OPTIMUM LAND USE PLANNING OF RAMANNAPET WATERSHED USING REMOTE SENSING AND GIS TECHNIQUES

By

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M. Sc. (Ag)

THESIS SUBMITTED TO THE
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CERTIFICATE

This is to certify that the thesis entitled " **OPTIMUM LAND USE PLANNING OF RAMANNAPET WATERSHED USING REMOTE SENSING AND GIS TECHNIQUES**" submitted in partial fulfillment of the requirements for the degree of Doctorate of Philosophy in the major field of Soil Science and Agricultural Chemistry of the Acharya N. G. Ranga Agricultural University, Hyderabad is a record of the bonafide research work carried out by Mr. T. Ram Prakash under my guidance and supervision. The subject of the thesis has been approved by the student's Advisory Committee.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part has been fully acknowledged. The author of the thesis has duly acknowledged all assistance and help received during the course of investigation.

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CERTIFICATE

Mr. T. Ram Prakash has satisfactorily prosecuted the course of research and the thesis entitled **"OPTIMUM LAND USE PLANNING OF RAMANNAPET WATERSHED USING REMOTE SENSING AND GIS TECHNIQUES"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been submitted by him for a degree of any university

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DECLARATION

I, T. RAM PRAKASH hereby declare that the thesis entitled "OPTIMUM LAND USE PLANNING OF RAMANNAPET WATERSHED USING REMOTE SENSING AND GIS TECHNIQUES." *submitted to the Acharya N. G. Ranga Agricultural University for the degree of Doctorate in Philosophy in agriculture in the major field of Soil Science and Agricultural Chemistry is the result of original work done by me. I also declare that any material contained in the thesis has not been published earlier.*

Date: 27/4/05

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ABSTRACT

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Ramannapet watershed located in Nalgonda district of Andhra Pradesh was selected to study the natural resources viz., soils, hydrogeomorphology, ground water potential, land use/ land cover and to generate the optimum land use plan. This watershed drains in to Musi river and is locatedin Mid-Musi cathment . The selected study area was characterized by semi-arid climate with distinct wet and dry seasons.

Remotely sensed data of IRS-1D LISS-III at 1:50,000 scale and PAN+ LISS-III merged data of IRS-1D satellite at 1:25,000 and 1:12,500 scale were utilized to study the resources. GIS (Geographical Information system) was utilized to analyze the data and to generate the optimum land use plans.

Drainage of the Ramannapet watershed is dendritic / sub-dendritic. Drainage density and the location of water bodies indicated that the area has high run-off potential which resulted in erosion of the soils.

Pediplain-shallow weathered, pediplain-shallow weathered-eroded, residual hills, denudational hills, Pediment, Inselbergs, Pediment-inselberg complexes, valley fill and

buried pediplain were the major geomorphic units in the study area. Ground water potential of valleys was rated as good, pediment as poor and stony waste areas as very poor. In case of the pediplains the ground water potential was moderate.

Altogether, ten soil mapping units were delineated in the study area at 1:50,000 scale. At 1:25,000 scale and 1:12,500 scale 12 and 17 mapping units were delineated, respectively. Soils of the study area were classified under three soil orders viz. Entisols, Inceptisols and Alfisols. Soils located in the valley physiographic unit were well developed in terms of depth, texture and structure compared to the pediplain soils. Soils located on the severely eroded pediplains were less developed

Land use/ land cover studies indicated that there were twelve land use classes in the watershed, of which agriculture was the dominant land use. Single crop cultivated land-*kharif*, was the single largest land use class in all the level-II classes, which indicated the rainfed nature of the agriculture in the study area. Waste land was the second largest land use class. In which, land with scrub was the dominant land use category.

Optimum land use plan map at 1:50,000 scale consisted of seven action items viz arid horticulture, arid horticulture + soil conservation, silvi-pasture+ soil conservation, improved agriculture, intensive agriculture, soil conservation+ agriculture and no action. At 1:25,000 scale, eleven action items were suggested viz., pasture+ soil conservation, soil reclamation+ agriculture, soil conservation+ irrigated agriculture, agro-forestry in addition to those suggested at 1:50,000 mapping. Eleven mapping items were identified for optimal utilization of the resources at 1;12,500 scale. These action items included agro-forestry, pasture+ soil conservation, intensive agriculture with Irrigated Dry crops and improved orchard management in addition to those suggested at 1:50,000 scale.

Optimum land use plans developed at 1:50,000 scale were useful for over all development of the area and the action items identified in the optimum land use plan generated at 1:12,500 scale were very specific to the level of implementation. High resolution satellite data enabled better characterization of the resources and site specific action plans.

LIST OF ABBREVIATIONS

A^0	:	Angstrom Units
^0C	:	Degree Celsius
CEC	:	Cation Exchange Capacity
cmol (P^+) kg^{-1}	:	Centimole per kilogram
cm	:	Centimeter
ds m^{-1}	:	Deci siemen per meter
EC	:	Electrolyte Conductivity
et. al.	:	and others
g cm^{-3}	:	gram per cubic centimeter
LISS	:	Linear imaging self-scanning
m	:	meter
MAAT	:	Mean Annual Air Temperature
MAR	:	Mean Annual Rainfall
MAST	:	Mean Annual Soil Temperature
MWST	:	Mean Winter Soil Temperature
mg kg^{-1}	:	milligram per kilogram
Mg m^{-3}	:	Mega gram per cubic meter
M ha	:	Million hectares
mm	:	millimeter
PAN	:	Panchromatic
ppm	:	parts per million
%	:	per cent
viz.,	:	namely

1. INTRODUCTION

Comprehensive information on natural resources of a region plays vital role in many of the man's activities. Among them soil resources are important for the development of both agriculture and non-agriculture sectors. The demand for the finite soil resources is increasing day by day due to ever increasing population pressure, rapid industrialization and urbanization.

Because of the over exploitation and mis-management of soil and other natural resources, the society is facing many environmental and land degradation problems. This calls for optimal utilization of the resources. The increasing demand for intensification of existing cultivation, especially in the areas with less favourable conditions implies that a new equilibrium has to be achieved between human factors and the factors of land evaluation is to select the optimum land use for each defined land unit, taking in to account both physical resources and conservations of environmental resources for future use. (Sys *et al.*, 1991).

A comprehensive knowledge on soil resources with respect to their spatial extent, variability, distribution and use potential is extremely important from the prospective of optimizing the land use. Therefore, in recent years, the focus is on soil resource base, current status of the soil degradation and soil based agro-technology for optimal utilization of the resources so that optimal productivity is maintained for the posterity. Land evaluation provides a rational basis for generating optimum land use plan on the analysis of relations between land use and land resource potentials and limitations.

According to Vink (1971), land use is any kind of permanent or cyclic human interventions to satisfy human needs, for a complex of natural and artificial resources, which together are called 'Land'.

The watersheds are the hydrological units, which are considered as more efficient and appropriate for necessary surveys and investigations for the assessment of natural resources and subsequent planning and implementation of various development programmes. The watershed approaches are more rational because the land and water resources have optimum interaction and synergistic effect when developed on watershed approach. In watershed approach, the development is not confined to just agricultural lands alone but even the non-agricultural areas starting from the highest point of the area (ridge line) to the out-let of the nala or the natural system.

Therefore, for land use planning based on watersheds, the information on land use / land cover is also important in spatial format because the present land use is the result of different causes and factors which are related to land form, soil physical, chemical and mineralogical properties as well as infrastructure conditions.

Among the contemporary technologies for study of the natural resources, space borne remote sensing technology has been proved to be valuable tool. Space borne sensors provide data on the natural resources in their spatial extent. Other benefits from remote sensing technology are the synoptic view and large area coverage, which helps in obtaining the 'Birds eye view' of various natural resources. The easy availability of repetitive data in the temporal domain from space borne sensors adds a new dimension to spatial information processing and monitoring the natural resources. Due to availability of very coarse resolution data (80m) during 1970s, remote sensing application were confined only to very large area studies at very small scales. Enhancement of spatial and spectral resolution achieved during the 1980s and up to mid 1990s made it possible to study the resources at larger scale for smaller area such as watersheds etc. During late 1990s and early years of this decade, further enhancement of the spatial resolution to less than 6m to 1m was achieved, which enabled the utilization of satellite data for micro-planning or even farm level planning.

Development of computers, especially the Geographic Information System, on the other hand provide valuable support for processing the voluminous data generated through conventional and remote sensing techniques both in spatial and non-spatial formats. It is tool that allows synergism between map data and tabular data in most efficient manner. Further GIS technology also allows the integration of the datasets for deriving meaningful information and outputting these information derivatives in the map format and tabular format. The integration of information derived from the remote sensing techniques with other data at different scales enables to study the potentials and limitations of natural resources and generate action plans for optimal utilization of the resources.

Nalgonda district, with a total geographical area of 14217 km^2, is located in Southern Telangana agro-climatic zone of Andhra Pradesh. This district, with an average annual rainfall of 753 mm, is a drought prone district due frequent failures of the monsoon. Musi, tributary of river Krishna, drains the Northern and Northwestern parts of the districts. Ramannapet watershed located in the mid-Musi catchment was selected as study area for development of optimum land Use plans, keeping in view the variations in the soils, land degradation and availability of the satellite data at different scales, employing the remote sensing and GIS technologies, with the following objectives

1. Preparation of the soil, land use land cover maps of the watershed at 1:50,000 scale using the satellite data.
2. Preparation of the drainage map with watershed boundaries and road network map at 1:50,000 scale.

3. Preparation of the soil maps at 1:25000 and 1:12500 scales using PAN merged LISS-III data to study the effect of scale of satellite data on soil mapping at different scales and level of soil classification.
4. Creation of database for the above mentioned thematic maps of the watershed using the Geographical information system (GIS).
5. Development of Optimum Land Use Plan for the watershed.

2. Review of Literature

It is well-established fact that, information in terms of potentials and limitations of natural resources is a critical input for developmental planning. To prepare optimum land use plan for a given parcel of land require, information on spatial distribution of different kinds of soils and their characterization. Utilization of remote sensing and GIS in soil survey as well as in other resource inventory has become a common phenomenon owing to the rapidity and accuracy offered by these techniques in collecting, analyzing and manipulating the data. Review of literature on the research work done in these areas in India and abroad is presented in this chapter under the following head.

2.1 Remote sensing

2.2 Remote sensing in soil resources study

2.3 Land evaluation

2.4 Geographical Information System (GIS)

2.5 Land Use planning

2.6 Watershed studies

2.1 Remote sensing

Remote sensing is the technique of obtaining the information about objects or processes using sensors (cameras, scanners, radiometers, radars etc,) on the surface of the earth without physically coming into contact with them. This section deals with the principles of remote sensing, and interpretation of the satellite data.

2.1.1 Principles of remote sensing

Spectral reflectance patterns of various features on the remotely sensed data are interpreted to obtain information about various features on the earth surface. Basic and applied research has consistently led to the improvements in the existing capability to acquire, process, analyze and interpret the remotely sensed data.

In the visible wavelengths of Electro Magnetic Spectrum, pigmentation dominates the vegetation reflectance phenomenon; chlorophyll being the most important pigment. In the near infrared region, the reflectance rises noticeably because green leaves absorb very little energy in this region. The internal structure of the leaves largely controls the reflectance in the near infrared region. In the middle infrared region, water absorbs energy strongly in wavelengths, located around 1.0 and 1.90 micrometers.

The spectral reflectance of soils is generally less complex in appearance than those from vegetation. The reflectance of soils generally increases with increasing wavelengths, particularly in the visible and near infrared portions of the spectrum. However, the reflectance of the soils is influenced by various properties of the soil viz., soil colour, organic matter content (Baumgardner *et al*, 1985), iron oxides (Stoner *et al,* 1980), texture (Beck *et al,* 1976), soil moisture (Bower and Hanks, 1965), structure, surface roughness etc. In general there is an inverse relationship among spectral reflectance and organic matter content, soil moisture and iron oxide content in soils. Coarser the texture higher is the reflectance from the soils for a given soil wetness.

Based on the characteristic spectral response of the soil, vegetation and water, different features on the earth's surface are identified and interpreted for extracting thematic information from remotely sensed data.

2.1.2 Remote sensing Satellites

Remote sensing satellites are near polar orbiting, Sun synchronous, have synoptic view, cover the same area at regular intervals, collect and transmit spectral data. In India, the transmitted satellite data are received at the Earth station located near Hyderabad, Andhra Pradesh.

Space borne remote sensing started with launching of the Earth Resources Technology Satellite (ERTS 1) in 1972 by the NASA, USA that was later renamed as

Landsat -1. Landsat 2, 3, 4 and 5, followed it. Important features of remote sensing satellites are given in table.1.

India started its remote sensing program by launching the first operational Indian Remote Sensing Satellite (IRS), IRS-1A in March 1988. It has two Linear Imaging Self Scanning (LISS) cameras viz., LISS-I and LISS-II with 72.5m and 36.25m space resolutions respectively. This satellite collected information in blue, green, red and near infrared regions of the electro magnetic spectrum (EMS). IRS-1B was launched in 1991 with the same configuration as of IRS-1A.

The second generation satellites IRS-1C/1D was launched in December, 1995/1997 with three sensors viz., (a) LISS-III with a spatial resolution of 23.5m and receptivity of 24 days (b) Wide Field Sensor (WiFS) with 188m spatial resolutions and receptivity of 5 days and (c) Panchromatic (PAN) camera with resolution of 5.8m. These sensors are useful to generate resource information for regional level and micro level planning and in developing plans for management of resources. In the next generation of satellites with sensors larger than 5m spatial resolution in Panchromatic mode and 10m in multi spectral mode are planned

Table:1 **Important features of Landsat and IRS operational satellites.**

S,No	Satellite	Launch Year	Spectral bands (Micrometers)	Resolution (m)	Repeat cycle (days)
1.	LANDSAT SERIES				
	LANDSAT- 1	1972	4 MSS Bands	80	18
	2	1975	0.5-0.6		
	3	1978	0.6-0.7		
	4	1982	0.7-0.8		
			0.8-1.1		
	LANDSAT 5	1984	TM 7 Bands	30	16
			0.45-0.52		
			0.53-0.61		
			0.62-0.69		
			0.78-0.91		
			1.55-1.75		
			10.42-11.66	120	
2.	IRS Series		2.08-2.35	30	
	IRS-1A/1B	1988/1991	0.45-0.52		
			0.52-0.59	LISS-1	
			0.62-0.68	72.5	
			0.77-0.86	LISS-II	
	IRS-1C/1D	1995/1997	PAN	36.25	
			0.5-0.70	5.8	5
			LISS-II	23.5	24
			0.52-0.59		
			0.77-0.86		
			1.55-1.75		
			WiFS		
			0.62-0.68	188	5
			0.77-0.86		
			1.58-0.76		

2.1.3 Interpretation of the Satellite Data

Remote sensed data are analyzed in analog or digital format for extracting information on soils, crops, water, forests, geological features etc. In analog format, the hard copy photographic prints (black & white or colour) of remotely sensed data are visually interpreted to identify and classify different feature based on image characteristics like size, shape, tone, texture, pattern, location, association, shadow and aspect. The digital data is available on CCTs, CDs, Cartridges or Floppy diskettes and special image processing software are used for generating information on natural resources mainly based on spectral signatures of different resources.

2.2 Application Remote sensing in natural resources study

Because of various advantages with remotely sensed data, it is being increasingly employed in mapping of various resources like, soils, water and vegetation and also for monitoring these resourses over a period of time. The application of remotely sensed data in soil resources mapping, land use/land cover and hydrogeomorphological studies are given below:

2.2.1 Soil resources mapping

Aerial photographs and remote sensed satellite data are used for soil mapping at different scales. Remotely sensed data are being increasingly employed in soil resources study, because it reduces the amount of fieldwork and more accurate in depicting soil scape boundaries (DOS, 1999) both visual and digital techniques are employed in soil mapping using remote sensing data.

2.2.1.1 Aerial Photographs

Initially, aerial photographs were used as remote sensing tool in soil map preparation and their usage was on restricted basis. Samacharya and Srinivasan (1972) prepared small scale soil maps using systematic aerial photo interpretation with limited field check and soils have been mapped as associations of sub-groups and great-groups, respectively at 1:1,00,000 and 1 : 2,50,000 scale.

Iyer and Prasad (1981) conducted soil survey in Sharada sahayak command area of a part of Hardoi district, UP using aerial photographs and prepared the soil map of 1:25,000 scale. Rao *et al* (1983) studied an area of 7000 km2 in Macherla taluk of Guntur district, Andhra Pradesh using 1:25,000 aerial photographs and evaluated the soils of this area for their suitability to different crops.

Natarajan *et al* (1986) carried out soil and land use survey of Mewat area, Haryana using the aerial photographs of 1:50,000 scale. The land use was studied in relation to the physiographic units and associated soils in them. The legend adopted for land use classification has physiography at first level utility at second level and arrangement and identification at third and fourth levels, respectively. Black and white aerial photographs (1:25,000) scale) and Survey of India toposheets (1:50,000 scale) were used to study the geomorphology, soil, and land use in Southern parts of Mahendragarh district in Haryana (Sangwan *et al*, 1988).

2.2.1.2 Satellite data

Systematic application of remotely sensed data from space borne sensors over a period of time has resulted in well-established methods for utilizing satellite data in soil resource mapping. National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur has prepared nation wide soil resources map at 1:250,000 scale using landsat MSS/TM imagery.

Venkatratnam (1980) suggested that landsat data could be used for soil mapping and soil characterization using visual interpretation techniques and digital analysis. A colour coded map for the Southern part of Tamilnadu was published by him (1981). According to the author, Landsat MSS data enabled to categorize soils up to the level of association of soil sub groups and map prepared using computer was comparable to that prepared by conventional methods at small scale. In this study sub groups were delineated at 1:250,000 scale using computer aided multi spectral data analysis.

Dwivedi (1982) while preparing the soil map of Matatila catchment , Madhya Pradesh using Landsat images concluded that colour variations exhibited on false colour composite were found to be very useful in delineating soilscape boundaries. Murthy *et al*, (1982) stated geomorphic- soil relationships using the remote sensing techniques in five sample areas selected from heterogeneous climatic environments.

Sehgal (1985) used Landsat MSS data in the form of black & white imagery to generate soil map of Punjab, India. MSS bands 4,5,6 and 7 were interpreted singly and combined to form a composite interpretation map. Rao *et al*,(1986) prepared a soil map at 1:2,50,000 scale for a part of Prakasam Dist., Andhra Pradesh using Landsat MSS data, through monoscopic visual interpretation in conjunction with collateral information with limited field checks.

Singh and Dwivedi (1986) prepared the soil map of a part of Bundelkhand region and adjacent areas of Uttar Pradesh using landsat image interpretation in conjunction with the information from topo-sheets and field work. Landsat FCC of October and May 1977 were interpreted to map the soils of part of Punpun catchment under Chotanagpur plateau of Bihar through visual interpretation techniques by Karale *et al*, (1987).

Rao *et al.*,(1988) used IRS-1A, LISS-I and LISS-II data on 1:250,000 scale and prepared soil maps of Cuttack, Puri and Dhenkanol districts of Orissa. According to the authors LISS-I and LISS-II data had overall better image contrast and discernibility of natural features as compared to Landsat MSS and TM data respectively. Sen *et al.*, (1992) prepared soil resources map for parts of Dibrugarh district of Assam using remote sensing techniques. Landsat MSS data in the form of FCC prints were visually interpreted to prepare soil maps at

1:50,000 scale and soils were classified at the abstraction level of families and their association.

Ahuja *et al.*, (1992) through visual interpretation of IRS-1A LISS-II FCC at 1:50,000 scale have mapped soil resources of Bhiwani district, Haryana based on image characteristics, element analysis (land form, vegetation and erosion) and field traverses. After establishing the physiography - soil relationship, soils were mapped and classified up to the level of families and their associations. Each mapping unit was interpreted for suitability for various lan utilization type.

Sen *et.al.*,(1992) studied soils of a part of Dibrugharh district of Assam. Landsat – 4 MSS data in the form of false colour composites (FCC's) were visually interpreted for physiographic analysis in conjunction with toposheets and ground truth data were translated in terms of soils using composite interpretation map as base.

Satellite imageries (Landsat TM FCC Geocoded and IRS - IB LISS-II FCC Geocoded on 1:50,000 scale) were employed for soil mapping (1:50,000 scale) in the delta and coastal landforms of Ramanathapuram district of Tamil Nadu by Natarajan *et al*, (1998).

IRS - 1CPAN merged data of two seasons viz., *kharif* and *Rabi* were interpreted visually in conjunction with topo sheet and available ground data to prepare physiography-land use map. The PLU delineations explained a three tier approach comprising the landform, slope, land use characteristics of given parcel of land. Soils occurring on different PLU units were examined and PLU -soil relationships developed. The soil map depicting the phases of soil series was prepared using GIS. (Rajeev Srivasthava and Saxena, 2004)

2.2.2 Land use/ Land cover study

The information on existing land use/land cover is important not only for understanding the utilization of existing resources but also for optimum land use planning.

Remotely sensed data are not only used for mapping current land use but also to monitor changes over a period of time.

Dhinawa *et al.*,(1992) analyzed the land use changes in Bharatpur district of Gujarat using multidate remote sensing data (1986 and 1989 and GIS). Results revealed that agriculture was the predominant user of the land occupying 75 per cent of the area; forest cover in the area depleted from 5.6 to 3.1 per cent and area under waste lands increased from 6.34 to 7.89 per cent.

Sudhakar et al., (1994) studied the forest cover type and land use using IRS-1A LISS-II data in the Jalpaiguri region of West Bengal. Forest cover of the district was 1420.89 ha (22.82 per cent). Other land use /land cover dominant in the district included agricultural areas (45.20 per cent) and tea gardens (10.49 per cent).

Pande and Saha (1994) prepared the inventory of the land / use land cover ofWest Garo hills to appraise the changes in the land use pattern between 1975 to 1989 using temporal satellite data. The land use study indicated that there was a significant increase in (17.81 per cent) in shifting cultivation area leading to decrease in mixed deciduous forest. four alternate land use types viz., wet paddy, upland crops, plantation crops and forestry was suggested for the area after carefully considering the present land use practices, climate, socio-economic conditions environmental conservation view point and the soil and land characteristics of the soil-scape units identified in the area.

Pramod Krishna (1996) studied the usefulness of remote sensing data from the earth resource satellites for watershed management in one Eastern Himalayan watershed. The SPOT imagery was interpreted for land use/land cover categories and associated characteristics. These parameters were found to be significantly influencing towards evolving the management priorities for development of agriculture, soil conservation. afforestation and rainwater harvesting structures in ecologically fragile Himalayan region.

Murhty and Rao (1997) carried out land use/land cover investigation in Varaha river basin using remote sensing data of 1986 and 1992. It was inferred that land use/land cover pattern of the area was controlled by local topography, climate and other resources. Results revealed significant changes in the area of built up land, irrigated land, plantation, degraded forest and upland cover over a period of 6 years.

Land use / land cover in Thiruvallur area of Tamil Nadu were mapped by Palaniyandi and Nagarathinam (1997) through visual interpretation of Landsat – 5 TM and IRS-IA, LISS – II images over space and time. In the study area it was observed that built-up area and agricultural land use extensions were on upward trend whereas area under forest and wasteland had shown a declining trend.

Verma, *et al*, (1998) carried out integrated resource study in Ropar wet land eco system to analyze physiography, drainage, land use and vegetation status using aerial photographs at 1:20,000 scale and IRS-1A LISS-II FCCs on 1:50,000 scale. They identified causes for major threat to wetlands and suggested conservation measures.

Interpretation of multi date satellite data revealed the changes in the land use / land cover patterns in the Godavari Deltaic region of Andhra Pradesh during the past 26 years. The area under intensive agriculture has increased from 1459 km^2 3500 km^2 and extent of wetland from 368 to 648 km^2 during the period 1973 to 1999 (Sarma *et. al.*, 2001).

Sudhir Mahajan *et al.*, (2001) utilized the GIS applications to determine the effect of topography on land use in Ashwani Khad watershed in Himachal Pradesh. Results of the experiment revealed the significant influence of the altitude and aspect on the land use. Agriculture and wastelands have been found to be maximum in the mid-altitude (1300 - 1500m) and moderate slopes (13.2 to 26.4^0) whereas agriculture and forest have been maximum in flat and north aspect.

Utilization of remote sensing and GIS for monitoring the changes in Land Use and Land cover over a period of time has become a common phenomenon in the recent past. Several studies were carried out in several countries employing the remote sensing and GIS to study the land Use/ land cover changes. Jayakumar and Arockisamy (2003) in Tamil Nadu, India; Sadhu khan *et al.*,(2003) in West Bengal, India; Li *et al.*,(2004) in China, Dewidar (2004) in Eygypt crried out similar studies.

2.2.3 *Ground Water Potential*

Hydrogeomorphological studies are required to understand the lithology, landforms and ground water prospects of any region. The synoptic view of the terrain conditions as revealed on satellite data were found to be of great help in mapping hydrogeomorphological conditions and in identifying the ground water potential zones.

Seelan and Thiruvengadachari (1981) adopted the geomorphic approach in the study of central India comprising of hard rocks and alluvium. The satellite images were visually analyzed to prepare the hydrogeomorphological map on 1:250000 scale. This approach was later adopted in several studies carried out at National Remote Sensing Agency (NRSA, 1986) including the studies under the technology mission on drinking water wherein, hydrogeomorphological maps on the 1:250000 scale were prepared for entire India.

Seelan *et al.*, (1986) prepared ground water potential maps for the states of Karnataka and Tamil Nadu. This was done by a team Landsat TM data in two months time (one month for each state). The interpretations were done based on a hydrogeomorphic approach. The interpreted maps were overlaid on the imagery of 1:250000 scale along with location of the problem villages, and the results were used by the field investigation teams to sink bore wells in the identified problem villages. Merh and Laghate (1989) reported a similar usage of satellite imagery in Gujarat in 1987.

Kumar and Srivatsava (1991), in a study carried out in Bihar tried to analyze the spatial distribution of geomorphic classes and depth wise variation in aquifer material within the same class for determining the target horizon for further detailed investigation, using remote sensing and electrical sounding. Agarwal and Mishra (1992), delineated different hydrogeomorphological units in and around the immediate environs of Jhansi city and attempted correlation between well yields and hydrogeomorphic units prepared based on the satellite data interpretation. They observed a good correlation between geomorphic units and well yields.

Rao *et al.*, (1997) evaluated the hydrogeomorphological condition of Niva river basin of Chittoor District of Andhra Pradesh, through geological, hydrological and hydrogeomorphological studies using Landsat FCC data with adequate ground truth. According to them Niva river basin is occupied by granite and gneiss of Archean age with intrusions of dolerites. The recent alluvium was present along the stream courses.

In order to examine the influence of tectonic and morphological characteristics on the ground water in Khondalitic (garnetiferous sillimanite genesis) suite of rocks, hydrogeomorphological studies were carried out by Venkateswara Rao (1998), in a typical khondalitic terrain of Vizianagaram district of Andhra Pradesh. According to him, ground water prospects were located in shallow buried pediplains and wash plains in such a way that they were identified on gently sloping uplands situated between the lineaments. Non potential areas were those, which were, low lying areas i.e., beneath the streams that khondalite must have transformed itself into kaoline and acting as a barrier evidently preventing the movement of ground water forcing it to accumulate in the flat upland areas between the streams and lineaments.

Results of the study conducted by the Subba Rao *et al*,2001 around Guntur city to evaluate the ground water prospects indicated that deeply weathered pediplain (PPD), moderately weathered pediplain (PPM), shallow weathered pediplain (PPS) are good, moderate to good and poor to moderate respectively for ground water prospects. Lineaments parallel to the stream course and intersecting Lineaments are favorable indicators for the ground water development.

An attempt has been made by Gawande *et. al.,* (2002) to delineate the Kamthi area in Nagpur district of Maharashtra using remote sensing data with reference to ground water prospects in various geomorphological units. It has been observed that the sand stone litho units form excellent aquifers while the basalt and shale form moderate to poor aquifers, respectively.

2.3 Land Evaluation

Land evaluation is concerned with the assessment of land's specific use and involves in the interpretation of basic resources of an area like soils, climate and vegetation and other aspects of land in terms of the requirements of alternate forms of land use. It provides a rational basis for taking land use decisions. FAO (1976) provided a framework for land evaluation, which is being used widely. Mc Rae and Burnham (1981) have discussed the various methods of land evaluation prevalent all over the world along with different system of land capability classifications and evaluation of land resources for agriculture, forestry, irrigation and for non agricultural purposes. They have also discussed the use of computers in various land evaluation processes. Sys *et al.,* (1991) provided practical guidelines for parametric method of land evaluation.

Kudrat and Saha (1993) assessed the productivity potential of watershed in Song River basin in Utter Pradesh utilizing the soil-scape information generated by remote sensing, soil characteristics and terrain slope information.

The soil resource appraisal of the Tulasar charna-Bhawarli watershed, western Rajasthan revealed that except for the very deep to deep coarse textured soils of the buried pediment and older alluvial plain, the other physiographic units have severe limitations in terms of soil texture, soil depth, slope, rocky substrate, low water holding capacity and salinity and qualified for the class VI, VII, VIII land capability classes and class 3 & 4 for irrigability classes. This indicates that almost all the physiographic units or the soil resources in the entire watershed area are suitable only for non-arable farming like Horticulture, forest plantation, silvi-pasture and pasture. (Khan and Nepal Singh, 2000).

Soil and land resources of Tillari river Irrigation project command area was evaluated for their Land capability Classification and Irrigation suitability for its sustained use under irrigation. Land capability and land irrigability maps were generated as attribute maps. These maps were integrated to suggest the potential land use map. Current land use map prepared by the visual interpretation was spatially analyzed in relation to potential land use to study potential changes in land use / land cover using the GIS. This study revealed that 14.66 per cent of the area has no limitation and can be intensive agriculture by double cropping. (Suresh Kumar *et. al.*, 2002).

GIS technique was utilized for land capability evaluation in a part of Shaspur, region, Uttaranchal state. The Land use for physiographic -soil units was also suggested for sustainable development relating with Land capability class (Esther Shekina *et al.*, 2004)

Performance of different soils and their ability to produce crop yields has been recognized since ancient times in India as well as in abroad. Soil productivity determination is one of the several of soil survey interpretations made.

1.4 Geographical Information System

Geographical Information System (GIS) is computer system including software and hardware and graphics that analyses and displays multiple data layers derived from various sources. It provides and efficient means for integrating the spatial data. In recent times, application of GIS in the management of natural resources is increasing at a fast pace. In the land evaluation process, GIS has become an important tool. Major applications of GIS in the field of soil survey and land evaluation are Land capability classification (LCC), Land Irrigability classification, and Land suitability for different purposes, watershed management and generation of optimum land use maps.

GIS can perform several functions in the retrieval of soil map information together with location and ground elevation data, retrieve the soil attributes of a given site, calculate the distances and draw map overlays (Dyke, 1987). It is computerized data base management system for capturing. Storing, validating, maintaining, analyzing, displaying and managing the spatially referenced data with primary function to integrate data from variety of sources (Bailey, 1990).

Auerswald and Jung (1990) calculated the soil loss on a large scale where the universal Soil Loss Equation (USLE) was combined with a GIS (ARC/INFO) taking the geomorphological situation into account. The combination is called DUSLE, which considers spatial variations in slope inclinations, soil erodability and land uses.

Pathan *et al.,* (1992) studied the suitability of land for urbanization through evaluation of different land characteristics viz., soils, physiography, slope, land use etc. Remote sensed data from space borne sensors like, Landsat-TM, IRS-LISS-II/SPOT etc. have been used in the preparation of various thematic maps. They have employed GIS techniques for integration of different land parameters and generated urban land development units, which were evaluated with respect to physical constraints and the degree to which each class could limit the development for urban purpose. Udayraj *et al.,* (1993) have undertaken a study to evaluate the potentiality of remote sensing technology for mapping the soil and land resources at 1:50,000 scale and integrated the same with the GIS for identifying potential area for agricultural and other non-agricultural uses for red soils of India.

A treatment-oriented land-use planning scheme was compiled for a hilly watershed, subject to soil erosion, in the Western Ghats, India using a geographical information system (GIS). A remote sensing based physiographic soils map and a digital elevation model (DEM) were the sources of soil depth and slope steepness classes, respectively, and were the information databases for GIS analysis. The GIS was used to integrate these databases and manipulate the data. Rules were used to manipulate the databases and allow the establishment of a sustained land-use system in the watershed with correct soil and water conservation measures (Adinarayana and Krishna, 1995).

Nair *et al.*, (1996) prepared a digital map for Kerala using GIS and described the procedure for data input storage and processing. Prasad *et al.*, (1998) mapped the soils in Kotdwar area using IRS-1B LISS satellite data and evaluated them for optimal land use using GIS approach.

Rao and Ravisankar (1998) studied the soils of Thettivagu watershed in Tungaturthi mandal of Nalgonda district for their suitability to ground nut through remote sensing and GIS approach and reported that out of 27,234 hectares of land 19,454 hectares is highly suitable and 293 hectares is moderately suitable, 7008 hectares is marginally suitable; and 533 hectares of land is not at all suitable for ground nut cultivation.

The various layers of maps for watershed and sub-watershed boundaries, hydro-geomorphology, soil, land use/cover, slopes prepared by interpretation of satellite data (IRS-IB bands 2,3 & 4) and topographical maps were used for digitization and generation of a database on ARC/INFO GIS system and generation of a database. ARC/INFO GIS version 5.0/6.0 was used to digitize, edit, build, transform, display, analyze and plot the maps of a watershed in India. By using the 'union' module, geomorphology, soils, land use/land cover maps were combined to generate action plans (Sidhu *et al.*, 2000).

A geographical information system (GIS) based model for agro-ecological zoning (AEZ) was developed by Patel *et al*, 2000 using multi-sensor digital data from the Indian Remote Sensing Satellite and applied to the Malin watershed area in the Kotdwar and Bijnor districts of Uttar Pradesh, India. Five agro-climatic zones, 10 AEZ and 23 agro-ecological sub-zones were identified and information on their characteristics and size. The zoning revealed that 27 and 14 per cent of the area could be allocated for irrigated double cropping (sugarcane-wheat) and sole sugarcane cropping, respectively.

2.5 Land use Planning

In general, in optimal land use planning, the land use is based on the physical resources of the region and conservation of environmental resources for future use for each defined land unit. Young (1987) stated that special features needed for land use planning for agro forestry are institutional arrangements at a national level for research extension, a stage of diagnosis of problems; the incorporation of acceptability in to the design of the lane use systems; the inclusion of research; infrastructure and inputs for seedling plantation. Several of these features could with benefit be included in planning for other kinds of land use.

David Dent (1988) reported the FAO guidelines for land use planning and outlined to many possible adaptations of the procedure (i) Fire brigade planning - instant diagnosis and recommendations - and (ii) Incremental planning - step - by -step building up of information and institutional capability for planning and implementation.

Using remote sensing data, Ahuja *et.al.*,(1992) delineated the landscape of Bhiwani District in Haryana into major physiographic units viz., aeolian plain, fluvio-aeolian plain, transitional plain, alluvial plain, hills and pediments. These were delineated further into 34 sub units. Each sub-unit was evaluated for various land utilization types. Hills, pediments and scrublands were found to be suitable for forestry and horticulture. Dunal plains were best suited for grasses/bajra/oil seeds. Very gently sloping dunal plains and low-lying areas were suitable for wheat/red gram/cotton/sunflower.

Deshmukh and Bapat (1993) formulated effective land use planning programme through documentation of soil properties in a systematic form and evaluated dominantly occurring soils on six different physiographic units in parts Madhya Pradesh. Kushawaha and Oesten (1995) reported the development and application of rule based software programme combine for integration of thematic information in simplest possible way. The program was used for forest land use planning in a shifting cultivation area of NE-India.. This program can integrate 28 thematic information layers with up to 256 classes in each layer using 8 bit data.

Using capabilities offered by remote sensing and GIS, resource development planning for hill areas in Karnataka was done by Gupta *et.al.,* (1993). Integrated analysis of the factors such as topography, rainfall pattern, land use practices, status of the natural resources, land capability and environmental factors concerning the area was carried out to suggest development planning for the area.

Available information was analysed to design sustainable upland development in a watershed in Tak Province, Thailand. Landsat TM Imagery was used to study the land use/cover of the area and further analysis was supported with other spatial information such as soil erosion hazard, slope, soil texture and depth and geological materials. Climatic information was also included for GIS manipulation in the suitability assessment for major types of land utilization (rainfed paddy and upland cultivation). Agroforestry was very adoptable to the given biophysical and socio-economic conditions by adopting mixed/intercropping, alley and multiple tree cropping. The gap between the present land use and the inherent suitability of the land use was also identified for rainfed paddy and upland crop cultivation. Socio-economic information is indispensable to analyze the whole system (Ofren *et al*, 1991).

A study for district level planning was carried out in the Panchmahals district, Gujarat, India using the Composite Land Development Unit (CLDU) and the Service Center Hierarchy (SCH) for natural and socio-economic resources, respectively. The CLDU map was derived from slope, soil, groundwater prospect and land-use information using GIS techniques. Alternative land-use sites for grassland, horticulture, and afforestation were recommended based upon the soil-slope conditions of the CLDUs. Priority sub-watersheds in the district were identified for soil conservation measures. Analysis on SCH was based upon composite amenity index (AI).

According to Chary *et al.*,(1995) watershed based crop planning is an approach of area based planning of natural resources for managing land, water, and crops to sub verse socio-economic needs of the society. A study was undertaken in this regard in Khapri – Barokar watershed in Nagpur district of Maharashtra. A comprehensive plan was suggested for varying soils on different landforms in the watershed.

A method for compiling a treatment-oriented land use planning scheme for a hilly watershed in the Western Ghats region of India using a geographical information system (GIS) was presented by Adinarayana *et al*, (1995). This approach involved obtaining the soil depth and slope steepness classes a remote sensing based soil map and a digital elevation model, respectively. Integrated physical land units were created from the soil depth and slope steepness data. Knowledge based rules were used to manipulate the data and generate a sustainable land use system for the watershed.

Remote sensing and GIS were utilized to assess natural resources in rural areas of Haryana. A thorough analysis of climatic, socio-economic and natural resources were made.

A set of rules were formulated and all the information was integrated to prepare realistic action plan (Kushawaha *et al.,* 1996).

Saxena *et.al.,*(2000) studied land use / land cover for optimum land use planning in Gondakhairi watershed in Nagpur district of Maharastra using IRS – IC, LISS – III and IRS – IB LISS – II data. Soil conservation modules like field bunding / contour bunding improved moisture status in the soils of upper pediment. Grading and terracing of lower pediment resulted in harvesting of run-off water in farm ponds. Nala lining / plugging and check dams in valley improved the irrigation potential for crops in double cropping.

Land evaluation for their suitability in Tulasar Charna-Bhawarli watershed, western Rajasthan for rational land use planning as per the FAO frame work revealed that hills and very shallow pediment physiographic units are not suitable to sustain the vegetation and can be utilized for harvesting the rain water. Shallow to moderately deep pediment soils and buried pediments are marginally suitable for silvi-pasture development. Except dunal complexes, younger alluvial plains and medium to fine textured saline buried pediments and deep to very deep phases of the rest of the physiographic units are highly suitable for horticulture, forestry, silvi-pasture and pasture development. (Khan and Nepal Singh, 2000)

Gouranga Kar and Kar (2001) conducted a study on sustainable land resources development through remote sensing and geographical information systems conducted in the Yacharam watershed in Andhra Pradesh, India to identify the recommended land use systems for optimal utilization of the land.

A study was undertaken by Patel *et al.,*(2001) in a part of Solani watershed of Haridwar and Saharanpur districts in Uttaranchal and Uttar Pradesh, respectively; assessing the land capability to adopt suitable soil conservation measures and suggest appropriate land use through remote sensing and geographical information system (GIS) approaches. Spatial information was integrated using GIS techniques for generating basic resource maps such as composite land use and land capability. Present composite land use (*kharif* + *rabi*) and land capability maps were integrated and suitable criteria were framed to prepare land use adjustment plan for appropriate soil conservation needs and proper land utilization in parts of Solani watershed.

The remote sensing data and GIS based detailed geomorphological degraded land analysis ensure better understanding of land form eroded lands relationship and distribution to assess the status of land degradation at micro-geomorphological unit of reclamation, geo-environmental planning and management. Similar studies also help in the area of environmental planning and management, watershed management and hazard monitoring and mitigation. (Obi Reddy *et al*, 2002).

A study was undertaken by Sharma *et al.*, (2003) in Kawal Khad watershed, Himachal Pradesh to determine the categories priority categories of sub-watersheds based on their erosion status and to recommend/ suggest suitable soil conservation measures. Based on the classification, soil conservation measures such as regular monitoring of vegetation status, biotic interference, gap filling, safe disposal of run-off water, gully plugging, afforestation of the gullies to check erosion of the land were suggested for the watersheds which were prioritized for immediate action. in remaining watersheds treatments like bunding, terracing, land leveling farm forestry, gap filling and construction gradient control structures were suggested.

Obi Reddy and Maji (2004) identified seventeen distinct biophysical land units in Kanholi Bra river basin, Nagpur employing multi criteria overlay analysis of geospatial data base on elevation, slope, land form, soil depth, soil erosion, land use/ land cover and hydrogeomorphology. They opined that characterization of biophysical units helps in analysis of their potentials, problems and stress environment to plan and execute site-specific land management practices to maximize the productivity from each biophysical land unit.

Krishnan *et al.*,(2004) generated Optimum land use plan for Lakshadweep, India taking in to consideration the potentialities and limitations of the soils in these coral islands. These plans generated using Geographical Information system .

2.6 WATERSHEDS

Pant and Ray (1990) Stated that watershed management requires spatial knowledge of soils, vegetation attributes along with a land use in a socio-economically back ward region. Any development plan in this region requires an approach, which considers natural unit of watershed and its parameterization.

Studies have been carried out in India employing Landsat data and aerial photography to map soil type, land use, geology and landforms of various watersheds. The National Remote Sensing Agency (NRSA) and Space Application Center (SAC) used Landsat data and aerial photos for land use information at a reconnaissance level for a number of catchments. All India Soil and Land use survey (AIS and LUS) conducted watershed priority delineation surveys using 1:50 000 scale aerial photos and topomaps on a watershed basis for the major states. Through these surveys, very high and high sediment yielding priority watersheds were identified (Gunjal, 1990)

Recognizing the need for the integrated development of dry lands, the Government of India set up 99 watershed projects in 1982 in different agro-climatic regions of the country. The programme was given further impetus in 1983 when the World Bank came forward with financial assistance for the establishment of four watersheds, one each in Karnataka (Kabbalnala), Andhra Pradesh (Maheswaram), Maharashtra (Manoli) and Madhya Pradesh (Perunala). Effective watershed development programmes involve participation of all existing institutions including farmers. Establishment of 'Micro-Watershed Sanghs' in Karnataka has demonstrated how non-government agencies can successfully involve themselves in watershed development, even after the withdrawal of the project staff. Various aspects of programme implementation are afforestation and pasture development, management of assets created on non-arable lands, development of arable lands, farm ponds, contingency crop planning, institutional support, credit supply, input supply, crop insurance, market structure and human resources development (Ramanna, 1991)

Integrated watershed management is an approach in capability based land use planning aimed at sustainable biomass production and maintenance of ecological balance. Hegde and Pandurangaiah (1993) discussed the potential of this approach for land use planning and problems associated with this approach with respect to the situation in India.

Watershed management assumed urgency for planned development of land and water resources and to arrest land degradation process to preserve environment and ecological balance. Decision support to such management requires scientific knowledge of resource information, priority classification of watershed for conservation planning, technologies of remote sensing and GIS for database creation and appropriate decision making (Chakraborthi, 1994).

Adinarayana and Krishna (1995) conducted a priority sub-watersheds delineation survey in a Western Ghats watershed showed significant variation in the silt yield index values, indicating the need for conservation planning in high and very high priority sub-watersheds.

Agarwal (1998) studied drainage pattern of Varanasi District of Utter Pradesh using aerial data. The basin characteristics were analyzed in terms of basin morphology and related parameters Dibyendu Dutta *et al.*, (1997) studied the usefulness of digital remote sensing data, topographical maps, and aerial photography in assessing erosion hazard was demonstrated by studies conducted in Kishaganj tehsil, Rajahstan, India. Thematic maps indicated that 3.2, 19.2, 38.4 and 39.2 per cent of the 4 micro watersheds in the area were categorized as having very high, high, medium and low erosion hazard priorities, respectively.

Remote sensing and GIS were used for prioritization of the Upper Machkund watershed, Andhra Pradesh, India, which covers an area of 16,111 ha. The division of the watershed and sub-watershed areas was carried by visual interpretation of the geocoded IRS-IB (bands 2, 3 and 4), FCC prints (scale 1:50,000) and the drainage pattern of watershed area by Atlas of AIS LUS. The watershed area was classified as belonging to water region 4, Godavari basin, catchment of Sileru Machkund rivers, and sub-catchment of Machkund and 4E1B9 watershed. Based on secondary and tertiary drainage patterns, the watershed areas were further sub-divided into 8 sub-watersheds. Union modules (GIS), hydro-geomorphology, land use, land cover and slope maps were combined to generate erosion intensity and composite maps. Watersheds were prioritized following the sedimentation yield index (SYI) approach (Sidhu *et al*, 1998).

Arnold *et al*, (2000), through their investigations on remote sensing based decision support systems (DSS) for local land-use officials in Connecticut, USA, demonstrated that, when integrated with remote sensing applications and outreach to form tailored decision support systems, remote sensing information can greatly assist local officials to plan better the growth of their communities.

Survey of literature revealed that there are increasing number of studies reported on natural resources using remote sensing data and GIS techniques for integrated studies for optimal land use planning. However, very limited studies are reported on SIS for specific purpose land evaluation and efforts are going on to develop SIS based approaches for land evaluation studies because of several advantages with it.

3. MATERIALS AND METHODS

Study area, materials used and the methodology employed in the present study is as below:

3.1 Study area

The study area selected, Ramannapet watershed, is located in Nalgonda District of Andhra Pradesh. This watershed falls under the revenue limits of Ramannapet mandal. This area is characterized by undulating terrain, low rainfall and frequent recurrence of droughts.

3.1.1 Geographical area and extent

Ramannapet watershed, lies between 17° 2' 42" to 17° 20' 17" North latitude and 79° 2' 42" to 79° 10' 25" East longitude. It has a total geographical area of 10,167 ha with 10 revenue villages. It is located in Southern-Telangana Agro-climatic zone of Andhra Pradesh. Base map of the study area showing the watershed boundary, road network and villages is presented in Fig-1.

3.1.2 Physiography

The study area comprises of physiographic units like denudational hills, residual hills, dykes, inselbergs, pediment, pediplain and valley. The hills are scattered throughout the watershed with elevations ranging from 337 m to 462 m. The study area has general slope towards North - East direction with elevation of 340 m at the ridge point and an elevation of 270 m in the valley point. Hills and dykes have steep to moderately steep slopes, pediment is moderately sloping and pediplain is moderately to very gently sloping. Valleys are broad in nature with gentle to very gentle slopes with good ground water potential. In pediplain the ground water potential is moderate.

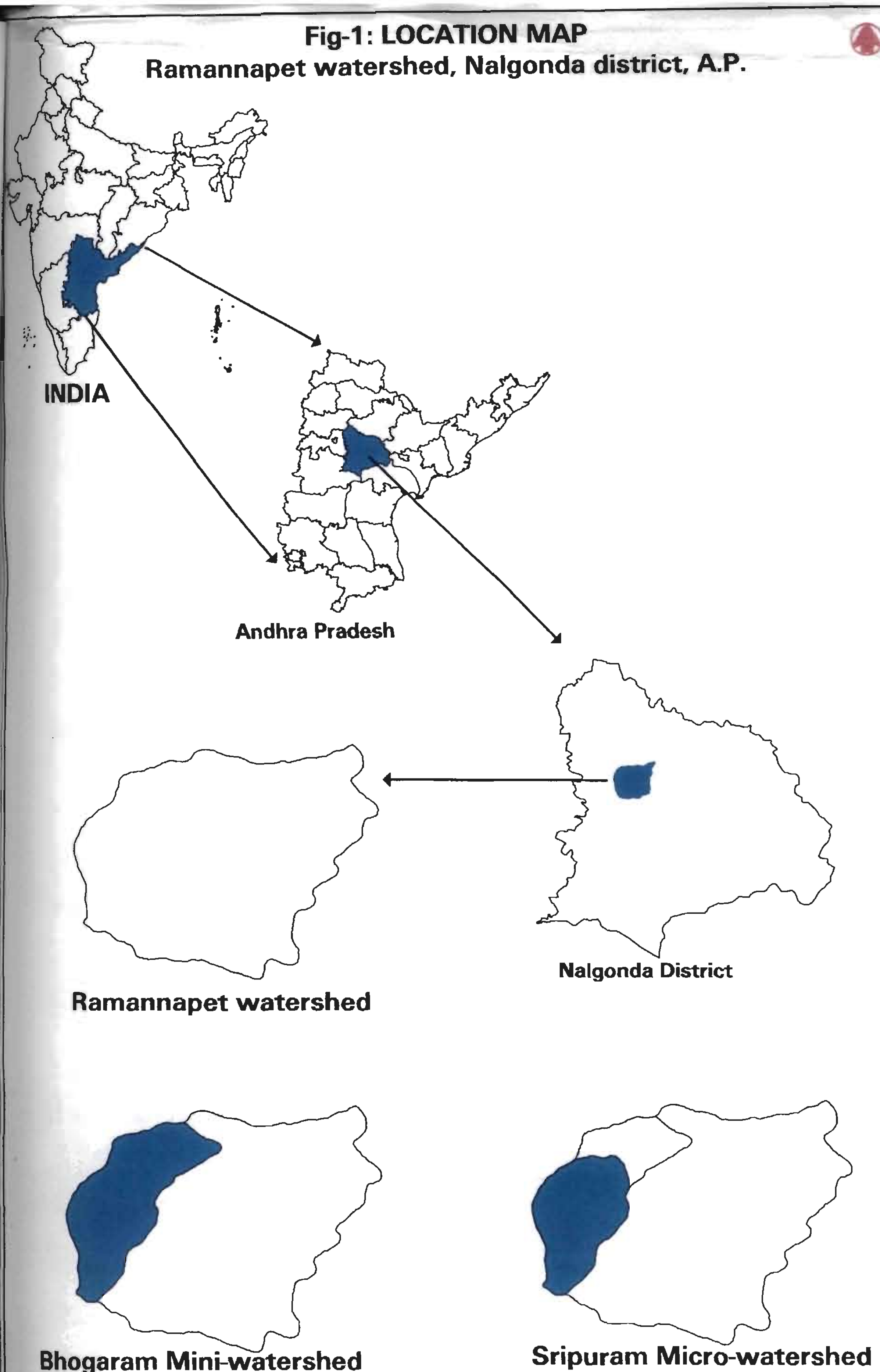
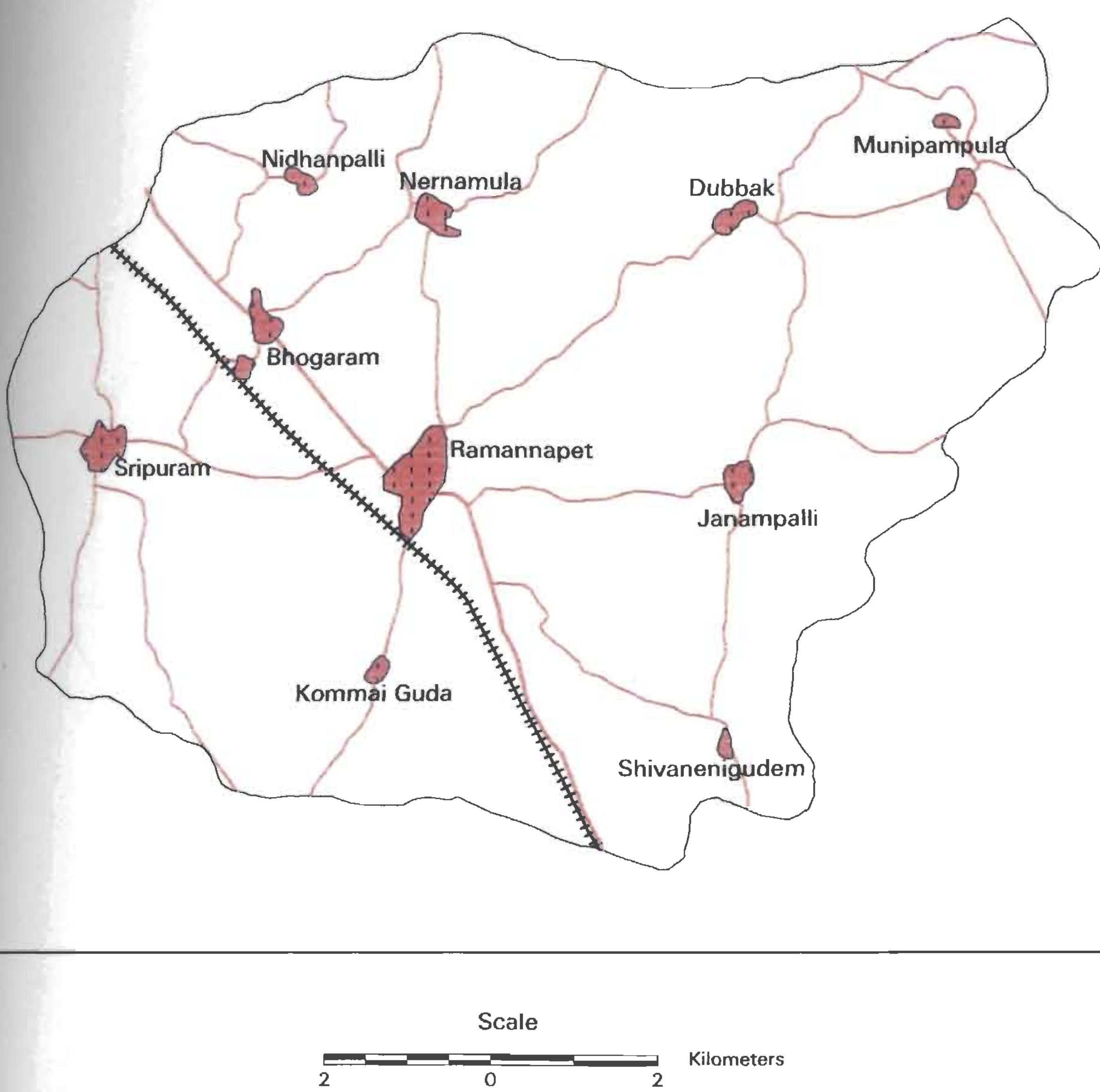


Fig-1: LOCATION MAP
Ramannapet watershed, Nalgonda district, A.P.

Fig-3 BASE MAP (1:50,000 scale)

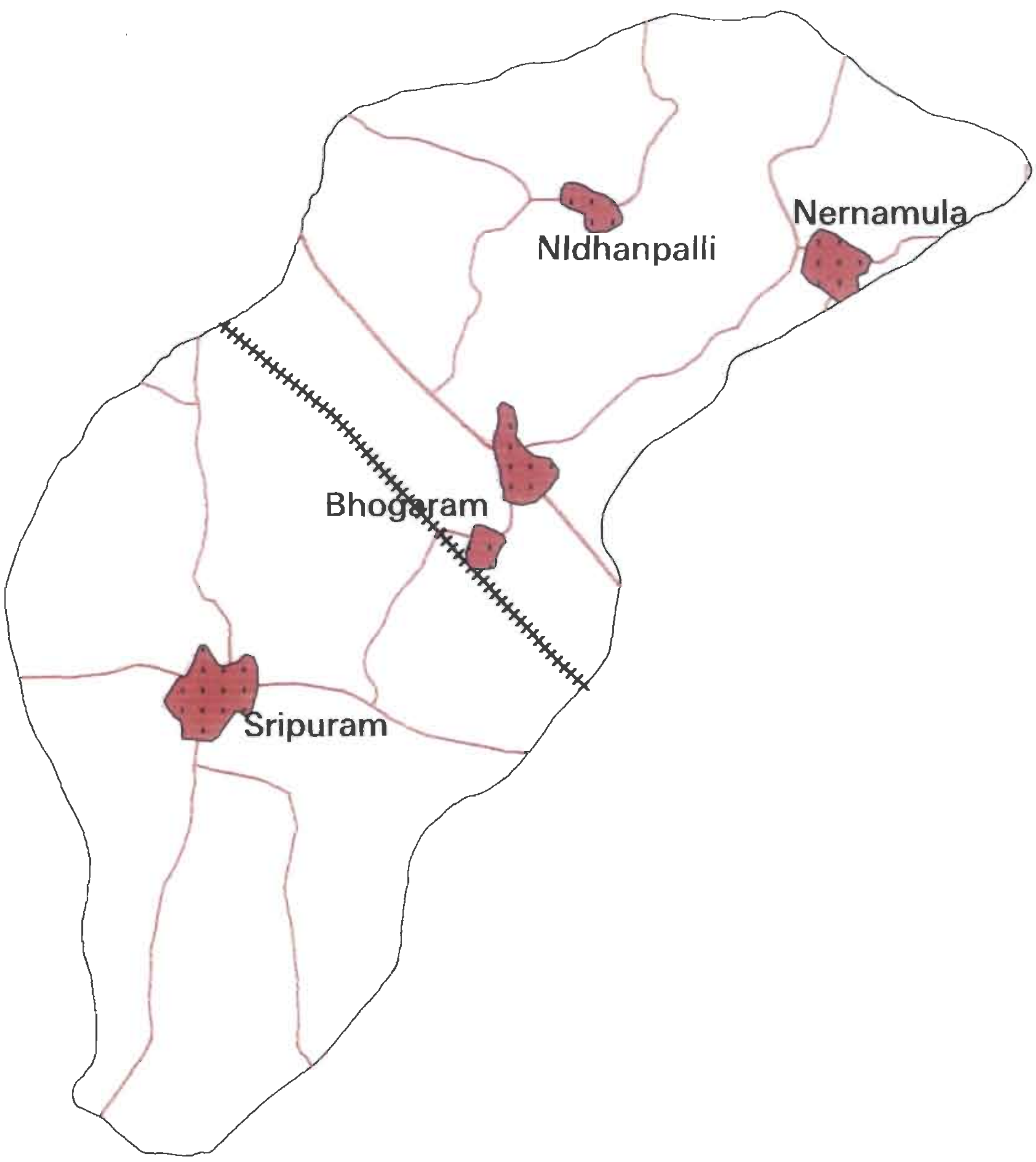
RAMANNAPET WATERSHED, NALGONDA DISTRICT, A.P.



Legend

Mapping symbol	Description
	Watershed boundary
	Railway track
	Roads
	Settlements

FIG 4 BASE MAP (1:25000)
BHOGARAM MINI-WATERSHED, NALGONDA DISTRICT, A.P.



Scale

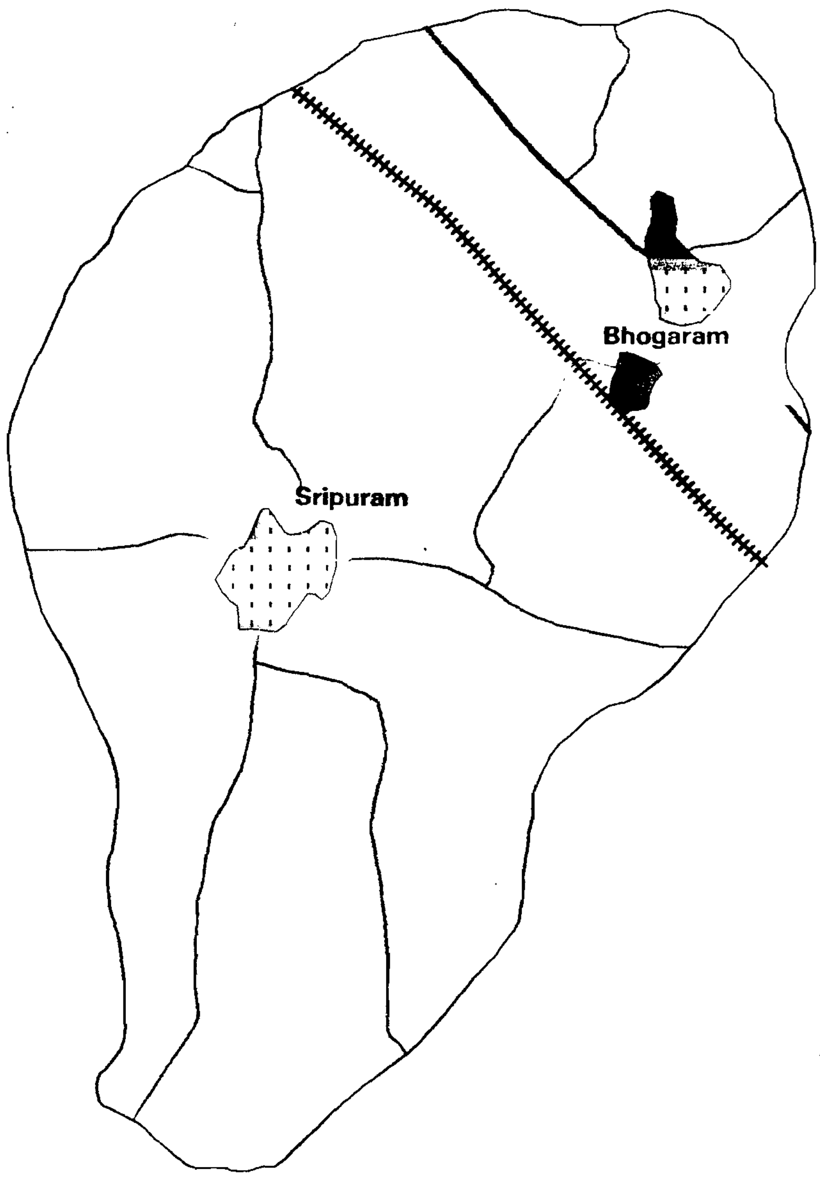
2 0 Kilometers

Legend

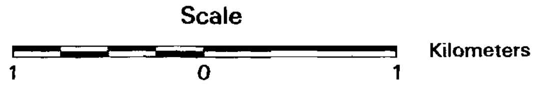
Mapping Symbol	
	Road
	Railway track
	Watershed boundary
	Settlement

Fig- 5 BASE MAP

SRIPURAM MICRO WATERSHED, NALGONDA DISTRICT, A.P.



Scale



Legend

Mapping symbol	
[Railway track symbol]	Railway track
[Road symbol]	Road
[Settlement symbol]	Settlement
[Watershed boundary symbol]	Watershed boundary

3.1.3 Geology

The study area is a part of Deccan plateau consisting of granite and granite-gneissic lithology. Geology of the area is Archean peninsular granite-gneiss. These are igneous rocks partially metamorphosed and remained stable as a shield over the area for a long time. The important rock types were granites, granodiorites and banded gneisses. In some areas peninsular gneisses were traversed by dolerite dykes.

3.1.4 Drainage

The study area, Ramannapet watershed falls in mid-Musi watershed (04), which is part of Musi river sub-catchment(E) . The Musi sub-catchment falls in the catchment-01, which is lower most Krishna catchment, below Nagarjunasagar dam. This catchment is part of Krishna river basin (D), which falls in the water resource region-4 (all drainage to Bay of Bengal except Ganges and Brahmaputra). The study area is characterized by typical semi-arid drainage with seasonal streams and depressions tanks. This watershed drains in to the Musi-river located in the Northern direction. Twenty-six small tanks and five large tanks lying across the entire area of the watershed collect the run-off that drains in to Musi-river. The streams are seasonal in nature and are often infested with prosophis. The valleys run across through entire area of watershed and the general flow direction is North /North East direction.

3.1.5 Soils

The study area was having soils formed from the granite - gneissic parent material. These soils were generally shallow in the pediplains and deep to very deep in the valley portions. Due to the coarse texture of the soils these soils are popularly known as *chalka* soils (red sandy loams or *dubba* soils (loamy sands). These soils were characterized by low organic carbon status. In general, Nitrogen deficiency is universal in these soils. Phosphorus content of the soils is medium and potassium content is high.

3.1.6 Climate

Climate of the study area is semi-arid with distinct summer winter and rainy seasons. Mean annual rainfall is 649 mm. The rainfall distribution is marked seasonal with more than 75 percent of rainfall received during the South -West monsoon period. Northeast monsoon and summer showers constitute remaining 30 per cent of the rainfall. Table 2 shows the average monthly rainfall and mean temperature data for the period 1993 to 2003. December is the coolest month of the year and May is the hottest month of the year with mean monthly temperatures of 23.97 ^{0}C and 32.92 ^{0}C, respectively.

Figure :2 shows the ombrothermic diagram for the area, plotted from the mean monthly rain fall data and mean monthly temperature data. This data reveals that wet and dry periods of a year and their duration, which are helpful in determining the soil moisture regime of the study area, crop growth period of the region. The study area is wet for slightly less than 6 months and dry for more than 6 months in a year.

Table : 2 **Mean monthly rain fall and temperature data of the study area**

S.No	Month	Average rainfall (mm)	Mean maximum temperature (^0C)	Mean minimum temperature (^0C)	Mean temperature (^0C)
1	January	0.60	30.95	17.30	24.12
2	February	2.75	33.95	19.80	26.87
3	March	5.61	37.05	23.15	30.10
4	April	10.85	39.50	26.35	32.92
5	May	13.67	39.85	27.95	33.90
6	June	149.04	35.20	25.35	30.27
7	July	117.26	31.75	23.75	27.75
8	August	127.84	29.65	22.90	26.27
9	September	110.45	31.60	23.00	27.30
10	October	80.08	32.25	21.75	27.00
11	November	16.74	31.70	18.20	24.95
12	December	1.73	31.25	16.70	23.97

Source : Chief Planning Officer , Nalgonda district (2002-03).

3.1.7 Natural vegetation:

Natural vegetation of the study area mainly comprised of trees belonging to Acacia spp, neem (*Azadiractha indica),* Ficus spp, Borassus, Prosophis spp etc. Vegetation of the waste lands mainly was constituted by thorny bushes, wild ber, prosophis, grasses etc,. In case of streams and water bodies, predominant vegetation species was Prosophis followed by Ipomea spp.

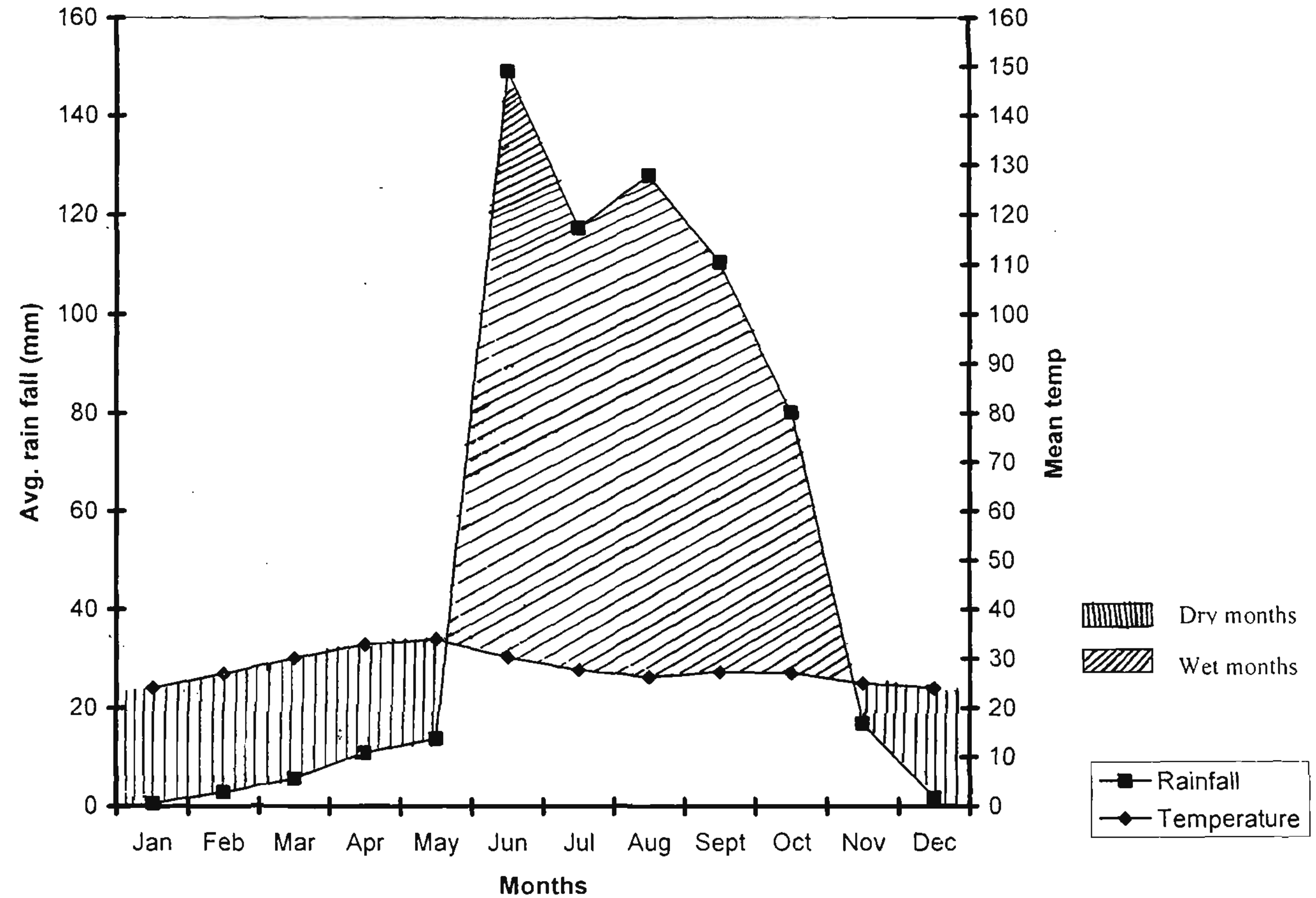


Fig. 2 OMBROTHERMIC DIAGRAM

Table : 3. Land Use pattern in Nalgonda district (2001-03).

S.No.	Category	2000-01 Area in ha	2001-02 Area in ha	2002-03 Area in ha	% to the total geographical area
1	Forest	211836	203983	203983	6.02
2	Barren and Uncultivable land	277,239	288071	278530	7.88
3	Land put to Non-Agricultural Uses	248063	265283	27369	7.05
4	Culturable Waste	83406	69593	74516	2.37
5	Peremenant Pastures and Other Grazing Land	165448	163766	164438	4.70
6	Miscellaneous tree crops and groves not included in net area sown	24317	24141	18273	0.69
7	Other Fallow Lands	420039	400449	434437	11.95
8	Current fallows	690054	865567	1015741	19.63
9	Net area sown	1394161	1210461	1030027	39.66
11	Total Cropped area	1636669	1442776	1666557	46.56
12	Area sown More than Once	242508	232315	136530	6.90
10	Total Geographical area	3514563	3491314	3491314	100

Source: Chief planning officer, Nalgonda district (2002-03).

Land use pattern of the district as revealed by the above table-3 indicates that, agriculture is major user of the land in the district constituting 46.56 per cent of the total area. Current fallows and other fallows contribute 19.63 per cent and 11.95 per cent respectively. Areas sown more than once contribute 6.90 per cent o the total geographical area.

3.1.8 Crops and cropping pattern:

Table: 4 Area, production, Productivity of Major crops in Nalgonda District (2003-04)

S. No	Crop	Area ('000hects.)	Production ('000 tons)	Yield (kg/ha)
1	Paddy	132	298	2260
2	Jowar	28	9	319
3	Bajra	15	6	413
4	Maize	3	8	2692
5	Redgram	26	5	212
6	Greengram	42	15	347
7	Groundnut	30	19	648
8	Seasamum	8	1	62
9	Castor	61	12	206
10	Cotton	77	67	148

Paddy is the principle crop of the district cultivated in more than one lakh ha with productivity of 2.2 t/ha followed by cotton, castor and green gram. However, there are wide variations in crops and cropping systems in the district among the areas irrigated by the Nagarjuna sagar project, where rice is the predominant crop; in the areas primarily irrigated by the ground water commercial crops like cotton, green gram ground nut are the predominant crops and in the rainfed areas castor, green gram, sorghum etc, are the major crops. Productivity of different crops cultivated in this district are low compared to the productivities of the state.

3.2 Materials

In this study satellite data, Survey of India topographical maps, ancillary data and computer hardware and software were used. The details of these materials is discussed is as below:

3.2.1 Satellite data

Two satellite data products of IRS-1D viz., IRS 1D LISS-III, PAN + LISS-III merged data in the form of digital and geo-coded False Colour Composite (FCC) prints were utilized in the study of natural resources of the watershed. The study area is covered by IRS 1D path 100 and row 60 and satellite data of 28th May, 1998 (Fig. 6,7 and 8) were used in the study to prepare soil and land use maps. The satellite data of rabi and monsoon periods were also referred in preparation of thematic maps.

The satellite data available with Agriculture and soils group of NRSA was utilized in this study.

3.2.2 Topographical Maps

Ramannapet watershed, the study area, was covered in 56 O/3 topographical map (1:50,000) of Survey of India (SOI). The topographical maps were utilized in delineation of the watersheds and identification of drainage lines and other features. These maps were also utilized during ground truth collection. Topographical maps 1:25,000 (56 O/3 SE and 56 O/3 SW), were utilized in delineation of mini watershed and micro watershed. These maps were also utilized in studying the slope of the Ramannapet watershed.

3.2.3 Ancillary data

Ancillary data in the form of published reports, district hand book, maps, climatic data and socio-economic conditions pertaining to the study are were collected during the field work and were used in interpretation of satellite data. Some of the Ancillary information data were collected during Ground truth mission.

Fig: 6 IRS-1D LISS-III data of Ramannapet watershed
Nalgonda district, A.P.

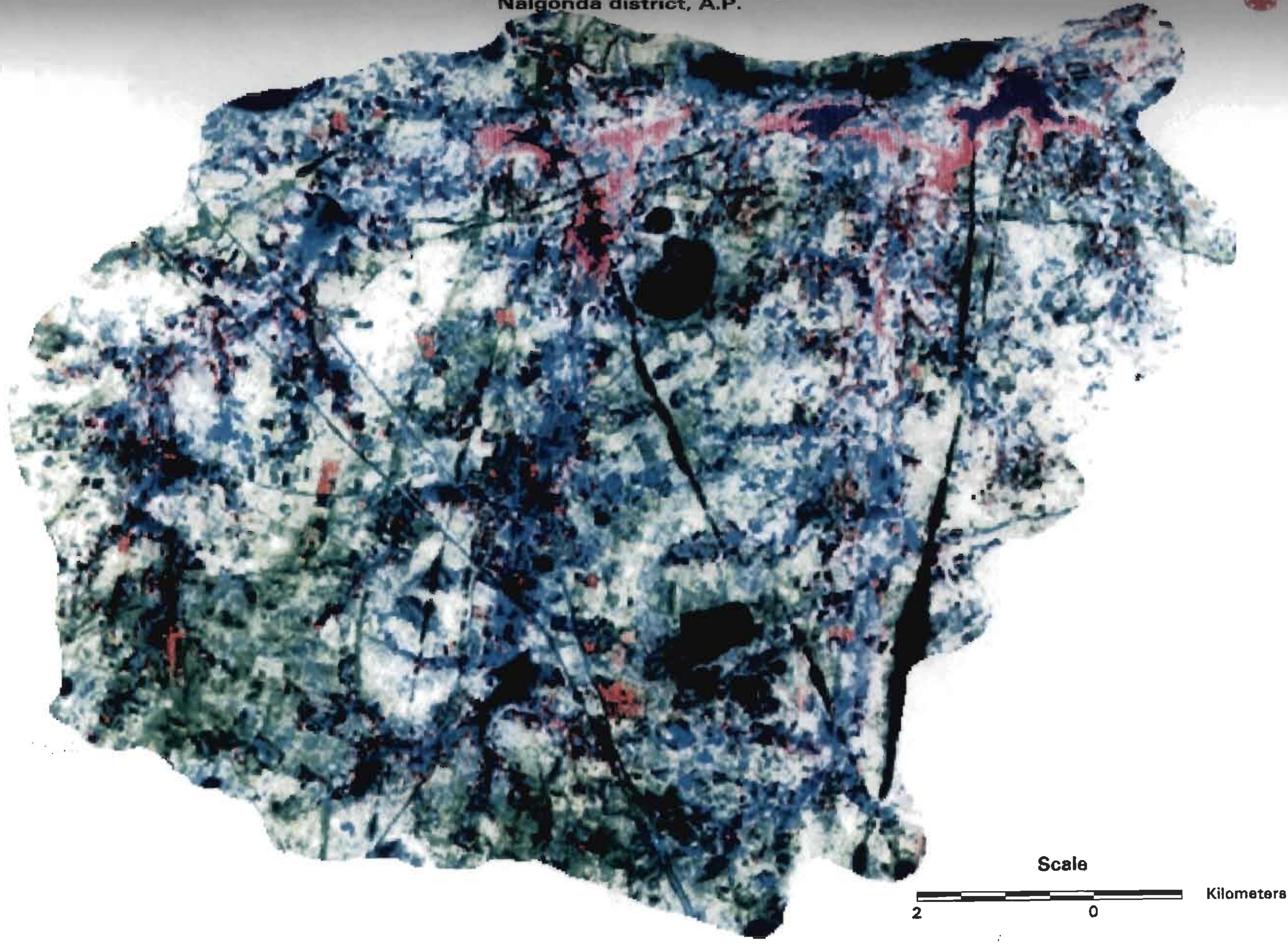


Fig-7 PAN + LISS-III Merged Data of Bhogaram Mini-watershed
Nalgonda district, A.P.

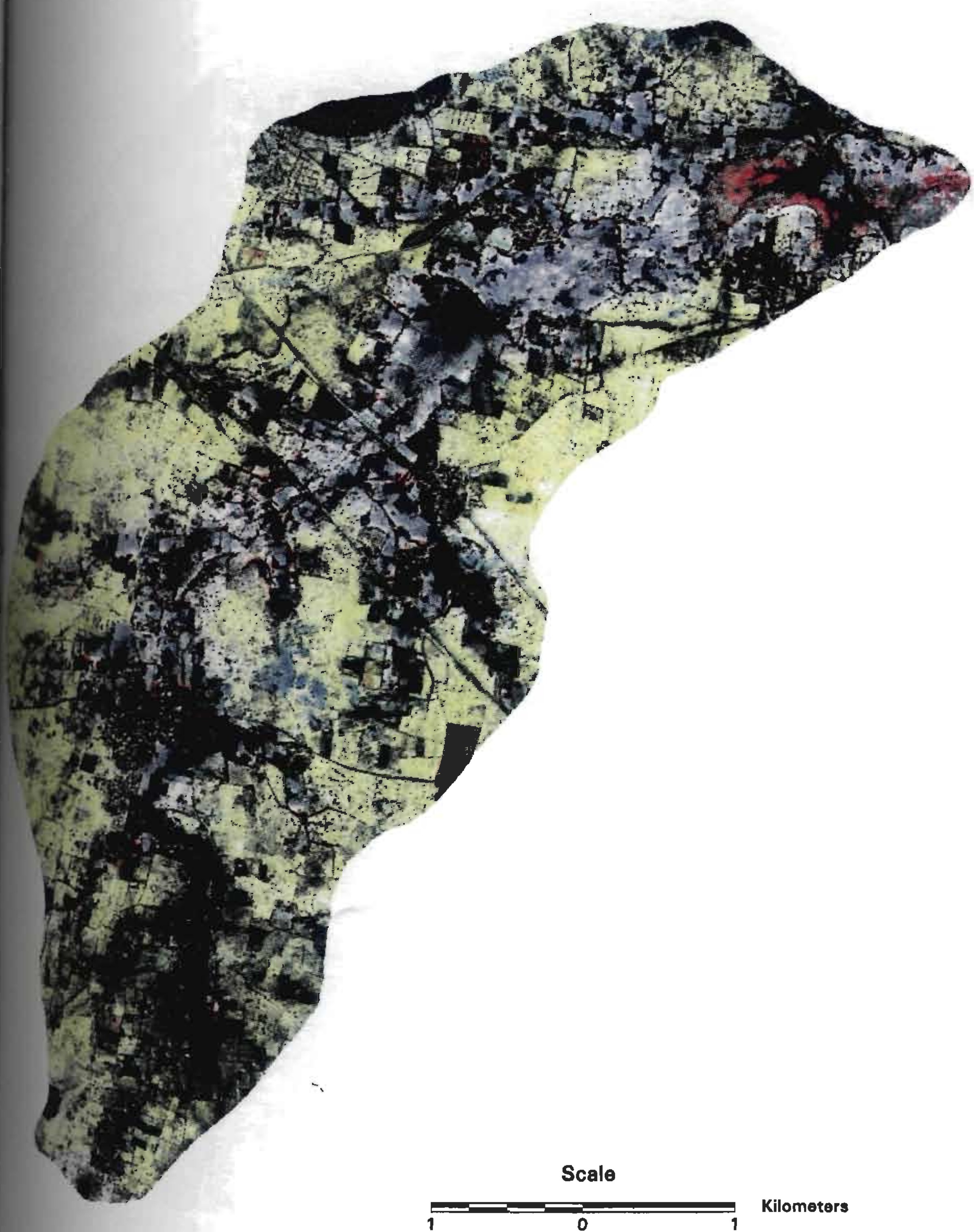


Fig-8 PAN + LISS-III Merged data of Sripuram Micro-watershed Nalgonda district, Andhra Pradesh

3.2.4 Computer facilities

In the present study image analysis package ERDAS Imaging version 8.5 available on SGI computer system was used to process the satellite data and in developing FCC prints of the satellite data. The Geographical Information System (GIS) package, ARC/GIS version 9.0 available on SGI computer system was also used to develop different maps and digital database. Map composition facilities of ERADAS Imaging were utilized in developing and printing of maps. The SGI systems available at Agriculture and soils group, National Remote sensing Agency, Hyderabad were utilized for the study.

3.2.5 Other facilities

Other facilities included light table required for satellite data interpretation, scanning of resource maps generated for digital database available at NRSA were utilized.

3.2.6 Soil laboratory facilities

Laboratory facilities available at soil science, college of agriculture, Rajendranagar and Agriculture and soils group, NRSA were utilized for analysis of soil samples collected during fieldwork.

3.3 Methodology

The methodology adopted for the study comprised of preparation of thematic maps, creation of digital database and generation of optimum land use plan for the study area.

3.3.1 Preparation of thematic maps

Satellite data of IRS 1D LISS-III, PAN + LISS-III merged data were utilized in association with SOI topographical maps, field investigations and ancillary data to prepare various resource maps. The methodology employed for individual thematic maps is discussed below :

3.3.1.1 Preparation of the soil map

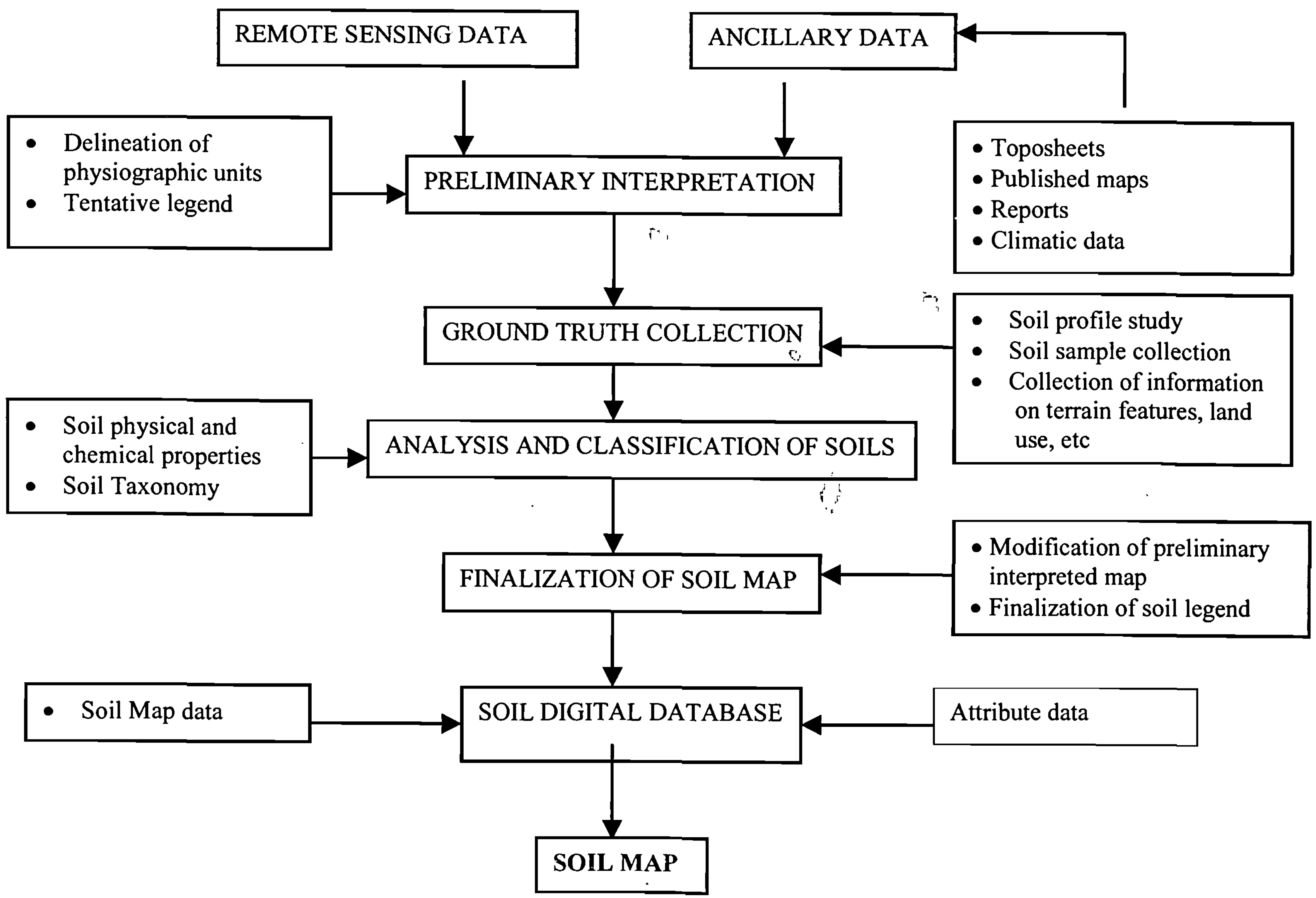
The methodology adopted for conducting the soil survey and preparation of the soil map are mono-scopic visual interpretation of the geo-coded False Color Composites of IRS-1 D LISS- III data and on 1: 50,000 scale for the soil map of 1: 50,000 scale and PAN merged LISS-III data for preparation of the soil maps at 1:25000 and 1:12500 scales. Schematic diagram for generation of soil map is presented in Fig.No.9

3.3.1.1.1 Pre-field interpretation

Entire study area was divided into different landscape units based on the various in the lithology. These units were further subdivided in to physiographic units with the help of topographical maps and False Color Composites etc. Each physiographic unit was again divided into different mapping units based on variations in land use/ land cover, slope, drainage pattern and image elements such as tone texture, size, shape and association. A tentative legend in terms of the landscape, physiography, land cover and erosion was formulated. Representative sample areas for the fieldwork were selected covering all the physiography cum image characteristics.

For soil survey at 1:25,000 scale a representative mini watershed named as Bhogaram mini watershed was selected. Sripuram micro watershed was selected to study the resources at 1:12,500 scale. PAN + LISS-III merged data of the selected watersheds was visually interpreted and sample strips were selected keeping in view the mapping units and road network of the study area. Boundaries of all the mapping units were checked through out the length. Observations were collected similar to above scale of survey but with higher intensity.

Fig. 9 METHODOLOGY FOR SOIL RESOURCE MAPPING USING SATELLITE DATA THROUGH VISUAL INTERPRETATION APPROACH



During the field work rapid traversing of the most of the study area was done to observe the broad soil landscape relationships and to adjust the sample areas according to the field conditions. In every mapping unit observations were collected in the form of mini-pits, auger bores and soil profiles. The soil profiles were studied systematically for their morphological features. Collection of the soil samples for chemical analysis in the laboratory and classifying the soils tentatively *in situ* up to family level was also done during the fieldwork.

3.3.1.1.2 Soil Chemical Analysis

Soil sample analysis was carried out the Soil Science laboratories of Department of Soil Science, College of Agriculture, Rajendranagar and NRSA, Balanagar by employing the following procedures.

3.3.1.1.2.1 Soil Reaction (pH)

pH of the soil samples was potentiometrically measured in the soil suspension of 1: 2 soil water ratio (Jackson, 1973).

3.3.1.1.2.2 Electrolyte Conductivity

The electrolyte conductivity of the 1:2 soil water suspension was measured using a conductivity bridge (Jackson, 1973).

3.3.1.1.2.3 Organic Carbon

Organic carbon was determined by chromic acid wet digestion method of Walkley and Black as described by Jackson (1973).

3.3.1.1.2.4 Free Calcium Carbonate

Free calcium content of the soil samples was determined by treating with known quantity of standard HCl and back titrating the unused acid with standard alkali (Hesse, 1971).

3.3.1.1.2.5 Cation Exchange Capacity (CEC)

Cation exchange capacity of the soil was determined by saturating a known weight of soil sample with 1N sodium acetate solution (pH 8.2). Excess sodium on the exchange sites was removed by washing with 95 per cent ethanol. The adsorbed sodium was displaced with N- ammonium acetate (pH 7.0). Concentration of sodium in the leachate was estimated by aspirating directly to flame photometer and CEC was expressed as c mol (P^+) Kg^{-1} (Bower *et.al,* 1952).

3.3.1.1.2.6 Exchangeable cations

Neutral normal ammonium acetate was used as extracting reagent for exchangeable cations in the soil samples, by centrifuge extraction procedure as described by Bower *et al.* (1952). The Na^+ and K^+ were determined from leachate by directly aspirating to the flame photometer. Exchangeable Ca^{++} and Mg^{++} were determined by Versenate method (Kanwar and Chopra, 1976).

3.3.1.1.2.7 Particle size analysis

The particle size analysis was carried out by international pipette method as described by Piper (1966).

3.3.1.1.3 Post-survey Interpretation

Preliminary interpreted soil boundaries were modified in light of the field information and soil chemical analysis results and the final thematic details were transferred on to the base maps. The tentative legends prepared during the fieldwork at all the scales of the mapping were finalized. The classification of the soils was finalized in light of the morphological features, soil Physical and chemical properties as per the Soil Taxonomy (1998).

3.3.1.2 Land Use / Land Cover

Different land Use land cover classes in the study area were demarcated on the translucent film through visual interpretation of the FCC. Ancillary data in the form of maps, charts, census records, reports and SOI topographical maps on 1: 50,000 scale were also utilized in identification and mapping of the land use and land cover classes.

The Scheme of Classification as suggested in the Manual of Land Use / Land Cover mapping using satellite imagery part-I and part-II (NRSA, 1989) was adopted in the preparation of land Use / land cover legend. Satellite data of *Kharif* and *Rabi* seasons was used to derive better information for delineation of some mapping units.

Ground truth was also collected during both *kharif* and *Rabi* seasons for all the land use classes identified on the satellite data. Final land use map was prepared by incorporating the field observations through cartographic work with an appropriate legend.

3.3.1.3 Hydrogeomorphology

To prepare hydrogeomorphological map, the inputs were rabi season satellite data, Survey of India toposheets and published geological maps and reports. FCC prints were visually interpreted to delineate various geomorphic units based on the image characteristics like tone, texture, pattern and association etc. Base map of the Ramannapet watershed was prepared on a translucent film from topomaps at 1:50,000 scale and superimposed on FCC prints and geomorphic units namely hills, pediments, inselbergs, valley etc., were delineated. Existing hydrogeomorphological and geological maps were also consulted in finalizing the map. Ground truth was collected for various mapping units in the study area and incorporated in the final thematic map. Final map was prepared with appropriate legend.

3.3.1.4 Drainage map

Drainage map of the study area at 1:50,000 was prepared from 1: 50,000 scale Survey of India topographical map. Topographical map of 1:25,000 scale was utilized in preparation of the drainage map at 1:25,000 and 1:12,500 scale. Initially, a base map of the study area was prepared on the same scales on a translucent film with minimum base details. All major streams, rivers and streamlets were drawn on the film from topographical maps under light table.

3.3.2 Creation of Database in GIS

This objective was achieved adopting the guidelines of NRIS node design standards (Natural Resources Information System), a major component of NNRMS (National Natural Resource Management Systems) for which the nodal agency is Department of Space.

NRIS seeks to provide and integrated database for use of remotely sensed data and collected information in the framework of spatial information system. The NRIS in a set of natural database organised in to two hierarchies.

Centre-State-District: Catering the resources and sectors requiring integrated resource management on for preparing plans according to administrative units.

Centre-Region-Project: Catering the sectoral management needs. For example water resources, Forestry etc. where the natural resources boundaries (forest unit, watershed etc.) in the unit.

The NRIS is an encompassing infrastructure consisting of databases, which are mainly GIS, based natural resources, economic and development oriented information system - all integrated and linked to basic spatial units.

The node database presented in this work consists of an integrated database of spatial and non-spatial data on natural and man-made resources. These data have been prepared from the remote sensing data or conventional data or combination of both. These data elements were grouped in to primary elements collected and entered in to the systems and derived elements, which were derived from the primary data using the GIS operations.

3.3.2.1 Primary data elements:

Primary database elements are the ones, which are directly digitized, and input to the GIS. Primary element database include maps of land use / land cover, hydrogeomorphological maps, soil map with type, depth, texture, stoniness etc. Up to series level, drainage, contours/ spot heights, settlement locations, roads, rail networks.

3.3.2.2 Derived data element

Derived data elements are those which were derived some of the primary elements in spatial modes. Water prospects designed from hydrogeomorphological elements, slope derived from contours and spot heights elements were the derived data elements presented in this study.

3.3.2.3 Feature Codification scheme

Feature codification scheme for every input element was worked out keeping in view the natural resource hierarchies with the feature class for each of the theme. All the data elements were given a unique name, which in self explanatory with short forms. These elements have been linked with an attribute table (Look up table) with an extension of LUT and a linking code (feature code) which links this LUT and database layer.

3.3.3 Land evaluation

Land evaluation enables better understanding of the soils in terms of their potentials and limitations for agricultural production. Land capability classification of a given area provides vital input for generation of Optimum land Use plan for an area. Land evaluation places soils in to interpretative groups based on their sustained use under specified agricultural system. The information generated through soil survey are evaluated for a variety of purposes like land capability classification, land irrigability assessment, land productivity etc. That helps in generating the Optimum Land Use plan or suitability to specific crop or plantation.

3.3.3.1 Land capability classification.

The land capability classification is widely used categorical system for evaluating land broad agricultural systems and not for specific crops or practices. It is interpretative grouping of the soils mainly based on the (1) Inherent soil characteristics (2) External land features and (3) Environmental factors that limit the use of the land. These factors individually and collectively control thee placement of the soil in particular class.

The land capability class is the highest level of generalization and it indicates the intensity of limitations. In all, eight land capability classes have been recognized and are presented in Roman numbers from I to VIII. Class I is the best land and Class VIII is the poorest land. Next lower category of Land Capability Classification is the land capability sub-class, where the main limitation or limitations are recognized. The sub classes are denoted by appropriate suffix or suffixes placed after the class number. Four major kinds of limitations were recognized at this level were e- erosion hazard, w- Excess water, s- soil limitation and c - climatic limitation. The lowest level of the classification is the land capability unit where the soils are grouped according to their response to management systems. In the present study soils are classified up to sub-class level.

3.3.3.2 Generation of optimal land use plan

This objective was achieved in a systematic manner keeping in view the production potential of the local resources to that the level of production is sustained without decline over time. The methodology employed in arriving at optimal land use plan is presented in Fig.10

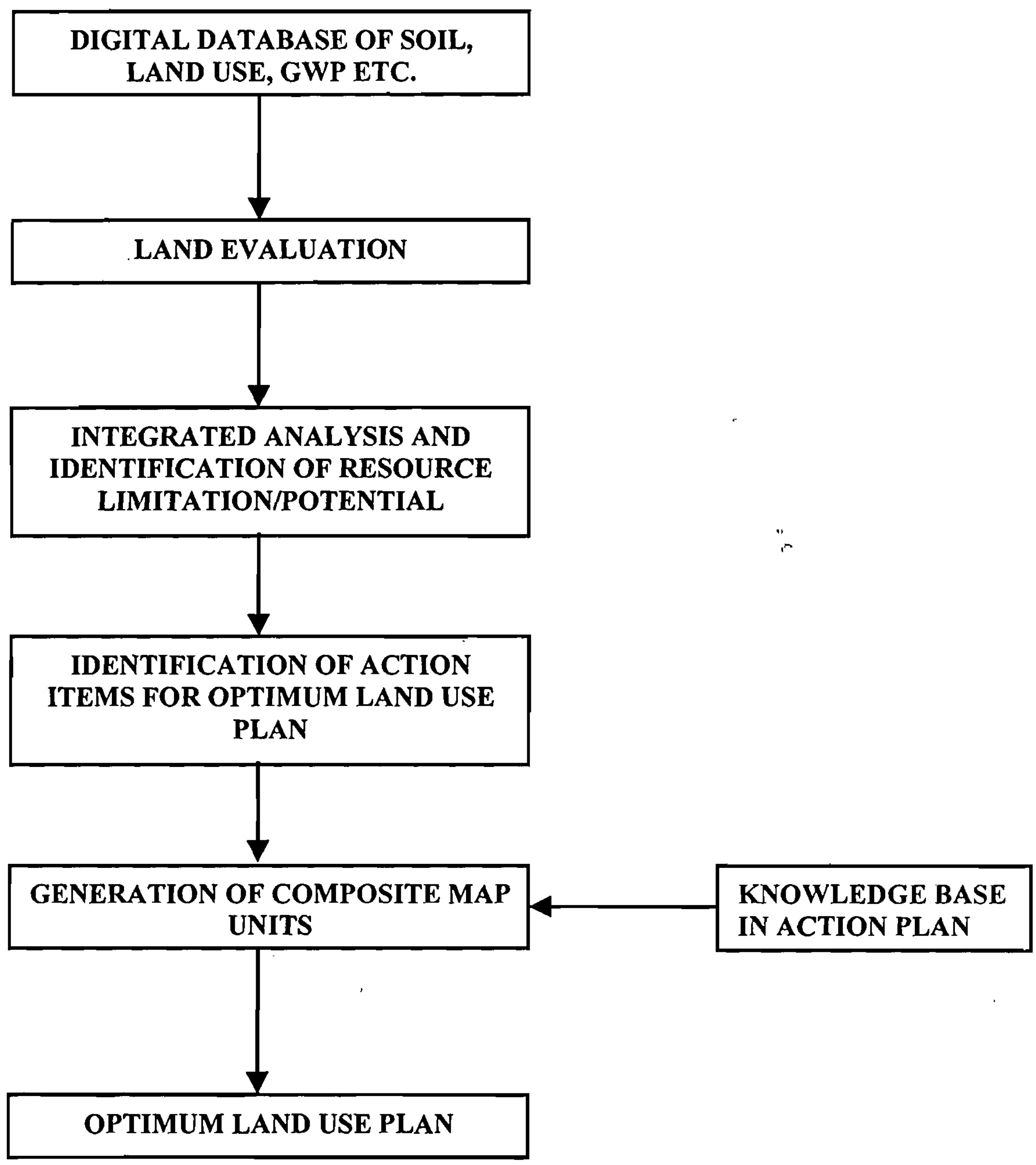
Initially the soil, land use, hydrogeomorphology, slope and ground water potential thematic maps in SIS were studied individually and the limitations/ potentials of the resources were identified in the spatial domain. This was achieved through land evaluation of soil mapping units in SIS for agriculture, pasture and forest/other tree species.

In the next stage the resource maps were studied as composite map, which was generated through combining the basic resource maps. The integrated analysis helped in not only better understands of the problems of the study area but also the potential that exist in the test site. The composite map polygons were labeled as 'Composite land development units' (CLDUs).

Action items for optimal utilization of resources of the test site were identified which enhances the agricultural productivity and contain land degradation. The action items identified were afforestation, soil conservation, agro-horticulture, soil conservation and afforestation, double cropping/intensive cropping and no action by taking soil resource as base. Rules were framed to match action items identified with a unique combination of soils, land use, hydrogeomorphology, slope and ground water potential. These were incorporated as knowledge base in SIS.

The CLDUs were analyzed with the knowledge base and the optimal land use plan map was generated. The final out puts were generated individual theme-wise, derived thematic maps and optimal land use map for the study area using the 'map composition' utilities in 'arclot' of ARC/INFO GIS package. the area statistics were generated using are utilities. The Final prints were taken on Tekgui laser jet Ink plotter.

Fig.10 Methodology for optimum land use planning



4. RESULTS

The results obtained on various resources viz., drainage and watersheds, soils, land use / land cover, ground water potential and optimal land use plan for the study area are presented in the following sections:

4.1 Drainage and watersheds

4.2 Soils

4.3 Land use land cover

4.4 Database

4.5 Optimal land use planning

4.1 Drainage and watersheds

Ramannapet watershed, located in Mid-Musi subcatchment drains into Musi river which is a tributary of river Krishna. This watershed has been coded as 4D1E4 in the watershed atlas of AIS&LUS. Total geographical area of the watershed is 10167 ha.

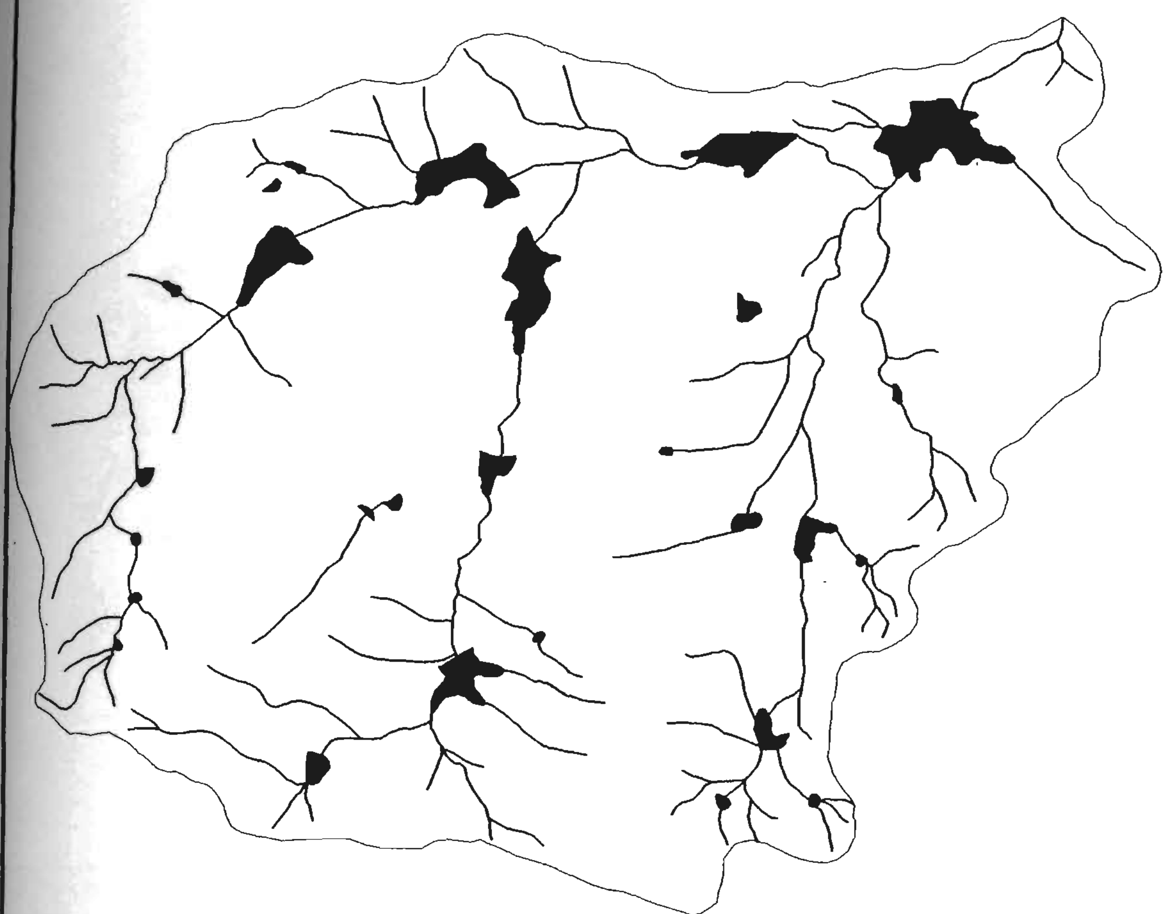
The surface and sub surface drainage of an area is very important from the viewpoint of hydrological regime of the area. Initially received rainfall is absorbed into the soil and once it gets saturated water flows out like surface run-off. The run-off varies with the surface conditions viz., length and degree of slopes, roughness, soil texture and structure, cover conditions and lithology of the terrain. Every geographical area has a defined drainage system/ pattern that determines the ground water potential.

4.1.1 Drainage Map (1:50,000 scale)

Drainage map was prepared at 1:50,000 scale which is presented in the Fig. 11 The study area was characterized by typical semi-arid drainage system with seasonal streams and depressions. Drainage pattern of the study area was found to be dendritic or subdendritic. This type of drainage, are characterized by irregular branching of tributary

Fig-11 DRAINAGE MAP (1:50,000 scale)

RAMANNAPET WATERSHED, NALGONDA DISTRICT, A.P.



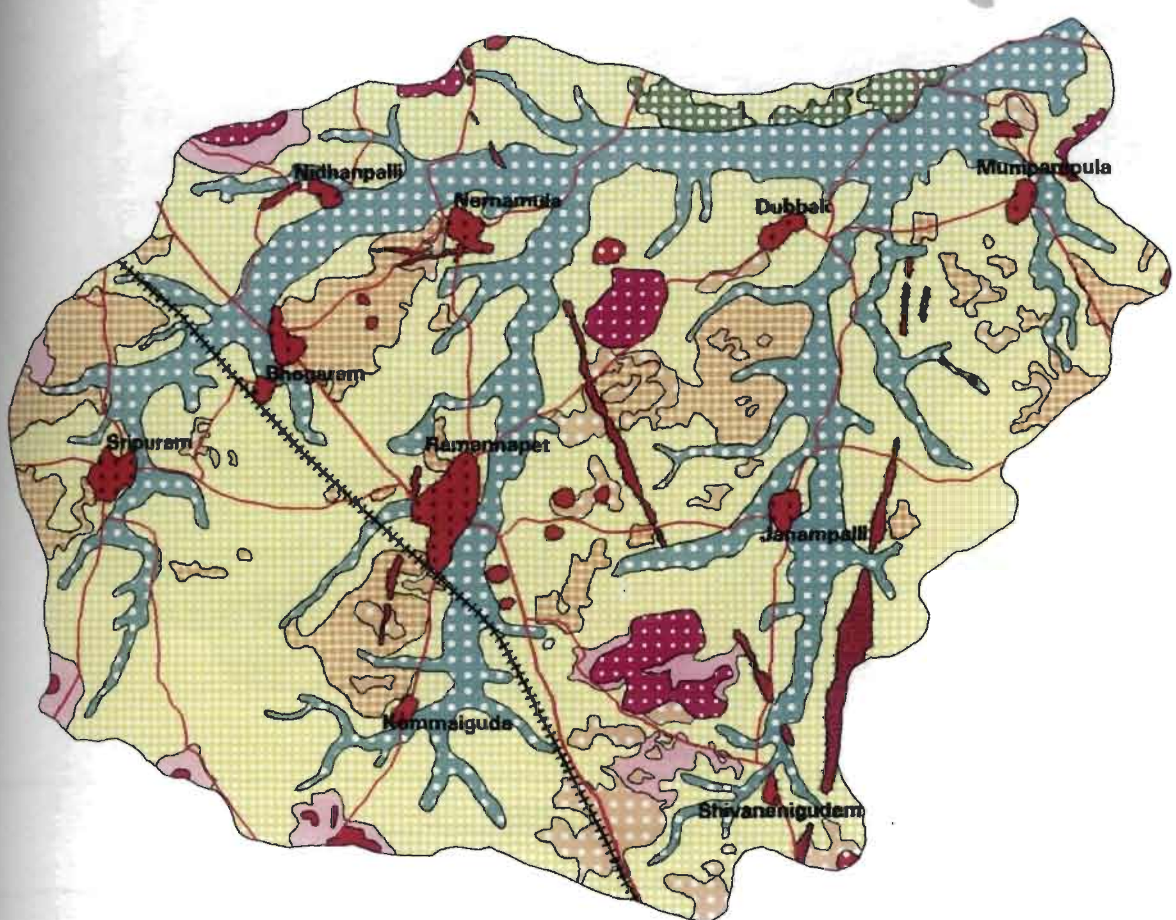
Scale

2 0 2 Kilometers

Legend

Mapping Symbol	
	Streams
	Water Body
	Watershed boundary

Fig-12 HYDROGEOMORPHOLOGICAL MAP (1:50,000 scale)
RAMANNAPETA WATERSHED, NALGONDA DISTRICT, A.P.



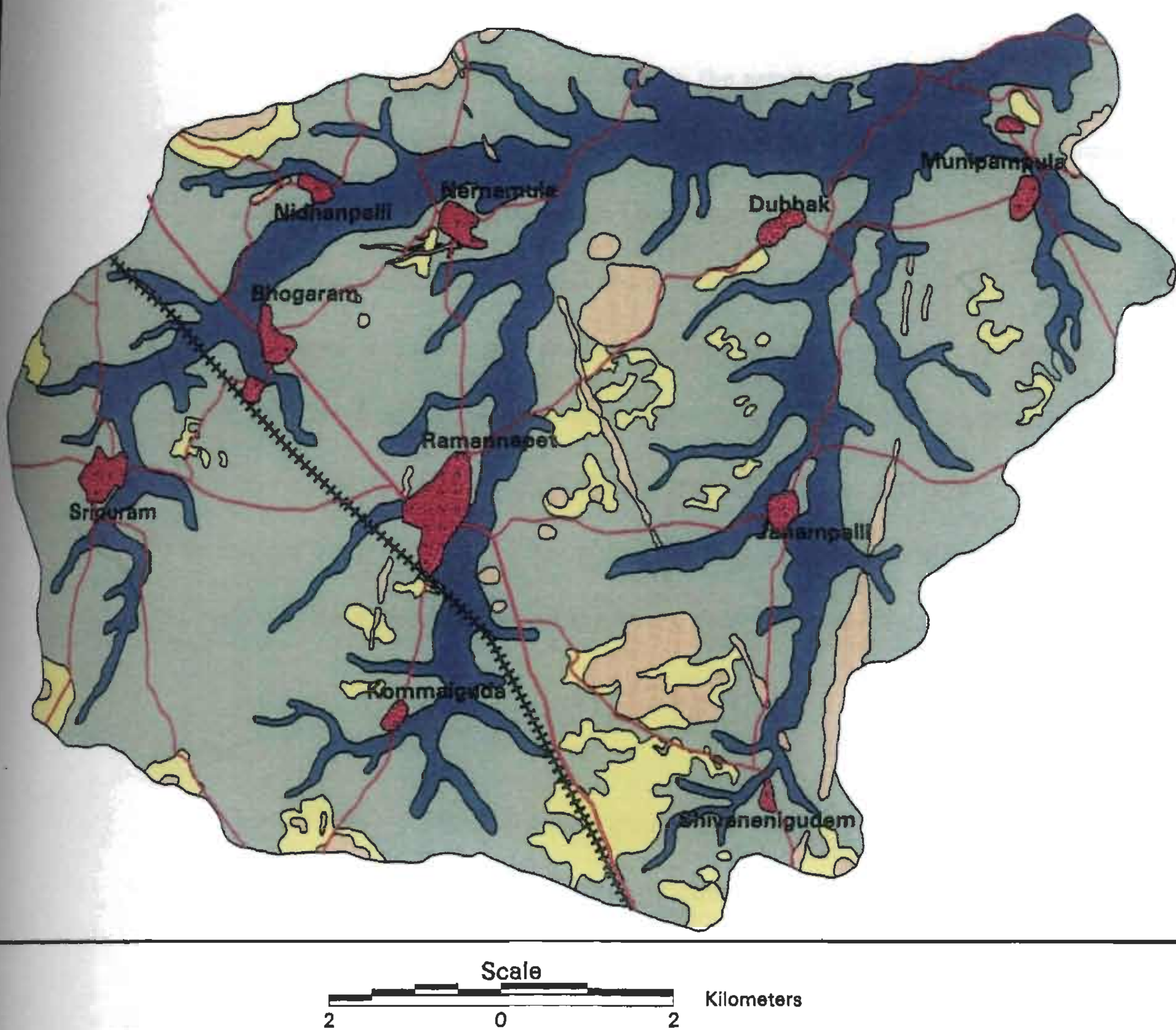
LEGEND

Scale 2 0 2 Kilometers

Map Symbol	Geomorphic Unit/ Landform	Rock type/ Lithology	Description	Groundwater Prospects	Remarks
	Valley Fill-Shallow (VFS)	RECENT Sand, Silt, Clay	*Formed between high relief/uplands and comprises of 0-5 mts fill material.*	Generally Good.Yields 150-200 lpm. Better prospects supported by fractures/lineaments	Recharge is good.Best site for ground water exploitation. Fluorine content is high.
	Buried Pediplain-Shallow Weathered (BPS-W)	ARCHAEAN (Peninsular Granite Gneissic Complex)	*Formed by the shallow overburden of transported/* foreign material on prior pediplain,the thickness of the overburden generally varies between 0-10 mts.	Good to Moderate .Yields 100-150 lpm. Fracture zones are suitable for groundwater exploitation.The area generally comprises of black soil.	*Recharge is poor when compared to PPM/* PPS.Fluorine content is high.
	Pediplain - Shallow Weathered (PPS)		Gently undulating plain ; highly weathered with shallow thickness and large in areal extent. Formed by the coale-*scence of several pediments and inselbergs of Archean* Granites. The depth of weathering generally ranges between 0-10 mts.	Good to Moderate .Yields 150-200 lpm.Better prospects along fractures / lineaments.The *sites along this zone are good for groundWater* exploitation.	Runoff is more.Recharge is less.Fracture zones are more suitable for ground water exploitation.Fluorine content is high. Generally associated with single crop.
	Pediplain Shallow Weathered-Eroded (PPS-E)		Same as PPS,*but it is relatively high upland and* erosion is dominant.	*Moderate to poor. Better prospects along the* fractures / lineaments.Fracture zones passing through Pediplain's acts as conduits for ground-water movement.	Runoff is generally more when compared to PPS.
	Pediment (P)		Gently undulating granitic plain often dotted with rock *outcrops,with or without thin veneer of soil cover.*	Generally poor.Yields 80-100 lpm.Acts as runoff zone.*Prospects limited to fracture/fissure zones.*	Mainly acts as runoff zone.Generally *associated with scrubs,single crop area.*
	Inselberg (I)		Isolated hill of massive type abruptly raising above surrounding plains.Formed by differential erosion.	Acts as runoff zone without any significant recharge or groundwater.	Acts as runoff zone.No scope of ground-water development.
	Pediment-Inselberg Complex (PIC)		Isolated low relief/hillock surrounded by gently sloping, smooth,erosional bed rock with thin veneer of soil cover or detritus.	Poor.Yields 35-50 lpm.Prospects limited to fractures/lineaments and some times controlled by joints.	Acts as runoff and recharge(less) zone,not suitable for ground water exploitation.
	Residual Hill (RH)		*Formed due to differential erosion and weathering;* occupies larger area when compared to inselberg. A more resistant rock formation stand as isolated hill.	*Acts as runoff zone.*	*Acts as runoff zone.*
	Denudational Hill (DH)		Formed due to differential erosion and weathering; *occupies larger area when compared to residual hill.* A more resistant rock formation stand as isolated hill.	Acts as runoff zone.	Acts as runoff zone.
	Dyke Ridge (DR)	Dolerite	A narrow linear resistant ridge formed by differential erosion.	Nil.Acts as barrier for groundwater movement.	Acts as runoff zone,but upstream side is good in prospect.

Fig-13 GROUND WATER POTENTIAL MAP

RAMANNAPET WATERSHED, NALGONDA DISTRICT, A.P.



Legend

Mapping symbol	Ground water prospects	Remarks	Area (ha) % to total area
	Good	Comprises of valleys and buried pediplain. Yields are100-200 lpm. Better prospects supported by fracture zones and lineaments.Recharge is good.	2352.21 (23.13)
	Moderate	Comprises of pediplain-shallow weathered (PPS) and PPS-eroded. Yields are 100-150 lpm. Better prospects along the fractures and lineaments. Run-off is more. Recharge is less.	6754.98 (66.42)
	Poor	Comprised of pediment and PIC. yields are 35-100 lpm.Prospects limited to fractures and lineaments.. Mainly acts as run-off zone. not suitable for exploitation	641.15 (6.30)
	Very Poor	Comprised of hills, inselbergs, dykes. Acts as run-off zones. Dykes act as barriers. No scope for ground water development.	421.34 (4.14)

streams in many directions and almost at any angle. In total 31 tanks are present in Ramannapet watershed of which 6 are large and remaining is small.

The water bodies appeared dark blue on the satellite image when filled with water and red when infested with weeds. In total, tanks occupied 356.02 ha, which constituted 3.50 per cent of the total watershed area. Total length of stream was found to be 92.6 km. General flow direction of the streams is North to North-East.

The stream frequency and drainage density are medium. Duff (1994) stated that, when the rocks have no conspicuous grain and offer nearly uniform resistance to erosion, a branch in drainage pattern is established, a tree-like in plan and described as dentritic. The undulating lands with medium stream frequency, drainage density and the density of water bodies in the watershed indicated moderate to rapid run-off potential of the soils.

4.2 Soils:

The relationship between physiography and soils is well established because the factors that are involved in physiographic process correspond to that of soil formation. This principle enabled to identify and map the soils of the study area under a given set of physiographic conditions.

Lithology of the study area was predominantly granite-gneis. Climate is semi-arid with distinct wet and dry periods. The temperature regime of the soils of the study area was 'Iso-hyperthermic, and the soil moisture regime was 'Ustic'. Mineralogy of the soils was 'mixed'.

Soils of the study area were studied at three different scales viz.,1:50000 scale, 1:25,000 and 1:12,500 scale through visual interpretation of the IRS-1D satellite data from different sensors. At larger scales, LISS-III +PAN merged data was utilized to delineate the soil physiographic units. Major physiographic units in the study area were identified based on image characteristics like tone, texture, size, shape, pattern, association etc.

4.2.1 Soil Mapping at 1:50,000 scale:

IRS-1 D LISS-III data was utilized at 1:50000 scale in identification of physiographic units and mapping the soils. The major physiographic units identified at this scale were hill, dyke, inselberg, pediment, pediment-inselberg complex, pediplain and valley. Based on erosion status and slope these major physiographic units were sub divided.

Altogether, ten soil mapping units were identified in the study area at 1:50000 scale. In these mapping units, soils were classified at the level of soil series or their associations.

Soil map of the study area prepared at 1:50,000 scale is presented in the fig no.14 Important physical, chemical and physico-chemical properties of the soils are presented in the Table no. 5. Morphological features of the profiles studied during the fieldwork are presented in the Appendix-I.

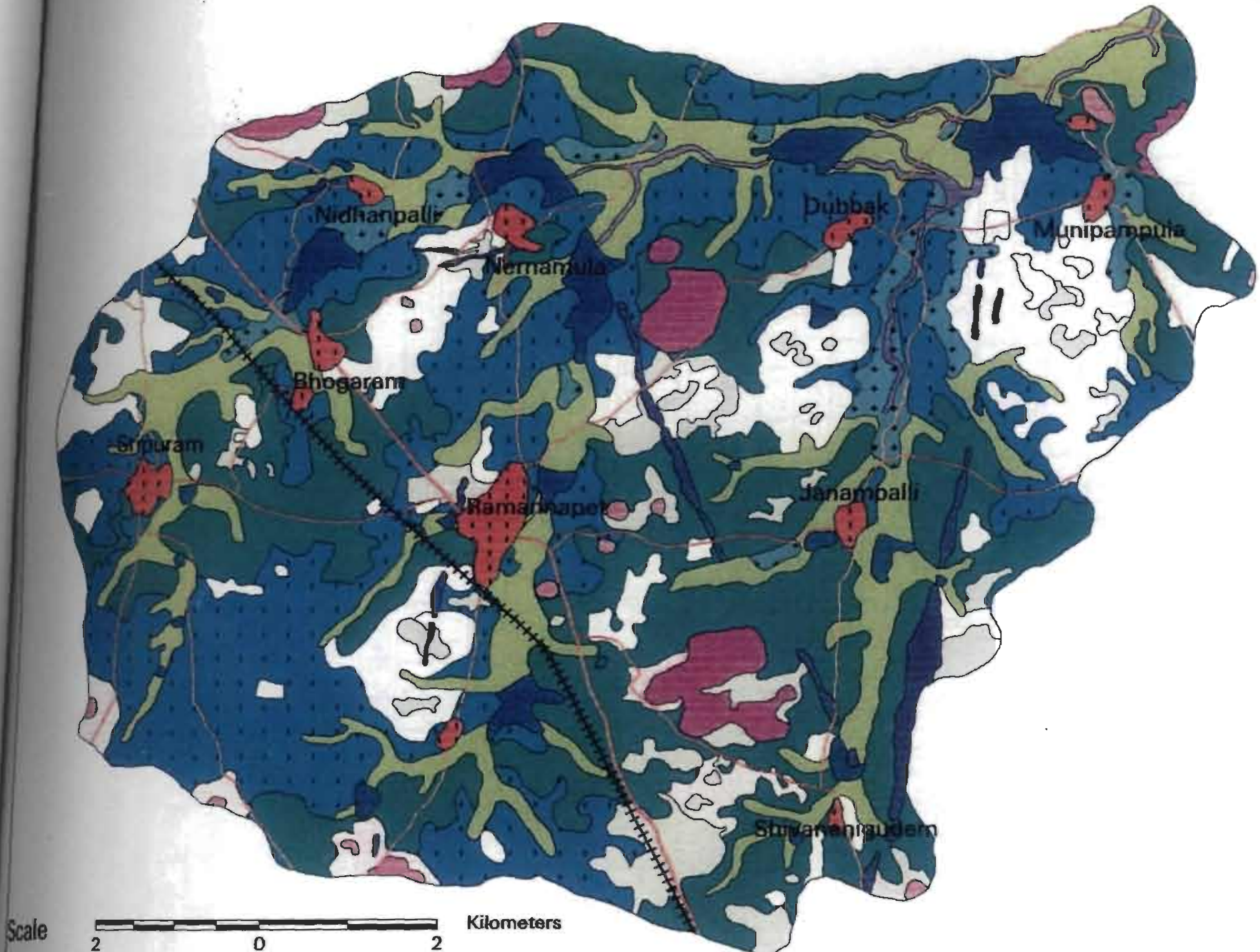
Soil mapping units identified in the study area at 1:50,000 scale are presented below.

4.2.1.1 Residual Hills (SMU-1)

This unit was identified by their very dark gray to black tones, irregular shape, with medium or coarse texture. Soils of this mapping unit were classified as Dubbak-1 series. Soils of this unit occurred on steep slopes ranging from 30-50 per cent. Boulders covered more than 75 per cent of the surface area. These soils were severely eroded and their location was confined to interspaces of the boundaries.

These soils were very shallow, excessively drained and runoff was very rapid and dark grayish brown colour. Slightly alkaline soil reaction and electrolyte conductivity

Fig - 14 : SOIL MAP (1:50000 SCALE)
RAMANNAPET WATERSHED, NALGONDA DISTRICT, A.P.



Legend

Mapping Unit	Physiographic Unit	Soil classification	Area (% to total area)
	Residual Hill	Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents and boulders	240.53 (2.36)
	Dykes	Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents and boulders	138.12 (1.36)
	Inselberg	Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents and boulders	38.88 (0.38)
	Pediment	Loamy skeletal, mixed, iso-hyperhtermic, Typic Haplustalfs	221.70 (2.18)
	Pediment inselberg complex	Loamy skeletal, mixed, iso-hyperhtermic, Typic Haplustalfs an rock outcrops	466.445 (4.587)
	Pediplain		
	Slightly eroded pediplain	Fine loamy, mixed, iso-hyperhtermic, Typic Haplustalfs / Fine, montmorillonitic, iso-hyperhtermic, vertic Haplustepts	2549.43 (25.07)
	Moderately eroded pediplain	Coarse loamy , mixed, iso-hyperhtermic,Typic Rhodustalfs / Loamy skeletal, mixed, iso-hyperhtermic, Typic Haplustalfs	3142.20 (30.90)
	Severely eroded pediplain	Coarse loamy, mixed, iso-hyperhtermic, Typic Ustorhtents	944.47 (9.29)
	Valley		
	Slightly eroded valley	Fine loamy Fluventic Haplustepts	1513.04 (14.88)
	Moderately eroded valley	Fine loamy Calcic Haplustepts / Loamy skeletal Calcic Haplustepts	309.42 (3.04)
	Stream		78.33 (0.77)
	Settlement		170.96 (1.68)
	Waterbody		356.03 (3.50)

Table: 5 **Physical, physico-chemical ,chemical analysis data of the soils in the study area**

Sample No	Depth (cm)	pH	EC (ds /m)	O.C (%)	Ca CO3 (%)	CEC c mol (P+)/ kg	Exchangeable cations c mol (P^+) / kg soil				ESP (%)	Sand (%)	Silt (%)	Clay (%)	Texture
							Na	K	Ca	Mg					
Dubbak-1 (Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents)															
1/1	0-13	8.07	0.292	0.72	22.5	15	0.635	0.484	8.61	3.04	4.23	62.26	14.25	23.22	sc
	13+	Bed rock													
Dubbak-2 (Coarse loamy, mixed, iso-hyperthermic, Typic Rhodustalfs)															
2/1	0-6	7.37	0.213	0.60	-	12.9	0.139	1.141	4.42	1.02	1.08	62.27	13.87	23.86	sl
2/2	6-20	6.85	0.162	0.58	-	12.43	0.217	3.179	4.80	0.41	1.74	53.18	14.76	32.06	scl
2/3	20-43	6.65	0.178	0.45	1.8	16.61	0.21	3.597	6.02	0.50	1.26	48.72	15.87	35.41	scl
2/4	43-60	6.38	0.227	0.22	2.3	17.72	0.496	0.62	8.20	1.62	2.79	47.23	16.02	36.75	sc
	65+	Weathered parent material													
Dubbak-3 (Loamy skeletal, mixed, iso-hyperthermic, Lithic Rhodustalfs)															
3/1	0-8	6.49	0.130	0.74	-	14.1	0.648	0.351	7.82	3.26	4.6	56.53	17.2	25.82	sl
3/2	8-26	6.65	0.061	0.58	-	17.2	0.835	0.24	10.4	5.44	4.9	50.82	18.21	30.97	scl
	26+	Bed rock													
Dubbak-4 (Loamy skeletal, mixed, iso-hyperthermic, Typic Haplustalfs)															
4/1	0-11	6.12	0.064	0.47	-	7.72	0.209	0.133	3.80	1.21	2.71	66.00	16.71	17.29	sl
4/2	11-23	6.29	0.057	0.29	2.6	12.61	0.261	0.138	6.42	1.64	2.07	57.12	19.86	23.02	scl
4/3	23-70	6.25	0.041	0.20	1.8	14.02	0.302	0.135	6.60	1.82	2.15	53.96	21.82	24.22	scl
	70+	Weathered parent material													
Ramannapet-1 (Fine loamy, mixed, iso-hyperthermic, Fluventic Haplustepts)															
5/1	0-10	8.052	1.387	0.82	9.2	30.82	3.126	0.589	17.9	5.22	10.1	58.53	8.16	33.48	scl
5/2	10-20	7.99	1.061	0.76	12.2	32.31	3.304	0.595	19.2	5.4	10.2	58.53	6.16	35.47	sc
5/3	20-34	8.43	0.557	0.54	8.7	27.50	4.689	0.349	15.6	4.4	17.7	65.29	5.24	29.47	scl
5/4	34-49	8.45	0.527	0.48	9.6	26.31	6.652	0.313	12	4.8	25.4	62.16	6.02	31.83	scl
5/5	49-68	9.70	2.18	0.21	10.8	27.33	14.52	0.343	6.22	3.66	53.1	60.17	8.21	31.62	scl
5/6	68-95	8.40	0.507	0.30	16.2	30.52	9.695	0.318	12.4	5.36	31.8	57.24	10.12	32.64	scl
5/7	95-105	8.35	0.459	0.18	16	28	5.348	0.185	14.8	5.40	19.1	54.71	13.22	32.07	scl

Sample No	Depth (cm)	PH	EC (ds /m)	O.C (%)	Ca CO3 (%)	CEC c mol (P+)/ kg	Exchangeable cations c mol (P^+) / kg soil Na	K	Ca	Mg	ESP (%)	Sand (%)	Silt (%)	Clay (%)	Texture
Ramannapet-2 (Fine loamy, mixed, iso-hyperthermic, Fluventic (sodic) Haplustepts)															
6/1	0-18	8.22	1.426	0.62	3.9	19.5	3.173	0.518	12.11	3.2	16.25	56.86	14.81	28.33	scl
6/2	18-47	9.83	1.440	0.55	5.3	25.9	10.43	0.556	8.64	3.87	40.3	52.21	16.27	31.52	scl
6/3	47-70	8.45	0.506	0.36	10.6	26.1	3.582	0.672	15.6	4.02	13.7	50.19	16.88	32.93	scl
6/4	70-90	9.49	1.887	0.28	5.2	29.1	13.38	0.902	10.22	2.46	45.9	47.67	17.31	35.02	scl
Nernamula-1 (Fine, montmorillonitic, iso-hyperthermic, Vertic Haplustepts)															
7/1	0-12	8.55	0.369	0.70	8.2	34.1	2.782	0.441	20.4	5.68	8.016	39.55	11.72	48.73	c
7/2	12-35	8.99	0.447	0.64	12.1	34.8	8.26	0.205	17.4	3.62	23.7	36.26	13.06	50.68	c
7/3	35-58	8.44	1.469	0.57	15.10	35.5	13.04	0.252	16.60	3.02	36.7	31.54	14.97	53.49	c
7/4	58-90	8.41	3.30	0.42	15.8	38.2	14.96	0.252	19.3	3.44	39.2	32.87	14.02	53.11	c
Bhogaram-1 (Loamy skeletal, mixed, iso-hyperthermic, Typic Rhodustalfs)															
8/1	0-8	6.97	0.13	0.51	-	9.73	0.625	0.441	4.96	2.18	6.42	80.42	7.42	12.34	ls
8/2	8-24	6.6	0.09	0.32	-	12.5	0.909	0.272	6.1	3.02	7.29	68.9	11.48	19.62	sl
8/3	24-45	6.77	0.104	0.18	1.1	16.6	0.66	0.123	11.8	2.81	4.02	55.23	18.71	26.06	scl
	45+	Weathered parent material													
Bhogaram-2 (coarse loamy, mixed, iso-hyperthermic,Typic Ustorthents)															
9/1	0-15	6.72	0.03	0.32	-	11.3	0.321	0.502	0.62	2.79	2.64	62.54	19.54	18.34	sl
9/2	15-30	6.79	0.03	0.28	-	14.1	0.291	0.141	6.59	1.79	2.15	53.96	20.82	25.22	scl
9/3	30-45	7.13	0.02	0.19	1.2	15.7	0.169	0.149	9.39	2.46	1.12	52.27	20.51	26.22	scl
	32+	Weathered parent material													
Bhogaram-3 (Fine loamy, mixed, iso-hyperthermic, Calcic Haplaustepts)															
10/1	0-10	8.25	0.802	0.68	12.7	22.43	0.943	0.251	13.62	4.82	4.21	48.86	22.26	28.88	scl
10/2	10-30	8.35	0.260	0.60	16.3	28.2	0.678	0.215	16.42	6.10	2.40	46.26	17.87	35.87	sc
10/3	30-50	8.10	0.248	0.47	21.8	33.71	2.522	0.251	18	8.88	7.48	52.91	9.87	37.22	sc
10/4	50-90	7.92	0.353	0.28	24.7	28.6	2.656	0.264	16	6.62	19.3	50.61	13.41	35.97	sc
10/5	90-107	7.13	0.163	0.20	9.2	34.1	3.304	0.303	14.16	8.88	9.67	58.34	19.53	32.16	scl
10/6	107-125	8.79	0.290	0.12	8.1	23.9	3.165	0.312	16.3	2.02	13.2	55.02	13.87	23.07	scl
10/7	125+	7.32	0.231	0.19	8.2	32.1	2.46	0.262	16.71	9.02	7.52	52.16	14.29	33.55	scl

Sample No	Depth (cm)	PH	EC (ds/m)	O.C (%)	Ca CO3 (%)	CEC c mol (P+)/kg	Exchangeable cations c mol (P^+) / kg soil				ESP (%)	Sand (%)	Silt (%)	Clay (%)	Texture
							Na	K	Ca	Mg					
Bhogaram-4 (Coarse loamy, mixed, iso-hyperthermic, Typic Haplustalfs)															
11/1	0-12	7.35	0.221	0.54	-	11.4	0.304	0.521	6.22	2.82	2.65	64.54	20.54	15.34	sl
11/2	12-28	7.39	0.161	0.36	-	12.5	0.652	0.379	7.26	2.90	5.20	58.26	21.27	20.47	scl
11/3	28-50	7.04	0.065	0.24	1.07	16.9	0.696	0.199	10.2	3.86	4.11	53.87	22.42	23.71	scl
	50+	Weathered parent material													
Sripuram-3 (Fine loamy, mixed, iso-hyperthermic, Typic Haplustalfs)															
12/1	0-10	6.91	0.171	0.80	-	10.17	0.121	0.292	5.70	1.80	1.18	62.55	15.33	22.12	sl
12/2	10-23	6.85	0.154	0.72	-	12.43	0.165	0.164	6.82	2.02	1.32	53.96	16.21	29.87	scl
12/3	23-46	7.15	0.117	0.40	2.1	15.52	0.174	0.142	9.44	2.40	1.12	52.27	16.51	31.22	scl
12/4	46-60	7.73	0.209	0.48	6.7	14.78	0.678	0.105	10.27	2.52	4.58	50.63	18.26	31.21	scl
	70+	Weathered parent material													
Nidhanpalli-1(Loamy skeletal, mixed, iso-hyperthermic, Calcic Haplaustepts)															
13/1	0-15	9.13	1.11	0.49	16.30	28.1	1.762	0.315	18.4	6.23	6.27	58.26	07.87	33.87	scl
13/2	15-35	9.42	0.59	0.26	21.80	29.30	1.869	0.251	15.2	6.71	6.39	59.34	20.53	20.13	scl
13/3	35-50	8.96	0.59	0.31	25.56	23.8	2.159	0.321	15.9	3.12	9.07	56.12	15.62	28.26	scl
	50+	8.79	0.66	0.13	30.52	24.6	1.42	0.351	14.9	4.02	5.77	57.26	16.02	26.72	scl
Nidhanpalli-2 (Coarse loamy, mixed, iso-hyperthermic, Typic Haplustalfs)															
14/1	0-16	6.97	0.06	0.47	-	13.9	0.156	1.562	4.85	1.12	1.13	72.27	8.87	18.88	sl
14/2	16-26	6.75	0.082	0.42	-	13.4	0.317	3.156	5.32	0.65	2.36	58.18	12.76	28.06	scl
14/3	26-46	6.56	0.071	0.38	1.2	17.5	0.31	4.01	7.12	0.62	1.77	46.72	17.87	35.41	scl
14/4	46-62	6.42	0.05	0.27	2.1	17.2	0.32	3.56	8.32	1.25	1.86	46.23	17.12	36.65	sc
	62+	Weathered parent material													
Nidhanpalli-3 (Coarse loamy, mixed, iso-hyperthermic, Lithic Haplustalfs)															
15/1	0-12	6.97	0.13	0.47	-	10.1	0.757	0.541	5.36	2.42	7.47	64.53	15.62	19.82	sl
15/2	12-25	6.6	0.09	0.36	-	12.5	0.909	0.272	6.1	3.02	7.29	55.87	21.42	22.71	scl
15/3	25-50	6.82	0.06	0.27	2.2	15.6	0.792	0.221	9.98	3.42	5.1	54.26	20.46	25.28	scl
	50+	Weathered parent material													

value of 0.292 ds /m were recorded in the surface horizon. Organic carbon status of the surface horizon was medium (0.72 per cent). High calcium carbonate content (22.5 per cent) was recoded in the surface horizon. Surface horizon had sandy clay texture with 62.26 percent sand, 14.25 percent silt and 23.22 per cent clay. CEC of the soil was 15.00 c mol (P^+)/ kg soil and calcium was the dominant cation on the exchange complex followed by magnesium. Soils of this series were classified as Loamy skeletal, mixed, iso-hypothermic Lithic Ustorthents. This mapping unit occupied a total area of 236.85ha (2.33 percent of the area of the watershed).

4.2.1.2 Dyke (SMU-2)

These units were identified on FCC print as linear features cutting across the landscape. These units appeared in very dark grey or black in colour with coarse texture. Soils of this mapping area were classified as Dubbak-3 series. Soils in this mapping unit occurred on moderately steep slopes (15-30 per cent) and the length of the slope varied from 50 to 100m. Boulders covered 60-65 per cent of the surface area and soils occurred in spaces between the boulders and relatively less sloping area.

These soils were very shallow in their depth. Colour of the soil in the surface horizon was dark reddish brown, where as in the sub-surface horizons it dark red.

These soils were neutral in their reaction and were non-saline. Texture of the soils was sandy loam in the surface horizon and sandy clay loam in the sub-surface horizon. Surface horizon had 56.53 per cent sand and 25.82 per cent clay and 17.20 per cent silt. Sand content decreased to 50.82 per cent and clay and silt contents increased to 30.97, 18.21 percent, respectively, with increasing depth. These soils had medium organic carbon status in the surface and sub-surface horizons. Cation Exchange Capacity of the surface horizon was units 14.1 c mol (P^+) /kg soil and it increased with increasing depth of soil. Calcium was the dominant cation on the exchange complex followed by magnesium in all the horizons.

These soils were excessively drained, severely eroded and the run-off was very rapid. Dubbak-3 series soils were classified as Loamy skeletal, mixed, iso-hypothermic Lithic Ustorthents. This mapping unit occupied a total area of 138.12 ha i.e.1.36 percent of the total area of the watershed.

4.2.1.3 Inselbergs: (SMU-3)

These units were identified on the FCC units as rounded features of very dark gray to black tones with coarse texture, small in size and isolated in their locations. These soils were also classified as Dubbak-1 series soils. Soils of this mapping unit occurred in Patches confined to interspaces of the boulders. This unit is very bouldry with more than 75 per cent of area occupied by boulders and stones. These soils occur on steep slopes, excessively drained, with rapid runoff and were severely eroded.

Physical, chemical and physico-chemical properties of (<2mm fraction) of the soil were similar to that those of soils of the present on the hills. These soils are classified as Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents. This mapping unit constituted 0.49 percent to the total area of the watershed with an area of 49.5 ha.

4.2.1.4 Pediment: (SMU-4)

This mapping was found to be associated with residual hills, dykes, inselbergs and occurring in between the hills and pediplains. Soils in this mapping unit belonged to Dubbak-4 series. This unit was identified on the image by its light gray colour and medium texture.

Dubbak-4 series soils were located on landscape with 3-5 per cent slope and were moderately eroded. Run off in this unit was moderate and these soils were well drained. Surface stoniness of the area ranged from 30-40 percent and the size of the stones varied from 2.5 to 7.5cm. Natural vegetation in this mapping unit was constituted by neem, Acacia spp, thorny shrubs etc.

Dubbak-4 series soils were neutral in reaction and were non-saline. Texture of the surface soil was sandy loam and coarse gravel constituted 30 per cent by weight. Organic carbon status of the soils was low through out the depth of the profile (0.47per cent to 0.2 per cent). CEC of the soils was low (7.72 c mol (P^+) /kg soil) in the surface horizon and it increased with depth. Calcium was the dominant cation on exchange complex followed by magnesium in surface as well as in sub surface layers. Texture of the sub surface horizon was sandy clay loam. Sand content decreased with depth (66.00 per cent to 53.96 per cent) and the silt and clay contents increased with depth from 16.71 per cent to 21.82 per cent and 17.29 per cent to 24.22 per cent, respectively. These soils were classified as Loamy skeletal, mixed, iso-hyperthemic, Typic Haplustalfs. Dubbak–4 series soils constituted 1.91 per cent to the total area of the watershed (193.88 ha)

4.2.1.5 Pediment-Inselberg complex: (SMU-5)

In this mapping unit pediment was found to be closely associated with inselbergs and the soils could not be separated from the inselbergs at this scale. These soils had shallower depth (52 cm) and higher surface stoniness compared to the pediment soils. This unit appeared as bluish gray on the FCC print with coarse texture. Quarried portion of the inselberg appeared blue on the image. Inselbergs occupied 40-75 per cent of the total surface area in this mapping unit. Soils of this mapping unit also belonged to Dubbak-4 series. Dubbak-4 series soils occurred on moderate sloping landscape with rapid run-off. These soils were severely eroded and drainage class was somewhat excessive. Physical, chemical and physico-chemical properties of (<2mm fraction) of these soils were similar to those of soils of the pediment. These soils were classified as

Loamy skeletal, mixed, iso-hyperthemic, Typic Haplustalfs. This mapping unit constituted 5.04 per cent of the total area covering an area of 513.33 ha.

4.2.1.6 Pediplain

Pediplain is the largest physiographic physiographic unit identified in the study area. This was further sub-divided on the basis of erosion as slightly eroded pediplain, moderately eroded pediplain and severely eroded pediplain. Results of these mapping units are as follows.

4.2.1.6.1 Slightly eroded pediplain(SMU-6)

This is the second most dominant mapping unit of the study area, covering an area of 2672.41 ha, which constituted 26.27 per cent of the total area of the watershed. These soils appeared greenish yellow to greenish on the FCC print with smooth texture.

Association of two soil series was noticed in this mapping unit viz., Sripuram-3 and Nernamula-1 of which Sripuram-3 was the dominant series and Nernamula-1 was the sub-dominant series. Sripuram-3 series soils were found to occur in relatively higher elevation ranging from 340m to 300m. Nernamula-1 series soils were present on the landscape with elevation less than 280 m and were located nearer the Musi river compared to the Sripuram-3 soils.

Soils of the mapping unit were present on the very gently sloping terrain with 1-3 per cent slope. These soils were slightly eroded and run-off was slow. Drainage class of the soils was well drained. Surface stoniness of the area was less than 3 per cent and the size of the stones was less than 2.5cm in diameter. Rock outcrops were not present in this mapping unit. Natural vegetation of the unit was constituted by Acacia spp, neem, Borassus spp.

Sripuram-3 soils

Sripuram-3 soils were moderately deep (76cm) with distinct argillic horizon. These soils were neutral in reaction and non-saline through out the depth. Organic carbon status of the surface horizon was medium and it was medium to low in the sub-surface horizons. Organic carbon content decreased with depth. Free calcium carbonate was not present in the surface horizon. However, in the sub-surface horizons the $CaCo_3$ increased with depth (2.1 to 6.7 percent). Texture of the surface soils was sandy loam with 62.55 per cent sand, 15.32 per cent silt and 22.12 per cent clay. In the sub-surface horizons the texture was sandy clay loam. Increasing clay content and silt content with depth and decreasing sand content with depth made the sub-surface horizon finer in their texture compared to the surface layers. An increasing trend of CEC with depth was observed in these soils (10.2 c mol (P^+) / kg soil to 15.5 c mol (P^+) /kg soil). These soils were non-sodic with calcium as dominant cation on the exchange sites. Soils of this Sripuram -3 were classified as Fine loamy, mixed, iso- hyperthermic, Typic Haplustalfs.

Nernamula-1

These soils were moderately deep (90cm) and slightly alkaline to moderate strong alkaline in their reactions. However, no definite trend of pH with depth was observed in these soils. Relatively higher electrolyte conductivity of the soils was observed in these soils. EC values ranging between 0.447 ds /m to 3.30 ds /m were recorded in different horizon. An increasing trend with increasing depth was observed in these soils. Organic carbon status was medium in upper two horizons and low in lower two horizons. An increasing trend of $CaCO_3$ with depth was observed in these soils. The free $CaCO_3$ value increased from 8.2 per cent in the surface horizon to 15.8 per cent in the lower horizon. In correspondence with the increasing clay content and silt contents with the depth the CEC value also increased with depth. CEC values of different horizons increased from 34.1 c mol (P^+) / kg soil to 38.2 c mol (P^+) / kg soil.

Texture of the soils was clay through out the depth of the profile. A slight increase in clay content with depth was noticed in these soils. Sand content decreased and silt content increased with depth. Calcium was found to be the dominant cation on exchange sites, followed by sodium. ESP value of the soils indicated that these soils were sodic in their nature. ESP value ranging from 8.016 in the surface horizon to 39.2 in lower horizon was observed in the profile. The soils of Nernamula-1 series were classified as Fine, Montmorillonitic, Vertic Haplustepts.

4.2.1.6.2 Moderately eroded Pediplain (SMU-7)

This mapping unit appeared light yellow on the satellite imagery. This unit is the largest mapping unit of the watershed in term of the area (3028.95 ha) and it constituted 29.78 per cent to the total area.

In this mapping unit association of two series viz., Dubbak-2 and Bhogarm-1 were observed, of which Dubbak-2 was the dominant series and Bhogarm-1 was the sub-dominant series.

These soils occurred on a landscape with 3-5 per cent slope and were moderately eroded. Run-off in this unit was moderate and these soils were well drained. Surface stoniness of the area varied between 3-15 percent.

Dubbak-2 Series

Soils of this series were moderately shallow in their depth (60cm) with Distinct argillic horizon in sub-surface layers. These soils were neutral in reaction and were non-saline. Texture of the surface horizon was sandy loam, and in case sub-surface horizons the texture was sandy clay loam. Coarse fragments component increased with depth in these soils. In surface soils, gravel content was 5 per cent and in case of sub-surface layers the gravel content increased from 50 to 60 per cent.

Sand content in different horizons varied from 62.27 per cent to 47.23 per cent and it exhibited a decreasing trend with depth. Silt and clay contents varied from 13.87 per cent to 16.02 per cent and 23.86 to 36.75 per cent, respectively. An increasing trend with depth was noticed in these particle size classes. CEC values varied from 12.9 to 17.7 c mol (P^+) / kg soil and they exhibited an increasing trend with increasing depth of the soil. Exchange sites were predominantly occupied by calcium followed by potassium and magnesium. Organic carbon status of the surface horizons was medium whereas it was low in case of sub-surface horizons. Soils of this series were classified as coarse loamy, mixed, iso-hyperthermic Typic Rhodustalfs

Bhogarm-1

The soils of Bhogaram-1 series soils were shallow in their depth with coarse texture. These soils were moderately eroded and well drained. Stones of 2.5 to 7.54 cm size covered in 15-40 per cent of the surface area. These soils were present on landscape with 3-5 per cent slope. They were well drained and had moderate run-off potential. An increasing trend in the case of silt and clay contents and a decreasing trend in clay content were recorded with increasing depth in this series. These soils were neutral in their reaction and were non-saline. Organic carbon status of the surface as well as the sub-surface horizons was low. Low CEC values ranging between 9.73 to 16.6 cmol (P^+)/ kg soil were observed in different horizons. An increasing trend with depth was recorded in CEC values with dominance of calcium on the exchange sites followed by magnesium. Soils of this series were classified as Loamy skeletal, mixed, iso-hyperthermic Typic Rhodustalfs

4.2.1.6.3 Severely eroded pediplain (SMU-8)

These soils constituted 9.465 per cent of the area of the watershed covering an area of 962.61 ha. These units appeared as whitish yellow to white with coarse texture on the FCC. Soils of this mapping unit belonged to Bhogarm-2 series.

The soils of Bhogarm-2 series were present landscape with 8-10 per cent slope and were shallow in depth (32cm). These soils were severely eroded, somewhat excessively drained with rapid run-off. Moderate-alkaline soil pH and electrolyte conductivity values ranging between 0.151 to 0.155 ds /m were observed in these soils. High $CaCo_3$ content varying from 21.5 per cent (surface layers) to 24.6per cent (sub-surface horizon) was recorded in this profile. Sand content of the surface horizon was 75.6 per cent and clay and silt contents were 13.68 and 11.26 per cent, respectively, which resulting in loamy sand texture of the soil. Sub surface soil texture was sandy loam with 66.32 per cent sand, 12.08 per cent silt and 21.60 per cent clay. CEC values varied from 14.5 to 16.6 cmol (P^+)/ kg soil and these values increased with depth. Dominant cation on the exchange sites was calcium followed by magnesium. These soils were classified as Coarse loamy, mixed, iso-hyperthermic, Typic Ustorthents.

4.2.1.7 Valley

Soils of this physiographic unit were found to occur along stream courses and areas adjacent to stream courses. Soils of the valley were identified with their characteristic bluish tone on the FCC print. This physiographic unit was further subdivided based on the erosion status as slightly eroded valley and moderately eroded valley.

4.2.1.7.1 Slightly **eroded valley (SMU-9)**

Soils of this mapping unit were classified as Fine loamy, mixed, iso-hyperthermic, Fluventic Haplustepts of Ramannapet-1 series. This mapping unit exhibited bluish to dark bluish tones with smooth texture on the image. This unit constituted 14.39 per cent of the total watershed area covering a total area of 1464.08 ha.

Soils in this mapping unit occurred on very gently sloping land and were none to slightly eroded. Drainage of the soils was imperfect and run-off was very slow. Coarse fragment in the surface as well as sub surface layers were very low (less than 1 per cent). Length of the slope varied from 300 to 600m.

Depth of Ramannapet-1 series soils was 105 cm. Surface horizon had 33.48 per cent clay, 8.16 per cent silt and 58.53 per cent sand contents resulting in sandy clay loam texture. With depth, particles of different size classes (sand, silt and clay) did not exhibit any definite trend. In the sub-surface horizons also the texture was predominantly sandy clay loam. However, sandy clay texture was noticed in the B_{11} horizon. These soils exhibited slightly alkaline pH values (7.99 to 8.45) and EC value were below 1.387 ds /m, except in the B_{22} where relatively higher pH value of 9.7 and EC value of 2.18 were recorded. In the surface horizon the organic carbon content was high (0.82 per cent) and its content decreased with depth.

CEC values, in correspondence, with the clay content, did not exhibit any significant trend with depth. However, relatively higher CEC values ranging from 26.3 to 32.8 c mol (P^+) / kg soil were recorded in different horizons. Exchange sites were predominantly occupied by Calcium in the entire horizons except in horizons B_{22}, where in sodium was the dominant cation. Up to 49cm depth second most dominant cation on exchange sites was magnesium. Predominance of Calcium was followed by sodium in the depth ranging from 68 to 105 cm.

4.2.1.7 .2 Moderately eroded valley (SMU-10)

In this mapping unit association of two series viz., Bhogaram-3 and Nidhanpalli-1 was noticed. Bhogaram – 3 was the dominant series and Nidhanpalli-1 was sub-dominant series. These mapping units appeared bluish white / white in association with slightly eroded valley on the FCC.

In this mapping unit soils were found to occur on gently sloping landscape. These soils were moderately eroded, with imperfect drainage and slow run-off. These soils covered an area of 304.47 ha, which constituted 2.99 per cent to the total area.

This unit consists of soils located on gently sloping lands (1-3per cent) moderately eroded with moderate run-off. These soils were moderately well drained and had 15-40 per cent of the surface area covered by the stones

Bhogaram – 3

Soils of this series were deep (125 cm) and stones of 2.5cm size covered 5-10 per cent of the surface area. Rock outcrops were not present in this mapping unit.

These soils were slightly alkaline in their reaction and non- saline. Organic carbon status of the surface horizon was medium whereas it was low in the sub-surface horizons. Calcium carbonate content ranging from 8.1 per cent to 24.7 per cent was recorded in different horizons. The $CaCO_3$ content increased with depth up to 90cms depth below which a decreasing trend was noticed. CEC values ranging between 22.4 to 34.1 c mol (P^+) / kg soil were noticed in different horizons. These values exhibited increasing trend up to 50cms depth below which no definite trend was recorded. On the exchange sites calcium was the dominant cation followed by the magnesium.

Sandy clay loam texture was noticed in the surface horizon where as the texture of sub-surface horizons was sandy clay up to 90cm depth, below which it was sandy clay loam and sandy clay. Sand content varied between 46.26 to 58.34 per cent, whereas, silt content varied from 9.87 to 22.26 per cent. Clay content of different horizons ranged from 23.07 to 37.22 per cent. Sand, silt and clay contents did not exhibit any trend with depth. These soils were classified as Fine loamy, mixed, iso-hyperthemic Calcic Haplustepts.

Nidhanpalli-1 Series

This unit consists of soils located on gently sloping lands (3 per cent) with 15-20 per cent of the surface area occupied by the stones. These soils were moderately well drained, moderately eroded, with moderate run-off.

Strong alkaline reaction in the surface layers (9.13 to 9.42) and moderately alkaline reaction in the sub surface layers (8.79 to 8.96) was observed in the profile. Higher $CaCo_3$ content ranging from 16.3 to 30.52 per cent was recorded in the soils with an increasing trend in depth. Even though the Ca was the dominant cation on the exchange sites ESP values ranging from 6.27 to 9.07 were observed in different horizons. Sandy clay texture was observed in the surface horizon. In the sub surface horizons the texture was sandy clay loam. With depth, no definite trend with regard to sand, silt or clay contents was noticed. Organic carbon status of all the horizons was low. These soils were classified as Loamy skeletal, mixed, iso-hyperthermic, Calcic Haplustalfs.

4.2.2 Mapping of Soils at 1:25,000 scale

Mapping of soils at 1:25,000 scale was done for soils of Bhogaram mini-watershed of 2493 ha geographical area. It was selected as a representative of the Ramannapet watershed for conducting the soils surveys for large areas at large scale is time consuming and tedious. Soil map of Bhogaram watershed is presented in the fig 15. The legend for the map is presented in the fig.16

At this scale, a hybrid satellite data product (PAN + LISS-III merged data) was utilized to delineate the soil physiographic units. The physiographic units identified at 1:50000 scale were sub divided based on broad land use categories at this scale. In total 15 soils mapping units were at this scale. The soils were classified up to series level. The soil mapping units that were encountered in this unit is listed here below

FIG15SOIL MAP (1 : 25,000 scale)

BHOGARAM MINI-WATERSHED, NALGONDA DISTRICT, A.P.

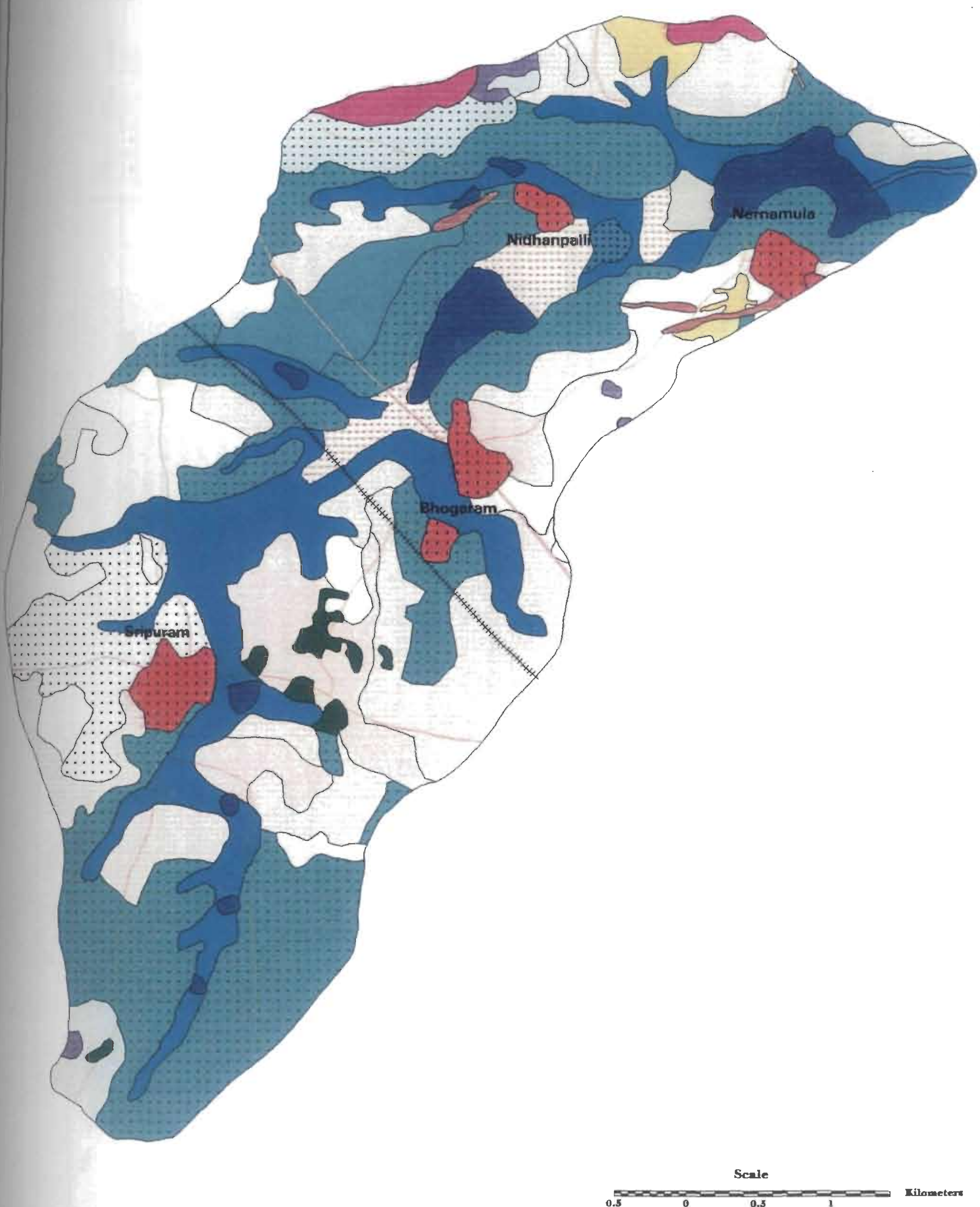


FIG 16 Legend of the soil map (1:25000)

Mapping symbol	Soil - Physiographic Unit	Series name	Soil Classification	Area (ha) (% to total area)
SMU-1	Hill	Dubbak-1	Rocks associated with Loamy skeletal, Mixed, Iso-hyperthermic, Lithic Ustorthents	29.646 (1.189)
SMU-2	Dyke	Dubbak-3	Rocks associated with Loamy skeletal, Mixed, Iso-hyperthermic, Lithic Ustorhtents	10.162 (0.407)
SMU-3	Inselberg	Dubbak-1	Rocks associated with Loamy skeletal,Mixed, Iso-hyperthermic, Lithic Ustorhtents	10.886 (0.436)
SMU-5	Pediment Inselberg Complex	Dubbak-4	Boulders associated with Loamy skeletal, Mixed, Iso-hyperthermic,Typic Haplustepts	25.851 (1.036)
	Pediment			
SMU-41	Pediment- uncultivated	Dubbak-4	Loamy skeletal Mixed, Iso-hyperthermic,Typic Haplustepts	31.772 (0.125)
SMU-42	Pediment-cultivated	Nidhanpalli-3	Coarse loamy Mixed, Iso-hyperthermic, Lithic Haplustalfs	48.088 (1.928)
	Pediplain			
	Slightly eroded pediplain			
SMU-61	Sli. eroded pediplain-uncultivated	Bhogaram-4	Loamy skeletal,Mixed, Iso-hyperthermic, Typic Haplustalfs	82.792 (3.320)
SMU-62	Slightly eroded pediplain-cultivated	Sripuram-3	Fine loamy,Mixed, Iso-hyperthermic, Typic Hapalustalfs	801.868 (32.16)
	Modearately eroded pediplain			
SMU-71	Mod. eroded pediplain-uncultivated	Bhogaram-1	Loamy skeletal, Mixed, Iso-hyperthermic, Typic Rhodustalfs	167.285 (6.710)
SMU-72	Mod. eroded pediplain-cultivated	Dubbak-2	Coarse loamy, Mixed, Iso-hyperthermic, Typic Rhodustalfs	297.99 (11.953)
	Severely eroded pediplain			
SMU-81	Sev. eroded pediplain-uncultivated	Sripuram-4	Coarse loamy, Mixed, Iso-hyperthermic, Typic Ustorthents	332.881 (13.352)
	Valley			
	Slightly eroded valley			
SMU-91	Slightly eroded valley-uncultivated	Ramannapet-2	Fine loamy, Mixed, Iso-hyperthermic, Fluventic (Sodic) Haplustepts	7.326 (0.293)
SMU-92	Slightly eroded valley-cultivated	Ramannapet-1	Fine loamy, Mixed, Iso-hyperthermic, Fluventic Haplustepts	368.262 (14.771)
	Modeartely eroded calley			
SMU-101	Mod. eroded valley-uncultivated	Nidhanpalli-1	Loamy skeletal, Mixed, Iso-hyperthermic, Calcic Haplustepts	24.314 (0.975)
SMU-102	Mod. eroded valley-cultivated	Bhogaram-3	Fine loamy, Mixed, Iso-hyperthermic, Calcic Haplustepts	63.939 (2.564)
SMU-11	Stream			3.117 (0.125)
SMU-12	Settlement			72.097 (2.891)
SM	Water body			92.498 (3.710)
	Rock out crops			22.23 (0.891)

SMU-1 Residual hill

SMU-2 Dyke

SMU-3 Inselberg

Pediment-

SMU-41 Pediment- Uncultivated

SMU-42 Pediment- Cultivated

SMU-5 Pediment- inselberg complex

Pediplain

Slightly eroded pediplain-

SMU-61 Slightly eroded Pediplain-Uncultivated

SMU-62 Slightly eroded Pediplain-Cultivated

Moderately eroded pediplain

SMU-71 Moderately eroded Pediplain -Uncultivated

SMU-72 Moderately eroded Pediplain- Cultivated

Severely eroded pediplain -

SMU-81 Severely eroded pediplain -Cultivated

Valley

Slightly eroded valley

SMU-91 Slightly eroded valley-Uncultivated

SMU-92 Slightly eroded valley-Cultivated

Moderately eroded valley

SMU-101 Moderately eroded valley -Uncultivated

SMU-102 Moderately eroded valley -Cultivated

Results obtained on morphological, physical, physico-chemical characteristics for the above mentioned mapping units are presented as follows.

4.2.2.1 Residual hill (SMU-1)

This mapping unit was encountered in a total area of 29.64 ha, which constituted 1.18 per cent to the total area of the mini-watershed. Soils of this mapping unit were classified as Dubbak-1 series. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils were similar to those of Dubbak-1 series soils presented in 1:50,000 scale.

4.2.2.2 Dyke (SMU-2):

Soils of this mapping unit were classified as Dubbak-3 series. These soils covered a total area of 10.16 ha, i.e. 0.41 per cent of the total area of the mini-watershed. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils are similar to those of Dubbak-3 series soils presented in 1:50,000 scale.

4.2.2 .3 Inselberg (SMU-3):

This mapping unit was encountered in a total area of 10.88 ha (0.44 per cent). Soils of this mapping unit belonged to Dubbak-1 series. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils were similar to those of Dubbak-1 series soils presented in 1:50,000 scale.

4.2.2.4 : Pediment:

This physoigraphic unit was sub-divided on the basis of land use/ land cover at this scale as pediment-uncultivated and pediment cultivated. Results of these mapping units are as following.

4.2.2.4.1 Pediment Uncultivated (SMU-41):

Soils of this mapping unit were classified as Dubbak-4 series. These soils were found to occur in a total area of 31.77 ha, which constituted 1.27 per cent of the total area of the mini-watershed. Taxonomic classification, properties of the soils and morphology of the pedons were similar to those of Dubbak-4 series soils, as described in 50,000 scale.

4.2.2.4.2 Pediment Cultivated (SMU-42)

This mapping unit of Nidhanpalli-3 series appeared grayish or grayish white with medium texture on the FCC print. These types of soils were present in a total area of 48.08 ha, which constituted 1.93 per cent to the total area of the mini-watershed. These soils were moderately shallow, occurred on 3-5 per cent slopes. Nidhanplli-3 series soils were well drained, moderately eroded with moderate run-off. These soils were neutral in reaction and non-saline. Stones of 2.5-7.5 cm diameter cover 40 per cent of the surface area.

Texture of the surface layer is sandy loam with 64.53 per cent sand, 15.62 per cent silt and 19.82 per cent clay. Distinct argillic horizon was observed in the sub-surface layers. These soils had low CEC values ranging from 10.1 - 15.6 cmol (P^+)/kg soil, and these values increased with depth. Dominant cation on the exchange sites was calcium followed by magnesium. Organic carbon status of the surface as well as sub surface horizons low. These soils were classified as Fine loamy, mixed, iso-hyperthermic, Typic Haplustalfs.

4.2.2.4 Pediment- inselberg complex (SMU-5)

Soils of this series were present in an area of 25.85 ha (1.03 per cent). These soils belonged to Dubbak-3 series. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Dubbak-3 series soils presented in 1:50,000 scale.

4.2.2.5 Slightly eroded Pediplain

This mapping unit was subdivided at this scale as Slightly eroded Pediplain-uncultivated and Slightly eroded Pediplain-Cultivated based on land use. Results of these mapping units are as following:

4.2.2.5.1 Slightly eroded Pediplain- uncultivated (SMU-61):

Soils of this mapping unit were classified as Bhogaram-4 series soils. These soils appeared greenish-to-greenish yellow with smooth to medium texture on the satellite image. Soils in the mapping unit are well drained, slightly eroded with 30-40 per cent surface stoniness. These soils occurred on slopes less than 3 per cent and had slow run-off.

These soils were shallow, with more than 30 percent gravel in surface horizons. Gravel content increased with depth and it was greater than 60 per cent in second horizon and greater than 70 per cent in third horizon. These soils were grayish brown in colour, non-saline, neutral. Texture in the surface horizon was sandy loam and in sub surface horizon texture was sandy clay loam. These soils exhibited low CEC values ranging from 11.4 to 16.9 c mol (P^+) /kg soil with calcium as dominant cation on the exchange sites followed by magnesium. These soils were classified as Coarse loamy, mixed, iso-hyperthermic, Typic Haplustalfs. These soils covered 31.77 ha, which constituted 1.27 per cent of total area of the mini-watershed.

4.2.2.5.2 Slightly eroded Pediplain-Cultivated (SMU-62)

Soils of this mapping unit were classified as Fine loamy, mixed, iso-hyperthermic, Typic-Haplustalfs (Sripuram-3). These soils were found to occur in an area of 801.86 ha (32.16 per cent) of total area. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Sripuram-3 series soils presented in 1:50,000 scale.

4.2.2.6 Moderately eroded Pediplain

This mapping unit was subdivided at this scale as Moderately eroded Pediplain-uncultivated and Moderately eroded Pediplain-Cultivated based on land use. Results of these mapping units are as following

4.2.2.6.1 Moderately eroded Pediplain -Uncultivated (SMU-71):

Soils in this mapping unit were classified as Bhogaram-1 series. This mapping unit was encountered in 167.28 ha which constituted in 6.71 per cent of the total area of the mini- watershed. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils were similar to those of Bhogaram-1 series soils presented in 1:50,000 scale.

4.2.2.6.2 Moderately eroded Pediplain- Cultivated (SMU-72):

Soils of this mapping unit were present in 297.99 ha i.e., 11.95 per cent of the area of the micro-watershed. These soils were classified as Dubbak-2 series. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils are similar to those of Dubbak-2 series soils presented in 1:50,000 scale.

4.2.2.7 Severely eroded pediplain -Cultivated (SMU-81)

Soils of this series were present in an area of 332.88 ha (13.35 per cent). Theses soils belonged to Bhogaram-2 series. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Bhogaram-2 series soils presented in 1:50,000 scale.

4.2.2.8 Slightly eroded valley

This mapping unit was subdivided at this scale as Slightly eroded valley - uncultivated and Slightly eroded valley -Cultivated based on land use. Results of these mapping units are as following

4.2.2.8.1 Slightly eroded valley Uncultivated (SMU-91):

Soils of this series belonged to Ramannapet-1 soil series. They appeared bluish on the FCC print with smooth texture. They occupied 7.32 ha which constituted 0.29 per cent to the total area of the mini-watershed. These soils had sandy clay loam texture in the surface, sandy clay to clay texture in the sub-surface horizons. Due to the dominance of exchangeable Sodium (3.173 to 13.38 c mol (P^+) /kg soil) on the exchangeable sites, the ESP of the soils was found to be high. ESP values ranging from 16.25 (surface horizon) to 45.9 (sub surface horizon) were recorded. Strongly alkaline to moderately strong alkaline soil reaction was observed in these soils. Relatively higher EC values ranging from 0.506 to 1.887 ds /m were recorded in this profile. CEC of the surface soil was 19.5 cmol (P^+)/kg soil. CEC values increased with depth to 29.1 cmol (P^+)/kg soil in the lower most horizons. An increasing trend in clay content (28.33 to 35.02 per cent), and silt (14.81 per cent to 17.31per cent) and a decreasing trend in sand content (56.86 to 47.67 per cent) were recorded in these soils. ESP values and exchangeable sodium percentage did not exhibit any trend with increasing depth of the soil.

4.2.2.8.2 Slightly eroded valley - Cultivated (SMU-92):

Soils of the series were classified as Ramannapet-1 series. These soils occurred in a total area of 368.26 ha (14.77 per cent). Taxonomic classification, properties of the soils and morphology of the pedons were similar to those of Ramannapet-1 series soils, as described in 50,000 scale.

4.2.2.9 Moderately eroded valley

This mapping unit was subdivided at this scale as moderately eroded valley - uncultivated and moderately eroded valley -cultivated based on land use. Results of these mapping units are as following

4.2.2.9.1 Moderately eroded valley Uncultivated (SMU-101):

This mapping unit in which the soils belonged to Bhogaram-3 series ha covered an area of 24.31. Taxonomic classification, properties of the soils and morphology of the pedons were similar to those of Bhogaram-3 series soils, as described in 50,000 scale.

4.2.2.9.2 Moderately eroded valley cultivated (SMU-102):

These soils constituted 2.56 per cent of the total area of the micro-watershed covering an area of 63.93 ha. These soils belonged to Nidhanpalli-1 series. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils were similar to those of Nidhanpalli-1 series soils presented in 1:50,000 scale.

4.2.2.10 Rock out crops (SMU-100):

These units appeared as bluish patches associated with eroded pediplain or pediment on the FCC prints. This unit constituted 0.89 per cent to the total area of the micro watershed covering a total area 22.23 ha. This mapping unit did not have soil.

4.2.3 Soil mapping units at 1:12,500 scale

Mapping of the soils at 1:12,500 scale was also done utilizing PAN + LISS-III merged data of IRS-1D satellite in Sripuram micro-watershed. Mapping at 12,500 scale enabled further subdivision of the mapping units identified at 1:25,000 scale and purification of boundaries. Spatial resolutions of 5.8 m of PAN component and multi-spectral characteristics of the LISS-III component enabled better delineation of soils. At this scale land use was used as basis for classification of the soil mapping units. In total 14 soil mapping units were identified in the soil maps prepared at this scale.

Soil map of the Sripuram micro-watershed (1:12,500 scale) is presented in the Fig.17 and the legend for the soil map with dominant phases is presented in Fig.18. At this scale, slope, erosion, soil depth, surface stoniness, surface soil texture phases of the different series were used as differentiating criteria for classifying the soils. Description of phases of the soil series is presented in the table 6. The soil mapping units encountered in the Sripuram micro-watershed are listed as below:

SMU-3 Inselberg

SMU-5 Pediment- inselberg complex

Pediment-

SMU-411 Pediment- Uncultivated-Fallow

SMU-412 Pediment- Uncultivated - Scrub

Pediplain

Slightly eroded pediplain-

SMU-611 Slightly eroded Pediplain-Uncultivated- Scrub

SMU-612 Slightly eroded Pediplain-Uncultivated-Fallow

SMU-621 Slightly eroded Pediplain-Cultivated

SMU-622 Slightly eroded Pediplain-Cultivated-Paddy

SMU-623 Slightly eroded Pediplain-Plantation

Moderately eroded pediplain

SMU-711 Moderately eroded Pediplain –Uncultivated-scrub

SMU-712 Moderately eroded Pediplain –Uncultivated-fallow

SMU-721 Moderately eroded Pediplain- Cultivated

Severely eroded pediplain -

SMU-81 Severely eroded pediplain -Cultivated

Valley

Slightly eroded valley

SMU-92 Slightly eroded valley-Cultivated

Moderately eroded valley

SMU-102 Moderately eroded valley -Cultivated

Results of morphological, physical, physico-chemical characteristics for the above mentioned mapping units are presented as following:

4.2.3.1 Inselberg (SMU-3):

This mapping unit was encountered in a total area of 2.21 ha (0.12 per cent) Soils of this mapping unit belonged to Dubbak-1 series. Very shallow depth, gravelly sandy clay texture, steeply sloping, severe erosion, very strongly stony were the dominant phases in these soils. Morphological features of the pedons, physical, physico-chemical and chemical properties and-taxonomic classification of these soils were similar to those of Dubbak-1 series soils presented in 1:50,000 scale.

4.2.3.2 Pediment uncultivated:

This mapping unit was subdivided at this scale as pediment uncultivated-Fallow and pediment Uncultivated-Scrub based on land use. Results of these mapping units are as following

4.2.3.2.1 Pediment uncultivated-Fallow (SMU-411)

This mapping unit of Nidhanpalli-3 series soils occurred in a total area of 17.65 ha which constituted 1.02 per cent to the total area of the micro-watershed. Shallow depth, gravelly sandy loam texture, gently sloping, moderate erosion, moderately stony were the dominant phases in these soils. Taxonomic classification, morphological features of the

FIG.17 SOIL MAP (1:12,500 SCALE)
SRIPURAM MICRO-WATERSHED, NALGONDA DISTRICT, ANDHRA PRADESH

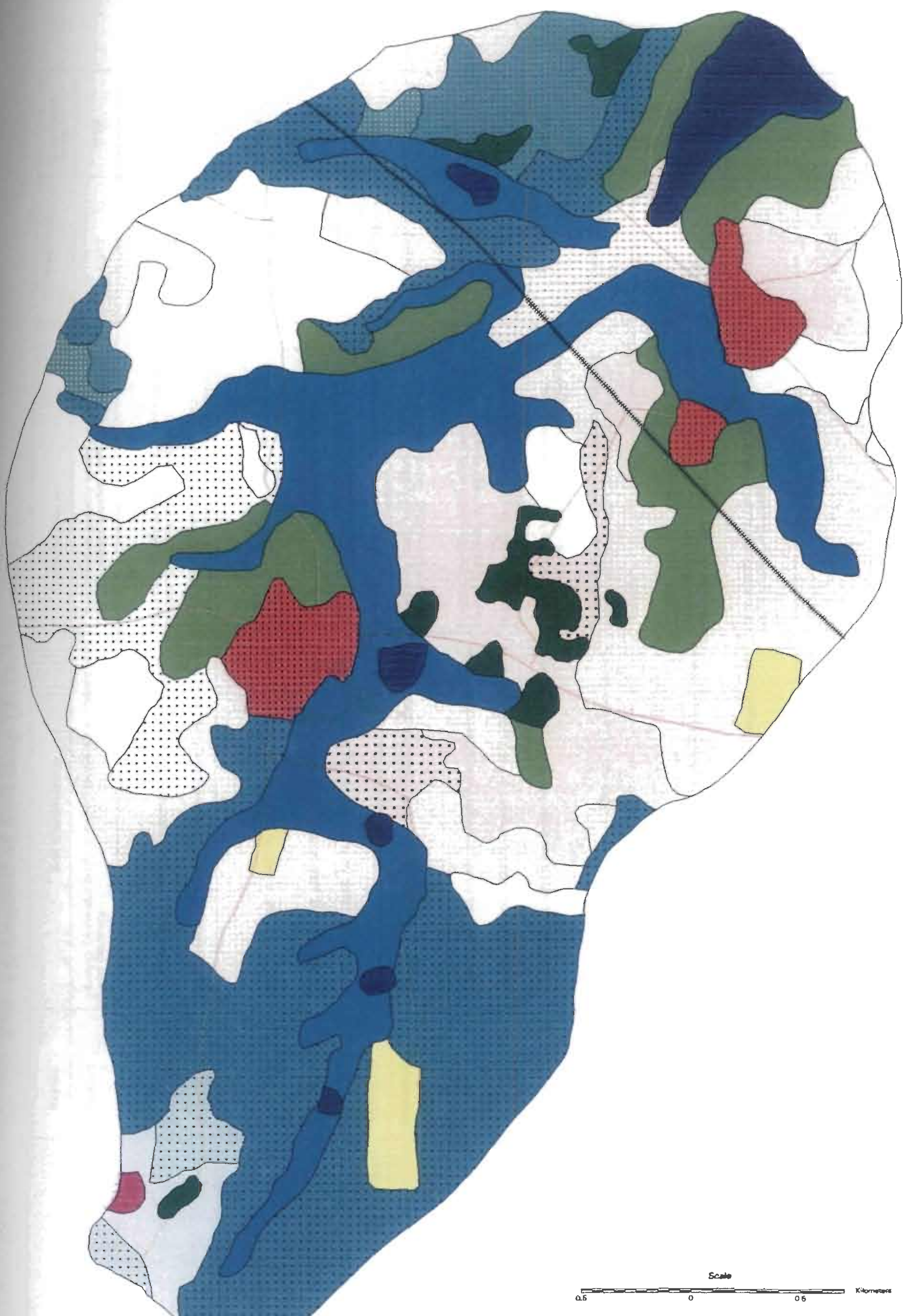


FIG. 18 Legend of Soil map (1:12,500 scale)

	Soil physiographic Unit	Series	Soil Classification	Dominant phases	Area (ha)	% to Total area
	Inselberg	Dubbak-1	Loamy Skeletal,mixed, iso-hyperthermic, Lithic Ustorthents and Boulders	Very shallow, gravelly sandy clay, steep sloping, severe erosion, very gently stony	2.217	0.13
	Pediment					
-411	Pediment-Fallow	Nidhanpally-3	Coarse loamy, mixed, iso-hyperthermic, Lithic Haplustalfs	Shallow, gravelly sandy loam, gently sloping, moderate reosion, moderately stony	17.654	1.03
-412	Pediment-Scrub	Dubbak-4	Loamy skeletal, mixed, iso-hyperthermic,Typic Haplustalfs	Ver shallow, gravelly sandy clay, steep sloping, severe erosion, very strongly stony	21.636	1.28
	Pediplain					
	slightly eroded pediplain					
-611	Slightly eroded pediplain-scrub	Bhogaram-4	Loamy skeletal mixed iso-hyperthermic, Typic Haplustepts	shallow, gravelly sandy loam, gently sloping, slight erosion, strongly stony	45.392	2.64
-612	Slightly eroded pediplain-Fallow	Bhogaram-4	Loamy skeletal, mixed, iso-hyperthermic,Typic Haplustalfs	Moderately shallow, gravelly sandy loam, gently sloping slight erosion, moderately stony	9.608	0.56
U-624	Slightly eroded pediplain-Cultivated	Sripuram-3	Fine loamy, mixed, iso-hyperthermic, Typic Haplustalfs	Moderately deep, sandy loam, very gently sloping, slight erosion,non-stony	416.938	24.31
U-622	Slightly eroded pediplain-Paddy cultivated	Sripuram-3	Fine loamy, mixed, iso-hyperthermic,Typic Haplustalfs	Moderately deep, sandy clay loam, nearly level, none to very slight erosion, non-stony	143.744	8.38
U-623	Slightly eroded pediplain-plantation	Nidhanpalli-2	Coarse loamy, mixed, iso-hyperthermic,Typic Haplustalfs	Moderately deep, sandy loam, very gently sloping, slight erosion, slightly stony	24.843	1.44
	Moderately eroded pedoplain					
U-711	Moderately eroded pedoplian-scrub	Bhogaram-1	Loamy skeletal, mixed, iso-hyperthermic,Typic Haplustalfs	Shallow, gravelly loamy sand, gently sloping, moderate erosion, strongly stony	132.228	7.71
U-712	Moderatelly eroded pediplain-Fallow	Bhogaram-1	Loamy skeletal, mixed, iso-hyperthermic,Typic Haplustalfs	Shallow, gravelly sandy loam, gently sloping, moderate erosion, modeartely stony	29.2752	1.70
U-721	Moderately eroded pediplain-Cultivated	Dubbak-2	Coarse loamy, mixed, iso-hyperthermic,Typic Rhodustalfs	Modearately shallow, gravelly sand loam, gently sloping, modeartely eroded, slightly stony	274.028	15.98
	Severely eroded pediplain					
U-911	Severely eroded pediplain-open scrub	Bhogaram-2	Coarse loamy, mixed, iso-hyperthermic, Typic ustorthents	Very shallow, gravelly loamy sand, moderately sloping, severe erosion, strongly stony	183.74	10.71
	Valley					
	Slightly eroded valley					
	Slightly eroded valley-Cultivated	Ramannapet-1	Fine loamy, mixed, iso-hyperthermic,Fluventic Haplustepts	Deep, sandy clay loam, nearly level, none to very slight erosion, non-stony	261.252	15.23
	Moderately eroded valley					
IU-102	Moderately eroded valley-Cultivated	Bhogaram-3	Fine loamy, mixed, iso-hyperthermic,Calcic Haplustepts	Deep, sandy clay loam, nearly level, none to very slight erosion, non-stony	24.167	1.40
	Settlement				48.082	2.80
	Water Body				44.802	2.61
	Rock out crop				34.844	2.03

pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Nidhanpalli-3 series soils presented in 1:25,000 scale.

4.2.3.2.2 Pediment Uncultivated-Scrub (SMU-412):

Soils of this mapping unit were classified as Dubbak-4 series. These soils were found to occur in a total area of 21.63 ha, which constituted 1.26 per cent of the total area of the mini-watershed. Dominant phases in these soils were moderately shallow depth, gravelly sandy loam texture, gently sloping, moderate erosion, and strongly stony surface. Taxonomic classification, properties of the soils and morphology of the pedons were similar to those of Dubbak-4 series soils, as described in 50,000 scale.

4.2.3.3 Slightly eroded Pediplain- uncultivated:

This mapping unit was subdivided at this scale as slightly eroded pediplain-uncultivated -Fallow and slightly eroded pediplain- uncultivated -Scrub based on land use. Results of these mapping units are as following

4.2.3.3.1 Slightly eroded Pediplain- uncultivated- scrub (SMU-611):

Soils of this mapping unit were classified as Bhogaram-4 series soils. These soils covered 45.39 ha, which constituted 2.64 per cent of total area of the micro watershed. Dominant phases in these soils were shallow depth, gravelly sandy loam texture, gently sloping, slight erosion, and strong surface stoniness. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of the these soils were similar to those of Bhogaram-4 series soils presented in 1:25,000 scale

4.2.3.3.2 Slightly eroded Pediplain- uncultivated- Fallow (SMU-612):

These soils covered 9.61 ha, which constituted 0.56 per cent of total area of the micro watershed. Soils of this mapping unit were classified as Bhogaram-4 series soils Dominant phases in these soils were moderately shallow depth, gravelly sandy loam texture, gently sloping, slight erosion, moderate surface stoniness. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of the these soils are similar to those of Bhogaram-4 series and presented in 1:25,000 scale

4.2.3.4 Slightly eroded Pediplain- cultivated:

This mapping unit was subdivided at this scale as slightly eroded pediplain- cultivated, slightly eroded pediplain- cultivated paddy and slightly eroded pediplain- plantation based on land use. Results of these mapping units are as following

4.2.3.4.1 Slightly eroded Pediplain-Cultivated (SMU-621)

Dominant phases of moderately deep, sandy loam texture, very gently sloping and slight erosion were observed in Sripuram-3 series. These soils were found to occur in an area of 416.93 ha (24.31 per cent). Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Sripuram-3 series and presented in 1:50,000 scale.

4.2.3.4.2 Slightly eroded Pediplain-Cultivated-Paddy (SMU-622)

In this mapping unit dominant phases were moderately deep , sandy clay loam texture, nearly level, nil to very slight erosion, were observed in Sripuram-3 series. These soils were found to occur in an area of 143.74 ha (8.38 per cent). Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils were similar to those of Sripuram-3 series and presented in 1:50,000 scale.

4.2.3.4.3 Slightly eroded Pediplain- plantation (SMU-623):

The mapping unit appears bright red patches of regular shapes (squares/rectangles) in all the seasons of the year on the FCC. This mapping unit covers a total area 24.84 ha, which constitutes 1.45 per cent to the total area of the Sripuram micro-watershed. Soils of this mapping unit occur on gently sloping lands (1-3per cent slope) with 50-150m slope length. These are slightly eroded, well drained with moderate run-off. Stones cover 5-10per cent of the surface area. Rock out crops were not observed in this mapping unit.

Dominant phases of Nidhapalli-2 series viz., moderately deep, sandy loam texture, very gently sloping, slight erosion, slightly stony surface were present in the soils of this mapping unit. These soils were characterized by neutral soil pH, low organic Carbon status through out the depth. Very low $CaCo_3$ content less than 2.1per cent was recorded in the lower horizons of the profile. These soils had sandy loam texture in the surface horizon and sandy clay loam texture in the second horizon and clay loam texture in next two lower horizons. An increase in clay content from 18.66 per cent in the surface horizon to 36.65 per cent in the lower most horizon was recorded. Sand content decreased with the depth from 72.27 per cent to 46.23 per cent. In correspondence with the increase in clay content the CEC of the soils increased with depth. CEC values ranging from 13.9 to 17.5 c mol (P^+)/ kg soil were recorded. Calcium was the dominant cation on the exchange sites followed by potassium. These soils were classified as Fine Loamy, mixed iso-hyperthermic, Typic Haplustalfs .

4.2.3.5 Moderately eroded Pediplain –Uncultivated

This mapping unit was subdivided at this scale as moderately eroded pediplain- uncultivated-scrub, moderately eroded pediplain –uncultivated-fallow based on land use. Results of these mapping units are as following

4.2.3.5.1 Moderately eroded Pediplain –Uncultivated-scrub (SMU-711):

Dominant soil phases of Bhogaram-1 series viz., shallow depth, gravelly sandy loam texture, gently sloping, moderate erosion, strongly stony surface were observed in these soils. This mapping unit was encountered in 132.22 ha which constituted in 7.71 per cent of the total area of the micro-watershed. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils were similar to those of Bhogaram-1 series soils presented in 1:50,000 scale.

4.2.3.5.2 Moderately eroded Pediplain –Uncultivated-Fallow (SMU-712):

Dominant soil phases of Bhogaram-1 series viz., shallow depth, gravelly sandy loam texture, gently sloping, moderate erosion, moderately stony surface were observed in these soils. This mapping unit was encountered in 29.27 ha which constituted in 1.70 per cent of the total area of the micro-watershed. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils are similar to those of Bhogaram-1 series soils presented in 1:50,000 scale.

4.2.3.6 Moderately eroded Pediplain- Cultivated (SMU-721):

Soils of this mapping unit were present in 274.03 ha i.e., 15.98 per cent of the area of the micro-watershed. These soils were classified as Dubbak-2 series in which dominant phases viz., moderately shallow depth, gravelly sandy loam texture, gently sloping, moderate erosion, slightly stony surface were observed. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils are similar to those of Dubbak-2 series soils presented in 1:50,000 scale.

4.2.3.7 Severely eroded pediplain -Cultivated (SMU-81)

Soils of this series were present in an area of 183.74 ha (10.71 per cent). Theses soils exhibited shallow depth, gravelly loamy sand texture, gently sloping, severe erosion, and strongly stony surface phases of Bhogaram-2 series. Taxonomic classification, morphological features of the pedons, physical, physico-chemical and chemical properties of these soils are similar to those of Bhogaram-2 series soils presented in 1:50,000 scale

4.2.3.8 **Slightly eroded valley - Cultivated (SMU-92):**

Dominant phases of Ramannapet-1 series viz., deep soils, sandy clay loam texture, nearly level, nil to very slight erosion were observed in this mapping unit. These soils occurred in a total area of 261.25 ha (15.23 per cent). Taxonomic classification, properties of the soils and morphology of the pedons were similar to those of Ramannapet-1 series soils, as described in 50,000 scale.

4.2.3.9 Moderately eroded valley cultivated (SMU-102):

These soils constituted 1.40 per cent of the total area of the micro-watershed covering an area of 24.16 ha. Dominant phases of Bhogaram-3 series viz., deep soils, sandy clay loam texture, nearly level, nil to very slight, were observed in these soils. Morphological features of the pedons, physical, physico-chemical and chemical properties and taxonomic classification of these soils are similar to those of Bhogaram-3 series soils presented in 1:50,000 scale.

4.2.3 Soil mapping units at different scales

(As discussed in previous sections soil maps were prepared for the study area at 1:50,000, 1:25,000 and 1:12,500 scales using remotely sensed data. To see the effect of scale of soil map and remote sensing spatial resolutions, a comparative study was made. The results of comparation are given in table 13)

Table No.13 **Comparative evaluation of LISS-III and PAN + LISS-III merged data at different scales for soil mapping**

(Rating: Excellent, Very good, Good, Poor and Very poor)

S.No.	Particulars	IRS – ID data		
		LISS-III (1:50,000)	**PAN + LISS-III merged data (1:25,000)**	**PAN + LISS-III merged data (1:12,500)**
1.	No. of mapping units	10	12	17
2.	No. of Polygons	42	57	72
	Discernability of the soils			
7.	Soil mapping units	Good	Very Good	Excellent
8.	Stoniness	Poor	Good	Very good
9.	Erosion	Good	Very good	Very good
	Discernability of cultural features			
3.	Road/Foot path	Very poor	Poor	Good
4.	Settlement	Good	Very good	Excellent
5.	Land use/Land cover	Good	Very good	Very good
6.	Field bunds/Fencing	Very poor	Good	Very good

As mentioned in the Materials and Methods chapter, two different satellite data products viz., IRS-ID, LISS-III of 23.5 m spatial resolution and IRS-ID PAN+LISS-III data (5.8m spatial resolution) were utilized in soil mapping. At 1:50000 scale LISS-III data and at 1:25,000 and 1:12,500 scales IRS-ID PAN+LISS-III data were utilized for soil mapping. Results of soil maps prepared at different scales for the same study area (Sripuram micro watershed) are discussed here under.

Interpretation of satellite data was done based on image elements like tone, texture, pattern, association, size, shape and contextual information. Visual perceptions were used to delineate the mapping units on the FCC print. There is no quantitative information for the image elements on the FCC print. Hence the image elements as appeared in the satellite data of different scales were interpreted as per qualitative ratings.

A total number of polygons at 1:50,000 scale were 42, whereas at 1:25,000 scale 57 polygons and at 1:12,500 scale 72 polygons could be delineated. This indicates that with increase in scale the number of polygons in the same area increased i.e., purification of major mapping units drawn at smaller scales, sub division of polygons in light of better information available in terms of land use or erosion could be accomplished. Moreover, utilization of satellite data of higher spatial resolutions for soil mapping at larger scale helped in more accurate delineation of different mapping units at larger scale.

4.2.4.1 Soils:

In total, 10 soil mapping units were delineated in the study area at 1:50,000 scale. At 1:25,000 scale 16 soil mapping units and 1:12,500 scale 15 mapping units were delineated.

At 1:50,000 scale mapping of the soils was done for the entire watershed area of 10167 ha, whereas 1:25,000 a mini watershed (a part of the watershed) of 2493 ha area was taken as the study area for mapping the soils. A micro watershed of 1743 ha area was selected to study the soils keeping in view the scale and presentation limitations at larger scale.

At 1:50,000 scale 7 soil physiographic units viz., hill, dyke, inselberg, pediment, PIC, pediplain and valley were delineated based on the geomorphological units. These units were sub divided based on erosion status. At 1:25,000 scale the soil physoigraphic units were sub divided based on the land use characteristics. These units were further purified and sub divided at 1:12,500 scale based on the different phases of soils depth, erosion, stoniness, texture etc.

Physiographic units viz., residual hills, dykes, inselbergs could not be sub divided at larger scales also based on erosion or land use.

Pediment soils, which were closely associated with hills, dykes and inselbergs, were classified as single mapping units at 1:50,000 scale. At 1:25,000 scale this unit was sub divided as pediment-uncultivated and pediment-cultivated based on land use. The pediment uncultivated unit (1:25,000 scale map) was further sub divided as pediment-fallow, pediment-scrub mapping units based on the land use at 1:12,500 scale. Pediment-cultivated mapping unit was not present in the study area of 1:12,500 scale.

4.2.4.1.1 Pediment-inselberg-complex

The complex association of pediments and inselbergs was mapped as PIC at 1:50,000 scale. In the mapping units, where these two associated units could not be separated as individual mapping units, they were represented as PIC at 1:25,000 scale also. These soils belonged to Dubbak-4 series, which were classified as Loamy skeletal, Typic Haplustalfs. At 1:12,500 scale PIC mapping units were not observed in the study area.

4.2.4.1.2 Pediplain

Erosion was considered as basis for sub dividing this physiographic unit at 1:50,000 scale. The mapping units were slightly eroded pediplain, moderately eroded pediplain and severely eroded pediplain. In the slightly eroded pediplain two soil series association viz., Sripuram-3 and Nernamula-1, which were classified as Fine Loamy Typic Haplustalfs and Fine Vertic Haplustepts, respectively. Association of Dubbak-2 and Bhogaram-1 series (Coarse loamy Typic Rhodustalfs and Loamy skeletal Typic Rhodustalfs, respectively) was observed in moderately eroded pediplain. Soils of severely eroded pediplain belonged to Bhogaram-2 series.

4.2.4.1.2.1 Slightly eroded pediplain

In the mini watershed studied at 1:25,000 scale two soil mapping units (Slightly eroded pediplain cultivated, slightly eroded pediplain uncultivated) belonging to two series viz., namely Sripuram-3 and Bhogaram-4 were delineated.

The slightly eroded pediplain-uncultivated mapping unit was sub divided based on the land use at 1:12,500 scale as slightly eroded pediplain-scrub and slightly eroded pediplain-fallow. These two mapping units belong to the same series (Bhogaram-4). However, phases of the soils viz., depth, and surface stoniness were used in mapping them as different units.

The slightly eroded pediplain-cultivated (1:25,000 scale) mapping unit was sub divided as 1:12,500 scale based on the land use as slightly eroded pediplain-cultivated, slightly eroded pediplain-paddy cultivated, slightly eroded pediplain-plantation. The first two mapping units belong to the same soil series viz., Sripuram-3 (Fine Loamy Typic Haplustalfs) with variations in erosion, surface soil texture and surface stoniness. The paddy cultivated soils were relatively less slopping, finer in texture and less stony compared to the soils of slightly eroded pediplain-cultivated. A new soil series viz., Nidhanpalli-2 (Coarse loamy Typic Haplustalfs) was identified in the slightly eroded pediplain-plantation mapping unit. Soils of this series were relatively stonier in surface as well as sub surface horizons, compared to the Sripuram-3 Soils.

4.2.4.1.2.2 Moderately eroded pediplain

Association of two soil series viz., Dubbak-2 (Coarse loamy Typic Rhodustalfs) and Bhogaram-1 (Loamy skeletal Typic Rhodustalfs) was found in the Moderately eroded pediplain mapping unit at 1:50,00 scale. This mapping unit was sub divided based on the land use as moderately eroded pediplain- cultivated and moderately eroded pediplain-uncultivated, which belonged to two different soil series viz., Dubbak-2 and Bhogaram-1, respectively. Even though, these soils were similar in their properties up to suborder level of taxonomic classification, coarse gravel content in the surface and sub surface horizon was used as differentiating criteria at family level.

Due to uniformity in the properties and other land related aspects, moderately eroded pediplain-cultivated mapping unit could not be sub divided at 1:12,500 scale. However, in the moderately eroded pediplain- uncultivated mapping unit (Bhogaram-1) the soils were sub divided based on the land use and surface stoniness phases of the series and presence or absence of scrub.

4.2.4.1.2.3 Severely eroded pediplain

Soils of this mapping unit belong to Bhogaram-2 series (Coarse loamy Typic Ustorthents). These soils were not sub divided even at larger scales owing to their uniformity.

4.2.4.1.3 Valley

This mapping unit was classified as slightly eroded valley (Ramannapet-1 series) and moderately eroded valley (association of Bhogaram-3 and Nidhapalli-1 series) based on the erosion status of the soils.

4.2.4.1.3.1 Slightly eroded valley

This mapping unit was sub divided at 1:25,000 scale as slightly eroded valley cultivated (Ramannapet-1 series) and slightly eroded valley uncultivated (Ramannapet-2 series). In the slightly eroded valley-uncultivated mapping unit the soils were sodic in their nature. This mapping unit could not be delineated as a separate mapping unit at 1:50,000 scale due to its small area. These soils were classified as Fine loamy Fluventic (Sodic) Haplustepts. However, at 1:12,500 scale this mapping unit was not present in the study area. Slightly eroded valley-cultivated soils were represented as same unit at 1:12,500 scale also keeping in view the uniformity of the soils and land use (Paddy cultivated).

4.2.4.1.3.2 Moderately eroded valley

Based on land use this mapping unit was sub divided at 1:25,000 scale as moderately eroded valley -cultivated and moderately eroded valley -uncultivated which belonged to two different series viz., Bhogaram-3 (Fine loamy Calcic Haplustepts) and Nidhanpalli-1 (Loamy skeletal Calcic Haplustepts), respectively. At 1:12,500 scale no further purification of these units could be attained because of similarity of the soils and land use. Moderately eroded valley-cultivated mapping unit was not present in the study area.

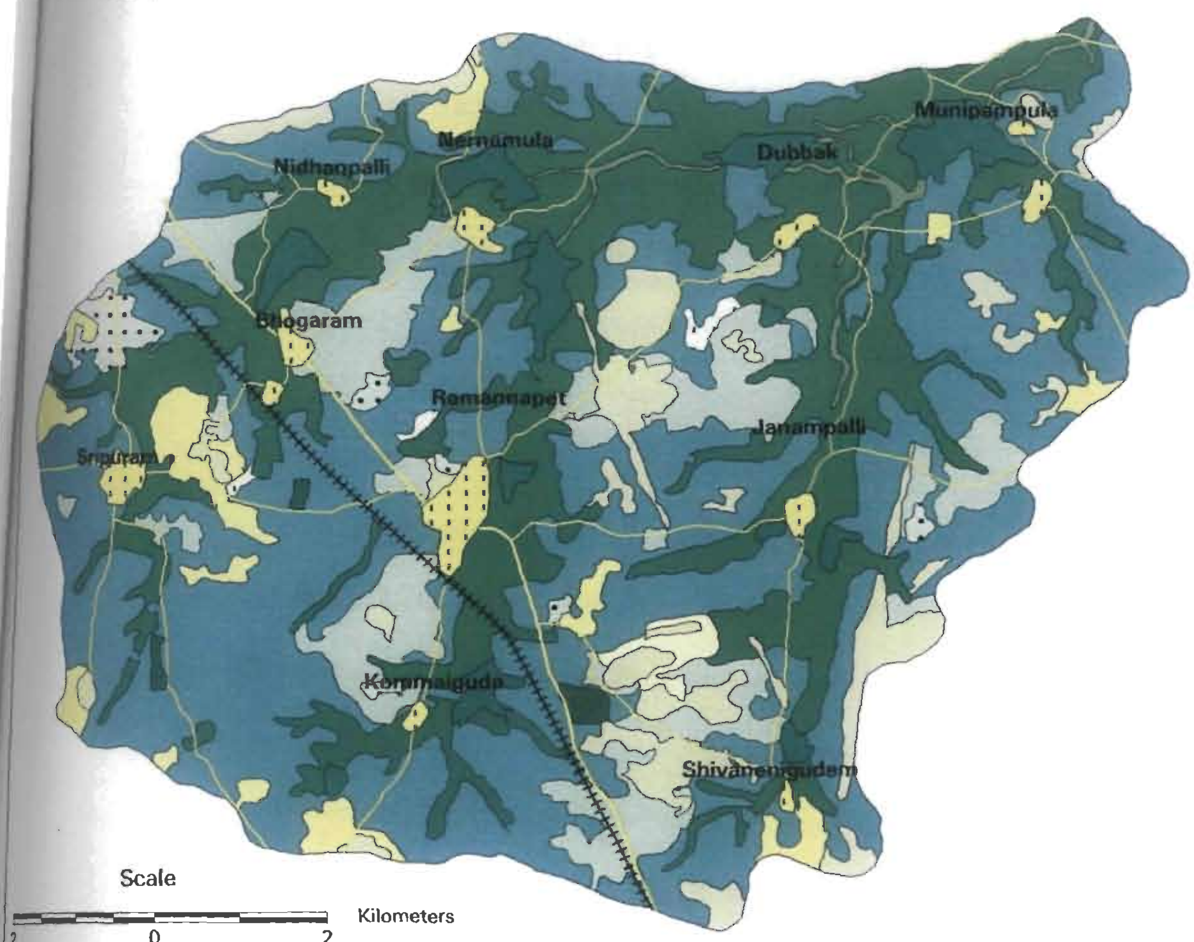
4.3 Land Use/ Land Cover Mapping

Remotely sensed data from IRS-1D LISS-III in the form of false colour composite prints (bands 2, 3, 4) at 1:50,000 scale pertaining to kharif and rabi periods enabled to identify major land use / land cover classes in Ramannapet watershed. Pramod Krishna 1996 and Murthy & Rao 1997 have successfully employed remote sensing data in deriving land use / land cover classes because of good correlation between land use / land cover and ground realities. Altogether 12 land use/ land cover classes were encountered in the study area as per level-II classification legend.

The land use/ land cover map (1:50,000 scale) prepared using the satellite data and corresponding statistics are presented in the Fig.19. Results of the land use /land cover classes of the watershed are presented below:

Level-I	Level-II
Built up land	1.Built up land
Agricultural land	2. Cultivated area- kharif
	3. Cultivated area- rabi
	4.Cultivated area- double crop
	5.Fallow

FIG 19 LAND USE / LAND COVER MAP (1:50,000 scale)
RAMANNAPET WATERSHED, NALGONDA DISTRICT, A.P.



Legend

Mapping Unit	LEVEL- I	LEVEl - II	Area (ha)	% to the total area
	Built up area	Villages	151.2	1.49
	Agriculture		4517.28	44.41
		Cropped land	30.24	0.29
		Single crop-kharif		
		Single crop-rabi	2851.2	28.03
		Double crop		
		Fallow land	355.68	3.49
		Plantation	40.32	0.39
	Forest	Degraded Forest	36.00	0.35
	Waste land	Land with surub	972.00	9.55
		Land with out surub	106.56	1.04
		Barren Rock/ stony waste/ *sheet rock area*	737.28	7.24
	Water bodies	Stream	87.84	0.86
		Tanks	339.84	3.34

6.Plantation

Forest 7.Degraded forestland

Waste lands 8.Land with scrub/

9.Land with out scrub

10.Barren rocky/ stony waste. / sheet rock area

Water bodies 11.Stream

12.Tank

4.3.1 Built up land:

This unit appeared gray/grayish red on the FCC imagery. In total 10 villages were identified on the FCC images of which, Ramannapet was the largest village and it was centrally located in the watershed. Built-up land (settlement) occupied a total area of 151.2 ha, which constituted 1.49 per cent of the total watershed area.

4.3.2 Agriculture:

Agriculture was identified as major land use class (level-1) in the watershed. Cropped land was further divided in to five categories viz., Single crop (Kharif), single crop (Rabi), Double crop, fallow, plantation. Agricultural land use, in total, covered a total area of 7794.72 ha constituting 76.23per cent of the total area of the watershed.

4.3.2.1 Cultivated area (single crop kharif) :

This land use class (level-II) was the largest unit amongst all the LU classes in the watershed area. This mapping unit was present in a total area of 4517.28 ha, which was 44.41 percent of the total area of the watershed. This unit was identified on the FCC print by the presence of vegetation/ crop which exhibited red colour during the kharif season and greenish to greenish yellow during Rabi season depending on the presence or absence of stubbles, grasses. Predominant crops cultivated unit are castor or sorghum or bajra as sole crops or inter cropped with red gram.

4.3.2.2Cultivated (single crop Rabi):

This mapping unit was identified on the FCC unit by the presence of crop during the Rabi season and absence during the Kharif seasons. This unit was found over an area of only 30.24 ha, which is 0.27 per cent of the total watershed area. Paddy was found to be the major crop cultivated in this land use class.

4.3.2.3 Cultivated area (Double crop):

This land use class was identified in a total area of 2851.2 ha (28.03per cent). Double crop signifies presence of crops during both Kharif season data and Rabi season data, which exhibited red Colour on the FCC prints. This unit was predominantly Paddy cultivated area occurring in valleys.

4.3.2.4 Fallow:

Absence of crop cover during all the cropping seasons (Kharif, rabi and summer), association of this unit with single cropped area and appearance as patches yellowish white colour with coarse texture indicated the fallow lands. This unit constituted 3.49 per cent of the total area of watershed covering an area of 355.68 ha.

4.3.2.5 Plantation :

Plantation appeared as bright red patches of regular shapes (rectangle/squares) during all seasons of the year on the FCC prints. Location of the patches in the pediplain area where drainage is not a problem also qualified them for plantation land use class. This mapping unit appeared in 40.32 ha area constituting 0.39 per cent of the total area of the watershed.

4.3.3 Waste Land:

Waste land class was the second largest land use class in the watershed occupying 1815.84 ha (17.75per cent), after the agricultural land use class (level-1).

This major unit was sub divided in to land with scrub/ land without scrub and stony waste area based on the presence or absence of scrub and stoniness. This unit was closely associated with hills/ pediments/ severely eroded lands.

4.3.3.1 Land with Scrub:

This mapping unit was found to be the largest unit (level-II) in wasteland category covering an area 972.00 ha, which is 9.55 per cent of the total area of the watershed. This unit was closely associated with the other wasteland units viz., land without scrub and stony area. This unit was delineated by the whitish appearance with mottles of reddish colour and coarse texture. Scrub in this mapping unit was constituted by the Acacia spp, ber, thorny shurbs, Borassus spp, neem, grasses etc.

4.3.3.2 Land without scrub:

This wasteland class was found to cover a total area of 106.56 ha (1.04 per cent). This unit appeared bright yellowish white or white on the FCC print. This mapping unit was associated with severely eroded lands.

4.3.3.3 Barren Rocky/ Strong waste/ Sheet Rock area:

This mapping unit comprised of hills, dykes, inselbergs and rock-out crops with more than 75 per cent surface stoniness. This unit exhibited dark gray or black colour with coarse texture in case of hills dykes and inselbergs and bluish gray to bluish colour in rock outcrops and quarry areas, respectively.. In total, 737.28 ha (7.24per cent) of the study area were classified as stony waste.

This unit had vegetation of grasses or thorny shrub wherever the soil was present.

4.3.4 Forest

4.3.4.1 Degraded Forest:

This land use unit boundary was taken from SOI topographical map. On the topographical map this unit was classified as reserved forest and was associated with a hill near Shivanenigudem Village. However, on the FCC print this unit exhibited greenish colour with red patches indicating the presence sparse vegetation. This unit occurred on 36.00 ha which is 0.35 per cent of the total watershed area.

4.3.5 Water bodies

4.3.5.1 Streams:

These units were identified primarily by their association with water bodies and linear shape. These units exhibited red colour due to infestation of Prosophis and weeds. This unit covered 0.86 per cent of the area of watershed (87.84 ha).

4.3.5.2 Tanks:

Boundaries of the tanks taken from the SOI topographical maps were modified in light of the satellite data of different seasons. These units appeared blue / deep blue in colour in the portion where water was present and reddish in the portions where weed infestation was present.

This unit covered an area of 339.84 ha which constitutes 3.34 per cent of the total area of the watershed.

4.4 Creation of Database

Creation of Database is essential to develop decision support system to generate optimum land use plan for a given area. Spatial database elements studied (Table.7) and results of the database created in the form of attribute tables and structure of the tables for soils and land use elements are presented in tables (8-12). Results of other database elements used in the study are presented in Annexure-5.

Table: 7 Spatial data base elements used in the study

S.No.	Element	Type	Feature code	Attribute table	Source
1	Soil	Poly	Soil-code Soil-code Assl-code	Soil.lut Soil.dat Soil.lut	RS based soil map Soil profile data Soil Association
2	Luse	Poly	Lu-code	Luse.lut	RS based map
3	Geom	Poly	Gu-code	Geom.lut	RS based hydrogeo-morphological map
4	Slope	Poly	Slp-code	Slope.lut	Prepared from SOI topo maps
5	Drainl	Line	Drnl-code	Drainl.lut	Toposheet/RS
6	Drainp	Poly	Drnp-code	Drainp.lut	RS based luse map
7	G water	Poly	GW-code	Gwater.lu	Derived from hydro-geomorphological map
8	Landcap	Poly	Lcap-code	Landcap.lut	Soil map
11	Cldu	Poly	Lrdef-code	Cldu.lut	Various thematics
12	Roads	Line	Rd-code	Roads.lut	Topo sheets

Table : 8 Attribute tables for soil coverage -SOIL.LUT

Field Name	Field	Key field	Remarks
SOIL-CODE	16,16,C	Yes	16 Digit primary link code
ASSI-CODE	16,16,C	Yes	Secondary link code
ORDER	15,15,C	No	Order description
SB-ORDER	15,15,C	No	Sub-order description
GR-ORDER	30,30,C	No	Great Group description
SB-GROUP	30,30,C	No	Sub-Group description
FAMILY-TEX	30,30,C	No	Family level textural description
FAMILY-MIN	30,30,C	No	Family level mineralogy
FAMILY-TEMP	30,30,C	No	Family level Temperature

Table : 9 Structure of the tables for soil coverage SOIL.DAT

FIELD NAME	FIELD TYPE	KEY FIELD	REMARKS
SOIL-CODE	16,16,C	Yes	16 Digit link code
SOIL-DEPTH	10,10,N,0	No	
MIN-DEPTH	6,6,N,2	No	
MAX-DEPTH	6,6,N,2	No	
SAND-PER	5,5,N,2	No	
SILT-PER	5,5,N,2	No	
CLAY-PER	5,5,N,2	No	
TEXTURE	15,15,C	No	
PH	5,5,N,2	No	
EC	5,5,N,2	No	
OC-PER	5,5,N,2	No	
EX-NA	5,5,N,2	No	
EX-K	5,5,N,2	No	
EX-CA	5,5,N,2	No	
EX-MG	5,5,N,2	No	
CEC	6,6,N,2	No	
BS	6,6,N,2	No	
LCC	5,5,C	No	Land capability class
LPI	6,6,N,2	No	Land productivity class
SIR	6,6,N,2	No	Storie Index Rating

Table No. 10: 16 Digit Codes for Soils of the Watershed

Soil code	Series Name	Classification
0405050103070901	Dubbak-1	Loamy, Skeletal, Mixed, Iso-hyperthermic Lithic Ustorthent
0103081703070903	Dubbak-2	Loamy, Skeletal, Mixed, Iso-hyperthermic Typic Haplustalfs
0103070407070902	Dubbak-3	Coarse loamy Mixed, Iso-hyperthermic Typic Rhodustalfs
0604051108070904	Ramannapet-1	Fine loamy Mixed, Iso-hyperthermic Fluventic Haplustepts
0604051108070905	Ramannapet-2	Fine loamy Mixed, Iso-hyperthermic Fluventic (sodic) Haplustepts
0604050412010906	Nernamula-1	Fine Montmorillonitic Mixed, Iso-hyperthermic Vertic Haplustepts
0103070403070907	Bogaram-1	Loamy, Skeletal, Mixed, Iso-hyperthermic, Typic Haplustalfs
0405051007070908	Bogaram-2	Coarse Loamy Mixed, Iso-hyperthermic Typic Ustorthent
0604051408070909	Bogaram-3	Fine Loamy Mixed, Iso-hyperthermic Calcic Haplustepts
0103081707070910	Bogaram-4	Coarse Loamy Mixed, Iso-hyperthermic Typic Haplustalfs
0604051808070911	Sripuram-2	Fine Loamy Mixed, Iso-hyperthermic Typic Haplustepts
0103081708070912	Sripuram-2	Fine Loamy Mixed, Iso-hyperthermic Typic Haplustalfs
0604051408070913	Nidhanpalli-1	Loamy, Skeletal, Mixed, Iso-hyperthermic Calcic Haplustepts
0103080107070914	Nidhanpalli-1	Coarse Loamy Mixed, Iso-hyperthermic Lithic Haplustalfs

Table No.11 Attribute Code table for Land use/ Land cover: LUSE . LUT

LU -CODE	Discr L-1	Discr L-2	Discr L-3
010200	Built up land	Villages	-
020101	Agriculture	Crop Land	Kharif
020102	Agriculture	Crop Land	Rabi
020103	Agriculture	Crop Land	Kharif + Rabi (Double cropped)
020201	Agriculture	Fallow	Current Fallow
020300	Agriculture	Plantation	-
030203	Forest	Dry Deciduous	Scrub Forest
040300	Waste Land	Land with Scrub	-
040400	Waste Land	Land without Scrub	-
050101	Water body	River	Water Channel Area
050500	Water body	Tanks	-

Table No. 12: Structure of the LUSE. LUT Table

Field Name	Field	Key field	Remarks
LU-CODE	8,8,C	Yes	Feature code
Discr- L1	30,30,C	No	Level 1 Classes
Discr- L2	30,30,C	No	Level 2 classes
Discr- L3	30,30,C	No	Level 3 classes

4.5 Optimum land use planning:

According to FAO, land use planning is the systematic assessment of land and water potential, alternative patterns of land use and other physical, social and economic conditions, for the purpose of selecting and adopting land use options that are most beneficial to the land users without degrading the resources or the environment, together with the selection of measures most likely to encourage such land uses.

In the present study, optimum land use plan for the Ramannapet watershed located in Nalgonda dist. Of Andhra Pradesh was generated analyzing the potentials and limitations of the resources viz., soil, land form, climatic etc. at three scales (1:50,000, 1:25,000, 1:12,500).

In these plans measures were identified to optimize the utilization of resources based on their potentials and limitations. The action items were selected for optimal utilization of the resources in such a way that soil erosion is controlled/ contained and increase the cropping intensity.

Results of the optimum land use planning done for the Ramnnapet watershed, Bhogaram mini watershed and Sripuram micro watershed at 1:50,000, 1:25,000, 1:12,500, respectively are presented as below:

4.5.1 Optimum land use plan: (1:50,000 scale)

Optimum land use plan generated for the study area is presented in Fig. 20. The criteria considered in identifying the action items and there ratings are presented in table no.15.

At 1:50,000 seven-action items were suggested considering the potentials and limitations of resources. A description of these suggested action item are presented below.

Table : 14 Evaluation of different SMU in the study area with respect to different crops.

S.No.	Soil mapping unit	Paddy	Sorghum	Red gram	Groundnut	Castor	Cow pea	Mango	Citrus	Maize	Sun flower	Grasses	Arid fruit crops
1.	SMU-1	N2	N1	N1	N1	N1	N1	N1	N1	N1	N1	S2	S3
2.	SMU-2	N2	N1	N1	N1	N1	N1	N1	N1	N1	N1	S2	S3
3.	SMU-3	N2	N1	N1	N1	N1	N1	N1	N1	N1	N1	S2	S3
4.	SMU-411	S3	S3	S3	S3	S3	S3	N1	N1	S3	S3	S1	S1
5.	SMU-412	S3	S3	S3	S3	S3	S3	N1	N1	S3	S3	S1	S2
6.	SMU-421	S3	S3	S3	S3	S3	S3	N1	N1	S3	S3	S1	S1
7.	SMU-5	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	S3
8.	SMU-611	S2	S2	S2	S2	S3	S3	S3	N1	S2	S3	S1	S1
9.	SMU-612	S2	S2	S1	S1	S2	S3	S3	N1	S2	S3	S1	S1
10.	SMU-621	S2	S1	S1	S1	S2	S1	S2	S3	S1	S2	S1	S1
11.	SMU-622	S1	S1	S1	S1	S2	S1	S2	S3	S1	S2	S1	S1
12.	SMU-623	S2	S1	S1	S1	S2	S1	S2	S3	S2	S2	S1	S1
13.	SMU-711	S2	S2	S3	S2	S3	S2	N1	N1	S3	N1	S1	S2
14.	SMU-712	S2	S2	S3	S2	S3	S3	N1	N1	S3	N1	S1	S1
15.	SMU-721	S2	S1	S2	S1	S2	S3	S3	N1	S2	S3	S1	S1
16.	SMU-811	S3	S3	S3	S3	N1	N1	N1	N1	N1	N1	S1	S3
17.	SMU-91	S1	S2	S2	N1	S2	S2	S3	S3	S2	S2	S1	S2
18.	SMU-92	S1	S2	S2	N1	S1	S2	S3	S3	S2	S2	S1	S2
19.	SMU-101	S2	S2	S2	N1	S2	S2	S3	S3	S2	S2	S1	S2
20.	SMU-102	S1	S2	S2	N1	S1	S2	S3	S3	S2	S2	S1	S2
21.	SMU-100	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1

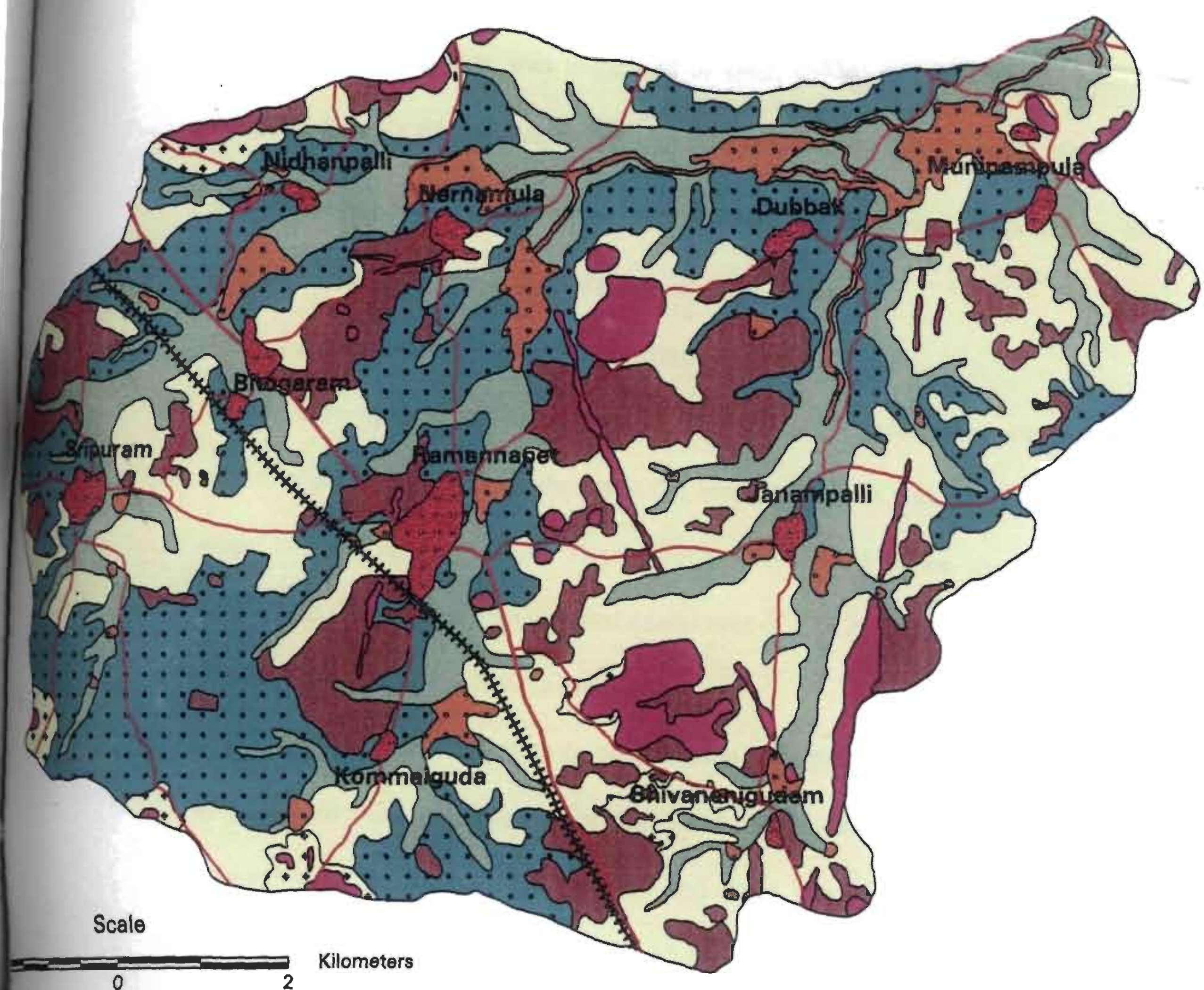
S1 - Slight limitations
S2 - Moderate limitation
S3 - Severe limitation
N1- Not suitable

Table : 15 Criteria used for Optimum land use plan action item identification (1:50,000 scale)

Mapping unit	Name of the mapping unit	Depth (cm)	Slope (%)	Erosion	GWP	Drainage	Land Use	Land capability class	Problems	Action Item
1	Residual hill	13	30-40	Severe	V.poor	Excessive	Waste land	VIes	Steep slope, severe erosion, stoniness, shallow depth, Excessive drainage, very poor Ground water potential	Arid horticulture
2	Dyke	26	25-30	Severe	V.poor	Excessive	Waste land	VIes	Steep slope, severe Erosion, stoniness, shallow depth, excessive drainage, very poor G potential	Arid horticulture
3	Inselberg	22	25-30	Severe	V.poor	Excessive	Waste land	VIes	Steep slope, erosion, stoniness shallow depth, excessive drainage, very poor Ground water potential	Arid horticulture
4	Pediment	45	3-8	Moderate	Poor	Well	Cultivated or scrub	IVes	Stoniness, shallow depth, slope, moderate erosion	Agro-forestry + Soil Conservation
5	Pediment Inselberg complex	45	8-15	Severe	Poor	Some what excessive	Waste land	VIes	Stoniness, slope, moderate erosion, rapid runoff, poor Ground water potential	Arid horticulture

6	Slightly eroded pediplain	76	1-3	Slight	Moderate	Moderately well	Cultivated single crop or double crop	IIs	Moderate Ground water potential	Improved agriculture
7	Moderately eroded pediplain	60	3-8	Moderate	Moderate	Well	Cultivated single crop or fallow or scrub	IIIes	Moderate erosion, slight stoniness, Moderately shallow soil, Moderate Ground water potential	Soil Conservation + Agriculture
8	Severely eroded pediplain	32	8-15	Severe	Moderate	Some what excessive	Fallow or scrub	IVes	Shallow soil, severe erosion, slope, some what excessive drainage, Moderate Ground water potential	Pasture + Soil conservation
9	Slightly eroded valley	105	0-1	Very slight	Good	Imperfect	Cultivated-Double crop	IIw	Imperfect drainage	Intensive Agriculture
10	Moderately eroded valley	125	1-3	Moderate	Good	Imperfect	Cultivated-Double crop or fallow	IIIw	Moderate erosion, imperfect drainage	Intensive Agriculture

Fig- 20 Optimum Land Use Plan Map (1: 50,000 scale)
Ramannapet watershed, Nalgonda district, A.P.



Legend		
Mapping symbol	Action Item	Area (ha) % to total
	Planting Ber or Annona spp or pomgranate on patches of soil present in depressions	444.36 (4.35)
	Agroforestry	173.25 (1.69)
	Silvi-pasture	1387.30 (13.60)
	Improved Agriculture	2622.52 (25.71)
	Soil conservation + Agriculture	3134.30 (30.73)
	Intensive Agriculture	1806.54 (17.71)
	No Action	629.51 (6.17)

4.5.1.1 Arid Horticulture:

This action item was suggested to hills, dykes, and Inselbergs, where the soils were not suitable for cultivation of crops due to the steep slope, severe erosion, stoniness shallow depth, and excessive drainage. This action item was suggested to 444.36 ha, which constituted 4.35 percent of the study area.

4.5.1. 2 Agro-forestry+ soil conservation:

Agro-forestry system in combination with soil conservation was suggested to the pediment soils where the limitation to the crop production was Stoniness, shallow depth, slope and moderate erosion. Theses soils were found to be marginally suitable to agriculture. This action item covered a total area of 173.25 ha (1.69 per cent).

4.5.1.3. Silvi-pasture + Soil conservation:

This production system in combination with the soil conservation was suggested as action item for improvement of the Pediment inselberg complexes. These soils are plagued with stoniness, slope, erosion and rapid runoff problems that make the land unsuitable for agriculture. In total 13.60 per cent of the total watershed area-covering 1387.30 ha was suggested with this action item.

4.5.1.4 Improved Agriculture:

Crop cultivation with improved management practices and high yielding cultivars was suggested to the soils of the slightly eroded pediplain, where the problems for crop cultivation are minimum. This action item was suggested to 2622.52 ha, which constituted 25.71 per cent of the total area of the watershed.

4.5.1.5 Soil conservation+ Agriculture:

Moderately eroded pediplain with the moderate erosion, slight stoniness, moderately shallow soil depth limitations for crop production were suggested with this action item. An area of 3134.30 ha i.e. 30.73 per cent of the total watershed area was suggested with this land use.

4.5.1.6 Intensive Agriculture:

Valley lands with high productivity were suggested with this action item. Cultivation of two crops in a year and adoption of improved management practices were suggested in this action item this action item was suggested to 1806.54 ha which constituted 17.71 % to the total area the watershed

4.5.1.7 No Action:

'No action' item was recommended for the built up areas, Water bodies, streams where no activity in terms of optimizing the land use can be taken up. This recommendation was made to 629.51 ha which constituted 6.17 per cent of the total area of the watershed.

4.5.2 Optimum land Use plan map (1:25,000 scale)

Optimum land use plan at 1:25,000 scale was prepared using the slope, erosion, run-off, pH, texture of the surface soil, ground water potential, stoniness, drainage and land use criteria. In this map preparation information available in the thematic layers, information collected during the fieldwork was utilized.

Optimum land use plan map of the study area (1:25,000 scale) is presented in the figure 21. Legend and description of the action items are presented in the figure: 22. Criteria for selecting the action items are presented in table no. 16.

4.5.2.1 Arid Horticulture

This action item was suggested to hills, dykes, and Inselbergs, where the soils were not suitable for cultivation of crops due to the steep slope, severe erosion, stoniness, shallow depth, and excessive drainage.

Fig-21 Optimum land Use Plan Map (1;25,000 Scale)

Bhogaram mini-watershed, Nalgonda district, A.P.

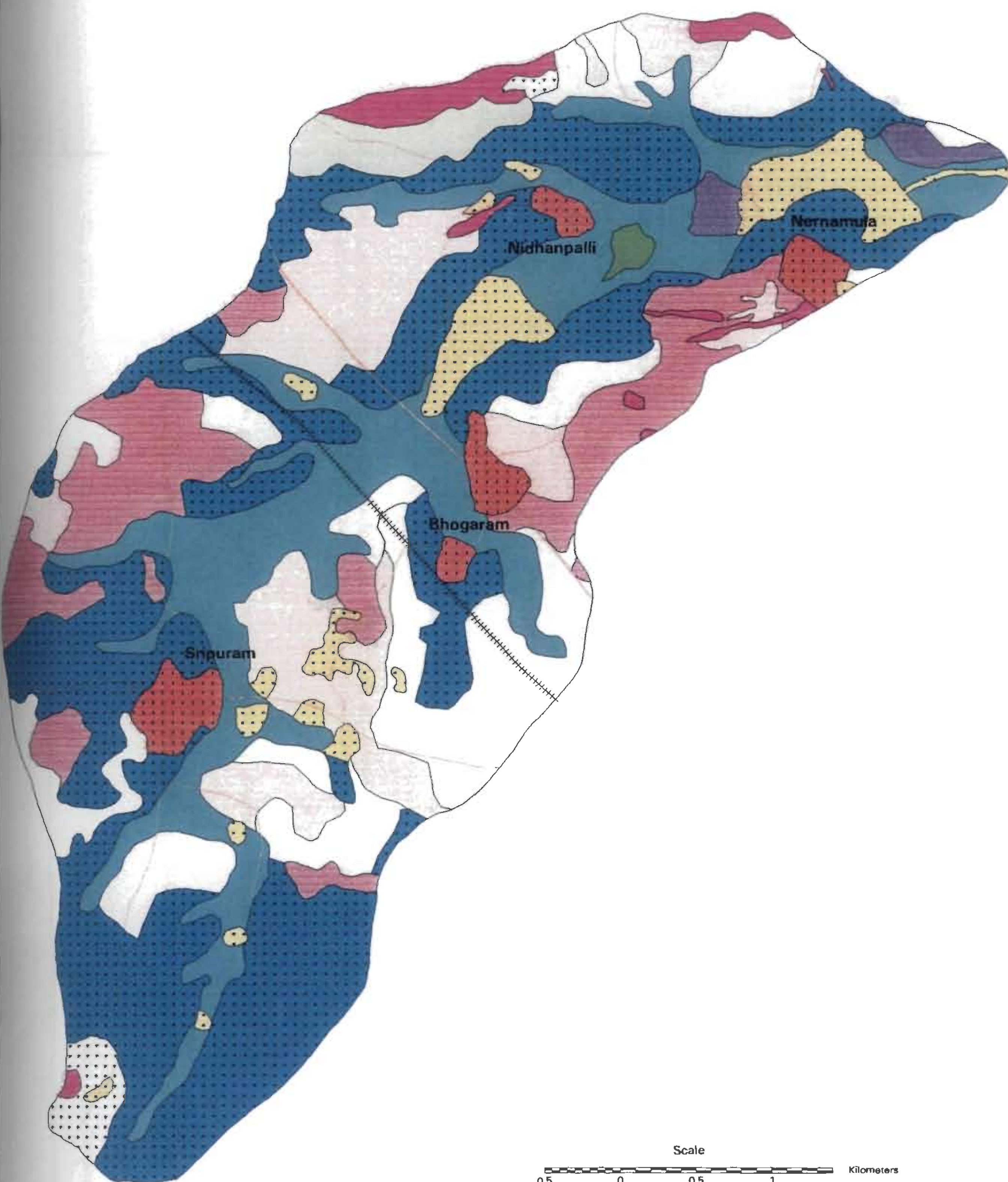


Fig- 22 Legend of Optimum Land Use Plan Map (1:25,000)

Mapping symbol	Action item	Area (ha) % to total
	Drought resistant fruit tree species	49.76 (1.99)
	Agro-Forestry + soil Conservation: **Multipurpose forest tree species+ Drought tolorerant crops+** contour bunding+nala plugging	32.14 (1.28)
	Arid Horticulture + soil conservation: **Drough tolerant friut tree species+contour bunding+grassed water** ways+nala plugging	47.17 (1.88)
	Silvi-pasture+ Soil Conservation: Tree component(multi-purpose, fast growing, drought resistant tree Species + Pasture componet (Drought resistant species) +Soil Conservation(Tree species in the trenches across slope, pasture species on ridges and furrows across slope)	270.08 (10.81)
	Improved Agriculture: Cultivation of crops (Castor, Sorghum,red gram cow pea)+ sole crops / intercropped + Recommended package of paractices.	798.85 (31.99)
	Soil Conservation+ Agriculture : Contour Cultivation and contour bunding+Strip cropping/intre cropping(Sorghum, Bajra, Castorred gram, cow pea, horse gram) Bulky organic manures+ tank silt+INM+recommended package of practices	370.13 (14.82)
	Pasture+ Soil Conservation:- Pasture componet : Drought tolerant, fast growing, fodder species +Soil Conservation: Planting on ridges and furrows across slope+contour bunding	263.34 (10.55)
	Soil Reclamation + Agriculture : Gypsum application + sodicity resistant varities of paddy +green manure crops + micro-nutrient	8.81 (0.35)
	Intensive Agriculture: Paddy(*kharif*) +*Rabi*: *Irrigated* dry crops (Maize, sunflower, Bengal gram, Rabi sorghum). **HYVs/ Hybrids+** recommended practices+INM	437.53 (17.52)
	Soil conservation + Agriculture : Strengthening bunds+**nala-bunds.+Levelling and terracing + Paddy, maize, sunflower** +micro-nutrient +green manuring+INM	23.437 (7.82)
	No Action	195.43 (7.82)

Table : 16 Criteria used for Optimum land use plan action item identification (1:25,000 scale)

Mapping unit	Name of the mapping unit	Depth (cm)	Slope (%)	Erosion	Run-off	pH	ESP	GWP	Stoniness	Drainage	Land Use	Land capability classification	Problems	Action Item
1	Residual hill	13	30-40	Severe	Very rapid	8.07	4.23	Very poor	very boul--dry	Excessive	Waste land	VIIes	Steep slope, severe erosion, stoniness, shallow depth, excessive drainage, very poor Ground water potential	Arid Horticulture
2	Dyke	26	25-30	Severe	Very rapid	6.49	1.08	Very poor	Boulders	Excessive	Waste land	VIes	Steep slope, severe erosion, stoniness, shallow depth, excessive drainage, very poor Ground water potential	Arid Horticulture
3	Inselberg	22	25-30	Severe	Very rapid	6.57	4.15	Very poor	Boulders	Excessive	Waste land	VIes	Steep slope, erosion, stoniness, shallow depth, excessive drainage, very poor Ground water potential	Arid Horticulture
41	Pediment-Uncultivated	70	3-5	Moderate	Moderate	6.12	2.71	Poor	stony	Well	Scrub	Ves	Stoniness, slope, moderate erosion, poor Ground water potential	Agro-forestry + Soil conservation
42	Pediment-Cultivated	50	3-5	Moderate	Moderate	6.97	7.47	Poor	Slightly stony	Well	Cultivated -single crop	IVes	Shallow depth, moderate erosion, poor GWP, slope	Arid Horti culture+Soil Conservation
5	Pediment Inselberg complex	52	8-15	Severe	Rapid	6.12	2.71	Poor	stony	Some what excessive	Waste land	VIes	Stoniness, slope, moderate erosion, rapid runoff, very poor Ground water potential	Arid Horticulture
61	Slightly eroded pediplain-Uncultivated	50	1-3	Slight	Slow	7.35	2.65	Moderate	Stony	Well	Scrub	IVs	Shallow soil, stoniness, moderate Ground water potential	Pasture + Soil Conservation

62	Slightly eroded pediplain-Cultivated	76	1-3	Slight	Slow	6.91	1.18	Mode rate	non-stony	Mode rately well	Cultivated -single crop or double crop.	IIes	Moderate Ground water potential	Improved Agriculture
71	Moderately eroded pediplain-Uncultivated	45	3-5	Mode rate	Mode rate	6.97	6.42	Mode rate	Very stony	Well	scrub	IVes	Shallow soil, slope, moderate erosion, stoniness, moderate Ground water potential	Pasture + Soil Conservation
72	Moderately eroded pediplain-cultivated	60	3-5	Mode rate	Mode rate	7.37	1.08	Mode rate	slight ly stony	Well	Cultivated -single crop	IIIes	Moderate erosion, slight stoniness, moderately shallow soil, moderate Ground water potential	Agriculture +Soil Conservation
81	Severely eroded pediplain-Uncultivated	32	8-10	Severe	Rapid	8.17	2.87	Mode rate	very bould ry	Some what excess ive	Scrub	VIes	Shallow soil, severe erosion, slope, some what excessive drainage, moderate Ground water potential	Pasture + Soil Conservation
91	Slightly eroded valley-Uncultivated	90	0-1	very slight	Very slow	8.22	16.25	Good	Non stony	Poor	Fallow	IIIws	Alkalinity, poor drainage	Soil reclamation + Agriculture
92	Slightly eroded valley-Cultivated	105	0-1	Very slight	Very slow	8.01	10.1	Good	Non stony	Imper fect	Cultivated -Double crop	IIw	Imperfect drainage	Intensive Agriculture
101	Moderately eroded valley-Uncultivated	62	1-3	Mode rate	Mode rate	9.13	6.27	Good	Stony	Moder ately Well	Fallow	IIIs	Moderately shallow soil moderate erosion, moderately alkaline soil pH	Soil conservation + Irrigated agriculture
102	Moderately eroded valley-Cultivated	125	1-3	Mode rate	Slow	8.25	4.21	Good	Non-stony	Imper fect	Cultivated -Double crop	IIwe	Moderate erosion, imperfect drainage	Intensive Agriculture

Amla/ Ber/ Annona spp/ Soapnut plantations can be taken up in these soils during monsoon period. This suggested action item covers an area of 49.76 ha in the total watershed (1.99 per cent of the area).

4.5.2.2 Agroforesty:

Stoniness, slope, moderate erosion, poor ground water potential were the major limitations of these soils for cultivation of crops. Keeping these points in view, this action item was formulated such that the selected components would survive in these conditions and give economic returns.

Forestry component : Multi purpose tree species viz., Subabul, *Acacia albida, Albizia lebbeck*, sissoo, Eucalyptus spp

Agriculture component: Drought tolerant crops like castor, sorghum, redgram

An area of 32.14 ha i.e.1.28 percent of the area of the mini-watershed was recommended with this action item.

4.5.2.3 Arid Horticulture+ soil conservation

Shallow depth, moderate erosion, poor ground water potential, slope constraints were taken in to consideration while formulating the action item.

Amla /Ber/ Annona spp/ / Soapnut plantations on the soils during monsoon period

Soil conservation : Trench planting/ Contour bunding / nala plugging

This suggested action item covers an area of 47.17 ha in the total watershed (1.88 per cent of the area).

4.5.2.4 Silvi-pasture+ soil conservation

These soils have stoniness, slope, erosion and rapid runoff problems that make these lands unsuitable for agriculture. The suggested action item will increase the total biomass production of the mapping unit and help in curtailing the degradation of the soil.

Trees : Drought resistant tree species Israeli Babool, (*Acaia nilotica*), Babool (*Acacia arabica*), Siris (*Albizia lebek*)

Grasses: Anjan grass (*Cenchrus ciliaris),* Stylo *(Stylosanthus hamata,) Chrysopogan fulvus*

Soil conservation: Contour bunding / Contour furrowing and trenching / contour furrowing and pitting.

This action item was suggested to 270.08 ha which constituted 110.81per cent to the total area of the mini-watershed.

4.5.2.5 Soil Conservation + pasture:

These lands are not suitable for crop cultivation owing to their surface stoniness, shallow depth and severe erosion. To control the soil erosion and to prevent further degradation of these lands this action item was suggested.

Grasses: Anjan grass (*Cenchrus ciliaris),* Stylo *(Stylosanthus hamata,) Chrysopogan fulvus*

Soil Conservation: In undulating area, adequate soil-water-conservation measures viz., Pitting, contour bunding and contour surrounding should be adopted.

An area of 263.34 ha i.e 10.55 per cent of the total area of the mini-watershed was suggested with this action item

4.5.2.6 Improved Agriculture:

This action item was suggested for the slightly eroded pediplain. Soil limitations for cultivation of crops are medium coarse texture resulting in low moisture holding capacity of the soil and moderate ground water potential.

Crops:

Cultivation of the crops that are tolerant to moisture stress viz., castor / sorgham / bajra as sole-crops or intercropped with cow pea/ green gram /red gram at recommended ratios. Adoption of INM and recommended package of practices.

This action item was suggested in a total area of 798.85 ha (31.99 per cent of total area of the watershed

4.5.2.7 Soil Conservation + Agriculture :

Soils of the moderately eroded pediplain with constraints of erosion, slight stoniness, moderately shallow soil, medium coarse texture and moderate ground water potential were suggested with this action item.

Soil Conservation:

Contour cultivation, contour bunding and adoption of strip cropping with erosion permitting crop such as sorghum, castor, redgram and erosion arresting crops viz, cowpea, green gram, horse gram.

This action item was suggested to 370.14 ha which is 14.83 per cent of the total area of the watershed.

4.5.2.8 Soil reclamation + agriculture:

The action item was recommended for the valley soils with sodicity and poor drainage problems.

- Reclamation of these soils by application of gypsum.
- Cultivation of green manure crops such as daincha, sesbania or green leaf Manuring with glyricidia, pongamia species.
- Application of recommended quantities of organic manures.
- Application micronutrients especially zinc at 100kg/ha.

- Considering the water logging nature of the soils, paddy was identified as the best suited crop for these soils..

This action item was suggested for 8.81 ha which constituted 0.35per cent of total mini-watershed area.

4.5.2.9 Intensive agriculture:

This action item was suggested to the valley lands and buried pediplain areas. Potentials of the soils viz., good ground water potential, slight erosion, and depth were considered to suggest intensive agriculture action item to these soils.

This action item involves cultivation of two crops (double cropping) in a year. Cropping systems can be Paddy-Paddy/ Paddy-ID crops.

In total this action item was suggested to 437.53ha of the watershed, which constitute 17.52 per cent of the total area of the watershed.

4.5.2.10 Soil Conservation + irrigated agriculture:

These soils were moderately eroded valley soils with surface stoniness, moderate erosion, and shallow depth. Limitations in these soils for production were moderately shallow soil, moderate erosion, and moderately alkaline soil pH

Soil conservation activities suggested in the areas was leveling, terracing the lands / strengthening of the field bunds, plugging of the gullies/nalas with stones at several places.

Keeping in view the physiographic locations of the soils (Valleys) cultivation of the semi-dry paddy with varieties suitable for the watershed.

An area of 23.32 ha which constituted 0.93 percent of the total area of the mini-watershed was suggested with this action item.

4.5.2.11 No Action:

'No action' item was recommended for the built up areas, Water bodies, streams where no activity in terms of optimizing the land use can be taken up. This mapping was suggested to 195.43 ha which constituted 7.82 per cent of the total area of the watershed.

4.5.3.Optimum Land use Planning (1:12,500 scale)

Optimum land use plan at 1:12,500 scale was prepared using the slope, erosion, run-off, pH, texture of the surface soil, texture of the sub-surface soil, ground water potential, stoniness, drainage and land use criteria. In this map preparation information available in the thematic layers, information collected during the fieldwork was utilized.

Optimum land use plan map of the study area (1:12,500 scale) is presented in the figure 23. Legend and description of the action items are presented in the figure 24. Suitability of the crops was determined by evaluation of the land for cultivation of crops (crop suitability classification). Criteria suggested by Sehgal (1997) and Sys et.al, (1991) were utilized in assessing the lands for cultivation of different crops (Appendix-III). Results of evaluation of the various mapping units for cultivation of suitable crops are presented in table14. Criteria for selecting the action items are presented in table no. 17. Verities and Hybrids suitable to the study area are presented in the table no.18.

In total, 11 action items were suggested for optimization of the land use at this scale. The description of the action items is as follows

4.5.3.1 Arid Horticulture

This suggested action item covers an area of 2.53 ha in the micro-watershed (0.14 per cent). Considering the unsuitability of the land for cultivation of crops and other agricultural systems due to limitations viz., in terms of stoniness, depth, slope, erosion this action item was suggested.

Table : 17 Criteria used for Optimum land use plan action item identification (1:12,500 scale)

Mapping unit	Name of the mapping unit	Depth (cm)	Slope (%)	Erosion	Run-off	pH	Txt-surface	Txt-sub-surface	GWP	Stoniness	Drainage	Land use	LCC	Problems	Action item
3	Inselberg	22	25-30	Severe	Very rapid	6.57	sl	sl	V.poor	Boulders	Excessive	Waste land	VIes	Steep slope, erosion, stoniness, shallow depth, Excessive drainage very poor Ground water potential	Arid Horticulture
411	Pediment-Fallow	42	3-5	Moderate	Moderate	6.97	sl	sl	Poor	Stony	Well	Fallow	IVes	Stoniness, slope, moderate erosion, poor ground water potential	Arid Horticulture
412	Pediment-Scrub	45	8-10	Moderate	Moderate	6.12	sl	scl	Poor	Very stony	Well	Scrub	IVes	Stoniness, slope, moderate erosion, poor ground water potential	Arid Horticulture + Soil conservation
611	Slightly eroded pediplain-Scrub	50	3-5	Slight	Moderate	7.35	sl	scl	Moderate	Stony	Well	scrub	IVes	Shallow soil, stoniness, moderate ground water potential	Pasture + Soil Conservation
612	Slightly eroded pediplain-Fallow	55	1-3	Slight	Slow	7.35	sl	scl	Moderate	Slightly stony	Moderately Well	Fallow	IIIs	Moderately shallow soil, moderate ground water potential	Silvi-pasture+ Soil Conservation
621	Slightly eroded pediplain-Cultivated	76	1-3	Slight	Slow	6.91	sl	scl	Moderate	Slightly Gravelly	Moderately Well	Cultivated-single crop	IIs	Moderate ground water potential	Improved Agriculture
622	Slightly eroded pediplain-Cultivated-Paddy	76	0-1	Very Slight	Very slow	6.91	sl	scl	Moderate	Non Gravelly	Imperfect	Cultivated-single crop or double crop	IIs	Medium coarse texture, Moderate ground water potential	Intensive agriculture with ID crops

623	Slightly eroded pediplain-Plantation	62	1-3	Slight	Slow	6.97	sl	cl	Moderate	Slightly Gravelly	Moderately Well	Plantation	IIs	Moderately shallow soil, coarse texture, Moderate ground water potential	Improved orchard management
711	Moderately eroded pediplain-Scrub	42	3-5	Moderate	Moderate	6.97	ls	scl	Moderate	Stony	Well	scrub	Ves	Shallow soil, slope, moderate erosion, stoniness, very coarse texture, Moderate ground water potential	Silvi-pasture + Soil Conservation
712	Moderately eroded pediplain-Fallow	49	3-5	Moderate	Moderate	6.97	sl	scl	Moderate	stony	Well	Fallow	IVes	Moderately shallow soil, moderate erosion, slope, very coarse soil, stoniness,v	Silvi pasture+ Soil Conservation
721	Moderately eroded pediplain-Cultivated	60	1-3	Moderate	Moderate	7.37	sl	scl	Moderate	Slightly stony	Well	Cultivated-single crop	IIIes	Moderate erosion, slight stoniness, moderately shallow soil,v	Agriculture+ Soil Conservation
811	Severely eroded pediplain-Scrub	32	8-10	Severe	Rapid	8.17	ls	sl	Moderate	Very stony	Somewhat excessive	Scrub	VIes	Shallow soil, severe erosion, slope, some what excessive drainage, Moderate ground water potential	Pasture+ Soil Conservation
92	Slightly eroded valley-Cultivated	105	0-1	Very slight	Very slow	8.01	scl	scl	Good	Non Stony	Imperfect	Cultivated-double crop	IIw	Imperfect drainage	Intensive agriculture
102	Moderately eroded valley-Cultivated	125	1-3	Moderate	Slow	8.25	scl	sc	Good	Non Stony	Imperfect	Cultivated-double crop	IIw	Moderate erosion, imperfect drainage	Intensive agriculture

Fig 23 Optimum Land Use Plan Map (1:12,500)
Sripuram Micro-watershed, Nalgonda district, A.P.

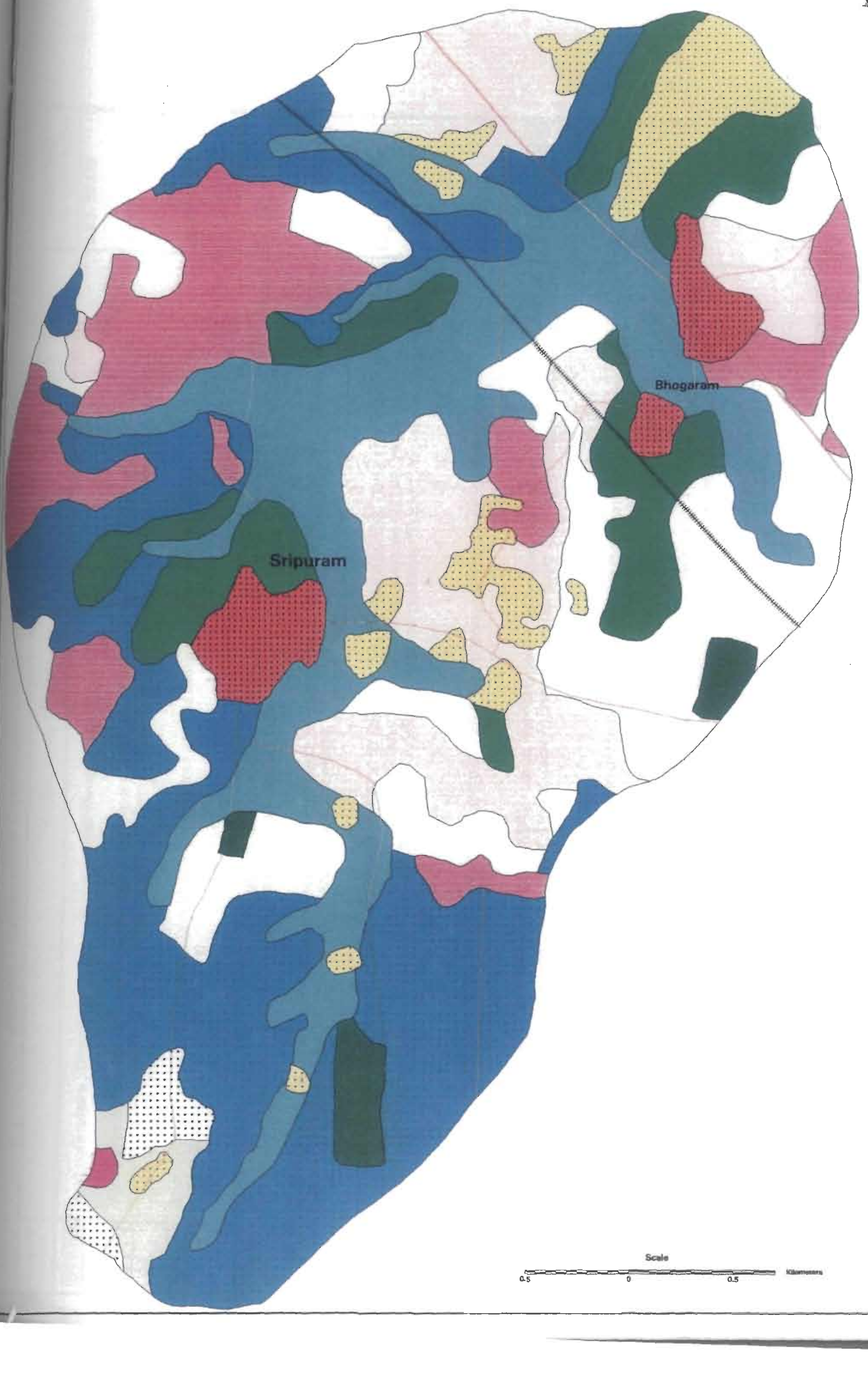


Fig-24 : Legend of Optimum Land Use Plan Map (1:12,500)

Mapping Symbol	Action Item Description	Area (ha) % to total area
	Arid horticulture ; Drought resistant fruit tree species (Amla, Annona spp, Ber).	2.53 (0.15)
	Agro-Forestry and Soil Conservation: Multipurpose forest tree species (Sissoo, Subabul, Pongamia, Glyricidia) +Drought tolerent crops:castor (Kranthi, Haritha) : Sorghum (Palem-1, Palem-2) +soil and water conservation (contour bunding+ contour trench planting)	17.97 (1.05)
	Arid Horticulture+ soil conservation: Drough tolerant friut tree species :Amla/Annona/ Ber/soapnut + contour bunding+ ring pit planitng	22.35 (1.31)
	Pasture+ Soil Conservation:- Pasture : Drought tolerant, fast growing grass spp(cenchrus spp, Stylosanthus spp)+Soil Conservation: Planting of grasses on ridges and furrows across slope+ contour bunding	207.36 (12.11)
	Improved Agriculture: HYvs of the crops: Castor(Kranthi, Haritha, Kiran), Sorghum(Palem-1, Palem-2, CSV-15) redgram (PRG-100, PRG-158 or LRG-30) + Recommended paractices+INM.	415.87 (24.29)
	Intensive Agriculture (ID crops): Crop diversification (paddy to ID crops) Kharif: Maize(DHM-103, DHM-105, DHM-107), Sunflower(APSH-1), Cotton(Narasimha or Mungari cotton varities),chillies. Rabi: Rabi sorghum (NTJ-2, Phule yashoda), Ground nut(vemana,TMV-2, ICGS-11) sunflower (Private hybrids)+Recommended practices+Efficient Irrigation systems +**INM.**	143.31 (8.37)
	Improved orchard Management: Agri-horti system in young orchards+green manures+ drip irrigation+Fertigation	25.80 (1.51)
	Silvi-pasture+ Soil Conservation: Tree component -MPTs (sissoo, subabul, neem, Cassia spp. Pasture componet : Drought tolerant (cenchrus spp+ stylosanthus spp. Soil Conservation: Tree planting in trenches across slope. Planting grasses on ridges and furrows across slope.	181.325 (10.59)
	Soil Conservation+ Agriculture : Contour Cultivation and contour bunding+Strip cropping (sorghum/castor/redgram with cowpea/green gram /Horse gram)+Bulky organic manures+Tank silt+INM +Recommended practices	283.392 (16.55)
	Intensive Agriculture: Kharif -paddy (Early samba, sagar samba). Rabi: ID crops maize (DHM-103, DHM-107, DHM-109), **cotton** (Narsimha / mungari cottons), sunflower (APSH-1) Rabi sorghum(Phule Yashda, NTJ-2)+ Recommended practices+INM	284.77 (16.63)
	No Action	126.95 (7.42)

Planting of Amla/ Ber/ Annona spp / Soapnut in the soil patches during monsoon period. and after they get established and they will be left with out any management.

4.5.3.2 Agroforesty + soil conservation:

This action item was suggested for the pediment area. Coarse texture of the soil, poor ground water potential slope, stoniness and erosion render these areas marginally suitable for agriculture.

An area of 17.97 ha (1.69 per cent of the area of the micro-watershed) was recommended with this action item.

Forestry component : *Acacia nilotica*, Neem or fast growing tree species viz., Subabul, *Acacia albida, Albizia lebbeck*, sissoo.

Agriculture component: crops like castor, sorghum, red gram, cowpea and sunflower were recommended under this system, with suitable pruning of the tree species.

An area of 17.97 ha (1.04 per cent of the area of the micro-watershed) was recommended with this action item.

4.5.3.3 Arid Horticulture + Soil conservation:

This action item was suggested to the pediment soils that are marginally suitable for cultivation of crops because of the stoniness, slope and erosion Problems.

In this action item planting of the fruit crops suitable for the Arid /semi-arid zones viz., Amla (Narendra-7, Annona Spp (Balanagr x Atimoya), Ber (Gola), Soapnut (local collections) were recommended to the areas. Seedlings of these trees should be planted during the monsoon period in ring pits and grown as rain fed with minimum management..

Soil conservation:

Planting of the seedlings should be done in the trenches dug across the slope and dead furrows should be opened at every 3.6m interval and nala plugging should be taken.

Pit Size: A pit size of 30 cm x 30 cm x 45 cm was found to be optimum

Pit Filling In each pit, dugout soil need to be mixed with 8 kg of FYM, 50 gm of DAP, 10 kg of black earth and 0.5 kg neem cake for better establishment of seedlings

Moisture Conservation: Application of paddy husk in the basins to a thickness of 7.5 cm help in conserving the moisture

This action item was recommended for 22.34 ha which is 1.30 per cent of the area of the micro watershed.

4.5.3.4 Silvi-pasture+ soil conservation

This action item was suggested to the soils that were not suitable for agriculture (moderately eroded pediplain-scrub). An area of 207.36ha (12.11 ha)was suggested with this recommendation.

For the study area some of the fodder trees that have promise in with the grass species are

Trees		**Grasses**
1. Israeli Babool	(*Acaia nilotica*)	1. Buffel grass (Anjan) (*Cenchrus ciliaris)*
2.Babool	(*Acacia arabica*)	2. Stylo *(Stylosanthus hamata)*
3.Siris	(*Albizia lebek*)	3. Birds wood grass *Cenchrus setigerus*)

Tree planting: 'Shallow depth ridge' planting for the trees component as the depth of the soil is very shallow and the sub-soil is either loose gravel or murrum with a very low water holding capacity.

Population: 400 trees / ha with a spacing of 5m x 5m

Grasses Seed rate : Grasses: 5 kg/ha

Legumes + grasses : 12 kg+ 5kg/ha

Soil Conservation measures

In undulating area, adequate soil-water-conservation measures viz., Pitting, contour bunding and contour surrounding should be adopted. Harvesting of the rainwater by plugging the gullies, streams or nallas or construction of the check bunds at several points in the streams should also be done to stop the rainwater for utilization during the periods of moisture stress.

Contour bunds: These bunds are to be positioned in the field at an vertical interval of 1.4m and horizontal interval of 20 m (calculating the average slope as 10 per cent).

- Construction of the contour bunds should be from top to bottom.
- Burrow pits should be positioned on the up-stream side of the bund.
- In the ridge areas, which are not cultivated, bunding is generally taken up. In those areas diversion drains should be constructed to prevent damage to the contour bunds in case of heavy rainfall.

Social fencing of the pastureland/ silvi-pasture land:

The pasturelands that are seeded or reseed are to be protected during first season after sowing so that they get well established in the soil and give better yields from the next season. In this regard, they are either physically fenced or socially fenced (the practice of abandoning the grazing in that particular piece of land through community initiative).

4.5.3.5 Improved Agriculture:

This action item was suggested for the slightly eroded pediplain with moderate ground water potential. Soil limitations for cultivation of crops are medium coarse texture resulting in low moisture holding capacity of the soils.

Cultivation of the crops that are tolerant to moisture stress eg. Castor (kranthi, Haritha), Sorgham (palem-1, Palem-2), Bajra (Mallikarjuna) as sole-crops or intercropped with cow pea or green gram or Red gram. Adoption of recommended package of practices, application of organic manures and Integrated Nutrient management.

This action item was suggested in a total area of 415.87 ha, which constituted 24.29 per cent of total area of the watershed.

4.5.3.6 Intensive agriculture(ID crops)

This action item was suggested to the slightly eroded pediplain areas where rice is cultivated. However, these soils are medium coarse in texture and ground water potential is moderate. Hence crop diversification from paddy to Irrigated Dry crops was suggested. ID crops viz., maize (DHM-103, DHM-107) sunflower (APSH-1) can be cultivated in theses areas during kharif season. During rabi season Rabi sorghum (NTJ-2), Ground nut (vemana, TPT-2), sunflower (APSH_1), maize (DHM-103, DHM-107) can be cultivated.

This action item was suggested to 143.309 ha, which is 8.37 per cent of the total area of the watershed.

4.5.3.7 Improved Orchard management

This action item was suggestedto the established orchards of citrus and mango in the study area occurred in an area of 25.80 ha i.e. 1.50 per cent of the micro-watershed area.

Adoption of intercropping with pulses viz., green gram/ horse gram or sorghum/ maize in young orchards.

Efficient irrigation systems (drip)

Adoption fertgation.

Balanced fertlizer management and application of organic manures.

4.5.3.8 Soil Conservation + Agriculture :

Soils of the moderately eroded pediplain with constraints of erosion, slight stoniness, moderately shallow soil, medium coarse texture and moderate ground water potential were recommended with this action item.

Keeping in view the limitations of the land contour cultivation, contour bunding and adoption of strip cropping with erosion permitting crop such as sorghum, castor, red gram and erosion arresting crops. cowpea, green gram was suggested. This action item was suggested to 283.39 ha, which is 16.55 per cent of the total area of the watershed.

Off-season deep tillage was recommended to increase the infiltration of water in to soil. Blading of the soil and off-season tillage form soil mulch and reduce weed growth by uprooting them thus reducing the competition for the crops to be cultivated.

Establishment of optimum or slightly excess plant population would ensure optimum canopy cover and reduce the rain-splash erosion.

Contour bunds:

This action item was suggested to the moderately eroded pediplain soils with 3-5 per cent slopes. These bunds are to be positioned in the field at a vertical interval of 1m and horizontal interval between two bunds was suggested to be 20 m (calculating the slope as 5 per cent).

- Construction of the contour bunds should be from top to bottom.
- Burrow pits should be positioned on the up-stream side of the bund.

- In the ridge areas, which are not cultivated, bunding is generally taken up. In those areas diversion drains should be constructed to prevent damage to the contour bunds in case of heavy rainfall.

4.5.3.9 Pasture + Soil conservation

These lands are not suitable for crop cultivation owing to their surface stoniness, shallow depth and severe erosion. To control the soil erosion and to prevent further degradation of these lands this action item was suggested.

Grasses: Anjan grass (*Cenchrus ciliaris),* Stylo *(Stylosanthus hamata,)* *Chrysopogan fulvus*

Soil Conservation: In undulating area, adequate soil-water-conservation measures viz., Pitting, contour bunding and contour surrounding should be adopted.

An area of 263.34 ha i.e 10.55 per cent of the total area of the mini-watershed was suggested with this action item

4.5.3.10 Intensive agriculture:

This action item was suggested to the valley lands and buried pediplain areas. Potentials of the soils viz., good ground water potential, slight erosion, depth and other features were considered to classify these mapping units under intensive agriculture action item category.

This action item involves cultivation of two crops (double cropping) in a year. Cropping systems can be Paddy-Paddy/ Paddy-ID crops. Irrigated Dry crops like sunflower, maize, sorghum can be cultivated in those areas. Adoption of recommended package of practices, INM was also recommended.

In total this action item was suggested to 284.77 ha of the watershed, which constitute 16.63 per cent of the total area of the watershed.

4.5.3.11 No Action:

'No action' item was recommended for the built up areas, Water bodies, streams where no activity in terms of optimizing the land use can be taken up. This mapping was suggested to 126.95 ha, which constitute 7.41 per cent of the total area of the watershed.

Table no 18. List of Varieties of the crops suitable to the Watershed

S.No.	Crop	Suitable Varieties	
I.	**Arid Fruit Crops**		
1.	**Amla**	Narendra -7, Narendra-10	
2.	**Sitaphal**	Atimoya x Balanagar, Atimoya, Balanagar	
3.	**Ber**	Gola, Karki, Banaras Karki	
4.	**Jamun**	Local collections	
5.	**Tamarind**	PKM-1, Local collections	
6.	**Soapnut**	Local collections	
7.	**Koronda**	Local collections	
8.	**Agele spp (Maredu)**	Local collections	
9.	**Wood apple**	Local collections	
II	**Field Crops**	Suitable Varieties	
		Kharif	Rabi
1.	**Rice**	Early Samba (RNRM-7) Samba Mashuri (BPT-5204) Rajavaddlu (RNR-99377) Phalguna (RPW-6-17) **Saline Soils** Vikas Swarna CSR-13	Surekha Tella Hamsa Satya (RNR-1446) **Saline Soils** Vikas
2	**Sorghum**	Palem-1 Palem-2 CSV-15	NTJ-! NTJ-2 PJ-890 Phule Yashoda

3.	**Maize**	**Irrigated**: DHM-1 DHM-7 DHM-9 Suitable private hybrids **Rain fed**: Aswini Varun Harsha	**Irrigated**: DHM-1 DHM-7 DHM-9 Suitable private hybrids **Rain fed**: Aswini Varun Harsha
4.	**Castor**	Kranthi (PCS-4) Haritha (PCS-124) Kiran (PCS-136) Jyothi (DCS-9)	Kranthi (PCS-4) Haritha (PCS-124) Kiran (PCS-136) Jyothi (DCS-9)
5.	**Groundnut**	**Irrigated**: Vemana (k-134) TPT-2 TMV-2 TPT-4 TPT-1 **Rain fed**: Vemana (k-134) JL-24 Narayani	**Irrigated**: Vemana (k-134) TPT-2 JL-24 ICCS-11 **After rice**: Kadiri -4
6.	**Sunflower**	Mordan APSH-1 Suitable private hybrids	Mordan APSH-1 Suitable private hybrids
7.	**Ragi**	Maruthi Kalyani	Maruthi Kalyani
8.	**Cotton**	Narsimha MCU-5 LRA-5166 LK-861 Suitable private hybrids	-
9.	**Green gram**	WGG-2 WGG-7 LGG-407	-

III	**Grasses**	
1.	**Anjan grass**	Marwar Anjan (CAZRI, Jodhpur) CAZRI-1263 Pusa gaint (IGFRI) Bundel Anjan Local collections
2.	**Cenchrus setigerus**	Marwar Dhaman S-175 / S-298 / S-412 / S-416 / Local collections
3.	**Marvel Grass (Dicanthium annulatum)**	S32 / S-65 / IGFRI-1981 or Local collections

Table no: 6 Description of soil phases (1:12,500 scale)

S.No.	Map Symbol	Mapping Unit	Description of soil phases
1	SMU-3	Dbk1 2eFe4st5	Dubbak-1, Very shallow, gravelly sandy clay, steeply sloping, severe erosion, very strongly stony
2	411	Ndn3 3rCe3st3	Nidhanpalli-3, Shallow, gravelly sandy loam, gently sloping, moderate erosion, moderately stony
3	412	Dbk4 4rCe3st4	Dubbak-4, Moderately shallow, gravelly sandy loam, gently sloping, moderate erosion, strongly stony
4	621	Spm3 5rBe2st1	Sripuram-3, Moderately deep, sandy loam, very gently sloping, slight erosion, non stony
5	622	Spm3 5mAe1st1	Sripuram-3, Moderately deep, sandy clay loam, Nearly level, nil to very slight, non stony
6	623	Ndn2 5rBe2st2	Nidhanpalli-2, Moderately deep, sandy loam, very gently sloping, slight erosion, slightly stony
7	612	Bgm4 4rCe2st3	Bhogaram-4, Moderately shallow, gravelly sandy loam, gently sloping, slight erosion, moderately stony
8	611	Bgn4 3r Ce2st4	Bhogaram-4, Shallow, gravelly sandy loam, gently sloping, slight erosion, strongly stony
9	721	Dbk2 4rCe3st2	Dubbak-4, Moderately shallow, gravelly sandy loam, gently sloping, moderate erosion, slightly stony
10	712	Bgm1 3rCe3st3	Bhogaram-1, Shallow, gravelly sandy loam, gently sloping, moderate erosion, moderately stony
11	711	Bgm1 3rCe3st4	Bhogaram-1, Shallow, gravelly sandy loam, gently sloping, moderate erosion, strongly stony
12	811	Bgm2 3sCe4st4	Bhogaram-2, Shallow, gravelly loamy sand, gently sloping, severe erosion, strongly stony
13	92	Rpt1 6mAe1st1	Ramannapet-1, Deep, sandy clay loam, nearly level, nil to very slight, non stony
14	102	Bgm3 6mAe1st1	Bhogaram-3, Deep, sandy clay loam, nearly level, nil to very slight, non stony
15	100	Rock out crops	-

5. DISCUSSION

In watersheds, remote sensing and GIS techniques play a significant role in the preparation of inventory of natural resources such as soils, ground water, crops and land use / land cover because of many inherent advantages with these new techniques. Remote sensing data provide synoptic view of the environs of the watershed and with the advancement of time significant improvement is seen in spatial and spectral resolution of remote sensing sensors. The state of remote sensing technology has improved to an extent that we can obtain PAN data at 0.6 m and multi spectral data at 2.5 m and we can study the resources of a micro watershed or watershed up to 1:4,000 scale. The development of land and water resources on a sustainable basis without land degradation and reduction in crop productivity is being aimed at in resource management. The watershed approach is more rational because land and water have optimum interaction and synergistic effect when developed together. The piecemeal approaches such as contour bunding or terracing on individual holding or a group of farmers, marginally benefit the farmer as they are done ignoring what happens to other area which are influencing the hydrological characteristics. Such sporadic actions failed to attract farmers, as they do not yield benefits proportional to the efforts and investments made. Thus for maximizing the advantages, all developmental activities are to be undertaken in a comprehensive way on watershed basis.

Therefore the watershed has become a practical planning unit for transfer of rain fed agricultural technology from lab to land and for formulating the varies developmental programmes to improve the crop production and minimize land degradation resulting in optimum land use planning. The watershed management aims to optimize moisture retention and reduce soil erosion, thus maximizing productivity and minimizing land degradation. Improved moisture management increases the productivity of improved seeds and fertilizers. Therefore, conservation and productivity enhancement measures are complimentary to each other. The watersheds are considered as more appropriate and efficient units for assessing the natural resources for subsequent planning and implementation of various developmental programmes.

The easy availability of synoptic data in the temporal domain from space borne sensors adds a new dimension to the spatial information extraction. Processing and monitoring natural resources objectively. On the other hand, development of Geographical Information System (GIS) provides valuable support to handle voluminous data in both spatial and non-spatial formats. Further GIS allows the integration of data sets for deriving meaningful information in map or tabular formats. (Ravi shankar and Raman Murthy ,2004).

Remote sensing and GIS are being increasingly used for resource inventory studies as they reduce the time required for survey and evaluation of resources for variety of applications.

In the recent years, the GIS has become an important tool in land evaluation process. Major application of GIS in the field of soil surveys and land evaluation are land capability classification, land irrigability assessment, land suitability for different purposes and generation of optimum land use maps based on watershed approach.

In the present study and attempt has been made to study the natural resources and to generate optimum land use plan for a watershed located in drought prone, socio-economically backward region of Nalgonda District located in Andhra Pradesh, utilizing the potentials offered by the remote sensing and GIS techniques. Soil resource inventory of the study area was done at different scales viz., 1:50,000, 1:25,000, 1:12,500 with an aim to generate the land use plans for the over all development of the watershed and specific interventions related to increasing the agricultural productivity at micro watershed level.

In this chapter, results obtained on soils and land use / Land cover and optimum land use plans generated at various scales are discussed below.:

6.1 Soils

The soils of the study area were classified under three major soil orders viz., Entisols, Inceptisols and Alfisols as per Keys to soil taxonomy (1998). Entisols were located at relatively higher toptographic position compared to the Alfisols which were located on pediplains with lesser slopes. Inceptisols of fluvial origion and vertic nature were located in relatively lesser elevations compared to Alfisols. The origin and development of the soils of the study area based on the factors of soil formation is discussed as follows.

6.1.1 Pedogenesis

The study area experienced semi-arid monsoonic climate with distinct summer March, April June), winter (November, December, January) and rainy season (July, August, September, October). The average annual rainfall is 649mm. More than 75 per cent of the rainfall is received during June, July, August and September months which is a characteristic feature of monsoonic climate. As evident from the climatic data of the study and Omerothermic diagram highest rainfall received June month. Winters are cool and dry with a rainfall ranging from 0.6 to 16.74mm. Equal duration of wet and dry seasons in a year indicate that the climate of the study area was 'semi-arid'. The mean annual air temperature was 23.97 ^{0}C. The soil moisture regime was ustic and soil temperature regime was iso-hyperthemic. These climatic observations are in good agreement with those of Sehgal (1996).

Parent material of the study area was archean granite gneissic. The parent material for development of soils in the valley portions of the study area was alluvium. Singh *et al.*, (1998), Paramsivam and Gopal swamy (1993) reported similar occurrence of red soils originated from granite gneissic parent material from various parts of India. Coarser texture of the soils in the study area developed on this kind of parent material which was resistant to weathering resulting in lesser clay content was earlier reported by Syampura *et al.*, (1993) in soils of Rajasthan.

The climate being similar over the entire study area variations in parent material and topography played vital role in developing the soils of the study area. Soils located at relatively higher elevations (hills, dykes, inselbergs, pediments) were shallower in depth with coarser texture compared to the soils located at lower elevations of the landscape. Soils associated with pediplains red in colour while the soils of valleys were gray in colour. The red soils of the pediplain had well drained condition, coarse texture, high sand content, shallow depth, lower CEC less base saturation compared to the valley soils. These observations were in good agreement with those of Sharma *et al* (1996). Gajbhiye and Deshmukh (1992) reported the occurrence of soils with similar properties in a topo sequence in Maharastra.

The skeletal nature and shallow depths of soils located at higher elevations indicated their lesser age (immature) nature compared to the soils located at lower elevations, which were relatively better developed in terms of depth, texture and structure. Non-availability of adequate water for prolonged periods and erosional losses of surface soils might have restricted the development of the soils located higher elevations. Differential profile development due to slope variations was earlier reported by Gupta and Chera (1996) in middle Shiwaliks. Fine particles removed from the surface layers by runoff water and deposited at lower pediplain, which resulted in shallow pedons at higher slopes and deeper pedons at relatively less sloping areas. Impeded drainage kept the soil moist for longer periods providing conditions congenial reduction of ions, which consequently led to darker coloured soils at lower elevations. Similar results were earlier reported by Diwakar and Singh (1994) in soils of Bihar.

The dominant vegetation of the study area were sconstituted by Acacia species, Neem, Borassus, Tamarind, Prosophis, grasses etc. Similar composition of natural vegetation in soils of semi-arid regions was earlier reported by Anitha (1996) in Andhra Pradesh. The influence of natural vegetation on soil development and variation in soil profiles were not evident as it was spares and of similar nature.

6.2 Mapping of soils

6.2.1 1:50,000 scale soil map

A soil map of the watershed at 1:50,000 scale was prepared using IRS-1D LISS-III geocoded FCC print. LISS-III data owing to its synoptic view multispectral nature offered valuable clues in delineating the soil mapping units based on erosion and land use. In addition, Hydrogeomorphology, ground water potential of the study area could also be studied from the satellite data.

Based on remote sensed data, lithology of the study area could be assessed which provided valuable clues in identification of broad physiographic units in the study area. Similar utilization of LISS-III data for study of soil resources at 1:50,000 scale was earlier reported by Ravi shankar and Tammappa (1998) in their study on soils of Guntur dist.of Andhra Pradesh. Pediplain was the dominant physiograsphic unit delineated in the study area which was further sub divided based on erosion status. Similarly valley soils were also sub divided based on erosion status. Utilisation of erosion as basis for sub dividing major physiographic units was earlier reported by Rao *et al.*, (2003) in their study on soils and Malipungal micro watershed in Koraput Dist. of Orissa and several other workers throughout the world. Agriculture and soils groupof NRSA mapped soils at 1:50,000 scale covering an area of 56.018 million ha in different parts of country covering Raichur Dist. Of Karnataka and Kurnool dist. of A.P. and Kamasin block, Banda dist. and Sonebhadra Dist. of U.P using IRS-1A/1B satellite data (NRSA 1995B).

6.2.2 1:25,000 scale soil map

To prepare a soil map on 1:25,000 scale, remotely sensed data obtained from a sensor of better than 23.5m spatial resolutions is required. When the research work was initiated during 2000 year, remotely sensed data from IRS-1D PAN (5.8m) and LISS-III (23.5m)sensors were the best available data. LISS-III sensor data were available in green, red and infra-red spectral band and were suitable for thematic mapping up to 1:50,000 scale. During late 90s, 5.8m panchromatic (PAN 0.52 –0.72 micrometer) data was available from IRS-1C and 1D satellites. Efforts were initiated to exploite spastial resolutions of PAN sensor and multispectral nature of LISS-III sensor which when combined through mathematical tranformation would generate hybrid data combining the advantage of both the sensors. Hybrid FCC of such data enable to prepare soil or land use or thematic maps at scales larger than 1:50,000 scale.

A representative mini-watershed named as Bhogaram mini-Watershed with a geographic area of 2743 ha was selected within the watershed for studying the soil resources at 1:25,000 scale using IRS-1D PAN + LISS-III hybrid FCC data. To geo reference the satellite data, the topographical maps (1:25,000 scale) of Survay of India were employed. Subsequently, the multispectral LISS-III data were converted to intensity, hue and saturation channels. The intensity channel was replaced with PAN data and the old data set were retransformed to red, green and channels. The resultant was

PAN merged LISS-III hybrid FCC which could withstand enlargement beyond 1:50,000scale. Therefore, soil mapping in the study area was carried out at 1:25,000 scale. PAN merged LISS-III data helped in further delineation of mapping units at this scale. Utilization of similar hybrid data products for soil mapping at 1:25,000 scale in Pudukottai sugar factory command area were earlier reported by NRSA (2002). Similarly, soils of entire Dadtra and Nagarhaweli were mapped using IRS-1D satellite data along with other resources at 1:25,000 scale for land use board of Dadtra and Nagarhaweli union territory by NRSA (2000a).

At this scale, 12 soil mapping units could be delineated in the mini-watershed study area. The soil units were depicted with sharp contrast and boundaries on hybrid FCC prints than on LISS-III FCC prints. Identification of these units on PAN data alone was found to be difficult. The erosional features and land use / land cover in the study area were also highlighted in hybrid data that contributed for further sub division of soil mapping units.

6.2.3 1:12,500 scale soil map

At 1: 12, 500 scale soil mapping also the PAN + LISS-III merged data of IRS-1D was utilized. To study the scale up to which PAN + LISS-III merged data product could be utilized for mapping the soils, the satellite data was sequentially enlarged till the soil mapping units / features and the boundaries retained their shape and sharpness. It was observed beyond 1:12,500 scale, the data could not withstand the enlargement and blurring in features was noticed along with staircase effect in linear features like roads, canals etc. resulting in poor delineation of the mapping units. Therefore, soil mapping at 1:12,500 scale was taken up in 1 micro watershed within one watershed.

All together 17 soil mapping units were delineated at the scale in Sripuram micro watershed study area. Rajiv Srivastava and Saxena (2004) reported the utilization of IRS 1C PAN merged LISS-III data in conjunction with Survey of Indian topographical maps and available ground truth data to prepare a soil map at 1:12,500 scale.

At all the scales the satellite data of summer period was utilized as the data was clod free and the vegetation cover was at the least during this summer period which enabled better delineation of the mapping units. At 1:50,000 scale, Series or association of series was the taxonomic unit of the soils of the mapping unit. Soil series was the taxonomic unit of the mapping units at 1:25,000 scale. Phases or association of phases of a series was utilized as the taxonomic unit of the soil mapping unit at 1:12,500 scale.

To study the effect of scale of soil mapping with LISS-III and PAN merged LISS-III data, Sripuram micro watershed, which was the common study area at all the three scales indicated that, the total number of polygons at 1:50,000scale were 42, whereas at 1:25,000 scale 57 polygons and at 1:12,500 scale 72 polygons could be delineated. This indicated that with increase in scale the number of polygons in the same study area increased i.e., purification of major mapping units drawn at smaller scales and sub division of polygons in light of better information available in terms of land use or erosion. Moreover, utilization of satellite data of higher spatial resolutions for mapping at larger scale helped in more accurate delineation of different mapping units at larger scale.

In case of soils located on a pediment only one mapping unit was present at 1:50,000 scale. This polygon was sub divided as pediment fallow (2 polygons) and pediment scrub (2) polygons at 1:12,500 scale.

With increase in scale from 1:50000 to 1:12,500, 6 polygons of the slightly eroded pediplain mapping unit, could be sub-delineated as 12 polygons belonging to two separate mapping units viz., slightly eroded pediplain-cultivated (10) and slightly eroded pediplain-uncultivated (2) . The slightly eroded pediplain-uncultivated polygons (2) were subdivided into 4 polygons belonging to two different mapping units viz., slightly eroded pediplain-scrub (2) slightly eroded pediplain-fallow (2), at 1:12,500 scale. Similarly, the 17 polygons belonging to three different mapping units viz., slightly eroded pediplain-cultivated (7), slightly eroded pediplain-paddy cultivated (7), slightly eroded pediplain-plantation could be demarcated from 10 polygons of slightly eroded pediplain-cultivated mapping unit of 1:25,000 scale.

In case of moderately eroded pediplain, 8 polygons were identified at 1:50,000 scale. These were sub divided into 13 polygons belonging to two mapping units viz., moderately eroded pediplain- uncultivated (4) and moderately eroded pediplain-cultivated (9) at 1:25,000 scale. The moderately eroded-uncultivated mapping unit polygons (4) were sub delineated at 1:12,500 scale as moderately eroded pediplain-scrub (4) and moderately eroded pediplain-fallow (2).

6.3 Land use

Satellite data was utilized in identifying land use and land cover categorization of study area. Satellite data owing to its synaptic view provided valuable information regarding land use / land cover classes that existed in the study area. For the study of land use satellite data of kharif and rabi seasons were utilized to derive information in terms of presence of crops during the season of study and their spatial distribution.

Land use /Land Cover was used as criteria for delineating the soil mapping units at larger scales. Cultivated area – kharif single crop was the largest land use category in terms of area at level-2 classification, which indicated the rainfed nature of agriculture on monsoon in the study area. This land use was appeared mainly in slightly eroded and moderately eroded pediplain with moderate ground water potentials. Dominant crops in this category were Cotton, Castor, Sorghum and green gram. Double cropped area was confined mostly to the valley portions of the watersheds where ground water potential was good. Paddy-Paddy cropping system supported by ground water and tank irrigation was the most dominant cropping system in the double cropped mapping unit.

The second largest mapping unit of level 1 classification was wasteland of which, land with scrub was the most dominant land use class (level 2) followed by stony waste area. Sarma *et al.,* (2001), Bisht and Kothiyari (2001), Jay kumar and Arochisamy (2003), Sadhu khan (2003), Lie *et al.,* (2004), Dewidar (2004) reported the utilization of satellite data for land use / land cover classification, monitoring the changes in land use / land cover in various parts of the world.

6.4 Ground water potential:

Ground water potential as derived from the hydrogeomorphology indicated that, most of the area in the Ramannapet watershed had moderateg ground water potential. Ground water potential of valleys was rated as good, pediment as poor and stony waste areas as very poor. Utilisation of remote sensed data in generation of hydrogeomorphological maps to study the ground water prospects was earlier reported by Ranjan R Gawande *et al* (2002), Subba rao *et al* (2001) in Nagpur dist. of Maharastra and Guntur town of Andhra Pradesh respectively.

6.5 Optimum land use planning

Optimum land use plan maps were generated at three scales (1:50,000, 1:25,000, 1:12,500) considering the potentials and limitations of the soils. Climate and crop growth period (length of the growing season) being same for entire watershed, type of the soil, physiography, ground water potential and land related features played a major role in selecting the optimum land use action items.

In formulating the action items current land use and socio-economic parameters of the area were also considered to assess the technical suitability and feasibility for adoption of the suggested action item. However, major issues that were addressed by the proposed action plan items were sustainability of the production capacity of the soils over time and space, maintaining the soil quality and controlling the land degradation.

The thematic maps – soils, alnd use and ground water potentials were converted to digital data bases for integrated analysis of resources data. ARC/INFO and ERDAS imaging GIS facilities utilized for this purpose. The soil, land use and ground water potential maps were combined through 'union' operation to develop a composite map. Each composite map unit has unique combination of soil, land use and ground water potential. Rules were framed for different action items in terms of above thematic resources. These rules formed the knowledge base for converting the composite map units into action plan maps. At all three scales studied this procedure was adopted to generate action plan map.

At 1:50,000 scale, 7 action items was identified to optimize the land use viz., Arid horticulture, Agro-forestry, Silvi-pasture + soil conservation, improved agriculture, soil conservation + agriculture, intensive agriculture and no action. At 1:25,000 scale, 11 action items were recommended. The additional action items suggested at this scale were arid horticulture + soil conservation, pasture + soil conservation, soil reclamation + agriculture, soil conservation+ irrigated agriculture. At 12,500 scale the additional action items suggested in addition to those at 1:50,000 include arid horticulture, pasture + soil conservation, improved orchard management and intensive cultivation (ID crops).

6.5.1 Arid Horiculture

This item was suggested for the hills, inselbergs, PIC complex keeping in view severe limitations of the units for crop growth in terms of slope, stoniness, depth, erosion, and texture, GWP etc. In these mapping units soils were present only in thin patches confined to interspaces of the boulders, relatively flat area in the hills etc. As these lands are not suitable for arable crop cultivation / plantation it was suggested that planting of Ber/ Annona spp/ Amla / Soapnut/ which are drought resistant, hardy and can survive under inhospitable conditions also.

6.5.2 Agro forestry + Soil Conservation

Agro forestry item was suggested to soils located on pediment, with 5-10 per cent slopes. Surface stoniness, moderate erosion, moderate run-off, coarse texture and poor ground water potential were the major constraints for crop production in this mapping unit. Even though, these soils were marginally suitable for arable cropping, some parts of the pediment are cultivated by small and marginal farmers. Low water holding capacity of soils and poor ground water potentials predisposes the crops to drought.

Agro forestry system has the principle advantage of increasing the fertility of the soil through leaf fall, utilization of different root feeding zones of the soil and stabilizing the landscape through reduction of erosion (optimum crop cover and root binding effects). In addition they provide fuel, fodder during lean season and green leaf manure.

Keeping in view the low fertility of the soil Multi Purpose Tree Species viz., Sissoo (*Delbergia sissoo)* Neem, Siris (*Albizzia lebek*), Subabul were suggested to be grown along with moisture stress tolerant crops like Castor and Sorghum. Soil conservation measures were to contain the degradation of these soils. Pande and Saha (1994) suggested the agroforestry + soil conservation as most suitable land use for the eroded pediment areas of West Garoo hills in India.

6.5.3 Pasture+ Soil conservation

This action item was recommended to the soils of the severely eroded pediplain where severe limitations to crop production such as severe erosion, very shallow soil, surface and sub-surface stoniness, slope, moderate Ground Water Potential exist. Keeping in view, the inability of the soils to support any tree component these soils were suggested with this action item. Grasses suggested in this action item are drought tolerant, perennial, have very good regeneration capacity, trampling resistance, over grazing resistance. Moreover, grass can effectively reduce the soil erosion through their surface cover and binding effect of their fibrous roots on the soils particles.

Soil conservation measures such as contour furrows+ trenching and contour furrowing and pitting were recommended as they help in better establishment of the grasses and prevent further degradation. In addition to contour bunding, measures like establishment of grassed waterways, nala-plugging and construction of earthen bunds at several places on the streams were also suggested keeping in view the requirement of integrated efforts for amelioration of the lands. Khan and Nepal singh (2000) recommended pasture + conservation for pediment soils for a watershed located in arid western Rajasthan.

6.5.4 Silvi-pasture + soil conservation

This action item was recommended to the lands that are not suitable for arable farming (Land Capability Class VI es) because their severe limitations in terms of surface stoniness, severe erosion, shallow depth and rapid run-off. Conservation of the soil was the main aim in finalizing this action item wherein the tree and grass components provide canopy cover at different heights and reduce the rain splash erosion. Grass component of this system will add organic matter to the soil, provide protective cover against the erosive rains and strongly binds the soil particles with its prolific root system.

This system is ideally suited to the eroded land as it increases the total bio-mass production of the area through the draught resistant flora and conserve soil and water.

Keeping in view the marginality of the soils, grasses (Cenchrus spp, Stylosanthus spp), that are drought tolerant, perennial, have very good regeneration capacity, trampling resistance, over grazing resistance, shade resistance and have compatibility with tree species were recommended in the silvi-pastoral system, even though their yields considerably low compared to grasses cultivated with irrigation. In combination with the grasses, trees that can survive in marginal soils were suggested (Acacia nilotica, Acacia arabica, Albizzia lebek).

6.5.5 Improved agriculture

Land development units that have very slight limitations for crop cultivation except moderate ground water potentials, medium coarse texture and low organic carbon content were suggested with this action item.

In these soils the existing land use was cultivated single crop or cultivated- double crop. Keeping in view the low productivity of crops, adoption of improved varieties/hybrids was suggested in addition to Integrated Nutrient Management and application of bulky organic manures to improve organic carbon satus of the soils.

6.5.6 Intensive agriculture

Valley soils, which have very slight limitations to the crop production, were suggested with this action item. In this action item, cultivation of medium / short duration paddy cultivars instead of long duration cultivars like BPT -5204 was suggested keeping in view the length of the growing season and possibility of taking up of corps during the rabi season.

Cultivation of paddy during the kharif season was recommended, as these soils are prone to water logging because of their low slope and imperfect drainage., Cultivation of short or medium duration Irrigated Dry crops such rabi sorghum, maize and sunflower was recommended for the soils where supplementary irrigation facility is available.

Rao *et al.,* (2003) recommended rice as suitable crop for Kottanpalli watershed of Chattisgarh, Malli pungar micro watershed in Orissa and Piakabinkatara micro-watershed in Orissa, keeping in view their potential.

6.5.7 Agriculture + Soil Conservation

This action item was recommended to the soils of the moderately eroded pediplain, that were having moderate limitations to crop production such as moderate erosion, slight stoniness, medium coarse texture, moderate Ground Water Potential. These soils are traditionally single crop cultivated areas with out adoption of soil conservation measures. Keeping these problems in view, emphasis was placed on adoption of soil conservation measures (both agronomic and engineering) in addition to agriculture in these soils.

Considering the dominant slope as 3 per cent, construction of the contour bunds at an vertical interval of 0.915 m and horizontal interval of 18.3 m was suggested.

In addition, agronomic measures like contour cultivation and contour sowing were recommended as they are non-monetary but give good results when adopted.

Slightly higher seed rate and early sowing were recommended as they ensure good crop canopy coinciding with the erosive rains.

Strip cropping and intercropping were suggested as they act as assurance against drought and help in conserving the soil and moisture through better canopy cover compared to sole crops.

Cow pea sorghum / cow pea- castor inter cropping were suggested keeping in view the ability to survive in moisture stress conditions and reduction of erosion.

Sharma *et al.,* (2003) recommended treatments like bunding, construction of gradient control structures in Kawalkhad watershed in southern Himachal Pradesh with remote sensing and GIS.

6.5.8 Arid Horticulture + Soil Conservation

Arid Horticulture was suggested to pediment lands that are cultivated. These soils were found to be not suitable for agriculture because of the shallow depth, slope, surface stoniness, poor ground water potential, moderate erosion and moderate run-off potential limitations. This action item was supposed to give better income to farmers with low input, compared to field crops.

Arid Horticulture species Amla, Annona spp, Ber, soap nut, tamarind, Koronda, Wood apple are drought resistant hardy fruit crops that survive in rocky soils which are marginally suitable or unsuitable to field crops.

A new method of pitting viz, ring pit was suggested to the arid horticulture in which the pit is surrounded by a ring which as micro-basin for storing the water in the event of rains and recharge of the root zone of the seedling ensuring the survival of the tender seedlings.

Considering the dominant slope as 5 per cent construction of the contour bunds at an vertical interval of 1.12 m and horizontal interval of 22.3 m was suggested.

6.5.9 Soil reclamation + Agriculture

This action item was suggested to the soils that have sodicity problem. This mapping unit is located in the valley portion of the watershed. In these soils existing land use is fallow. Keeping in view of the potentials of the soils such as good ground water potential, fine soil texture, high water holding capacity of the soil an limitations, these soils suggested this action item.

Cultivation of green manures crops, application of bulky organic manures and correction of the micro-nutrient deficiencies is very essential in these in soils for successful crop production as they reduce the impact of sodicity on the standing crops in addition to reclaiming the lands.

6.5.10 Improved Orchard Management

This action item was suggested to the standing orchards in the field. Keeping in view the moderate ground water potential of the soils on which they established, adoption efficient irrigation management systems such as drip irrigation was recommended. Cultivation of leguminous arable crops in the orchards during first five years of establishment was recommended as it would provide farmers with additional income and protect soil from erosion during the rains. Similarly, cultivation of green manures in established orchards ensure improvement of soil fertility and also help in reduction of erosion.

6.5.11 Intensive Agriculture (ID crops)

This action item was suggested to slightly eroded pediplain-paddy cultivated soils, which have the problems of moderate ground water potential and medium coarse texture resulting in low water holding capacity of the soils. Farmers cultivate paddy in these soils with very low water use efficiency. Keeping in view their potential suitability to Irrigated Dry crops rather than paddy they were suggested with this action item.

6.5.12 No action:

This action item was assigned to those land development units such as settlements, water bodies, streams where no actions to optimize their use could be suggested.

The action items at different scales formulated at different scales were based on the information available at different scales in terms of soils.

At 1: 50,000 scale, the criteria used in finalizing the action items include soil depth, Ground Water Potential, slope, runoff, existing land use and length of growing season. At 1:25,000 scale, in addition to the above parameters, pH and ESP of the soil and texture of the soil were used as the criteria in deciding the action items. Stoniness, texture of the sub-surface soil and Ca CO_3 were the additional parameters considered in arriving at final action items.

In total seven action items were identified at 1:50,000 scale. However, heterogenity of the resources in the mapping units that occur over large areas (soils of slightly eroded pediplain and moderately eroded pediplain, pediments) could not be considered in formulation of the action items at this scale, due to lack of availability of data to define the heterogeneity at this scale.

In case of the pediment soils, agro-forestry action item had to be recommended even though some of soils were suitable for arid horticulture.

In slightly eroded pediplain all the soils were recommended with improved agriculture action item. However, some of the soils were more suitable for silvi-pasture compared to the agriculture and some parts of the unit were suitable plantation crops. Hence, this action plan can be considered as general plan for optimum land use of the area.

At 1:25,000 scale, relatively more homogeneity of the resources with in the mapping units (soils, land use) compared to the 1:50,000 scale, made it possible to formulate more site specific action items suitable for the mini-watershed selected for study at 1:25,000 scale.

Recommendations such as soil reclamation + agriculture to the soils with a problem of sodicity, and arid horticulture to the pediment soils, pasture+ soil conservation to the severely eroded pediplain soils could be suggested at this scale due to availability of data that clearly defined the requirements of the action item at this scale.

However, at this scale (1:25,000) also variations in the soils of slightly eroded pediplain could not be considered in finalizing the action items. Improved agriculture action item suggested at this scale may result in under utilization of the soils of slightly eroded-paddy cultivated areas of the watershed, which have the potential to support two crops (irrigated dry crops). Similarly, the plantation boundaries could not be established at this scale and these units were suggested improved agriculture action item. Even though, the action items suggested at this scale are specific in nature, their validity for land use planning at micro-watershed level is relatively less.

At 1:12,500 scale eleven action items were identified to optimize the land use of the selected micro-watershed. The action items suggested were very specific in terms of crops and varieties and soil conservation measures. The land development units for which the optimum land use items were generated are more uniform in their resource potentials and problems compared to the units generated at 1:50,000 scale or 1:25,000 scale.

Even at this scale also the variations of slope over small distances, depth and width of the gullies / streams etc., which are essential for locating the water harvesting structures, could not be assessed accurately. Hence, for location of the water harvesting structures mapping of the resources at scales larger than 1:10,000 are essential.

SUMMARY AND CONCLUSIONS

A comprehensive soil information with respect to types of soils, spatial extent, and distribution and use potential plays an important role in land use planning. Land evaluation provides a rational basis for generating optimal land use plan based on analysis of relation between land use and land resource potential / limitations.

Remotely sensed data of IRS-1D LISS-III was utilized in studying the resources viz., hydrogeomorphology , ground water potential, soils land use/ land cover of the Ramannapet watershed at 1:50,000 scale.

Ramannapet watershed located in Nalgonda district of Andhra Pradesh was selected as the study area, in which the natural resources were studied and integrated analysis of resources was done to arrive at optimum land use plan for the watershed. The study area is located in Mid-Musi sub-catchment in Krishna basin. The selected watershed drains in to the Musi river.

The study area was characterized by semi-arid climate with distinct wet and dry seasons. Average annual rain fall of the study area was 649 mm. Soil moisture regime was Ustic, Soil temperature regime was Iso-hyperthermic.

Drainage of the Ramannapet watershed is dendritic / sub-dendritic. Drainage density and the location of water bodies indicated that the area has high run-off potential which resulted in erosion of the soils.

Lithology of the study area is Archean granite gneissic. Parent material of the soils was granite-gneiss. Geomorphlogical studies of revealed that pediplain-shallow weathered, pediplain-shallow weathered-eroded, residual hills, denudational hills, Pediment, Inselbergs, Pediment-inselberg complexes, valley fill and buried pediplain were the major geomorphic units in the study area.

Ground water potential as derived from the hydrogeomorphology indicated that, most of the area in the Ramannapet watershed had moderate ground water potential. Ground water potential of valleys was rated as good, pediment as poor and stony waste areas as very poor.

The soil map of the study are was generated on 1:50,000 scale establishing the soil-physiographic relationships. Altogether, ten soil mapping units were delineated in the study area which could be classified under three soil orders viz. Entisols, Inceptisols and Alfisols. Soils situated in high elevations (Hills, dykes, inselbergs) were less developed, with shallow depth and skeletal nature. They were classified as Entisols. Soils of the pediplain were classified Alfisols and Inceptisols. Soils situated in valleys were deeper, finer in texture dark grayish brown to very dark grayish brown colours. Soils of the pediplain were red to dark reddish brown depending on the erosion status. Soils located on the slightly eroded pediplain were exhibited relatively better developed profiles compared moderately eroded pediplain soils. Soils of the severely eroded pediplain, owing to the slope of the landscape on which they were situated, were very shallow, loamy skeletal in nature.

Soil mapping for the Bhogram mini-water shed, which was selected as representative of the Ramannapet watershed, at 1:25,000 scale was done utilizing PAN+ LISS-III data of IRS-1D satellite,. In total, twelve soil mapping units could be delineated. Similarly, at 12,500 scale soil mapping was done in Sripuram micro-watershed where 17 soil mapping units cold be delineated. Higher spatial and spectral resolution offered by the hybrid product enabled better delineation of soils in the respective study areas.

Land use/ land cover studies indicated that there were twelve land use classes in the watershed, of which agriculture was the dominant land use. Single crop cultivated land-*kharif*, was the single largest land use class in all the level-II classes, which indicated the rainfed nature of the agriculture in the study area. Waste land was the second largest land use class. In which, land with scrub was the dominant land use category.

Optimum land use plan were generated through integrated analysis of all the resources in the study area after identifying the potentials and limitations of the mapping units. Geographical Information system (GIS) technique enabled better analysis of the resources which were available in the form of thematic maps. In these plans measures were identified to optimize the utilization of resources based on their potentials and limitations. The action items were selected for optimal utilization of the resources in such a way that soil erosion is controlled/ contained and increase the cropping intensity.

Optimum land use plan map at 1:50,000 scale consisted of seven action items viz arid horticulture, arid horticulture + soil conservation, silvi-pasture+ soil conservation, improved agriculture, intensive agriculture, soil conservation+ agriculture and no action. At 1:25,000 scale, eleven action items were suggested viz., pasture+ soil conservation, soil reclamation+ agriculture, soil conservation+ irrigated agriculture, agro-forestry in addition to those suggested at 1:50,000 mapping. Eleven mapping items were identified for optimal utilization of the resources at 1;12,500 scale. These action items included agro-forestry, pasture+ soil conservation, intensive agriculture with Irrigated Dry crops and improved orchard management in addition to those suggested at 1:50,000 scale.

The action plan suggested at 1:50,000 scale was for over all development of the Ramannapet watershed. The action items suggested at 1:25,000 scale were specific in their nature but not to the level of implementation. However, the optimum land use plan generated at 1:12,500 scale for the Sripuram watershed was very specific in identifying action items to the level of implementation.

Better information on resources of the study area , made available through the high resolution satellite data and their integrated analysis in Geographical Information system (GIS) made it possible to recommend site-specific action items at 1:12,500 scale.

The main conclusions that were drawn from the study are:

- Medium resolution remote sensing data (24 m spatial resolution) is useful for district and watershed level resource inventory studies and generation of optimum land use plans. High resolution satellite data (Quick Bird, IKONOS, IRS-P6)provide valuable input for generation of Optimum land use plans at 1:8000 or still larger scales, which will be helpful not only for identification of action items for the operational watersheds but also monitoring the implementation process and impact assessment.

- GIS is a very powerful tool to generate data bases and to conduct integrated analysis of the resources. There is vast scope to develop automated land evaluation procedures for which the geo-data base are very essential. This will lead to development of Decision Support Systems(DSS) for optimal utilization of the resources.

- The satellite remote sensing data in combination with the GIS provided very strong platform for generation optimum land use plans by making the data available for quick and accurate assessment of the resource potentials and limitations with limited field work and there by offering capabilities for integrated analysis of the resources.

Future line of work.

- The stereo capabilities of the satellite data (CARTOSAT) are to be exploited for mapping the soils and land/ land cover because they provide three dimensional perspective of the terrain.

- Potentials offered by the very high resolution satellite data are to exploited for mapping the soils based on the cadastral maps of the villages, so that the transfer of the agro-technologies can be done quickly and accurately.

LITERATURE CITED

Adinarayana J and Krishna N R 1995 An approach to land-use planning in a hilly watershed using geographical information systems. Land Degradation and Rehabilitation 6: (3) 171-178.

Adinarayana J, Singh R B and Haigh M J. An approach for sustainable land use reconstruction of a hilly watershed using geographical information systems. Sustainable reconstruction of highland and headwater regions. Proceedings of Third International Symposium on Headwater Control, New Delhi, India. 6-8 October, 1995 pp 319-328.

Agarwal C S 1998 Study of drainage pattern through aerial data in Varanasi District of Utter Pradesh. Journal of The Indian Society of Remote Sensing 26(4): 169-177.

Agarwal A K and Mishra D 1992 Evaluation of ground water potential in the environs of Jhansi city, UP using hydrogeomorphological assessment by satellite remote sensing technique. Journal of Indian Society of Remote Sensing. 20 (2&3): 121-128.

Ahuja R L, Manchanda M L, Sangawan B S, Goyal V P and Agarwal R P 1992 Utilization of remotely sensed data for soil resource mapping and its interpretation for land use planning of Bhiwani District, Haryana. Journal of The Indian Society of Remote Sensing 20(2): 105-120.

Arnold C L Jr, Clvco D L, Prisloe M P Jr, Hurd J D and Stocker J W 2000 Remote sensing enhanced outreach education as a decision support system for local land-use officials. Photogrammetric Engineering and Remote Sensing 66: (10), 1251-1260.

Auerswald K and Jung W 1990 The development of high resolution erosion forecast maps using the DUSLE. Mitteilungen der Deutschen Bodenkundlichen 61, 9-12.

Bailey T C 1990 GIS and simple systems for visual interactive spatial analysis. The Cartographic Journal 27 (2): 79-84.

Beck R H, Robinson B F, Mc Fee W W and Peterson J B 1976 Spectral characters of the soils related to the interaction of soil moisture, organic carbon, and clay content. LARS information Note 081176, Purdue University, W. Lafayatte, Indiana, USA.

Bisht B S and Kothiyari B P 2001 Land cover change analysis for Garur Ganga water shed using GIS and Remote sensing techniques. Journal of Indian Society of Remote Sensing 29(3) 137-141.

Bower C A, Reitemeier R F and Fireman M 1952. Exchangeable cation analysis of saline alkali soils. Soil science 73: 251-161.

Bower S S and Hanks R J 1965 Reflection of radiant energy from soils. Soil Science. 100: 130-138.

Bumgardner M F, Sila L F, Bielal L L and Stoner E R 1985 Reflactance properties of soils. Advances in Agronomy. 38:1-4

Chakraborthi A K 1994 Strategies for watershed management planning using remote sensing techniques. Journal of The Indian Society of Remote Sensing 21(2): 87-97.

Chary G R, Sivaramu H S, Yadav S C, Sehgal J L and Gaikawad S T 1995 Watershed based crop planning towards a rational land resource management. Indian Journal of Landscape Systems and Ecological Studies 18(2): 50 – 57.

Chief Planning Officer 2002-03 – Nalgonda district Handbook published by Chief Planning Offier, Nalgonda district, Government of Andhra Pradesh, India.

David Dent 1988 Guidelines for land use planning in Developing countries. Soil Survey and Land Evaluation 8 : 67-76

Deshmukh S N and Bapat M V 1993 Land evaluation for different Uses. Journal of the Indian Society of Soil Science 41 (1) :202-204

Dewidar KH M 2004 Detection of Land use/ land cover changes for Northern part of the Nile Delta (Bullarus Region), Eygpt. International Journal of Remote Sensing 25 (20) : 4079-4089

Dhinawa P S, Pathan S K, Sastry S V C, Mukunda Rao, ajumdar K, V L, Choteri M L, Premnath Singh J, and Sinha R L P. 1992 Land use change analysis of Bharathpur district using GIS. Journal of Indian Society of Remote Sensing 20 (4) :237-250.

Dibyendu Dutta, Das S N, Sharma J R, Kudrat M, Manchanda M L and Dutta D 1997 Prioritization of watersheds for perspective land use planning using remote sensing and geographic information system. Annals of Arid Zone Research 36 (2) : 103-114.

Diwakar D P S and Singh R N 1994 Characterization of soils of daira land occurring in Gangetic plains of Bihar. Journal of the Indian Society of Soil Science 42: 420-424

DOS 1999 Applications of remote sensing in soil resources mapping. Peer review document.

Duff G H 1991 Principles of Geomorphology. Oriental – Longman Publishers, New Delhi pp 367-390.

Dwivedi R S 1982 Comparison of soil maps prepared through aerial photo interpretation and Land at image interpretation. Proceedings of resource survey for land use planning and environmental conservation. Indian Institute of Photo interpretation, Dehradun, October 20th to 22nd pp : 147-151.

Dyke P T 1987Compiling and managing the database and GIS - In A Bunting ed. Agricultural Environments: Characterization, classification and mapping. CAB international, Wallingford, UK.

Esther Shekina D, Sha S K and Rajaur Rehman 2004 Land capability evaluation for land use planning using GIS. Journal of Indian Society of Soil Science 52 (3): 232-237.

FAO 1976 A frame work for land Evaluation. FAO Soils Bulletin No. 32.

Gajbhiye K S and Deshmukh S N 1993 studies on crop response in relation to soil and soil site characteristic. Journal of the Indian Society of Soil Science 40: 521-527.

Gawande R R, Srivasthva A K and Jaya Rao A 2002 Geological Geomorphological , hydrogeological and land use/ land cover studies around Kamthi area in Nagapur district , Maharashtra using remote sensing technology. Journal of Indian Society of Remote sensing 30 (1 & 2) : 95-104.

Gouranga Kar and Kar G 2001 Remote sensing and GIS techniques for land use planning a case study in Yacharam watershed, Andhra Pradesh. Indian Journal of Soil Conservation. 29 (1): 77-81

Gunjal S S Remote sensing in watershed management in India. Proceedings of the twenty-third international symposium on remote sensing of environment: Volume II 18-25 April 1990 Bangkok, Thailand. Pp. 805-806.

Gupta A K, Nageswar Rao R P, Ganesh Raj K, Dutt C B S and Chandrasekhar M G 1993 An Integrated Approach for Resource Development using Remote Sensing and GIS – Specific hill area case study. Journal of The Indian Society of Remote Sensing 21(2): 99-108.

Gupta S K and Chera R S 1996 Soil characteristics as influenced by slope in middle Siwaliks. Agropedology 6: 43-48.

Hegde B R and Pandurangaiah K 1993 Watershed management-prospects and problems. Fertilizer News. 38 (4) : 49-52.

Hesse P R 1971 A Text book Soil Chemical Analysis. John Murray Limited, London.

Iyer H S, and Jitendraprasad 1981 Soil survey of the command area for planning of water management. A case study in Hardoi district of Uttar Pradesh. Journal of Indian Society of Remote Sensing 9 (2) : 27-32

Jackson M L 1973 Soil Chemical Analysis, Prentice Hall India Pvt Limited, New Delhi.

Jaykumar S and Arickisamy D I 2003 Land use land cover mapping and change detection in parts of Eastern ghats, Tamil nadu using Remote sensing and GIS. Journal of Indian Society of Remote Sensing 31 (4) : 251-260.

Kanwar J S and Chopra S L 1976 Analytical Agricultural Chemistry. Kalyani publishers, New Delhi pp.279.

Karele R L, Sharafat Ali, Kamal Narayan and Seshgiri Rao K V 1987 mapping of soils, land use and land upgradation using remotely sensed data in Pun-Pun catchment, Bihar. National Symposium on Remote Sensing in Land Transformation and Management, NRSA, Hyderabad (India), Decembaer pp.26-29.

Khan M A and Nepal Singh 2000 Application of Remote sensing data in mapping of the soil resources for water shed planning in arid western Rajasthan. Journal of Indian Society of Remote Sensing 28 (2 & 3) : 93-113.

Krishnan P, Nair K M, Naidu L G K, Srinivas S, Arti Kongal, Nasra, R A, Ramesh M and Gajbhiye K S 2004 Land, soil, land use of laksha Dweep coral islands. Journal of Indian Society of Soil Science 52 (3) : 226-231

Kudrat M and Saha S K 1993 Land productivity assessment and mapping of watershed through integration of satellite and terrain slope data. Journal of The Indian Society of Remote Sensing 21(3) : 157-166.

Kumar A and Srivastava S K 1991 Geomorphological units, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar. Journal of Indian Society of Remote Sensing. 19(3) : 205-215.

Kushawaha S P S and Oestsn G (1995) A rule based system for forest land use planning. Photonirvachak, Journal of Indian Society of Remote Sensing, Vol.19, No.3, pp: 205-215.

Kushawaha S P S, Subramanian S K, Chennaiah G C, Ramana Murthy J Kameswar Rao S V C, Perumal A and Behera G 1996 Interfacing remote sensing and GIS methods for sustainable rural development. International Journal of Remote Sensing 17(15): 3055 – 3069.

Li Z, Li X, Wang Y, Ma A and Wang J 2004Land use change analysis in Yulin perfecture NW China using remote sensing and GIS. International Journal of Remote Sensing25 (24) : 5691-5703.

Mc Rae S G and Burnham C P 1981 Land evaluation, Clarendon Press, Oxford.

Murthy K S R and Venkateswara Rao V 1997 Temporal studies of land use/ land cover in Varaha river basin, A.P. India. Journal of The Indian Society of Remote Sensing 25(3): 145-154.

Murthy R S, Pofali R M and Sexena R K 1982 Remote sensing techniques in establishing the geomorphic - soil relationship. Journal of Indian Society of Remote Sensing. 10(2): 21-28.

Nair K M, Krishna P, Venugopal K R, Srinivas S and Sehgal J L 1996 soil information processing, application of GIS technology. Journal of Indian Society of Soil Science 44 (1): 115-122.

Natarajan S, Gajabe M V and Manchanda M L 1986 Land Use study in Mewat area, Haryana using remote sensing techniques. Journal of Indian Society of Remote Sensing.14(1):17-24.

Natarajan S, Jayanthi D, Selva Kumari G and Chellamuthu S 1998 Remote sensing of soil productivity assessment in delta and coastal land forms of Ramanathapuram, district of Tamil Nadu. Proceedings of Remote sensing and GIS for Natural Resourse Management. Annual convention and symposium, November 26 -28, 1997, Hyderabad, pp: 44-46

NRSA 1986 Report on the ground water potential of drought prone district of Karnataka and Maharastra based on Landsat TM data. National Remote Sensing Agency, Department of Sapce, Hyderabad.

NRSA 1989 Manual of nation wide land use / land cover mapping using remote sensing data. National Remote Sensing Agency, Department of Sapce, Hyderabad.

NRSA 1995 Soil resource mapping of Kamas and block, Kurnool district using IRS-1A satellite data - A project report. National Remote Sensing Agency, Department of Sapce, Hyderabad.

NRSA 2000 Soil resource mapping of Dadra and Nagahaweli union territories using IRS 1D data - A project report. National Remote Sensing Agency, Department of Sapce, Hyderabad.

NRSA 2002 Large scale soil mapping of Pudukottai sugar factory command area, Tamil Nadu – A project report. National Remote Sensing Agency, Department of Sapce, Hyderabad.

Obi Reddy G P and Maji A L 2004 Characterisation of bio physical land units using Remote sensing and GIS. Journal of Indian Society of Remote Sensing 32 (2) : 159-165

Obi Reddy G P, Maji A K, Srinivas C V and Velayutham M 2002 Geomorphologiacl analysis for inventory of degraded lands in a river Basin of Basaltic terrain using Remote sensing and GIS. Journal of Indian Society of Remote sensing 30 (1 & 2) : 15-31.

Ofren R S, Eiumnoh A, Weber K, Suselo T B, Murty V V N and Eiumnoh A. Upland cultivation assessment and sustainable resource development planning of Nong Luang watershed, Amphoe Umphang, Tak Province. Proceedings of International workshop on conservation and sustainable development, 22-26 April, 1991, AIT-Bangkok and Khao Yai National Park, Thailand.pp : 323-334.

Palaniyandi M and Nagarathinam V 1997 Land use/ Land cover mapping and change detection using space born data. Journal of The Indian Society of Remote Sensing 25(1): 27-34.

Pande L M and Saha S K 1995 Temporal change monitoring and land use planning using satellite remote sensing. Asia- Pacific journal of Remote sensing 6 (2) 19-29.

Panth DN and Ray PS 1990 Vegetation and land use analysis of Aglar watershed using satellite remote sensing data. Journal of The Indian Society of Remote Sensing 18(4): 1-14.

Paramasivam P and Gopalswamy A 1993 Characteristics and classification of some soils of lower Bhavani project command area, Tamil Nadu. Agropedology 3: 105-109

Patel N R, Jitendra Prasad, Suresh Kumar, Prasad J and Kumar S 2001 Land capability assessment for land use planning using remote sensing and GIS.Agropedology. 11(1) : 1-8.

Patel N R, Mandal U K and Pande L M 2000 Agro-ecological zoning system- A remote sensing and GIS perspective. Journal of Agrometeorology. 2(1) :1-13.

Pathan, S K, Jothimani P, Gopal K Choudary, N N Som and Kalyan Mukharjee 1992. Urban land use suitability Analysis - A case study of Calcutta Metropolitan Area. Journal of Indian Society of Remote Sensing 20 (2 & 3) : 73-85.

Piper C S 1966 Soil and plan analysis. Hans publications, Bombay pp.59.

Pramod Krishna A. 1996 Remote sensing approaches for watershed based resource management in the Sikkim Himalaya - A case study. Journal of Indian Society of Remote Sensing 24 (2) : 69-83.

Rajeev Srivasthava and Saxena R K 2004 Techiniques of large scale soil mapping in basaltic terrain using satellite remote sensing data. International Journal of Remote Sensing 25 (4) : 679-688.

Ramanna R 1991 Watershed approach to dry land agricultural development. Indian Journal of Agricultural Economics. 46(3): 251-260.

Ranjan R Gawande, Sreevastava A K and Jaya rao A 2002 Geological, Hydrogeological and land use/ land cover studies around Kanthi area, Nagpur district, Maharastra using Remote sensing techniques. Journal of Indian Society of Remote Sensing 30 (1&2) : 95-104.

Rao B R M and Ravisankar T 1998 Soil suitability for crops : A GIS approach - A case study on groundnut. Project report. Agriculture and soils group, NRSA, Hyderabad.

Rao B R M, Dwivdi R S and Venkatratnam L 1983 Evaluation of soils of Macherla taluka of Guntur district using aerial photographs – a project report. National Remote Sensing Agency, Department of Sapce, Hyderabad.

Rao B R M, Ravishankar T and Dinesh Kar 2003 Prescriptions of problems of micro-watersheds under crop production system using remote sensing and GIS techniques. Soils and Crops. Eds Venkatratnam L, Ravishankar T And Sudarshana R NRSA publishers Hyderabad pp.: 316-327

Rao B R M, Ravishankar T and Tahammappa S S Hydrogeomorphic evaluation of Niva river basin in Chittor district of Andhra Pradesh - A project report. National Remote Sensing Agency, Department of Sapce, Hyderabad.

Rao B R M, Thammappa S S and Venkataratnam L 1988 Evaluation of IRS 1A, LISS-I and LISS-II data - A case study over a part of Orissa. Proceedings of National seminar on IRS 1A mission and its application potential, NRSA, Hyderabad.

Ravishankar T and Thammappa S S 1998 Satellite data interpretation and analysis for soil mapping : Soils and Crops. Eds Venkatratnam L, Ravishankar T And Sudarshana R NRSA publishers Hyderabad pp.: 69-81

Sadhu khan I, Lohar D and Pal D K 2003 Land use alterations and its possible impact on pre-monsoon climatic variables. Journal of Indian Society of Remote Sensing 31 (4) : 262-269.

Samacharya K and Srinivasan T R 1972 use of small scale aerial photographs for the preparation of small scale soil maps. Paper presented in 12th Congress of International Society of Photogrametry, Ottawa, USA.

Sangwan P S, Kuhad M S, Sangwan B S and Karwasra S P S 1988. Geomorphology, soils and Land use studies in Southern parts of Mahenragarh district of Haryana. Journal of Indian Society of Soil Science 36 : 296-302.

Sarma V V L N, Muralikrishna G, Hemamalini B and Nageswar Rao K 2001 Land use land cover change detection through remote sensing and its climatic implication in the Godavari delta region of A P. Journal of Indian Society of Remote Sensing 29 (1& 2) : 85-91.

Sarma V V L N, Murali Krishna G, Hema Malini B and Nageswara Rao K 2001 Land use/ land cover change detection through remote sensing its climatic implications in the Godavari delta region of Andhra Pradesh, India. Journal of Indian Society of Remote Sensing 29 (1 & 2) : 85-91.

Saxena R K, Verma K S, Chary G R, Srivasthava R and Barthwal A K 2000 IRS – IC data application in watershed characterization and management. International Journal of Remote Sensing 21(17): 3197 – 3208.

Seelan S K 1986. Role of Satellite Remote Sensing in Ground water exploration programmes. Proceedings of the workshop on "Mangament of Ground water for Rural Development Programmes WAMERTI, Hyderabad."

Seelan S K and Thiruvengadachari S 1981 Satellite sensing for extraction of groundwater resource information. Proceedings of 15th international symposium on Remote Sensing of Environment, Ann Arbor, Michigan USA.

Seelan S K, Hegde V S, Reddy P R, Rao P S, Sharma A K, Raj G and Narayan L R A 1986 Ground water targeting in drought situation in Maharastra state, India using Landsat TM data. Proceedings of the seventh Asian Conference on remote sensing, Seoul pp.: 253-262

Sehgal J 1996 Pedology: Concepts and Applications. Kalyani publishers, New Delhi pp: 176-185.

Sehgal J L, Sharma P K, and Karale R L (1985) Soil resource inventory of Punjab using remote sensing technology, proceedings of the sixth Asian Conference on remote sensing, NRSA, Hyderabad, pp:298-301.

Sen T K, Pande L M, Sehgal J L and Maji A K and Chamuah G S 1992 Satellite remote sensing in soil resource inventory of Dibrugarh district Assam. Journal of Indian Society of Remote Sensing 20 (2&3) : 96-104

Sen T K, Pande L M, Sehgal J L, Maji A K and Chamuah G S 1992 Satellite remote sensing in soil resource inventory in Dibrugharh District in Assam. Journal of The Indian Society of Remote Sensing 20(2): 95-104.

Sharma J C, Jitendra Prasad, Bandari A R and Sharma K R 2003 Prioritization and management needs of Kawal Khad water shed based on erosional losses in southern Himachal Pradesh. Journal of Indian Society of Soil Science 51 (3) : 291-297.

Sharma S S, Totawat K L and Shyampura R L 1996 Characterisation and classification of soils in a toposequence over basaltic terrain. Journal of the Indian Society of Soil Science 44: 470-475.

Shyampura R L, Giri J D, Krishna N D R and Sehgal J L 1993 Genesis and classification of red soils of Dungarpur District, Rajasthan. Agropedology 3: 39-47.

Sidhu G S, Das T H, Singh R S, Sharma R K, Jadaun S P S, Ravishankar T and Rao B R M 2000 Soil resource inventory of watersheds for land use planning - a GIS approach. Indian Journal of Soil Conservation. 28(1): 22-29.

Sidhu G S, Das T H, Singh R S, Sharma R K and Ravishankar T 1998 Remote sensing and GIS techniques for prioritization of watersheds: a case study in Upper Machkund watershed, Andhra Pradesh. Indian Journal of Soil Conservation. 26(2) : 71-75

Singh A N and Dwivedi R S 1986 The Utility of Landsat MSS data as an integral part of database for small scale soil mapping. International Journal of Remote Sensing 7(9): 1099-1108.

Singh R N, Diwakar D T S and Singh A K 1993 Mineralogy of some important soils of Son basin. Journal of the Indian Society of Soil Science 46: 124-127.

Soil Taxonomy 1998 Soil Survey Staff, United States Department of Agriculture, Blacksburg, Virginia.

Stoner E R, Bumgarderner M F, Weismillar R A, Biehl L L and Robinson R L 1980. Extension of Laboratory measures soil spectra to the field conditions. Soil Science Society of America Journal 45 : 572-574.

Subba Rao N, Chakradhar G K J and Srinivas V 2001 Identification of potential zones using remote sensing technology in and around Guntur city, Andhra Pradesh, India. Journal of Indian Society of Remote sensing 29 (1&2):69-78.

Sudhakar S, Das R K, Chakraborthy D, Bhattacharya B K, Raha A K, Shukla P (1994) Stratification approach for forest cover type and land use mapping using IRS-1A LISS-II data – A case study. Photonirvachak, Journal of the Indian Society of Remote Sensing, Vol.22, No 4, pp:237-250.

Sudhir Mahajan, Pankaj Panwar and Deepak Koundal 2001 GIS applications to determine the effect of topography on the land use in Ashwni Khad watershed, Himachal Pradesh. Journal of Indian Society of Remote sensing 30 (3): 157-166.

Suresh Kumar, Shriram B Dhaimodkar and Pande L M 2002 The assessment of potential land use in the project irrigation command using Remote sensing and GIS. Journal of Indian Society of Remote sensing 30 (3): 157-166.

Sys C, Van Runste and Debaveye J 1991 Land evaluation, part-II: Methods in land evaluation, Agricultural publication No.7, General administration for development and cooperation, Brussels, Belgium.

Udayraj, Reddy R S, Shivaprasad C R, Adiga S and Ramesh K S 1993 Application of Satellite and GIS technologies for evaluating the soil and Land recourses of a Redsoil watershed in Karnataka, India. Proceedings of the International seminar on "Managing the red and Lateritic soils for sustainable developments. 2 pp: 44-46.

Venkateswara Rao B 1998 Hydrogeomorphological investigations in a typical Khoridalitic terrian using remote sensing data. Journal of Indian Society of Remote Sensing 26 (1 & 2) : 77-93.

Venkatranam L 1980 Use of remote sensing data for soil sampling. Journal of Indian Society of Remote Sensing 8 (2) : 19-25.

Venkatratnam L 1981 Delineation of soil associations for apart of Tamil Nadu by digital processing of Landsat multispectral data. Journal of Indian Society of Remote Sensing 9 (1) : 11-16.

Verma, Rajiv Chopra V K, Sharmap K and Charanjit Singh (1998) Integrated resource study for conservatin and management of Ropar wetalnd ecosystem, Punjab. Photonirvachak, Journal of Indian Society of Remote Sensing, Vol.26, No.4, pp: 186-195.

Vink 1971 Land use principles and methods, Blackrose publishers, California, U.S.A. pp.224

Young A 1987 Distinctive features of Land use planning for agro-foresty. Soil Survey and Land Evaluation. 7 :133-140

APPENDIX - 1

MORPHOLOGICAL DESCRIPTION OF SOILS

Loamy skeletal, mixed, iso-hyperthermic, Lithic Ustorthents(Dubbak-1)

Location	:	Fifty meters towards left side of the road on the hill on Ramannapet to Dubbak road at approximately 2.5 km from Ramannapet village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Hill
Slope	:	15-30 per cent
Land Use	:	Barren rocky/ stony waste. / sheet rock area.
Drainage	:	Excessive
Stoniness	:	More than75 per cent
Erosion	:	Severe
Natural vegetation:		Bushes, Neem, Prosophis.

Morphological description

Horizon	Depth (cm)	Description
A	0-13	Dark brown (10 YR 3/3), sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky and slightly plastic; medium to coarse, many roots; slight effervescences; clear smooth boundary
R	13+	Parent material

Coarse loamy, mixed, iso-hyperthermic, Typic Rhodustalfs(Dubbak-2)

Location	:	One hundred Fifty meters towards right side of the road opposite to the hill on Ramannapet to Dubbak road at approximately 2.5 km from Ramannapet village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Moderately eroded pediplain
Slope	:	3-5 per cent
Land Use	:	Cultivated land (single crop)
Drainage	:	Well
Stoniness	:	None
Erosion	:	Moderate
Natural vegetation:		Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-6	Yellowish red (5 YR 4/4, dry), Dark reddish brown (2.5 YR 3/4 moist); sandy loam; medium, weak, sub-angular blocky; hard, firm, sticky, plastic; fine, common roots; strong effervescences, clear smooth boundary.
Bt1	6-20	Dark red (2.5 YR 3/6, dry), Dark reddish brown (2.5 YR 3/4moist);sandy clay loam; fine, moderate, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; fine, common pores ferrans, thin, patchy cutans; very fine few roots; clear smooth boundary
Bt2	20-43	Dark reddish brown (2.5 YR 3/4 dry and moist); sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; medium, common pores; gradual smooth boundary
BC1	43-60	Dark reddish brown (2.5 YR 3/4 dry), Dark reddish brown (2.5 YR 2.5/4, moist); sandy clay ; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; medium, few pores; gradual smooth boundary
Cr	60+	Weathered parent Material

Loamy skeletal, mixed, iso-hyperthermic, Lithic Rhodustalfs (Dubbak-3)

Location	:	Two hundred meters towards right side of the road on a dyke on Ramannapet to Dubbak road at approximately 1.5km from Ramannapet village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Dyke
Slope	:	8-15 per cent
Land Use	:	Barren rocky/ stony waste. / sheet rock area.
Drainage	:	Excessive
Stoniness	:	More than75%
Erosion	:	Moderate
Natural vegetation:		Bushes, Thorny shrubs

Morphological description

Horizon	Depth (cm)	Description
A	0-8	Dark reddish brown (2.5YR 3/4) ; sandy loam; fine, weak sub-angular blocky; slightly hard friable, non-sticky, non plastic; fine to medium, common roots; clear smooth boundary
C	8-26	Dark red(2.5YR 3/6) ; sandy clay loam; fine, weak, sub-angular blocky; slightly hard, friable, non-sticky, non plastic; medium to coarse, many roots; gradual smooth boundary.
R	26+	Bed Rock

Loamy skeletal, mixed iso-hyperthermic Typic Haplustalfs (Dubbak-4)

Location	:	Three hundred meters towards right side of the road on Ramannapet to Dubbak road at approximately 2.5km from Ramannapet village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Pediment
Slope	:	0-1 per cent
Land Use	:	Scrub.
Drainage	:	Well
Stoniness	:	15-40
Erosion	:	Moderate
Natural vegetation	:	Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
A	5-11	Strong Brown (7.5YR 5/6, dry), strong brown (10 YR 4/6 moist); sandy loam; fine, weak, sub-angular blocky; loose, very friable, medium many pores; medium, few roots; clear smooth boundary.
Bt1	11-23	Yellowish red (5YR 4/6, dry), reddish brown (5 YR 4/4 moist); sandy clay loam; medium, moderate, sub-angular blocky; loose, very friable; gradual wavy boundary.
C	23-70	Dark red (2.5YR 3/6, dry), Dark reddish brown (2.5 YR 3/4 moist); sandy clay loam; medium, moderate, sub-angular blocky; loose, very friable, gradual wavy boundary.
R	70+	Bed rock

Fine loamy, mixed, iso-hyperthermic, Fluventic Haplustepts (Ramannapet-1)

Location	:	Two hundred meters towards left side of the road on Ramannapet to Dubbak road at approximately 0.5km from Ramannapet village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Valley Fill
Slope	:	0-1 per cent
Land Use	:	Cultivated land (Double crop)
Drainage	:	Imperfect
Stoniness	:	Less than 3 %
Erosion	:	None to very slight
Natural vegetation	:	Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-10	Dark gray (10YR 4/1, dry), very dark gray (10 YR3/1, moist); sandy clay loam; medium, weak, sub-angular blocky; hard, firm, sticky, plastic; fine, common roots; strong effervescence, clear smooth boundary
B11	10-20	Very dark gray (10 YR 3/1, moist); sandy clay; medium, strong, sub-angular blocky; hard, firm, sticky, plastic; fine, few roots; strong effervescence, clear smooth boundary
B12	20-34	Gray (10YR 6/1, dry), dark grayish brown (10 YR 4/2, moist); sandy clay loam; fine, moderate, sub-angular blocky; hard, firm, sticky, plastic ; fine, few roots; slight effervescence, clear smooth boundary
B21	34-49	Yellowish brown (10 YR 5/4, moist); sandy clay loam; fine, weak, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; slight effervescences, clear smooth boundary
B22	49-68	Yellowish brown (10 YR 5/4 moist); sandy clay loam; fine, weak, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; slight effervescence, gradual smooth boundary
B23	68-95	Yellowish brown (10 YR 5/4, moist); sandy clay loam; fine, weak, sub-angular blocky; hard, firm, sticky, plastic; violent effervescence, gradual smooth boundary
BC	95-105	Yellowish brown (10 YR 5/4, moist); sandy clay loam; fine, weak, sub-angular blocky; slightly hard, friable, slightly sticky, slightly plastic; violent effervescences, gradual smooth boundary

Fine loamy, mixed, iso-hyperthermic, Fluventic (sodic)Haplustepts (Ramannapet-2)

Location	:	One hundred fifty meters towards right side of the road on Ramannapet to Dubbak road at approximately 0.5km from Ramannapet village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Valley
Slope	:	0-1 per cent
Land Use	:	Uncultivated land (Salt affected culturable waste)
Drainage	:	Imperfect
Stoniness	:	1-3%
Erosion	:	None to very slight
Natural vegetation:		Neem, Acacia, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-18	Very dark grayish brown (10YR 3/2); sandy clay loam; medium, moderate, angular blocky; hard, firm, sticky, plastic; fine, few roots; clear smooth boundary
Bn1	18-47	Dark yellowish brown (10YR 4/6); sandy clay; medium, moderate, angular blocky; slightly hard, firm, sticky, plastic; fine, few roots; gradual smooth boundary
Bn2	47-70	Dark yellowish brown (10YR 4/6); sandy clay; medium, moderate, angular blocky; slightly hard, firm, sticky, plastic; fine, few roots; gradual smooth boundary
BC	70-90+	Very dark grayish brown (10YR 3/2); sandy clay loam; medium, moderate, angular blocky; hard, firm, sticky, plastic; fine, few roots; clear smooth boundary

Fine, montmorillonitic, iso-hyperthermic, Vertic Haplustepts (Nernamula-1)

Location	:	One hundred fifty meters towards right side of the road on Lakshapuram to Nernamula road at approximately 2.0 km from Lakshmapuram village.
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Slightly eroded pediplain
Slope	:	1-3 per cent
Land Use	:	Cultivated land (single crop)
Drainage	:	Imperfect
Stoniness	:	None
Erosion	:	Very slight
Natural vegetation:		Neem, Acacia, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-12	Dark grayish brown (10YR 4/2 clay; coarse, strong, angular blocky; slightly hard, firm, sticky, plastic; fine to medium, common roots; strong effervescence, gradual smooth boundary
B11	12-35	Very dark grayish brown (10YR 3/2); clay; coarse, strong, angular blocky; hard, firm, sticky, plastic; medium, few roots; slight effervescence, gradual smooth boundary
B12	35-58	Very dark grayish brown (10YR 3/2); clay; coarse, strong, angular blocky; hard, firm, sticky, plastic; coarse, few roots; strong effervescence, gradual smooth boundary
BC	58-90+	Very dark grayish brown (10YR 3/2); clay; coarse, strong, angular blocky; hard, firm, sticky, plastic; strong effervescence, gradual smooth boundary

Cracks of 2-5 cm width were observed up to 50-60cm depth.

Fine, mixed , iso-hyperthermic, Calcic Haplustepts (Bhogaram-3)

Location	:	Three hundred meters towards Right side of the road on Ramannapet to Bhogaram road at approximately 1.5km from Ramannapet village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Valley fill
Slope	:	0-1 per cent
Land Use	:	Intensively cultivated land (Cultivable land)
Drainage	:	Imperfect
Stoniness	:	Less than 3 %
Erosion	:	Moderate
Natural vegetation:		Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-10	Gray (10YR 5/1, dry), Dark grayish brown (10 YR 4/2 moist); sandy clay loam; fine, weak, sub-angular blocky; slightly hard, firm, sticky, plastic; fine common pores; very fine, few roots; violent effervescences, clear smooth boundary.
B11	10-30	Gray (10YR 5/1, dry), Dark grayish brown (10 YR 4/2 moist); sandy clay ; medium, weak, sub-angular blocky; slightly hard, firm, sticky, plastic; fine few pores; very fine, few roots; violent effervescences, clear smooth boundary
B21	30-50	Light brownish Gray (10YR 6/2, dry), grayish brown (10 YR 5/2 moist); sandy clay ; medium, moderate, angular blocky; hard, firm, sticky, plastic; very fine few pores; violent effervescences, clear smooth boundary
B22	50-90	Light Gray (10YR 7/1, dry), light brownish gray (10 YR 6/2 moist); sandy clay ; medium, moderate, angular blocky; hard, firm, sticky, plastic; very fine few pores; violent effervescences, gradual smooth boundary
BC	90-107	Light Gray (10YR 7/1, dry), light brownish gray (10 YR 6/2 moist); sandy clay loam; fine, weak, sub- angular blocky; hard, firm, sticky, plastic; very fine few pores; violent effervescences, gradual wavy boundary
C	107-125	Yellowish brown (10YR 5/4, dry), Dark yellowish brown (10 YR 4/4 moist); sandy loam; fine, weak, sub- angular blocky; slightly hard, friable, non-sticky, non-plastic; coarse common pores; strong effervescences, gradual wavy boundary
2B	125+	Brownish yellow (10YR $^{6/6}$, dry), yellowish brown (10 YR $^{5/4}$ moist); sandy loam; medium, weak, sub- angular blocky; slightly hard, firm, slightly sticky, slightly plastic; very fine few pores; strong effervescences.

Fine loamy, mixed , iso-hyperthermic, Typic Haplustalfs (Sripuram-3)

Location	:	Two hundred meters towards right side of the road on Sripuram to Vellanki at approximately 1.0 km from Sripuram village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Slightly eroded pediplain
Slope	:	1-3 per cent
Land Use	:	Cultivated land
Drainage	:	Well
Stoniness	:	less than 3 %
Erosion	:	Very slight
Natural vegetation:		Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
A	0-10	Dark yellowish brown (10 YR 4/4, dry), Dark yellowish Brown (10 YR 3/4, moist); sandy loam; very fine, weak, sub-angular blocky; soft, very friable, medium common pores, fine common roots; clear smooth boundary
Bt1	10-23	Dark yellowish brown (10 YR 3/6, dry), Dark yellowish Brown (10 YR 3/4, moist); sandy clay loam; fine, weak, sub-angular blocky; soft, friable, medium common pores, fine common roots; clear smooth boundary
Bt2	23-46	Dark yellowish brown (10 YR 3/6, dry), Dark yellowish Brown (10 YR 3/4, moist); sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, slightly sticky, slightly plastic; fine few pores, ferrans, thin, patchy cutans; fine few roots; gradual smooth boundary
BC	46-76	Dark yellowish brown (10 YR 3/4, dry), very dark Brown (10 YR 2/2, moist); sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, slightly sticky, slightly plastic; fine few pores, ferrans, thin, patchy cutans; fine few roots; gradual smooth boundary
Cr	76+	Weathered Parent Material

Loamy skeletal, mixed, iso-hyperthermic, Calcic Haplustepts (Nidhanpalli-1)

Location	:	One hundred meters towards left side of the Nernamula to Nidhanpalli road at approximately 1.0 km before Nidhanpalli village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Moderately eroded valley
Slope	:	1-3 per cent
Land Use	:	fallow land
Drainage	:	moderately well
Stoniness	:	30-40 %
Erosion	:	Moderate
Natural vegetation:		Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-15	Pale brown (10YR 7/3D to 10YR 6/3 M); sand clay loam; fine weak sub-angular blocky; soft very friable, fine medium pores; $CaCo_3$ violent effervescence; clear smooth boundary.
Bw	15-35	Yellowish brown (10YR 5/4 M); sandy clay loam; medium moderate sub-angular blocky; slightly hard friable, slightly sticky and slightly plastic; fine medium common pores, fine common Ca nodules; violent effervescence; gradual smooth boundary
B2	35-50	Yellowish brown (10YR 5/6 M); sandy clay loam; medium moderate sub angular blocky; slightly hard friable, slightly sticky and slightly plastic; fine to medium, common; violent effervescence; gradual smooth boundary
BC	50+	Yellowish brown (10YR 5/6 M); sandy clay loam; slightly hard friable, slightly sticky and slightly plastic; fine to medium common; violent effervescence

Coarse loamy , mixed, iso-hyperthermic Typic Haplustalfs (Bhogaram-4)

Location	:	Five hundred meters towards left side of the Valigonda to Bhogaram road at approximately 1.5 km before Bhogaram village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Slightly eroded pediplain
Slope	:	1-3 per cent
Land Use	:	Scrub land
Drainage	:	Well
Stoniness	:	25-30 %
Erosion	:	Moderate
Natural vegetation:		Neem, Borassus, Prosophis etc

Morphological description

Horizon	Depth (cm)	Description
A	0-8	Yellowish red (5YR 5/6 D to 5YR 4/6 M); sandy loam; fine weak granular; slightly hard very friable, fine medium common pores; fine common roots
Bt1	8-28	Red (2.5YR 4/6); gravelly sandy clay loam; medium moderate sub-angular blocky; hard, firm sticky and plastic; fine medium common pores, fine common roots
BC	28-50	Red (2.5YR 4/6 M); gravelly sandy clay loam; medium moderate sub-angular blocky; hard firm, sticky and plastic; fine medium common pores
Cr	50+	Weathered parent material

Coarse loamy, mixed, iso-hyperthermic Typic Ustorthents (Bhogaram-2)

Location	:	Three hundred meters towards right side of the Bhogaram to Nernamula road at approximately 1.5 km before Bhogaram village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Severely eroded pediplain
Slope	:	8-10 per cent
Land Use	:	Scrub land
Drainage	:	Well
Stoniness	:	30-40 %
Erosion	:	Severe
Natural vegetation	:	Thorny bushes, neem, Borassus spp, Prosophis spp etc

Morphological description

Horizon	Depth (cm)	Description
A	0-12	Pale brown (10YR 6/3 D) to yellowish brown (10Y/R 5/4M); loamy sand; fine weak sub-angular blocky; slightly hard friable, fine medium many pores; violent effervescence
BC	12-32	Yellowish brown (10Y/R 5/4M); gravelly loamy sand; fine moderate granular sub-angular blocky; slightly hard friable, fine medium common pores; violent effervescence
C	32+	Weathered parent material

Coarse loamy, mixed, iso-hyperthermic, Lithic Haplustalfs (Nidhanpalli-3)

Location	:	Two hundred meters towards right side of the Nidhanpalli to Tummalagudem road at approximately 2.0 km from Nidhanpalli village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Pediment
Slope	:	5-8 per cent
Land Use	:	Cultivated land
Drainage	:	Well
Stoniness	:	10-15 %
Erosion	:	Moderate
Natural vegetation:		Neem, Borassus spp etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-12	Brown (7.5YR 4/4); sandy loam; fine, weak single grain; slightly hard, friable, fine to medium common pores; very fine few roots, slight effervescence, clear smooth boundary
Bt1	12-25	Red (2.5Y/R 4/8); sandy clay loam; fine, weak, single grain; slightly hard, friable, slightly sticky and slightly plastic; fine to medium many pores; fine few roots, slight effervescence; gradual smooth boundary
Bt2	25-50	Red (2.5Y/R 4/8); sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky and slightly plastic; medium few pores; medium few roots, slight effervescence; gradual wavy boundary
C	50+	Weathered parent material

Coarse loamy, mixed, iso-hyperthermic, Typic Haplustalfs (Nidhanpalli-2)

Location	:	Two hundred meters towards right side, in mango orchard, on the Nidhanpalli to Tummalagudem road at approximately 1.0 km from Nidhanpalli village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Slightly eroded pediplain
Slope	:	1-3 per cent
Land Use	:	Plantation
Drainage	:	Well
Stoniness	:	10-15 %
Erosion	:	slight
Natural vegetation	:	Acacia spp, Neem, Borassus spp etc

Morphological description

Horizon	Depth (cm)	Description
Ap	0-16	Strong brown (10 YR 4/6) moist, Strong Brown (7.5YR 5/6, dry); sandy loam; fine, weak, sub-angular blocky; slightly hard, friable, fine to medium common pores; very fine few roots, clear smooth boundary
Bt1	12-26	Reddish brown (5 YR 4/4 moist and dry); sandy clay loam; medium, moderate, sub-angular blocky, slightly hard, friable, slightly sticky and slightly plastic; fine to medium many pores; fine few roots, gradual smooth boundary
Bt2	26-46	Yellowish red (5YR 4/6 Moist and dry); sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky and slightly plastic; medium few pores; medium few roots, slight effervescence; gradual wavy boundary
BC	46-62	Reddish brown (5 YR 4/4 moist and dry); sandy clay loam; medium, moderate, sub-angular blocky, slightly hard, firm, slightly sticky and slightly plastic; medium few roots, gradual smooth boundary
Cr	62+	Weathered parent material

Loamy skeletal, mixed, iso-hyperthermic, Typic Rhodustalfs (Bhogaram-1)

Location	:	Hundred meters towards left side on the Bhogaram to Nernamula road at approximately 0.5 km from Bhogaram village
Mandal	:	Ramannapet
District	:	Nalgonda
Physiography	:	Moderately eroded pediplain
Slope	:	5-8 per cent
Land Use	:	Scrub
Drainage	:	Well
Stoniness	:	50-60 %
Erosion	:	Moderate
Natural vegetation:		Prosophis spp, Acacia spp, Neem, Borassus spp etc

Morphological description

Horizon	Depth (cm)	Description
A	0-8	Dark red (2.5YR $^{4/6}$ Moist and Dry); loamy sand, fine, weak, sub-angular blocky; loose, very friable; fine to medium common pores; very fine few roots, clear smooth boundary
Bt1	8-24	Dark red (2.5YR $^{4/6}$ Moist and Dry); sandy loam; weak, moderate, sub-angular blocky, slightly hard, friable, slightly sticky and slightly plastic; fine few roots, gradual smooth boundary
Bt2	24-45	Dark reddish brown (2.5YR $^{3/4}$) ; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard friable, slightly sticky, slightly plastic; medium few roots; gradual wavy boundary
Cr	45+	Weathered parent material

APPENDIX - II
Database of spatial elements used in the study

Attribute tables for geomorphology coverage -GEOM.LUT

GU -CODE	Discr L-1	Discr L-2	Discr L-3
010205	Structural hill	Structural hill (large)	Dyke
020201	Denudational hill	Denudational hill	Dome type Denudational hill (small)
020301	Denudational hill	Residual hill	Dome type Residual hill
050101	Pediplain	Pediplain weathered/buried	Shallow weathered/Shallow buried
050104	Pediplain	Pediplain weathered/buried	Valley fill
050300	Pediplain	Pediment-Inselberg-complex	
050301	Pediplain	Pediment-Inselberg-complex	Pediment
050302	Pediplain	Pediment-Inselberg-complex	Inselberg

Structure of the GEOM. LUT Table

Field Name	Field Type	Key Field
GU-CODE	6,6,C	Yes
Discr-L1	30,30,C	No
Discr-L2	50,30, C	No
Discr-L3	100,30,C	No

Attribute Code table for Drainage/Stream (Single lines) : DRAINL . LUT

DRNL - CODE	DISC R
02	**Dry**

Structure of Drainage Table

Field Name	Field Type	Key Field
DRNL-CODE	2,2,C	Yes
DISCR	30,30,C	No

Attribute Coding for Watersheds WSHED.LUT

WSHED CODE		
04	Region	All drainage to Bay of Bengal except Ganges and Brahmaputra
04	Basin	Krishna River Basin
01	Catchment	Lower most Krishna below Nagarjuna Sagar dam
05	Sub catchment	Musi River
04	Watershed	Mid-Musi
04	Sub Watershed	Ramannapet Watershed

Structure of the table WSHED.LUT

Field Name	Field Type	Key	Remarks
WS-L-CODE	16,16,C	Yes	Link CODE with attribute table
WS-CODE	8,8,C	No	AISLUS-CODE
REGION	40,40,C	No	Description
BASIN	40,40,C	No	Description
CATCHMENT	40,40,C	No	Description
SUB-CATCHMENT	40,40,C	No	Description
WATERSHED	40,40,C	No	Description
SUB WATERSHED	40,40,C	No	Description

Attribute tables for the Roads : ROADS . LUT

RD-CODE	Road Type	Sub type
01-03	Metalled-Black Toped	District Road
02-04	Unmetalled Roads	Village Road

Structure of table for Roads

Field Name	Field Type	Key Field
RD-CODE	4,4,C	Yes
Type	30,30,C	No
Sub Type	30,30,C	No

Attribute Table for Rails : RAIL . LUT

RL-CODE	RAIL-Type	RAIL-DET
01-02	Broad Gauge	Single Track

Structure of the Table for Rails

Field Name	Field Type	Key Field
RL-CODE	4,4,C	Yes
RAIL-Type	30,30,C	No
RAIL-DET	30,30,C	No

Attribute table for Ground water Prospects: GWATER . LUT

GW-CODE	GW-PROS
04	Good
08	Moderate
10	Poor
11	Very Poor to nil

Structure of the table for GW Prospects

Field Name	Field Type	Key Field
GW-CODE	2,2,C	Yes
GW-PROS	30,30,C	No

Attribute Table for Slope : SLOPE . LUT

SLP-CODE	SLOPE
0100	0-1%
0200	1-3%
0300	3-5%
0400	5-10%
0500	10-15%
0600	15-35%
0700	>35%

Structure of the table for SLOPE. LUT

Field Name	Field Type	Key Field
SLP-CODE	4,4,C	Yes
SLOPE	30,30,C	No

APPENDIX - III

Criteria/Limitation rating for evaluating soil-suitability for PADDY

Soil-Site Characteristics	Degree of Limitation (L) & Suitability Class:				
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (V.severe)
		S1	S2	S3	N1 N2
CLIMATIC					
Unirrigated Conditions					
- Rainfall (Summer dominant) (mm)	>1500	1000-1500	750-1000	<750	-
- (During growing period)	>750	550-750	450-550	<450	-
TOPOGRAPHIC (Slope %)					
- Plain, irrigated	0-1	1-3	3-8	>8	Others
- Hilly, Unirrigated, but terraced	<3	3-8	8-15	15-30	>30
WETNESS					
- Flooding	moderate	strong	severe	-	-
- Drainage class	imperfect	mod.well, poor	poor, excessive	excessive	-
SOIL					
- *Textural class* *	*sic, coarse c(s)*	*sic,sc(s)*	*l,sl,sil(m)*	ls,fs	es
(%Clay)	40-60%				
- Silt +clay (%)	>80	50-80	30-50	<30	-
DEPTH (cm)	>80	50-80	25-50	<25	-
- $CaCo_3$ (%)	3-15	0-3; 15-25	25-50	50-75	-
- Gypsum (%)	0.3-2.0	<0.3; 2-5	5-10	10-25	>25
STONINESS (vol.%)					
- Surface	<3%	3-15	15-40	40-75	>75
-Subsoil	<15	15-40	40-75	-	-
SOIL FERTILITY					
- C.E.C. (cmol (p+)kg^{-1} on clay	>16	16-10	10-5	<5	-
- Base Saturation (%)	>80	80-50	50-35	<35	-
SOIL SALINITY (1m soil) dsm^{-1}					
- Fine, mod, fine texture with high and blackish ground water (within 1m)	<2	2-4	4-8	8-15	>15
- Coarse; medium texture with low good quality groundwater-table (below 1m)	<4	4-8	8-15	15-25	>25
SODICITY (ESP)	<15	15-25	25-40	>40	-
- Coarse, medium texture:					
- Fine texture : <8	8-15	15-25	25-40	>40	-

* Textural classes: S-sand, Si-Silt, l-loam, c-clay, e.g.sil-silt loam

** All sizes refer to coarse gravels and stones; fine gravel refers to size class <2.5 cm diameter

*** For NP evaluation, rating given on page.. are adopted.

Criteria/Limitation rating for evaluating soil-suitability for SORGHUM

Soil-Site Characteristics	Degree of Limitation (L) & Suitability Class: 0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (V.severe)	
		S1	S2	S3	N1	N2
CLIMATIC						
- Total Rainfall (mm)	750-850	650-750, >850	650-550	450-550	<450	-
- Rainfall growing season (mm)	700-600	500-600	400-500	300-400	<300	-
- Length growing period (days)	150-120	120-100	100-90	<90	-	-
- Mean temp. growing season (^{0}C)	32-26	26-24	24-22	22-20	<20	-
- Mean max. temp.grow. season (^{0}C)	<31	31-33	33-35	>35	-	-
- Mean min. temp. grow. season (^{0}C)	>22	22-18	18-15	<15	-	-
- Mean R.H. in growing season	70-60	60-50	50-40	<40	-	-
- Length of Dry Spells (days) (After sowing & during flowering)	<7	7-10	10-15	15-21	>21	-
TOPOGRAPHIC (Slope %)						
- Slope	<2.0	2-3	3-5	5-8	>8	-
- Erosion	e_0	e_0	e_1	e_2	e_3	-
WETNESS						
- Drainage	well	mod. well	Imperfect	Poor & Excessive	-	-
- Flooding						
- Water stagnation (days) (early stage)	<2	2-3	3-5	5-7	>7	-
SOIL						
- Textural class (%Clay)	Fine loamy	Fine	V.fine & C.loamy	Sandy, Skeletal	Fragmental	-
-Coarse fragments (vol %)						
. within 50 cm	<5	5-15	15-40	40-75	-	-
. below 50 cm	5-15	15-40	40-75	>75	-	-
- Depth (cm)	>100	100-50	50-20	<20	-	-
- $CaCo_3$ (%)	<5	5-15	15-25	>25	-	-
STONINESS (vol.%)	<5	5-15	15-30	30-60	>60	-
AWC (mm/m)	>200	150-200	100-150	50-100	<50	-
SOIL FERTILITY						
- C.E.C. (cmol (p+)kg^{-1}	>30	30-20	20-10	<10	-	-
- Base Saturation (%)	>80	80-50	50-35	<35	-	-
- Organic carbon (%) (0-20 cm)	>0.75	0.75-0.50	0.5-0.20	<0.20	-	-
SALINITY						
- ECe (dSm^{-1})	<0.2	0.2-0.4	0.4-0.8	0.8-1.0	>1.0	-
SODICITY (ESP)						
- ESP	<5	5-10	10-15	15-25	>25	-
- pH (1:2.5)	6.5-7.5	6.5-5.5, 7.5-8.0	5.5-5.0, 8.0-8.5	<5.0, 8.5-9.0	>9.0 -	- -

Criteria/Limitation rating for evaluating soil-suitability for GROUNDNUT

Soil-Site Characteristics	Degree of Limitation (L) & Suitability Class:					
	0	1	2	3	4	
	(None)	(Slight)	(Moderate)	(Severe)	(V.severe)	
		S1	S2	S3	N1	N2
CLIMATIC						
	GROUNDNUT Bunch)					
- Total Rainfall (mm)	600-700	500-600	400-500	<400	-	-
- Rainfall in growing season (mm)	500-600	400-500	300-400	<300	-	-
- Length growing period (days)	>120	110-120	100-110	90-100	<90	-
	GROUNDNUT Bunch)					
- Total Rainfall (mm)	700-800	600-700	500-600	<500	-	-
- Rainfall in growing season (mm)	600-700	500-600	400-500	<400	-	-
- Length growing period (days)	140-150	130-140	120-130	<120	-	-
- Rainfall at pegging & pod formation (mm)	80-100	50-80	30-50	<30	-	-
- Mean temp. during growing season (°C)	25-30	22-24	20-22	<20	-	-
- Mean max. temp.during grow. season (°C)	<33	33-35	35-37	37-40	>40	-
- Mean min. temp. grow. season (°C)	>20	17.5-20.0	15.0-17.5	12.5-15.0	-	-
- Mean R.H. in growing season	50-60	60-70	70-80	>80	-	-
- Length of dry spells (days)	<10	10-15	15-20	>20	-	-
TOPOGRAPHIC (Slope %)						
- Slope	0-1	1-3	3-5	5-8	>8	-
- Erosion	e_0	e_0	e_1	e_2	e_2	-
WETNESS						
- Drainage						
- Fine &medium-textured soil	Well	Well	Mod.well	-	Imperfect, (somewhat) excessive	
- Flooding	F_0	F_0	F_0	F_1	F_2	-
SOIL						
- Texture	Loamy	Coarse loamy	Fine	V.fine & sandy	Fragmental	-
-Coarse fragments (vol %)						
. within 50 cm	<3	3-15	15-20	20-25	>25	-
- Depth (cm)	60	50-60	30-50	20-30	<20	-
- $CaCo_3$ (%)	<5	5-15	15-25	>25	-	-
STONINESS ((Surface) (%)	<3	3-15	15-25	40	>40	-
AWC (mm/m)	>150	120-150	100-120	50-100	<50	-
SOIL						
- C.E.C.(soil) (cmol (p+)kg^{-1}	>15	12-15	10-12		<10	-
- Organic carbon (%) (0-15 cm)	>1%	-	-	-	-	-
SALINITY ECe (dS m^{-1})						
- coarse texture	<2	2-4	4-8	8-15	>15	-
- fine texture	<1	1-2	2-4	4-8	8-15	>15
SODICITY (ESP)						
- pH (1:2.5)	6.5-7.5	7.5-8.0	8.0-8.5	>8.5	-	-
- ESP						
coarse texture	<5	5-10	10-15	15	-	-
fine texture	<2.5	2.5-5.0	5.0-10.0	10.0-15.0	>15.0	-

Criteria/Limitation rating for evaluating soil-suitability for RED GRAM

Soil-Site Characteristics	Degree of Limitation (L) & Suitability Class: 0 (None)	1 (Slight) S1	2 (Moderate) S2	3 (Severe) S3	4 (V.severe) N1	4 (V.severe) N2
CLIMATIC						
- Total Rainfall (mm)	1200-1000	1000-850	850-700	700-550	<550	-
- Rainfall growing season (mm)	1000-850	850-750	750-600	600-500	<500	-
- Length growing period (days)	180-210	150-180	150-120	120-90	<90	-
- Mean temp. growing season (^{0}C)	28-26	26-24	24-22	22-20	<20	-
- Mean max. temp.grow. season (^{0}C)	35-32	32-28	28-26	26-24	<24 >40	-
TOPOGRAPHIC						
- Slope (%)	<2.0	2.0-3.0	3.0-5.0	5.0-8.0	>8.0	-
- Erosion	e_0	e_1	e_2	e_2 - e_3	e_3	-
WETNESS						
- Drainage	well	mod. well	Imperfect	Poor & Excessive	-	-
- Water stagnation (days)	<1	1-2	2-3	>3	-	-
SOIL						
- Textural	sicl,l,sil Sc,Sic,F,loamy F.silty	c,sc, Fine	V.fine Coarse loamy Csl,Scl	Sandy, Skeletal	-	-
-Coarse fragments (vol %)						
. within 50 cm	<5	5-15	15-40	40-75	>75	-
. below 50 cm	5-15	15-40	40-75	>75	-	-
- Depth (cm)	>125	125-100	100-50	50-25	<25	-
STONINESS (vol.%)	<3	3-15	15-40	40-75	>75	-
AWC (mm/m)	>200	200-150	150-100	100-50	<50	-
SOIL FERTILITY						
- C.E.C. (cmol (p+)kg^{-1}	>20	20-15	15-10	<10	<5	-
- Base Saturation (%)	>80	80-50	50-35	<35	-	-
- Organic carbon (%) (surface soil)	>0.75	0.75-0.50	0.5-0.20	<0.20	-	-
SALINITY						
- ECe (dSm^{-1})	<0.2	0.2-0.4	0.4-0.8	0.8-1.0	>1.0	-
SODICITY (ESP)						
- ESP	<2.5	2.5-5.0	5.0-7.5	7.5-1.0	>10.0	-
- pH (1:2.5)	6.5-7.5	7.5-8.5	8.5-9.0	>9.0	-	-

CLIMATIC REQUIREMENTS - MANGO

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Annual precipitation (mm)	>2000	2000-1000	1000-500	500-250	-	<250
Length of the dry season (months)	4.5-5	5-6	6-7	7-8	-	>8
(P < 1/2 PET)	4.5-4	4-3	3-2	2-1	-	<1
Monthly precipitation during dry season (mm)	<50	50-60	60-100	>100	-	-
Mean annual temp. ((^{0}C)	25-24	24-22	22-18	18-15	-	<15
	25-26	26-28	28-34	34-40	-	>40
Mean min. temp. (^{0}C) of coldest month	>18	18-16	16-13	13-8	-	<8
Annual relative humidity (%)	65-80	>80	-	-	-	-
	65-50	50-42	42-36	36-30	-	<30
n/N maturation stage	>0.7	0.7-0.5	<0.5	-	-	-
Land Characteristics						
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	-	-	F1+
Drainage	good groundw >200cm	good groundw. <200cm	moderate	imperfect	poor, but drainab	
Physical soil characteristics (s)						
Texture/struct.	L,Sil,SL,Si	SiCs, SCL,LfS,SiCL CL,SC	C<60s, fs,LcS	C>60s,S, C>60v	-	Cm, SiCm
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>150	150-100	100-75	75-50	-	<50
$CaCo_3$ (%)	0-3	3-5	5-10	10-25	-	>25
Gypsum (%)	0-1	1-2	2-3	3-5	-	>5
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>16	<16(-)	<16(+)	-	-	-
Base saturation (%)	>50	50-35	35-20	<20	-	-
Sum of basic cations (cmol(+)/kg clay)	>4	4-2.8	2.8-1.6	<1.6	-	-
pH H_2O	6.4-6.0	6.0-5.5	5.5-5.0	5.0-4.5	<4.5	-
	6.4-6.8	6.8-7.8	7.8-8.0	8.0-8.2	-	>8.2
Organic carbon (%)	>2	2-1.2	1.2-0.8	<0.8	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-4	4-6	6-8	-	>8
ESP (%)	0-8	8-15	15-20	20-25	-	>25

CLIMATIC REQUIREMENTS - MAIZE

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Precipitation of growing cycle (mm)	750-900 750-600	900-1200 600-500	1200-1600 500-400	>1600 400-300	- -	- <300
Precipitation of the 1st month (mm)	175-220 175-125	220-295 125-100	295-400 100-75	400-475 75-60	- -	>475 <60
Precipitation of the 2nd month (mm)	200-235 200-175	235-310 175-150	310-400 150-120	400-475 120-70	- -	>475 <70
Precipitation of the 3rd month (mm)	200-235 200-175	235-310 175-150	310-400 150-120	400-475 120-70	- -	>475 <70
Precipitation of the 4th month (mm)	165-210 165-125	210-285 125-100	285-400 100-80	400-475 60-90	- -	>475 <60
Mean temp. of the growing cycle ((°C)	24-22 24-26	22-18 26-32	18-16 32-35	16-14 35-40	- -	<15 >40
Mean min. temp. of the growing cycle ((°C)	17-16 17-18	16-12 18-24	12-9 24-28	9-7 28-30	- -	<7 >30
Relative humidity of devel. stage (%) (2nd month)	65-50 65-80	50-42 >80	42-36 -	36-30 -	- -	<30 -
Relative humidity maturation stage (%)	40-30 40-50	30-24 50-75	24-20 75-90	<20 >90	- -	- -
n/N develop. Stage (2nd month)	0.55-0.5 0.55-0.6	0.5-0.35 0.6-0.75	<0.35 >0.75	- -	- -	- -
n/N maturation Stage	>0.7	0.7-0.5	<0.5	-	-	-

LANDSCAPE AND SOIL REQUIREMENTS - MAIZE

Land Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	F1	-	F2+
Drainage (4)	good	moderate	imperfect	poor and	poor,	poor, not
(5)	imperfect	moderate	good	aeric	but drainab	drainab
Physical soil characteristics (s)						
Texture/struct.	<60s, Co, Sic, SicL, Si, Sil, CL	C<60v, SC C>60s, L SCL	C>60v, SL LFS, LS	FS,S,LCS	-	Cm, SiCm cS
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>100	100-75	75-50	50-25	-	<20
$CaCo_3$ (%)	0-6	6-15	15-25	25-35	-	>35
Gypsum (%)	0-2	2-4	4-10	10-20	-	>20
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>24	24-16	<16(-)	<16(+)	-	-
Base saturation (%)	>80	80-50	50-35	35-20	<20	-
Sum of basic cations (cmol(+)/kg clay)	>8	8-5	5-3.5	3.5-2	<2	-
pH H_2O	6.6-6.2	6.2-5.8	5.8-5.5	5.5-5.2	<5.2	-
	6.6-7.0	7.0-7.8	7.8-8.2	8.2-8.5	-	>8.5
Organic carbon (%)						
(6)	>2.0	2.0-1.2	1.2-0.8	<0.8	-	-
(7)	>1.2	1.2-0.8	0.8-0.5	<0.5	-	-
(8)	>0.8	0.8-0.4	<0.4	-	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-4	4-6	6-8	8-12	>12
ESP (%)	0-8	8-15	15-20	20-25	-	>25

CLIMATIC REQUIREMENTS - CASTOR BEANS

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Precipitation of growing cycle (mm)	1000-1200 1000-800	1200-1400 800-700	1400-1800 700-600	>1800 600-500	- -	- <500
Mean temp. of the growing cycle ((°C)	27-28 27-26	28-30 26-24	30-32 24-20	>32 20-16	- -	- <16
Mean min. temp. of the growing cycle ((°C)	17-18 17-16	18-20 16-14	>20 14-12	- 12-10	- -	- <10
Relative humidity of maturation stage (%)	40-30 40-50	30-24 50-75	24-20 75-90	<20 >90	- -	- -
Land Characteristics						
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	-	-	F1+
Drainage (4)	good	moderate	imperfect	poor and	poor,	poor,
(5)	imperfect	moderate	good	aeric	but drainab	not drainab
Physical soil characteristics (s)						
Texture/struct.	L,SL	SCL, SiCL LfS, CL	C<60s,SiC C><60s,LS	C>60v,fS, S,LcS	-	Cm, SiCm
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>150	150-100	100-75	75-50	-	<50
$CaCo_3$ (%)						
Gypsum (%)						
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>24	24-16	<16(-)	<16(+)	-	-
Base saturation (%)	>50	50-35	35-20	<20	-	-
Sum of basic cations (cmol(+)/kg clay)	>5	5-3.5	3.5-2	<2	-	-
pH H_2O	6.5-6.2 6.5-6.8	6.2-6.0 6.8-7.0	6.0-5.5 7.0-7.2	5.5-5.0 7.2-7.5	<5.0 -	- >7.5
Organic carbon (%)	>2	2-1.2	1.2-0.8	<0.8	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-4	4-6	6-8	-	>8
ESP (%)	0-8	8-15	15-20	20-25	-	>25

CLIMATIC REQUIREMENTS - CITRUS

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Annual precipitation (mm)	2300-3000 2300-1500	>3000 1500-1200	1200-1000	1000-800	-	<800
Number of dry months (P < ½ PET)	2.5-3 2.5-2	3-4 2-0	4-5 -	5-6 -	- -	>6 -
Mean annual temp. (°C)	26-30 26-22	30-33 22-19	33-36 19-16	36-39 16-13	- -	>39 <13
No. of months with mean min. temp. > 38°C	0-1	1-2	2-4	4-6	-	>6
No. of months with mean min. temp. > 13°C	0-1	1-2	2-4	4-6	-	>6
Absol. Min. t°C (°C) - lemon - grape fruit - orange - mandarines	 > -1 >-3 >-3.5 >-4.5	 (-1) – (-2) (-3) – (-4) (-3.5) – (-4) (-4.5) – (-5.5)	 (-2) – (-6) (-4) – (-7.5) (-4) – (-7.5) (-5.5) – (-8.5)	 (-6) – (-9) (-7.5) – (9.5) (-7.5) – (9.5) (-8.5) – (-12)	-	 <-9 <-9.5 <-9.5
Mean tem. In the 2 months aft. Harvest (°C)	13-10 13-15	10-8 15-18	8-6 18-20	6-4 20-25	- -	<4 >25
Mean temp. of the flowering stage (°C)	>15	15-10	10-5	5 to -5	-	<-5
Relative humidity in coldest month if frost (%)	<30	30-60	60-90	>90	-	-
Relative humidity at ripening stage (%)	45-60 45-30	60-70 <30	70-90 -	>90 -	- -	- -
Relative humidity at flowering (%)	75-70 75-80	70-50 80-90	<50 >90	- -	- -	- -

LANDSCAPE AND SOIL REQUIREMENTS - CITRUS

Land Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	-	-	F1+
Drainage	good groundw. >150cm	good, groundw. 100-150cm	moderate	imperfe.	poor, but drainab	poor, not drainab
Physical soil characteristics (s)						
Texture/struct.	SL,Sil,L, SiCL,CL, CL,Si	SCL,LS, LfS	C>60S, SC S,fS, SiCs, Co	C<60v, C>60s	-	Cm, SiCm C>60v
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>200	200-150	150-100	100-75	-	<75
$CaCo_3$ (%)	0-3	3-5	5-10	10-25	-	>25
Gypsum (%)	0-1	1-2	2-3	3-5	-	>5
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>16	<16 (-)	<16(+)	<16(+)	-	-
Base saturation (%)	>35	35-20	<20	-	-	-
Sum of basic cations (cmol(+)/kg clay)	>3.5	3.5-2	<2	-	-	-
pH H_2O	6.5-5.8	5.8-5.5	5.5-5.2	5.2-5.0	<5.0	-
	6.5-7.0	7.0-7.6	7.6-8.0	8.0-8.2	-	>8.2
Organic carbon (%)	>1.5	1.5-0.8	<0.8	-	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-4	3-4	4-6	-	>6
ESP (%)	0-8	4-8	8-12	12-15	-	>15

CLIMATIC REQUIREMENTS COWPEA

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Precipitation of growing cycle (mm)	500-550 500-400	550-900 400-300	900-1300 300-250	>1300 250-200	- -	- <200
Mean precipitation of the 1st month (mm)	100-75 100-150	75-50 150-255	50-25 255-400	- >400	- -	<25 -
Mean precipitation of the 2nd month (mm)	150-125 150-175	125-100 175-255	100-75 255-400	75-50 >400	- -	<50
Mean precipitation of the 3rd month (mm)	150-125 150-175	125-100 175-255	100-75 400-255	75-50 >400	- -	<50 -
Mean precipitation of the 4th month (mm)	<75	75-135	>135	-	-	-
Mean temp. of the growing cycle ((°C)	24-26 24-22	26-30 22-20	30-32 20-18	32-35 18-16	- -	<35 >16
Mean temp. at germination (°C) (1st month)	22-25 22-18	25-30 18-17	30-32 17-16	32-35 16-15	- -	<35 >15
Mean min. temp. of coldest (°C)	>18	18-16	16-13	13-7	-	<7
Relative humidity at harvest	<60	60-80	80-90	>90	-	-

LANDSCAPE AND SOIL REQUIREMENTS - COWPEA

Land Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	F1	-	F2+
Drainage (4)	good	moderate	imperfect	poor and	poor,	poor, not
(5)	imperfect	moderate	good	aeric	but drainab	drainab
Physical soil characteristics (s)						
Texture/struct.	SiCs, SiL Co, C<60s SiCL,CL	C>60s, SL C<60v, SC, L, SCL	C>60v, SL LfS, LS	S,fS	-	Cm, SiCm cS
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>75	75-60	60-50	50-20	-	<20
$CaCo_3$ (%)	0-6	6-15	15-25	25-35	-	>35
Gypsum (%)	0-2	2-4	4-10	10-20	-	>20
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>24	24-16	<16(-)	<16(+)	-	-
Base saturation (%)	>50	50-35	35-20	35-20	-	-
Sum of basic cations (cmol(+)/kg clay)	>4	4-2.8	2.8-1.6	3.5-2	-	-
pH H_2O	6.6-6.2	6.2-6.0	6.0-5.5	5.5-5.2	<5.0	-
	6.6-7.0	7.0-7.8	7.8-8.0	8.2-8.5	-	>8.2
Organic carbon (%)	>2.0	2.0-1.2	<0.8	<0.8	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-3	3-5	5-7	-	>7
ESP (%)	0-8	8-15	15-20	20-25	-	>25

CLIMATIC REQUIREMENTS - SUNFLOWER

Climatic Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Precipitation of growing cycle (mm)	650-800 650-500	800-900 500-400	900-1300 400-300	>1300 300-250	- -	- <250
Precipitation of the 1st month (mm)	105-135 105-75	135-215 75-60	>215 <60	- -	- -	- -
Precipitation of the 2nd month +3rd month (mm)	195-230 195-160	>230 160-125	125-85	85-70	-	<70
Precipitation of the 4th month (mm) (flowering stage)	250-315 250-190	315-450 190-140	450-750 140-120	>750 120-80	- -	- <80
Precipitation of the 4th month (mm) (yield formation)	100-120 100-75	120-150 <75	>150 -	- -	- -	- -
Mean temp. of the growing cycle ((°C)	22-20 22-24	20-18 24-26	18-16 26-28	16-13 28-30	- -	<13 >30
Relative humidity growing cycle (%)	65-50 65-80	50-42 80-90	42-36 >90	36-30 -	- -	<30 -

LANDSCAPE AND SOIL REQUIREMENTS - SUNFLOWER

Land Characteristics	Class, degree of limitation and rating					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	>6
(2)	0-2	2-4	4-8	8-16	-	>16
(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	F_0	-	-	F1	-	F2+
Drainage (4)	good	moderate	imperfect	poor and	poor,	poor, not
(5)	imperfect	moderate	good	aeric	but	drainab
					drainab	
Physical soil characteristics (s)						
Texture/struct.	C<60s, SiC,Co, SiL, Si, SiCL, CL	C>60s, SC, L, SCL C<60v	C>60v, SL LfS, LS	LCS, fS,S	-	Cm, SiCm
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>150	150-100	100-75	75-50	-	<50
$CaCo_3$ (%)	0-6	6-15	15-25	25-35	-	>35
Gypsum (%)	0-2	2-4	4-10	10-20	-	>20
Soil fertility Characteristics (f)						
Apparent CEC (cmol(+)/kg clay)	>24	24-16	<16(-)	<16(+)	-	-
Base saturation (%)	>50	50-35	35-20	<20	-	-
Sum of basic cations (cmol(+)/kg clay)	>4	4-2.8	2.8-1.6	<1.6		-
pH H_2O	6.6-6.2	6.2-6.0	6.0-5.5	5.5-5.0	<5.0	-
	6.6-7.0	7.0-7.5	7.8-8.0	8.0-8.5	-	>8.5
Organic carbon (%)	>2	2.0-1.2	1.2-0.8	<0.8	-	-
Salinity and Alkalinity (n)						
ECe (ds/m)	0-2	2-4	4-9	9-12	-	>12
ESP (%)	0-8	8-15	15-20	20-25	-	>25

APPENDIX – IV

(Field Photographs)

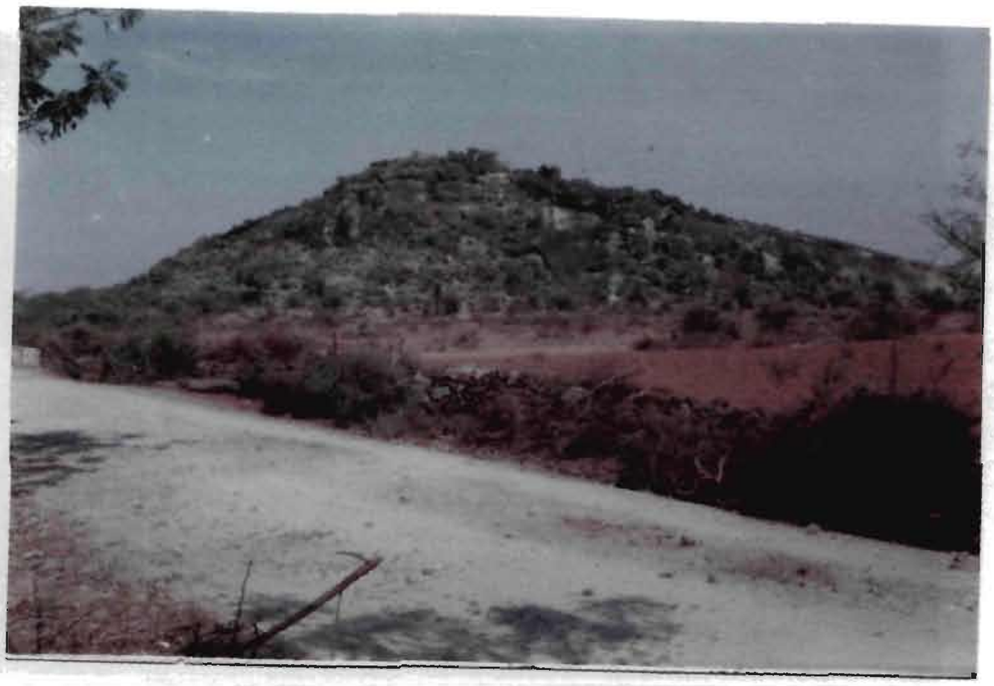


Plate - 1 : Typical residual hill

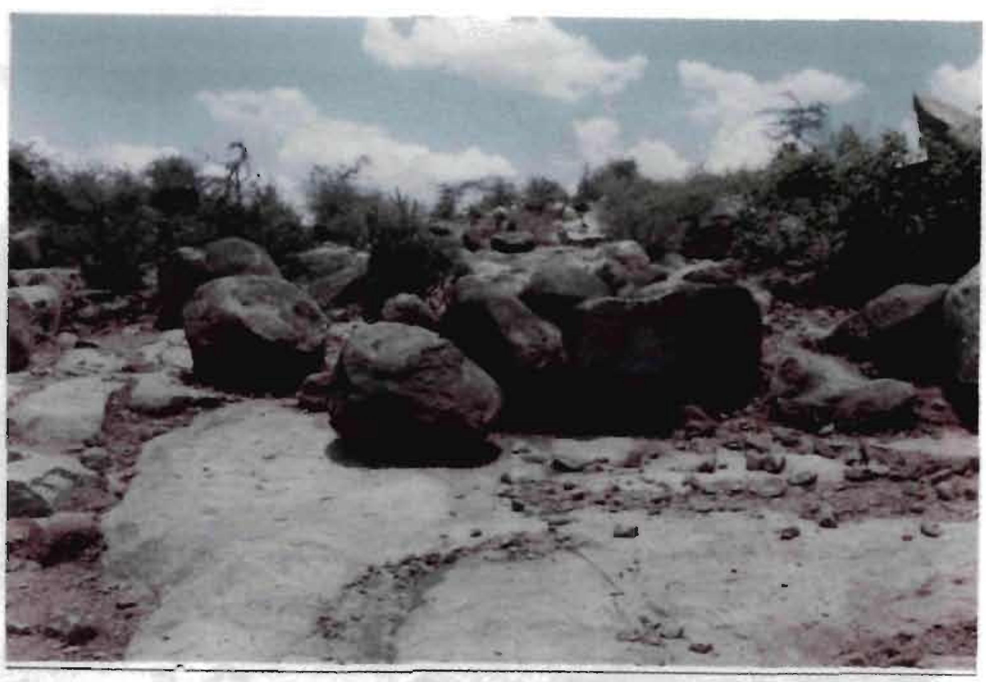


Plate - 2 : Typical view of dyke

Plate - 3 : Land with scrub

Plate - 4 : Thorny bushes vegetation on hills

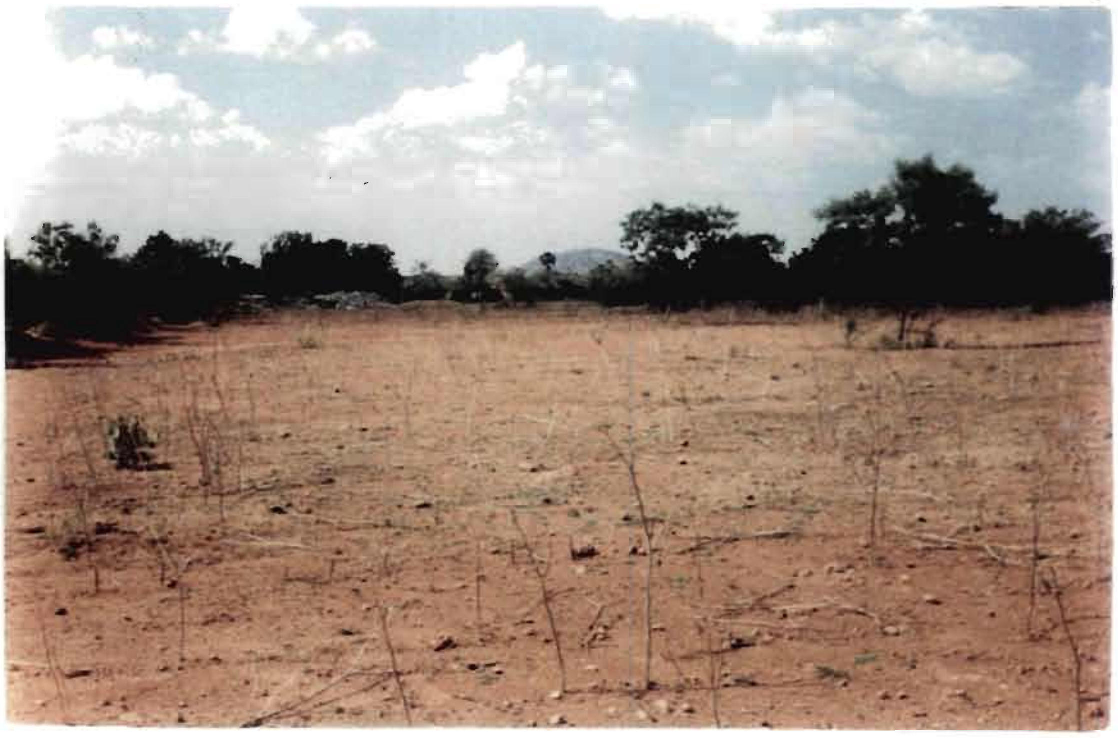


Plate - 5 : Moderately eroded pediplain

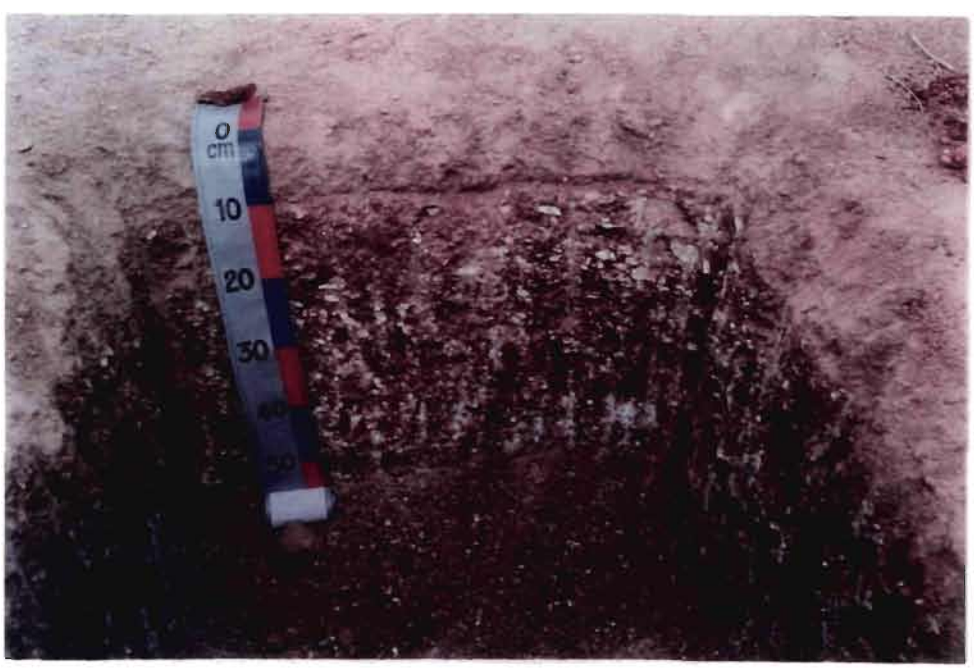


Plate - 6 : Dubbak-2 series pedon
(Coarse loamy, Typic Rhodustalfs)

Plate - 7 : Slightly eroded pediplain-cultivated

Plate - 8 : Sripuram-3 series
(Fine loamy, Typic Haplustalfs)

Plate - 9 : Slightly eroded pediplain

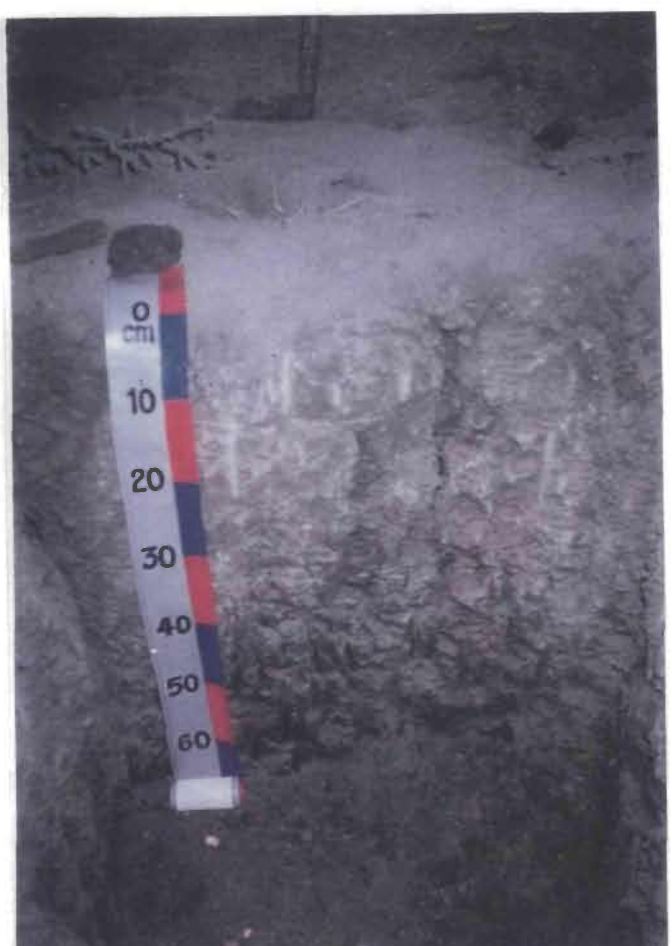


Plate - 10 : Nernamula-1 (Fine, Vertic Haplustepts)

Plate - 11 : Slightly eroded valley- uncultivated (Salt affected)

Plate - 12 : Rammannapet-2 series [Fine loamy, Fluventic (sodic) Haplustepts]

Plate - 13 : Intensively cultivated valley

Plate - 14 : Bhogaram-3 series
(Fine loamy, Calcic Haplustepts)

Plate - 15 : Dubbak-4 series
(Loamy skeletal, Typic Haplustalfs)

Plate - 16 : Bhogaram-2 series
(Coarse loamy, Typic Ustorthents)

Plate - 17 : Slightly eroded pediplain - plantation

Plate - 18 : Rock out crops

APPENDIX-V

Ratings of soil parameters used for differentiating phases of soil series

a. Surface texture

Symbol	Texture	Gravelly
e	sandy clay	e
m	sandy clay loam	m
l	loam	l
r	sandy loam	r
s	loamy sand	s

b. Slope

Symbol	per cent slope	Class
A	0-1	Nearly level
B	1-3	Very gently sloping
C	3-8	Gently sloping
D	8-15	Moderately sloping
E	15-35	Moderately steep
F	35-50	Steep

c. Erosion

Symbol	Class
e1	Nil to very slight
e2	Slight
e3	Moderate
e4	Severe

d. Stoniness

Symbol	Class	per cent area covered
st1	Non-stony	<3
st2	Slightly stony	3-15
st3	Moderately stony	15-40
st4	Strongly stony	40-75
st5	Very strongly stony	>75

e. Soil Depth

Symbol	cm	Gravelly
1	<10	Extremely shallow
2	10-25	Very shallow
3	25-50	Shallow
4	50-75	Moderately shallow
5	75-100	Moderately deep
6	100-150	Deep