(G-5)	>25	VII

*depending also on other factors, like texture, infiltration rate etc.

Drainage Conditions

As discussed earlier, the soil drainage condition (especially internal) is important and controls the soil-cum-water relationship and the supply of nutrients to plants relationship of drainage class with the capability class is given as under:

Drainage class	Symbol	Capability Class
Very poor (with Typic Subgroup)	D-1	V
Poor (with Aerie Subgroup)	D-2	IV or V
Imperfect	D-3	III
Moderately-well	D-4	II
Well	D-5	I
Somewhat-excessive	D-6	III
Excessive	D-7	IV

Soil permeability

Soil permeability is the rate at which water moves through a soil under a press gradient, usually defined as the amount of water traversing per cm^2 of soil surface un a pressure gradient of one dyne cm^{-1}.The permeability class depends largely on soil texture, structure, clay mineralo etc. and has a great bearing on soil-air-water relationship; hence its rating follows above factors as under:

Permeability Class	Rate (m/day)	Approximate Texture Class	Capability Class
Very slow	<0.03	fine clay	IV
Slow	0.03-0.12	clay	III
Moderately-slow,	0.12-0.48	silty clay, clay loam (fine)	II
Moderate	0.48-1.5	clay loam	I
Moderately-rapid	1.5-3.0	sandy clay loam, Silt-loam, loam, Sandy loam	II
Rapid	3.0-6.0	loamy sand	III
Very rapid	>6.0	sand	IV

* depending on the soil structure and land-use. In case of massive soil, the capability class goes by I class.

Infiltration Rate

The infiltration refers to the downward entry of water into a soil. The rate at which water enters a soil, at any given time, is termed as infiltration rate, and is expressed as cm. It depends on soil texture structure organic matter status exchangeable Na^+ and cl^+ mineralogy; hence its rating is highly controlled by these factors, and is outlined under:

Infiltration Class	Rate (cm/hr)	Capability Class
Very slow	<0.5	IV
Slow	0.5-1.0	III
Moderately-slow	1.0-2.0	II
Moderate	2.0-3.5	I
Moderately-rapid	3.5-5.0	II
Rapid	5.0-10.0	III
Very rapid	>10.0	IV

Physiography & Slope

Physiography, which takes care of topography and slope, is an important parameter for evaluating the suitability of land for irrigated agriculture. It also influences crop growth. As such, it has been considered in evaluating land for capability classification as under:

Physiographic Class	Mapping Symbol	Capability Class* (generalized)
Recent Alluvial Plain	P	I or II
Old Alluvial Plain:	O	I (up to II)
-without any aeolian cover	O1	I (II)
-partly-covered with aeolian material	O2	III (or IV)
Aeolian plain	E	IV or VI

* depending on other soil characteristics, such as texture, structure, infiltration and human intervention to level up the landform.

Slope

Slope (%)	Capability Class*
0-1	I
1-3	I-II
3-8	II-III
8-15	III-IV (depending on land use)
15-25	VI
25-50	VII
>50	VIII

* depending on stoniness

Soil Erosion

Degree of Erosion	Kind	Symbol	Soil Loss (estimated in t/ha/yr)	Capability
No erosion	----	e0	<5	I
Slight	Sheet	e1	5-10	II
Moderate	Rill	e2	10-20	III
Severe	Gullied	e3	20-40	VI
V.Severe	Ravinous (network of gullies)	e4	>40	VII

CRITERIA FOR EVALUATING SOIL-SITE SUITABILITY FORCROP GROWTH

The soil-site suitability evaluation was devoted to the implications of different parameters on soil productivity and its result on the overall suitability class under different land utilization types. However, at no stage, we could give the number and degree of limitations and their relation with the overall suitability class. This has been attempted in the following tables, which can be used as standard Tables to match an determine the degree of limitation of each parameter used for assessing the suitability of soil for a particular crop. Depending on the number of parameters and their degree of limitation, and using the criteria laid down, the overall suitability of different soil-units for a crop is evaluated. The efforts need to be continue for other crops, dominantly grown in different agro-ecological (sub)regions, for determining the suitability of soil-units for alternative crops for rationalizing land use.

Suitability Structure

Order (Kind of Suitability)	Class (Degree of suitability)	Subclass (With kind of limitation)	Unit
S	S1- (suitable)	(does not exist)	(does not exist)
	S2- (Mod. suitable)	S2m	S2m
	S3- (Marginally suitable)	S3e, S3me	S3e2, S3m3
N	N1-(Not suitable) (currently)		
	N2-(Not suitable) (permanently)		

Degree of Limitation(s) and Suitability Class

Degree of Limitation	Suitability Class &Capability Index	Equivalent Order and Class
0-No limitation:	-Suitability: capability Index (Ci>80)	S1
1-Slight limitations:	-Moderately: suitable (Ci 60-80)	S2
2-Moderale limitations:	-Moderately/Marginal-suitable(Ci 40-60)	S3
3-Severe limitations	Not suitable but potentially-suitable; Uneconomical for use(Ci 20-40)	N1
4-Very severe limitations	Not suitable (presentlyn and potentially) (Ci<20)	N2

Criteria for Determining Suitability Class based on Kind, Degree and Number of Limitations

S1-Limitation of 1 (upto 3 limitations)

S2-Limitation of 1 and/or of 2 (upto 3 correctable, or upto 1 incorrectable limit)

S3-Limitation of 2 and/or of 3 (upto 3 correctable, or upto 1 incorrectable limit)

N1-Limitation of 3 and/or of 4 (upto 3 correctable, or upto 1 incorrectable limit)

N2-Limitation of 4 (more than 3 correctable, or 2 incorrectable limit).

Criteria for Evaluating Available Nutrient

The available nutrients (nitrogen-N, phosphorus-P and potassium-K ratings have been evaluated and given in the soil-site suitability criteria for different crops.

Key for Available N, P and K ratings

Rating Class	Rating Limits		
	N(Kg/acre) (O.M. in %)	P (Kg/acre)	K2O (Kg/acre)
Low (L)	<110 (<0.5)	<5	<55
Medium (M)	110-220 (0.5-1.5)	5-9	55-110
High	>220 (>1.5)	>10	>110

Appendix -II
Soil-site suitability criteria for Bengal gram

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp, in growing	20-25	15-19	5-15	>30
	season (°C)			26-30	<5
	Total rainfall (mm)	800-1000	600-800	400-600	<400
Land quality					
Moisture availability	LCP (days)				
	Short-duration varieties	>100	90-100	70-90	<70
	Long-duration varieties	>150	120-150	90-120	<90
Oxygen availability	Soil drainage	WD	MWD, ID	PD, ED	VPD
to roots					
Nutrient availability	Texture	l, sil, cl, scl	sic, sicl, c	si, c > 60%	s, ls
	pH (1:2.5)	6.0-7.5	7.6-8.0; 5.5-5.7	8.1-9.0; 4.5-5.4	>9.0
Rooting conditions	Effective soil depth (cm)	>75	51-75	25-50	<25
	Gravel (%)	<15	15-35	>35	-
Soil toxicity	Salinity (ECe) satn.. (dS m^{-1})	<1.0	1.0-2.0	>2.0	-
	Sodicity (ESP, %)	<10	10-15	>15	-
Erosion hazard	Slope (%)	<3	3-5	5-10	-

Soil-site suitability criteria for black gram / green gram

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp, in growing season	20-35	36-40	15-18	
	at different stages (°C)		18-20	>40	
	Total rainfall (mm)	600-750	500-650	300-500	
			1200-1500	>1500	
Land quality					
Moisture availability	LCP (days)				
	Green gram	>60	45-60	<45	
	Black gram	>90	60-90	45-60	
Oxygen availability	Soil drainage	WD	MWD, SED, ID	PD, ED	VPD
to roots					
Nutrient availability	Texture	l, cl, scl, sil,	sic, sicl,	Sl c > 60	ls, s
		c (m + k)	c(s)		
	pH (1:2.5)	6-7.5	5-5.9	>8.5	
			> 0.6-8.5	<5.0	
Rooting conditions	Effective soil depth (cm)	>75	50-75	50-25	<25
	Gravel (%)	<15	15-35	35-40	>40
Soil toxicity	Salinity (ECe) satn.. (dS m^{-1})	<1.0	1.0-2.0	>2.0	
Erosion hazard	Slope (%)	<3	3-5	5-10	>10

Land-use requirement	Soil-site characteristics	Highly suitable SI	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing	24-30	22-23	20-21	<20
	season (°C)		31-33	34-40	>40
	Total rainfall (mm)	700-1000	500-700	350-500	<350
Land quality					
Moisture availability	LGP (days)				
	Bunch varieties	100-125	90-105	75-90	
	Spreading varieties	120-135	105-120	90-105	
Oxygen availability	Soil drainage	WD	MWD	ID	PD
to roots					
Nutrient availability	Texture Surface soil	ls, sl	cl, sicl, scl	c, sic	
	Subsoil	sil, l, scl, cl, sicl	Sc, sic, c	s, ls, si, c>60	
	pH (1:2.5)	6.0-8.0	8.1-8.5	>8.5	
			5.5-5.9	<5.5	
	$CaCO_3$ in root zone (%)	High	Medium	Low	
Rooting conditions	Effective soil depth (cm)	>75	51-75	25-50	<25
	Crusting	None	Slight	Moderate	
	Coarse fragments (vol. %)	<35	35-50	>50	
Soil toxicity	Salinity (ECe) satn (dS m^{-1})	<2.0	2.0-4.0	4.0-8.0	>8.0
	Sodicity (ESP, %)	Non sodic	5-10	>10	
Erosion hazard	Slope (%)	<3	3-5	5-10	>10

Soil-site suitability criteria for Groundnut

Soil-site suitability criteria for castor

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp, in growing	26-32	33-35	36-40	>40
	season (°C)		24-25	15-23	<15
	Total rainfall (mm)	650-750	400-600	250-400	<250
Land quality					
Moisture availability	LGP for different varieties				
	Early	>120	90-120	<90	
	Medium	>150	120-150	90-120	
	Late	>210	180-210	150-180	
Oxygen availability	Soil drainage	WD	MWD	ID	PD
to roots					
Nutrient availability	Texture	l, scl, sil, cl, si	sicl, sic, sc, c(m + ...)	ls, c(s)	s
	pH (1:2.5)	6.5-7.5	6.4-5.0	8.1-9.0	>9.0
			7.6-8.0	4.0-4.9	<4.0
	CaCO3 in root zone (%)	Non cal.	<5	5-10	>10
	O.C. (%)	Medium	High	Low	
Rooting conditions	Effective soil depth (cm)	>75	50-75	25-50	<25
	Gravel (%)	Non-gravelly	Upto 1 5	15-35	>35
Soil toxicity	Salinity (ECe) satn (dS m-1)	Non saline	1.0-2.0	2.0-4.0	>4.0
	Sodicity (ESP) (%)	Non sodic	10-15	15-20	>20
Erosion hazard	Slope (%)	<3	3-5	5-10	

Soil-site suitability criteria for cotton

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp. in growing	20-30	31-35	<19	
	season (°c)			>35	
	Rainfall in growing season (mm)	600-950	450-600	<450	-
Land quality					
Moisture availability	LGP (days)	180-240	120-180	< 120	-
	AWC (mm m⁻¹)	200-250	125-200	50-125	<50
Oxygen availability	Soil drainage	WD, MWD	ID	PD, SED	ED
to roots	Waterlogging in growing	1-2	2-3	3-5	>5
	season (days)				
Nutrient availability	Texture	sic, c	sicl, cl	si, sil, sc, scl, l	sl, s, ls
	pH (1:2.5)	6.5-7.5	7.6-8.0	8.1-9.0	>9.0
					<6.5
	CEC(cmol(p +) kg⁻¹)	>55	50-55	30-50	<30
	CaCO3 in root zone (%)	<3	3-5	5-10	10-20
	O.C. (%)	>1.00	0.75-1.0	0.50-0.75	<0.50
Rooting conditions	Effective soil depth (cm)	100-150	60-100	30-60	<30
	Stonnines (%)	<15	15-25	25-50	50-75
	Gravel (%)	<5	5-10	10-15	15-35
Soil toxicity	Salinity (ECe) satn (dS m⁻¹)	2-4	4-8	8-12	>12
	Sodicity (ESP, %)	5-10	10-20	20-30	>30
Erosion hazard	Slope (%)	1-2	2-3	3-5	>5

Soil-site suitability criteria for guva

Land-use requirement	Soil-site characteristics	Highly suitable SI	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climate regime	Mean temp. in growing	28-32	32-36	36-42	
	season (°c)		24-28	20-24	-
Land quality					
Moisture availability	LGP (days)	>150	120-150	90-120	<90
Oxygen availability	Soil drainage (class)	WD	MWD, ID	PD	VPD
to roots					
Nutrient availability	Texture	scl, 1, cl, sil	si, sicl, sic,	c(<60)	c(s>60)
			sc, c(m + k).		s, ls.
	pH (1:2.5)	6.0-7.5	7.5-8.0	8.0-8.5	>8.5
			5.0-6.0	4.5-5.0	<4.5
	CaCO3 in root zone (%)	Non-calcareous	<10	10-15	>15
	Fertility rating class (NPK)	High	Medium	Low	-
Rooting conditions	Effective soil depth (cm)	>100	75-100	50-75	<50
	Gravel (%)	Non-gravelly	<15	15-35	<35
Soil toxicity	Salinity (ECe) satn (dS m-1)	<2.0	2.0-4.0	4.0-6.0	>6.0
	Sodicity (ESP, %)	Non-sodic	10-15	15-25	>25
Erosion hazard	Slope (%)	<3	3-5	5-10	>10

Soil-site suitability criteria for maize

Land-use requirement	soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp, in growing	21-32	33-38	39-40	
	season (°C)		15-20	<15	
	Annual rainfall (mm)	900-1000	750-900	500-750	<500
Land quality					
Moisture availability	LGP (days)	>100	100-80	60-80	
Oxygen availability to	Soil drainage	WD	MWD, ID	PD, ED	VPD
Nutrient availability	Texture	1, cl, scl, sil	si, sicl, sic, c(n-s)	c (s-s), ls, s	-
	pH (1:2.5)	5.5-7.5	7.6-8.5	<5.0	
			5.0-5.4	8.6-9.0	-
	CEC, cmol (p +)kg-1	>20	15-20	10-15	-
	OC (%)	High	Medium	Low	-
Rooting conditions	Effective soil depth (cm)	75-100	50-75	5-250	<25
	Stoniness (%)	Non-gravelly	15-35	35-50	>50
Soil toxicity	Salinity (ECe) satn. (dS rrr1)	Non Saline	1.0-2.0	2.0-4.0	-
	Sodicity (ESP, %)	Non Sodic	10-15	>15	-
Erosion hazard	Slope (%)	<3	3.5	5-8	-

Soil-site suitability criteria for redgram

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Germination	30-35	25-29	20-24	<20
	Active vegetative	20-25	20-25	15-19	<15
	Flowering and pod setting	15-18	12-14	10-11	<10
	Maturity	35-40	30-34	25-29	<25
	Annual rainfall (mm)	800-1000	600-800	400-600	<400
Land quality					
Moisture availability	LGP (days)				
	Short duration	>120	100-110	80-90	<80
	Long duration	>180	150-180	120-160	<120
Oxygen availability	Soil drainage	WD	MWD, ID	PD, ED	VPD
to roots				-	
Nutrient availability	Texture	si, sil, cl, scl	sic, sicl, c	s, ls, c>60%	-
	pH (1:2.5)	6.0-7.5	7.6-8.0;	8.1-9.0;	>9.0
			5.5-5.9	4.5-5.4	
Rooting conditions	Effective soil depth (cm)	>100	85-100	40-85	<40
	Gravel (%)	<20	20-35	>35	-
Soil toxicity	Salinity (ECe) satn. (dS m⁻¹)	<1.0	1.0-2.0	>2.0	-
	Sodicity (ESP, %)	<10	10-15	>15	-
Erosion hazard	Slope (%)	<3	3-5	5-10	-

Soil-site suitability criteria for rice

Land-use requirement	Soil-site characteristics	Highly suitable SI	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp. in growing	30-34	35-38	39-40	>40
	season (°C)		21-29	15-20	<15
	Annual rainfall (mm)	1110-1250	900-1110	750-900	<750
Land quality					
Oxygen availability	Soil drainage	ID, PD	MWD	WD, SED	ED
to roots	Flooding (months)		3-4	2-3	-
	Depth to water table (cm)	<10	10-20	>20-40	>40
Nutrient availability	Texture*	c, sic, cl, sicl, sc	scl, sil, l	si, ls	s
	pH (1:2.5)	5.5-6.5	6.4-7.5	7.6-8.5	>8.5
			4.5-5.4		<4.5
	CaCO3 in root zone (%)	<15	15-25	25-30	>30
Rooting conditions	Effective soil depth (cm)	>75	51-75	25-50	<25
Soil toxicity	Salinity (ECe) satn.. (dS m-1)	<3	3-6	6-10	>10
	Sodicity (ESP, %)	<15	15-40	40-50	>50
Erosion hazard	Slope (%)	0-1	1-3	3-5	>5

Soil-site suitability criteria for sorghum

Land-use requirement	Soil-site characteristics	Highly suitable SI	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temp. in growing	26-30	31-34	35-40	>40
	season (°C)		24-25	20-23	<20
	Rainfall in growing	500-700	400-500	300-400	<300
	season (mm)				
Land quality					
Moisture availability	LGP (days)	120-150	t00-90	<90	
Oxygen availability	Soil drainage	WD, MWD	ID, PD	PD, ED	VPD
to roots	Water logging in growing	2-3	3-4	4-5	>5
	season (days)				
Nutrient availability	Texture	c, cl, sicl, sc	l ,sil, sic, scl	sl, ls	s, frag
	pH (1:2.5)	6.0-8.0	5.5-5.9	<5.5	>9.0
			8.1-8.5	8.6-9.0	
	CEC(cmol (p+)kg^{-1})	30-20	20-10	<10	-
	$CaCO_3$ in root zone (%)	5-10	10-25	>25	-
	OC (%)	0.50-0.75	0.50-0.20	<0.20	-
Rooting conditions	Effective soil depth (cm)	100-75	50-75	30-50	<30
	Stoniness (%)	5-15	15-30	30-60	>60
	Gravel (%)	5-15	15-40	40-75	>75
Soil toxicity	Salinity (ECe) satn (dS m-1)	2-4	4-8	8-10	>10
	Sodicity (ESP, %)	5-8	8-10	10-15	>15
Erosion hazard	Slope (%)	0-3	3-8	8-15	>15

Soil-site suitability criteria for soybean

Land-use requirement	Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing	25-28	29-32	33-36	>36
	season (DC)				
	Mean RH in growing season (%)	70-75	60-65	50-60	<50
	Total rainfall (mm)	600-750	500-600	400-500	<400
Land quality					
Moisture availability	LGP (days)	>120	100-120	85-100	<85
	AWC (mm m"1)	>200	150-200	150-50	
Oxygen availability to	Soil drainage	WD	MWD	PD-ID	
Nutrient availability	Texture	cl, scl, l, si l	sl, c, sic, sicl	c + (s-s), ls	s
	pH (1:2.5)	6.5-7.5	7.6-8.5	>8.5	
			6.4-6.0		
	O.C (%)	Medium	High	Low	
Rooting conditions	Effective soil depth (cm)	>75	50-75	50-25	<25
	Stoniness (%)	>15	15-25	25-35	
	Coarse fragments (vol %)				
Soil toxicity	Salinity (ECe) satn (dS m-1)	<1.0	1-2	2-4	>4
	Sodicity (ESP, %)	<5	5-10	10-15	>15
Erosion hazard	Slope (%)	<3	3.5	5-8	>8

Soil-site suitability criteria for sunflower

Land-use requirement	Soil-site characteristics	Highly Suitable SI	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing	24-30	31-34	35-38	>38
	season (°C)		20-23	16-19	<16
	Total rainfall (mm)	600-700	500-600	400-500	<400
Land quality					
Moisture availability	LGP (days)	>90	80-90	70-80	<70
Oxygen availability	Soil drainage	WD	MWD	ID	PD
to roots					
Nutrient availability	Texture	l, cl, sil, sc	scl, sic, c	c >60%, sl	ls, s
	pH (1:2.5)	6.5-8.0	8.1-8.5	8.6-9.0	>9.0
			5.5-6.4	4.5-5.4	<4.5
Rooting conditions	Effective soil depth (cm)	>100	76-100	50-75	<50
	Coarse fragments (vol. %)	<15	15-35	>35	
Soil toxicity	Salinity (ECe) satn (dS m"1)	<1.0	1.0-2.0	2.0-4.0	>4.0
	Sodicity (ESP, %)	<10	10-15	>15	
Erosion hazard	Slope (%)	<3	3-5	5-10	>10

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