SOIL RESOURCE INVENTORY USING REMOTE SENSING AND GIS TECHNIQUES FOR UTILIZATION IN WATERSHED DEVELOPMENT

By

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M.Sc. (Ag.)

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

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DECLARATION

I, **Mrs. B. ASHA JYOTHI** here by declare that the thesis entitled **"SOIL RESOURCE INVENTORY USING REMOTE SENSING AND GIS TECHNIQUES FOR UTILIZATION IN WATERSHED DEVELOPMENT"** submitted to Acharya N.G.Ranga Agricultural University for the Degree of **DOCTOR OF PHILOSOPHY** is a result of original research work done by me. It is further declared that the thesis or any part there of has not been published earlier in any manner.

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ABSTRACT

The present study was taken up with the objectives to generate soil map, to suggest optimum land use plan and to prepare digital database for soil besides studying the spatial variability of the soil properties in a part of the study area for giving site-specific nutrient recommendations using remote sensing and GIS techniques.

The part of Dagala watershed located in Kachch district, Gujarat was selected for the study. The study area experiences aridic climate with scanty and erratic rainfall as well as extremes of temperatures. Soil moisture regime is aridic and soil temperature regime is hyperthermic. Satellite data of IRS-IC PAN + LISS-III was used, which helped to delineate the soils at 1:12,500 scale with the abstraction level of pure series. Fourteen soil series were established in the study area.

Different physiographic units were identified and horizonwise soil samples confined to these units were collected. Soils were analysed for morphological, physical, physico-chemical, chemical properties and clay mineralogy. They were classified according to USDA Soil Taxonomy. Later on, soil map was generated with appropriate legend.

Physiographic units identified in the study area were hills, pediment-inselberg complex, pediment, pediplain and valley. Each unit was further sub-divided based on the erosion and slope. Major part of the study area was occupied by the undulating pediplain with moderate erosion (16.93%) followed by undulating pediplain with severe erosion (16.63%).

Soils occurred in the study area were belonging to orders-Aridisols and Entisols. At subgroup level, soils were classified as Typic Haplocambids that occurred in all physiographic units. The other soils were classified as Vertic Haplocambids that occurred in pediment, Sodic Haplocambids that occurred in valley and Typic Haplocalcids that occurred in pediplain. Among Entisols, Typic Torriorthents were identified in upper foot slopes, pediplain and valley fringe while Typic Torripsamments were identified in the pediplain only. At family level, soils were classfied as 'sandy' to 'fine' textural class and 'hyperthermic' temperature regime. Identification of clay minerals was done through X-ray diffraction techniques. Seven representative samples were analysed and the dominant clay minerals were identified as kaolinite and smectite for inclusion at family level.

Soils located in the higher elevations were shallow with coarse texture than that of the lower elevations. Comparatively well developed structure with more clay, high CEC and high base saturation was found in the soils of valley and nearly levelled pediplains. Relative proportion of kaolinite was noticed which decreased down the slope while reverse trend was observed with smectite. Genesis of the soils was influenced by the topography and parent material besides climate over a period of time.

Soils in each mapping unit were evaluated for their potential and limitations using USDA land capability classification method and Riquier's parametric approach. USDA method provided the generalized classification of soils for agriculture and non-agricultural uses while Riquier's method provided the information on actual productivity of the soil for different uses such as field crops, pastures and forest/other trees. Moreover, it helped to know the potential productivity of the soil. keeping in view of the potentialities and limitations of the land, optimum land use is suggested with suitable management practices.

Digital database was created for soils and the derivative maps were generated. The digital database will be useful for future workers to retrieve and update the data for generating action plans over a period of time for land resource management of study area, which is cost effective and time saving.

Spatial variability of soils for site-specific nutrient management as a model to focus the importance of precision farming had been attempted for part of the study area. Spatial variability of soil properties such as pH, EC, OC and nutrient status of available nitrogen, phosphorus and potassium was studied and maps were generated using geo-statistics. The available potassium exhibited more variation among all properties followed by OC while pH showed the least variation. Site-specific nutrient recommendations for major nutrients were given according to the variability of nutrient contents in soils.

LIST OF ABBREVIATIONS

%	:	per cent
@	:	at the rate of
&	:	And
BS	:	Base saturation
CEC	:	Cation Exchange capacity
Cmol (p^+) kg^{-1}	:	Centimole per kilogram
et al.	:	and others
EC	:	Electrical Conductivity
dS m^{-1}	:	DeciSiemens per meter
Fig	:	Figure
ESP	:	Exchangeable sodium percentage
etc	:	Et cetera (Latin)
FCC	:	Flase colour composite
GIS	:	Geographic information systems
GPS	:	Global Positioning System
ha	:	Hectare
i.e.	:	that is
IRS	:	Indian Remote Sensing Satellite
K^+	:	Potassium
kg ha^{-1}	:	Kilogram per hectare
LISS	:	Linear Imaging Self Scanning Sensor
LPI	:	Land Productivity Index
K_2O	:	Available potassium
Na^+	:	Sodium
Mg^{2+}	:	Magnesium
N	:	Nitrogen
NBSS & LUP	:	National Bureau of Soil Survey and Land Use Planning
NRSA	:	National Remote Sensing Agency
°C	:	Degree celsius
P_2O_5	:	Available Phosphorus
OC	:	Organic carbon
PAN	:	Panchromatic
pH	:	Soil reaction
USDA	:	United States Department of Agriculture
viz.,	:	Namely
XRD	:	X-Ray diffraction
>	:	Greater than
<	:	Less than

ABBREVIATIONS USED ACCORDING TO SOIL SURVEY STAFF (1998)

Texture	:	ls- loamy sand; l - loam; cl - clay loam; scl - sandy clay loam; c - clay.
Structure	:	a) Grade (G): 0 - structure less; 1 - weak; 2 - moderate; 3 - strong. b) Size (S): f - fine; m - medium; c - coarse; vc - very coarse. c) Type (T): abk- angular blocky; sbk - subangular blocky; gr - granular; sg - single grain.
Consistence	:	**Dry soil:** l - loose; s - soft; sh - slightly hard; h - hard; vh - very hard; eh - extremely hard. **Moist soil:** l - loose; vfr - very friable; fr - friable; fi - firm; vfi - very firm; efi - extremely firm. **Wet soil :** s_0 - non sticky; ss - slightly sticky; s - sticky; vs – very sticky; p_0 - non plastic; sp - slightly plastic; p - plastic; vp - very plastic
Effervescence	:	e - slight; es - strong; ev - violent
Boundary	:	D - distinctness; a - abrupt; c - clear; g - gradual; d - diffuse; T - topography; s -smooth; w - wavy; I - irregular; b - broken

INTRODUCTION

CHAPTER I

INTRODUCTION

The broad aim of soil research is to increase and maintain soil productivity which will help to produce food for people, fodder for the animals and raw materials for the industry. For the prosperity of the country, it is essential that the land is so managed as to get the best out of it. Proper land utilization and soil management using modern agricultural technology for optimum crop production should be adopted in such a way that the productivity of the soil per unit area is increased and maintained without environmental degradation so as to safeguard the interest of future generation.

Soil is a vital natural resource and a precise knowledge about its characteristics, extent, location, potential and limitations is necessary for the socio-economic development of a country and sustainable use of its natural resources. This finite resource is currently under tremendous pressure by highly conflicting demands of an expanding population. The problem is further aggravated due to indiscriminate and unsound management practices and are manifested in various types of land degradation problems. A qualitative as well as quantitative assessment of land resource is there, required for the optimum use in agricultural and non-agricultural sectors and other land development programmes. The importance of soil resource inventory to plan for their efficient/optimum land use is at present well recognized. Soil survey and land use planning is a basic pre-requisite for extension of agriculture to new areas or improving productivity of the area already under cultivation or amelioration of deteriorated soils.

In earlier days, scientific inventory of soil resources was obtained through conventional soil survey methods. Even though the acquired data are reliable and accurate, the field work was frequently handicapped by consideration of time, distance, weather and diversity of area. The recent advancements in space and information technology especially remote sensing plays an important role in soil resource inventory reducing the above constraints. Remote sensing offers a very accurate, rapid and cost effective mode of natural resource appraisal in a synoptic way. 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 coarse resolution data (80m) during 1970's, remote sensing applications were confined only to very large area studies at very small scales. Improved spatial and spectral resolution achieved during the 1980s and upto and 1990s made it possible to study the resources at larger scale for smaller area such as watersheds etc. During 1990's and currently, further enhancement of spatial resolution to less than 6 m upto 1 m (CARTOSAT AND IKONOS) was achieved, which enables the utilization of satellite data for micro level planning or even for farm level planning.

The availability of data from multi sensors on board a common platform had led to investigate various methods for merging of multi sensor data. The merged output optimally combines the best from different sets of input data. A hybrid output of IRS-IC PAN and LISS-III has an advantage of high spatial resolution of PAN (5.8 m resolution) and multi-spectral nature of LISS-III (23.5 m resolution) in a variety of applications including soil inventory. Thus, it helps in achieving better soil unit delineations to get accurate/better soil mapping units.

The use of computers for analyzing large quantities of data can be applied to agriculture in general, and soil surveys in particular. GIS is a powerful tool for storing voluminous spatial and non-spatial data and for an integrated analysis of resource data to develop sustainable action plans. Remote sensing and GIS are being increasingly used for resource inventory studies as they reduce the time required for survey, evaluation of resources for variety of applications and data transfer. Creation of digital database for soil maps enables to study the variation in soil properties in space and time. It has an added advantage of reproduction of derived and other interpretative maps. It also helps for periodic updation of maps/information that are useful for generating action plans for land resources management of a region/watershed which is cost effective and time saving.

The aim of precision agriculture in relation to cropping is "to match resource application and agronomic practices with soil attributes and crop requirements as they vary across a site" (Mc Bratney and Whelan, 1995). Traditional cropping has regarded the field as the smallest convenient unit of management. Considered relatively homogeneous, the field is generally managed by practices such as uniformity in sowing, fertilizer and pesticide applications, which ignored the spatial variability of the soil, and thus, the site-specific crop requirements. Precision agriculture system matches resource availability to crop capability for efficient management for which the knowledge of soil spatial variability is essential.

The geo-statistical theory enables one to measure spatial dependence of properties and to use it for practical purposes like interpolation and mapping. Thus, maps prepared can be transformed to nutrient recommendations suited for a particular crop and soil conditions

Watershed has become a practical unit for transfer of rainfed agricultural technology from lab to land and for formulating the various developmental programmes to improve the crop production and minimize land degradation resulting in optimum land use planning. Development of watersheds at micro-level is given a top priority by the administrators both at state level and national level. Several management practices have to be taken up to improve the productivity in watershed area. Soil resource inventory plays a vital role to recommend suitable measures for the watershed development. The availability of modern technologies such as remote sensing with high spatial resolution and GIS offers an excellent scope to undertake the development programmes at micro-level planning. Keeping in view of the importance of soil resource inventory in development of watershed, a study has been taken using modern tools like remote sensing, GIS with the following objectives.

1) To Map soils of a watershed using high-resolution satellite data (PAN +LISS–III) at appropriate scale.
2) Creation of digital soil database and query mechanism to enable efficient use of the database that is flexible, updateable and user friendly.
3) Evaluate land to develop optimum land use plan through spatial analysis of soils.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Timely and reliable information on soils with respect to their nature, extent, spatial distribution, potential and limitations is very crucial for optimal utilization of available natural resources on a sustained basis. Soil surveys, which hither to have been conducted through conventional approach, provide such information. Remote sensing ushered in a new era by way of augmenting the efficacy of soil survey programme. Development of geographical information system (GIS) provides valuable support to handle voluminous data in both spatial and non-spatial formats. A brief sketch of research investigations relevant to the present study entitled "Soil resource inventory using remote sensing and GIS techniques for utilization in watershed development" is reviewed under the following sub-heads:

2.1 Remote sensing – Evolution and its applications in soil resource inventories

2.2 Soil characterization

2.2.1 Morphometric characteristics

2.2.2 Physico-chemical properties

2.2.3 Exchangeable properties

2.2.4 Mineralogy of clays

2.3 Soil classification

2.4 Land productivity assessment

2.5 Spatial variability of soils using classical and geo-statistical techniques

2.1 REMOTE SENSING - EVOLUTION AND ITS APPLICATIONS IN SOIL RESOURCE INVENTORIES

Until the late 1920's, soil survey has been carried out through conventional approach which is tedious, time-consuming, cost prohibitive and impractical to inhospitable terrain. Subsequent availability of aerial photographs and the development of aerial photo interpretation helped in improving the efficacy of soil survey programme. Furthermore, the developments in sensor technology and concomitant image analysis facilities have further augmented this process.

The systematic observation of the earth from space started in 1960 with the launch of Television Infrared Observation Satellite (TIROS-I) which was designed primarily for meteorological observations. Photographs from space also became available from the Gemini and Apollo missions. U.S. Geological survey used these photographs to generate a plan for repetitive surveys of the earth for the investigation of resources and the environment. These efforts led to the Earth Resources Technology Satellite (ERTS-1) project under NASA, which was launched in July, 1972. With the launch of the second satellite in January 1975, the name of the series was changed to LANDSAT.

The development of the first satellite, Aryabhatta was an enormous leap forward in satellite technology in India. In 1979, the first earth observation satellite BHASKARA – 1 was launched, followed by BHASKARA – II in 1981. Later, as a first step to provide remotely sensed data for natural resource application, ISRO designed and developed a series of Indian Remote Sensing Satellites (IRS). The IRS-1A was the first of a series of such satellites, launched on March 17, 1988 and it was the major land mark in satellite based remote sensing programme in India (Kasturirangan *et al.*, 1991). The other satellites included in this series were IRS-1B, 1C, 1D, P_3 and P_4. IRS-1B, similar to IRS-1A, which was equipped with LISS-I and LISS-II sensors, was launched in 1991. IRS-1C and 1D were identical in their design. They carry three sensors namely LISS – III with 23.5m resolution, PAN with 5.8 m and WiFS with 188 m resolution and were launched in 1995 and 1997, respectively.

All these satellites extended the remote sensing applications to several new areas. Recently, RESOURCESAT –1 which is an improved version of the IRS-1C/1D was launched. It carried an improved LISS-III camera (LISS III[1]) with four bands (red, green, near IR and SWIR), all with 23 m resolution, three banded multispectral LISS-IV with a spatial resolution of 5.8 m and WiFS with 70 m spatial resolution. All these sensors make RESOURCESAT-1 a unique satellite for multiple applications.

Recent advances in remote sensing technique have opened new vistas in mapping and monitoring of natural resources in general and soil resource inventory in particular. A knowledge of the spectral response of soil is inevitable for the soil resource mapping. The parameters which influence the spectral response of soil are moisture content, organic matter, iron oxide, relative percentages of clay, silt and sand and the roughness of the soil surface. Baumgardner *et al.* (1970) and Kristof and Zachary (1978) reported that soil properties such as type, texture, colour, moisture content and organic matter content can be distinguished by numerical analysis of space borne multispectral scanner data.

Lewis *et al.* (1975) studied the mullispectral imagery acquired by Landsat-1 over the sand hills region of Nebraska and reported that mullispectral scanner data are suitable for the visual interpretation of soil associations.

LANDSAT-MSS data enabled observation and delineation of soil patterns, land use, slope effects and drainage patterns and preparation of soil association maps for the entire state of South Dakota through a systematic monoscopic visual interpretation approach (Westin and Frazee, 1976).

Mapping of soil resources of entire country at 1:250,000 by NBSS&LUP is the testimony of the vast potential of LANDSAT data and subsequently these were used for generating derivative maps such as land capability maps, land irrigability maps and crop suitability maps (NRSA, 1978 and 1984). Salt affected soil maps for entire country were also prepared at 1:250,000 scale in collaboration with the national and state soil survey organizations, Regional Remote Sensing Services and State Remote Sensing Centers using LANDSAT TM standard FCC images.

Weismiller and Kaminisky (1978) noticed that computer aided analysis of satellite mullispectral data would aid soil scientists in preparing soil association maps.

Thompson *et al.* (1981) found that LANDSAT-MSS had the capability for separating vegetated (grassland and wood land) soil landscapes on the basis of soil characteristics related to vegetative growth conditions. They reported a maximum overall classification accuracy of 42 per cent at the soil family level and 58 per cent accuracy at the suborder level of soil classification.

Manchanda *et al.* (1982) conducted soil and land use surveys in Patna area, Bihar using aerial photos of 1:25,000 scale. Three physiographic units were identified in this area and dominant soils found were coarse loamy Vertic Haplustalfs and fine loamy Aeric Haplaquepts in Ganges system, Coarse loamy/Fine loamy Typic Ustochrepts in Gandak system and Fine loamy Aeric Ochraqualfs and Fine loamy Typic Ochraqualfs in interfluvial plain area.

Thompson *et al.* (1984) found that the improved spectral and spatial characteristics of TM could indeed provide information pertinent to soil boundaries delineation, even in intensively cropped areas in central Iowa. Thompson and Henderson (1984) also predicted that the improved characteristics of TM data offers potential to separate important soil properties even in a region with similar soils and under a dense vegetation canopy.

Roundabush *et al.* (1985) found LANDSAT-TM data was useful for locating soil series boundaries and soil scapes upto family level. Su *et al.* (1989) used SPOT-MLA data for generating information on soil resources through visual interpretation approach and soils were mapped at family level.

Based on the results of wasteland mapping in India on 1:1 million scale with the help of LANDSAT-MSS data, the second phase of wasteland mapping project of 84 critically affected districts in various states in the country was taken up by the NRSA at the instance of the National Wasteland Development Board using IRS-1A LISS-II geocoded data. (Rao *et al.,* 1991). From this study, it was demonstrated that the data from IRS can be used to map and monitor wastelands rapidly and economically and the spatial information on wasteland at a village level can be utilized for various reclamation measures and subsequent uses.

Karale *et al.* (1991) examined three approaches of soil mapping using digital classification of IRS-1A LISS-II data in areas of complex soil scapes in three different states (Tamil Nadu, Madhya Pradesh and Maharashtra). Results showed that IRS LISS-II data in conjunction with appropriate methodology, consistent with the pedogenic realm of the area, provide details of soil classes that are often found missing on existing soil maps of reconnaissance and semi detailed intensities.

Rao *et al.* (1991) delineated and mapped the sodic soils in part of the Indo-Gangetic plains of Uttar Pradesh, India using LANDSAT-TM data at 1:50,000 scale.

Rao and Venkataratnam, (1991) monitored the salt affected soils of the Ukai-Kakarapar Command area, Gujarat by comparing the maps prepared at 1:25,000 scale using aerial photographs of December 1977, and Salyut-7 space photographs taken in April, 1984 and LANDSAT-TM data of December, 1985. They noticed an increase in the area affected by soil salinity/alkali problem from 36.3 per cent in 1977 to 80.3 per cent of the total mapped area in 1984. They also concluded from the study that the boundaries were sharper in the FCC and band number 4 of MKF-6M than in the aerial photographs.

The launch of the IRS-1A in 1988 with two sensors, namely LISS-I and II similar to LANDSAT-MSS and TM, in terms of spatial resolution provided the backup for soil resources mapping and land degradation studies at 1:250,000 and 1:50,000 scales (Karale, 1992; Rao and Venkataratnam, 1992),

Kudrat *et al.* (1992) prepared soil resource map for Kandi area adjacent to Chandigarh, India using IRS-1A LISS-II digital data. Six soil scape units, namely hills, valleys, moderate and severe eroded piedmonts, alluvial plain and river terraces were identified and delineated digitally. Major soils encountered in various soil scape units were Typic/Lithic Ustorthents, Typic/Udic Ustochrepts, Typic Haplustalfs, Typic Ustipsamments and Typic Ustifluvents.

A decrease of 9.9 per cent of area of salt affected soils over 11 years was observed in a study conducted by Dwivedi (1992) while monitoring the spatial extent of salt affected soils and to assess the effect of image scale on the delineation of these soils using LANDSAT data in the Indo-Gangetic plains of Uttar Pradesh, India using LANDSAT-TM data acquired in 1975 and 1986. This was attributed to ameliorative efforts by farmers and State Government Agencies. Effect of image scale on the delineation of these soils interpreted that enlargement of the LANDSAT- TM data was helpful in refining the boundaries of salt affected soils and also assisted in identifying patches with relatively small dimensions.

Identification and mapping of areas affected by various degradation processes in medium textured alluvial plain soils of arid regions of Rajasthan was performed by Pramila *et al.* (1993) using LANDSAT-TM FCC data. The kind, extent and severity of degradations were mapped and found that 52 per cent of the area was degraded due to soil stripping, sheet wash and gully erosion and eight per cent due to salinity.

Wallace *et al.* (1993), while working in western Australia on waterlogged and non-waterlogged crops, reported that spectral discrimination can be easily established using either 13-band air borne MSS data or LANDSAT-TM data. Near infrared and thermal bands were found to be important in providing the observed discrimination.

Rao and Chandrasekhar (1996) reported that multidate LISS II data have been used extensively to prepare soil resources map with the abstraction level of soil series/association for about one-third area of our country under the integrated mission for sustainable development (IMSD) Project. Multidate satellite data used in such studies, have facilitated to improve delineation of soil scape boundaries especially in complex landscapes. These soil maps have been used as an input for generation of derivative maps.

Verma *et al.* (1996) used multidate remotely sensed data in the form of aerial photographs and IRS-1A LISS-II geocoded FCC on 1:50,000 scale and interpreted visually to map physiography and soils of the arid tract of Punjab.

Karla and Joshi (1996) compared the potentiality of LANDSAT, SPOT and IRS satellite imagery for recognition of salt affected soils in Indian arid zone and observed that the LANDSAT-MSS band 4 could only provide the overall extent of salinity.

A well defined relationship between geomorphic surfaces and development of soils was established by Deka *et al.* (1996) in Siwalik hills of the semiarid tract in Punjab, India by analyzing remotely sensed satellite data of IRS-1B LISS-I. Results revealed that soils from unstable geomorphic surfaces (shoulder, toe slope and rivulent) showed A-C profiles and were classified as Typic Ustorthents and Typic Ustipsamments while soils developed on relatively stable geomorphic surfaces (back slope and foot slope) were classlfied as Ustochrepts.

National Remote Sensing Agency (1997a) conducted soil survey in tribal areas of Andhra Pradesh and generated soil resource map at 1:50,000 scale by visual interpretation of IRS-1B LISS-II satellite data. Soils were classified at the level of soil family and their associations.

IRS-1C PAN merged with LISS-III were used to delineate soils at 1:12,500 scale with the abstraction level of individual soil series in parts of Kurnool district, Andhra Pradesh through visual interpretation and digital analysis (NRSA, 1997b).

Dwivedi *et al.* (1997) evaluated the LANDSAT-MSS, TM and IRS-1A LISS-III data for part of South Tripura in North East India to derive qualitative information on eroded areas. They found that these data were useful in assessing and monitoring eroded lands in a rugged terrain.

Saxena *et al.* (1997) assessed the extent of wastelands in chikli watershed in Jalgaon district of Maharashtra using TM FCC at 1:50,000 scale and reported that 14.8 per cent area of watershed was occupied by waste land while erosion and deforestation were found to be the dominant land degradation problems. From this study it was inferred that the soilscape data and their interpretation for each waste land category form the basis for management recommendations.

Rahman *et al.* (1997) compared the GIS-generated soil map with existing general (order 4) and detailed (order 3) soil maps prepared for U.S. Forest Service (USFS) in the western USA. Results of this study suggested that transecting and GIS-based mapping can be an effective technique for producing general soil maps, and can aid in placing soil boundaries for detailed soil maps.

Pohl and Gendersen (1998) stated that the evolution of digital image fusion is a valuable tool in remote sensing image evaluation, with the availability of multi sensor, multitemporal, and multiresolution image data from operational earth observation satellites.

Srinivas and Dwivedi (1998) evaluated the potentials of various image fusion techniques like the fusion of high spatial resolution data from PAN and multispectral data from LISS II and noticed that the principal component analysis (PCA) was better than Intensity Hue Saturation (IHS) and Brovey image fusion techniques.

Sinha *et al.* (1998) assessed the problems of degradation in part of Orissa using Landsat TM data. They found that digital analysis of Landsat TM data gave a better discrimination of land use, soil classes and type and level of land degradation compared to visual analysis and principal component analysis.

Dwivedi and Srinivas (1998) compared the IRS-1C LISS-III and IRS-1B LISS-II data in delineation of salt affected and waterlogged areas in the Indo-Gangetic plains and found that relatively poor classification accuracy was achieved from LISS-III data compared to LISS – II data.

The advantages of image fusion were studied by Saraf (1999) and reported that fusion improved visual interpretation by demonstrating the merging of IRS-1C PAN with IRS-1C LISS-III data. It was also noticed that the merged image had full length spatial quality of PAN data and spectral quality of LISS-III multispectral data.

Ahmed *et al.* (1999) used remote sensing and GIS techniques for assessment of soil resources. They generated physiographic soil map of Rajasthan at family level using IRS-1C LISS III data at 1:50,000 scale and concluded that GIS analysis (ILWIS 2.1) was a useful tool for handling spatial and non-spatial data, by which various interpretative maps were prepared in the GIS environment.

Kumar *et al.* (1999) prepared soil map for lower Palar-Manimuthar watershed in Tamil Nadu using IRS-1B LISS-II FCC geocoded imageries at 1:50,000 scale and reported that ten soil series were recognized in the study area and were classified as Entisols, Inceptisols and Alfisols.

A well defined relationship between landscape and development of soils in Punjab was established by Deka and Deka (1999) by visual interpretation of IRS-1B LISS-I data at 1:50,000 scale and stereoscope interpretation of aerial photographs at 1:20,000 scale. Eight landscape units were recognized and concatenation of soils on these landscape elements was found to be as a result of surface and subsurface movement of materials.

The potential of remote sensing for soil resources appraisal in the arid region of Rajasthan was investigated by Joshi *et al.* (1999) and it was noticed that the IRS LISS II data helped to map soils at series/phase level whereas types of soil degradation and their severity, caused by wind erosion, water erosion and salinisation could be mapped using LANDSAT/IRS FCC sub scenes. IRS-1B LISS-II data was used by Dwivedi *et al.* (2000) for mapping of soil resources in part of northern India, through a systematic monoscopic visual interpretation approach to classify soils upto series level whereas Srivastava *et al.* (2000) used geocoded FCC of IRS-1C LISS-III to delineate soils of Jhilpi watershed.

Thierry and Lucein (2000) predicted that the combination of both high spatial and high spectral resolution images could provide a more complete and accurate data. Raut *et al.* (2000) prepared the geomorphologic map, soil map and land use map of Jonai Nala watershed, Keonjhar district, Orissa using merged product of IRS-1C LISS-III and PAN data.

A precise inventory of a watershed was done by Saxena *et al.* (2000) by visually interpreting the watershed components using FCCs of IRS-1B LISS-II and IRS-1C LISS-III at 1:50,000 scale. The dominant soils observed were loamy skeletal Lithic Ustorthents, loamy skeletal Lithic Ustochrepts, fine calcareous Typic Ustochrepts, fine Vertic Ustochrepts and very fine Typic Haplusterts.

A study was conducted by Sharma *et al.* (2000) in order to map and characterize salt affected soils, with the aim of applying management techniques in Etah district of Uttar Pradesh, India using IRS-LISS-II data at 1:50,000 scale. Five categories of salt affected soils requiring specific reclamation measures were identified and management operations were suggested.

Dwivedi *et al.* (2001) evaluated the potential of high spatial resolution (5.8 m) PAN data and LISS-III data from IRS-1C for detection and delineation of salt affected soils of Uttar Pradesh, a portion of the Indo-Gangetic alluvial plains of northern India. Results indicated a deterioration in the overall accuracy of salt affected soils derived from LISS – III data as compared to IRS-1B LISS-II data owing to an improvement in the spatial resolution (23.5 m for LISS-III versus 36.5 m for LISS-II), leading to enhanced intra-class spectral variability. The PAN and LISS-III hybrid data without any transformation ranked last in terms of overall accuracy.

Mapping of the coastal waterlogged areas of Daya-Bhargavi, Bhargavi Kushbhadra and Kushbhadra Devi doabs in Orissa was performed by Panda (2001) using optical remote sensing technique. The study showed that reliable information on waterlogging was obtained through visual interpretation of LANDSAT-MSS/TM data.

A soil map was prepared by Kumar *et al.* (2002) in lower palar – Manimuthar watershed, Tamilnadu using IRS-1B LISS-II data. Manchanda *et al.* (2002) utilised wide field imaging sensor, IRS-1, LISS-III and PAN data and generated soil map of Doan valley, Uttar Pradesh, India.

Kar *et al.* (2003) conducted a study to investigate the land degradation pattern in the Kachch region of arid Gujarat, India adjoining the Thar desert of Rajasthan by visual interpretation of standard false colour composits of the LANDSAT-MSS and TM bands, the IRS LISS-II bands, as well as SPOT MLA bands, spanning a period between mid-1980's and mid–1990's. From this study they noticed that the land degradation was mainly due to water erosion and salinisation and human activities are only assisting in the aggravation of the degradation processes in some localities of Kachch and Wagad.

A soil map depicting phases of soil series in basaltic terrain was generated by Srivastava *et al.* (2004) using IRS-1C PAN merged data of two seasons, namely late k*harif* and *rabi* for which ILWIS Software was used.

2.2 SOIL CHARACTERISATION

2.2.1 Morphometric characteristics

Morphology is the index for identifying the genetic processes in soil development attributing to unique properties of the soil.

2.2.1.1 Soil colour

Soil colour is an important property of soil by which its description and classification can be made. It is related to specific physical, chemical and biological properties of the soil and it can be easily determined in the field itself.

The colour indicates mineralogical nature of the soil. Tiwary *et al.* (1989) reported that the differentiation in soil types as well as soil colour might be due to the variation in the mineral suites coupled with other prevailing pedological features.

Rao and Chatterjee (1990) reported that the red colour of Alfisols is related to dehydrated iron oxides although manganese dioxide and partially hydrated iron oxides might also be responsible for the red colour. It was also reported that the free iron oxides might have imparted red colour to Alfisols under prevailing high temperature of semi-arid climate.

Sidhu and Sharma (1990) noticed that soils of sand dunes in the ustic and aridic moisture regimes had comparatively brighter colour throughout the profile which may be due to very low organic carbon content. Boettinger and Southard (1991) found that Haplargid pedons had redder hues and higher chroma than the Durorthid.

Saxena (1992) studied the sandy calcareous soils of Ghaggar plains occurring on nearly level to gently sloping lands having yellowish brown to dark brown colour. Singh *et al.* (1993) reported that the colour of the alluvial soils varied from pale yellow (2.5 Y 7/4) to olive (5 Y 5/3) of various shades probably due to the degree of hydration of oxides.

Prasad *et al.* (1994) observed that the soils of pediments and colluvial plains were well developed mature Alfisols and Inceptisols with red colours and the soils of low lands were recent Entisols with grey colours. Singh *et al.* (1995) predicted that the soil colour was the function of free iron oxide to clay ratio, wider the ratio brighter the colour and *vice-versa.*

Sharma *et al.* (2002) studied the colours of soil in Nara-Dada Manjhi watershed in semi-arid hilly tract of Punjab and reported that the soils on hills and peidmont plains, which were well drained, exhibit colour with hue 10 YR whereas the soils on rivulet bed not only showed yellower hue (2.5 Y 6/3), but also had mottles at sub surface horizons, indicating reduced condition during some period in a year.

2.1.2.2 Soil texture

Singh *et al.* (1989) studied an alluvial pedogenic complex of Varanasi and reported the texture as silty loam to silty clay loam. Gupta and Verma (1992) reported that the texture of Typic Ustochrepts in Kondibelt of Jammu Shiwalik hills was gravelly sandy loam at the surface and gravelly loam to loam at the sub-surface horizons.

Shyampura *et al.* (1994) studied the soils of Dungarpur district of Rajasthan and reported that the soils on very steep slopes were shallow and coarser in nature with excessive drainage whereas the soils of gently sloping pediment and undulating plains were deep, finer in texture and have better structural development. Sidhu *et al.* (1994) observed that the texture of Entisols of Punjab varied from sand to clay.

Vadivelu and Bandyopadhyay (1997) noticed sandy, sandy loam and loamy sand textures for the Entisols in Minicoy Island, Lakshadweep. Jawahar *et al.* (1999) stated that the textural class of the soils (Ustipsamments) was sandy at surface whereas in the subsurface, it ranged from loamy sand through sandy clay loam to sandy clay.

Singh and Nayak (1999) observed the texture of Entisols (Ustorthents) as sandy clay loam to sandy loam. Walia *et al.* (1999) reported that the soils of Ladakh region in Jammu and Kashmir were gravelly and the textural variations were due to the differences in the composition of parent materials as chemical weathering is very much restricted under frigid and arid pedo-environment.

2.2.1.3 Soil structure

Sidhu *et al.* (1994) noticed that the soils in the hills, flood plains and interdunal area of Punjab, which were classified as Entisols, were lacking the structural development in the control section. Kaistha and Gupta (1994) found that Inceptisols of north western Himalayan region had sub-angular blocky structure.

Singh *et al.* (1995) observed that the black soils developed from basalt and basaltic alluvium in Rajasthan had granular to angular blocky or sub-angular blocky to massive structure.

Rogasik *et al.* (1999) reported that numerous soil ecological functions are influenced by soil structure through its impact on spatial and temporal distributions of soil particles, water and air within the soil profile.

Sharma *et al.* (1999) attributed the stableness of the landform due to the presence of greater proportion of silt and clay particles that caused aggregation in Typic Ustochrepts in Haldi Ghati region of Rajasthan.

Tamgadge *et al.* (1999) noticed sub-angular blocky structure at the surface horizons and angular blocky structure in the subsurface horizons of soils developed on basaltic terrain in Madhya Pradesh.

2.2.1.4 Diagnostic horizons

Nettleton *et al.* (1969) stated that Aridisols may contain argillic horizons, apparently pleistocene relicts, with weak and discrete clay skins in non-swelling horizons. Sometimes, argillans on ped surfaces are lacking (Gile and Grossman, 1968) and their destruction is attributed to authigenic calcite crystal growth. However, Gal *et al.* (1974) and Eghbal and Southard (1993) noticed that the clay transformation is also possible in response to environmental conditions.

Boettinger and Southard (1991) noticed argillic and calcic horizons in the Aridisols on a granitic pediment, western Mojave Desert, California. The presence of salic horizon was observed at different soil depths in some of the soils in arid regions of Jordan by Taimeh (1992). Soil properties and prevailing climatic conditions in this area suggested that saturation was not attainable in this area and, thus, it was proposed that saturation condition be waived as a requirement for the recognition of the salic horizon in Aridisols and this was accepted by the International Committee on the Classification of Aridisols (ICOMID, 1989) and Taxonomy was also changed.

Sidhu *et al.* (1994) examined Entisols in different soil moisture regimes of Punjab and revealed that all the Entisols exhibited only A-C profiles indicating weak pedogenic development.

Aridisols with smectite B horizons are usually classified as Argids although the argillic characters may not always be present. Ducloux *et al.* (1995) described a soil sequence along a slope characterized by a progressive increase in clay content from Orthids to Argids. This clay enrichment was controlled by the < 0.2 μm clay size fraction and small amounts of polygorskite. It was also reported that the Argids resulted principally from clay neogenesis under this climatic conditions.

Walia *et al.* (1999) predicted that the soils of Ladakh region were skeletal with A-C profile due to the effect of topography and aridic climate that restrict the chemical weathering.

Sharma *et al.* (2002) investigated the soils of Nara-Dala-Manjhi watershed in semiarid hilly tract of Punjab and reported that soils on the upper parts of Shiwalik hills were characterized by limited profile development, having A-C sequence of horizons and the soils from lower parts of the hills were characterized by immature profile with no diagnostic horizons except an ochric epipedon, whereas soils from pediment plains were characterized by weak profile development as indicated by the presence of a cambic (Bw) subsurface diagnostic horizon.

2.2.2 Physico-chemical properties

2.2.2.1 Particle size distribution

Boettinger and Southard (1991) observed that there was sufficient clay increase for an argillic horizon and the Bk and BCk horizons of the calcareous Haplargid. The horizon between 80 cm and 180 cm contain more clay and silt in calcareous Haplargids than horizons at similar depths in the non-calcareous Haplargid pedon, which may reflect differences in original grain size and chemical composition of the parent rock.

A decrease in clay content with depth was observed in the saline sodic Vertisols of coastal plains of Gujarat that contained as high as 86.7 per cent clay

(Bhattacharyya *et al.*, 1994). Alternatively, clay content gradually increased down the depth and sand and silt content gradually decreased with depth in some Ustochrepts of Punjab (Singh and Singh, 1996) and in Aquepts of an irrigated river flood plain in Eastern coastal region (Bhattacharyya *et al.*, 1997). Irmak and Gundogan (2000) found a gradual increase in clay with depth in soils of Vertic Cambids and Fluventic Cambids.

Verma *et al.* (2001) reported that sand and silt constituted the major portion in mechanical composition of soils of Uttar Pradesh belonging to Typic Ustipsamments. The downward increasing pattern of sand was observed which could be due to sandy parent material whereas illuviation of clay in subsurface horizon was observed in soils belonging to Typic Haplustepts.

2.2.2.2 Soil reaction (pH)

Sidhu *et al.* (1994) reported that the soils on the convex slopes of hills in the udic zone were neutral in reaction (pH 7.3 to 7.5) whereas soils of active and recent flood plains, interdunal areas and sand dunes were alkaline with pH ranging from 7.7 to 8.9. Mishra and Ghosh (1995) found that the soils developed from mica-rich parent material had high pH, which was attributed to basic nature of parent material.

Vadivelu and Bandyopadhyay (1997) estimated pH of the soils (Entisols) of Minicoy Island, Lakshadweep. pH values varied from 7.9 to 8.7 and lower pH values (7.9 to 8.0) were noticed in the surface soils, which might be due to the decomposition of organic matter and production of some acids.

Verma *et al.* (2001) reported slightly alkaline nature (pH 7.6 to 8.6) in some Entisols (Ustipsamments and Typic Ustorthents) of Etawah District in Uttar Pradesh.

Moharana and Singh (2001) found that the soil pH of western arid Rajasthan soils varied from 8.2 to 8.7.

Sharma *et al.* (2002) estimated the pH of soils in semi arid hilly tract of Punjab and reported that the hill soils had relatively higher pH (mean pH 8.3 to 8.4) compared to other soils such as piedmont plains and choe beds (mean pH 6.6 – 8.1), which was possibly due to the influence of calcareous parent rocks.

2.2.2.3 Electrical conductivity

Yadav *et al.* (1995) estimated the EC values in different soils. Alluvial Sierozem soils (Typic Torripsamments) had EC values ranging from 0.21 to 0.32 dSm^{-1} whereas desert plain (Typic Torripsamments) had 0.31 to 0.51 dSm^{-1}.

Chinchmalatpure *et al.* (1998) compared the EC of soils developed from different parent materials and inferred that EC of soils developed on sandstone was very low (0.02 to 0.06 dSm^{-1}) while with basaltic parent material, it was 0.07 to 0.23 dSm^{-1}. Meena and Singh (1998) observed that the EC values of three different soil orders namely Aridisols, Inceptisols and Vertisols were 0.13, 0.08 and 0.14 dSm^{-1}, respectively.

Low EC values of relatively coarse textured soils (mean EC = 0.05 – 0.12 dSm^{-1}) as compared to that in finer textured soils (mean EC : 0.15 – 0.21 dSm^{-1}) were noticed by Sharma *et al.* (2002) in semi-arid hilly tract of Punjab.

2.2.2.4 Organic carbon

Das *et al.* (1992) stated that the status of organic carbon increased instead of decreasing due to cultivation in virgin soils which were newly brought under cultivation when an annual rainfall was less than 1050 mm. This might be attributed to slow microbial degradation of accumulated organic matter at low rainfall situation.

Srivastava and Prasad (1992) observed that the organic carbon content of swell shrink soils in semi-arid tropics of India varied from 0.21 to 0.68 per cent and the content decreased with increasing depth. Elahi *et al.* (1996) predicted that high temperature and cultivation had resulted in the less accumulation of organic matter in soils (Inceptisols) of Bangladesh.

Organic carbon content of some Entisols and Inceptisols of sedimentary and alluvial origin was estimated by Singh and Mishra (1997) and found that Typic Ustorthents had 2.7 to 3.2 g kg^{-1} whereas Typic Ustochrepts had comparatively higher values of 10 to 33 g kg^{-1} organic carbon.

Gangopadhyay *et al.* (1998) noticed irregular distribution of organic carbon with depth and concluded that it was due to the impact of fluvial cycles in these soils and higher organic carbon at the surface of horizon, which was a characteristic feature of waterlogged soils.

Sharma *et al.* (1999) noticed a decreasing trend of organic carbon content with depth in Typic Ustochrepts and Lithic Ustorthents while uneven distribution was observed in Typic Ustifluvents in Haldi Ghati Region of Rajasthan. It was due to the occurrence of different cycles of deposition in Typic Ustifluvents.

Irmak and Gundogan (2000) found that organic carbon content was low in all soils of Aridisols (*i.e.* Vertic Cambids and Fluventic Cambids). Organic carbon exhibited decreasing trend with depth in Vertic Cambids whereas irregular trend was noticed in case of Fluventic Cambids.

2.2.2.5 Calcium carbonate

Subbaiah and Manickam (1992) reported that soils derived from lime charged granite-gneiss and lime charged shales contained higher (6.7 to 48.2%) $CaCO_3$

content while soils derived from granite showed the least (0.6 to 1.9%) $CaCO_3$ content.

Tertiary era denuded sandstone plateau soil belonging to Aridisols had $CaCO_3$ upto 2.4 per cent whereas Pleistocene alluvial plain soil had even upto 26.7 per cent (Choudhuri, 1993).

Singh *et al.* (1995) reported that the soils on hills, plateau and gently sloping plains were, in general, low in $CaCO_3$ (4.1 to 8.5%) whereas an abrupt rise in $CaCO_3$ content (8.5 to 11.7%) and a zone of $CaCO_3$ accumulation was observed between 56-80 cm depth of some pedons developed on basallic terrain indicating that pedoturbation was not sufficient to erase out the effect of old pedogenic activities.

A gradual increase in $CaCO_3$ content in the lower horizon of river flood plains of eastern coastal region of India was observed by Sahu and Mishra (1996) and it might be due to calcification and inheritance from parent material.

Bhaskar and Nagaraju (1998) found positive correlation between $CaCO_3$ and silt fraction by working on the soils in Chitravathi river basin of Andhra Pradesh which had $CaCO_3$ values ranging from 7.4 to 148 g kg^{-1}. Perezzamora (1999) stated that nature of the parent material, decalcification process, amount of rainfall and location of the soil in the landscape could be related to $CaCO_3$ accumulation in the soil.

Prasad and Gajbhiye (1999) observed that soils of semi-arid region had the lowest available Fe than the soils of sub-humid region which might be due to higher values of $CaCO_3$ content.

2.2.3 Exchangeable properties

2.2.3.1 Cation exchange capacity

Sidhu and Sharma (1990) stated that the variations in CEC of most of the soils could be attributed to the variations in clay content. Subba Rao *et al.* (1996) stated that CEC of soils was dependent on the clay and organic carbon contents of the soil and relative contribution of clay and organic carbon to CEC was likely to vary with the pH, amount and nature of clay and organic carbon.

Low values of CEC in proportion to their organic matter in clay content in some Inceptisols of Arunachal Pradesh were observed by Walia and Chamuah, (1996) which might be assigned either due to dominance of illitic and kaolinitic clays or due to formation of complexes of clays and sesquioxides with organic matter which led to blocking of exchange sites.

Bhattacharya *et al.* (1997) observed decreasing pattern of CEC with depth in Typic Epiaquepts whereas increasing pattern of CEC with depth was noticed in Vertic Epiaquepts. Walia *et al.* (1997) noticed low CEC values for the soils of slightly undulating flood plains in Bundelkhand region of Uttar Pradesh inspite of their enrichment with smectites.

Trivedi *et al.* (1998) found higher CEC values in Vertisols ranging from 31.6 to 38.9 cmol(p^+)kg^{-1} in comparision with Entisols having 11.2 to 37.9 cmol(p^+)kg^{-1}. High CEC of some kaolinites was observed by Machi *et al.* (1999) which was due to smectite layers on the surface of kaolinite crystals.

Karmakar and Rao (1999) estimated the CEC of soils in different physiographic units of lower Brahmaputra Valley zone of Assam and found more CEC [10.9 – 27.9 cmol(p^+)kg^{-1}] in the peidmont plain containing the highest organic matter under forest vegetation. They also reported from these findings that organic matter and clay content contributed to CEC of the soil, which was supported by positive correlation of CEC with organic matter (r = 0.867) and clay content (r = 0.779).

Variation in CEC from 2.6 to 15.2 cmol(p^+)kg^{-1} was observed by Sharma *et al.* (2002) in soils of semi-arid hilly tract of Punjab and they concluded that this variation might be ascribed primarily to differences in clay content as these soils are generally low in organic matter.

2.2.3.2 Base saturation and exchangeable cations

Diwakar and Singh (1994) reported that Vertisols and associated soils of Bihar were having high base saturation (91-97%) while Entisols developed on granite - gneiss complex on upland rolling topography had base saturation of 66-71 per cent.

The base saturation of Typic Ustorthents was 93 per cent whereas Typic Entrochrepts had base saturation upto 99 per cent (Singh and Mishra,1997). Walia *et al.* (1997) found base saturation of Epiaquepts of Bandaplain region ranging from 75 to 89 per cent.

Base saturation in some aquepts occurring in Brahmaputra valley of Assam was estimated by Gangopadhyay *et al.* (1998) and they reported that it was ranging from 20 to 88 per cent. The exchangeable calcium was the dominant cation followed by magnesium both of which showed decreasing trend with increasing soil depth.

Tamgadge *et al.* (1999) studied the soils of basaltic terrain in north deccan plateau, Madhya Pradesh and it was inferred from their findings that the base saturation of these soils ranged from 70 to 99 per cent with lowest values in Typic

Ustorthents developed on residual hills and higher values in Typic Haplusterts on plateau.

Hamdam *et al.* (2000) reported that the extreme depletion of major elements (K, Na, Ca and Mg) and significant enrichment of Al, Fe, Ti and Cu caused low CEC and base saturation values in soils of Malaysia.

2.2.4 Mineralogy of clays

Soils of arid lands are produced primarily by mechanical weathering and wind transfer. It is thought that their clay minerals are commonly inherited from the parent materials. The predominant clay mineral is smectite (Nettleton and Peterson, 1983); subordinately kaolinite and illite and sometimes polygorskite-sepiolite groups occur in calcic soils (Mc Grah and Hawley, 1987).

Choudhuri *et al.* (1990) noticed the presence of mica (illite), smectite, vermiculite, mixed layer minerals and kaolinite in the soils of Aridisols of western Rajasthan.

Potassium mineralogy in sixteen benchmark soil series (from arid, ustic and udic zones) of Punjab was investigated by Sidhu *et al.* (1993) using X-ray diffraction and petrographic techniques. These soils belonged to the Entisols, Inceptisols, Alfisols and Aridisols. The dominant potassium minerals in the sand fraction of all soils tested were micas (biotite and muscovite) and K feldspars. They also observed that the biotite content was greater in arid soils compared with ustic and udic soils. Illite was the dominant potassium mineral in the clay fractions of these soils.

Adhikari and Si (1993) examined the mineralogy of few Entisols from western tract of West Bengal and found that the dominant clay mineral is mica in association with minerals like kaolinite, smectite, vermiculite, chlorite, microcline coupled with considerable amount of amorphous minerals.

Kaushal *et al.* (1996) reported that the soil clays of Entisols/Inceptisols under forest in temperate zone of Himalayas were dominated by illite followed by kaolinite, interstratified minerals and chlorite. Sangwan *et al.*(1998) estimated clay mineralogy of Entisols and Inceptisols of Satluj-Yamuna divide in the north Indian plains. They reported that all the soils were dominated by mica (> 55%) due to its inheritance from the parent materials and other clay minerals associated were chlorite, smectite and mixed layer minerals.

The results of X-ray diffraction of some Aridisols (Vertic Cambids and Fluventic Cambids) showed that smetite was the dominant clay mineral and polygorskite was the second most abundant after smectite (Irmak and Gundogan, 2000). Khresat (2001) identified the clay minerals smectite, vermiculite, kaolinite and illite in Aridisols of north-western Jordan.

2.3 SOIL CLASSIFICATION

Taimeh (1992) classified the soils in some arid regions of Jordan as Haplosalids, Gypsic Haplosalids and Haplosalids with a cambic horizon.

Sawhney *et al.* (1992) classified the soils of semiarid and arid tracts of Punjab. According to them, the young and stratified soils from unstable landforms representing more recent alluvium were classified as Typic Ustipsamments or Typic Ustifluvents. Severely eroded and shallow soils of the foothills were classified as Typic Ustorthents, Soils developed on relatively stable landforms were classified as Ustochreptic Camborthids, Typic Ustochrepts and Aquic Ustochrepts and the soils of old alluvial terraces were classified as Typic Haplustalfs.

Saxena (1992) classified the soils of recent flood plain and meadow plain of Punjab as Typic Ustipsamments. Rao (1993) classified the sandy soils of Chakicharla village of Prakasam District, Andhra Pradesh as Typic Ustipsamments. The soils on Tertiary and Pleistocene landforms in Rajasthan were classified as Typic Camborthid and Calcic Camborthid by Choudhuri (1993). Ahuja *et al.* (1996) had classified the sand dunal toposequence of Haryana as Entisols and Aridisols. Dhaliwal *et al.* (1996) had classified the flood plain soils of North-Western India as the Entisols at order level and Orthents, Fluvents and Psamments at suborders level.

A soil map of the arid zone of Rajasthan was generated by Dhir *et al.* (1997). The results revealed that the Entisols and Aridisols constituted 51.84 per cent and 41.05 per cent of the total area, respectively. Torripsamments were the dominant among the Entisols whereas Cambids and Calcids were found as dominant suborders in Aridisols. According to Faroda *et al.* (1999), the soils identified in Kachch alluvial plain belonged to Haplocambids, Lithic Calcids, Haplocalcids and Ustipsamments.

Salt-affected alluvial soils with poor structure and low productivity from the Chitravathi river basin, Cuddapah district, Andhra Pradesh were classified as Aridisols by Bhaskar *et al.* (2000). According to their findings, Penzuvi soils were classified as Ustic Haplocambids, Chautupalli soils were classified as Ustic Fluventic Haplocambids and Jammalamadugu soils were classified as Sodic Ustic Haplocambids.

Irmak and Gundogan (2000) classified the soils on three terraces of the Kizilimark river, Turkey and reported that soils on first terrace had cambic diagnostic horizon, cracks 1-5 cm in width in the surface and were having aridic soil moisture regime and so they were classified as Vertic Cambids whereas the soils in second and third terraces were classified under Fluventic Cambids.

The soils of north western Jordan were examined by Khresat (2001) and were classified as Typic Calcixerepts, Xeric Calciargids and Xeric Haplocalcids. Omar *et al.* (2002) studied the soils in Sabkhat environment in Kuwait and found that most soils were Aquisalids. The major part of the coastal Sabkhat were classified under the order of Aridisols and the suborder Salids, which were further recognized mainly as Gypsic Aquisalids and to a minor extent as Typic Aquisalids.

Soils of Nara-Dala-Manjhi Watershed in semiarid hilly tract of Punjab were classified by Sharma *et al.* (2002). The soils of the upper Shiwalik hills were classified as Typic Ustipsamments associated with Lithic Ustipsamments whereas lower Shiwalik hills were classified as Typic Ustorthents associated with Llithic Ustorthents. Soils of Peidment plains were classified as fine loamy Fluventic Ustepts and fine silty Typic Ustepts and the soils on choe beds were classified as coarse loamy Typic Ustifluvents and Typic Ustipsamments.

2.4 LAND PRODUCTIVITY ASSESSMENT

The problems of ever increasing population and increased competition for a variety of demands have induced tremendous pressure on shrinking land resources. It is, therefore, essential to assess the potential of the available land in terms of its capability and productivity for proper land use planning (Kharche and Gaikawad, 1993). The determination of soil productivity on the basis of its properties is the most important objective, but is the most difficult task because productivity seldom depends upon a single factor. Soil productivity is a function of the intrinsic properties of soil and is, thus, influenced by countless characteristics.

Several approaches of land productivity assessment are in use. Land capability classification of U.S. Department of Agriculture (Soil Conservation Service) and FAO

(Food and Agricultural Organisation) frame work of land suitability evaluation (FAO, 1976) have been widely used and other land evaluation approaches were proposed by Riquier *et al.* (1970) and Storie (1978) as Storie Index Rating of soil.

Soils of Bihar were evaluated by Manchanda *et al.* (1982) using FAO framework for land evaluation and reported that out of the total land area, 23.3 per cent was highly, 33.6 per cent moderately, 10.1 per cent marginally suitable while 20.9 per cent area was non-suitable for wheat and maize cultivation. For Paddy 38.9 per cent, 14.5 per cent, 10.7 per cent and 24 per cent area was highly, moderately, marginally and non-suitable, respectively.

Naidu *et al.* (1986) assessed the productivity and potentiality of eight extensively occurring soil series of Delhi by Riquier method. The productivity and potentiality indices derived from the rating assigned for each of the parameters showed that Holambi, Nabha and Ghoga series fell under productivity class good, Daryapur, Hamidpur and Palm as average, while Kakra and Razapur series came under poor category due to their inherent physico-chemical properties. Among the attributes considered for productivity and potentiality classification, texture and soil moisture were found to be the predominant factors governing the rating indices.

Kharche and Gaikawad (1993) evaluated the production potential of different soils of Saongi watershed in Nagpur district by employing parametric approaches of land evaluation with respect to cotton and sorghum productions.

Kudrat and Saha (1993) assessed the land productivity and generated the land productivity map using modified Storie Index following integrated approach. This approach utilized soil scape information (derived from digital IRS-1A LISS-II data), soil characteristics (field observed and laboratory analysed) and terrain slope information (obtained from Survey of India topographical maps). They prepared maps for the Storie Index productivity rating factors and integrated these maps to generate land productivity map. The results indicated that in the watershed, 30.6 per cent, 19.6 per cent, 12.2 per cent, 11.8 per cent and 18.8 per cent areas were under good, fair, poor, very poor and not suitable land productivity classes, respectively.

The productivity and potentiality of some tal soils of Bihar was assessed by Diwakar and Singh (1993) and reported that all soils had average productivity due to poor organic matter content, swell/shrink clays, seasonal flooding and drought and poor drainage. Improved tillage, drainage, fertilizer amendment and irrigation could raise productivity of the soils from 1.8 to 2.1 times. It was concluded that as the land capability classification system is based on soil limitations alone, it could not provide adequate information on land capacity and that coefficients of improvement gave a more useful estimate.

Mathan *et al.* (1994) studied the major soil groups of Kamarajar district, Tamilnadu applying the concept of fertility capability classification. In this study, twenty one soils, belonging to subgroups Typic Chromusterts, Typic Ustropepts, Udic Haplustalfs, Typic Haplustalfs, Vertic Haplustalfs and Typic Ustorthents were grouped in eight fertility capability classification units based on type, substrata type and condition modifiers.

Productivity potential of a Typic Chromustert was assessed for sorghum, wheat, cotton and groundnut using Riquier's index and Sys land index (Naphade *et al.*, 1994). The study identified that with Riquier's evaluation the productivity index was 32.64 and the soil was rated as good for raising crops. The calculated land indices indicated that the land was suitable for sorghum (53.4) followed by wheat (37.6), cotton (34.2) and groundnut (31.2). The productivity rating index (PRI) and land indices showed that Typic Chromusterts were suitable for sorghum in *kharif*, Wheat in *rabi* and marginally suitable for cotton and groundnut.

Srivastava *et al.* (1994) studied some dominant soils of West Bengal for rainfed rice cultivation using FAO frame work of land evaluation (FAO, 1976). The soil characteristics of each soil series were expressed in terms of the limitations. The results revealed that the Kalyaneswar soils (Lithic Ustochrepts) were suitable for some horticulture/plantation crops/agroforestry, Beldanga series (Ultic Paleustalfs) were moderately suitable for rainfed rice and Balidanga (Typic Epiaquepts) series were highly suitable for rice cultivation.

A study on soil survey and land evaluation for agricultural land use planning in tribal areas of Andhra Pradesh was undertaken by NRSA (1997a). In this study all the thematic maps were prepared using IRS-1B LISS-II satellite data and productivity was assessed using land capability classification. Land capability classes II, III, IV and VII were encountered and on overall Class IV and VII were dominating consisting more than 60 per cent area, thus, indicating that the land available for cultivation in the tribal areas is very limited.

Soils in West Bengal belonging to sugarcane cultivation were evaluated by Das *et al.* (1997). The results revealed that soils occurring in comparatively lower land forms (Aeric Endoaquepts and Vertic Ochraqualts) and in rugged topography (Lithic Ustochrepts and Rhodic Paleustalfs) were rated as marginally suitable and currently not suitable, respectively and soils occurring as nearly level to gently sloping land form were assessed as moderately to highly suitable.

Padole and Deshmukh (1998) studied the soil survey interpretation for land use planning in salt affected soils of Purna Valley of Vidarbha, Maharashtra by applying the methods of land capability classification, soil and land irrigability classification, land suitability classification (FAO, 1976) using Riquier *et al.* (1970) parametric approach and Sys parametric approach. All the interpretative systems indicated that the soils viz., Sodic Haplusterts and Sodic Calciusterts were marginal for cotton while Aridic Haplusterts and Aridic Calciusterts were moderately suitable for cotton due to moderate limitations of drainage, available water holding capacity and $CaCO_3$.

Kumar *et al.*(1998) studied the applicability of IRS-1A LISS-II data for land evaluation in semi-arid climatic zone. Soil and land resource units were evaluated for their suitability for major agricultural crops by matching the relevant land qualities against the land requirements. The study showed that upper fluvial plains were moderately suitable for mustard, gram and pearl millet, lower fluvial plains and buried pediments were moderately suitable for wheat and gram, interdunal depression and sandy plains were marginally suitable for pearl millet and dissected buried pediments and sand dunes were not suitable for agriculture, but by introduction of sprinkler irrigation, sand dunes can be brought under agricultural or arid horticulture systems.

A study was undertaken in a part of solani watershed of Haridwar and Saharanpur districts in Uttaranchal and Uttar Pradesh, respectively by Patel *et al.* (2001) for assessing the land capability to adopt suitable soil conservation measures and suggested land use plan through remote sensing and GIS approaches. 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.

The soils from four watersheds of Gujarat state were evaluated for productivity potential by Chinchmalatpure *et al.* (2001). Results revealed that under proper management of severity of correctable limitations, an increase of yield to an extent of 10 to 54 per cent in cotton, 12 to 20 per cent in pearlmillet and 40 to 69 per cent in wheat could be obtained over the actual yield.

For sustainable land resources development through remote sensing and GIS, a study was taken up by Kar (2001) in Yacharam watershed of Ibrahimpatnam block of Ranga Reddy district, Andhra Pradesh. This study revealed the usefulness of remote sensing technology for providing up-to-date, reliable and accurate information on different natural resources. The GIS technique is helpful to integrate the information into a composite land unit development map to generate alternate land use system.

Kumar *et al.* (2002) assessed the potential land use in the proposed irrigation command using remote sensing and GIS in Goa. They generated land capability and land irrigability maps as attribute maps and integrated to suggest potential land use map. Current land use/land cover map was also prepared by visual analysis and was spatially analysed in relation to potential land use to study potential changes in land use/land cover using GIS. This study showed that 14.66 per cent area had no limitation and can be brought to intensive agriculture by double cropping and nearly 17.70 per cent land can be brought to agro-horticulture.

Sarkar *et al.* (2002) characterised, classified the soils of Laktak catchment area of Manipur and a suitable land use plan was suggested. From the study, it was concluded that the high and medium hill soils were highly degraded due to very steep to steep slope, rapid runoff, shifting cultivation etc., which require proper soil conservation measures like afforestation, contour bunding, contour terracing etc. The foot hill soils may be put under social and agroforestry, horticultural crops like pineapple, pears, palm, banana etc. and plantation crops like tea. The plain land may be cultivated with rice in *kharif* season and vegetables, mustard, pulses, oilseeds during *rabi* season while aquaculture in low land areas where water stagnates during rainy season. Besides, long term measures for construction of water harvesting structures in middle and foot hill areas may help in proper utilization of water for agricultural purposes and also reduce the siltation in the Laktak lake areas.

Sharma *et al.* (2002) evaluated the soils of Nara-Dada Manjhi watershed, situated on the southern slopes of the Shiwalik hills in Hoshiarpur district of Punjab using Storie Index Rating method. The results revealed that the soils of this watershed belonged to four land productivity grades. The soils of lower piedmont plains belonged to grade 2 and are suitable for most crops with good yield potential, whereas soils from upper piedmont plains qualified for grade 3 and may be used for selected crops. The soils developed on choe beds and hills qualified for grades 5 to 6 respectively. The soils on choe beds had limited use, except for pasture, whereas soils on hills are not suitable for agriculture.

Sharma and Kumar (2003) evaluated the soils and suggested a sustainable land use planning for upper Maulkhand catchment in mid-hills zone of Himachal Pradesh.. They observed that the coefficient of improvement for soils under crop lands, pastures and forests and plantation crops ranged from 1.38 to 4.00, 1.50 to1.79 and 1.33 to 5.20, respectively. The catchment had IIe, IIes, IIIe, IVe, IVes, VIe and VIIe land capability and 2t, 3t, 4t, 5t and 6t land irrigability sub-classes indicating topography as a major constraint for sustainable land productivity. By taking all these into consideration, 11,10, 10,15,1,27,4,5 and 4 per cent of total area was suggested to be under intensive cultivation, agro-horticulture, agro-forestry, tea, horticulture, dense forests, afforestation, reforestation and silvi pasture, respectively by following scientific management practices.

2.5 SPATIAL VARIABILITY OF SOILS USING CLASSICAL AND GEO-STATISTICAL TECHNIQUES

The aim of precision agriculture in relation to cropping is to match "resource application and agronomic practices with soil attributes and crop requirements as they vary across a site" (Mc Bratney and Whelan, 1995). As soils serve as a growth medium for crops, its condition is a major factor affecting potential and actual yields. Traditional cropping regarded the field as the smallest convenient unit of management. Considered relatively homogeneous, the field was generally managed by practices such as uniformity in sowing, fertilizer and pesticide applications which ignored the spatial variability of the soil, and, hence, the site-specific crop requirements. Burrough (1993) in addressing the question of why information on soil spatial variability is of such importance, stated : "The driving force behind wanting to understand soil variability is a need for improving control over the world's physical environment". A precision agriculture system matches resource availability to crop capability for efficient management for which knowledge of soil spatial variability is essential.

The combination of many factors may have contributed to the variation of soils present today *i.e.*, soil formation, cropping history, past field delineation, crop nutrient removal and crop input applications such as fertilizers, lime, manure and pesticides (Sawyer, 1994). Gathering the requisite soil information adequately to describe soil spatial variability may be a major impediment to the successful implementation of precision agriculture.

The variability of soil properties has often been described by classical statistical methods (Beckett and Webster, 1971, Wilding and Drees, 1983). They included the estimation of sample mean, variance, co-efficient of variation, analysis of variance and calculations of samples had become necessary to estimate the mean within some specified confidence interval from frequency distribution of the data. These methods do not provide a complete description of the variability of a parameter because the calculated variance does not account for the distance between observations, but depends only on the theoretical frequency distribution.

Classical statistics do not accurately describe patterns in spatial variability for samples exhibiting spatial correlation, since classical statistical techniques do not account for the relation between the value of a sample and its location in a field. Instead, an analysis technique known generally as geo-statistics is more useful. The geo-statistical theory enables to measure spatial dependence and to use it for practical purposes like interpolation and mapping, determining mean and its dispersion statistics and deciding optimal sampling strategy.

Cipra *et al.* (1972) studied the variability in fertility status with distance in seven fields located at 8 to 145 km apart in western Kansas, USA and reported that adequate fertility characterization of a soil requires many more samples than that are commonly taken.

The Science of kriging was first applied to soil science by Burgress and Webster (1980 a, b), Burgress *et al.* (1981) in Europe and in the United States by Vauclin *et al.* (1982, 1983). Since then geo-statistical methods have become popular in soil science. The spatial information given makes this approach a powerful technique for dealing with spatial variability. The interpolation techniques commonly used in agriculture include inverse distance weighing and kriging (Franzen and Peck 1995, Weisz *et al.*, 1995).

Geo-statistical procedure account for spatial auto-correlation and can be used to estimate the spatial distribution of soil properties. By utilizing geo-statistical procedures one can recognize the spatial dependence of various soil properties, improving precision and accuracy when estimating the values for a region or for points not sampled.

Burgress and Webster (1980 a) from their studies reported that no other linear interpolation method provides less bias in predictions than kriging which is known as a best linear unbiased predictor (BLUP).

Geo-statistical methods had been applied to soil studies over distances of meters or tens of meters (Vieira *et al.*, 1982). There were few applications of these methods over distances of several kilometers as might be useful in mapping of soils and soil properties, study of soil forming factors, study of nutrient variation and requirements over areas which might be independently managed, or over distances which might delineate size and uniformity of soil management units or fertilizer recommendation domains.

Yost *et al.* (1982a) measured the spatial dependence of soil chemical properties over large land areas of Hawaii and the ranges of semi variograms for soil pH, Ca, Mg, K and P were 32 to 42 km. The results suggested that soil chemical properties may be spatially dependent and that the spatial dependence in this example represents the imprint of soil forming processes and perhaps, management.

Yost *et al.* (1982b) estimated the soil P sorption by soil analysis from transects on the Island of Hawaii by means of kriging and spline interpolation methods. The results suggested that the map of kriged points corresponded more closely with known soil behaviour than did the spline map.

Creutin and Obled (1982) and Tabios and Salas (1985) compared kriging with several other interpolation techniques including inverse distance weighing for annual precipitation distributions and found kriging was superior to inverse distance weighing.

Trangmar *et al.* (1986) assessed the anisotropic spatial dependence of particle size fractions, pH and 25% HCl extractable phosphorus and identified that top soil textural components and pH were more variable than in the subsoils showing larger sample variance and larger anisotropy ratios.

Ameyan (1986) assessed the spatial variability of textural and soil chemical properties (pH, exchangeable cations, cation exchange capacity, EC, BSP, ESP, available P and organic carbon) of surface horizon and revealed that pH is the least variable among the properties and hence, smallest number of samples were found to be sufficient for its estimation.

Laslett *et al.* (1987) obtained more accurate pH predictions by using kriging than by using inverse distance weighting. Warrick *et al.* (1988) also reported kriging to be better than inverse distance weighting for mapping potato yield and soil properties such as percent of sand, Ca content and infiltration rate. They suggested that kriging would be the best choice for interpolator, because it is the only method that allows the variance of an interpolated point to be estimated.

Mulla (1987) stated that kriging and cokriging can be used to produce survey maps of spatially variable soil patterns and can also be used to improve management decisions regarding other soil properties including soil salinity, soil alkali, aluminium toxicity, plant available water and crop yield.

Cokriging produced superior results to kriging in an investigation by Yates and Warrick (1987) for the estimation of water content in a one hectare field in Tucson, Arizona. However, this method is complex and time consuming compared to kriging.

Stein *et al.* (1988) estimated moisture deficit values from 500 sample points in the eastern part of Netherlands. They made statistical predictions on 100 random points using the techniques of kriging and cokriging and reported that the number of sampling points could be reduced from 400 to 160 with cokriging without any reduction in the accuracy of predictions.

West *et al.* (1989) found wide variations across short distances (30 m) in soil organic C (16.2 – 34.8 g kg^{-1}) and total N (1.94 – 4.64 g kg^{-1}) in surface horizons (0-7.5 cm) in their studies with grazed pastures. Their work, which focused on animal deposition concentrates near watering areas, noted that differences in soil organic C in the sampled pastures tended to be more associated with native soil variations and unrelated to distance from the water source, as was observed for extractable soil P and K.

Agbu and Olson (1990) investigated two areas of contrasting spatial variability in east-central Illinois using grid sampling to determine the composition of soil map units and the variability of significant soil properties within map units. The surface characteristics of the sample sites showed extremely high variability, especially in slope and aspect with CVs of 93.5 per cent and 83.6 per cent, respectively. The depth of A horizon showed high variability with CV of 35 per cent for both areas. The degree of colour variability increased in the order hue, value and chroma. The A horizon showed very high variability in sand content with a CV of 74.4 per cent but silt and clay contents both showed moderate variability with CVs of 22.9 per cent and

23.6 per cent respectively. The organic carbon content showed moderate variability with CV of 15 per cent and was more variable in the highly undulating landscape.

Voltz and Webster (1990) found that the spline based interpolation was better than kriging only in situations where an abrupt change in measured soil property values occurs across a short distance.

Leenaers *et al.* (1990) found kriging to be superior to inverse distance weighting for the majority of their soil Zn content data sets. Several other studies, however, found inverse distance weighing to be more accurate than kriging. Weber and Englund (1992) found that square inverse distance weighting produced better interpolation results than any other method including kriging.

Bhatti *et al.* (1991) measured the spatial variation of soil organic carbon, soil phosphorus and available soil water, on four 655 m transects in E. Washington, using classical statistics and geo-statistics. LANDSAT-TM images of bare soil were used to estimate soil organic matter. The CV of organic carbon and soil phosphorus varied from 25 to 50 per cent. Spherical variograms of soil properties showed strong spatial dependence with a range of influences of 17-45. The semivariogram for LANDSAT estimated organic matter was almost identical to that of organic matter measured in the surface transects.

Grewal *et al.* (1992) evaluated the spatial variability in the available N content in Haryana by collecting the soil samples at a grid of 10 km x 10 km. The classical statistical analysis technique showed a normal distribution of their available N content with a mean of 186 kg ha^{-1}, standard deviation 71.7 kg ha^{-1}, co-efficient of variation 38.5 and range 28 to 440 kg ha^{-1}. They also stated from the results that the number of observations required to estimate yield with mean ± 10 per cent of the true mean at

95 per cent confidence level was 57.

Estimation of random and spatial variability of soil properties of a loamy sand (Typic Ustochrept) in the semiarid region of the Punjab by Singh *et al.* (1993) showed that pH, EC, OC, available P and available K were normally distributed. Soil pH showed least variation (CV= 2%) followed by EC and OC, while available P showed the highest variation (CV = 59%).

A research work conducted by Mulla (1993) with an objective to quantitatively measure and assess the magnitude and extent of spatial variability in soil fertility of wheat yields on a locally eroded farm in the Palouse region using geo-statistical techniques reported that the variability in various soil properties was as a function of position on the landscape but not random. Results also showed coefficients of variation ranging from about 11 per cent for soil pH to about 50 per cent for phosphorus.

Spatial variability of organic carbon content in Haryana soils was assessed by Kumar *et al.* (1993) by collecting 470 samples at the nodes of 10 km x 10 km grid from all over Haryana. They also compared the classical and geo-statistical methods. From their work, it was observed that the estimation variances calculated by point and block kriging were 1.54 and 10 times less than that obtained by the classical theory. The number of observations required to obtain the mean with ± 10 per cent of the true mean at 80, 90, 95, 97.5 and 99 per cent confidence levels, was much less by kriging technique as compared to classical techniques, which showed clearly that the kriging interpolation technique will reduce the sampling efforts and cost considerably for mapping.

Variability of available potassium in a cultivated Inceptisol in Jorhat was studied by Patgiri and Baruah (1994) using classical statistics as well as geo-statistical approach. They found the available potassium was in medium category and have medium variability in both top soil and subsoil. However, variability was more in subsoil compared to in top soil which was confirmed with high values of standard deviation. S, variance S^2 and CV (54.5%) in subsoil than that of top soil (42.9%). They also estimated that 282 and 455 numbers of samples for top soil and subsoil, respectively would have to be drawn in order to estimate the mean with 95 per cent probability and allowing an error of 5 per cent of variation around the true mean.

Cahn *et al.* (1994) studied much smaller scale spatial variation in soil test parameters in 3.3 ha in the surface layer (0 to 15 cm) in central Illinois, USA. This work indicated that reducing samples intervals from 50 to 1 m reduced the variance of measured soil water content, soil organic carbon, NO_3-N, PO_4 – P and K by > 25 per cent.

Spatial variability of organic carbon content of Haryana soils was studied geo-statistically using 470 soil samples collected at the nodes of a 10 km x 10 km grid by Kumar *et al.* (1994). From this study they observed that isarithmic map of organic carbon content prepared from observed and kriged values (Point kriged estimates) was very spotty and discontinuous and the spottiness and the discontinuity in the map, disappeared considerably when block kriged values were used. It was clear from the comparison that block kriging is a better technique for interpolation of real value of the parameter which may help in smooth mapping. Maps, thus, prepared might prove useful in making suitable management decisions by the planners and user agencies, as they show the spatial display of a given parameter over the large areas.

Geo-statistical procedures were used by Gonzalez and Zak (1994) to
determine spatial auto-correlation of the properties such as forest floormass, soil texture, pH, organic C and available P and processes such as N mineralization and net nitrification by collecting samples at 4 m intervals in a secondary tropical dry forest, St. Lucia, West Indies. Semivariogram parameters were used in a block kriging procedure to produce spatial maps of soil properties. Most soil properties exhibited spatial autocorrelation at a distance of 24 m or less. Varying degrees of similarity were found between patterns of forest floor mass, organic C, Net N mineralization, net nitrification and available P. No similarity was found between soil texture or pH and other properties.

Wollenhaupt *et al.* (1994) compared inverse distance weighting and kriging for mapping soil P and K levels and found inverse distance to be relatively more accurate. They concluded from the comparisons of interpolation techniques that the interpolation accuracy was more dependent on the adequacy of the sampling design than on the type of interpolator used.

Rahman *et al.* (1996) studied the spatial variability of forest soils along 5 transects at an interval of 200 m and indicated that thickness and coarse fragment contents of A and B horizons and solum thickness were spatially independent, whereas pH and organic carbon were spatially correlated. Geo-statistics provided insight into the nature of variability of soil properties when compared to conventional statistics.

Gotway *et al.* (1996) observed the best results in mapping soil organic matter contents and soil NO_3^- levels for several fields when inverse distance was used as an interpolation technique. They also reported that when the intensive sampling is conducted on a regular grid, there may be only small differences in interpolation with kriging, inverse distance weighting or cubic splines.

Mongia *et al.* (1997) estimated the spatial variability (both horizontal and vertical) of sodic soils in semiarid climatic region of Haryana by collecting the samples upto a depth 0-0.20 m, 0.20 – 0.6 m and 0.6 – 1.10 m at a grid of 4 m x 4 m. Results revealed that pH, EC, OC, available P and $CaCO_3$ contents were normally distributed. However, soil pH showed least variation (CV = 7.39%) and $CaCO_3$ the highest (CV = 81.03%). They also reported that 178 observations were required for $CaCO_3$, one observation for pH whereas 64, 111, 142 observations were required for estimation of EC, OC and available P, respectively.

Banton *et al.* (1997) studied the spatial variability of physical properties such as particle size distribution, porosity, hydraulic conductivity, bulk density and organic matter content by collecting the samples at different depths on a 6 m x 15 m grid. Correlations were established between these parameters with the EC. The best correlations were between the EC and the sand, silt, clay and organic matter contents. No relation was established between the EC and the porosity, the bulk density or the hydraulic conductivity. EC seems to be influenced by the soil texture *i.e.* by the electrical properties of the soil constituents than by the structure i.e. water related properties.

Dampney (1997) studied the variability of pH and available phosphorus, potassium and magnesium in soils within arable fields in England by collecting 31 composite soil samples from the 0-15 cm soil depth in each field (mean field size 20.5 ha) using a grid pattern. The data showed that the mean CV values were 5.1 per cent for soil pH, 36.1 per cent for soil P, 27.2 per cent of soil K and 28.5 per cent for soil Mg.

Based on the results from a three-year experiment conducted by Ostergaard (1997) in Denmark, it was estimated that the direct potential economic benefit in the fields examined from precision agriculture was \$40-\$50 ha^{-1} compared to an even application of N, P, K and lime.

Results of the geo-statistical exploitation of field data collected in different landscapes in northern Germany by Haneklaus *et al.* (1997) showed that, in general, the ranges derived from semi-variogram analyses increase in the order : soil organic matter and texture ≤ crop yield << available nutrients in soil ≤ nutrient concentrations in plants.

Raun *et al.* (1998) assessed the micro-variability in soil test, plant nutrient and yield parameters in Bermuda grass pastures in Okalahoma, USA and it was reported that significant differences in surface soil test analysis were observed even when samples were < 1 m apart for both mobile and immobile nutrients.

Spatial variability of Ca, Mg, Mn, NO_3-N, P, K and Zn and organic matter and pH of soil from 55 grids of 20 m x 20 m size in coastal plains of Virginia, USA was estimated by Gupta *et al.* (1999). NO_3-N, P, K and Zn exhibited greater degrees of variability compared to other parameters. Among the nine parameters, NO_3-N and Zn had the greatest spatial variation with coefficient of variation (CV) of 40 and 49 per cent, respectively, while pH had the lowest variation (4%).

A comparative study of interpolation methods such as inverse distance weighting, ordinary kriging and lognormal ordinary kriging by Kravchenko and Bullock (1999) by using data for P and K from 30 experimental fields. They suggested that ordinary kriging seems to be a safer choice of interpolation technique than lognormal ordinary kriging for data sets with more than 200 data points.

Gaston *et al.* (2001) studied the spatial variability of soil properties such as soil microbial activity, pH, organic carbon and texture in 50 ha sub areas of two sites in Mississippi delta, using geo-statistics. Soil microbial activity exhibited limited spatial dependence, but pH, OC and texture semivariograms were well described with spherical models.

Mueller *et al.* (2001) conducted a study to evaluate the effect of different soil mapping methods and grid interpolation schemes on the quality of soil fertility maps in south central Michigan, USA. They reported that inverse distance weighted (IDW) method was superior to kriging and the performance of kriging relative to IDW methods improved with increasing sampling intensity *i.e.* IDW was superior to kriging for 100 per cent cases with the 100 m grid, 79 per cent of the cases with the 61.5m grid scale and 67 per cent of the cases with the 30m grid. They also noted that practically, there was little difference between these interpolation methods.

Schloeder *et al.* (2001) compared ordinary kriging and inverse distance weighting method with limited, coarse scaled soils data from a Vertisol plain in Omo Basin, Ethiopia and found both the interpolation methods similarly accurate and effective.

MATERIALS
AND
METHODS

CHAPTER III

MATERIALS AND METHODS

The details of the site characteristics of the study area, materials used and methods adopted are presented below:

3.1 THE STUDY AREA

The study area is Dagala watershed located in Kachch district of Gujarat state.

3.1.1 Location and extent

This watershed lies between 23°15'-23°20'N latitude and 69°54'-70° E longitude with a spatial extent of 7908.64 ha. The area is covered by Survey of India topographic map No. 41E/15. It is located in north-western agro-climatic zone of Gujarat. The study area comprises of six villages *i.e.* Dagala, Mokhana, Kanyabe, Amrutanagar, Dhaneti and Yoginagar. Location map is given in Fig.1.

3.1.2 Geology

Kachch district has a varied geological record. The most prominent is the sedimentation of Jurassic and cretaceous rock beds, mainly under marine to estuarine situations during the early Mesozoic period, followed by emergence, igneous activities and tectonism in subsequent era. Middle to lower cretaceous formations comprising mainly Bhuj series (part of study area) are composed of coarse grained sandstone with shales. It consists of soft sandstone with minor sandy shales, deposited under a fluviatile to estuarine condition.

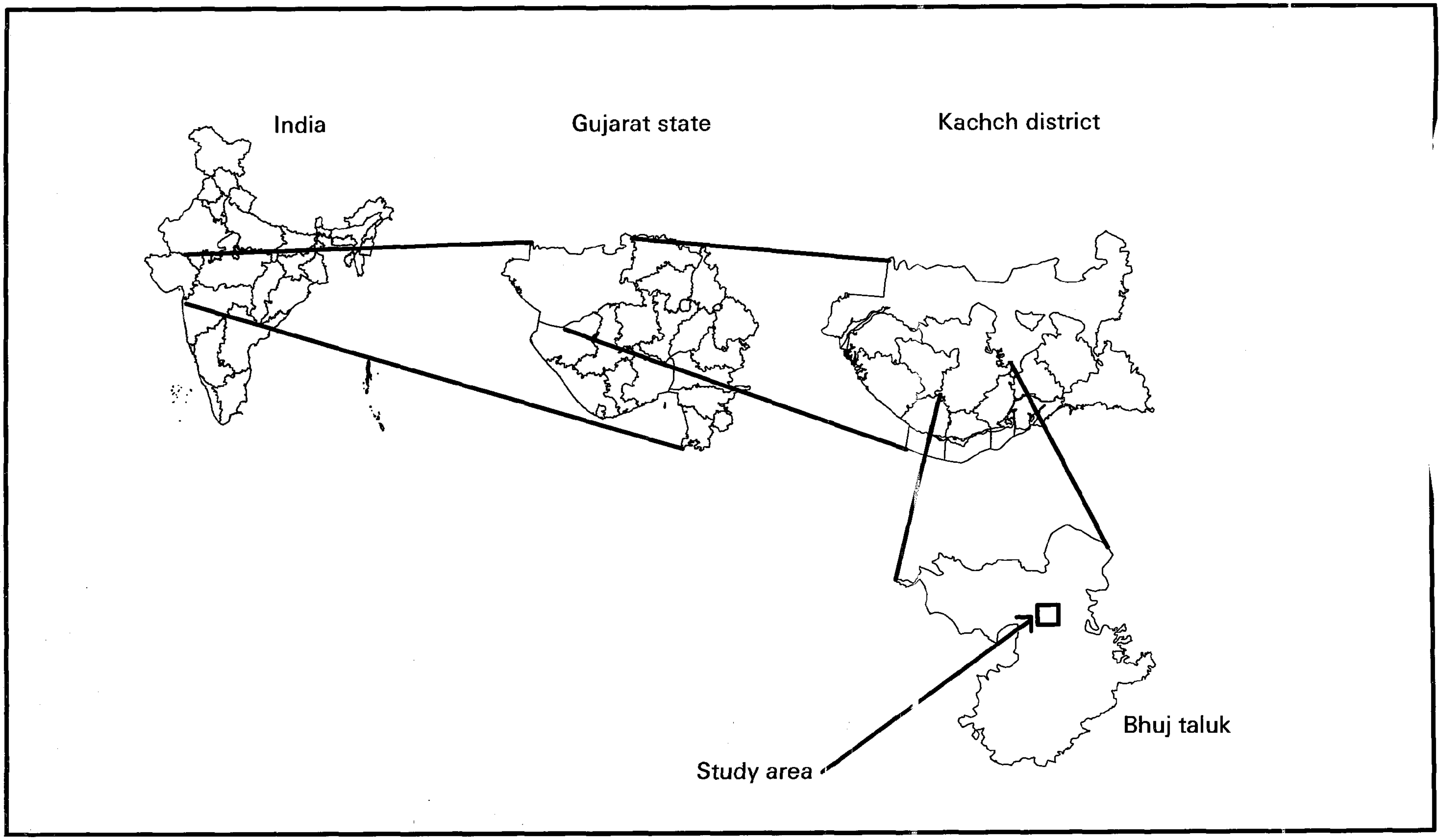

Fig. 1 : Location map of study area

3.1.3 Physiography

The study area comprises of different physiographic units such as hills, pediment-inselberg complexes, foot slopes of hills pediment, pediplain (nearly levelled and undulating), valley, valley fringe and toe/side slopes of valley. Out of these physiographic units, undulating pediplain with moderate erosion occupied more area (16.93%) followed by undulating pediplain with severe erosion (16.69%). Hills and pediment-inselberg complex have steep to moderate steep slope, while pediment has moderate slope and pediplain has moderately to very gentle slope and valley has gentle to very gentle slope.

3.1.4 Drainage

The drainage pattern is mostly dendritic. The major stream present in the study area is Sang river flowing towards south-east direction. Drainage system is complex with irrigation tanks and intervening streams. Streams are active during rainy season only.

3.1.5 Soils

The study area consists of soils derived from limestone and alluvium. These are shallow in higher elevations (foot slopes and pediment), moderately deep (pediplains) and deep in valley portions. These soils are coarse textured and well drained with low organic carbon status. Soils encountered in the area belong to Aridisols and Entisols.

3.1.6 Climate

The climate of the area is an arid with a mean moisture index of 79.0. Rainfall is scanty and erratic with extreme temperature resulting in high rates of evaporation. The mean annual rainfall is 342.4 mm. The south-west monsoon normally sets over the district in the month of June when the coastal belt receives rainfall. By the end of July monsoon spreads to the other parts. Monsoon ends by the end of September or early October. This area experiences highest temperature of 38.3°C in May (mean annual temperature over 10 years) and the mean daily minimum temperature in January (coldest month) is 11.2°C (Table 1). Extreme variations in temperatures were observed in this area. In the hot season, the maximum recorded temperature was 47.8°C. As and when western disturbances pass over north India during the winter, cold wave conditions prevail in this district and the lowest recorded night temperature at Bhuj was 1.1°C. The ombrothermic diagram showing the wet and dry periods is shown in the Fig. 2.

3.1.7 Agriculture and land use

Most of the study area is mono-cropped, cultivated in rotation with 30-60 per cent intensity. Saline, waste lands with scrub and stony gravelly waste lands were also observed. The main crops grown in this area are *bajra*, groundnut, *guar*, *jowar*, moth, sesamum and cumin.

Land use classification in Kachch district is given in Table 2. From this data, it can be inferred that total cropped area is only 5,01,300 ha contributing to 10.98 per cent of total geographical area. Most of the area is barren indicating that soils have major limitations due to aridic climate with scanty and erratic distribution of rainfall. (Statistical out line-Gujarat State, 2004).

Area, production and average yield per ha of important crops in Kachch district are given in Table 3. It indicated that groundnut is the major crop grown followed by *bajra* and pulses. Rice crop is not grown due to non-availability of water. (Statistical out line-Gujarat State, 2004).

Table 1: Mean meteorological data of the study area (Bhuj)

Months	Daily air temperature (^oC)			Monthly precipitation (mm)
	Maximum	Minimum	Mean	
January	26.2	11.2	18.7	2.2
February	28.8	13.6	21.2	3.7
March	33.9	18.1	26.00	2.6
April	37.70	22.00	29.85	0.80
May	38.30	25.00	31.65	5.20
June	36.30	26.70	31.50	29.00
July	32.60	25.70	29.15	144.50
August	31.30	24.70	28.00	96.00
September	33.50	23.80	28.65	43.40
October	35.60	21.40	28.50	9.40
November	32.20	16.70	24.45	4.80
December	27.20	12.30	19.75	0.80
Annual	32.80	20.10	26.45	(Total) 342.40

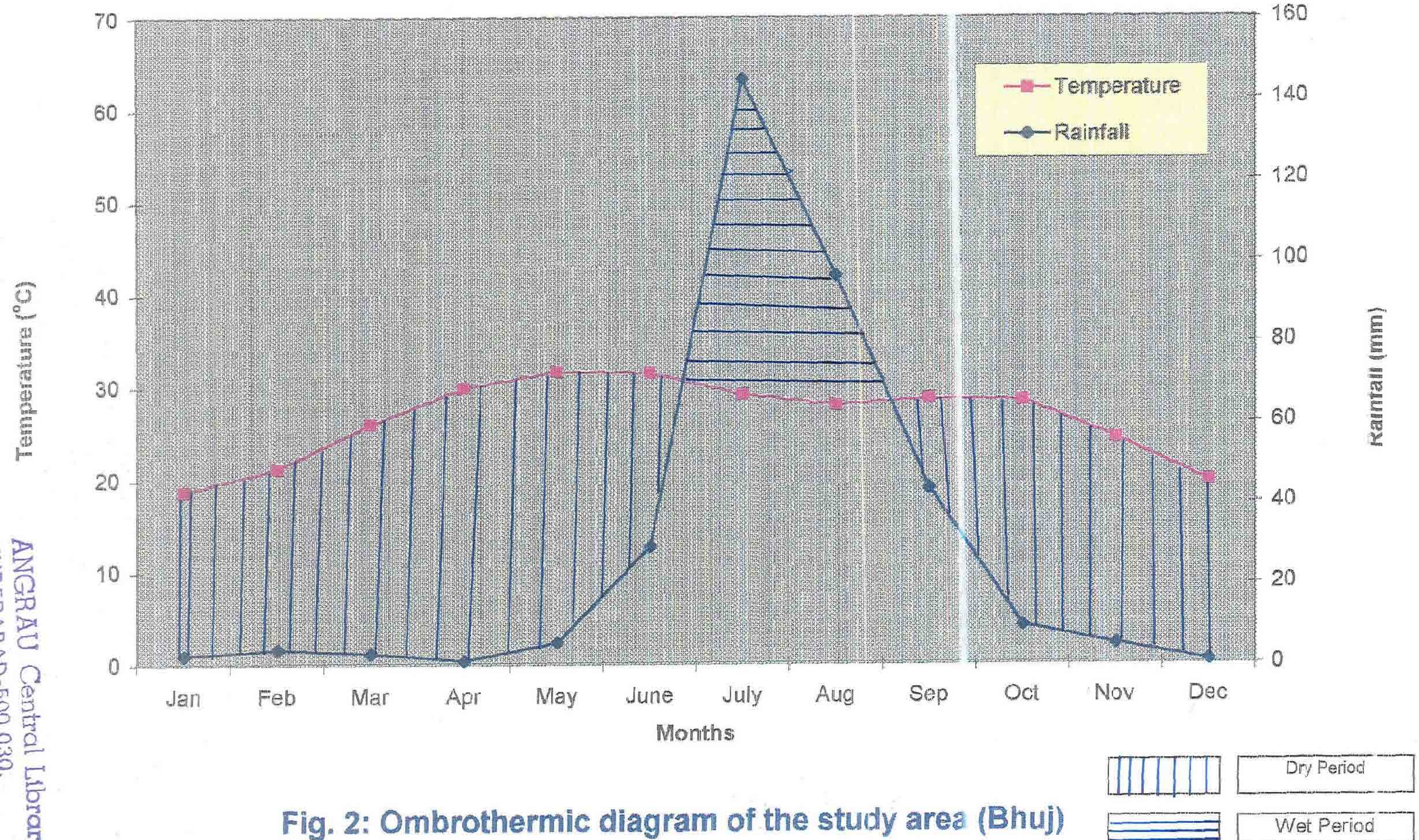

Fig. 2: Ombrothermic diagram of the study area (Bhuj)

Table 2: Land use classification in 1999-2000 in Kachch district

S. No.	Land use	Area ('00 ha)	Per cent to total area
	Geographical area	45652	-
1	Area under forest	2879	6.31
2	Land not available for cultivation	17786	38.96
	a) Land put to non-agricultural uses	730	1.60
	b) Barren and uncultivable land	17056	37.36
3	Other uncultivated land excluding fallow	17512	38.36
	a) Permanent pastures and other grazing lands	700	1.53
	b) Land under Misc. tree crops and grooves not included in net area sown	0	-
	c) Culturable waste	16812	36.83
4	Fallow land	2562	5.61
	a) Fallow land other than current follow	0	-
	b) Current fallow	2562	5.61
5	Net area sown	4913	10.76
6	Area sown more than once	100	0.22
7	Total cropped area	5013	10.98
8	Percapita net area sown	0.39	0.0008
9	Cropping intensity	102.04	0.22

Source: Statistical outline- Gujarat State, 2004, Directorate of Economics and Statistics, Government of Gujarat, Gandhinagar

3.1.8 Natural vegetation

Natural vegetation of the area was dominated by shrubs and grasses. The shrub species observed are *Alhagi pseudalnagi, Salvadora oleoides, Euphorbia caduclifolia, Salvadora persica, Maytenus emarginatus, Aristida sp, Zizyphus* sp., *Calotropis* sp., *Prosophis juliflora* and *Prosophis* sp. The grasses include *Cenchurus setigerus, C.depressus, Corchorus trilocularis*.

Table 3: Area, production and average yield of important crops in Kachch district (1999-2000)

Crops	Area ('000 ha)	Production ('000 tonnes)	Yield in (kg ha^{-1})
Bajra	68	28	411
Wheat	19	52	2817
Pulses	47	12	264
Groundnut	77	123	1590
Sesame	13	4	330
Rapeseed and mustard	11	11	997
Sugarcane	1	3	6200
Total oilseeds	142	175	1233

Source: Statistical outline – Gujarat State, 2004, Directorate of Economics and Statistics. Government of Gujarat, Gandhinagar

3.2 DATABASE

3.2.1 Space borne multi spectral digital data

IRS-IC PAN+LISS-III merged data in the form of digital and geo-coded false colour composites (FCC) were utilized for soil resource inventory of the study area. Satellite data acquired on March, 2002 was used.

3.2.2 Topographic maps

Survey of India topographic map (41 E/15) at 1:50,000 scale covering the study area was used. Satellite data provided by National Remote Sensing Agency (NRSA), Hyderabad were utilized for this study.

3.2.3 Ancillary data

Ancillary data in the form of published reports, districts hand book, maps, climatic data and the socio-economic conditions pertaining to the study area were collected during the ground truth collection and were used.

3.3 EQUIPMENT AND INSTRUMENTS USED

3.3.1 Field equipment

Tools for profile digging, Munsell colour chart, magnifying lens, measuring tape, wash bottle with dilute HCl, cloth bags etc. were used for field work during ground truth collection. Global positioning system (GPS) receiver (Model : Magellan Promark-X) was utilized for correct location of the pedons and also for studying the spatial variability of soils.

3.3.2 Lab equipment

Light table available at NRSA, Hyderabad was used for visual interpretation of satellite data. Other lab facilities available in Department of Soil Science and

Agricultural Chemistry, College of Agriculture, Rajendranagar were utilized for analysis of soil samples collected during field work.

3.3.3 Computers and peripherals

In the present study, image analysis software ERDAS imagine version 8.5 available on SGI (Silicon Graphics) computer system was used to process the satellite data, merging of two images and in developing FCCs of the satellite data. Geographic information system (GIS) software, ARC/GIS version 9.0 which was also available on SGI system was used for the analysis of data, creation of digital database and preparation of different maps. 'Tektronix phaser 560" type printer was used for getting the prints of different maps. All these computer facilities such as SGI computer system, software and printers are available in the Agriculture and Soils group, National Remote Sensing Agency (NRSA), Hyderabad.

3.4 METHODOLOGY

The methodology adopted for the present investigation is described hereunder.

3.4.1 Preparation of digital database

Initially, the digital data were processed to transform it for improving the image contrast and to generate photo-products for subsequent analyzer/interpretation. The standard monoscopic visual interpretation was employed to realize the objectives. The LISS-III and PAN digital data were down loaded on to Silicon Graphics work station with ERDAS/IMAGINE image analysis software. Initially, the study area was identified and extracted in both the data sets. Using map to image transformation algorithm, ground control points (GCPs) were identified both on the PAN image as well as the topographic map and the former was geo-referenced with a sub-pixel accuracy using first order polynomial transformation. Later on, LISS-III and PAN data were registered to each other with a sub-pixel accuracy and LISS-III was resampled using cubic convolution algorithm. Thus, both the data sets were brought to a common projection.

The next step followed was to generate LISS-III and PAN hybrid image. While merging higher resolution data with the lower resolution images, usually high resolution image (here PAN data with 5.8 m spatial resolution) was used as a reference for respective enhancement of the coarser resolution data (LISS-III data with 23.5 m spatial resolution). To begin with, the three bands 0.52 – 0.59 μm, 0.62 – 0.68 μm and 0.77 – 0.86 μm of resampled LISS-III data were transformed to Intensity, Hue and Saturation (IHS). 'Intensity' (Munsell's value) refers to the total brightness of a colour; 'Hue' generally, refers to the dominant or average wavelength of light contributing to a colour and 'Saturation' specifies the purity of a colour relative to grey. The intensity component was then replaced by PAN data during back transformation of IHS data to RGB (Red-Green-Blue) components. A print of IHS transformed digital data of LISS-III and PAN data was generated on a Hewlett Packard Design Jet 755 CM Plotter. Images of PAN, LISS-III and PAN+LISS-III are presented in Figs. 3, 4 and 5.

3.4.2 Delineation of the study area

Study area was delineated with the help of topographic maps on PAN + LISS-III merged image.

3.4.3 Base map

Base map was prepared using topographic map and PAN + LISS-III FCCs by drawing the features like road network, railways, streams and settlements.

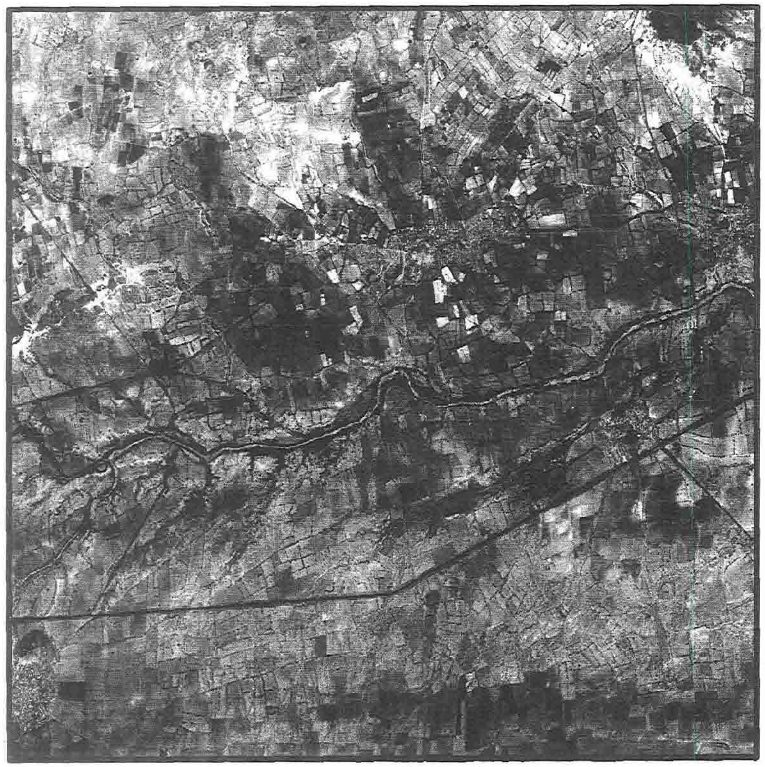

Fig. 3 : IRS-1C PAN Image of the study area

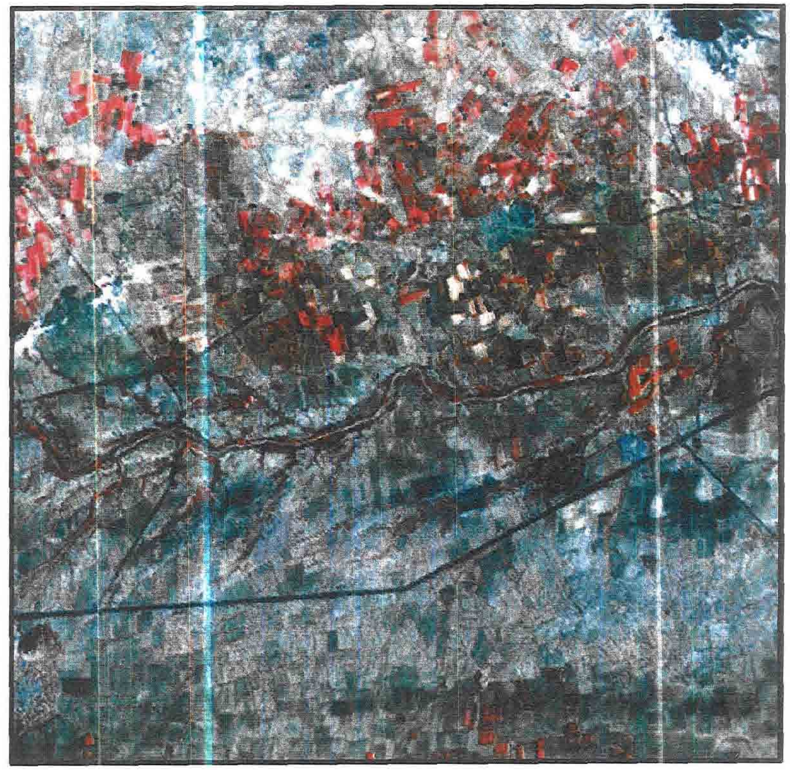

Fig. 4 : IRS-1C LISS-III image of the study area

Satellite data used in the present study

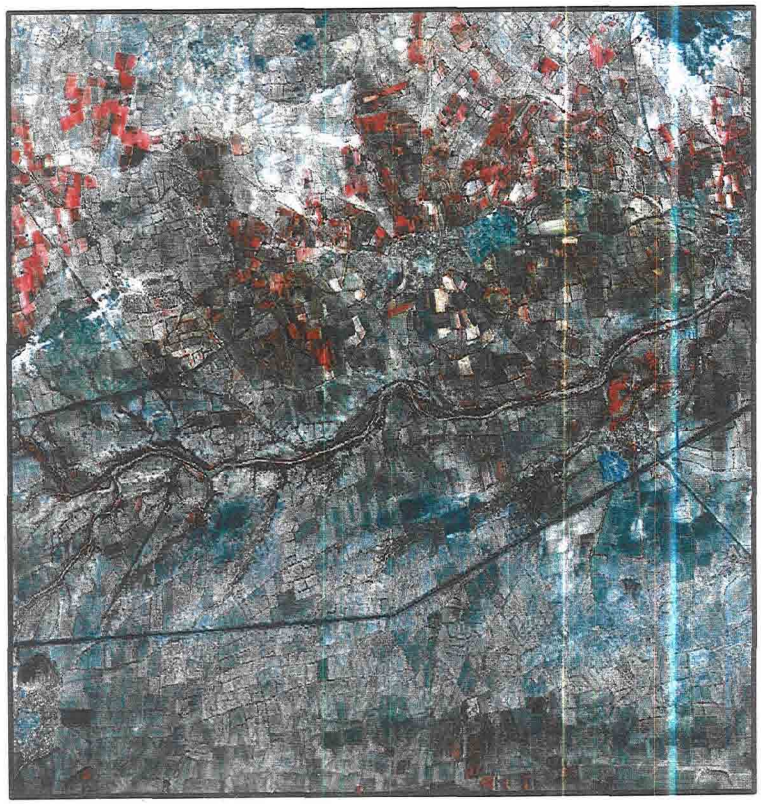

Fig. 5 : IRS-1C PAN+LISS-III merged image of the study area

3.4.4 Preparation of soil map

This involves visual interpretation of satellite data based on image elements, ground truth collection (soil profile study, minipit examination and auger bore study for finalizing mapping unit delineation), analysis of soil samples in the laboratory for physical, physico-chemical and chemical properties, classification of soils and map finalisation with legend. Schematic diagram showing the methodology for generation of soil resource mapping using remote sensing data through visual interpretation approach is shown in Fig. 6.

3.4.4.1 Pre-field visual interpretation of satellite data

Overlays with base map details were super-imposed on satellite imagery. Physiographic units were delineated with the help of toposheet information, geology, geomorphology and by using the elements of image interpretation. Understanding the spectral signatures of soils is the key needed to map soils. Each physiographic unit was divided into soil mapping units based on certain individual and combinations of image interpretation elements like colour, tone, texture, size, shape, association and pattern etc., land use/land cover, slope and erosion. A tentative legend was formulated. Sample strips, where soils to be studied were identified in each mapping unit and were marked on the overlays.

3.4.4.2 Preparation of tentative legend

Based on lithology, physiography, contour formation, land use/land cover and erosion status obtained from satellite imagery and toposheet information, a tentative legend was prepared.

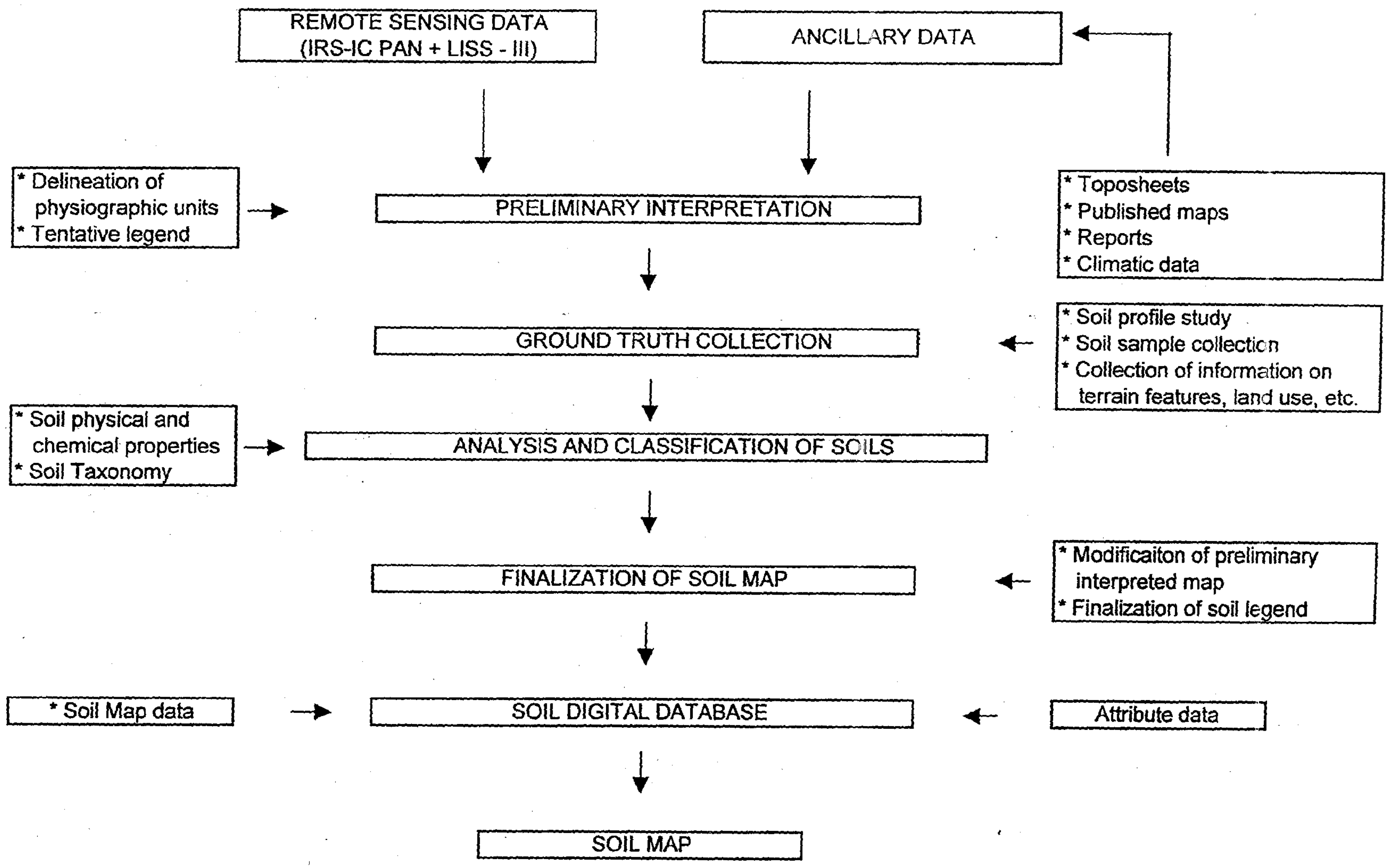

Fig. 6: Schematic diagram showing the methodology for soil resource mapping

3.4.4.3 Ground truth collection

Delineation of soil mapping units done by visual interpretation based on image characteristics were confirmed by field visits and the points, where observations to be made were marked precisely on the overlays. Later, soil profiles were dug at selected points upto a depth of 1.5 m or lithic/paralithic contact and detailed examination on morphological characteristics such as depth, boundary of each horizon, matrix colour as per Munsell's colour chart (Munsell, 1950), texture, structure, coarse fragments, consistency, roots, pores, clay cutans or any concretions and effervescence was carried out as per the procedure given by USDA, (Soil Survey Staff, 1951). The horizon designations were made as outlined in the "Keys to Soil Taxonomy" (Soil Survey Staff, 1998). Besides these morphological observations, data regarding the topography, parent material, location (latitude and longitude), slope, rock outcrops, erosion, drainage and land utilization were also observed and recorded in the profile description sheets. After detailed study of the profile, soil samples were collected horizonwise, packed in polythene bags and properly labelled. Also, soil samples from augerbores and mini pits were collected for this study.

3.4.4.4 Laboratory analysis of soil samples

Soil samples collected were air dried under shade, ground with mortar and pestle, passed through a 2 mm sieve and then were used for laboratory analysis after proper labeling. These soil samples were analysed for estimating physical, physio-chemical and chemical properties of the soil using the standard methods which are given in Table 4. Clay mineralogy was studied by X-ray diffractometry. The X-ray diffraction analysis was carried out for the clay fraction ($< 2\ \mu$) of the soils collected from control section (25-100 cm) of the pedons. Seven representative soil samples based on the taxonomic classification upto sub group level as well as the textures

Table 4: Methods of soil analysis

S. No.	Parameter	Method	Reference
1	Mechanical analysis	International pipette method	Piper (1966)
2	Soil reaction (pH)	Potentiometry	Jackson (1973)
3	Electrical conductivity (EC)	Conductometry	Jackson (1973)
4	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
5	Free $CaCO_3$	Rapid titration method	Piper (1966)
6	Cation exchange capacity (CEC)	Neutral normal ammonium acetate method	Bower *et al.* (1952)
7	Exchangeable calcium	Versenate titration	Kanwar and Chopra, (1976)
8	Exchangeable magnesium	Versenate titration	Kanwar and Chopra, (1976)
9	Exchangeable sodium	Flame photometry	Jackson (1973)
10	Exchangeable potassium	Flame photometry	Jackson (1973)
11	Available nitrogen	Alkaline potassium permanganate method	Subbaiah and Asija (1956)
12	Available phosphorus	Olsen's method	Watanabe and Olsen (1965)
13	Available potassium	Flame photometry	Jackson (1973)
14	Gypsum (%)	Rapid conductometric method	Bower and Huss (1948)

were analysed for clay mineralogy. The clay fractions (< 2 μ) separated out as per the procedure outlined by Jackson (1979) were subjected to X-ray diffraction (XRD) analysis for identification of clay minerals using Philips diffractometer with Ni-filtered Co K α radiation at a scanning speed of $2^\circ\ 2\theta\ min^{-1}$. The X-ray diffraction analysis was carried out at NBSS & LUP, Nagpur. Samples were saturated with Ca and K, solvated with ethylene glycol, and heated to 110°C, 300°C and 550°C. Minerals present in the clay fraction were identified following the criteria of Jackson (1979). Semi-quantitative estimation of the clay minerals was computed by following the procedure given by Gjems (1967).

Based on the morphological characteristics and the analytical results of physical, physico-chemical and chemical properties, the soils were classified according to Soil Taxonomy (Soil Survey Staff, 1998).

3.4.4.5 Finalisation of the legend

The tentative legend prepared was modified based on ground truth collection and results of analytical properties. Mapping units with similar soil composition were merged into a single unit and in some cases, a given unit was further divided based on variations in soils. Thus, a final map legend was prepared.

3.4.4.6 Map finalisation

Based on the ground truth data, modifications were effected and soil boundaries drawn during preliminary visual interpretation were modified by displaying the LISS-III and PAN merged image into colour monitor of the silicon graphics workstation and the legend showing soil series/association was prepared. Soil scape boundaries were transferred into base maps and digital copy of the soil map was generated after vectorisation in ERDAS/IMAGINE software. Areas under different soil scape units were computed using ARC/INFO software. The finalized soil map was printed with a Tektronix phaser 560 printer at 1:12,500 scale.

3.5 LAND EVALUATION

Land evaluation enables better understanding of the soils in terms of their potentials and limitations for agricultural production. In the present study, land evaluation was done by adopting two methods viz. USDA land capability classification (Klingebiel and Montogomery, 1966) and parametric method for land evaluation as proposed by Riquier *et al.* (1970). Comparative evaluation of these methods was also done and based on the potentialities and limitations considered in the two methods, optimum land use was suggested for the study area.

3.5.1 USDA land capability classification

The land capability classification is widely used categorical system for evaluating land on 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.

Factors considered for determining the capability are topography (slope and erosion), wetness (flooding, drainage, permeability), physical soil conditions (surface texture, surface coarse fragments, surface stoniness, sub-surface coarse fragments, soil depth and profile development) and fertility status of the soil (CEC, base saturation, OC, salinity and gypsum content). Criteria used for the land capability classification is given in Appendix-II. In the present study, capability classification was done upto sub class level.

3.5.2 Parametric method of land evaluation by Riquier *et al.* (1970)

The parametric method for land evaluation by Riquier *et al.* (1970) was followed in assessing the land productivity. This is a parametric system of assessing the land productivity of soils based on soil and site parameters that influence the yields through mathematical equations. This system suggests the calculation of a productivity index considering nine factors for determining soil productivity, viz., moisture (H), drainage (D), effective depth (P), texture/structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A) and mineral reserve (M).

Productivity index = H x D x P x T x N x S x O x A x M

Each factor is rated on a scale from 0 to 100, the actual percentages multiplied by each other. The resultant index of productivity, also lies between 0 and 100 was set against a scale placing the soil in one or other of following five productivity classes (Table 5). Soil characteristics considered for assigning categories to the factors and ratings for each factor are given in Appendix-I.

Table 5: Actual (P) and Potential (P^1) productivity ratings of LPI values for productivity classes

Actual productivity (P)	Productivity classes	Rating	Potential productivity (P^1)
1	Excellent	100-65	I
2	Good	64-35	II
3	Average	34-20	III
4	Poor	19-8	IV
5	Extremely poor to nil	7-0	V

In the present study, actual productivity index (P) and potential productivity index (P^1) were calculated. In actual productivity index the value of the ratings refer to the present day situation and in potential productivity index, the ratings will be given according to the situations after soil management. Thus, actual and potential productivity indices were calculated for all soil types for field crops, pastures and forest/other trees separately and the potentiality for growing them was discussed.

3.5.3 Preparation of land capability and land productivity maps

Land capability and productivity for all soil units were calculated using above mentioned methods and digital database was created by linking these attribute data to the soil layer. From this, derivative maps (land capability and land productivity maps) were generated using ARC/Info software.

3.6 CREATION OF SOIL DIGITAL DATABASE

This objective was achieved by adopting the guidelines of Natural Resources Information System (NRIS)-Node, Design and Standards, which were developed by National Natural Resources Management System (NNRMS, Department of Space, 2000). NRIS seeks to provide an integrated database for the use of remotely sensed data and collateral information in the framework of a spatial information system.

3.6.1 Steps in Database creation

3.6.1.1 Scanning of finalized soil map

The soil map was finalised by incorporating post-field interpretative data and with the finalisation of legend. Thus finalised soil map was scanned and was projected to polyconic projection.

3.6.1.2 Digitisation of features

The features present in the scanned map were digitised using GIS package. Soil map, drainage and other water bodies, boundary and settlements were digitised as separate layers.

3.6.1.3 Coverage editing

The digitized coverage was processed for digitisation errors such as dangle nodes and pseudo-nodes because of overshoots and undershoots for arcs and labels for polygons. These constitutes obtaining a report of these errors and then a manual editing of these features. Finally, the coverage was processed for topology creation.

3.6.1.4 Attribute coding

The standard codes as defined in the NRIS document for different categories were assigned and additional attributes such as feature name, description etc. were added into the feature database. The look up tables (.LUT) and data attribute tables (.DAT) were created as the structure defined in the NRIS document.

The database presented in this work consists of an integrated database of spatial and non-spatial data. These database elements were grouped into primary database elements collected and entered into the system and derived elements, which were derived from the primary data using GIS operations.

3.6.1.4.1 Primary database elements

Primary database elements are the ones which were directly digitized and are utilised as input to the GIS. In the present study, primary database elements like soil map with type, depth, texture, stoniness etc. upto series level, drainage, settlements and roads were included.

3.6.1.4.2 Derived database elements

Derived database elements are those, which were derived using the primary elements in spatial and non-spatial modes. Derived database elements in the present study were land capability and land productivity from primary elements of soil map.

3.6.1.4.3 Feature codification scheme

Feature codification scheme for every input element has been worked out keeping in view the natural hierarchy within the feature class for theme. All data elements are given a unique name, which is self explanatory with short forms. This has attribute table (look up table) with the extension of LUT and a linking code (feature code) which links this LUT and the database layer. Detailed coding scheme with its description part for soil layer is given in Table 6.

3.7 SPATIAL VARIABILITY OF SOIL PROPERTIES

A small part of watershed (32.56 ha area) was studied for spatial variability of soil properties such as pH, EC, OC and major nutrients in order to make site-specific recommendations as a part of precision farming. In this area, surface soil samples upto 30 cm depth were collected at a grid of 60 m x 60 m.

The soil samples were air dried under shade, pounded with mortar and pestle and passed through a 2 mm sieve. The soils were analysed for the above mentioned properties by following the standard procedures given in Table 4. Statistical analysis was done for all properties using classical and geo-statistical procedures such as kriging.

Table 6: CODING SCHEME FOR SOIL LAYER (*SOIL. LUT*)

Soil Code will be AA-BB-CC-DD-EEFFGG-HH (16 digits)

AA : Order (Two Digits)
BB : Sub order (Two Digits)
CC : Great group (Two Digits)
DD : Sub group (Two Digits)
EEFFGG : Family (Six Digits)
HH : Series

EE	**Textural Classification**	**FF**	**Mineral Classification**	**GG**	**Soil Temperature Region**
CODE	Class	CODE	Class	CODE	Class
00	Nil	01	Montmorillonitic	01	Pergic
01	Fragmental	02	Carbonatic	02	Frigid
02	Sandy skeletal	03	Illitic	03	Mesic
03	Loamy skeletal	04	Ferritic	04	Thermic
04	Clayey skeletal	05	Kaolinitic	05	Hyperthermic
05	Sandy	06	Gypsic	06	ISO Frigid
06	Loamy	07	Mixed	07	ISO Mesic
07	Coarse loamy	08	Siliceous	08	ISO Thermic
08	Fine loamy	09	Micaceous	09	ISO Hyperthermic
09	Coarse silty	10	Gibbsitic	98	Habitation Mask
10	Fine silty	11	Vermiculitic	99	Water Body Mask
11	Clayey	98	Habitation Mask		
12	Fine	99	Water Body Mask		
13	Very fine				
14	Contrasting Particle Size				
98	Habitation Mask				
99	Water Body Mask				

3.7.1 Generation of soil spatial variability maps

Soil spatial variability maps were prepared by the interpolation of point data. Initially, the geo-referenced soil test results for all properties such as pH, EC, OC, available N, available P (P_2O_5) and available K (K_2O) were plotted using ARC/Info software. Soil test values were grouped into different zones based on the cut off values representing the mean $\pm$ one SD (Standard deviation). Subsequently, the point data was interpolated to create a continuous surface. The interpolation technique used was ordinary kriging.

The kriging method assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging fits a mathematical function to a specified number of points or all points within a specified radius, to determine the output value for each location.

The general formula for kriging is shown below:

$$\hat{Z}(S_o) = \sum_{i=1}^{N} \lambda_i Z(S_i)$$

Where - $Z(S_i)$ is the measured data at the i^{th} location.

λ_i is an unknown weighing factor for the measured data at the i^{th} location

S_o is the prediction location

N is the number of neighbouring measured data points used in the interpolation scheme.

$\hat{Z}(S_o)$ is the estimated value of the prediction location

3.7.2 Site-specific nutrient recommendations

For major nutrients, site-specific nutrient recommendations were given to the study site for different crops such as pearl millet, sorghum, castor, cowpea, greengram and clusterbean based on the spatial variability of these nutrients. For this, uniform crop recommendations as suggested by CRIDA (Central Research Institute for Dryland Agriculture) were taken as the standard reference. The CRIDA recommended dose is suggested for the zone having lowest nutrient values. The amount of nutrients to be applied for other zones were calculated by taking into consideration the average value of each zone.

RESULTS

CHAPTER IV

RESULTS

The results of the present study entitled "Soil resource inventory using remote sensing and GIS techniques for utilization in watershed development" are furnished below under the following sub-heads:

4.1 Delineation of physiographic units using satellite data

4.2 Salient characteristics of soils of the study area

4.3 Clay mineralogy

4.4 Soil classification

4.5 Land evaluation

4.6 Creation of soil digital database

4.7 Spatial variability of soil properties

4.1 DELINEATION OF PHYSIOGRAPHIC UNITS USING SATELLITE DATA

Remote sensing with its synoptic view capability provides immense potential in mapping of natural resources, particularly soils. It has proved to be efficient, economic and reliable to prepare a comprehensive inventory of soil resource database. In the present study, soil mapping was done based on visual interpretation approach. Delineation of different units of soils using satellite images requires good knowledge on image interpretation as the reflectance characteristics of soil depend on a variety of factors. However, systematic analysis of physiography provides sufficient clues for delineation of boundaries between different types of soils because the factors that are involved in physiographic process correspond to that of soil formation. Hence, in the present investigation, good relationship between physiography and soils was well established. At higher elevations shallow soils with coarse texture and in lower elevations moderately deep/deep soils with fine texture were noticed.

In the present study, PAN + LISS-III merged product was used which helped to delineate the soils at 1:12,500 scale with the abstraction level of pure series. The merged product has given the advantage of high spatial resolution of PAN (5.8 m) and multi spectral nature of LISS-III with spatial resolution of 23.5 m. The individual images of PAN, LISS-III and merged images of PAN + LISS – III are shown in figure 3, 4 and 5, respectively. Initially, lithological units were identified followed by the delineation of different physiographic units through systematic visual interpretation.

Physiographic units of the study area

Different physiographic units identified in the study area include hills, pediment-inselberg complex, foot slopes, pediment, pediplain and valley. Pediment is sub-divided based on erosion. Depending upon the slope pediplain was divided into nearly leveled and undulating pediplain and further sub divided into pediplain with slight erosion, moderate erosion and severe erosion based on the information available on erosion status of the soil. Valley is categorized as valley, valley fringe and toe/side slopes. The different types of soils encountered in all these physiographic units are described hereunder (Table 7).

4.1.1 Hills

These are found mainly in the north-western and north-eastern regions of the study area. The soils in this unit are shallow which is due to erosion, and severly eroded soils developed on slopes ranging from 50-60 per cent. Soils are mostly covered with 95 per cent of rock outcrops and scrubs. The area covered under this unit is 76.74 ha, which accounts to 0.97m per cent of the study area.

4.1.2 Pediment – Inselberg complex

Pediment – Inselberg complex with isolated residual hills and hillocks is found in the north and north-western parts of the study area. The soils encountered in this area are mainly composed of 50 per cent rock out crops with slope ranging from 15-50 per cent. This unit covered 72.47 ha area which comprises of 0.92 per cent of the study area.

4.1.3 Foot slopes

This unit is sub-categorized into upper foot slopes and lower foot slopes based on the slope.

4.1.3.1 Upper foot slopes

The soils in this unit are severely eroded with slope 10-15 per cent and are fully covered with scrub. This unit constitutes to 151.18 ha which counts to 1.91 per cent of study area. These soils do not support any type of cultivation. The soils are classified under Mokhana series.

4.1.3.2 Lower foot slopes

The soils in the lower foot slopes are severely eroded with slope ranging from 5-10 per cent. The soils are moderately deep, covered with scrub (*Prosophis* sp. mostly) and are included in Dagala-3 series. 3.97 per cent of study area is occupied by this unit (313.77 ha).

4.1.4 Pediment

Pediment unit is categorized into sub-categories such as pediment with slight, moderate and severe erosions based on the erosion status of the soils.

4.1.4.1 Pediment with slight erosion

This unit represents the deep to moderate deep soils, slightly to moderately eroded soils with slope 1-3 per cent and the soils have enough moisture in subsurface horizons of profiles and support crop cultivation. This unit extends in the eastern part of the study area with an area of 77.81 ha and termed as Amrutanagar series soils.

4.1.4.2 Pediment with moderate erosion

The soils in this unit are moderately deep, with slope 1-3 per cent and the surface is covered with scrub such as *Prosophis* sp. This unit extends to an area of 634.49 ha that constitutes 8.02 per cent of the study area. The soils of this unit come under Dhaneti-1 series.

4.1.4.3 Pediment with severe erosion

This unit comprises severely eroded soils with 3-4 per cent slope and the soils are shallow to moderately deep. This unit comes under Kanyabe-2 series covering 242.66 ha area which amounts to 3.07 per cent of the study area.

4.1.5 Pediplain

Largest part of the study area is occupied by this unit. It is categorized into pediplain with nearly levelled land and undulating pediplain depending on the slope and again each one is further sub-categorized into peidplain with slight, moderate and severe erosion based on the erosion status of the soil.

4.1.5.1 Nearly levelled pediplain

4.1.5.1.1 Nearly levelled pediplain with slight erosion

The soils in this unit are deep, slightly eroded with slope 1-3 per cent and are under cultivation. 181.24 ha of area is occupied by this unit which comes to 2.29 per cent of total study area and classified under the Kanyabe-1 series.

4.1.5.1.2 Nearly levelled pediplain with moderate erosion

The soils in this unit are moderately deep, moderately eroded with slope 1-3 per cent. These soils are presently under cultivation of single crop in a year. These soils are classified under Dhaneti-2 series. This unit extended to an area of 727.53 ha covering 9.20 per cent of the study area.

4.1.5.1.3 Nearly levelled pediplain with severe erosion

The soils in this unit are also cultivated soils, moderately deep, but severely eroded with slope 2-4 per cent. These soils are classified under Yoginagar-1 series that covered 8.08 per cent (638.69 ha) of the study area.

4.1.5.2 Undulating pediplain

4.1.5.2.1 Undulating pediplain with slight erosion

This unit comprises of moderately deep soils with slight erosion having slope of 2-5 per cent under cultivation of two crops in a year. This unit occupied 11.71 per cent of study area *i.e.* 926.27 ha. They are classified under Dagala-1 series.

4.1.5.2.2 Undulating pediplain with moderate erosion

This unit also comprises moderately deep, moderately eroded soils with slope of 3-5 per cent but are partly used for cultivation of crops and partly covered with scrub. These soils are classified under Yoginagar-2 series with an area of 1338.54 ha (16.93 % of the study area).

4.1.5.2.3 Undulating pediplain with severe erosion

The soils in this unit are moderately deep, severely eroded with slope of 3-5 per cent and are covered with scrub (*Prosophis* sp.). This unit occupied 1319.84 ha area which constitutes to 16.69 per cent of the study area and are classified under Dagala-2 series.

4.1.6 Valley

The valleys are not very well developed but are symbolically categorized as they are in initial stages of valleys. This unit represents relatively low-lying areas with gentle slope as compared to other units and are formed along the basic drainage pattern. This unit is further sub-divided into actual valley, valley fringe and toe/side slopes of the valley.

4.1.6.1 Valley bottom

This unit has dense scrub lands with moderately deep due to moderate erosion and soils were qualified under Sangnadi-1 series with an area of 731.09 ha.

4.1.6.2 Valley fringe

This unit comprises of barren lands covered with dispersed scrub. The soils in this unit are deep, moderately eroded belonging to Kanyabe-3 series with an area of 56.75 ha that constitutes 0.72 per cent of the study area.

4.1.6.3 Toe/side slopes of valley

This unit has cultivable lands which support single crop in a year. The soils in this unit are moderately deep and qualified under Sangnadi-2 series with an area of 193.85 ha (2.45 % of the study area).

4.2 SALIENT CHARACTERISTICS OF SOILS OF THE STUDY AREA

All the soils in the study area have developed under arid climate with mean annual rainfall of 342.40 mm and mean annual air temperature of 26.45°C. Ombrothemic diagram for the study area based on the last decade climate data is depicted in the Fig. 2. The temperature regime of the soils in the study area is 'Hyperthermic' and the soil moisture regime is 'Aridic'. All the soils in the study area were classified under 14 types of soil series and series wise detailed description of typifying pedons under each series with morphological characteristics, physical, physico-chemical and chemical characteristics is given hereunder. Vertical distribution of sand, silt and clay for all the soil series depicted in fig. 8-a, b and c. Similarly, depth wise variations of exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) for all the pedons of the study area are shown in fig. 9-a, b and c. Depth wise distribution of organic carbon, calcium carbonate, CEC, base saturation are shown in fig. 10, 11, 12 and 13, respectively. Soil map representing the different kinds of soils in different physiographic units of the study area is depicted in the Fig. 7.

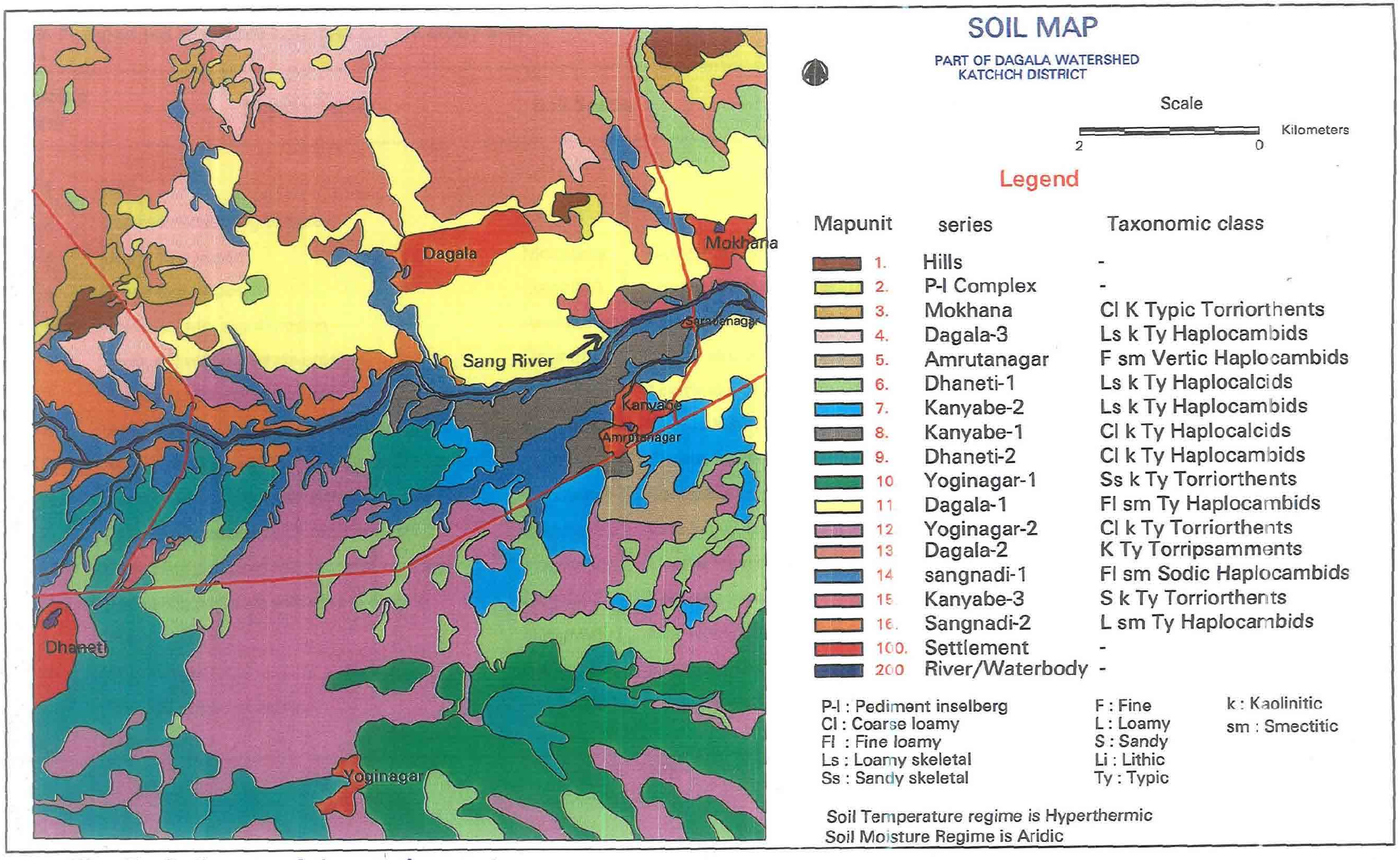

Fig. 7 : Soil map of the study area

Table 7: Extended legend of soil map for the study area

Mapping unit	Physiography	Soil Series	Soil Taxonomy	Area (ha)	Per cent to total area
1	Hills	-	-	76.74	0.97
2	Pediment-Inselberg complex	-	-	72.47	0.92
3	Upper foot slopes	Mokhana	Corarse loamy kaolinitic hyperthermic Typic Torriortnents	151.18	1.91
4	Lower foot slopes	Dagala-3	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	313.77	3.97
5	Pediment with slight erosion	Amrutanagar	Fine smectitic hyperthermic Vertic Haplocambids	77.81	0.98
6	Pediment with moderate erosion	Dhaneti-1	Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids	634.49	8.02
7	Pediment with severe erosion	Kanyabe-2	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	242.66	3.07
8	Nearly levelled pediplain with slight erosion	Kanyabe-1	Coarse loamy kaolinitic hyperthermic Typic Haplocalcids	181.24	2.29
9	Nearly levelled pediplain with moderate erosion	Dhaneti-2	Coarse loamy kaolinitic hyperthermic Typic Haplocambids	727.53	9.20
10	Nearly Levelled pediplain with severe erosion	Yoginagar-1	Sandy skeletal kaolinitic hyperthermic Typic Torriorthents	638.69	8.08
11	Undulating pediplain with slight erosion	Dagala-1	Fine loamy smectitic hyperthermic Typic Haplocambids	926.27	11.71
12	Undulating pediplain with moderate erosion	Yoginagar-2	Coarse loamy kaolinitic hyperthermic Typic Torriorthents	1338.54	16.93
13	Undulating pediplain with severe erosion	Dagala-2	Kaolinitic hyperthermic Typic Torripsamments	1319.84	16.69
14	Valley bottom	Sangnadi-1	Fine loamy smectitic hyperthermic Sodic Haplocambids	731.09	9.24
15	Valley fringe	Kanyabe-3	Sandy kaolinitic hyperthermic Typic Torriorthents	56.75	0.72
16	Toe/side slopes of valley	Sangnadi-2	Loamy smectitic hyperthermic Typic Haplocambids	193.85	2.45
100	Settelement	-		225.72	2.85
			Total	7908.64	100.00

4.2.1 Pedon – 1 (Mokhana series) - "Coarse loamy kaolinitic hyperthermic Typic Torriorthents"

4.2.1.1 Description of typifying pedon

Location	:	23° 18` 21.9" N latitude 69° 59` 24.72" E longitude
Physiography	:	Upper foot slopes
Parent material	:	Limestone
Slope	:	10-15 %
Erosion	:	Moderate
Drainage	:	Well drained
Natural vegetation	:	*Prosophis juliflora*
Present land use	:	Scrub land

Horizon	Depth (cm)	Morphological description
A1	0-7	Strong brown (7.5 YR 4/6 M) and brown (7.5YR R 4/4 D); loamy sand; fine structureless single grain structure; loose (dry), loose (moist), non-sticky and non-plastic; few fine pores; few very fine roots; slightly effervescent; clear wavy boundary.
A2	7-17	Brown (5 YR 4/3 M) and strong brown (7.5 YR 5/6 D); loamy sand; fine structureless massive; loose (dry), loose (moist), non-sticky and non-plastic; common medium nodules; strongly effervescent; clear smooth boundary.
AC	17-52	Brown (5 YR 4/3 M); strong brown (7.5 YR 5/6 D); loamy sand; fine massive; loose (dry), loose (moist), non-sticky and non-plastic; many medium indurated lime nodules; violently effervescent; clear wavy boundary.
C	52+	Lithic contact which is strongly cemented with limestone and sandstone.

4.2.1.2 Morphometric characteristics

This pedon was shallow in depth with four horizons *viz.*, A1, A2, AC and C. The colour of these soils ranged from brown (5YR 4/3) to strong brown (7.5 YR 4/6). The structure was fine structureless single grained throughout the profile. The consistence was loose in both dry and moist conditions whereas non-sticky and non-plastic under wet conditions. Effervescence increased with depth showing violent effervescence in last horizon (C) (Table 8a).

4.2.1.3 Physical, physico-chemical and chemical properties

The physical, physico-chemical and chemical properties of Mokhana series are presented in the Table 8b. The sand content ranged from 82.29 to 85.75 per cent with the highest content observed in surface horizon. Silt content varied from 2.20 to 4.80 per cent. Clay content ranged from 12.05 to 13.61 per cent. The texture was loamy sand throughout the profile. The organic carbon content was very low and decreased with depth (0.19 to 0.16%). The $CaCO_3$ content ranged from 3.78 to 10.86 per cent showing the increasing trend with depth. E C values were in between 1.85 to 2.30 dSm^{-1} with more salinity in surface horizon. pH ranged from 7.68 to 7.72.

4.2.1.4 Ion exchange properties

The exchangeable cations in this pedon were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ with more content in A2 horizon. The exchangeable calcium content ranged from 4.72 to 6.15 cmol (p^{+}) kg^{-1} and Mg^{2+} ranged from 2.15 to 3.00 cmol(p+)kg^{-1}. The ranges of exchangeable Na^{+} and K^{+} were 0.43 to 0.70 and 0.15 to 0.20 cmol(p+) kg^{-1} respectively. The CEC varied form 10.10 to 11.80 cmol(p^{+}) kg^{-1}. The exchangeable sodium percentage was in between 6.07 to 8.61 per cent and

Table 8a: Morphometric characteristics of typifying pedon in Mokhana series (Pedon-1)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
A1	0-7	7.5YR 4/6	7.5YR 4/4	f	0	sg	l	l	$s_0 p_0$	e	c	w
A2	7-17	5YR 4/3	7.5YR 5/6	f	0	m	l	l	$s_0 p_0$	es	c	s
AC	17-52	5 YR 4/3	7.5YR 5/6	f	0	m	l	l	$s_0 p_0$	ev	c	w
C	52+	Lithic contact (Not sampled)										

Table 8b: Physical, physico-chemical and chemical properties of typifying pedon in Mokhana series (Pedon-1)

Horizon	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
A1	0-7	7.68	2.30	85.75	2.20	12.05	ls	0.19	3.78	0.016
A2	7-17	7.70	2.24	82.29	4.10	13.61	ls	0.17	5.25	0.020
AC	17-52	7.72	1.85	82.35	4.80	12.85	ls	0.16	10.86	0.022
C	52+	Lithic contact (Not sampled)								

Table 8c: Ion exchange properties of typifying pedon in Mokhana series (Pedon-1)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
A1	0-7	4.72	2.86	0.50	0.15	10.10	6.07	81.48
A2	7-17	6.15	3.00	0.70	0.20	11.80	6.96	85.17
AC	17-52	5.38	2.15	0.43	0.17	10.16	8.61	80.02
C	52+	Lithic contact (Not sampled)						

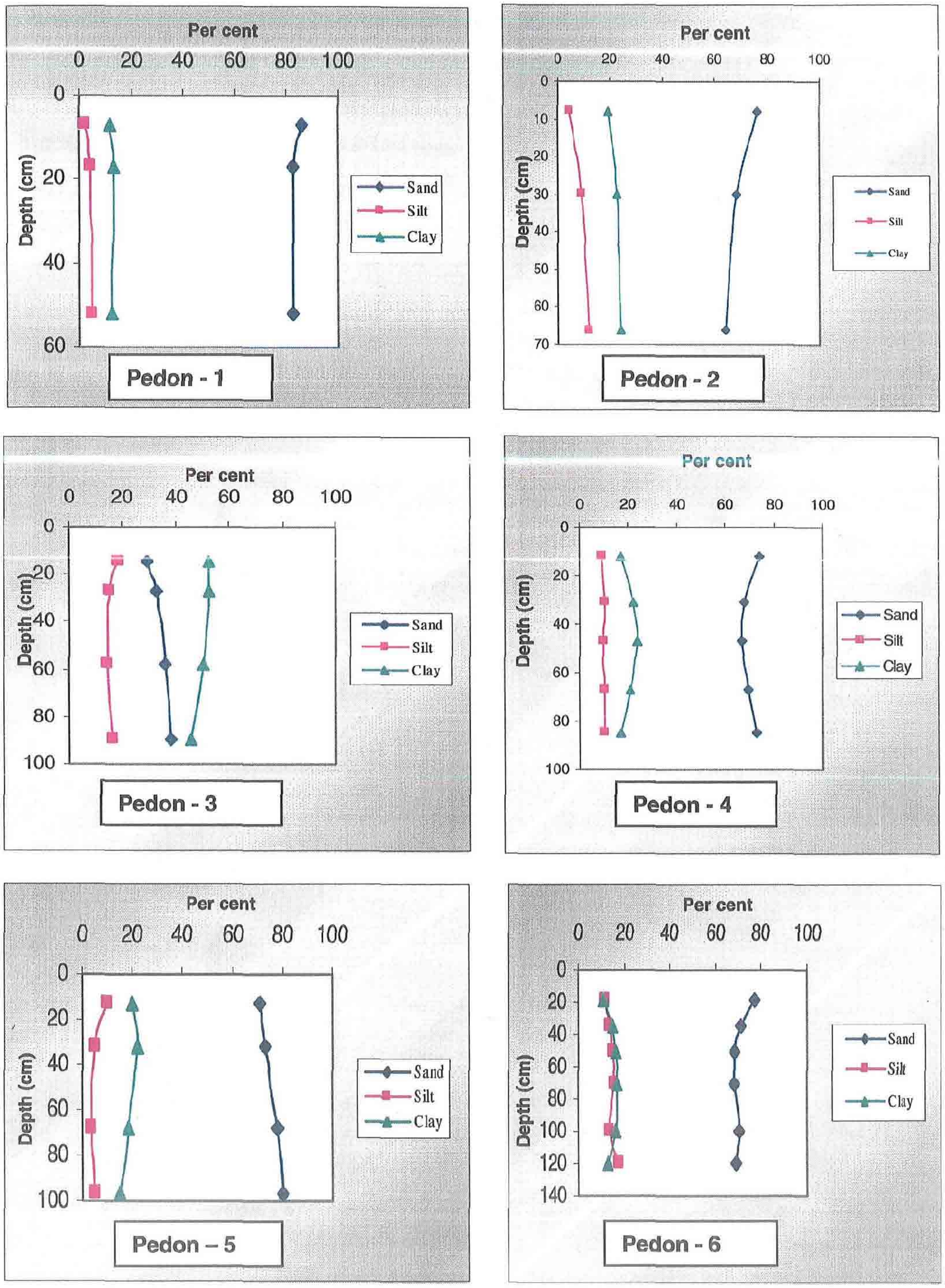

Fig.8a : Depth wise distribution of soil particles (Pedons 1-6)

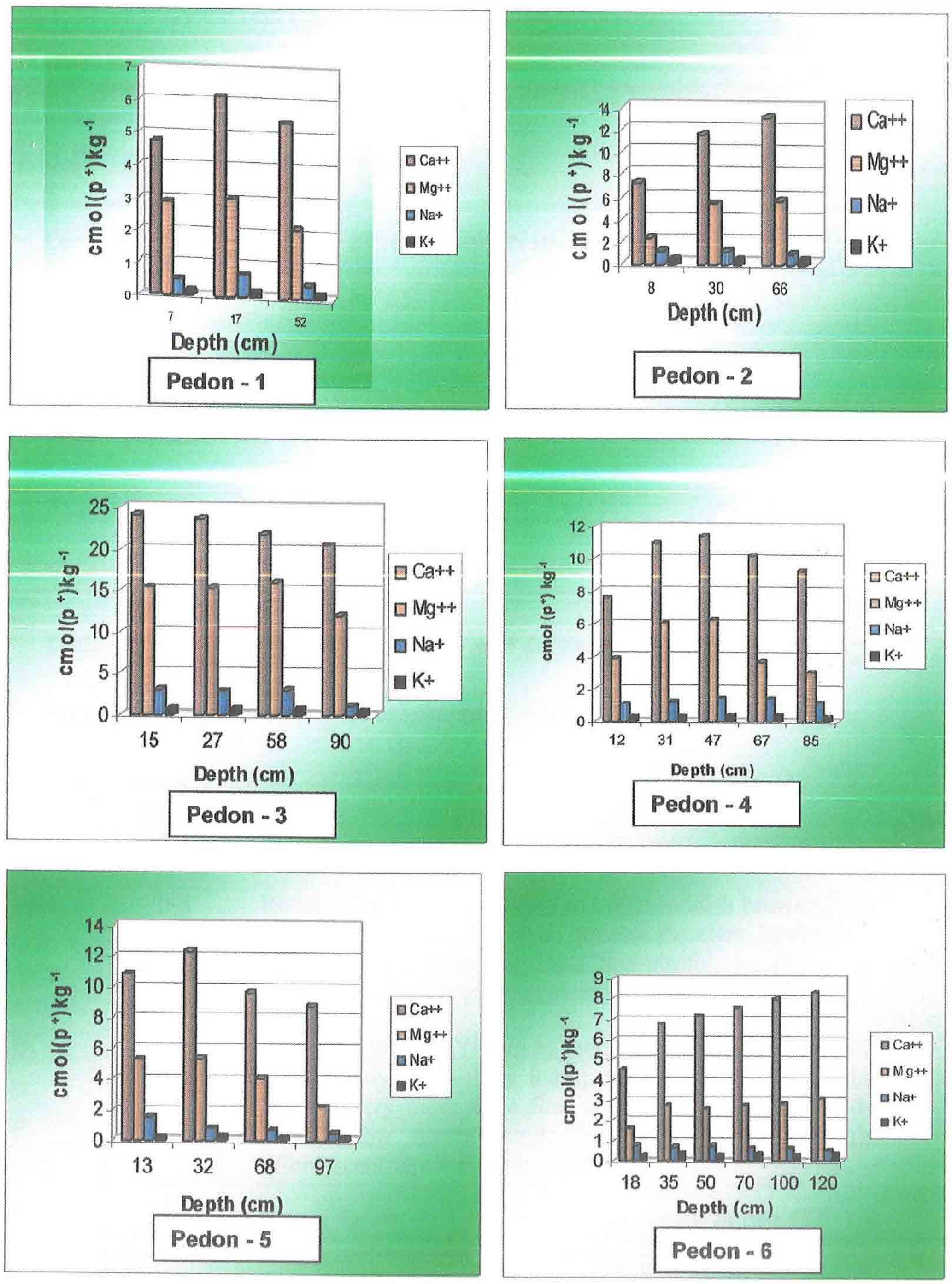

Fig.9a : Depth wise distribution of exchangeable cations (Pedons 1-6) showed increase with increase in depth. Base saturation values varied from 80.02 (AC) to 85.17 (A2) per cent (Table 8c).

4.2.2 Pedon – 2 (Dagala-3 series) – "Loamy skeletal kaolinitic hyperthermic Typic Haplocambids"

4.2.2.1 Description of typifying pedon

Location	:	23° 17' 34.20" N latitude 69° 55' 51.6" E longitude
Physiography	:	Lower foot slopes
Parent material	:	Lime stone
Slope	:	5-10%
Erosion	:	Moderately eroded
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp
Present land use	:	Scrub land

Horizon	Depth (cm)	Morphological description
A1	0-8	Reddish brown (5 YR 4/4M) and light reddish brown (5 YR 6/4D); sandy loam; fine weak massive structure; loose(Dry), loose (Moist), non-sticky and non-plastic; common fine pores; slightly effervescent; clear smooth boundary.
BCw1	8-30	Strong brown (7.5 YR 5/6 M) and strong brown (7.5 YR 4/6 D); gravelly sandy clay loam; coarse strong sub angular blocky; very hard, very firm, slightly sticky and slightly plastic; few disseminated fine lime nodules; strongly effervescent; gradual wavy boundary.
BCw2	30-66	Strong brown (7.5 YR 5/6M) and strong brown (7.5 YR 4/6D); gravelly clay loam; coarse strong angular blocky; extremely hard, extremely firm, slightly sticky and slightly plastic; many disseminated fine lime nodules; strongly effervescent.
C	66+	weathered parent material

4.2.2.2 Morphometric characteristics

This pedon was moderately deep, (66 cm) with 3 horizons (AP, BCw1, BCw2 and C). The colour of these soils varied from reddish brown (5 YR 4/4 M) in surface to strong brown (7.5 YR 5/6 M) in subsurface horizons. The consistency was loose in surface horizon under both dry and moist conditions and became harder down the profile. This difference in consistency was observed under wet conditions also as it was non-sticky and non-plastic in surface horizon while slightly sticky and slightly plastic in BCw1 and BCw2 horizons. Strong effervescence was observed in sub surface horizons. Boundary was clear smooth at surface and gradual wavy boundary at subsurface layers (Table 9a).

4.2.2.3 Physical, physio-chemical and chemical properties

The physical, physico-chemical and chemical properties are shown in Table 9b. The sand contents varied from 63.93 to 76.26 per cent. It decreased with depth. Higher sand content was observed in Ap horizon (76.26%) while the sand content was lower in BCw2 horizon (63.93%). Silt contents varied from 4.21 (Ap) to 11.92 (BCw2) per cent while clay content ranged from 19.53 (Ap) to 24.15 (BCw2) per cent. Silt and clay content showed increased trend with depth. The texture of the soil was sandy loam in the surface horizon and sandy clay loam in the subsurface horizons. The organic carbon content varied from 0.171 (BCw2) per cent to 0.241 per cent (Ap). Organic carbon decreased with depth. Calcium carbonate content increased with depth with the highest value in BCw2 horizon (5.73%). Salinity (EC) varied from 2.14 to 2.24 dSm^{-1}. Soil reaction (pH) increased with depth in a range of 7.39 to 7.71 and the highest value was noticed in Ap horizon.

Table 9a: Morphometric characteristics of typifying pedon in Dagala-3 series (Pedon-2)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-8	5YR 4/4	5YR 6/4	f	1	m	l	l	s_0 p_0	e	c	s
BCw1	8-30	7.5YR 5/6	7.5YR 4/6	c	3	sbk	vh	vfi	s_s p_s	es	g	w
BCw2	30-66	7.5YR 5/6	7.5YR 4/6	c	3	abk	eh	efi	s_s p_s	es	-	-
C	66+	Weathered parent material										

Table 9b: Physical, physico-chemical and chemical properties of typifying pedon in Dagala- 3 series (Pedon-2)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-8	7.39	2.23	76.26	4.21	19.53	sl	0.241	3.20	0.010
BCw1	8-30	7.52	2.24	68.21	9.00	22.79	scl	0.221	4.86	0.016
BCw2	30-66	7.71	2.14	63.93	11.92	24.15	scl	0.171	5.73	0.020
C	66+	Weathered parent material								

Table 9c: Ion exchange properties of typifying pedon in Dagala- 3 series (Pedon-2)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-8	7.28	2.24	1.1	0.24	11.25	10.13	96.53
BCw1	8-30	11.58	5.33	1.15	0.30	20.51	6.26	89.52
BCw2	30-66	13.15	5.58	0.88	0.32	23.58	4.41	84.52
C	66+	Weathered parent material						

4.2.2.4 Ion exchange properties

The content of exchangeable calcium was highest in BCw2 horizon (13.15 cmol (p+)kg^{-1}) with a range from 7.28 to 13.15 cmol(p+)kg^{-1}. Mean contents of exchangeable Mg^{++}, Na^{+} and K^{+} were 4.35, 1.04 and 0.28 cmol(p+)kg^{-1}, respectively. The values of exchangeable ions were in the order $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ in all horizons. ESP decreased with increasing depth; the highest value being observed in Ap horizon (10.13%). Cation exchange capacity ranged in-between 11.25 and 23.58 cmol(p^{+})kg^{-1} with the highest value being observed in BCw2 horizon. Base saturation values ranged from 84.52 to 96.53 per cent showing a decrease down the profile (Table 9c).

4.2.3 Pedon – 3 (Amrutanagar series) – "Fine smectitic hyperthermic Vertic Haplocambids"

4.2.3.1 Description of typifying pedon

Location	:	23° 16' 24" N latitude 69° 59' 37.2" E longitude
Physiography	:	Pediment with slight erosion
Parent material	:	Limestone
Slope	:	1-3%
Erosion	:	Slightly eroded
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp, ber
Present land use	:	Cultivated land (Single crop)

Horizon	Depth (cm)	Morphological description
Ap	0-15	Brown (10 YR 4/3 M) and yellowish brown (10 YR 5/4 D); clay; medium moderate subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; fine common pores; fine common roots; strongly effervescent; clear smooth boundary.
B_1	15-27	Brown (10 YR 4/3 M) and yellowish brown (10 YR 5/4 D); clay; medium moderate subangular blocky structure with shiny pressure faces; hard, friable, slightly sticky and slightly plastic; few fine pores, few disseminated very fine, lime nodules; strongly effervescent; clear wavy boundary.
B_2	27-58	Brown (10 YR 4/3M) and yellowish brown (10 YR 5/4 D); clay; coarse moderate subangular blocky structure with shiny pressure faces; hard, firm, sticky and plastic; fine common nodules; violently effervescent; clear wavy boundary.
BC	58-90	Brown (10 YR 4/3 M) and yellowish brown (10 YR 5/4 D); clay; coarse moderate subangular blocky structure with shiny pressure faces; hard, firm, sticky and plastic; violently effervescent.

4.2.3.2 Morphometric characteristics

This pedon was moderately deep (90 cm depth) and had four horizons viz. Ap, B1, B2 and BC. These soils were brown in colour in all horizons (10 YR 4/3 M). Structure was medium, moderate and subangular blocky in Ap and B1 horizons whereas coarse, moderate and subangular blocky in remaining horizons. Cracks of more than 5 mm wide upto a depth of 40 cm and slicken sides in the sub-surface horizons were observed. Consistency was slightly hard, very friable to friable and slightly sticky and slightly plastic upto a depth of 27 cm and hard, firm sticky and plastic in lower layers. Effervescence was strong upto 27 cm depth (Ap and B1 horizons) and was violent in deeper horizons. Clear smooth boundary was observed in surface horizon while clear wavy boundary was observed in sub surface horizons (Table 10a).

Table 10a: Morphometric characteristics of typifying pedon in Amrutanagar series (Pedon-3)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-15	10YR 4/3	10YR 5/4	m	2	sbk	sh	vfr	s_s p_s	es	c	s
B1	15-27	10YR 4/3	10YR 5/4	m	2	sbk	h	fr	s_s p_s	es	c	w
B2	27-58	10YR 4/3	10YR 5/4	c	2	sbk	h	fi	s p	ev	c	w
BC	58-90	10YR 4/3	10YR 5/4	c	2	sbk	h	fi	s p	ev	-	-

4.2.3.3 Physical, physico chemical and chemical properties

The physical, physico-chemical and chemical properties of pedon – 3 are presented in Table 10b and the range in characteristics are discussed below. Sand content varied from 29.13 per cent (Ap) to 38.15 per cent (BC) whereas silt and clay were high in the surface layers. The clay content was more than 45 per cent throughout the profile, which resulted in clayey textural class. A decreasing trend in organic carbon was observed with increase in depth showing the content of 0.51 per cent in the surface horizon. $CaCO_3$ content was more in bottom most horizon (6.85 %) with a range from 4.66 to 6.85. Gypsum per cent increased down the profile from 0.060 to 0.073 per cent. Increase in pH and salinity values were observed with depth. The pH ranged from 7.62 to 8.15 while EC from 1.48 to 1.82 dSm^{-1}

4.2.3.4 Ion exchange properties

Among the exchangeable cations, Ca^{2+} predominated followed by Mg^{2+} > Na^+ > K^+ and these were decreasing with increase in depth. Ca^{2+} and Mg^{2+} content ranged from 20.53 to 24.17 $cmol(p^+)kg^{-1}$ and 12.02 to 15.96 $cmol(p^+)kg^{-1}$, respectively. The Na^+ and K^+ values ranged from 1.12 to 2.94 and 0.49 to 0.68 $cmol(p^+)kg^{-1}$, respectively. Higher values of Ca^{2+} and K^+ in Ap horizon and Mg^{2+} and Na^+ in B2 horizon were found. Gradual decrease in CEC was observed down the profile with a range from 39.25 (BC horizon) to 48.18 (Ap horizon) $cmol(p^+)kg^{-1}$. ESP varied from 3.28 to 7.11 with highest value observed in B2 horizon. Similarly, base saturation also followed the trend of CEC with the highest value of 93.66 per cent in B2 horizon (Table 10c).

Table 10b: Physical, physico-chemical and chemical properties of typifying pedon in Amrutanagar series (Pedon-3)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-15	7.62	1.48	29.13	18.38	52.49	c	0.510	5.15	0.060
B1	15-27	7.88	1.53	32.86	15.01	52.13	c	0.412	4.66	0.065
B2	27-58	8.10	1.71	36.00	14.00	50.00	c	0.305	6.36	0.071
BC	58-90	8.15	1.82	38.15	16.23	45.62	c	0.225	6.85	0.073

Table 10c: Ion exchange properties of typifying pedon in Amrutanagar series (Pedon-3)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-15	24.17	15.40	2.92	0.68	48.18	6.76	89.60
B1	15-27	23.60	15.25	2.86	0.65	47.00	6.75	91.19
B2	27-58	21.87	15.96	2.94	0.58	44.15	7.11	93.66
BC	58-90	20.53	12.02	1.12	0.49	39.25	3.28	87.03

4.2.4 Pedon – 4 (Dhaneti-1 series) – "Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids"

4.2.4.1 Description of typifying pedon

Location	:	23°16'3.6" N latitude 69°57'40.2" E longitude
Physiography	:	Pediment
Parent material	:	Limestone
Slope	:	1-3%
Erosion	:	Moderate
Drainage	:	Well drained
Natural vegetation	:	*Prosophis juliflora*
Present land use	:	Scrub land

Horizon	Depth (cm)	Morphological description
A	0-12	Brown (7.5 YR 4/3M) and brown (7.5 YR 4/4 D); sandy loam; moderate medium subangular blocky; loose, very friable, non-sticky and non-plastic; common fine pores; few very fine roots; few disseminated fine lime nodules; strongly effervescent; clear smooth boundary.
Bw1	12-31	Very dark yellowish brown (10 YR 3/2 M); dark yellowish brown (10 YR 4/2 D); sandy clay loam, moderate medium sub angular blocky; slightly hard, friable, slightly sticky and non-plastic; few very fine pores; many disseminated fine lime nodules; violently effervescent; clear smooth boundary.
Bw2	31-47	Dark Yellowish brown (10 Y R 4/6 M) and dark Yellowish brown (10 Y R 4/4 D); sandy clay loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many indurated fine lime nodules; violently effervescent; abrupt smooth boundary.

Bw3k	47-67	Brown (10 YR 5/3 M) and brown (10 YR 5/3 D); sandy clay loam; fine weak subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; coarse fragments coated with powdery lime and few indurated lime nodules, violently efferevescent; gradual wavy boundary.
BCk	67-85	Yellowish brown (10 YR 5/6 M) and dark yellowish brown (10 YR 4/6 D); sandy loam; weak fine granular structure; hard, firm, slightly sticky and non-plastic; coarse fragments coated with powdery lime and few indurated lime nodules; violently effervescent.

4.2.4.2 Morphometric characteristics

This pedon had a depth of 85 cm which was divided into 5 horizons viz. Ap, Bw1, Bw2, Bw3k, BCk based on morphological and chemical properties. The colour of the soil was brown (7.5 YR 4/3) in the surface horizon and yellowish brown to dark yellowish brown (10 YR 3/2, 4/6, 5/3 and 5/6 in the sub surface horizons. The structure was medium, moderate, subangular blocky upto a depth of 47 cm, fine weak subangular blocky in Bw3k horizon and was fine weak granular in bottom most horizon. Consistency was loose, very friable, non-sticky and non-plastic in the surface horizon. It became slightly hard, friable, slightly sticky and slightly plastic down the profile and was hard, firm, slightly sticky and non-plastic in last horizon. Strong effervescence was observed in Ap horizon and was violent in all the remaining horizons with its intensity increasing down the profile. The boundary was clear, smooth upto a depth of 31 cm, abrupt, smooth in Bw2 horizon followed by gradual wavy in penultimate horizon (Table 11a).

4.2.4.3 Physical, physico-chemical and chemical properties

Sand was more in surface horizon (74.01%) and it ranged from 66.56 to 74.01 per cent. Silt varied from 9.17 to 10.30 per cent and clay varied from 16.82 to 23.86

Table 11a: Morphometric characteristics of typifying pedon in Dhaneti-1 series (Pedon-4)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-12	7.5YR 4/3	7.5YR 4/4	m	2	sbk	l	vfr	s_0 p_0	es	c	s
Bw1	12-31	10YR 3/2	10YR 4/2	m	2	sbk	sh	fr	s_s p_0	ev	c	s
Bw2	31-47	10YR 4/6	10YR 4/4	m	2	sbk	sh	fr	s_s p_s	ev	a	s
Bw3k	47-67	10YR 5/3	10 YR5/3	f	1	sbk	sh	vfr	s_s p_s	ev	g	w
BCk	67-85	10YR 5/6	10YR 4/6	f	1	g	h	fi	s_s p_0	ev	-	-

per cent and the highest content of clay was observed in Bw2 horizon. This composition of soil separates resulted in sandy loam texture in surface horizon and sandy clay loam texture in the subsurface horizons. Organic carbon decreased down the profile from 0.389 to 0.196 per cent whereas $CaCO_3$ increased with depth with a range from 8.56 to 18.26 per cent. The range of gypsum content was from 0.019 to 0.048 per cent. Salinity was more in the surface horizon (2.34 dSm^{-1}) and decreased with the depth showing EC values ranging from 2.34 to 2.18 dSm^{-1}. pH ranged from 7.52 to 7.70 with highest value in bottom most horizon (Table 11b).

4.2.4.4 Ion exchange properties

Among the exchangeable cations, Ca^{2+} was higest followed by $Mg^{2+} > Na^+ > K^+$ with higher contents of all cations observed in Bw2 horizon (Table 11c). CEC ranged form 14.13 to 21.72 $cmol(p^+)kg^{-1}$ with its highest value in Bw2 horizon. ESP ranged from 6.62 to 9.12 and base saturation decreased with the depth showing variation from 87.21 to 91.08 per cent.

4.2.5 Pedon – 5 (Kanyabe-2 series) – "Loamy skeletal kaolinitic hyperthermic Typic Haplocambids"

4.2.5.1 Description of typifying pedon

Location	:	23° 16\` 20.4" N latitude
		69° 58\` 39.6" E longitude
Physiography	:	Pediment
Parent material	:	Limestone
Slope	:	3-4 %
Erosion	:	Very slightly eroded

Table 11b: Physical, physico-chemical and chemical properties of typifying pedon in Dhaneti-1 series (Pedon-4)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-12	7.52	2.34	74.01	9.17	16.82	Sl	0.389	8.56	0.019
Bw1	12-31	7.60	2.33	67.65	10.30	22.05	scl	0.345	10.23	0.026
Bw2	31-47	7.56	2.33	66.56	9.58	23.86	scl	0.295	12.56	0.031
Bw3k	47-67	7.62	2.30	69.43	9.89	20.68	scl	0.228	17.18	0.033
BCk	67-85	7.70	2.18	72.67	10.16	17.17	sl	0.196	18.26	0.048

Table 11c: Ion exchange properties of typifying pedon in Dhaneti- 1 series (Pedon-4)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-12	7.59	3.86	1.10	0.32	14.13	8.55	91.08
Bw1	12-31	10.96	6.04	1.23	0.35	20.63	6.62	90.06
Bw2	31-47	11.35	6.26	1.45	0.40	21.72	7.45	89.59
Bw3k	47-67	10.15	3.68	1.43	0.42	17.98	9.12	87.21
BCk	67-85	9.21	3.06	1.20	0.35	15.58	8.68	88.70

Drainage	:	Well drained
Natural vegetation	:	*Prosophis* sp.
Present land use	:	Partly cultivated and partly waste land with *Prosophis* sp.

Horizon	Depth (cm)	Morphological description
A1	0-13	Brown (10 YR 4/3 M) and yellowish brown (10 YR 5/4 D); sandy loam; fine weak subangular blocky; soft, very friable, non-sticky and non-plastic; common fine pores; few fine roots; few disseminated fine lime nodules; strongly effervescent; clear smooth boundary.
AC	13-32	Brown (10 YR 4/3 M); yellowish brown (10 YR 5/4 D); sandy clay loam; moderate medium subangular blocky; slightly hard, very friable, non-sticky and non-plastic; few fine pores; few disseminated fine lime nodules; strongly effervescent; clear wavy boundary.
C2	32-68	Yellowish brown (10 YR 5/6 M) and dark yellowish brown (10 YR 4/6 D); gravelly sandy loam; medium weak sub angular blocky structure; slightly hard, very friable, non-sticky and non-plastic; many indurated fine lime nodules; violently effervescent; gradual wavy boundary.
C3	68-97	Yellowish brown (10 YR 5/6 M) and dark yellowish brown (10 YR 4/6 D);gravelly loamy sand; medium weak subangular blocky structure; soft, very friable, non-sticky and non-plastic; many indurated lime nodules; violently effervescent.

4.2.5.2 Morphometric characteristics

This pedon was 97 cm deep with four horizons (Viz. A1, AC, C2 and C3. The colour was brown (10 YR 4/3 M) upto a depth of 32 cm and yellowish brown (10 YR 5/6 M) from 32-97 cm. Structure was fine weak subangular blocky in A1 horizon, while medium moderate subangular blocky and medium weak and subangular blocky in last two horizons. Consistence was soft, very friable, non sticky and non plastic throughout the profile except slightly hard in AC and C2 horizons. Strong effervescence was noticed upto a depth of 32 cm and it became violent in lower layers. Boundary was clear smooth in surface horizon, clear wavy in AC horizon, followed by gradual and wavy boundary in C2 horizon (Table 12a).

4.2.5.3 Physical, physico-chemical and chemical properties

The physical, physico-chemical and chemical properties of Kanyabe-2 series are presented in Table 12b. Sand content increased with increase in depth and ranged from 70.74 to 80.15 per cent while silt content and clay contents showed irregular trends with depth. More content of silt was observed in A1 horizon (9.63%) and more content of clay in AC horizon (21.82%). Texture was sandy loam in surface horizon and was sandy clay loam in AC horizon. Organic carbon decreased down the profile with a range from 0.483 (A1) to 0.195 per cent (C3). $CaCO_3$ increased with depth with 11.90 per cent observed from 32 cm depth onwards. Gypsum content varied from 0.058 to 0.088 per cent pH ranged from 7.63 to 8.10 and EC ranged from 2.34 to 2.77 dSm^{-1} (Table 12b).

4.2.5.4 Ion exchange properties

Ca^{2+} content was highest among total exchangeable cations and all cations are more in AC horizon except Na^{+}. CEC ranged from 12.12 to 19.93 cmol(p+)kg^{-1} with its maximum value in AC horizon. ESP was more in surface horizon and ranged from 4.43 to 8.66. Base saturation varied from 93.49 to 96.53 per cent with more content in last horizon (Table 12c).

Table 12a: Morphometric characteristics of typifying pedon in Kanyabe-2 series (Pedon-5)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
A1	0-13	10YR 4/3	10YR 5/4	f	1	sbk	s	vfr	s_0 p_0	es	c	s
AC	13-32	10YR 4/3	10YR 5/4	m	2	sbk	sh	vfr	s_0 p_0	es	c	w
C2	32-68	10YR 5/6	10YR 4/6	m	1	sbk	sh	vfr	s_0 p_0	ev	g	w
C3	68-97	10YR 5/6	10YR 4/6	m	1	sbk	s	vfr	s_0 p_0	ev	-	-

Table 12b: Physical, physico-chemical and chemical properties of typifying pedon in Kanyabe-2 series (Pedon-5)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
A1	0-13	7.63	2.77	70.74	9.63	19.63	sl	0.483	7.50	0.058
AC	13-32	7.87	2.45	73.17	5.01	21.82	scl	0.385	7.92	0.065
C2	32-68	8.05	2.39	78.27	3.49	18.24	sl	0.220	11.90	0.074
C3	68-97	8.10	2.34	80.15	5.22	14.63	ls	0.195	11.90	0.088

Table 12c: Ion exchange properties of typifying pedon in Kanyabe-2 series (Pedon-5)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
A1	0-13	10.85	5.26	1.55	0.22	18.59	8.66	96.18
AC	13-32	12.33	5.34	0.83	0.25	19.93	4.43	94.08
C2	32-68	9.65	4.10	0.70	0.21	15.68	4.77	93.49
C3	68-97	8.76	2.25	0.52	0.17	12.12	4.44	96.53

4.2.6 Pedon – 6 (Kanyabe-1 series) – "Coarse loamy kaolinitic hyperthermic Typic Haplocalcids"

4.2.6.1 Description of typifying pedon

Location	:	23° 17' 34.38" N latitude 69° 59' 36.72" E longitude
Physiography	:	Nearly levelled pediplain
Parent material	:	Alluvium
Slope	:	1-3%
Erosion	:	Slight
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis sp*
Present land use	:	Cultivated land (single crop)

Horizon	Depth (cm)	Morphological description
Ap	0-18	Dark yellowish brown (10 YR 4/6 M) and yellowish brown (10YR 5/4 D); sandyloam; fine weak crumby structure; soft, very friable, non-sticky and non-plastic; few fine roots; disseminated fine lime nodules; strongly effervescent; gradual smooth boundary.
B1	18-35	Brown (7.5 YR 4/3 M) and yellowish brown (10 YR 5/4 D); sandy loam; medium moderate crumby structure; slightly hard, friable, slightly sticky and non-plastic; disseminated few fine lime nodules; violently effervescent; clear wavy boundary.
B2	35-50	Brown (7.5 YR 4/3 M); yellowish brown (10 YR 5/4 D); sandy loam; moderate medium subangular blocky; hard, firm, slightly sticky and slightly plastic; disseminated few fine lime nodules; violently effervescent; clear wavy boundary.
Bk1	50-70	Brown (7.5 YR 4/3 M); yellowish brown (10 YR 5/4 D); sandy loam; moderate medium subangular blocky; hard,

		firm, slightly sticky and slightly plastic; many medium indurated lime nodules; violently effervescent; gradual smooth boundary.
Bk2	70-100	Brown (7.5 YR 4/3 M); yellowish brown (10 YR 5/4 D); sandy loam; moderate medium subangular blocky; hard, firm, slightly sticky and slightly plastic; violently effervescent; clear wavy boundary
BCk	100-120	Yellowish brown (10 YR 5/6 M); yellowish brown (10 YR 5/6 D); sandy loam; medium weak massive; hard, firm, non-sticky and non-plastic; many medium indurated lime nodules; violently effervescent.

4.2.6.2 Morphometric characteristics

This pedon was 120 cm deep with six horizons viz. Ap, B1, B2, Bk1, Bk2 and BCk. Colour was dark yellowish brown (10 YR 4/6 M) in the surface horizon while it was brown (7.5 YR 4/3 M) in sub-surface horizon. Last horizon was yellowish brown (10 YR 5/6 M). Structure was fine, weak and crumby in surface horizon, medium and moderate upto Bk2 horizon but was crumby upto B2 horizon and subangular blocky structure in Bk1 and Bk2 horizons. In last horizon, it was medium, weak and massive. Consistence was soft, very friable, non-sticky and non-plastic in Ap horizon and turned hard, firm slightly sticky and slightly plastic down the profile. However, it was non-sticky and non-plastic when wet in the last horizon. Strong effervescence was observed in surface horizon and more violent effervescence was noticed in sub surface horizons due to the presence of calcic horizon. Boundary was gradual smooth in surface horizon (upto 18 cm depth), clear wavy in all sub-surface horizons except gradual and smooth boundary in Bk1 horizon (Table 13a).

4.2.6.3 Physical, physico-chemical and chemical properties

Sand ranged from 68.10 (Bk1) to 77.08 per cent (Ap) while silt and clay ranged from 11.79 (Ap) to 17.88 (BCk) and 11.13 (Ap) to 16.65 (Bk1) per cent,

Table 13a: Morphometric characteristics of typifying pedon in Kanyabe-1 series (Pedon-6)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-18	10YR 4/6	10YR 5/4	f	1	cr	s	vfr	s_0 p_0	es	g	s
B1	18-35	7.5YR 4/3	10 YR 5/4	m	2	cr	sh	fr	s_s p_0	ev	c	w
B2	35-50	7.5YR 4/3	10 YR 5/4	m	2	cr	h	fi	s_s p_s	ev	c	w
Bk1	50-70	7.5YR 4/3	10 YR 5/4	m	2	sbk	h	fi	s_s p_s	ev	g	s
Bk2	70-100	7.5YR 4/3	10 YR 5/4	m	2	sbk	h	fi	s_s p_s	ev	c	w
BCk	100-120	10YR 5/6	10YR5/6	m	1	m	h	fi	s_0 p_0	ev	-	-

respectively. The texture was sandy loam throughout the profile. Organic carbon ranged from 0.170 to 0.212 per cent and showed a decreasing trend with an increase in depth. $CaCO_3$ ranged from 9.59 to 18.26 per cent and calcic horizon (> 15 %) was noticed at a depth of 50 cm and above. Gypsum increased gradually from 0.020 to 0.029 per cent with depth (Table 13b). Irregular trend was observed for pH with a range from 7.97 to 8.31 while gradual decrease in EC was noticed with a range from 1.00 to 1.98 dSm^{-1}.

4.2.6.4 Ion exchange properties

Among the exchangeable cations, $Ca^{2+}$and Mg^{2+}increased with depth whereas Na^{+} and K^{+} followed irregular trends with depth. Ca^{2+} and Mg^{2+} ranged from 4.53 to 8.34 and 1.65 to 3.06 $cmol(p^{+})kg^{-1}$, respectively. Na^{+} and K^{+} ranged from 0.55 to 0.78 and 0.30 to 0.40 $cmol(p^{+})kg^{-1}$, respectively. Highest contents of Na^{+} were noticed in Ap and B2 horizons while that of K^{+} maximum was observed in BCk horizon. CEC varied from 9.8 to 14.15 $cmol(p^{+})kg^{-1}$ with its highest value in Bk1 horizon. ESP decreased down the profile and it was less than 15 throughout the profile. Base saturation varied from 74.08 to 86.78 per cent with its maximum value associated in Bk2 horizon (Table 13c).

4.2.7 Pedon - 7 (Dhaneti-2 series) – "Coarse loamy kaolinitic hyperthermic Typic Haplocambids"

4.2.7.1 Description of typifying pedon

Location	:	23° 15` 10.6" N latitude
		69° 55` 25.2" E longitude
Physiography	:	Nearly levelled pediplain

Table 13b: Physical, physico-chemical and chemical properties of typifying pedon in Kanyabe-1 series (Pedon-6)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-18	7.97	1.98	77.08	11.79	11.13	sl	0.212	9.59	0.020
B1	18-35	8.10	1.72	71.02	13.78	15.20	sl	0.201	10.23	0.021
B2	35-50	8.22	1.53	68.45	15.15	16.40	sl	0.181	13.45	0.023
Bk1	50-70	8.10	1.25	68.10	15.25	16.65	sl	0.180	16.15	0.026
Bk2	70-100	8.20	1.10	70.05	13.83	16.12	sl	0.174	17.58	0.027
BCk	100-120	8.31	1.00	69.00	17.88	13.12	sl	0.170	18.26	0.029

Table 13c: Ion exchange properties of typifying pedon in Kanyabe-1 series (Pedon- 6)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-18	4.53	1.65	0.78	0.30	9.8	10.74	74.08
B1	18-35	6.76	2.73	0.70	0.38	12.6	6.62	83.88
B2	35-50	7.15	2.74	0.78	0.35	13.0	7.18	83.54
Bk1	50-70	7.56	2.76	0.69	0.37	14.15	6.06	80.42
Bk2	70-100	7.98	2.85	0.63	0.36	13.63	5.33	86.78
BCk	100-120	8.34	3.06	0.55	0.4	11.53	4.45	86.36

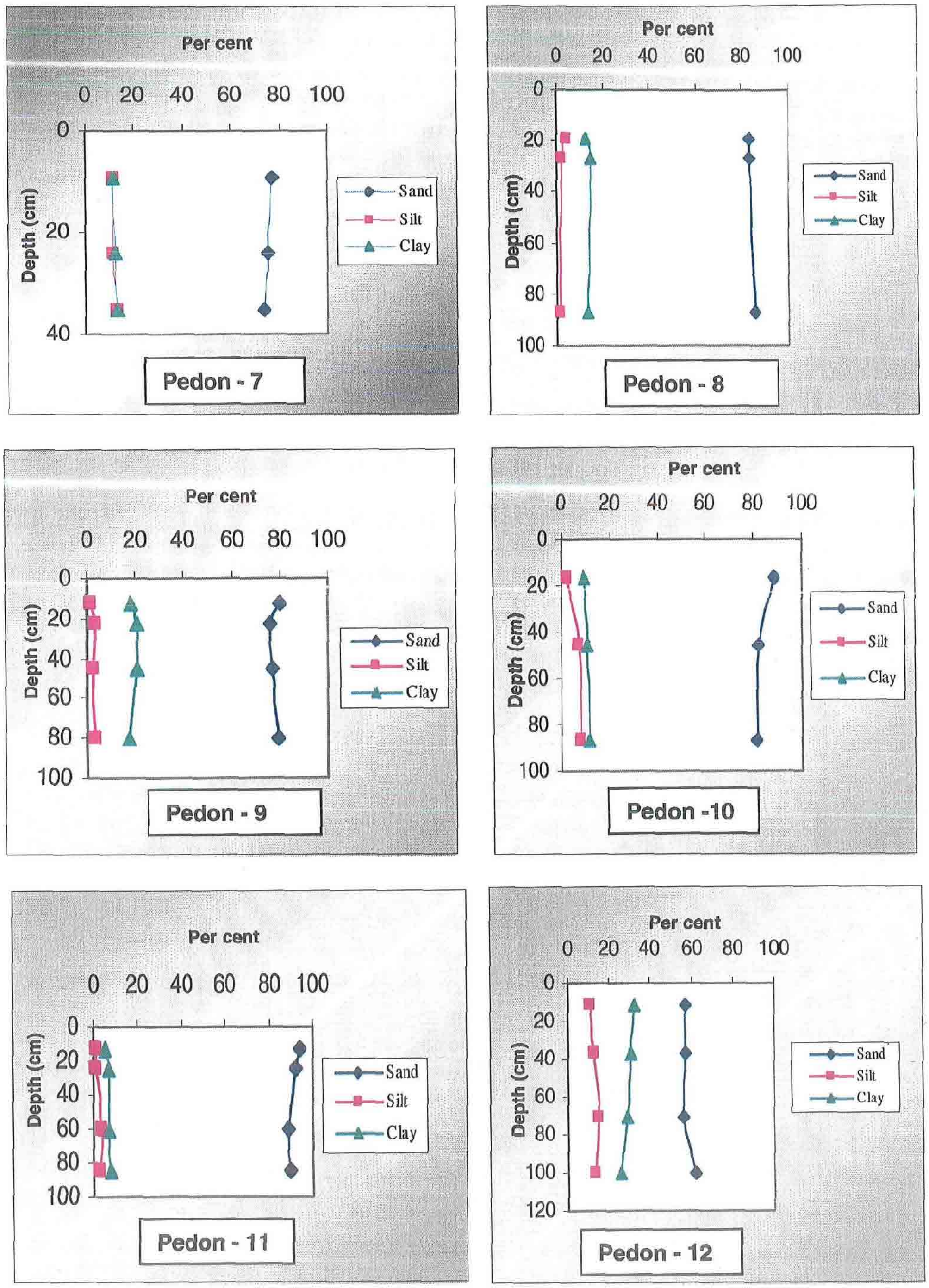

Fig.8b : Depth wise distribution of soil particles (Pedons 7-12)

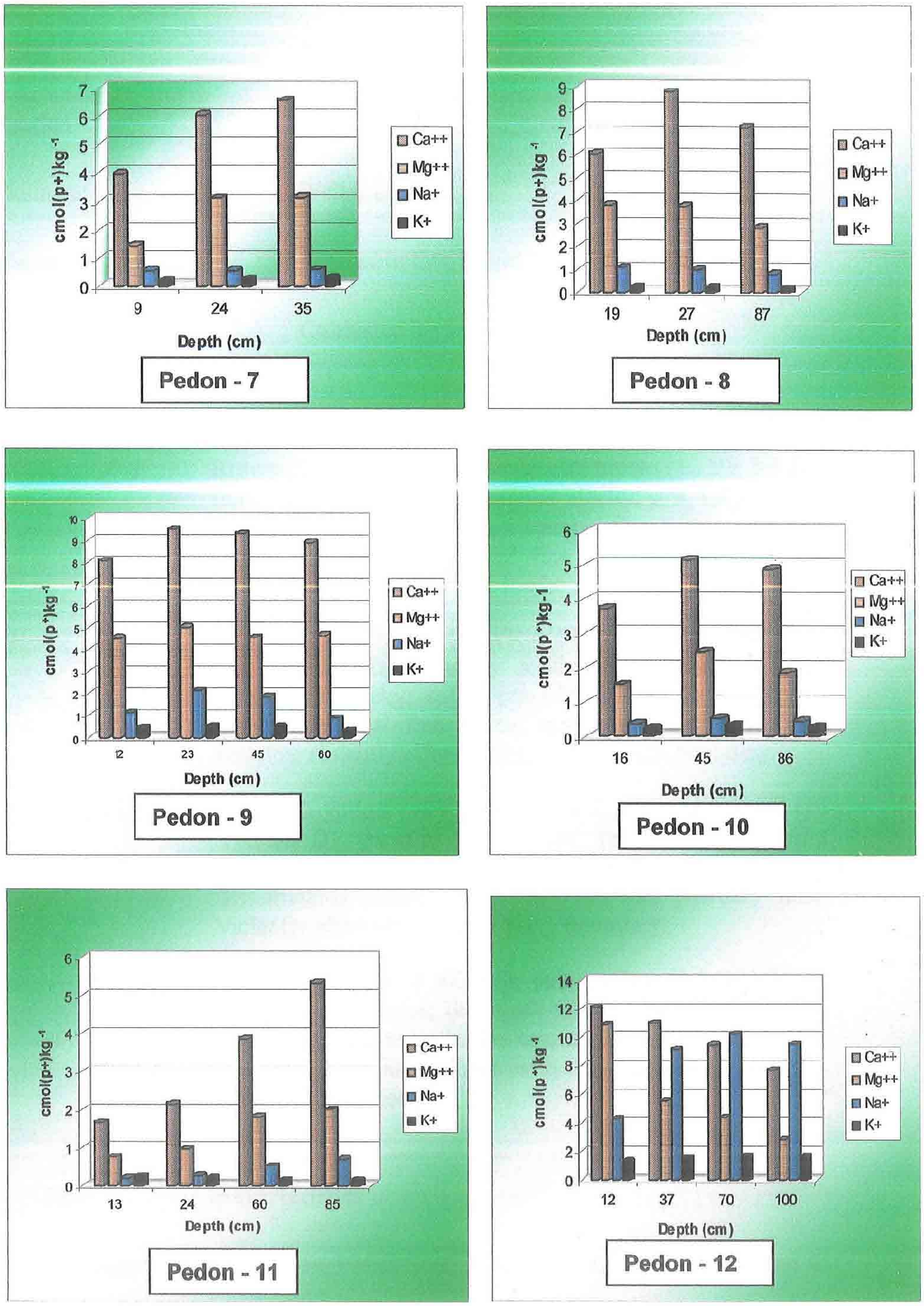

Fig.9b : Depth wise distribution of exchangeable cations (pedons 7-12)

Parent material	:	Lime stone
Slope	:	1-3%
Erosion	:	Slight
Drainage	:	Well drained
Natural vegetation	:	*Prosophis,* Ber, Neem
Present land use	:	Cultivated land (single crop)

Horizon	Depth (cm)	Morphological description
Ap	0-9	Brown (10 YR 4/3 M) and yellowish brown (10 YR 5/4 D); sandy loam; fine weak subangular blocky; soft, very friable, non-sticky and non-plastic; common fine pores; common fine roots; few disseminated fine lime nodules; strongly effervescent; clear smooth boundary
AC1	9-24	Dark yellowish brown (10 YR 4/4 M) and yellowish brown (10 YR 5/4 D); gravelly sandy loam; medium weak subangular blocky; soft, very friable, slightly sticky and non-plastic; few fine pores; many indurated fine lime nodules; violently effervescent; clear smooth boundary.
ACk	24-35	Brownish yellow (10YR 4/6 M) and yellowish brown (10 YR 5/6 D); gravelly sandy loam; fine weak subangular blocky; soft, very friable, slightly sticky and non-plastic; disseminated indurated lime nodules and powdery lime; violently effervescent; clear wavy boundary.
C	35-66	Pale yellow (2.5 Y 8/3 M); pale yellow (2.5 Y 8/2 D); gravelly sandy loam; fine weak massive; soft, very friable, non-sticky and non-plastic; coarse fragments coated with powdery lime and mixed with indurated lime nodules; violently effervescent.

4.2.7.2 Morphometric characteristics

This pedon was 66 cm deep with four horizons – Ap, AC1, ACk and C. Colour was brown (10 YR 4/3 M) in the surface horizon and was pale yellow (2.5Y 8/3) in last horizon through dark yellowish brown (10 YR 4/4 M) and brownish yellow (10 YR 4/6 M) in AC1 and ACk horizons. Structure was fine weak subangular blocky upto a depth of 35 cm and massive in bottom most horizon. Consistence was soft, very friable, non- sticky and non-plastic throughout the profile but slightly sticky in AC1 and ACk horizons. Effervescence was strong in the surface horizon and violent in the sub surface horizons. Boundary was clear and smooth upto a depth of 24 cm and clear and wavy in ACk horizon (Table 14a).

4.2.7.3 Physical, physico-chemical and chemical properties

The physical, physico-chemical and chemical properties of Dhaneti-2 series are presented in Table 14b. Sand ranged from 74.05 to 77.10 per cent and reduced down the profile whereas clay and silt increased with depth showing a range from 11.12 to 13.15 and 11.70 to 12.80 per cent, respectively. Texture was sandy loam throughout the profile. Organic carbon ranged from 0.283 to 0.198 per cent from Ap to last horizon whereas $CaCO_3$ content increased down the profile with its highest value in ACk horizon (17.52%). Gypsum varied from 0.020 to 0.030 per cent. Variation in pH was observed from 7.74 to 7.86 while variation in EC was noticed from 2.47 to 2.77 dSm^{-1} in these soils.

4.2.7.4 Ion exchange properties

All exchangeable cations increased with increase in depth showing the decreasing of contents $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. CEC also increased with depth and ranged from 8.00 to 11.85 $cmol(p^{+})kg^{-1}$. ESP varied from 5.48 to 8.78, highest value being seen in Ap horizon whereas base saturation varied from 76.87 to 90.45 per cent, highest being present in AC1 horizon (Table 14c).

Table 14a: Morphometric characteristics of typifying pedon in Dhaneti-2 series (Pedon-7)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-9	10YR 4/3	10YR 5/4	f	1	sbk	s	vfr	$s_0 p_0$	es	c	s
AC1	9--24	10YR 4/4	10YR 5/4	m	1	sbk	s	vfr	$s_s p_0$	ev	c	s
ACk	24-35	10YR 4/6	10YR 5/6	f	1	sbk	s	vfr	$s_s p_0$	ev	c	w
C	35-66	2.5Y 8/3	2.5Y 8/2	f	1	m	s	vfr	$s_0 p_0$	ev	-	-

Table 14b: Physical, physico-chemical and chemical properties of typifying pedon in Dhaneti-2 series (Pedon-7)

Horizon	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-9	7.74	2.77	77.10	11.78	11.12	sl	0.283	6.40	0.020
AC1	9-24	7.86	2.56	75.72	11.70	12.58	sl	0.241	11.12	0.022
ACk	24-35	7.77	2.47	74.05	12.80	13.15	sl	0.198	17.52	0.030
C	35-66	Weathered parent material								

Table 14c: Ion exchange properties of typifying pedon in Dhaneti-2 series (Pedon-7)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-9	3.96	1.45	0.54	0.20	8.00	8.78	76.87
AC1	9-24	6.05	3.12	0.55	0.23	11.00	5.53	90.45
ACk	24-35	6.58	3.16	0.58	0.26	11.85	5.48	89.28
C	35-66	Weathered parent material						

4.2.8 Pedon – 8 (Yoginagar-1 series) – "Sandy skeletal kaolinitic hyperthermic Typic Torriorthents"

4.2.8.1 Description of typifying pedon

Location	:	23^0 15` 19.2" N latitude $69^0$ 57` 27" E longitude
Physiography	:	Nearly levelled pediplain
Parent material	:	Lime stone
Slope	:	1-3%
Erosion	:	Moderately to severely eroded
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp
Present land use	:	Degraded uncultivable land or waste land with *Prosophis* sp.

Horizon	Depth (cm)	Morphological description
A1	0-19	Dark yellowish brown (10 YR 3/4 M) and dark yellowish brown (10 YR 4/4 D); loamy sand; medium moderate sub-angular blocky; soft very friable, non-sticky and non-plastic; few fine pores; very fine few disseminated lime nodules; few very fine roots; violently effervescent; clear smooth boundary.
AC	19-27	Dark yellowish brown (10 YR 4/6 M) and yellowish brown (10 YR 5/6 D); gravelly loamy sand; fine weak massive structure; loose, friable, non-sticky and non-plastic; many indurated lime nodules; violently effervescent; clear wavy boundary.
C	27-87	Yellow (10 YR 7/8M) and yellow (10 YR 7/6 D); gravelly loamy sand; coarse weak massive structure; loose (dry), loose (moist), non-sticky and non-plastic; weathered. hard limestone; violently effervescent.

4.2.8.2 Morphometric characteristics

The depth of this pedon was 87 cm which was divided into three horizons viz. A1, AC and C. This pedon showed dark yellowish brown (10 YR 4/3 M and 4/6 M) colour upto a depth of 27 cm and yellow (10 YR 7/8 M) colour in last horizon. Structure was medium moderate subangular blocky in surface horizon, weak and massive in sub surface horizons but fine in AC horizon and size became coarse in last horizon. Consistence was non-sticky and non-plastic when wet throughout the profile while soft (dry) and very friable (moist) in surface horizon and became loose down the profile. Effervescence was violent throughout the profile. More over, its intensity increased down the profile. Boundary was clear smooth in surface horizon whereas it was clear wavy in sub surface horizon (Table 15a).

4.2.8.3 Physical, physico-chemical and chemical properties

There was not much variation in sand and clay with depth and had a range from 83.12 to 85.65 per cent and 12.50 to 14.86 per cent, respectively. Silt ranged from 1.23 to 4.38; the highest content being present in A1 horizon. Hence, there was no change in texture throughout the profile and it is a loamy sand. Decrease in organic carbon with increase in depth was observed with a range from 0.243 to 0.195 per cent whereas increasing trend was observed in $CaCO_3$. The $CaCO_3$ and gypsum were varying from 7.66 to 11.64 per cent and 0.016 to 0.022 per cent, respectively. pH ranged from 7.75 to 7.85 with gradual increase down the profile while EC ranged from 1.80 to 2.29 dSm^{-1} with gradual increase with depth of the profile (Table 15b).

4.2.8.4 Ion exchange properties

Exchangeable Ca^{2+} and K^{+} were more in AC horizon while exchangeable Mg^{2+} and Na^{+} were more in surface horizon. The contents of exchangeable cations

Table 15a: Morphometric characteristics of typifying pedon in Yoginagar-1 series (Pedon-8)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
A1	0-19	10YR 3/4	10YR 4/4	m	2	sbk	s	vfr	$s_0 p_0$	ev	c	s
AC	19-27	10YR 4/6	10YR 5/6	f	1	m	l	fr	$s_0 p_0$	ev	c	w
C	27-87	10YR 7/8	10YR 7/6	c	1	m	l	l	$s_0 p_0$	ev	-	-

Table 15b: Physical, physico-chemical and chemical properties of typifying pedon in Yoginagar-1 series (Pedon-8)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
A1	0-19	7.75	2.29	83.12	4.38	12.50	ls	0.243	7.66	0.016
AC	19-27	7.83	2.21	83.19	1.95	14.86	ls	0.216	11.53	0.020
C	27-87	7.85	1.80	85.65	1.23	13.12	ls	0.195	11.64	0.022

Table 15c: Ion exchange properties of typifying pedon in Yoginagar-1 series (Pedon-8)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
A1	0-19	6.05	3.8	1.10	0.23	13.10	9.77	85.95
AC	19-27	8.75	3.76	1.00	0.24	15.25	7.27	90.16
C	27-87	7.23	2.85	0.82	0.19	14.98	7.39	74.03

followed the order: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. Calcium ($Ca^{2+}$) and K^{+} contents ranged from 6.05 to 7.23 cmol(p^{+})kg^{-1} and 0.19 to 0.24 cmol(p^{+})kg^{-1} whereas Mg^{2+} and Na^{+} ranged from 2.85 to 3.8 cmol(p^{+})kg^{-1} and 0.82 to 1.10 cmol(p^{+})kg^{-1}, respectively. CEC varied from 13.10 to 15.25 cmol(p^{+})kg^{-1} having maximum value noticed in AC horizon. Variation from 7.27 to 9.77 was observed in ESP values, which showed highest value in surface horizon. Base saturation ranged from 74.03 to 90.16 per cent with its maximum value being noticed in AC horizon (Table 15c).

4.2.9 Pedon – 9 (Dagala-1 series) – "Fine loamy smectitic hyperthermic Typic Haplocambids"

4.2.9.1 Description of typifying pedon

Location	:	23° 18` 06" N latitude
		69° 59` 16.2" E longitude
Physiography	:	Undulating pediplain
Parent material	:	Lime stone and sandstone
Slope	:	2-5%
Erosion	:	Slight
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp.
Present land use	:	Cultivated land (single crop)

Horizon	Depth (cm)	Morphological description
Ap	0-12	Strong brown (7.5 YR 4/6 M) and brown (7.5 YR 4/4 D); sandy loam; very fine weak massive; loose, very friable, non-sticky and non-plastic; few fine pores; few fine roots;

		few disseminated lime nodules; violently effervescent; clear smooth boundary
B1	12-23	Strong brown (7.5 YR 4/6 M) and brown (7.5 YR 4/4 D); sandy clay loam; fine weak subangular blocky structure; slightly hard, friable, non-sticky and non-plastic; few very fine pores; few disseminated fine lime nodules; violently effervescent; clear wavy boundary.
B2	23-45	Strong brown (7.5 YR 4/6M) and brown (7.5 YR 5/4 D); gravelly sandy clay loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; few indurated fine lime nodules; violently effervescent; clear irregular boundary.
BC	45-80	Dark yellowish brown (10 R 3/6 M) and dark yellowish brown (10 R 4/6 D) gravelly sandy loam; coarse strong angular blocky structure; very hard, firm, slightly sticky and slightly plastic; few indurated lime nodules; violently effervescent.
C	80 +	Weathered parent material of lime stone and sand stone.

4.2.9.2 Morphometric characteristics

This pedon had a depth of 80+ cm comprising five horizons viz. Ap, B1, B2, BC and C. This pedon was strong brown in colour (7.5 YR 3/6 M) upto 45 cm depth and dark red (10 YR 3/6 M) below this depth. Structure was very fine weak massive in the surface horizon and improved down the profile. The pedon had coarse strong and angular blocky structure in last horizon. Consistence was loose, very friable, non-sticky and non-plastic in surface horizon and became hard with the depth and very hard, firm, slightly sticky and slightly plastic in BC horizon. Effervescence was violent throughout the profile. Boundary was clear throughout the profile among different horizons and was smooth in surface horizon which it was wavy and irregular in B1 and B2 horizons, respectively (Table 16a).

Table 16a: Morphometric characteristics of typifying pedon in Dagala-1 series (Pedon-9)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-12	7.5YR 4/6	7.5YR 4/4	vf	1	m	l	vfr	s_0 p_0	ev	c	s
B1	12-23	7.5YR 4/6	7.5YR 4/4	f	1	sbk	sh	fr	s_0 p_0	ev	c	w
B2	23-45	7.5YR 4/6	7.5YR 5/4	m	2	sbk	sh	fr	s_s p_s	ev	c	l
BC	45-80	10 R 3/6	10 R 4/6	c	3	abk	vh	fi	s_s p_s	ev	-	-
C	80+		Weathered parent material									

4.2.9.3 Physical, physico-chemical and chemical properties

Sand ranged from 76.00 to 80.40 per cent with highest in Ap horizon whereas silt and clay ranged from 1.53 to 3.70 and 17.15 to 21.00 per cent, respectively. Silt was more in last horizon while clay was more in B1 horizon. Texture was sandy loam in surface and bottom horizon whereas sandy clay loam in B1 and B2 horizons. Organic carbon varied from 0.186 to 0.245 showing the maximum content in surface horizon. CaCO3 ranged from 8.93 to 10.57 per cent; the highest content being associated with B2 horizon. It increased with depth upto 45 cm while a sudden drop from 10.57 to 8.93 per cent was observed in deeper layer. Variation in gypsum from 0.041 to 0.062 was noticed with maximum value in BC horizon. Irregular trend with depth was found in pH with a range from 7.23 (B1) to 8.16 (B2) whereas gradual increase in EC with depth was found (2.14 to 2.40 dSm^{-1} (Table 16b).

4.2.9.4 Ion exchange properties

All the exchangeable cations were more in B1 horizon showing range from 8.05 to 9.47 for Ca^{2+}, 4.53 to 5.03 for Mg^{2+}, 1.13 to 2.14 for Na^+ and 0.32 to 0.52 $cmol(p^+)kg^{-1}$ for K^+. CEC ranged from 15.20 to 18.35 $cmol(p^+)kg^{-1}$ with a maximum value of 18.35 $cmol(p^+)kg^{-1}$ was observed in B1 horizon. Exchangeable sodium ranged from 5.97 to 12.47 $cmol(p^+)kg^{-1}$ and base saturation varied form 89.54 to 93.51 per cent. These two parameters showed highest values in B1 horizon only (Table 16c).

Table 16b: Physical, physico-chemical and chemical properties of typifying pedon in Dagala-1 series (Pedon-9)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-12	7.88	2.14	80.40	1.53	18.07	sl	0.245	9.12	0.032
B1	12-23	7.23	2.22	76.00	3.00	21.00	scl	0.203	9.34	0.041
B2	23-45	8.16	2.38	76.72	2.66	20.62	scl	0.186	10.57	0.058
BC	45-80	7.62	2.40	79.15	3.70	17.15	sl	0.192	8.93	0.062
C	80+	Weathered parent material								

Table 16c: Ion exchange properties of typifying pedon in Dagala-1 series (Pedon-9)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-12	8.05	4.53	1.13	0.45	15.20	7.98	93.16
B1	12-23	9.47	5.03	2.14	0.52	18.35	12.47	93.51
B2	23-45	9.30	4.55	1.86	0.48	18.08	11.48	89.54
BC	45-80	8.88	4.66	0.88	0.32	16.12	5.97	91.44
C	80+	Weathered parent material						

4.2.10 Pedon – 10 (Yoginagar-2 series) – "Coarse loamy kaolinitic hyperthermic Typic Torriorthents"

4.2.10.1 Description of typifying pedon

Location	:	23° 15' 9.6" N latitude 69° 57' 22.8" E longitude
Physiography	:	Undulating Pediplain
Parent material	:	Lime stone
Slope	:	3-5%
Erosion	:	Moderate to severely eroded
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp.
Present land use	:	Waste land with *Prosophis* sp.

Horizon	Depth (cm)	Morphological description
A1	0-16	Brown (7.5 YR 4/4 M) and strong brown (7.5 YR 5/6 D); sand; fine weak single grain structure; soft, very friable, non-sticky and non-plastic; very fine, common pores; very fine few roots; slightly effervescent; clear wavy boundary.
AC1	16-45	Strong brown (7.5 YR 5/8 M) and strong brown (7.5YR 5/6 D); loamy sand; fine weak massive; slightly hard, firm, non-sticky and non-plastic; strongly effervescent; gradual broken boundary.
AC2	45-86	Pale yellow (2.5 Y 8/3 M) and pale yellow (2.5 Y 8/3 D); loamy sand; coarse weak massive; hard, firm, non-sticky and non-plastic; violently effervescent.

4.2.10.2 Morphometric characteristics

Depth of this pedon was 86 cm with three horizons viz. A1, AC1 and AC2. Colour was brown (7.5 YR 4/4 M)in surface horizon and strong brown (7.5 YR 5/8 M) in AC1 horizon. Structure was fine weak upto a depth of 45 cm with single grained upto 16 cm (A1) while massive in AC1 horizon. In the last horizon, it was coarse weak and massive. Consistence was soft, very friable, non-sticky and non-plastic in surface horizon while it was slightly hard, firm and non-sticky and non-plastic in sub surface horizons. Slight effervescence was observed in surface horizons and became strong and violent down the profile. Boundary was clear and wavy in surface horizon while gradual and broken in sub surface horizon (Table 17a).

4.2.10.3 Physical, physico-chemical and chemical properties

Sand ranged from 81.15 to 88.71 per cent showing a decrease with depth while silt and clay increased with depth, the ranges being 2.14 to 7.59 and 9.15 to 11.26 per cent, respectively. Hence, this composition resulted in sandy texture in surface layer and loamy sand in the sub surface horizons. Organic carbon varied from 0.241 to 0.191 per cent from surface horizon to last horizon. $CaCO_3$ increased from 3.70 to 7.52 per cent down the profile. An increase with depth was also observed in gypsum content with a range from 0.012 to 0.021 per cent. There was not much variation in soil reaction which ranged from 7.77 to 7.82. The EC varied from 2.20 to 2.26 dSm^{-1} without showing much variation with depth (Table 17b).

4.2.10.4 Ion exchange properties

All the exchangeable cations were more in AC1 horizon with a range from 3.71 to 5.13 for Ca^{2+}, 1.50 to 2.46 for Mg^{2+}, 0.38 to 0.53 for Na^+ and 0.23 to 0.33 $cmol(p^+)kg^{-1}$ for K^+. CEC was also more in AC1 horizon with a range from 7.12 to

Table 17a: Morphometric characteristics of typifying pedon in Yoginagar-2 series (Pedon-10)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
A1	0-16	7.5YR 4/4	7.5YR 5/6	f	1	sg	s	vfr	$s_o p_o$	e	c	w
AC1	16-45	7.5YR 5/8	7.5YR 5/6	f	1	m	sh	fi	$s_o p_o$	es	g	b
AC2	45-86	2.5Y 8/1	2.5Y 8/1	c	1	m	sh	fi	$s_o p_o$	ev	-	-

Table 17b: Physical, physico-chemical and chemical properties of typifying pedon in Yoginagar-2 series (Pedon-10)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
A1	0-16	7.82	2.20	88.71	2.14	9.15	s	0.241	3.70	0.012
AC1	16-45	7.77	2.22	82.17	7.15	10.68	ls	0.208	7.46	0.018
AC2	45-86	7.80	2.26	81.15	7.59	11.26	ls	0.191	7.52	0.021

Table 17c: Ion exchange properties of typifying pedon in Yoginagar-2 series (Pedon-10)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
A1	0-16	3.71	1.50	0.38	0.23	7.12	6.53	81.74
AC1	16-45	5.13	2.46	0.53	0.33	10.42	6.27	81.09
AC2	45-86	4.85	1.85	0.45	0.28	9.23	6.06	80.49

10.42 cmol$(p^+)kg^{-1}$ having lowest value in A1 horizon. Variation was not observed in ESP and BS values which ranged from 6.06 to 6.53 and 80.49 to 81.74 per cent showing highest values in A1 horizon in both cases (Table 17c).

4.2.11 Pedon – 11 (Dagala-2 series) – "Kaolinitic hyperthermic Typic Torripsamments"

4.2.11.1 Description of typifying pedon

Location	:	23° 18` 56.4" N latitude 69° 58` 58.2" E longitude
Physiography	:	Undulating pediplain
Parent material	:	Lime stone
Slope	:	3-5%
Erosion	:	Severe
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp.
Present land use	:	Scrub land

Horizon	Depth (cm)	Morphological description
Ap	0-13	Dark yellowish brown (10 YR 4/4 M) and yellowish brown (10 YR 5/4 D); sand; very fine structureless single grain structure; loose (dry), loose (moist), non-sticky and non-plastic; common fine pores; few fine roots; violently effervescent; clear smooth boundary.
A2	13-24	Dark yellowish brown (10 YR 5/4 M) and yellowish brown (10 YR 5/4 D); sand; fine weak massive structure; loose, non-sticky and non-plastic; common fine pores; few disseminated fine lime nodules; violently effervescent; clear smooth boundary.

AC	24-60	Dark yellowish brown (10YR 4/4 M) and yellowish brown (10 YR 5/6 D); sand; fine weak massive; soft, very friable, non sticky and non plastic; many indurated lime nodules; violently effervescent; gradual smooth boundary.
C	60-85	Dark yellowish brown (10 YR 4/4 M) and yellowish brown (10 YR 5/6D); sand; fine weak massive structure; soft, very friable, non-sticky and non-plastic; many indurated lime nodules; strongly effervescent.

4.2.11.2 Morphometric characteristics

This pedon was 85 cm deep and divided into 4 horizons from 0-13, 13-24, 24-60 and 60-85 cm and named as Ap, A2, AC and C horizons. Colour was yellowish brown (10 YR 5/4 M) upto 24 cm depth and is dark yellowish brown (10 YR 4/4 M) from there onwards till bottom of the profile. Structure was very fine structureless with single grained in surface horizon and fine weak massive in all sub-surface horizons. Consistence was loose under dry and moist conditions upto a depth of 24 cm. It is soft, friable in last two horizons. It was non-sticky and non-plastic under wet conditions throughout the profile. This pedon showed violent effervescence upto a depth of 60 cm and strong effervescence in last horizon. Boundary was clear smooth in Ap and A2 horizons whereas gradual smooth in AC horizon (Table 18a).

4.2.11.3 Physical, physico-chemical and chemical properties

Sand ranged from 89.27 to 93.8 per cent showing maximum content in Ap horizon whereas silt and clay ranged from 0.68 to 3.73 and 5.10 to 7.80 per cent, respectively showing the highest content in both AC and C horizons. Texture was sandy throughout the profile. Organic carbon varied from 0.148 to 0.206 per cent whereas $CaCO_3$ varied from 3.15 to 5.25 per cent with the highest value observed in Ap horizon in both the cases. There was decrease in OC and $CaCO_3$ with increase in

Table 18a: Morphometric characteristics of typifying pedon in Dagala-2 series (Pedon-11)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-13	10YR4/4	10YR5/4	vf	0	sg	l	l	$s_0 p_0$	ev	c	s
A2	13-24	10YR4/4	10YR5/4	f	1	m	l	l	$s_0 p_0$	ev	c	s
AC	24-60	10YR4/4	10YR5/6	f	1	m	s	fr	$s_0 p_0$	ev	g	s
C	60-85	10YR4/4	10YR5/6	f	1	m	s	vfr	$s_0 p_0$	es	-	-

depth. There was not much variation in gypsum and ranged from 0.020 to 0.026 per cent (Table 18b).

4.2.11.4 Ion exchange properties

Among the exchangeable cations, Ca^{2+}, Mg^{2+} and Na^+ increased with depth and were more in C horizon whereas a decreasing trend in K^+ with depth was noticed. The range of contents of Ca^{2+}, Mg^{2+}, Na^+ and K^+ were 1.66 to 5.33, 0.76 to 2.00, 0.20 to 0.70 and 0.13 to 025 cmol(p^+)kg^{-1}, respectively. CEC ranged from 3.92 to 8.63 cmol(p^+)kg^{-1} with the highest value observed in AC horizon. ESP ranged from 6.97 to 8.58 showing increasing trend down the profile. Base saturation ranged from 70.89 to 79.53, which showed irregular trend with depth though highest values were associated with C horizon (Table 18c)

4.2.12 Pedon – 12 (Sangnadi-1 series) – "Fine loamy smectitic hyperthermic Sodic Haplocambids"

4.2.12.1 Description of typifying pedon

Location	:	23° 17 '40.8" N latitude
		69° 57' 30" E longitude
Physiography	:	Valley
Parent material	:	Limestone
Slope	:	3-8%
Erosion	:	Moderately eroded
Drainage	:	Moderately well drained

Table 18b: Physical, physico-chemical and chemical properties of typifying pedon in Dagala-2 series (Pedon-11)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-13	7.62	2.15	93.89	1.01	5.10	s	0.206	5.25	0.020
A2	13-24	7.70	2.10	92.50	0.68	6.82	s	0.182	4.76	0.023
AC	24-60	7.77	1.88	89.27	3.73	7.00	s	0.170	4.21	0.026
C	60-85	7.82	1.72	89.74	2.46	7.80	s	0.148	3.15	0.025

Table 18c: Ion exchange properties of typifying pedon in Dagala-2 series (Pedon-11)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-13	1.66	0.76	0.20	0.25	3.92	6.97	73.21
A2	13-24	2.15	0.96	0.27	0.20	5.05	7.54	70.89
AC	24-60	3.86	1.82	0.52	0.15	8.63	8.19	73.58
C	60-85	5.33	2.00	0.70	0.13	8.15	8.58	79.53

Natural vegetation : *Prosophis juliflora*

Present land use : Scrub land

Horizon	Depth (cm)	Morphological description
A_1	0-12	Dark yellowish brown (10 YR 4/4 M) and brownish yellow (10 YR 6/6 D); sandy clay loam; medium moderate subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; common fine pores; few fine roots; very few lime nodules; slightly effervescent; clear smooth boundary.
B21	12-37	Dark yellowish brown (10 YR 4/4 M) and brownish yellow (10 YR 6/6 D); sandy clay loam; coarse prismatic structure breaking into moderate medium sub angular blocky peds; hard, firm, slightly sticky and slightly plastic; few disseminated fine lime nodules; strongly effervescent; clear wavy boundary.
B22	37-70	Olive brown (2.5 Y 4/3) and light olive brown (2.5 Y 5/4 D); sandy clay loam; coarse columnar or prismatic structure breaking into moderate medium sub angular blocky peds; slightly hard, firm, slightly sticky and slightly plastic; many indurated lime nodules; violently effervescent; clear wavy boundary.
BC	70-100	Olive brown (2.5 Y 4/3 M) and light olive brown (2.5 Y 5/4 D); gravelly sandy clay loam; coarse strong prismatic structure breaking into moderate medium sub angular blocky peds; slightly hard, firm, slightly sticky and slightly plastic; many indurated coarse lime nodules; Violently effervescent; clear wavy boundary.
C	100 +	Olive brown (2.5 Y 4/3 M); light olive brown (2.5 Y 5/4 D); weathered parent material.

4.2.12.2 Morphometric characteristics

This pedon was 100 cm deep with five horizons viz. A1, B21, B22, BC and C based on morphometric properties. Colour was dark yellowish brown upto a depth of 37 cm and olive brown from there onwards. Structure was medium moderate subangular blocky in the surface horizon and is prismatic breaking into medium moderate subangular blocky peds in the subsurface horizons. It was coarse strong and prismatic in BC horizon. Consistence was slightly hard, friable under dry and moist conditions in surface horizon whereas it became firm down the profile in the sub-surface horizons. It was slightly sticky and slightly plastic under wet conditions throughout the profile. Slight effervescence was observed in surface horizon, which increased and became strong and violent down the profile. Boundary was clear and smooth in surface horizon and clear wavy in all sub surface horizons (Table 19a).

4.2.12.3 Physical, physico-chemical and chemical properties

Sand ranged from 56.41 to 61.62 per cent; the maximum being observed in BC horizon. Silt varied from 10.93 (A1) to 14.65 per cent (B22). Clay decreased gradually from 32.32 to 25.52 per cent down the profile. There was no change in texture among all horizons and it was sandy clay loam. Organic carbon decreased with depth; the range being 0.268 – 0.144 per cent whereas reverse trend was observed in case of $CaCO_3$ and gypsum with a range from 5.48 to 12.28 per cent and 0.563 to 0.925 per cent, respectively (Table 19b). Soil reaction was alkaline with pH ranging from 8.50 to 8.90; highest value being observed in BC horizon. Salinity was also more with EC values ranging from 3.90 to 10.33 dSm^{-1}. Highest value of EC has associated with BC horizon exhibiting the saline nature of the soil.

4.2.12.4 Ion exchange properties

Among exchangeable cations, the content of Ca^{2+} and Mg^{2+} were found to decrease gradually from 12.05 to 7.65 and 10.86 to 2.85 $cmol(p^{+})kg^{-1}$, respectively with increase in depth. The content of K^{+}, however showed a reverse trend; the values being ranged from 1.33 to 1.70 $cmol(p^{+})kg^{-1}$ whereas Na^{+} showed irregular trend with depth showing the contents ranging from 4.25 to 10.16 $cmol(p^{+})kg^{-1}$. The

Table 19a: Morphometric characteristics of typifying pedon in Sangnadi-1 series (Pedon-12)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
A1	0-12	10YR 4/4	10YR 6/6	m	2	sbk	sh	fr	s_s p_s	e	c	s
B21	12-37	10YR 4/4	10YR 6/6	m	2	pr	h	fi	s_s p_s	es	c	w
B22	37-70	2.5Y 4/3	2.5Y 5/4	m	2	pr	sh	fi	s_s p_s	ev	c	w
BC	70-100	2.5Y 4/3	2.5Y 5/4	c	3	pr	sh	fi	s_s p_s	ev	c	w
C	100+	2.5Y 4/3	2.5YR 5/4	Weathered parent material								

Table 19b: Physical, physico-chemical and chemical properties of typifying pedon in Sangnadi-1series (Pedon-12)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
A1	0-12	8.50	3.90	56.75	10.93	32.32	scl	0.268	5.48	0.563
B21	12-37	8.75	9.70	57.21	12.00	30.79	scl	0.159	7.37	0.887
B22	37-70	8.87	10.22	56.41	14.65	28.94	scl	0.151	10.16	0.893
BC	70-100	8.90	10.33	61.62	12.86	25.52	scl	0.144	12.28	0.925
C	100+	Weathered parent material								

Table 19c: Ion exchange properties of typifying pedon in Sangnadi -1 series (Pedon-12)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
A1	0-12	12.05	10.86	4.25	1.33	30.40	14.92	92.73
B21	12-37	11.01	5.52	9.15	1.58	28.64	33.56	95.18
B22	37-70	9.47	4.40	10.16	1.65	27.15	39.56	94.58
BC	70-100	7.65	2.85	9.52	1.70	23.26	43.83	93.38
C	100+	Weathered parent material						

maximum content of Na^+ was recorded in B22 horizon. CEC decreased from 30.40 to 23.26 cmol(p^+)kg^{-1} with increase in depth of the profile. ESP was 14.92 per cent in surface horizon while it was more than 15 in sub surface layers; the range being 14.92 to 43.83 showing maximum ESP in BC horizon. Base saturation ranged from 92.73 to 95.18 per cent with the highest value in B21 horizon (Table 19c).

4.2.13 Pedon – 13 (Kanyabe-3 series) – "Sandy kaolinitic hyperthermic Typic Torriorthents"

4.2.13.1 Description of typifying pedon

Location	:	23° 16` 15.48" N latitude 69° 55` 10.08" E longitude
Physiography	:	Valley fringe
Parent material	:	Alluvium
Slope	:	2-4%
Erosion	:	Moderate
Drainage	:	Moderately well drained
Natural vegetation	:	*Prosophis* sp.
Present land use	:	Scrub land

Horizon	Depth (cm)	Morphological description
Ap	0-29	Yellowish brown (10 YR 5/4 M) and yellowish brown (10 YR 5/6 D); sand; fine weak massive; soft, loose, non-sticky and non-plastic; common, fine pores; few disseminated fine lime nodules in the matrix; few very fine roots; violently effervescent; abrupt wavy boundary.
AC	29-47	Yellowish brown (10 YR 5/4 M) and yellowish brown (10 YR 5/6 D); gravelly sand; medium single grain structure; loose (dry), loose (moist), non-sticky and non-plastic; common, medium pores; many disseminated lime nodules in

		the matrix; violently effervescent; abrupt wavy boundary.
C	47-105	Yellowish brown (10 YR 5/4 M) and yellowish brown (10 YR 5/6 D); gravelly sand; medium single grain structure; loose (dry), loose (moist), non-sticky and non-plastic; many indurated lime nodules; violently effervescent.

4.2.13.2 Morphometric characteristics

The profile was 105 cm deep with three horizons viz. Ap, AC and C. The colour was yellowish brown throughout the profile. The structure was fine weak massive in surface horizon and medium structureless (single grained) in sub surface horizons. There was no variation in consistence throughout the profile and was loose non-sticky and non-plastic except in surface horizon under dry conditions, which was soft. Violent effervescence was observed throughout the profile. The horizons showed abrupt wavy boundary (Table 20a).

4.2.13.3 Physical, physico-chemical and chemical properties

Sand varied from 93.84 to 95.82 per cent; highest content being associated with Ap horizon. Silt showed a decrease with depth. It ranged from 0.75 to 0.95 per cent. Clay varied from 3.23 to 5.35 per cent showing highest content in AC horizon. Organic carbon varied from 0.185 (C) to 0.213 per cent (Ap) with decreasing trend towards the bottom. The $CaCO_3$ of this pedon ranged from 10.23 to 12.56 per cent. EC and pH values were found to range from 1.50 to 2.17 d S m^{-1} and 7.55 to 7.82, respectively (Table 20b).

4.2.13.4 Ion exchange properties

Among the exchangeable cations, calcium (Ca^{2+}) predominated followed by $Mg^{2+} > Na^{+} > K^{+}$, all showing maximum contents in Ap horizon. Ca^{2+} and Mg^{2+} contents ranged from 1.18 to 5.49 and 0.42 to 3.05 cmol(p^{+})kg^{-1} while Na^{+} and K^{+} ranged from 0.11 to 1.00 and 0.14 to 0.31 cmol(p^{+})kg^{-1}, respectively. The cation

Table 20a: Morphometric characteristics of typifying pedon in Kanyabe-3 series (Pedon-13)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-29	10YR 5/4	10YR 5/6	f	1	m	s	l	$s_0 p_0$	ev	a	w
AC	29-47	10YR 5/4	10YR 5/6	m	0	sg	l	l	$s_0 p_0$	ev	a	w
C	47-105	10YR 5/4	10YR 5/6	m	0	sg	l	l	$s_0 p_0$	ev	-	-

Table 20b: Physical, physico-chemical and chemical properties of typifying pedon in Kanyabe-3 series (Pedon-13)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-29	7.55	2.17	95.82	0.95	3.23	s	0.213	10.23	0.017
AC	29-47	7.82	2.05	93.84	0.81	5.35	s	0.198	12.56	0.023
C	47-105	7.80	1.50	94.15	0.75	5.10	s	0.185	12.10	0.026

Table 20c: Ion exchange properties of typifying pedon in Kanyabe-3 series (Pedon-13)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-29	5.49	3.05	1.00	0.31	11.25	10.15	87.55
AC	29-47	1.88	0.65	0.15	0.22	4.10	5.17	70.73
C	47-105	1.18	0.42	0.11	0.14	3.02	5.94	61.26

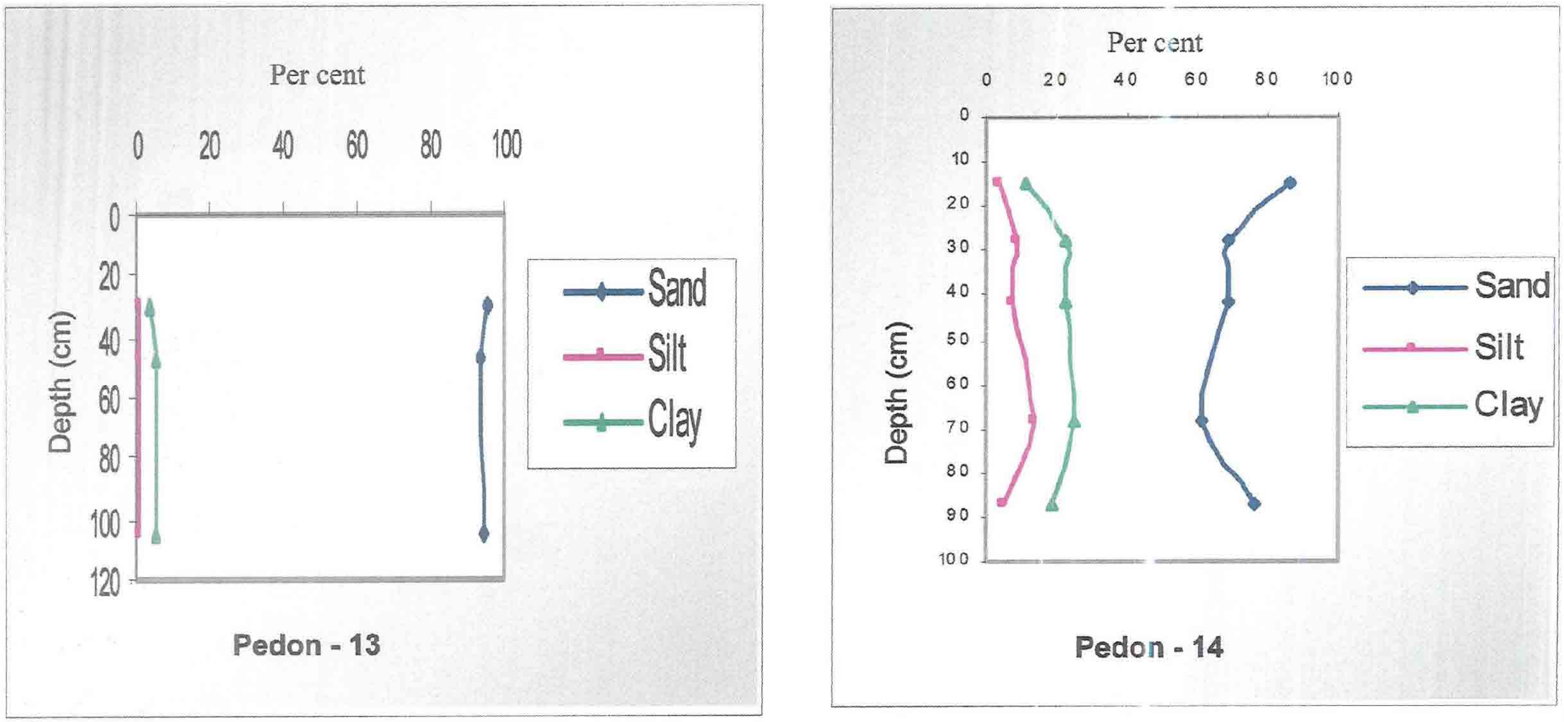

Fig. 8c : Depth wise distribution of soil particles (Pedons 13 & 14)

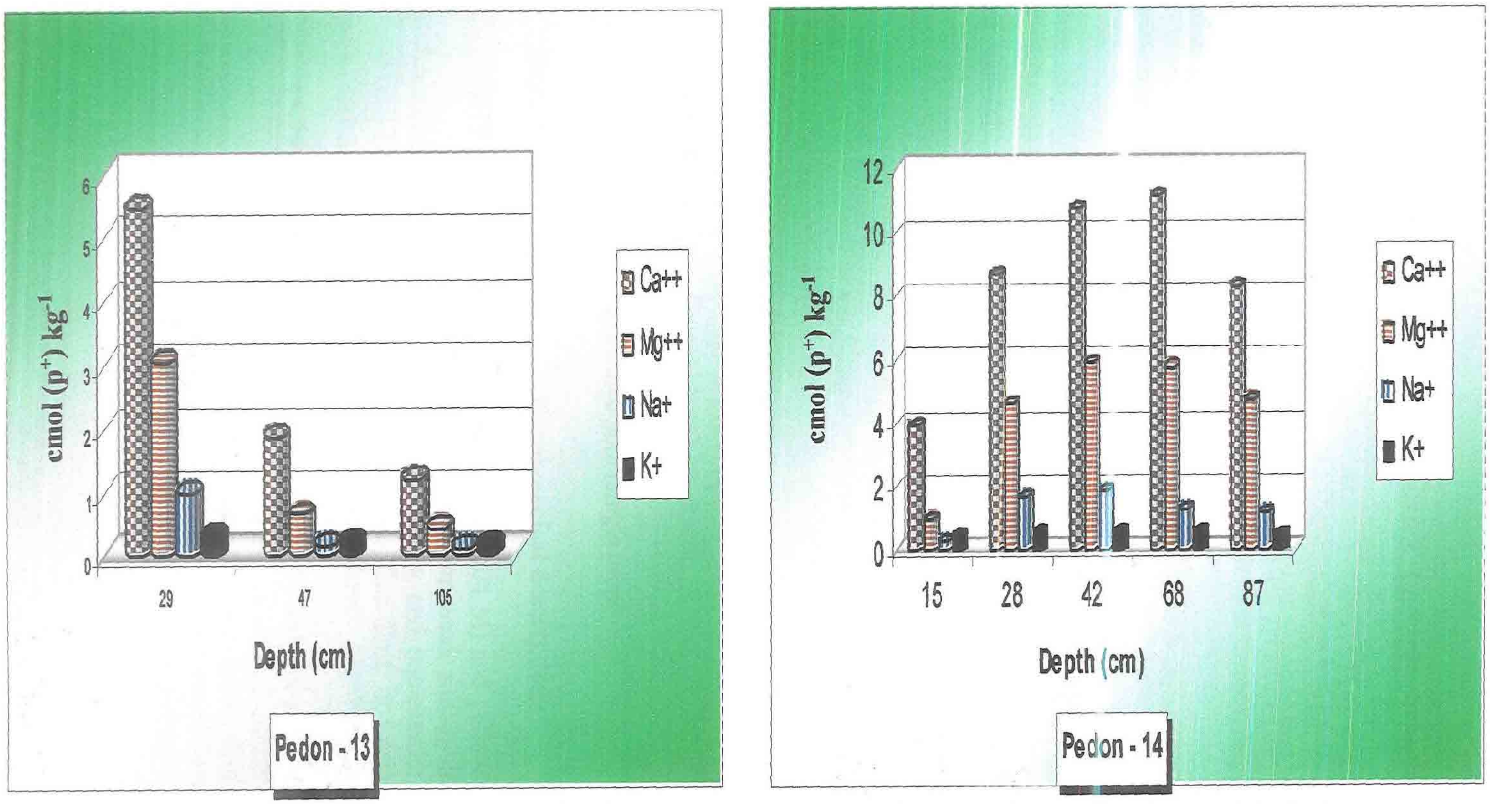

Fig. 9c : Depth wise distribution of exchangeable cations (Pedons 13 & 14) exchange capacity values varied from 3.02 (C) to 11.25 cmol(p^+)kg^{-1} (Ap). ESP was < 15 in all horizons. Base saturation was ranging from 61.26 to 87.55 per cent. With increase in depth, CEC, ESP and base saturation values showed decreasing trend from surface to deeper horizons (Table 20c).

4.2.14 Pedon - 14 (Sangnadi-2 series) – "Loamy smectitic hyperthermic TypicHaplocambids"

4.2.14.1 Description of typifying pedon

Location	:	23° 16` 58.2" N latitude 69° 56` 33.6" E longitude
Physiography	:	Toe/side slopes of valley
Parent material	:	Limestone
Slope	:	1-3%
Erosion	:	Moderate
Drainage	:	Well drained
Natural vegetation	:	*Prosophis* sp., ber, neem
Present land use	:	Cultivated land (single crop)

Horizon	Depth (cm)	Morphological description
Ap	0-15	Dark yellowish brown (10 YR 4/4 M) and yellowish brown (10 YR 5/4 D); loamy sand; fine weak subangular blocky; soft, very friable, slightly sticky and non-plastic; common fine pores; few disseminated fine lime nodules; strongly effervescent; clear smooth boundary.
A3	15-28	Dark yellowish brown (10 YR 4/4 M) and yellowish brown (10 YR 5/4 D); gravelly sandy clay loam; medium moderate subangular blocky structure; slightly hard, firm, slightly sticky and non-plastic; many medium indurated lime nodules; violently effervescent; gradual irregular boundary.

B1	28-42	Dark Yellowish brown (10 YR 4/4 M); and yellowish brown (10 YR 5/4 D); gravelly sandy clay loam; medium moderate subangular blocky; slightly hard, firm, slightly sticky and plastic; many medium indurated lime nodules; violently effervescent; gradual broken boundary.
BC	42-68	Yellowish brown (10 YR 5/4 M) and light yellowish brown (10 YR 6/4 D); gravelly sandy clay loam; coarse weak massive; slightly hard, firm, slightly sticky and non-plastic, many medium indurated lime nodules, violently effervescent, gradual broken boundary.
C	68-87	Yellowish brown (10 YR 5/6 M) and yellowish brown (10 YR 5/6 D); sandy loam; coarse structureless massive structure; loose, friable, slightly sticky and non-plastic; stones/pebbles mixed with soil matrix and coarse fragments with lime nodules; violently effervescent.

4.2.14.2 Morphometric characteristics

This pedon was 87 cm deep with five horizons viz. Ap, A3, B1, BC and C. Colour was dark yellowish brown (10 YR 4/4 M) upto a depth of 42 cm and was yellowish brown (10 YR 5/4 M) in last two horizons. Structure was sub angular blocky upto a depth of 42 cm but fine and weak in surface horizon while medium and moderate in other two horizons. It became massive down the profile with coarse and weak in BC and coarse and structureless in C horizons. Consistence was soft, very friable in surface horizon under dry and moist conditions which became slightly hard, firm in sub surface layers and again is was loose and friable in last horizon. Under wet conditions, consistence was slightly sticky and non plastic throughout the profile except in B1 horizon which was slightly sticky and plastic.

Strong effervescence was noticed in surface horizon followed by violent effervescence in sub surface horizons. Boundary was clear smooth in surface horizon and clear gradual in all sub surface horizons with irregular boundary in A3 horizon and broken boundary in B1 and BC horizons (Table 21a).

Table 21a: Morphometric characteristics of typifying pedon in Sangnadi-2 series (Pedon-14)

Horizon	Depth (cm)	Colour		Structure			Consistence			Effervescence	Boundary	
		Moist	Dry	S	G	T	Dry	Moist	Wet		D	T
Ap	0-15	10YR 4/4	10YR 5/4	f	1	sbk	s	vfr	s_s p_o	es	c	s
A3	15-28	10YR 4/4	10YR 5/4	m	2	sbk	sh	fi	s_s p_o	ev	g	l
B1	28-42	10YR 4/4	10YR 5/4	m	2	sbk	sh	fi	s_s p	ev	g	b
BC	42-68	10YR 5/4	10YR 6/4	c	1	m	sh	fi	s_s p_o	ev	g	b
C	68-87	10YR 5/6	10YR 5/6	c	0	m	l	fr	s_s p_o	ev	-	-

4.2.14.3 Physical, physico-chemical and chemical properties

Sand was more in Ap horizon (85.95%), decreased with depth upto 68 cm (61.40 %) and again increased to 76.52 per cent in bottom most horizon (C). Silt and clay increased with depth upto BC horizon and a drop in these values was observed in last horizon to 5.33 and 18.15 per cent, respectively. Silt ranged from 3.24 to 13.60 per cent while clay varied from 10.81 to 25.00 per cent. Texture of this pedon was loamy sand in surface horizon, sandy clay loam upto the penultimate horizon and sandy loam in the last horizon. Organic carbon ranged from 0.183 to 0.305 per cent showing decreasing trend with depth. $CaCO_3$ increased from 7.27 in surface horizon to 11.10 in A3 horizon and again there was not much difference upto last horizon. Gypsum varied from 0.038 to 0.062 per cent, which increased gradually down the profile. pH ranged from 7.43 to 8.26 and showed gradual increasing trend with depth while EC ranged from 1.40 to 2.23 dSm^{-1} showing a reverse trend with depth (Table 21b).

4.2.14.4 Ion exchange properties

The contents of all the exchangeable cations were more in B_1 horizon. However, maximum content of Ca^{2+} was observed in BC horizon. Ca^{2+} and Mg^{2+} contents ranged from 3.93 to 11.15 and 0.96 to 5.88 $cmol(p^+)kg^{-1}$, respectively. The contents of Na^+ and K^+ ranged from 0.31 to 1.89 and 0.48 to 0.61 $cmol(p^+)kg^{-1}$, respectively. CEC ranged from 7.15 to 22.45 $cmol(p^+)kg^{-1}$, the highest value being recorded in B1 horizon. ESP increased from surface (5.46 %) to next horizon (10.69 %) and from there, it decreased gradually with increase in depth. Base saturation varied from 79.44 per cent (Ap) to 89.87 per cent; with the highest value being observed in B1 horizon (Table 21c).

Table 21b: Physical, physico-chemical and chemical properties of typifying pedon in Sangnadi-2 series (Pedon-14)

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	Particle size distribution (%)			Texture	OC (%)	$CaCO_3$ (%)	Gypsum (%)
				Sand	Silt	Clay				
Ap	0-15	7.43	2.23	85.95	3.24	10.81	ls	0.305	7.27	0.038
A3	15-28	8.23	1.98	68.90	8.13	22.97	scl	0.263	11.10	0.042
B1	28-42	8.25	1.89	68.85	8.05	23.10	scl	0.241	11.25	0.051
BC	42-68	8.34	1.63	61.40	13.60	25.00	scl	0.208	11.50	0.060
C	68-87	8.36	1.40	76.52	5.33	18.15	sl	0.183	12.13	0.062

Table 21c: Ion exchange properties of typifying pedon in Sangnadi-2 series (Pedon-14)

Horizon	Depth (cm)	Exchangeable cations [cmol (p+) kg^{-1}]				CEC [cmol (p+) kg^{-1}]	ESP	BS (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
Ap	0-15	3.93	0.96	0.31	0.48	7.15	5.46	79.44
A3	15-28	8.69	4.63	1.66	0.55	18.46	10.69	84.13
B1	28-42	10.75	5.88	1.89	0.61	22.45	9.88	89.18
BC	42-68	11.15	5.75	1.24	0.58	21.00	6.62	89.14
C	68-87	8.23	4.69	1.15	0.50	16.58	6.94	87.87

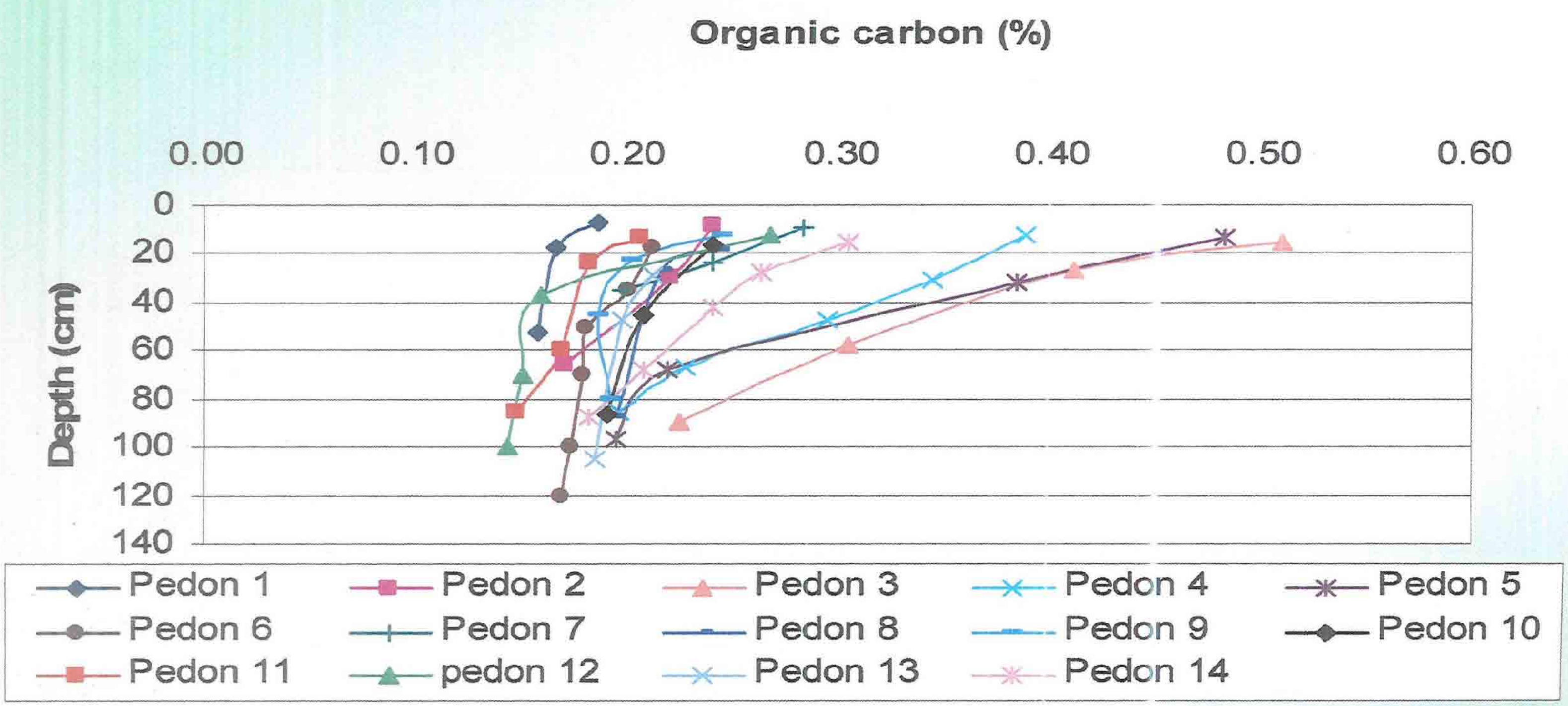

Fig.10 : Depth wise distribution of organic carbon in various pedons

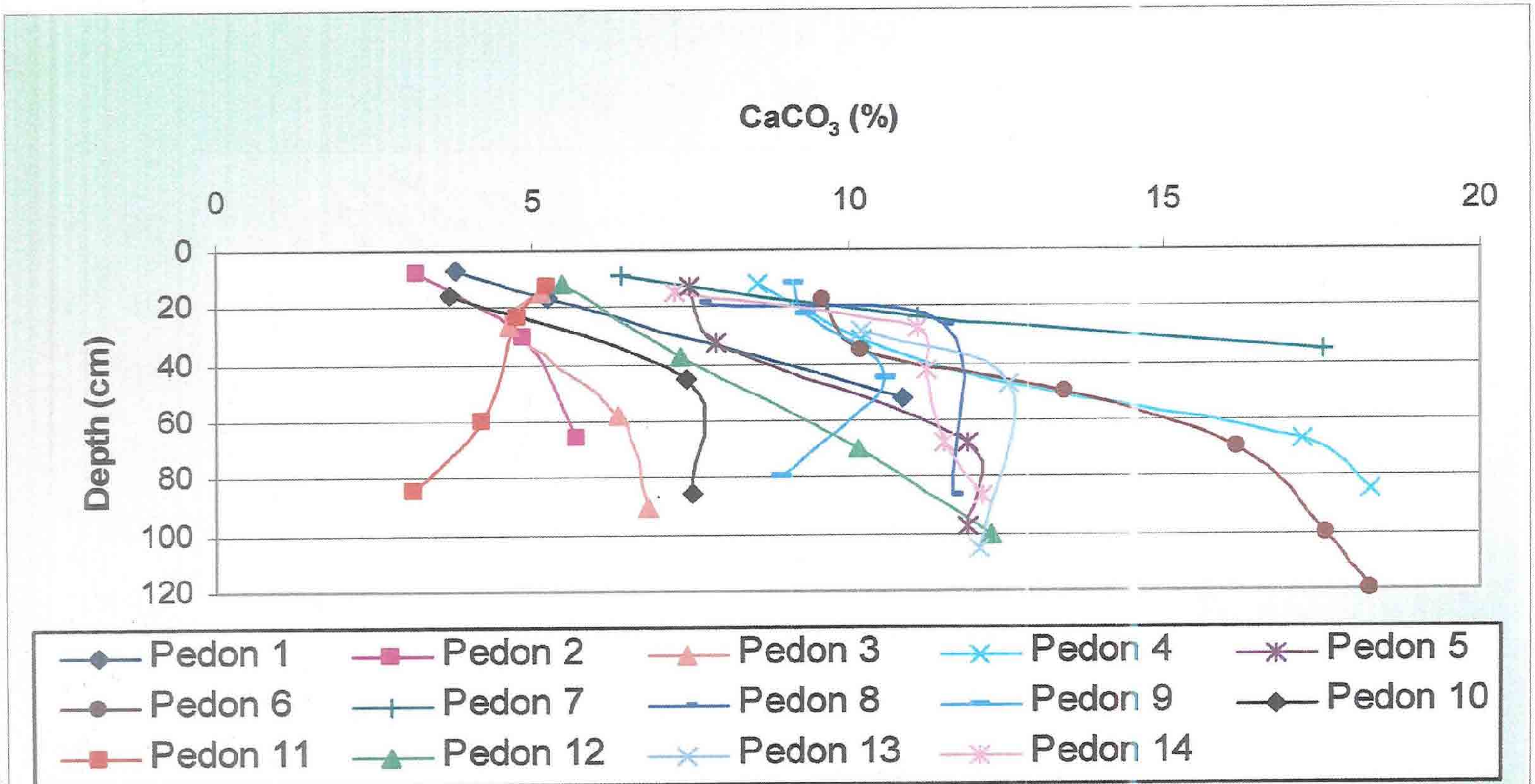

Fig.11 : Depth wise distribution of Calcium carbonate in various pedons

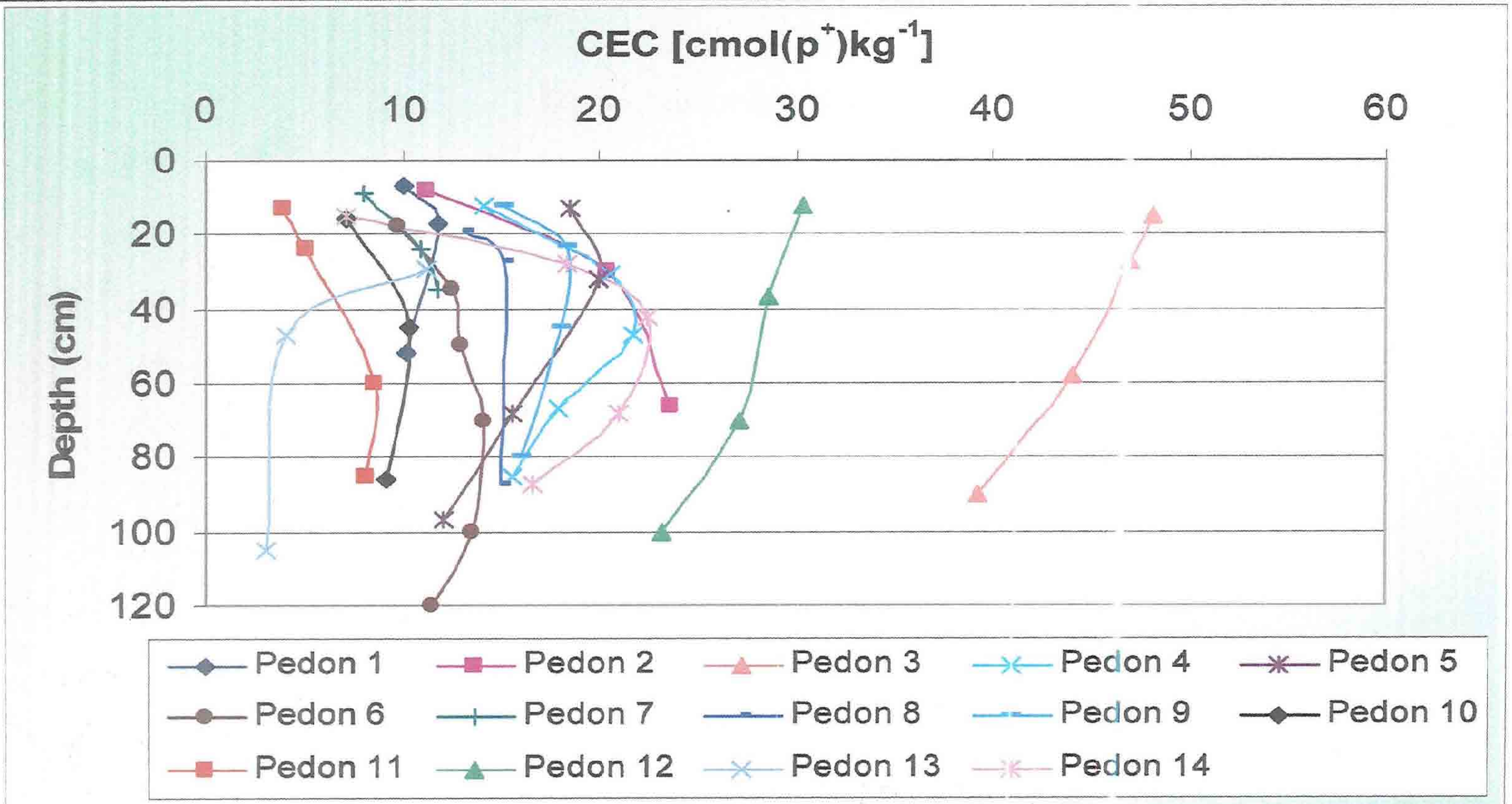

Fig.12 : Depth wise distribution of CEC in various pedons

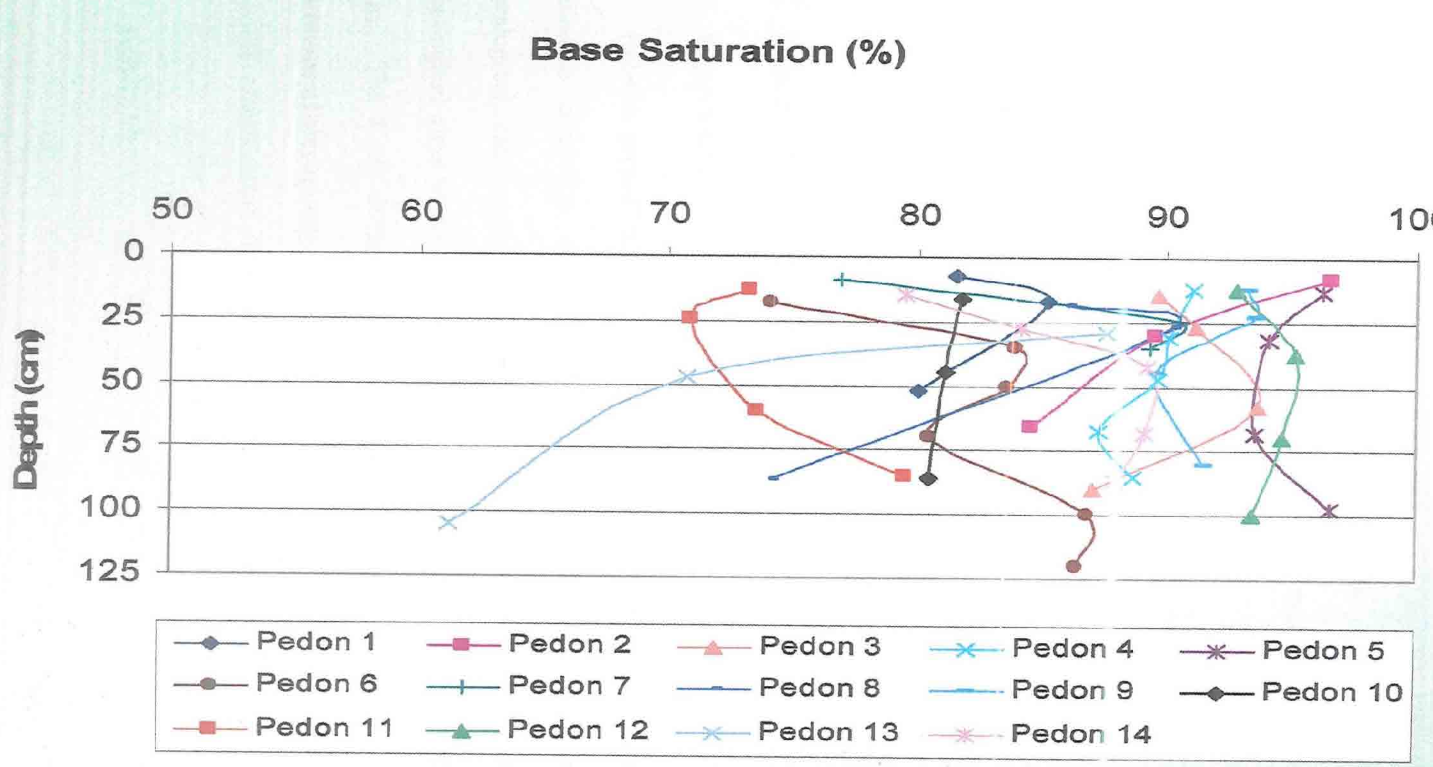

Fig.13 : Depth wise distribution of Base Saturation (%) in various pedons

4.3 CLAY MINERALOGY

Identification and quantification of clay minerals is essential to classify the soils for mineralogical class at family level. The X-ray diffraction analysis was carried out for the clay fractions (<2 micron) of the soils collected from the control section (25-100 cm) of the pedons. Seven soil profiles were analysed for clay mineralogy based on the taxonomic classification upto sub-group level besides considering the textures as shown in the Table 23. Clay minerals were identified by studying the X-ray diffractograms of soil clays after subjecting them to the following six treatments:

1. Ca-saturated at room temperature (25°C)
2. Ca-saturated and ethylene glycerol solvated
3. K-saturated at room temperature (25°C)
4. K-saturated and heated to 110 °C
5. K-saturated and heated to 300 °C
6. K-saturated and heated to 550 °C

Relative proportions of clay minerals were also estimated by means of semi-quantitative estimation method. Based on the relative proportions of soils, mineralogical class was assigned to the XRD analyzed soil samples. Same mineralogical class was attributed to other soils belonging to same sub-group and texture. The X-ray diffractograms are depicted in figs. 14 to 20 and the relative proportions of clay minerals are given in the Table 22. The dominant clay mineral and taxonomic classification of soils upto family level are given in Table 23.

Table 22 : Relative proportions of the clay minerals (per cent) in total clay fraction of respresentative pedons of study area

S. No.	Physiographic unit	Soil type	Kaolinite	Mica	Smectite	Chlorite	Quartz	Gibbsite	Attapulgite
Aridisols									
1	Lower foot slopes	*Ls Typic Haplocambids	79.84	13.02	-	-	7.19	-	-
2	Pediment	Fl Vertic Haplocambids	15.15	-	64.81	-	19.44	-	-
3	Pediment	Ls Typic Haplocalcids	49.50	20.85	2.90	5.44	18.13	3.18	-
4	Pediplain	Fl Typic Haplocambids	32.41	6.89	51.54	-	9.17	-	-
5	Valley	Fl Sodic Haplocambids	19.85	-	66.18	-	13.79	-	-
Entisols									
6	Pediplain	**Cl Typic Torriorthents	35.59	12.00	-	24.91	2.85	1.07	23.48
7	Pediplain	Typic Torripsamments	85.66	3.61	-	6.76	3.16	0.81	-

Ls = Loamy skeletal
Cl = Coarse loamy
Fl = Fine loamy

* Interstratified 1:1 mica montmorillonite
** Chloritised montmorillonite

Table 23: Clay mineralogy and taxonomic classification of the soils upto family level

Classification at Subgroup level	Dominant clay mineral	Pedon classification upto family level	Physiographic unit
ARIDISOLS			
Typic Haplocambids			
a) Coarse textured	Kaolinite	*Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	Lower foot slopes
	Kaolinite	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	Pediment with severe erosion
	Kaolinite	Coarse loamy kaolinitic hyperthermic Typic Haplocambids	Nearly levelled pediplain with moderate erosion
b) Fine textured	Smectite	*Fine loamy smectitic hyperthermic Typic Haplocambids	Undulating pediplain with slight erosion
	Smectite	Loamy smectitic hyperthermic Typic Haplocambids	Toe/side slopes of valley
Sodic Haplocambids	Smectite	*Fine loamy smectitic hyperthermic Sodic Haplocambids	Valley
Vertic Haplocambids	Smectite	*Fine smectitic hyperthermic Vertic Haplocambids	Pediment with slight erosion
Typic Haplocalcids	Kaolinite	*Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids	Pediment with moderate erosion
	Kaolinite	Coarse loamy kaolinitic hyperthermic Typic Haplocalcids	Nearly levelled pediplain with slight erosion
ENTISOLS			
Typic Torriorthents	Kaolinite	Coarse loamy kaolinitic hyperthermic Typic Torriorthents	Upper foot slopes
	Kaolinite	Sandy skeletal hyperthermic Typic Torriorthents	Nearly levelled pediplain with severe erosion
	Kaolinite	*Coarse loamy hyperthermic Typic Torriorthents	Undulating pediplain with moderate erosion
	Kaolinite	Sandy hyperthermic Typic Torriorthents	Valley fringe
Typic Torripsamments	Kaolinite	*Kaolinitic hyperthermic Typic Torripsamments	Undulating pediplain with severe erosion

* Representative soil samples for XRD analysis

4.3.1 Aridisols

4.3.1.1 Typic Haplocambids (Coarse textured) - Dagala - 3 series (Pedon – 2)

The X-ray diffraction pattern of clay samples of the typifying pedon of Dagala-3 series (Loamy skeletal hyperthermie Typic Haplocambids) showed strong peaks at 7.22 (001) and 3.59 A° (002) in Ca-saturated, Ca-ethylene glycolated and K-saturated samples heated to temperatures 25°, 110° and 300 °C, which disappeared on heating the sample to 550 °C, thus, indicating the presence of kaolinite (Fig. 14).

The presence of illite was indicated by the sharp basal reflections at 10.10 (001) and 5.00 (002) A°, which remained unaffected on glycerolation, K-saturation and heating treatments.

Prominent sharp peaks were observed at 3.34 (001) and 4.26 A^0 (002), which remained unchanged in its position in all the treatments. This suggests the presence of quartz in clay fraction.

Interstratification of 1:1 mica-mntmorillonite was observed in this pedon, which was indicated by the presence of peak at 27.83 A° in Ca-Eg treatment. Relative proportions of clay minerals (Table 22) indicated that kaolinite was the dominant mineral in these soils (79.84%) followed by illite (13.02%) and quartz (7.14%).

4.3.1.2 Typic Haplocambids (Fine textured) - Dagala – 1 series (Pedon – 9)

The X-ray diffractograms of the clay fractions of typifying pedon (Fine loamy hyperthermic Typic Haplocambids) in Dagala-1 series are depicted in Fig. 15. Diffractograms showed that the minerals present in these soils are kaolinite, smectite, illite and quartz. However, smectite was identified as the dominant mineral followed by kaolinite > quartz > mica (Table 22).

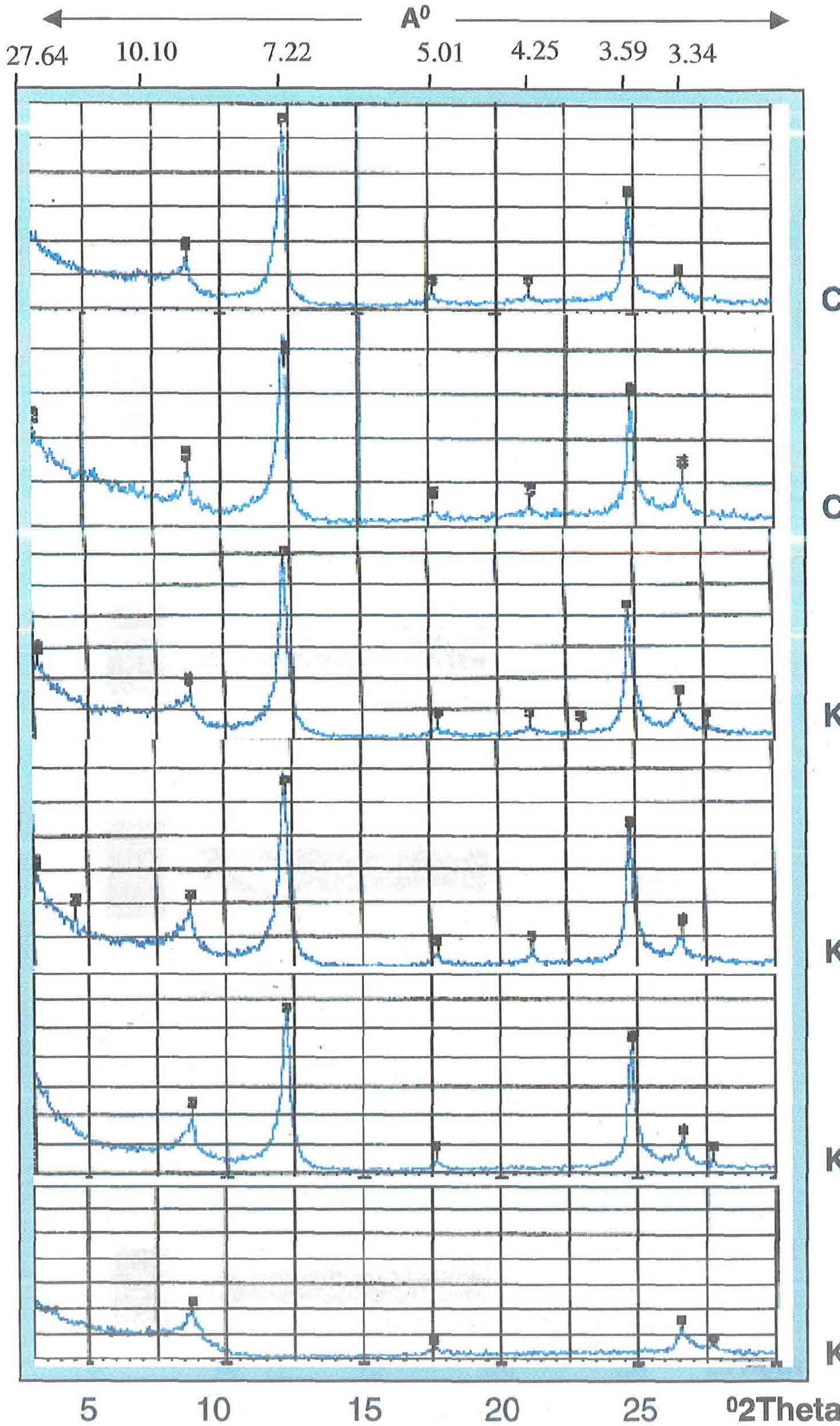

Fig. 14 : X-ray diffractograms of clay fraction of soils in Dagala-3 series

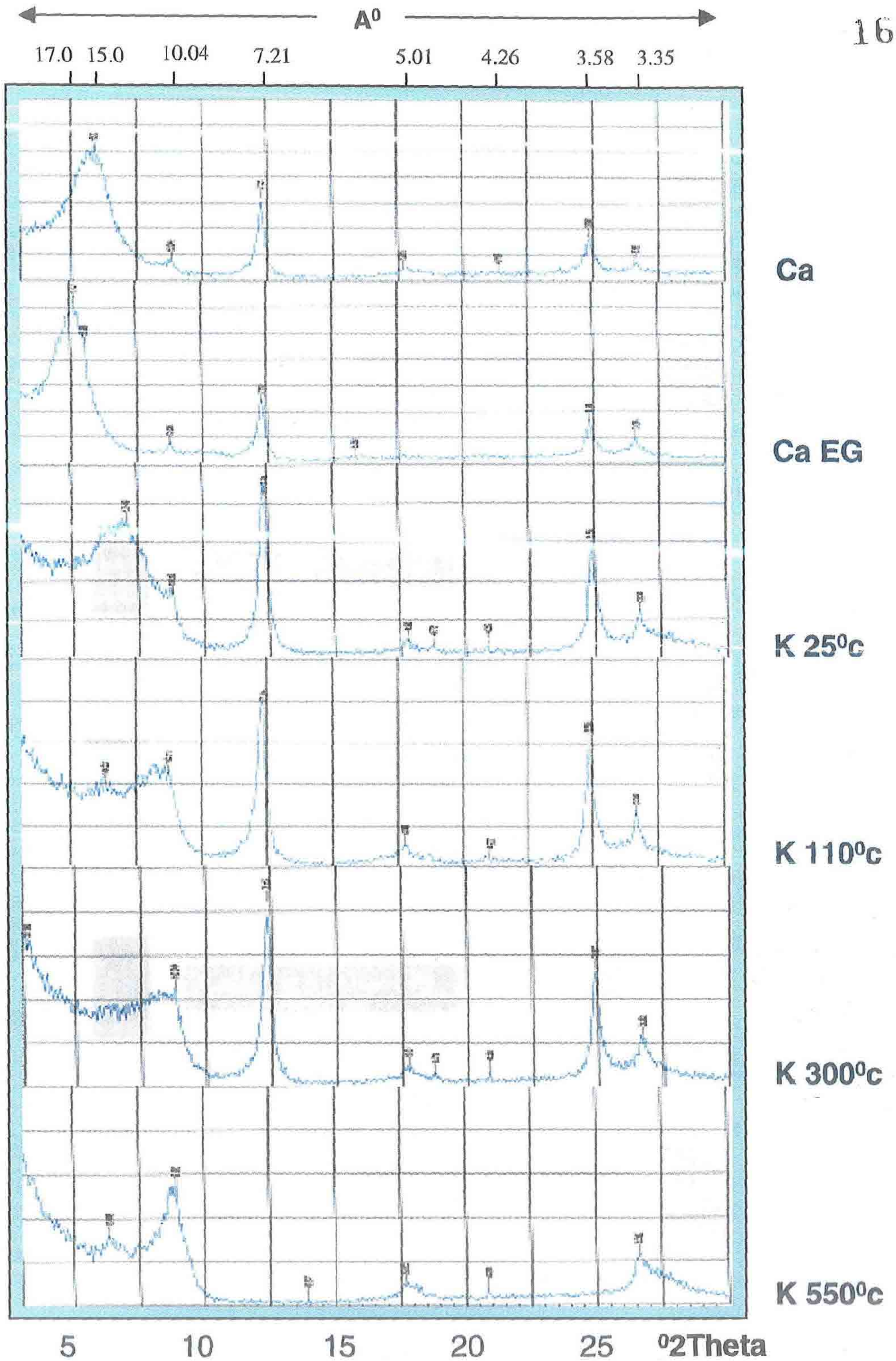

Fig.15 : X-ray diffractograms of clay fraction of soils in Dagala - 1 series

The presence of kaolinite was ascertained by the presence of sharp peaks at 7.21 and 3.58 A° in all treatments expect K–saturation at 550°C. Basal reflections of 10.1 A° and 5.1 A° in all treatments, which were unaltered even by heating to 550°C in respect of K-saturation, indicated the presence of illite whereas a shift to 17.2 A° in Ca-glycerolated specimen suggested the presence of smectite. Prominent peaks at 3.34 (001) and 4.26 (002) A° in all treatments, which remained unchanged in their positions confirmed the presence of quartz.

4.3.1.3 Sodic Haplocambids - Sangnadi-1 series (Pedon – 12)

The X-ray diffractograms of clay fractions of typifying pedon (Fine loamy hyperthermic Sodic Haplocambids) in Sangnadi-1 series are depicted in Fig. 16. From the diffraction patterns, it was inferred that kaolinite, smectite and quartz were the minerals observed in these soils. However, smectite was the dominant clay mineral among these minerals which was evidenced from the relative proportions of clay minerals (Table 22).

The presence of prominent peak at 14.34 A° in Ca saturated specimen which shifted to 18.06 (0.01) A° with two higher order peaks at 8.76 (002) and 5.74 (0.03) A° in Ca-glycerolated specimen and which again shifted to 10.1 A° in K-saturated specimen heated to 550°C suggested the presence of smectite.

The presence of kaolinite was detected through the basal reflections at 7.17 and 3.58 A° in all treatments, which collapsed on heating the K-saturated specimen to 550°C. Prominent peaks at 3.34 (001) and 4.26 (002) A° in all treatments, which remained unaltered in their positions, indicated the presence of quartz.

Fig.16 : X-ray diffractograms of clay fraction of Sangnadi-1 series

4.3.1.4 Vertic Haplocambids - Amrutangar series (Pedon – 3)

The X-ray diffraction patterns of clay fractions of typifying pedon in Amrutanagar series (Fine hyperthermic Vertic Haplocambids) are depicted in Fig. 17. These diffraction patterns showed a peak at 14.3A° in Ca-saturated treatment, which on glycerolation shifted to 17.0 and collapsed to 10 A° in K-saturation at 550°C which confirmed the presence of smectite.

These soils also exhibited the presence of kaolinite, which was indicated by the presence of basal reflections at 7.20 and 3.58 A° in all treatments of Ca-saturation, Ca-ethylene glycolation, K-Saturation at 25, 110 and 330 °C, which later collapsed on heating the K-saturated specimen to 550 °C.

Basal reflections of 3.34 (001) and 4.26 A° (002) in all the treatments suggested the presence of quartz. From the relative proportions of clay minerals, it was inferred that smectite was the dominant clay mineral followed by quartz > kaolinite (Table 22).

4.3.1.5 Typic Haplocalcids - Dhaneti-1 series (Pedon – 4)

The X-ray diffraction patterns of clay fractions of typifying pedon in Dhaneti-1 series are depicted in Fig. 18. The diffraction patterns suggested the presence of kaolinite, smectite, illite, chlorite, quartz and gibbsite. However, the dominant mineral was kaolinite (49.50%) followed by illite, quartz, chlorite, gibbsite and smectite (Table 22), with the contents showing a decreasing order.

A series of prominent sharp peaks at 7.2 (001) and 3.58 A° (002) in Ca and K-saturated treatments, which disappear after heating K-saturated specimen to 550 °C confirmed the presence of kaolinite.

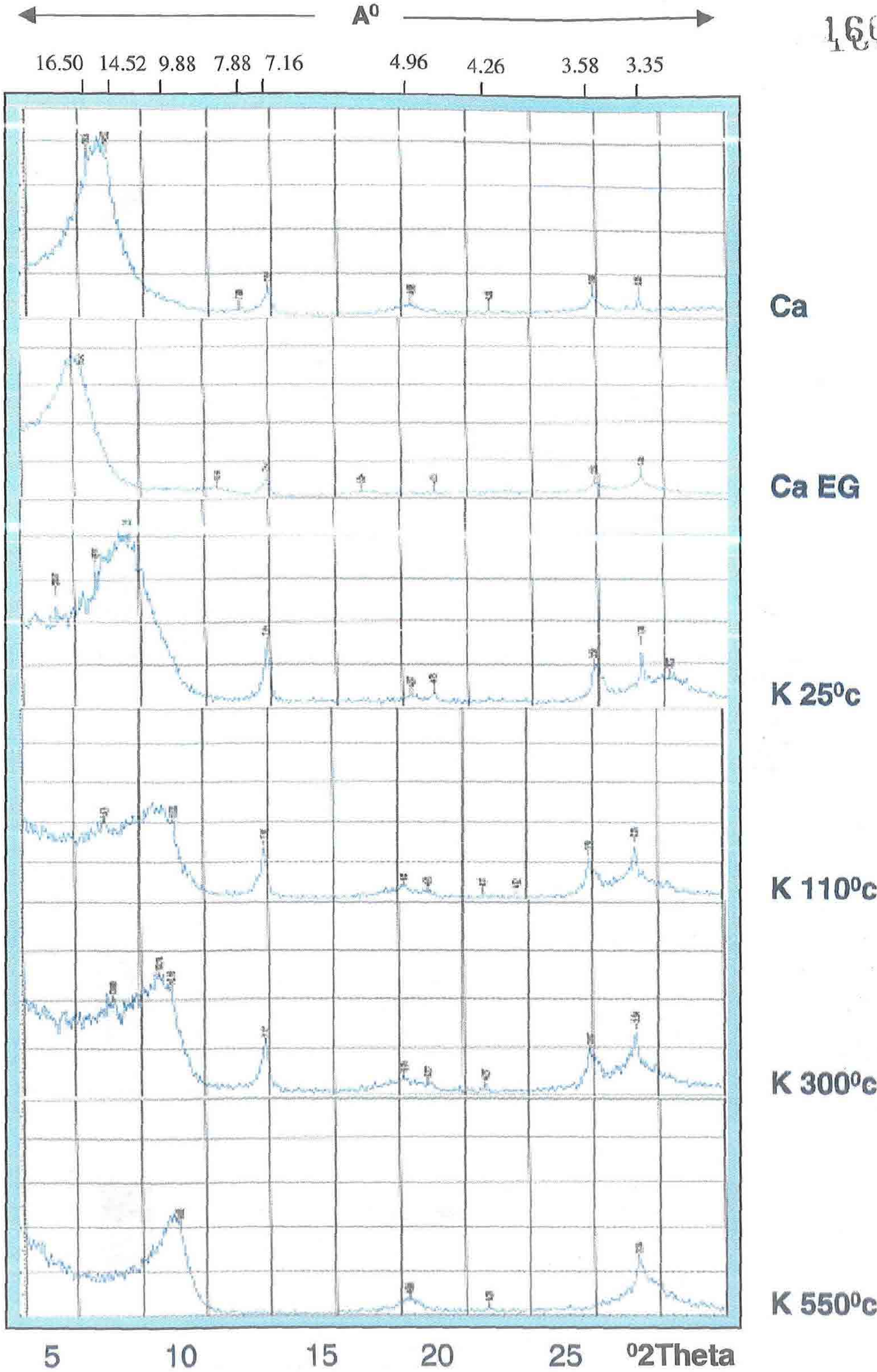

Fig.17 : X-ray diffractograms of clay fraction of soils in Amrutanagar series

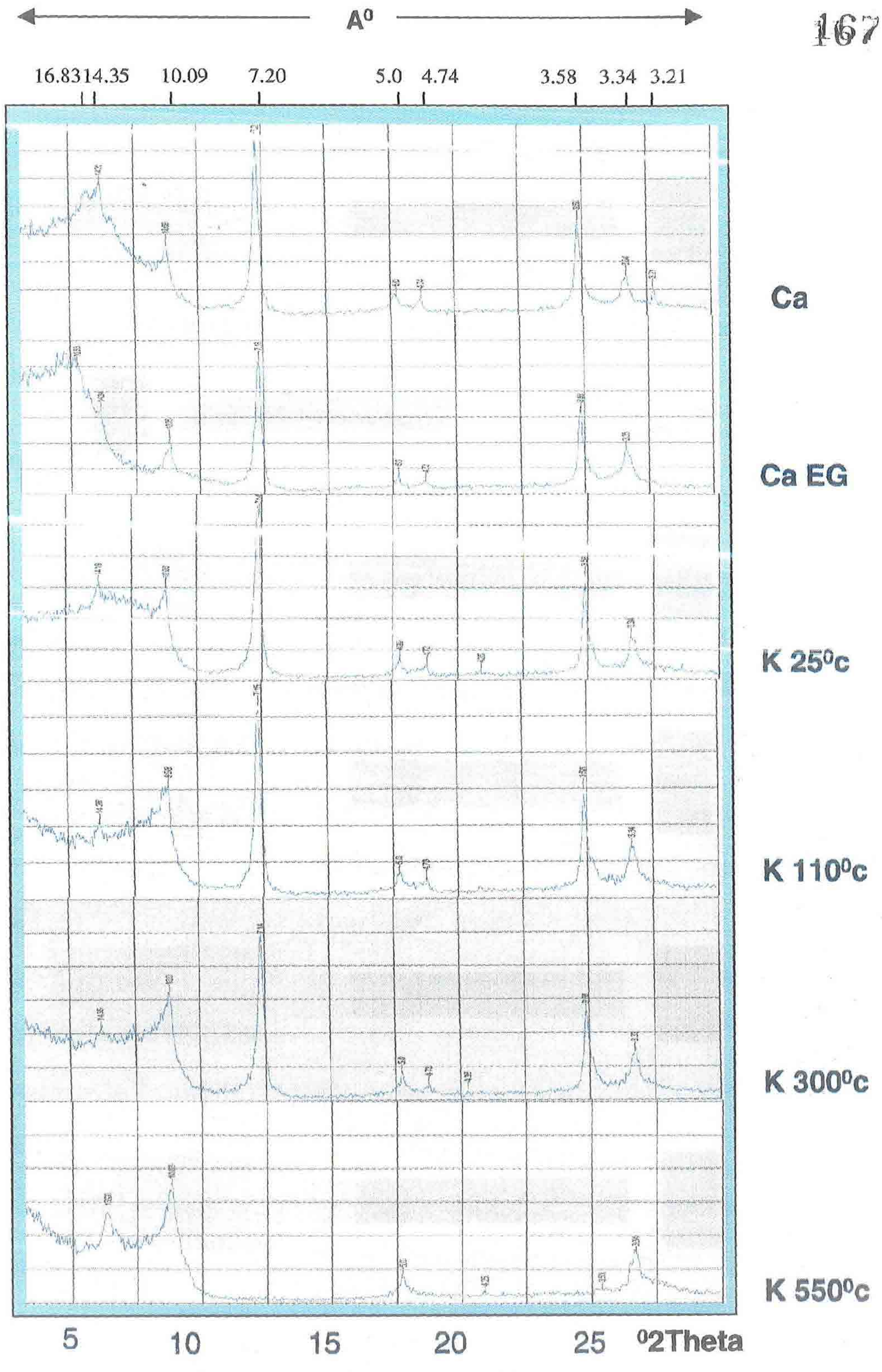

Fig.18 : X-ray diffractograms of clay fraction of soils in Dhaneti - 1 series

The presence of illite was indicated by the sharp basal reflections at 10.1 (001) and 5.0 (002) A°, which remained unaffected on glycerolation, K-saturation and heating treatments. The existence of peak at 14.3 A° in Ca-saturated specimen, which on glycerolation shifted to 17.0 A°.

The presence of gibbsite was ascertained by the presence of 4.74 A° peak in Ca-saturated, Ca-glycerolated, K-saturated specimens which collapsed by heating to 550°C.

4.3.2 Entisols

4.3.2.1 Typic Torriorthents - Yoginagar-2 series (Pedon – 10)

The X-ray diffractograms of the clay fractions of typifying pedon (Coarse loamy hyperthermic Typic Torriorthents) in Yoginagar-2 series are depicted in Fig. 19. Based on these diffractograms, different minerals identified in these soils were kaolinite, illite, chlorite, attapulgite, quartz and gibbsite.

The presence of kaolinite was ascertained by the presence of peaks at 7.2 (001) and 3.58 (002) A°, in Ca and all K saturated treatments at 25°, 110° and 300 °C, expect at 550°C where the peak was collapsed. Attapulgite was identified by a 10.5 A° in all treatments which was replaced by a broad halo on heating the K-saturated specimen above 400°C. Presence of series of reflections at 10.1 and 5.01 A°, which existed even in K-saturated and heating treatment of 550°C confirmed the presence of illite.

Prominent peaks at 3.34 (001) and 4.26 (002) A°, which remained in all treatments suggested the presence of quartz. Presence of basal reflections at 4.75 A° in Ca-saturated and Ca-glycerolated specimen, which disappeared in K-saturation and heating treatments to 550°C was an indication of the presence of gibbsite.

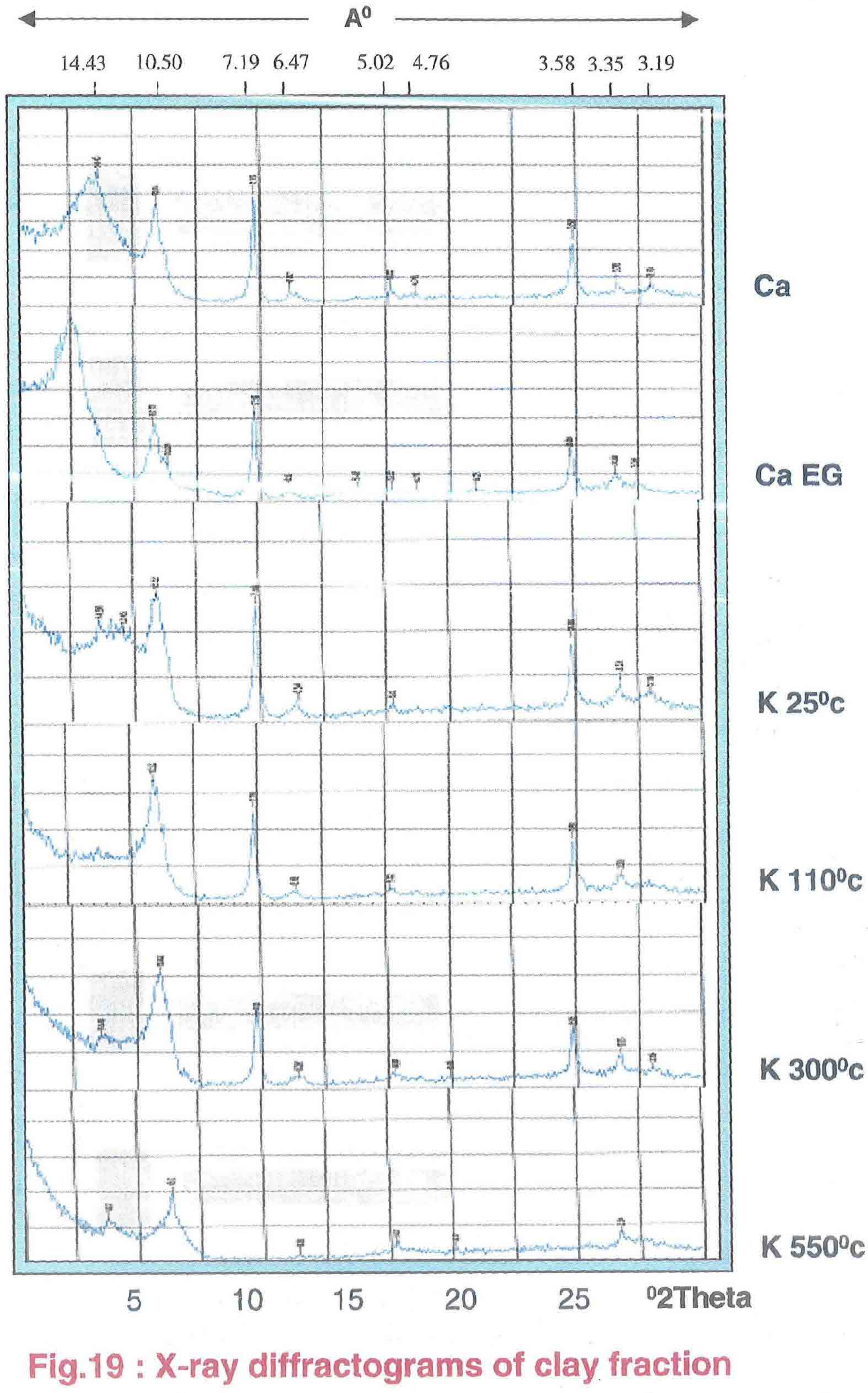

Fig.19 : X-ray diffractograms of clay fraction of soils in Yoginagar-2 series

The type of chlorite observed in this pedon was swelling chlorite (or) chloritised montmorillonite. This was confirmed by the peak at 18 A° spacing in Ca-glycerolated specimen and 14 A° peak on heating to 550°C (K-saturation). From the relative proportions of the clay minerals, it was inferred that kaolinite was the dominant mineral followed by chlorite > attapulgite > mica (Table 22).

4.3.2.2 Typic Torripsamments - Dagala-2 series (Pedon – 11)

The X-ray diffractograms of clay fractions of the typifying pedon (Typic Torripsamments) in Dagala-2 series are depicted in Fig. 20. From these diffractograms, it was inferred that kaolinite was the dominant mineral in these soils. However, other minerals such as illite, chlorite, quartz and gibbsite were also present which are in less fractions compared to kaolinite. (Table 22).

The presence of prominent and sharp peaks at 7.19 and 3.58 A° in Ca and K-saturated specimens which collapsed on heating to 550°C (K-saturation) conformed the presence of kaolinite. Presence of basal reflections at 10.1 (001), 5.0 (002) A° and a basal reflection at 14.3 A° in all the treatments, which remained unaltered even by heating to 550°C (K-saturated) suggested the presence of illite and chlorite, respectively.

Two basal reflections at 3.34 (001) and 4.26 (002) A° in all treatments indicated the presence of quartz. The presence of gibbsite was ascertained by the presence of basal reflections at 4.76 A° in all Ca and K-saturated treatments, which collapsed in heating treatments above 330°C.

4.4 SOIL CLASSIFICATION

Soils of the study area were classified based on the morphological, physical, physico-chemical, chemical properties and clay mineralogy according to "Keys to

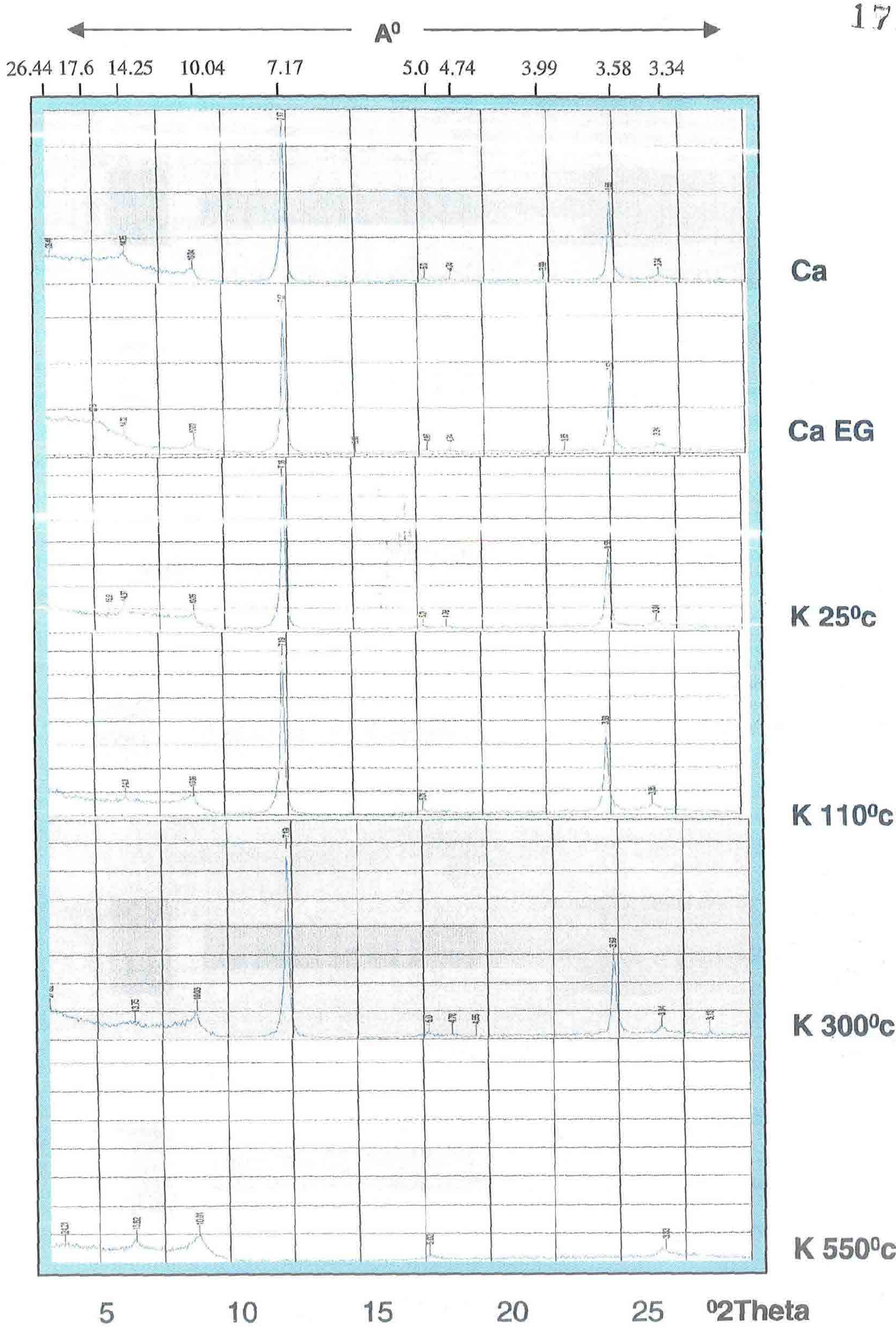

Fig. 20 : X-ray diffractograms of clay fraction of soils in Dagala - 2 series

Soil Taxonomy" (USDA Soil Survey Staff 1998). Two orders were identified namely Aridisols and Entisols. 50.93 per cent of study area was covered with Aridisols and 44.33 per cent with Entisols.

4.4.1 Aridisols

Nine pedons viz. 2, 3, 4, 5, 6, 7, 9, 12 and 14 were classified as Aridisols at order level. Two sub-orders such as Cambids and Calcids were identified under Aridisols. Pedons-4 and 6 were keyed out as Calcids while remaining pedons (Pedons-2, 3, 5, 7, 9, 12 and 14) as Cambids.

At great group level, Cambids were keyed out as Haplocambids and Calcids were keyed out as Haplocalcids.

At sub-group level, Haplocambids were classified into three sub-groups viz. Typic Haplocambids (Pedon-2, 5, 7, 9, 14), Vertic Haplocambids (Pedon-3) and Sodic Haplocambids (Pedon-12). Haplocalcids were classified under only one sub-group *i.e.* Typic Haplocalcids (Pedon-4 and 6).

At family level, soils were classified under particle size classes of 'Loamy skeletal' (Pedon – 2, 4 and 5) 'Coarse loamy' (Pedons-6 & 7), 'Fine loamy' (Pedons – 9 and 12), 'Loamy' (Pedon-14) and as 'Fine (Pedon-3). Soils of pedons-2, 4, 5, 6, 7 were classified as 'kaolinitic' mineralogical class while pedons – 3, 9, 12 and 14 were as "smectitic" based on the relative proportion of clay minerals identified. All the soils of the study area were keyed out under soil temperature class "hyperthermic".

At series level, soils were classified by giving local village names to the particular soil found in each area. Thus Aridisols were classified under 9 soil series. Pedon wise classification of soils under each series are given in Table 24.

Table 24: Pedon wise classification of soils under different soil series of study are

Pedon No.	Soil series	Soil classication
1	Mokhana	Corarse loamy kaolinitic hyperthermic Typic Torriortnents
2	Dagala-3	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids
3	Amrutanagar	Fine smectitic hyperthermic Vertic Haplocambids
4	Dhaneti-1	Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids
5	Kanyabe-2	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids
6	Kanyabe-1	Coarse loamy kaolinitic hyperthermic Typic Haplocalcids
7	Dhaneti-2	Coarse loamy kaolinitic hyperthermic Typic Haplocambids
8	Yoginagar-1	Sandy skeletal kaolinitic hyperthermic Typic Torriorthents
9	Dagala-1	Fine loamy smectitic hyperthermic Typic Haplocambids
10	Yoginagar-2	Coarse loamy kaolinitic hyperthermic Typic Torriorthents
11	Dagala-2	Kaolinitic hyperthermic Typic Torripsamments
12	Sangnadi-1	Fine loamy smectitic hyperthermic Sodic Haplocambids
13	Kanyabe-3	Sandy kaolinitic hyperthermic Typic Torriorthents
14	Sangnadi-2	Loamy smectitic hyperthermic Typic Haplocambids

4.4.2 Entisols

Five pedons viz. pedon-1, 8, 10, 11, 13 were classified as "Entisols" at order level that extends to an area of two suborders such as "Orthents" (Pedon – 1,8,10, and 13) and "Psamments" (Pedon-11) were identified under Entisols. At Great group level, Orthents were classified under "Torriorthents" while Psamments under "Torripsamments". At sub group level, Torriorthents were keyed out as "Typic Torriorthents" and Torripsamments were keyed out as "Typic Torripsamments".

At family level, soils were classified under particle size class of "Coarse loamy" (Pedon – 1 and 10), "Sandy skeletal" (Pedon-8) and "Sandy" (Pedon-13). All the Entisols were classified under "kaolinitic" mineralogical class and temperature regime of "hyperthermic".

At series level, soils were classified by giving local village names to the particular soil found in each area. Thus Entisols were classified under five soil series. Table 24 shows the pedon wise classification of soils under each soil series.

4.5 LAND EVALUATION

Two methods were adopted for evaluating the land viz. USDA method of land capability classification and parametric method of land evaluation (Riquier *et al.*, 1970). Land productivity was calculated for crops, pastures and forest trees or other trees. After assessing the capability and productivity of the land, optimum land use was suggested.

4.5.1 Assessment of land productivity (Riquier *et al.*, 1970 method)

Productivity was expressed in terms of productivity index, which is a function of nine factors namely moisture (H), drainage (D), effective soil depth (P), texture/structure (T), base saturation (N), soluble salt content (S), organic matter (O), mineral exchange capacity (A), and reserves of weatherable minerals (M). It was computed using the following formula:

Productivity Index = H x D x P x T x N x S x O x A x M.

Actual and potential productivity indices were calculated. In actual productivity index, values of the ratings refer to the present day situation and in potential productivity index, the ratings will be given according to the situation after soil management. Actual land productivity map was generated using GIS (ARC/Info) techniques (Fig. 21)

4.5.1.1 Factors considered for land productivity index

Soil factors considered for actual and potential LPI calculations of different soils of the study area are given in Table 25 and 26. Soil characteristics used for assigning categories to the factors considered for productivity calculation are given in Appendix-I.

Soil moisture content (H)

Soil moisture content has a direct impact on yield of crops. Ratings for this factor was given by taking into consideration the moisture content in the root zone whether below wilting point (or) between wilting point and field capacity for most of the year. In the present study, number of dry months were calculated from the ombrothermic diagram of the study area. All the soils of the study area were placed under H2c category.

Drainage (D)

Drainage factor is a measure of soil air and water relationship and the availability of oxygen for root activity depends on soil drainage. In the study area,

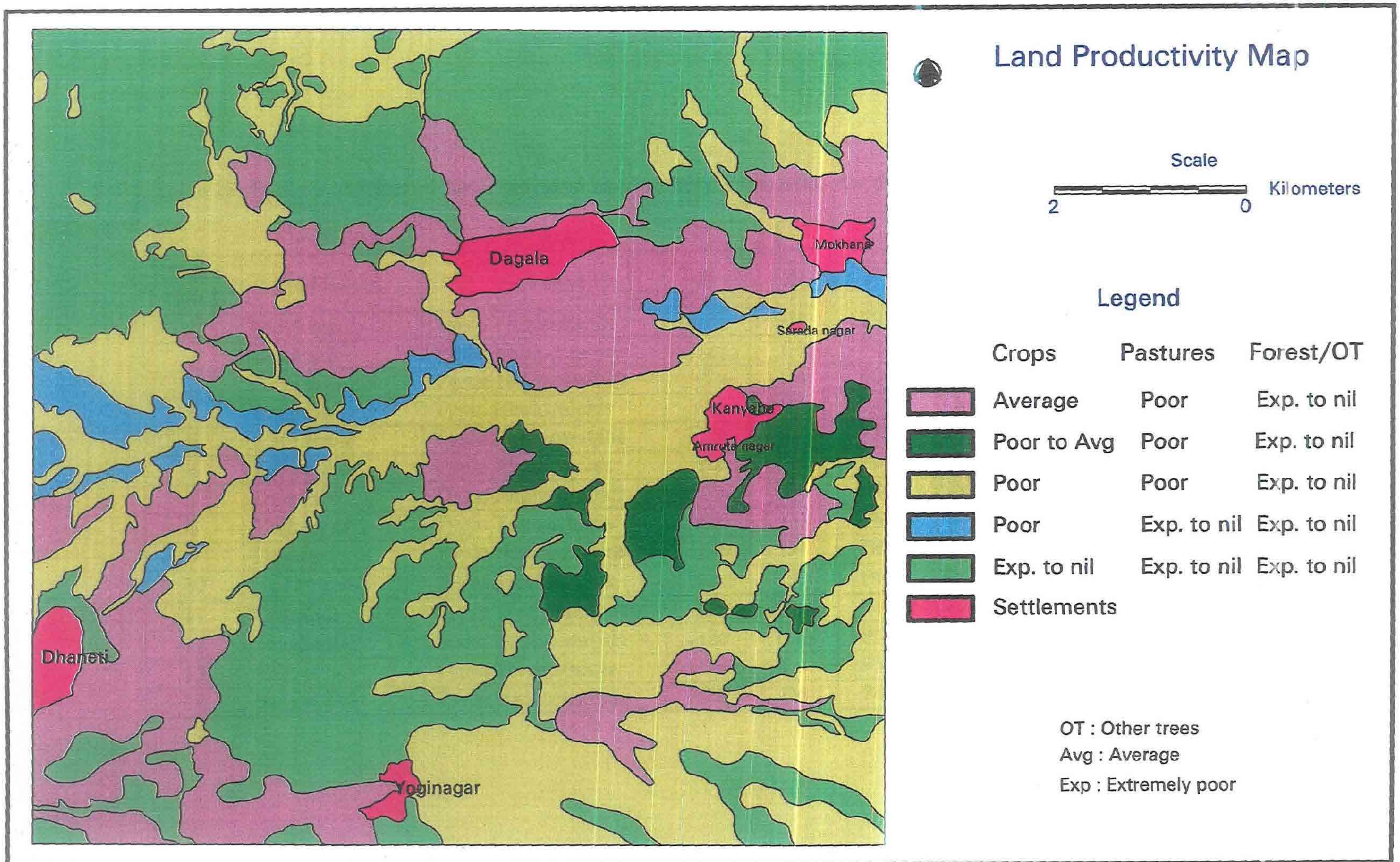

Fig. 21: Land productivity map of the study area

Table 25: Factors considered for actual land productivity calculation for different soils of the study area

Pedon No.	Soil Series	Soil type	H	D	P	T	N	S	O	A	M
1	Mokhana	Typic Torriorthents	H2c	D4	P2	T4a	N5	S1	O1	A2	M2c
2	Dagala-3	Typic Haplocambids	H2c	D4	P4	T4b	N5	S1	O1	A2	M1
3	Amrutanagar	Vertic Haplocambids	H2c	D4	P5	T5b	N5	S1	O1	A3	M1
4	Dhaneti-1	Typic Haplocalcids	H2c	D4	P4	T4b	N5	S1	O1	A3	M3c
5	Kanyabe-2	Typic Haplocambids	H2c	D4	P5	T4b	N5	S1	O1	A3	M2c
6	Kanyabe-1	Typic Haplocalcids	H2c	D4	P6	T4b	N4	S1	O1	A2	M3c
7	Dhaneti-2	Typic Haplocambids	H2c	D4	P4	T6b	N5	S1	O1	A2	M3c
8	Yoginagar-1	Typic Torriorthents	H2c	D4	P4	T4b	N5	S1	O1	A2	M2c
9	Dagala-1	Typic Haplocambids	H2c	D4	P4	T6b	N5	S1	O1	A3	M2c
10	Yoginagar-2	Typic Torriorthents	H2c	D4	P4	T2b	N5	S1	O1	A2	M1
11	Dagala-2	Typic Torripsamments	H2c	D4	P4	T2a	N4	S1	O1	A2	M2c
12	Sangnadi-1	Sodic Haplocambids	H2c	D3b	P5	T6a	N5	S3	O1	A2	M2c
13	Kanyabe-3	Typic Torriorthents	H2c	D4	P5	T4a	N5	S1	O1	A1	M2c
14	Sangnadi-2	Typic Haplocambids	H2c	D4	P4	T4a	N5	S1	O1	A2	M2c

Table 26: Factors considered for potential productivity calculation for different soils of the study area

Pedon No.	Soil Series	Soil type	H	D	P	T	N	S	O	A	M
1	Mokhana	Typic Torriorthents	H3a	D4	P2	T4b	N5	S1	O2	A2	M2c
2	Dagala-3	Typic Haplocambids	H3a	D4	P4	T4b	N5	S1	O2	A2	M1
3	Amrutanagar	Vertic Haplocambids	H3a	D4	P5	T5b	N5	S1	O2	A3	M1
4	Dhaneti-1	Typic Haplocalcids	H3a	D4	P4	T4b	N5	S1	O2	A3	M3c
5	Kanyabe-2	Typic Haplocambids	H3c	D4	P5	T5a	N5	S1	O2	A3	M2c
6	Kanyabe-1	Typic Haplocalcids	H3c	D4	P6	T4b	N4	S1	O2	A2	M3c
7	Dhaneti-2	Typic Haplocambids	H3c	D4	P4	T6b	N5	S1	O2	A2	M3c
8	Yoginagar-1	Typic Torriorthents	H3a	D4	P4	T5a	N5	S1	O2	A2	M2c
9	Dagala-1	Typic Haplocambids	H3c	D4	P4	T7	N5	S1	O2	A3	M2c
10	Yoginagar-2	Typic Torriorthents	H3a	D4	P4	T2c	N5	S1	O2	A2	M1
11	Dagala-2	Typic Torripsamments	H3a	D4	P4	T2b	N4	S1	O2	A2	M2c
12	Sangnadi-1	Sodic Haplocambids	H3c	D4	P5	T6b	N5	S1	O2	A2	M2c
13	Kanyabe-3	Typic Torriorthents	H3a	D4	P5	T4b	N5	S1	O2	A1	M2c
14	Sangnadi-2	Typic Haplocambids	H3c	D4	P4	T4b	N5	S1	O2	A2	M2c

drainage is not a limiting factor and all the soils were well drained with class D4 except Sodic Haplocambids, which were categorized under class D3b.

Effective depth of soil (P)

The depth of the soil is an important factor for crops and other trees as it suggests the volume of the soil from which the roots can extract the nutrients and water for their growth. Deep soils can provide good anchorage to crops especially for tree crops that have a deep root system. In the study area, most of the soils were under P4 class and three types of soils namely Typic Torriorthents (Pedon-1), Vertic Haplocambids (Pedon-3) and Typic Haplocalcids (Pedon-5) were classified under P2, P5 and P6 classes, respectively.

Texture and structure of the soil in the root zone (T)

Texture and structure of the soils in root zone play an important role in soil water availability, infiltration rate, drainage, tillage conditions and capacity to supply and retain the nutrients in soils. There was high variation in texture and structure of these soils which ranged from T2a to T6b for different soils in the study area.

Average nutrient content of A horizon (N)

This factor was calculated based on the base saturation per cent, which is an indicator of the status or level of nutrient availability in soils. The soils of the study area belonged to N4 and N5 classes. All the soils were placed in N5 class except two, which were placed in N4 class.

Soluble salt content (S)

This factor was obtained from EC of the soils which in excessive amounts affects the crop growth severely and reduces the yields drastically by making the nutrients present in the soil unavailable to the plants. All the soils of the study area were classified under S1 except Sodic Haplocambids which was classified under S3 due to high EC (3.90 to 10.33 dSm^{-1}).

Organic matter in A1 horizon (O)

Organic matter of the soils plays critical role in balancing all the soil properties such as CEC, water holding capacity, fertility status, colour, structure and texture. Soils of the study area have low organic matter due to the aridic climate and, hence, these soils were kept under O1.

Mineral exchange capacity and nature of the clay in B horizon (A)

The soil clay mineralogy plays a critical role in the cation exchange capacity and is an indicator of fertility level in soil. Mineral exchange capacity was computed by using the formula given below.

$$\text{Exchange capacity} = \frac{(\text{CEC of soil} - \text{K}) \times \%\ \text{OM} \times 100}{\%\ \text{clay}}$$

Where CEC = Cation exchange capacity at a depth of 60 cm for crops and forest/other trees and 30 cm for pastures.

K = Constant factor, 1.5 for tropical soils.

OM = Organic matter content

Out of the total soils in study area, ten were grouped under A2 class, three under A3 and only one under A1 class.

Reserves of weatherable minerals in B-horizon (M)

Reserves of weatherable minerals in B-horizon were assessed based on the lithology of the study area along with degree of development of soil profile. Eight types of soils were placed in M2C category whereas six types of soils were placed in M1 and M3C with three in each class.

4.5.1.2 Actual and potential productivity classes for different soil map units in the study area

Productivity classes of the different soils of the study were calculated by giving ratings to the above mentioned nine factors according to the tentative ratings for different characteristics, which are given in Appendix-I. Ratings considered for different factors in calculating actual LPI and potential LPI for different soils of the study area are presented in the Tables 27 and 28, respectively.

Productivity classes for field crops

Actual and potential productivity classes for field crops are given in Table 29. Soils in the series of Amrutanagar, Dhaneti-2 and Dagala-3 were classified as average whereas Kanyabe 2 was classified as poor to average. Seven types of soils were poorly suitable for crops whereas the remaining three types of soils were not suitable for crops. After improving the soil related constraints, the soil productivity changed from average to good and poor to average for eleven types of soils and no change was observed in soils of Mokhana, Kanyabe-2 and Dagala-2 series.

Productivity classes for pastures

According to the actual productivity index ratings, soils belong to Mokhana, Yoginagar-2, Dagala-2 and Kanyabe-3 and Sangnadi-2 series were rated under extremely poor to nil class while the remaining soils were rated under poor class. But after improving the limiting factors, soils of Dagala-1 and Sangnadi-1 series were changed from poor to good category whereas other soils under poor category were changed to average category. There was no change in soils of Yoginagar-1,

Table 27: Ratings used for different factors to calculate actual land productivity for different soil series of the study area

Pedon No.	Soil Series	Soils	Class	H	D	P	T	N	S	O	A	M	LPI	Productivity class
1	Mokhana	Typic Torriorthents	Crops	40	100	20	30	100	100	85	95	95	1.84	Ext. poor to Nil
			Pastures	30	80	60	30	100	100	85	95	95	3.31	Ext. poor to Nil
			Forest/OT	10	100	5	30	100	100	85	95	95	0.11	Ext. poor to Nil
2	Dagala-3	Typic Haplocambids	Crops	40	100	80	60	100	100	85	95	85	13.18	Poor
			Pastures	30	80	90	60	100	100	85	95	85	8.89	Poor
			Forest/OT	10	100	60	60	100	100	85	95	85	2.47	Ext. poor to Nil
3	Amrutanagar	Vertic Haplocambids	Crops	40	100	100	80	100	100	85	100	85	23.12	Average
			Pastures	30	80	100	80	100	100	85	100	85	13.87	Poor
			Forest/OT	10	100	80	80	100	100	85	100	85	4.62	Ext. poor to Nil
4	Dhaneti-1	Typic Haplocalcids	Crops	40	100	80	60	100	100	85	100	100	16.32	Poor
			Pastures	30	80	90	60	100	100	85	100	100	11.01	Poor
			Forest/OT	10	100	60	60	100	100	85	100	100	3.06	Ext. poor to Nil
5	Kanyabe-2	Typic Haplocambids	Crops	40	100	100	60	100	100	85	100	100	20.40	Poor to Average
			Pastures	30	80	100	60	100	100	85	100	100	12.24	Poor
			Forest/OT	10	100	80	60	100	100	85	100	100	4.08	Ext. poor to Nil
6	Kanyabe-1	Typic Haplocalcids	Crops	40	100	100	60	80	100	85	95	100	15.50	Poor
			Pastures	30	80	100	60	90	100	85	95	100	10.46	Poor
			Forest/OT	10	100	100	60	100	100	85	95	100	4.84	Ext. poor to Nil
7	Dhaneti-2	Typic Haplocambids	Crops	40	100	80	90	100	100	85	95	100	23.26	Average
			Pastures	30	80	90	90	100	100	85	95	100	17.44	Poor
			Forest/OT	10	100	60	90	100	100	85	95	100	4.36	Ext. poor to Nil

Table Contd...

Pedon No.	Soil Series	Soils	Class	H	D	P	T	N	S	O	A	M	LPI	Productivity class
8	Yoginagar-1	Typic Torriorthents	Crops	40	100	80	60	100	100	85	95	95	14.73	Poor
			Pastures	30	80	90	60	100	100	85	95	95	9.28	Poor
			Forest/OT	10	100	60	60	100	100	85	95	95	2.76	Ext. poor to Nil
9	Dagala-1	Typic Haplocambids	Crops	40	100	80	90	100	100	85	95	95	22.10	Average
			Pastures	30	80	90	90	100	100	85	95	95	14.91	Poor
			Forest/OT	10	100	60	90	100	100	85	95	95	4.14	Ext. poor to Nil
10	Yoginaga-2	Typic Torriorthents	Crops	40	100	80	10	100	100	85	95	85	2.19	Ext. poor to Nil
			Pastures	30	80	90	10	100	100	85	95	85	1.97	Ext. poor to Nil
			Forest/OT	10	100	60	10	100	100	85	95	85	0.41	Ext. poor to Nil
11	Dagala-2	Typic Torripsamments	Crops	40	100	80	10	80	100	85	95	95	1.97	Ext. poor to Nil
			Pastures	30	80	90	10	90	100	85	95	95	1.49	Ext. poor to Nil
			Forest/OT	10	100	60	10	100	100	85	95	95	0.46	Ext. poor to Nil
12	Sangnadi-1	Sodic Haplocambids	Crops	40	90	100	60	100	80	85	100	95	13.94	Poor
			Pastures	30	90	100	60	100	80	85	100	95	10.46	Poor
			Forest/OT	10	40	80	60	100	80	85	100	95	1.23	Ext. poor to Nil
13	Kanyabe-3	Typic Torriorthents	Crops	40	100	100	30	100	100	85	90	95	8.72	Poor
			Pastures	30	80	100	30	100	100	85	90	95	5.23	Ext. poor to Nil
			Forest/OT	10	100	80	30	100	100	85	90	95	1.74	Ext. poor to Nil
14	Sangnadi-2	Typic Haplocambids	Crops	40	100	80	30	100	100	85	95	95	7.36	Poor
			Pastures	30	80	90	30	100	100	85	95	95	4.97	Ext. poor to Nil
			Forest/OT	10	100	60	30	100	100	85	95	95	1.38	Ext. poor to Nil

OT = Other Trees
Ext.Poor to Nil = Extremely Poor to Nil

Table 28: Ratings used for different factors to calculate potential productivity for different soil series of the study area

Pedon No.	Soil Series	Soils	Class	H	D	P	T	N	S	O	A	M	LPI	Productivity class
1	Mokhana	Typic Torriorthents	Crops	70	100	20	50	100	100	90	95	95	6.30	Ext. poor to Nil
			Pastures	60	80	60	50	100	100	90	95	95	12.96	Poor
			Forest/OT	40	100	5	50	100	100	90	95	95	0.90	Ext. poor to Nil
2	Dagala-3	Typic Haplocambids	Crops	70	100	80	60	100	100	90	95	85	34.27	Average
			Pastures	60	80	90	60	100	100	90	95	85	26.44	Average
			Forest/OT	40	100	60	60	100	100	90	95	85	14.69	Poor
3	Amrutanagar	Vertic Haplocambids	Crops	70	100	100	80	100	100	90	100	85	42.84	Good
			Pastures	60	80	100	80	100	100	90	100	85	29.37	Average
			Forest/OT	40	100	80	80	100	100	90	100	85	19.58	Poor
4	Dhaneti-1	Typic Haplocalcids	Crops	70	100	80	60	100	100	90	100	100	30.24	Average
			Pastures	60	80	90	60	100	100	90	100	100	23.32	Average
			Forest/OT	40	100	60	60	100	100	90	100	100	12.96	Poor
5	Kanyabe-2	Typic Haplocambids	Crops	70	100	100	60	100	100	90	100	100	37.80	Good
			Pastures	60	80	100	60	100	100	90	100	100	25.92	Average
			Forest/OT	40	100	80	60	100	100	90	100	100	17.28	Poor
6	Kanyabe-1	Typic Haplocalcids	Crops	70	100	100	80	80	100	90	95	100	38.30	Good
			Pastures	60	80	100	80	90	100	90	95	100	28.61	Average
			Forest/OT	40	100	100	80	100	100	90	95	100	27.36	Average
7	Dhaneti-2	Typic Haplocambids	Crops	70	100	80	90	100	100	90	95	100	43.09	Good
			Pastures	60	80	90	90	100	100	90	95	100	33.24	Average
			Forest/OT	40	100	60	90	100	100	90	95	100	18.46	Poor

Table Contd...

Pedon No.	Soil Series	Soils	Class	H	D	P	T	N	S	O	A	M	LPI	Productivity class
8	Yoginagar-1	Typic Torriorthents	Crops	50	100	80	90	100	100	90	95	95	19.49	Average
			Pastures	30	80	90	90	100	100	90	95	95	10.53	Poor
			Forest/OT	10	100	60	90	100	100	90	95	95	2.92	Ext. poor to Nil
9	Dagala-1	Typic Haplocambids	Crops	70	100	80	100	100	100	90	95	95	50.40	Good
			Pastures	60	80	90	100	100	100	90	95	95	38.88	Good
			Forest/OT	40	100	60	100	100	100	90	95	95	21.60	Average
10	Yoginaga-2	Typic Torriorthents	Crops	50	100	80	30	100	100	90	95	85	9.18	Poor
			Pastures	30	80	90	30	100	100	90	95	85	4.95	Ext. poor to Nil
			Forest/OT	10	100	60	30	100	100	90	95	85	1.37	Ext. poor to Nil
11	Dagala-2	Typic Torripsamments	Crops	50	100	80	20	80	100	90	95	95	5.76	Ext. poor to Nil
			Pastures	30	80	90	20	90	100	90	95	95	3.50	Ext. poor to Nil
			Forest/OT	10	100	60	20	100	100	90	95	95	1.08	Ext. poor to Nil
12	Sangnadi-1	Sodic Haplocambids	Crops	70	100	100	90	100	100	90	100	95	56.70	Good
			Pastures	60	80	100	90	100	100	90	100	95	38.88	Good
			Forest/OT	40	100	80	90	100	100	90	100	95	25.92	Average
13	Kanyabe-3	Typic Torriorthents	Crops	50	100	100	50	100	100	90	90	95	19.24	Average
			Pastures	30	80	100	50	100	100	90	90	95	1.08	Poor
			Forest/OT	10	100	80	50	100	100	90	90	95	3.08	Ext. poor to Nil
14	Sangnadi-2	Typic Haplocambids	Crops	70	100	80	50	100	100	90	95	95	25.20	Average
			Pastures	60	80	90	50	100	100	90	95	95	19.44	Poor
			Forest/OT	40	100	60	50	100	100	90	95	95	10.80	Poor

OT = Other Trees

Ext.Poor to Nil = Extremely Poor to Nil

Table 29: Productivity classes of the soils of the study area for field crops

Pedon No.	Series	Actual Productivity (P)		Potential Productivity (P')	
		Rating	Class	Rating	Class
1	Mokhana	1.84	Ext. Poor- Nil	6.30	Ext. Poor- Nil
2	Dagala-3	13.18	Poor	34.27	Average
3	Amrutanagar	23.12	Average	42.84	Good
4	Dhaneti-1	16.32	Poor	30.24	Average
5	Kanyabe-2	20.4	Poor-Average	37.80	Good
6	Kanyabe-1	15.5	Poor	38.30	Good
7	Dhaneti-2	23.26	Average	45.36	Good
8	Yoginagar-1	14.73	Poor	21.60	Average
9	Dagala-1	22.1	Average	50.40	Good
10	Yoginagar-2	2.19	Ext. Poor- Nil	9.18	Poor
11	Dagala-2	1.97	Ext. Poor- Nil	5.76	Ext. Poor- Nil
12	Sangnadi-1	13.94	Poor	56.70	Good
13	Kanyabe-3	8.72	Poor	19.24	Average
14	Sangnadi-2	8.16	Poor	25.20	Average

Ext. Poor-Nil = Extremely Poor to Nil

Yoginagar-2 and Dagala-2 after improvement also. Productivity ratings are presented in Table 30.

Productivity classes for forest/other trees

All the soils of the study area were classified as extremely poor to nil category as the actual productivity index was below 7. But with improved management practices, the soils of the Kanyabe-1, Dagala-1 and Sangnadi-1 series would move to average category whereas soils of the Mokhana, Yoginagar-1, Yoginagar-2, Dagala-2 and Kanyabe-3 did not show change. Remaining soils were changed from extremely poor to nil class to poor class (Table 31).

4.5.2 Land capability classification

Criteria for land capability classification are given in Appendix-II. Parameters considered for assessing the land capability were topography (slope and erosion), wetness (flooding, drainage, permeability and infiltration rate), physical soil conditions (surface texture, surface coarse fragments, surface stoniness, sub-surface coarse fragments, soil depth and profile development) and fertility status of the soil (CEC, base saturation, OC, salinity and gypsum content). By taking into consideration of all these parameters, soils of the study area were categorized into five land capability classes (Table 32) and land capability map was prepared using GIS (ARC/Info) techniques, which is presented in the Fig. 22.

Soils of the Amrutanagar series had less limitations compared to other soils and therefore, were placed under Class III and that of Yoginagar-2 series had very severe limitations, which were, therefore, placed under class VIII. Soils of the series Kanyabe-1, Dhaneti-2 and Dagala-1 were classified as IV class as they had moderate limitations. The soils of the series – Dhaneti-1, Dagala-2, Yoginagar-1 and Kanyabe-

Table 30: Productivity classes of the soils of the study area for pastures

Pedon No.	Series	Actual Productivity (P)		Potential Productivity (P')	
		Rating	Class	Rating	Class
1	Mokhana	3.31	Ext. Poor- Nil	12.96	Poor
2	Dagala-3	8.89	Poor	26.44	Average
3	Amrutanagar	13.87	Poor	29.37	Average
4	Dhaneti-1	9.07	Poor	23.32	Average
5	Kanyabe-2	12.24	Poor	25.92	Average
6	Kanyabe-1	10.46	Poor	28.61	Average
7	Dhaneti-2	17.44	Poor	34.99	Average
8	Yoginagar-1	9.28	Poor	11.66	Poor
9	Dagala-1	14.91	Poor	38.88	Good
10	Yoginagar-2	1.97	Ext. Poor- Nil	4.95	Ext. Poor- Nil
11	Dagala-2	1.49	Ext. Poor- Nil	3.50	Ext. Poor- Nil
12	Sangnadi-1	10.46	Poor	38.88	Good
13	Kanyabe-3	5.23	Ext. Poor- Nil	10.80	Poor
14	Sangnadi-2	4.5477	Ext. Poor- Nil	19.44	Poor

Ext. Poor-Nil = Extremely Poor to Nil

Table 31: Productivity classes of the soils of the study area for forest/other trees

Pedon No.	Series	Actual Productivity (P)		Potential Productivity (P')	
		Rating	Class	Rating	Class
1	Mokhana	0.11	Ext Poor- Nil	0.90	Ext Poor- Nil
2	Dagala-3	2.47	Ext Poor- Nil	14.69	Poor
3	Amrutanagar	4.62	Ext Poor- Nil	19.58	Poor
4	Dhaneti-1	3.06	Ext Poor- Nil	12.96	Poor
5	Kanyabe-2	4.08	Ext Poor- Nil	17.28	Poor
6	Kanyabe-1	4.84	Ext Poor- Nil	27.36	Average
7	Dhaneti-2	4.36	Ext Poor- Nil	19.44	Poor
8	Yoginagar-1	2.76	Ext Poor- Nil	3.24	Ext Poor- Nil
9	Dagala-1	4.14	Ext Poor- Nil	21.60	Average
10	Yoginagar-2	0.41	Ext Poor- Nil	1.37	Ext Poor- Nil
11	Dagala-2	0.46	Ext Poor- Nil	1.08	Ext Poor- Nil
12	Sangnadi-1	1.23	Ext Poor- Nil	25.92	Average
13	Kanyabe-3	1.74	Ext Poor- Nil	3.08	Ext Poor- Nil
14	Sangnadi-2	1.38	Ext Poor- Nil	10.80	Poor

Ext. Poor-Nil = Extremely Poor to Nil

Table 32: Land capability classification for the soils of the study area

Pedon No.	Soil Series	Soil type	Land capability class	Land capability sub-class
1	Mokhana	Typic Torriorthents	VI	esc
2	Dagala-3	Typic Haplocambids	VI	esc
3	Amrutanagar	Vertic Haplocambids	III	sc
4	Dhaneti-1	Typic Haplocalcids	VII	sc
5	Kanyabe-2	Typic Haplocambids	VI	sc
6	Kanyabe-1	Typic Haplocalcids	IV	sc
7	Dhaneti-2	Typic Haplocambids	IV	sc
8	Yoginagar-1	Typic Torriorthents	VII	esc
9	Dagala-1	Typic Haplocambids	IV	sc
10	Yoginagar-2	Typic Torriorthents	VIII	sec
11	Dagala-2	Typic Torripsamments	VII	esc
12	Sangnadi-1	Sodic Haplocambids	VI	sc
13	Kanyabe-3	Typic Torriorthents	VII	sc
14	Sangnadi-2	Typic Haplocambids	VI	sc

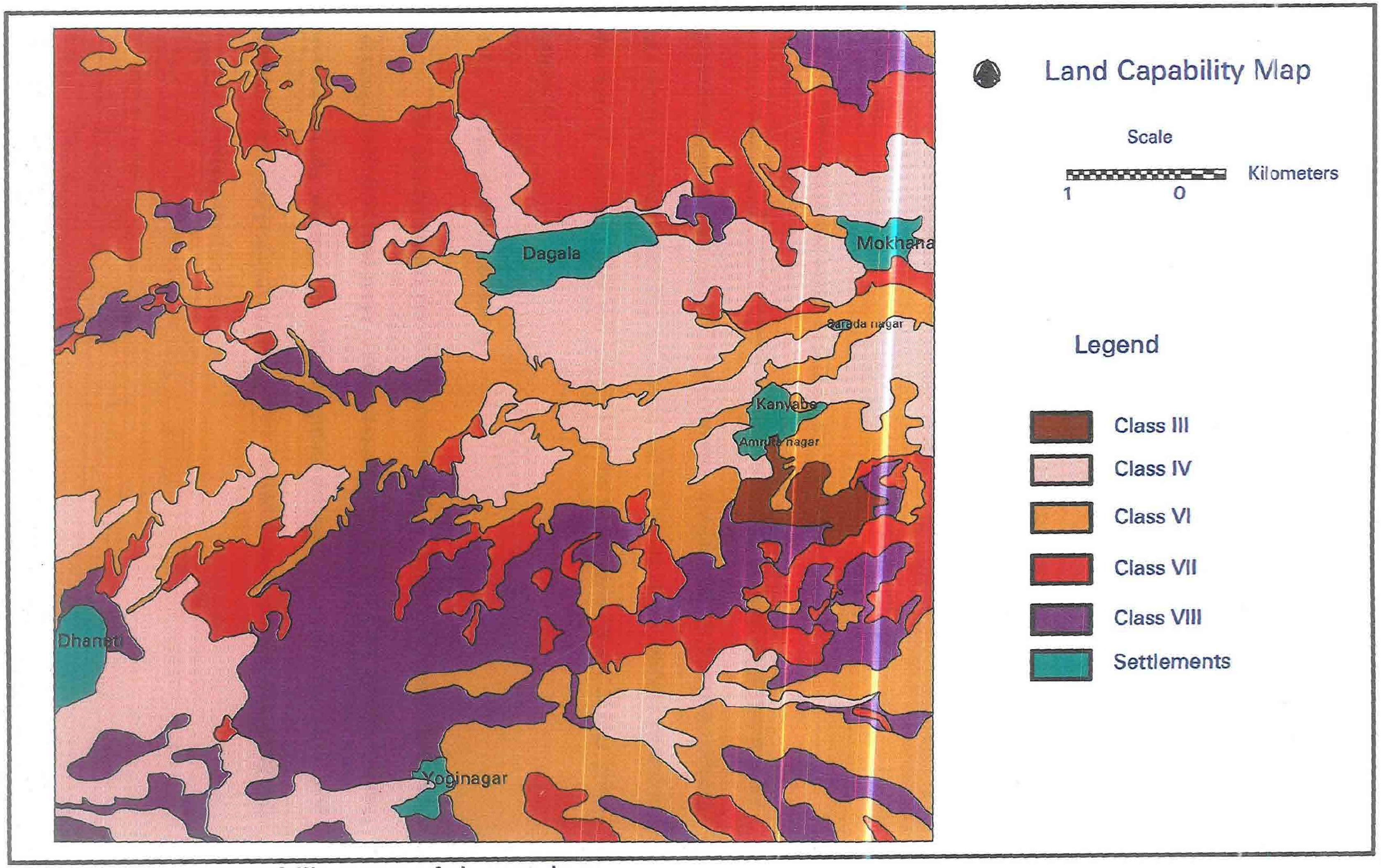

Fig. 22 : Land capability map of the study area

3 exhibited severe limitations and were placed under Class VII. The remaining six types of soils belonged to class VI.

The soils under class III and class IV were grouped under land capability sub class 'sc' which indicates the major limitation of soil followed by climate. However, climate was the limitation for all the soils of the study area as the soil temperature regime is aridic with an average annual rainfall of 350 mm. The sub-classes found in the capability class VI and VII of the soils of study area were 'sc' and 'esc', respectively. Soils of class VIII showed very severe limitations of soil factor followed by erosion and climate and so they were classified under sub class 'sec' (Table 32).

4.6 CREATION OF SOIL DIGITAL DATABASE

Creation of digital database is essential to develop decision support system for generating optimum land use plan of a given area. Spatial database elements (primary and derived database elements) are studied and the results of the database created in the form of attribute tables and structure of the tables for soils are clearly given hereunder.

4.6.1 Spatial database elements

The primary spatial database elements used in the present study were soils, drainage, settlements and roads. These elements were collected and entered into the system directly whereas the derived spatial database elements used were land capability and land productivity, which were derived from the primary data using GIS operations (Table 33).

Table 33: Spatial database elements used in the study

S. No.	Element	Type	Feature Code	Attribute table	Source
Primary data base elements					
1.	Soil	Poly	Soil-Code Soil-Code	Soil.lut Soil dat	RS based soil map Soil profile data
2.	Drainl	Line	Drnl-Code	Drainl.lut	Toposheet/RS
3.	Settlep	Point	S-Code	Settlep.lut	Toposheet
4.	Roads	Line	Rd-Code	Roads.lut	Toposheet/RS.
Derived database elements					
1.	Landcap	Poly	Lcap-Code	Landcap.lut	Soil
2.	Landprod.	Poly	Lprod-code	Landprod.lut	Soil

4.6.2 Attribute tables for soil layer

Attribute tables viz Soil.LUT and Soil.DAT for soil layer were created using NRIS standards. In Soil.LUT, the codification scheme of soil classes upto series level was described. Soil.DAT contained profile descriptions for each soil class/SOIL-CODE. In this table, soil properties were defined for individual soil horizon. These two tables were linked via Soil-Code as the key field. The structure of the attribute tables are given in Tables 34 and 35.

Table 34: Attribute table for soil coverage : SOIL.LUT

Field Name	Field Type	Key Field (Y/N)	Remarks
SOIL-CODE	16, 16, C	Yes	16 Digit primary link CODE
ORDER	15, 15, C	No	Order description
SB-ORDER	15, 15, C	No	Sub-order description
GR-GROUP	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 mineral description
FAMILY-TEMP	30, 30, C	No	Family level temperature regime description
SERIES	30, 30, C	No	Series name

4.6.3 Codification scheme for soil layer (SOIL.LUT)

Sixteen digits code was given for each soil series according to the NRIS standards and is represented in the Table 36.

Table 35: Attribute table for soil coverage : SOIL.DAT

Field Name	Field Type	Key Field (Y/N)	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-Ca	5, 5, N, 2	NO	
EX-Mg	5, 5, N, 2	NO	
EX-Na	5, 5, N, 2	NO	
EX-K	5, 5, N, 2	NO	
CEC	6, 6, N, 3	NO	
BASE-SATN	6, 6, N, 2	NO	
ESP	6, 6, N, 2	NO	
LCC	5, 5, C	NO	Land Capability Class
LPI	6, 6, N, 2	NO	Land Productivity Index

Table 36: Sixteen digits codes for the soils of the study area

Soil Series	Classification	Soil – Code
Mokhana	Coarse loamy kaolinitic hyperthermic Typic Torriorthents	04-05-02-03-08-05-05-01
Dagala-1	Fine loamy smectitic hyperthermic Typic Haplocambids	03-07-04-20-09-01-05-02
Dagala-2	Kaolinitic hyperthermic Typic Torripsamments	04-03-02-07-06-05-05-03
Dagala-3	Laomy skeletal kaolinitic hyperthermic Typic Haplocambids	03-07-04-20-04-05-05-04
Amrutanagar	Fine smectitic hyperthermic Vertic Haplocambids	03-07-04-19-99-01-05-05
Dhaneti-1	Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids	03-06-02-18-04-05-05-06
Dhaneti-2	Coarse loamy kaolinitic hyperthermic Typic Haplocambids	03-07-04-20-08-05-05-07
Kanyabe-1	Coarse loamy kaolinitic hyperthermic Typic Haplocalcids	03-06-02-18-08-05-05-08
Kanyabe-2	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	03-07-04-20-04-05-05-09
Kanyabe-3	Sandy kaolinitic hyperthermic Typic Torriorthents	04-05-02-15-06-07-05-10
Yoginagar-1	Sandy skeletal kaolinitic hyperthermic Typic Torriorthents	04-05-02-15-03-07-05-11
Yoginagar-2	Coarse loamy kaolinitic hyperthermic Typic Torriorthents	04-05-02-15-08-07-05-12
Sangnadi-1	Fine loamy smectitic hyperthermic Sodic Haplocambids	03-07-04-12-09-01-05-13
Sangnadi-2	Loamy smectitic hyperthermic Typic Haplocambids	03-07-04-20-07-01-05-14

4.7 SPATIAL VARIABILITY OF SOIL PROPERTIES

A part of the study area covering 32.56 ha was selected to find out the spatial variability in soil properties such as pH, EC, OC and major nutrients. Variability was studied using classical and geo-statistical procedures. Spatial variability maps were prepared by means as interpolation method *i.e.* Kriging. Based on the variability, site-specific recommendations of major nutrients were given for different crops. Taking into consideration, the recommendation given by CRIDA in respect of N, P_2O_5 and K_2O for arid soils.

4.7.1 Computation of results using statistical procedures

Location of sampled points and results of different properties studied for spatial variability of soils in sampled site are given in table 37 while a summary is given in Table 38. pH ranged from 7.2 to 8.2. The coefficient of variation of pH was very low among all properties indicating its less variability compared to other properties. EC values ranged from 1.36 to 2.68 dSm^{-1} with a mean value of 2.07 dSm-1 (Table 38). The OC was observed to be ranging from 0.120 to 0.530 per cent with a mean value from of 0.346 per cent; the CV being 25.65 per cent. Available nitrogen content varied from 136.42 to 321.44 kg/ha with a mean of 227.26 kg ha^{-1} showing a CV of 18.23 per cent. Variation in available P_2O_5 content was observed from 17.45 to 41.03 kg ha^{-1} with a mean of 29.48 kg ha^{-1} (CV 17.40%). The available K_2O ranged from 117.06 kg ha^{-1} to 372.69 kg ha^{-1} with a mean of 242.62 kg ha^{-1} (CV 29.45%). The data indicated high variability in available K_2O content followed by organic carbon status of soil.

Maps were prepared for spatial variability of all soil properties using geo-statistical procedures following kriging method. Soil test levels were grouped into

Table 37: Spatial variablity in soil properties

Sample No.	Latitude	Longitude	pH	E.C (dSm^{-1})	O.C. (%)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)
1	23° 16' 28.0"N	69° 58' 44.1"E	7.3	1.38	0.356	232.06	23.38	156.98
2	23° 16' 26.4"N	69° 58' 45.0"E	7.36	1.44	0.371	235.2	25.44	165.72
3	23° 16' 23.2"N	69° 58' 46.8"E	7.5	1.58	0.386	243.04	25.83	183.05
4	23° 16' 21.6"N	69° 58' 47.8"E	7.65	1.72	0.416	252.45	27.48	213.83
5	23° 16' 20.2"N	69° 58' 48.7"E	7.78	1.86	0.416	255.58	28.30	223.50
6	23° 16' 18.6"N	69° 58' 49.6"E	7.82	2.21	0.341	247.74	31.79	171.77
7	23° 16' 17.2"N	69° 58' 50.5"E	7.95	2.26	0.327	221.09	31.40	154.97
8	23° 16' 15.7"N	69° 58' 51.5"E	7.42	2.23	0.312	216.38	27.89	138.70
9	23° 16' 14.4"N	69° 58' 51.7"E	7.66	2.3	0.267	188.16	24.62	139.51
10	23° 16' 13.5"N	69° 58' 52.2"E	7.68	2.18	0.178	136.42	18.25	124.32
11	23° 16' 28.8"N	69° 58' 46.0"E	7.44	1.53	0.371	241.47	26.27	203.08
12	23° 16' 26.7"N	69° 58' 47.2"E	7.48	1.61	0.386	249.31	28.30	205.37
13	23° 16' 23.8"N	69° 58' 47.7"E	7.62	1.72	0.401	260.29	28.51	203.08
14	23° 16' 21.8"N	69° 58' 48.1"E	7.72	1.86	0.416	272.83	29.33	231.97
15	23° 16' 20.9"N	69° 58' 49.4"E	7.86	1.98	0.416	277.54	29.95	245.02
16	23° 16' 19.0"N	69° 58' 51.2"E	7.95	2.35	0.356	255.58	32.22	201.86
17	23° 16' 17.8"N	69° 58' 51.7"E	8.15	2.39	0.356	244.61	29.54	177.82
18	23° 16' 16.1"N	69° 58' 52.3"E	7.51	2.31	0.223	194.43	26.88	127.42
19	23° 16' 14.8"N	69° 58' 53.5"E	7.8	2.45	0.208	175.62	24.41	131.04
20	23° 16' 13.9"N	69° 58' 55.4"E	7.56	1.98	0.12	145.82	17.84	117.06
21	23° 16' 29.7"N	69° 58' 47.7"E	7.58	1.76	0.386	238.34	29.95	219.74
22	23° 16' 26.8"N	69° 58' 49.1"E	7.62	1.78	0.401	246.18	32.61	230.76
23	23° 16' 25.7"N	69° 58' 50.0"E	7.73	1.86	0.416	252.45	30.57	224.04
24	23° 16' 24.8"N	69° 58' 51.6"E	7.88	1.99	0.371	241.47	30.37	259.80
25	23° 16' 22.6"N	69° 58' 53.1"E	7.99	2.12	0.416	247.74	31.81	274.98
26	23° 16' 21.3"N	69° 58' 53.9"E	8.06	2.44	0.356	233.63	33.23	227.40
27	23° 16' 19.8"N	69° 58' 54.4"E	8.22	2.52	0.327	228.92	26.68	159.94
28	23° 16' 17.5"N	69° 58' 55.7"E	7.68	2.26	0.12	138	17.45	117.73
29	23° 16' 15.3"N	69° 58' 57.2"E	7.7	2.39	0.193	142.7	21.76	140.04
30	23° 16' 13.8"N	69° 58' 58.8"E	7.68	2.28	0.252	188.16	19.90	130.78
31	23° 16' 30.7"N	69° 58' 49.5"E	7.71	1.92	0.416	258.7	32.84	216.25
32	23° 16' 28.1"N	69° 58' 51.0"E	7.75	1.93	0.445	271.26	34.05	252.13
33	23° 16' 27.5"N	69° 58' 52.9"E	7.89	1.98	0.386	236.77	32.01	247.43
34	23° 16' 26.3"N	69° 58' 53.3"E	7.96	2.11	0.326	214.82	32.63	295.40
35	23° 16' 24.8"N	69° 58' 54.6"E	8.15	2.26	0.386	225.8	32.63	287.47
36	23° 16' 22.4"N	69° 58' 55.0"E	8.18	2.55	0.282	192.86	25.65	215.58
37	23° 16' 20.2"N	69° 58' 55.6"E	8.13	2.68	0.267	185.02	21.96	154.15
38	23o 16' 18.6"N	69° 58' 56.7"E	7.71	2.3	0.193	147.39	18.66	138.30
39	23° 16' 16.2"N	69° 58' 57.5"E	7.53	2.26	0.223	166.2	22.97	148.10
40	23° 16' 14.4"N	69° 58' 57.6"E	7.86	2.37	0.252	170.91	20.93	141.12
41	23° 16' 31.4"N	69° 58' 51.5"E	7.85	2.11	0.416	272.83	34.67	211.55
42	23° 16' 29.6"N	69° 58' 53.0"E	7.86	2.06	0.416	268.13	35.50	271.36
43	23° 16' 28.3"N	69° 58' 52.5"E	8.02	2.15	0.371	230.5	30.16	258.31
44	23° 16' 27.4"N	69° 58' 54.1"E	8.1	2.26	0.297	243.04	31.40	315.84
45	23° 16' 25.3"N	69° 58' 55.8"E	8.06	2.38	0.312	214.82	29.33	252.67
46	23° 16' 24.8"N	69° 58' 56.7"E	8.1	2.43	0.223	166.21	18.87	123.78
47	23° 16' 21.2"N	69° 58' 57.4"E	8.05	2.55	0.267	185.02	23.59	190.44
48	23° 16' 19.9"N	69° 58' 58.2"E	7.82	2.36	0.208	169.34	19.49	156.44
49	23° 16' 17.3"N	69° 58' 58.9"E	7.45	2.13	0.238	177.18	25.65	189.77

Table Contd...

Sample No.	Latitude	Longitude	pH	E.C (dSm^{-1})	O.C. (%)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)
50	23° 16' 13.8"N	69° 58' 59.4"E	7.78	2.26	0.267	191.29	22.58	148.78
51	23° 16' 31.8"N	69° 58' 53.4"E	7.96	2.2	0.392	239.9	36.94	238.97
52	23° 16' 30.5"N	69° 58' 55.4"E	7.98	2.15	0.392	243	33.64	297.96
53	23° 16' 29.1"N	69° 58' 54.1"E	8.04	2.28	0.316	221.1	27.71	241.51
54	23° 16' 28.5"N	69° 58' 55.0"E	8.22	2.38	0.271	177.18	28.30	279.68
55	23° 16' 25.9"N	69° 58' 55.8"E	7.89	2.26	0.286	186.59	25.42	232.25
56	23° 16' 25.2"N	69° 58' 57.2"E	7.98	2.36	0.196	147.39	20.93	151.33
57	23° 16' 23.3"N	69° 58' 57.9"E	7.87	2.4	0.301	211.68	25.65	217.73
58	23° 16' 19.2"N	69° 58' 58.8"E	7.77	2.27	0.286	186.59	22.14	213.70
59	23° 16' 18.4"N	69° 59' 0.1"E	7.38	2.06	0.332	214.81	28.51	223.37
60	23° 16' 15.0"N	69° 59' 1.8"E	7.63	2.18	0.316	219.52	24.21	165.98
61	23° 16' 32.4"N	69° 58' 55.6"E	8.05	2.32	0.362	224.22	36.32	270.14
62	23° 16' 31.8"N	69° 58' 57.2"E	8.12	2.28	0.347	230.5	30.78	252.26
63	23° 16' 30.2"N	69° 58' 55.8"E	7.92	2.36	0.316	222.66	29.54	271.36
64	23° 16' 29.4"N	69° 58' 56.4"E	8.14	2.28	0.211	181.88	26.68	246.22
65	23° 16' 27.8"N	69o 58' 57.4"E	7.72	2.19	0.286	191.3	27.48	259.26
66	23° 16' 26.3"N	69° 58' 58.3"E	7.82	2.31	0.226	174.05	25.44	167.06
67	23° 16' 24.8"N	69° 59' 0.8"E	7.7	2.26	0.332	217.95	27.89	243.80
68	23° 16' 22.6"N	69° 59' 2.5"E	7.62	2.18	0.376	230.49	24.62	258.46
69	23° 16' 19.4"N	69° 59' 3.4"E	7.35	1.96	0.362	235.2	31.19	250.92
70	23° 16' 16.2"N	69° 59' 4.2"E	7.55	2.06	0.392	241.47	25.44	183.72
71	23° 16' 33.8"N	69° 58' 56.2"E	8.18	2.47	0.316	219.52	33.64	310.46
72	23° 16' 32.5"N	69° 58' 58.3"E	8.21	2.35	0.286	194.43	27.69	238.30
73	23° 16' 31.2"N	69° 58' 57.4"E	7.8	2.27	0.331	221.08	30.16	298.10
74	23° 16' 30.6"N	69° 58' 58.1"E	7.95	2.12	0.271	191.3	27.48	285.73
75	23° 16' 28.8"N	69° 59' 0.4"E	7.61	2.08	0.316	213.25	29.95	280.22
76	23° 16' 27.6"N	69° 59' 1.8"E	7.78	2.22	0.241	172.48	29.13	186.82
77	23° 16' 25.2"N	69° 59' 2.6"E	7.59	2.13	0.392	241.47	29.75	252.54
78	23° 16' 23.4"N	69° 59' 3.4"E	7.55	2.06	0.422	265	26.68	295.27
79	23° 16' 20.5"N	69° 59' 4.6"E	7.42	1.82	0.41	250.88	32.63	279.82
80	23° 16' 17.4"N	69° 59' 6.6"E	7.42	1.88	0.422	260.29	29.75	203.62
81	23° 16' 34.6"N	69° 58' 57.8"E	7.96	2.25	0.288	186.16	30.37	350.52
82	23° 16' 33.2"N	69° 59' 0.3"E	8.06	2.39	0.301	214.82	29.75	252.67
83	23° 16' 32.6"N	69° 59' 1.2"E	7.68	2.19	0.333	222.66	32.40	343.93
84	23° 16' 31.8"N	69° 59' 1.8"E	7.77	2.08	0.288	189.73	30.98	313.42
85	23° 16' 30.4"N	69° 59' 2.0"E	7.49	1.88	0.333	214.82	31.79	345.67
86	23° 16' 29.2"N	69° 59' 2.8"E	7.66	2.16	0.318	208.54	32.40	250.92
87	23° 16' 27.7"N	69° 59' 3.3"E	7.45	1.98	0.424	261.86	33.85	279.82
88	23° 16' 25.1"N	69° 59' 4.6"E	7.43	1.89	0.485	279.1	31.19	313.42
89	23° 16' 23.8"N	69° 59' 6.9"E	7.36	1.69	0.47	268.13	35.91	319.33
90	23° 16' 18.0"N	69° 59' 7.2"E	7.36	1.62	0.47	258.72	32.63	217.46
91	23° 16' 35.9"N	69° 59' 0.0"E	7.82	2.18	0.318	216.38	32.01	359.11
92	23° 16' 34.5"N	69° 59' 1.2"E	7.95	2.23	0.318	221.09	31.60	271.49
93	23° 16' 33.3"N	69° 59' 2.3"E	7.52	2.06	0.348	232.06	33.23	363.82
94	23° 16' 32.0"N	69° 59' 3.1"E	7.62	1.89	0.333	217.95	32.63	351.05
95	23° 16' 31.1"N	69° 59' 4.8"E	7.33	1.73	0.394	244.61	33.43	361.54
96	23° 16' 30.1"N	69° 59' 5.2"E	7.52	1.98	0.47	277.54	37.14	276.86
97	23° 16' 29.6"N	69° 59' 5.8"E	7.32	1.72	0.454	291.65	35.08	316.51
98	23° 16' 27.2"N	69° 59' 6.3"E	7.37	1.75	0.515	302.62	33.23	334.25
99	23° 16' 25.1"N	69° 59' 7.0"E	7.32	1.54	0.5	299.5	38.15	346.88
100	23° 16' 20.9"N	69° 59' 8.2"E	7.29	1.48	0.515	294.78	34.67	240.17

Table Contd...

Sample No.	Latitude	Longitude	pH	E.C (dSm^{-1})	O.C. (%)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)
101	23° 16' 37.5"N	69° 59' 2.7"E	7.68	2.06	0.333	219.52	32.63	369.86
102	23° 16' 35.6"N	69° 59' 3.8"E	7.78	2.16	0.379	235.2	32.84	303.74
103	23° 16' 34.4"N	69° 59' 4.1"E	7.4	1.92	0.379	238.34	35.91	372.70
104	23° 16' 32.8"N	69° 59' 5.4"E	7.48	1.74	0.394	241.47	35.91	367.85
105	23° 16' 32.0"N	69° 59' 6.2"E	7.25	1.62	0.424	268.13	36.53	372.16
106	23° 16' 31.6"N	69° 59' 6.9"E	7.4	1.85	0.53	315.68	41.04	328.61
107	23° 16' 30.3"N	69° 59' 7.2"E	7.25	1.63	0.515	305.76	38.56	347.96
108	23° 16' 29.4"N	69° 59' 7.9"E	7.29	1.58	0.53	318.3	38.77	362.62
109	23° 16' 27.0"N	69° 59' 8.2"E	7.26	1.42	0.515	313.6	36.94	369.06
110	23° 16' 23.6"N	69° 59' 9.3"E	7.23	1.36	0.515	321.44	38.15	272.03

different categories based on the cut off values representing the mean ±1 SD (standard deviation) using GIS (ARC/Info) techniques. The final maps thus, generated gave the extent of spatial variability of various soil properties. The maps showing the spatial variability of different properties are furnished in Figs. 24 to 29. These maps represent spatial variability in soil properties generated by interpolating with measured values. Each soil property is given a range based on the above procedure and the data were studied using ARC/Info software to divide the total area within the study area into separate zones exhibiting the variation of soil properties.

Table 38: Summary of results on spatial variability of soil properties

S. No.	Soil Property	Range	Mean	SD	CV (%)
1	pH	7.2 – 8.2	-	0.27	3.51
2	EC (dSm^{-1})	1.36 – 2.68	2.07	0.29	14.13
3	OC (%)	0.12-0.53	0.34	0.08	25.65
4	N ($kg\ ha^{-1}$)	136.42 – 321.44	227.26	41.42	18.23
5	P_2O_5 ($kg\ ha^{-1}$)	17.45 – 41.04	29.48	2.24	17.40
6	K_2O ($kg\ ha^{-1}$)	117.06 – 372.69	242.62	59.53	29.45

4.7.1.1 pH map

pH map showed four zones (Fig. 24). The zone of pH ranging from 7.73 to 7.99 (Zone-3) occupied the largest area of 10.44 ha (32.06% of total area) while the pH zone with a range from 7.19 to 7.45 (Zone-1) covered the minimum area of 5.15 ha (15.82%).

4.7.1.2 EC map

The EC was represented in six zones, with in the range of 1.21 to 2.94 dSm^{-1}. The zone of 2.08 to 2.36 dSm^{-1} (Zone-4) covered the largest area of all. It spreaded over 47.18 per cent of the total area (15.36 ha). The zone of 2.66 to 2.94 dSm^{-1} (Zone-6) occupied the minimum area of 0.02 ha representing 0.062 per cent of the total area (Fig. 25 and Table 39).

4.7.1.3 Organic carbon map

Organic carbon map was categorized into five zones. The highest area was showing the range of contents from 0.36 to 0.44 per cent (Zone-4). The total area covered by this range was 11.82 ha (36.30% of total area). Zone-1 occupied the lowest area having an organic carbon content ranging from 0.09 to 0.17 per cent (Table 39). The total area coverage in this range was 0.53 ha (1.60% of total area). Organic carbon map is shown in Fig. 26.

4.7.1.4 Available nitrogen map

Available nitrogen map was divided into six zones with maximum area covered under the zone with range of contents 227.27 to 268.69 kg ha^{-1} (Zone-4). It occupied an area of 12.32 ha, which accounts to 37.84 per cent of total area. (Fig. 27 and Table 39). The zone-6 with available N contents ranging from 310.12 to 351.53 kg ha^{-1} occupied 1.26 per cent of total area (0.41 ha).

4.7.1.5 Available phosphorus map

The available phosphorus map was represented in six zones (Fig. 28). The zone showing the contents ranging from 29.49 to 34.61 kg ha^{-1} (Zone-4) covered 43.24 per cent of total area (14.08 ha), which was the largest area (Table 39). The

Table 39: Extent of spatial variability in soil properties

Zone No.	Range of property in the zone	Area (ha)	Percent to total area
	pH		
1	7.19 – 7.45	5.15	15.82
2	7.46 – 7.72	9.96	30.62
3	7.73 – 7.99	10.44	32.06
4	8.00 – 8.26	7.00	21.50
	EC (dSm^{-1})		
1	1.21 – 1.49	0.590	1.83
2	1.50 – 1.78	4.06	12.49
3	1.79 – 2.07	7.81	23.98
4	2.08 – 2.36	15.36	47.18
5	2.37 – 2.65	4.71	14.47
6	2.66 – 2.94	0.02	0.06
	OC (%)		
1	0.09 – 0.17	0.52	1.60
2	0.18 – 0.26	5.46	16.77
3	0.27 – 0.35	11.37	34.92
4	0.36 – 0.44	11.82	36.30
5	0.45 – 0.53	3.39	10.41
	Available nitrogen (kg ha^{-1})		
1	103 – 144.42	0.82	2.52
2	144.43 – 185.84	5.55	17.04
3	185.85 – 227.26	10.41	31.97
4	227.27 – 268.69	12.32	37.84
5	268.70 – 310.11	3.05	9.37
6	310.12 – 351.53	0.41	1.26
	Available phosphorus (kg P_2O_5 ha^{-1})		
1	14.09 – 19.22	0.41	1.26
2	19.23 – 24.35	4.89	15.02
3	24.36 – 29.48	9.65	29.64
4	29.49 – 34.61	14.08	43.24
5	34.62 – 39.74	3.47	10.66
6	39.75 – 44.87	0.06	0.18
	Available potassium (kg K_2O ha^{-1})		
1	99.75 – 171.18	5.39	16.55
2	171.19 – 242.62	9.55	29.33
3	242.63 – 314.06	12.73	39.10
4	314.07 – 385.50	4.89	15.02

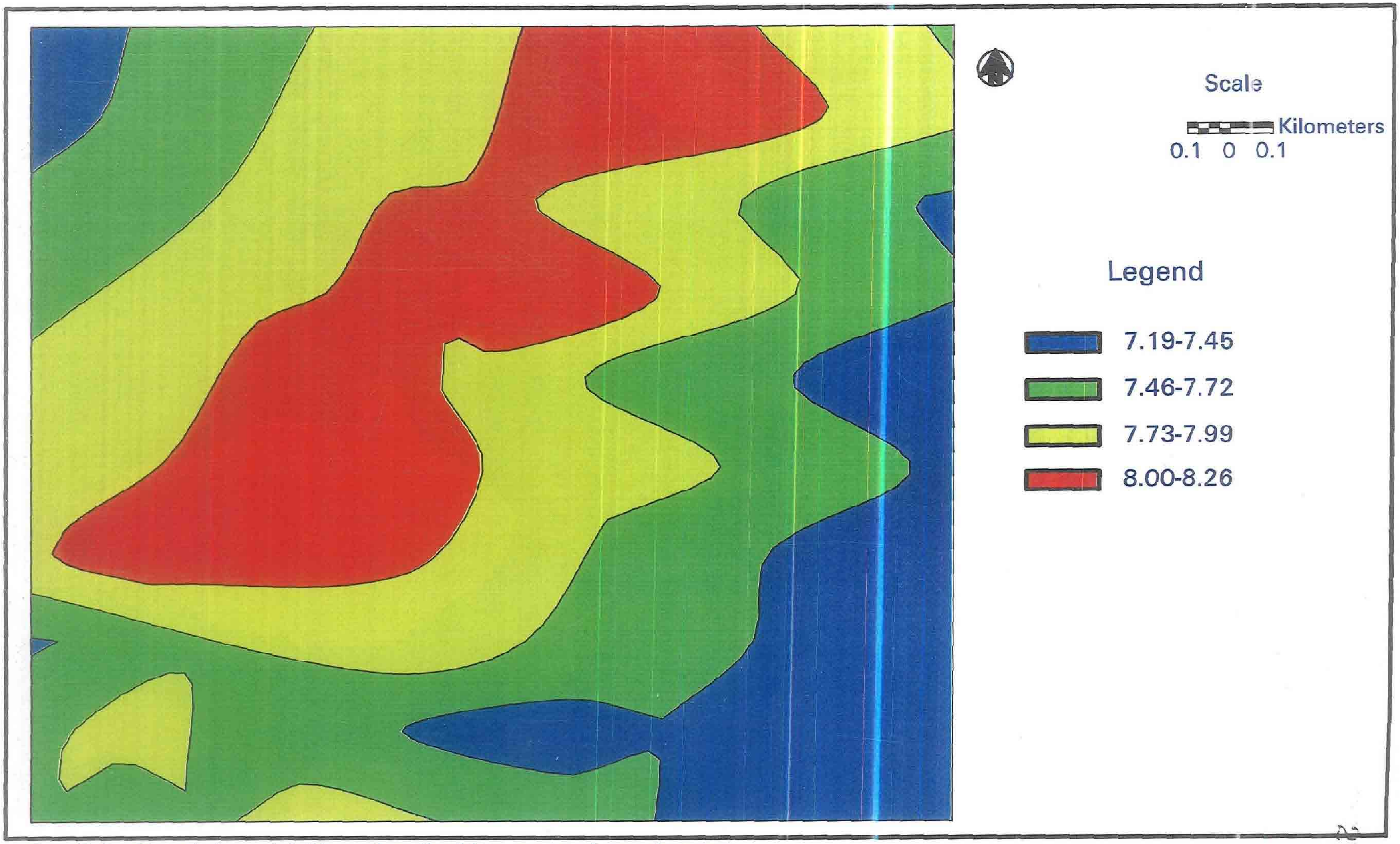

Fig. 24 : Spatial variability of soil pH in part of study area

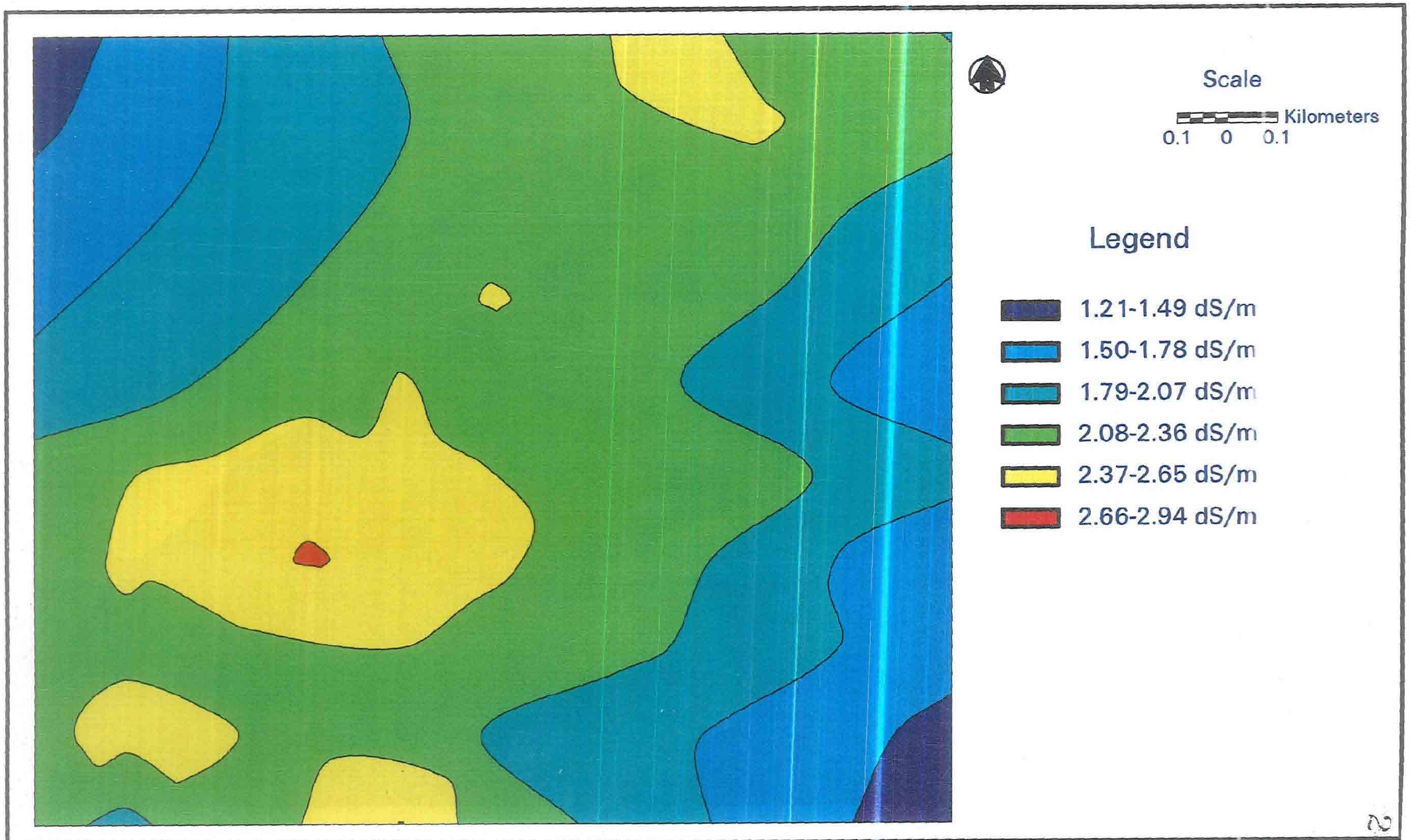

Fig. 25 : Spatial variability of soil EC in part of study area

Fig. 26 : Spatial variability of soil organic carbon in part of study area

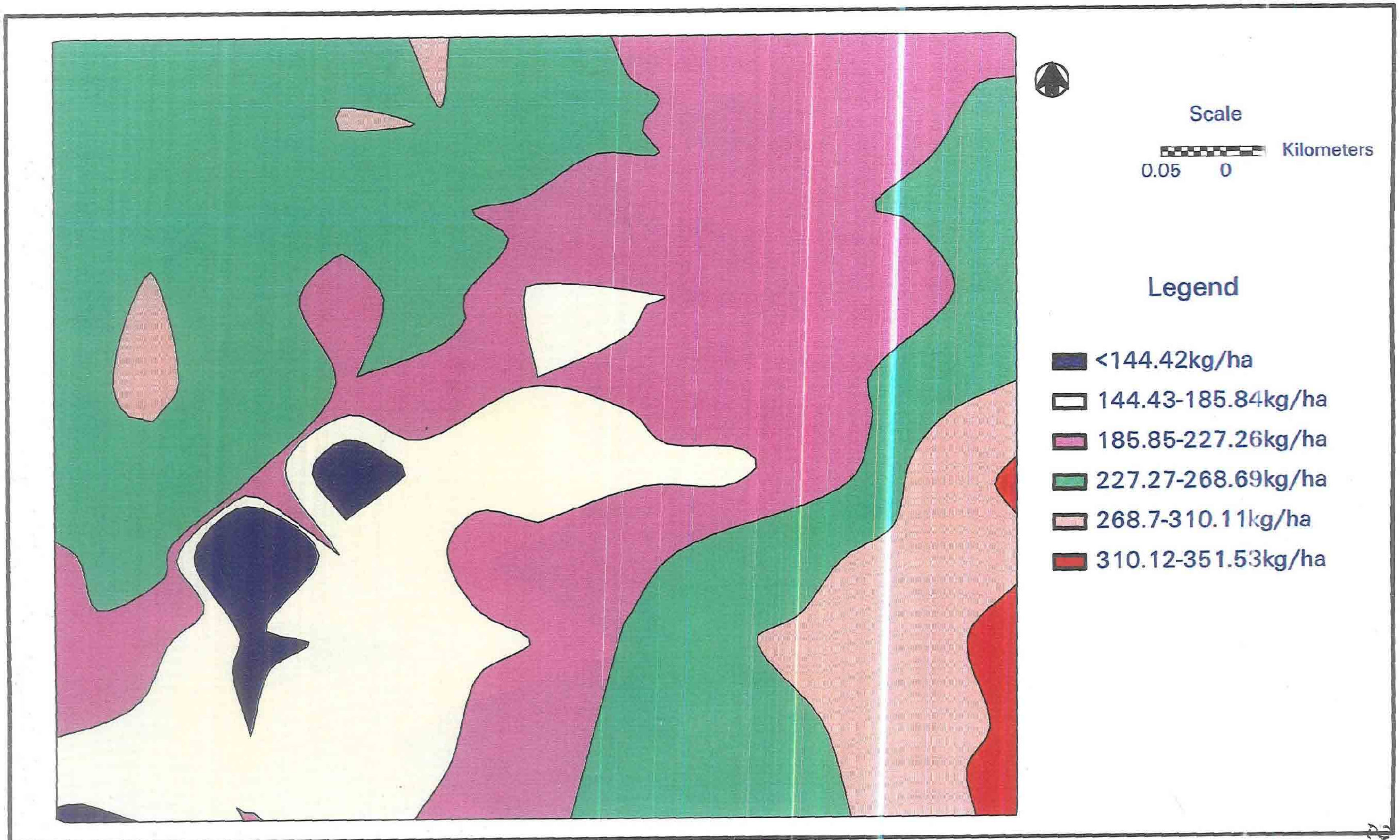

Fig. 27 : Spatial variability of available nitrogen in part of study area

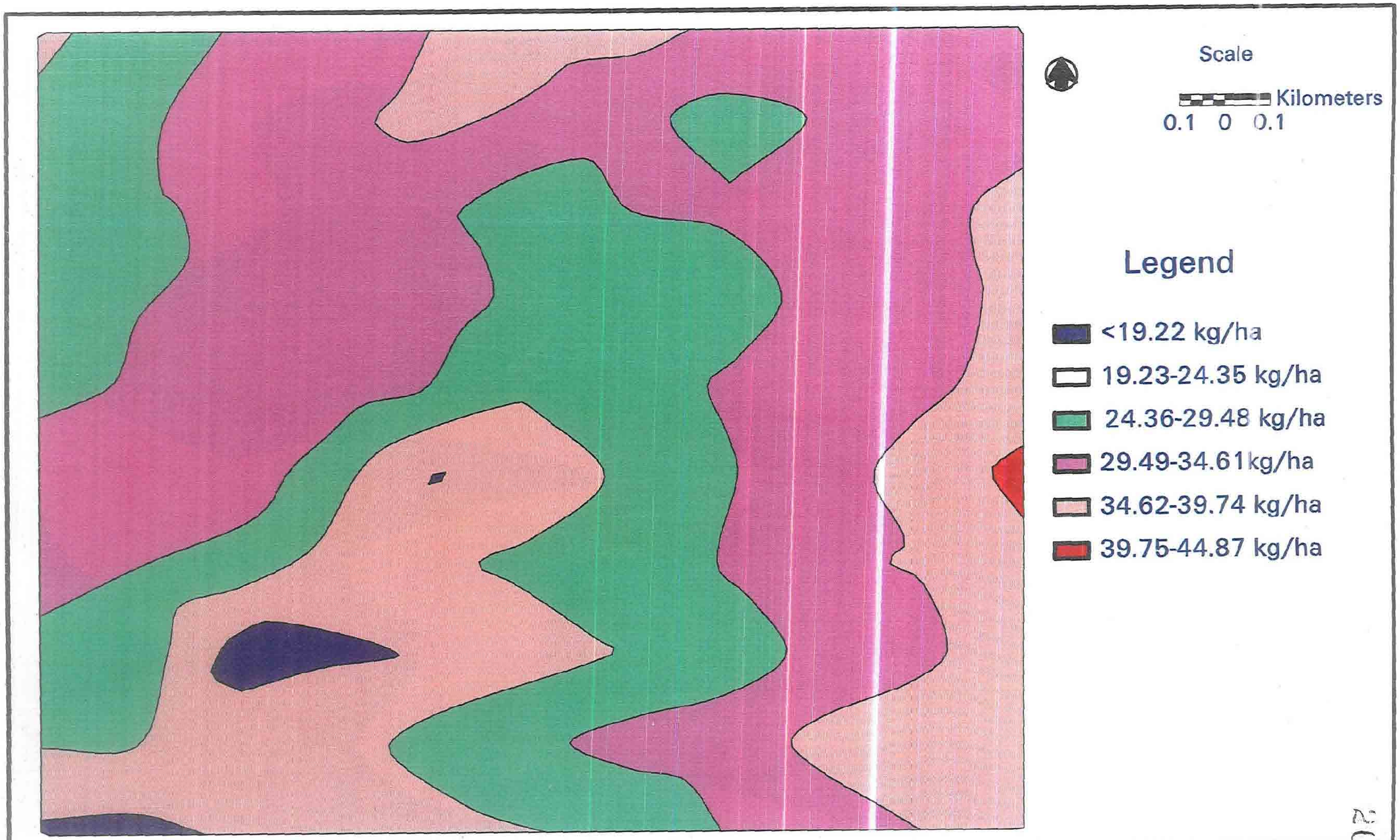

Fig. 28 : Spatial variability of available phosphorus in part of study area

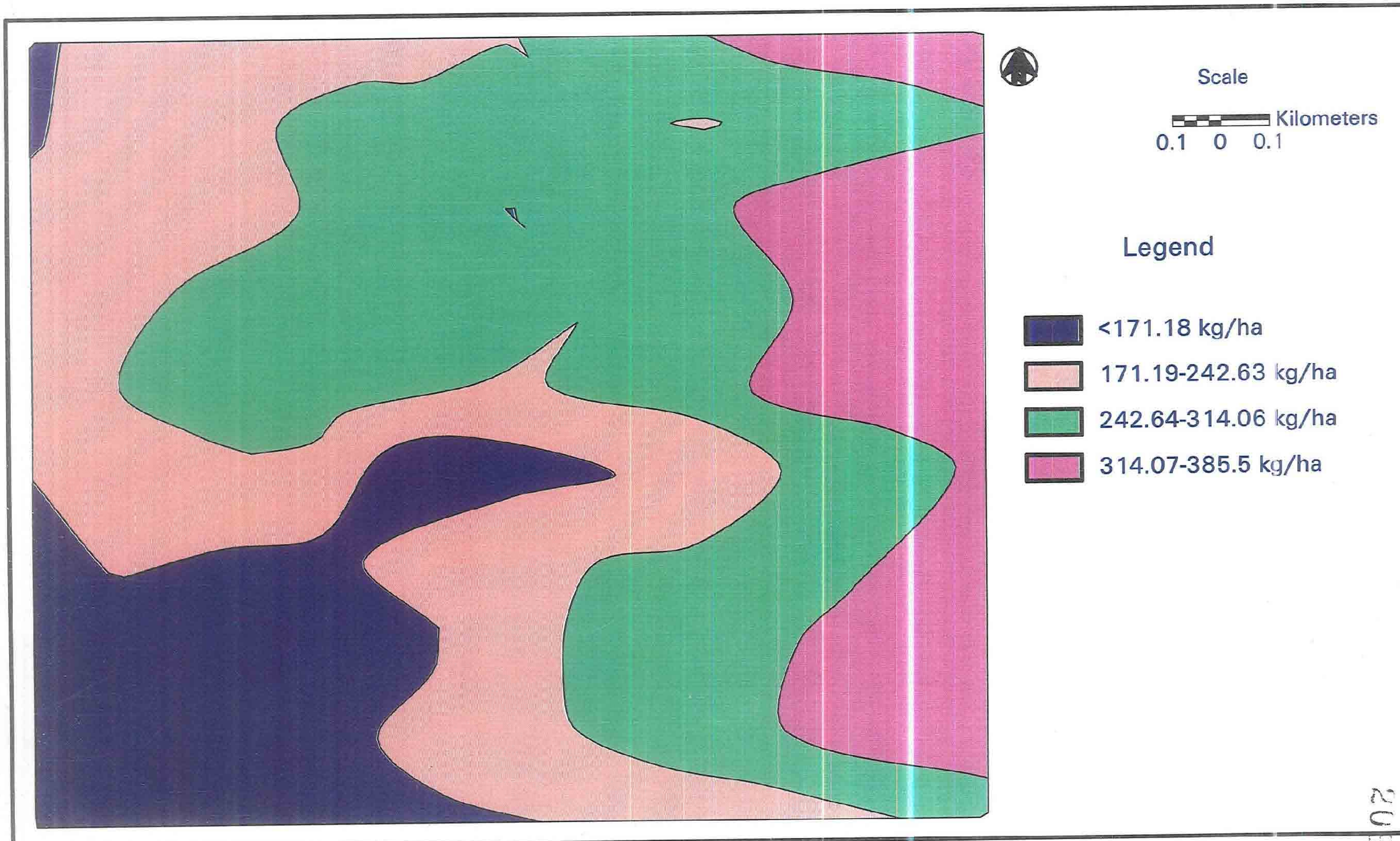

Fig. 29 : Spatial variability of available potassium in part of study area

zone with lowest available P_2O_5 content ranging from 39.75 to 44.87 kg ha^{-1} occupied only 0.06 ha (0.18% of the total area).

4.7.1.6 Available potassium map

Available potassium map representing four zones is given in Fig. 29. The zone having the content varying from 242.63 to 314.06 kg ha^{-1} (Zone-3) was noticed to be the largest area; the extent being 12.73 ha (34.10%). The smallest area of 4.89 ha (15.02%) was occupied by the Zone-4 showing the range 314.07 to 385.50 kg K_2O ha^{-1} (Table 39).

DISCUSSION

CHAPTER V

DISCUSSION

5.1 REMOTE SENSING AND GIS IN SOIL RESOURCES INVENTORY

Soil resource information is generated basically through soil surveys. Comprehensive knowledge about soils, especially their inherent physical, chemical and morphological properties, capabilities and limitations is needed for management of natural resources on a sustainable basis. Conventional soil surveys provide such information at a very high cost, and they take a great deal of time. Remote sensing has proved to be the most efficient, economical and reliable technique to prepare a comprehensive inventory of soil resources.

The launch of IRS-IC with LISS-III and PAN sensors with 23.5 m and 5.8 m spatial resolution, respectively in late 1995, opened a new era in soil mapping programme. In the present study, PAN+LISS-III merged data was used for soil resources mapping in which the advantages of large spatial resolution of PAN and spectral resolution of LISS-III were taken. This merged product helped in prompt delineation of physiographic units and soils at 1:12,500 scale with abstraction level of pure series. Geographical Information System (GIS) provides valuable support to handle voluminous data in both spatial and non-spatial formats. 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.

Watershed has become a practical planning unit for transfer of rainfed agricultural technology from lab to land and for formulating the various developmental programmes to improve the crop production and minimize land degradation resulting in optimum land use planning. In watersheds, remote sensing and GIS techniques play a significant role in the preparation of inventory of natural resources because of many inherent advantages with these new techniques. Hence, in the present study, a part of Dagala watershed in Kachch district, Gujarat was selected for soil resource inventory.

The different physiographic units identified in the study area were hills, foot slopes of hills, pediments, pediplain and valley which could be clearly delineated from the PAN + LISS-III image (Fig. 5). Again they were further sub-divided based on slope and erosion which could be achieved by the actual field traverse during the ground truth collection. However, valley and valley fringe were clearly delineated from the image itself. Major part of the study area was occupied by the physiographic unit of undulating pediplain with moderate erosion (16.93%) followed by undulating pediplain with severe erosion (16.69%).

Using the remote sensing and GIS techniques, the study area was divided into seventeen mapping units including settlements. Based on the physiography and soil boundaries, 14 soil series were identified. After classifying the soils as per USDA Soil Taxonomy, they were evaluated for soil potentials and limitations using USDA land capability and land productivity by Riquier *et al.* (1970) approach.

Part of this study area was selected to study the spatial variability of soils for site-specific nutrient management as a model to focus the importance of precision farming. The results pertaining to the above aspects are discussed here under:

5.2 MORPHOMETRIC CHARACTERISTICS

5.2.1 Aridisols (Pedons –2, 3, 4, 5, 6, 7, 9. 12 and 14)

Soils belonging to Aridisols occured in all physiographic units such as lower foot slopes (Pedon-2), pediment (Pedons-3, 4 and 5), pediplain (Pedons-6, 7 and 9) and valley (Pedons-12 and 14) with the depth ranging from 66 (lower foot slopes) to 120 cm. (nearly levelled pediplain with slight erosion). Similarly, shallow soils near hills, piedmonts and deep to very deep soils in valleys were also reported by Sharma *et al.* (2002). Soil depth appears to be related to slope and degree of erosion in this landscape position.

Development of cambic horizon was observed in these soils with profile development consisting of A-B-C horizons, except in pedons-5 and 7 in which only A-C horizons were observed. Cambic horizon in Aridisols was also reported by Sawhney *et al.* (1992) and Bhaskar *et al.* (2000). In pedon-4 (Dhaneti-1 series) Bw1, Bw2 Bw3k horizons were observed due to the improvement of colour in sub-surface horizon than the surface horizon. Bk, BCk and ACk horizons were assigned with the suffix 'k' in pedons-4, 6 and 7 due to the presence of calcic horizon. The presence of calcic horizon in Aridisols was also noticed by Choudhuri (1993) and Khresat (2001) in tertiary and pleistocene land forms in Rajasthan and north-western Jordan, respectively.

Soil colour in surface horizons ranged from reddish brown to dark yellowish brown through brown (moist). In sub surface horizons the soil colours varied from dark yellowish brown to olive brown with intermittent colours of yellowish brown, brown, strong brown and light yellowish brown. These soils exhibited reddish brown in the foot slopes of hills and became progressively yellower down the slope. These variations in soil colour might be due to the differences in content and hydration of iron oxide (Gerrad, 1981 and Shyampura *et al.*, 1994) and variation in mineral suites coupled with other prevailing pedological features (Tiwary *et al.*, 1989). Similar results were also reported by Saxena (1992), Choudhuri (1993) and Sharma *et al.* (2002).

Variation in structure in surface horizons was observed from fine weak massive in foot slopes of hills to medium moderate sub angular blocky in valleys. In almost all pedons, fine/coarse weak granular/massive structure was observed in deeper layers except in pedons-3, 5 and 9 in which, sub-angular blocky (Pedons-3 and 5) and angular blocky (Pedon-9) structures were observed. The fine weakly developed structure in foot slopes of hills and strong pedality in other pedons down the slope could be due to more finer materials received from higher topographic position and higher rate of weathering. Similar results were also reported by Shyampura *et al.* (1994).

Consistence of surface soils in all the pedons was loose and soft under dry, very friable under moist and non-sticky and non-plastic under wet conditions, except in pedons-3 and 12 (Amrutanagar and Sangnadi-1 series). Consistence became slightly hard to hard, friable to firm, slightly sticky and slightly plastic in deeper layers, except in pedons-5 and 7, which remained as soft, very friable, non-sticky and non-plastic and it was sticky and plastic in pedon-3 (Amrutanagar series). These differences in consistence were attributed due to the variation in clay content in different pedons.

Effervescence was slight to strong in surface horizons and became violent in deeper layers in all the pedons, except pedon-9 (Dagala-1 series), in which the soils were violently effervescent throughout the profile. The intensity of violent effervescence was strong in pedons-4, 6 and 7 in deeper layers, which might be due to more reserves of $CaCO_3$ as indicated by the presence of calcic horizon.

Clear smooth boundary was observed in surface horizon in all pedons, except pedon-6 (Kanyabe-1 series) in which, it was gradual. In majority of the soils, clear wavy and gradual wavy boundary were observed in deeper layers.

5.2.2 Entisols (Pedons-1, 8, 10, 11 and 13)

The Entisols were occurring in the physiographic units of upper foot slopes (Pedon-1), nearly levelled pediplain with severe erosion (Pedon-8), undulating pediplain with moderate erosion (Pedon-10), undulating pediplain with severe erosion (Pedon-11) and valley fringe (Pedon-13) of the study area. Wide variation in depth was noticed with a range from 52 to 105 cm. Mokhana series (Pedon-1) had a depth of 52 cm whereas Kanyabe-3 series (Pedon-13) had a depth of 105 cm and the remaining pedons were moderately deep with an average depth of 85 cm. These variations were mainly due to the topographic position *i.e.* slope and erosion. These soils showed less profile development with A-C horizons. Sehgal *et al.* (1992) reported no profile development in sandy soils of different parts of India. Murthy *et al.* (1982) and Vadivelu and Bandyopadhyay, (1997) also reported the same.

Strong brown colour (7.5 YR 4/6M) was observed in the upper foot slopes of hills and yellowish brown (10 YR 5/6 M) to dark yellowish brown colour (10YR 4/6 M) was noticed in remaining pedons with hue 7.5 YR to 10 YR. The above bright colours might be due to very low organic matter in the soils (Sidhu *et al.,* 1994). Similar observations were made by Rao (1993) and Ramalakshmi, (1999) reported the same.

Fine structureless to weak and single grain to massive structure was observed in all surface soils except in soils of Yoginagar-1 (Pedon-8) where medium, moderate sub angular blocky structure was observed. In sub-surface horizons, fine, weak, single grained to massive structure was found mostly. The absence of structure suggests minimal pedogenic activity and lack of re-organization of original skeletal grains. Sidhu *et al.* (1994) also reported lack of structural development in the Entisols of Punjab.

Consistence was soft and loose under dry and moist conditions, respectively in surface horizons whereas loose to friable in sub-surface horizons. However, it was slightly hard, firm in pedon-10 (Yoginagr-2 series). Under wet conditions, the soils of all pedon were non-sticky and non-plastic. This might be due to very low clay and non-colloidal materials present in these soils. Sidhu *et al.* (1998) noticed the non-sticky and non-plastic consistence in Ustipsamments developed on sand dunes. These soils were strongly to violently effervescent. Boundary was abrupt to clear and smooth to wavy in all soils except in pedon-10 where gradual broken boundary was found in sub-surface horizons.

5.3 PHYSICAL, PHYSICO-CHEMICAL AND CHEMICAL PROPERTIES

5.3.1 Aridisols

Sand content was lowest (29.3%) in pedon-3 studied in pediment with slight erosion and found to be highest in pedon-14 (85.95%), which was developed in valley fringe. In contrast to this, highest clay content (52.49%) was observed in pedon-3 and lowest (10.81%) in pedon-14. Moreover, increase in clay content was noticed down the slope from foot slopes of hills to valley with an exception in pedon-3. In all pedons, except in Dhaneti-1 series (Pedon-4) and Sangnadi-1 series (Pedon-12), clay content increased with depth. However, in pedons-4, 5, 9 and 14, increase was observed upto certain depth, thereafter decreased in deeper layers. Texture varied from loamy sand to clay with intermittent texture of sandy loam and sandy clay loam. The variations in texture might be due to topography and erosion. These results are in agreement with Bhattacharyya *et al.* (1994), Singh and Singh (1996) and Irmark and Gundogan (2000).

All the pedons of Aridisols were neutral to slightly alkaline in reaction with a pH range from 7.23 (Pedon-9) to 8.36 (Pedon-4), except Pedon-12 (Sangnadi-1), which was strongly alkaline in reaction with pH ranging from 8.5 (A1) to 8.90 (BC). Increasing trend of pH with depth was observed in all the pedons. Lower pH values in the surface soils might be due to the decomposition of organic matter and consequently the production of organic acids (Vadivelu and Bandyopadhyay, 1997). From the results, it could be inferred that soils on the slopes of hills (Pedon-2) were neutral in reaction, whereas soils in valleys (Pedons-12 and 14) were slightly alkaline in reaction. Similar results were also reported by Sidhu *et al.* (1994).

Salinity in the study area *i.e.,* EC ranged from 1.00 to 2.77 dSm^{-1} with an exceptional case in pedon-12, which showed the range of 3.90 to 10.33 dSm^{-1}. EC decreased with depth in majority of pedons whereas an increasing trend with depth was observed in Pedons-3, 9 and 12. However, irregular trend was noticed in pedon-2 (Dagala-2 series). The salinisation of upper layers might be due to the aridic climate resulting in the accumulation of soluble salts through capillary rise of saline water.

Organic carbon content ranged from 0.144 per cent (Pedon-12) to 0.510 per cent (Pedon-3). Low content of in O.C. in most of the pedons was due to the decomposition of organic matter under high temperature regime in the study area. Gradual decrease in organic carbon with depth was observed in all the pedons. The results are in confirmation with the findings of Dubey and Sharma (1990). Similar results were also reported by Khresat (2001), Srivastava and Prasad (1992), Elahi *et al.* (1996) and Irmark and Gundogan (2000).

Wide variation in $CaCO_3$ was found with a range from 3.2 per cent (Pedon-2) to 18.26 per cent (Pedon-4 and Pedon-6). $CaCO_3$ increased gradually with depth and calcic horizon was observed in pedons–4, 6 and 7. This might be due to calcification and inheritance from parent material. These results are in accordance with Gile *et al.* (1996) who reported that weathering of Ca-bearing minerals is the ultimate source for Ca in the soils of arid environments. Choudhuri (1993) and Khresat (2001) also reported the presence of calcic horizon in arid environments. Variation in gypsum was recorded from 0.01 per cent (foot slopes of hills) to 0.925 per cent (valley). An increased trend of gypsum was observed with increase in depth of the profile.

5.3.2 Entisols

These soils exhibited low clay content with a range from 3.23 per cent (Pedon-13) to 14.86 per cent (Pedon-8) and high sand content with a range from 81.15 per cent (Pedon-10) to 95.82 per cent (Pedon-13) with a variation in texture from sand to loamy sand. Higher sand and gravel contents could be attributed to severe erosion due to topographical elevations that removed most of the fine particles. Verma *et al.* (2001) reported that sand and silt constituted the major portion in mechanical composition of soils of UP belonging to Typic Ustipsamments. There was no particular trend in distribution of different particle sizes in these soils indicating that these soils were pedogenically not well developed. Sehgal *et al.* (1992), Vadivelu and Bandyopadhyay (1997) and Jawahar *et al.* (1999) also observed similar conditions in sandy soils.

The pH of these soils indicated that all soils were neutral in reaction with a range from 7.55 (Pedon-13) to 7.85 (Pedon-8). The EC values indicated that the soils were slightly saline (1.5 dSm^{-1} in Pedon –13 to 2.30 dSm^{-1} in Pedon-1). National Bureau of Soil Survey and Land Use Planning (1981) also reported the same in Psamments of Punjab. pH values showed increasing trend with increase in depth in all soils, except in pedon-10 (Yoginagar-2 series), where irregular trend was noticed. A decreasing trend of EC with depth was found in all pedons except in pedon-10, where salinity increased with depth. High salinity on surface soils might be due to aridic climate which leads to accumulation of salts in the surface soils.

Very low organic carbon content was observed in these soils with a range from 0.148 per cent in Yoginagar-2 series (Pedon-10) to 0.243 per cent in Yoginagar-1 series (Pedon-8). Vertical distribution of organic carbon with depth function indicated a decreasing trend. Low OC might be due to low clay content and high rate of decomposition due to high temperatures prevailed in aridic climate. Results are in confirmation with the observations made by Sehgal *et al.* (1992), Dhaliwal *et al.* (1996) and Sharma *et al.* (1999).

$CaCO_3$ content ranged from 3.15 per cent (Pedon-11) to 12.56 (Pedon-13). Comparatively higher values were noticed in soils of valley fringe and nearly levelled pediplain than others. Increasing trend of $CaCO_3$ accumulation of with depth was found in all soils, except in Dagala-2 series (Pedon-11). This gradual increase with depth might be attributed to the calcification and inheritance from parent material. The above results are in accordance with the findings of Sahu and Mishra (1996). Similarly, gypsum content also showed an increasing trend with depth showing a range of 0.012 to 0.026 per cent.

5.4 ION EXCHANGE PROPERTIES

5.4.1 Aridisols

Among the pedons studied, exchangeable complex was mostly saturated in order of Ca^{2+} > Mg^{2+} > Na^{+} >K^{+} except in pedon-12 (Sangnadi-1 series), where the order of saturation was Ca^{2+} >Na^{+} > Mg^{2+} >K^{+}. Moreover, in majority of soils, an increasing trend in content of these exchangeable cations was observed with depth down the profile. Increase in contents of exchangeable cations to a certain depth and then decrease thereafter in deeper layers was observed in some pedons. However, decreasing trend with depth was also noticed.

CEC ranged from 7.15 (Pedon-14) to 48.18 cmol(p^{+})kg^{-1} (Pedon-3), which followed the trend similar to that of exchangeable cations showing variability with depth. The exchangeable properties of the soils were mostly influenced by the clay content, kind of clay minerals and predominance of cations associated with colloidal complex. In the present study, it was noticed that the CEC increased with increase in clay content. The results are in agreement with Nayak *et al.* (1999), who reported that clay and organic matter were responsible for increase in CEC. Similar conclusions were also drawn by Sidhu *et al.* (1994), Sidhu and Sharma (1990) and Sharma *et al.* (2002). Variation in base saturation from 74.08 (Pedon-6) to 96.53 per cent (Pedon-2) was also observed in the soil sités.

High ESP (33.56 to 43.83) in pedon-12 was recorded indicating development of sodicity in this pedon. The sodicity of soils in Sangnadi-1 series (Pedon-12) might be due to the process of sodification /alkalization which led to accumulation of sodium ions on the exchange sites of the clay. When the water continuum exists in soil body even through normal capillary action, the chance of salt deposition on the surface is little. But if water continuum breaks, the vapour pressure exceeds the limit to cause stress which enables salts to accumulate. These salts being rich in sodium, dissociate and liberate sodium as ion which displaces other cations on exchange complex due to concentration gradient. Thus, salinization might also resulted in sodiumization at the place of study in the present investigation.

5.4.2 Entisols

The exchangeable complex of these soils was found mostly saturated with Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+} in all pedons except in pedon-11 where the order was $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. These soils exhibited low CEC values with a range from 3.02 (Pedon-13) to 15.25 (Pedon-8) cmol(p^{+})kg^{-1} soil. Low CEC values might be ascribed to the low clay and low organic matter contents with dominance of kaolinitic clays (Walia and Chamuah, 1996; Trivedi *et al.*, 1998). No particular trend of exchangeable cations and CEC was observed with increase in depth in these soils, which indicates less pedogenic development. Sidhu and Sharma (1990), Sehgal *et al.* (1992) and Sidhu *et al.* (1994) also reported the same.

Most of the pedons exhibited low base saturation with the range of 61.26 to 90.16 per cent. The lowest content in soils of Kanyabe-3 series (Pedon-13) and highest content in soils of Yoginagar-1 series (Pedon-8) were observed. These results are in agreement with Diwakar and Singh (1994), Singh and Mishra (1997) and Tamgadge *et al.* (1999). ESP values varied from 5.17 to 10.15 suggesting no sodicity in these soils.

5.5 CLAY MINERALOGY

In the present study, identification and quantification of clay minerals was done through the X-ray diffraction analysis of clay fractions (<2μ) of the soils collected from the control section (25-100 cm) of the pedons. Seven soil samples (Pedons-2, 3, 4, 11, 12, 13 and 14) were selected from the study area for clay mineralogical studies based on the Soil Taxonomic Classification upto sub-group level besides considering the texture. The same mineralogy was attributed for other soils having the same sub group and texture.

5.5.1 Aridisols

From the results, it was observed that the clay minerals identified in Aridisols were kaolinite, smectite, mica, chlorite, quartz, gibbsite and attapulgite. However, kaolinite and smectite were the dominant minerals.

Kaolinite was the dominant mineral in Typic Haplocambids (coarse textured) (79.84%) and Typic Haplocalcids (49.50%). Illite was the second dominant mineral (13.02%) followed by quartz in former one while gibbsite and chlorite were the other minerals present in latter one (Typic Haplocalcids). Interstratified layer of 1:1 mica montmorillonite was observed in Typic Haplocambids (coarse textured). Choudhuri *et al.* (1990) also noticed the presence of mica, smectite, vermiculite, mixed layer minerals and kaolinite in the soils of Aridisols of western Rajasthan. Similar observations were made earlier by Sehgal (1972) Irmark and Gundogan (2000) and Khresat (2001).

Smectite was the dominant clay mineral in Typic Haplocambids (fine textured (51.54%), Vertic Haplocambids (64.81%) and Sodic Haplocambids (66.18%). In Typic Haplocambids (fine textured) kaolinte was the second dominant clay mineral (32.41%) and quartz and mica were the other minerals present. In Vertic Haplocambids, second dominant mineral was quartz (19.44%) followed by kaolinite

(15.15%) whereas in Sodic Haplocambids kaolinite (19.85%) was the second dominant mineral followed by quartz (13.79%).

Sehgal (1972) reported the presence of vermiculite and intergrade minerals (chloritised vermiculite and montmorllonite) in semi-arid areas, montmorillonite, chloritised montmorillonite in the aridic soils, which suggest the transformation of illite to vermiculite and to montmorillonite. Raychaudari and Patel (1969) observed that montmorillonite and illite were the major minerals present in the saline and alkali soils of India. Balpande *et al.* (1997) also indicated that smectite was the dominant mineral in sodic soils.

5.5.2 Entisols

In case of Entisols, kaolinite was found to be the dominant clay mineral (35.59%) followed by chlorite (24.91%). Other minerals present in Typic Torripsamments were mica, quartz and gibbsite while in Typic Torriorthents, additionally attapulgite was also observed. The chlorite present in the Typic Torriorthents was chloritised montmorillonite. Similar results were reported by Chakravorthy *et al.* (1992), Adhikari and Si (1993), Kaushal *et al.* (1996) and Shivraj Bhusse (2001).

From the present study, it is evident that kaolinite is the dominant mineral present in foot slopes of hills and pediments compared to lower elements. Smectite content increased from foot slopes of hills to the valleys. Occurrence of 2:1 alumino silicates in the lower part of toposequence was noticed by Zueng Sang Chen *et al.* (1999).

5.5.3 Genesis of clay minerals and their relation with soil forming factors

Different clay minerals identified in the soils of the study area were kaolinite, smectite, mica, chlorite, quartz, gibbsite and attapulgite. Kaolinite and smectite were found to be the dominant minerals. Moreover, interstratified layers of 1:1 mica montmorillonite and chloritised montmorillonite were also observed. The genesis of dominant clay minerals and their relation with soil forming factors is discussed hereunder:

5.5.3.1 Kaolinite

Transformation and neo formation are the principle processes in the genesis of clay minerals. Transformation modifies a clay mineral without altering its structure while neo formation leads to the formation of new minerals. The process of elimination and recombination led to the formation of 2:1 or 1:1 type minerals (Padro *et al.*, 1969).

Generally kaolinite presence in the arid and semi-arid regions is attributed to K-feldspar derivatives. Since the study area is under aridic climate, kaolinite might have been derived from K-feldspars. Weathering of orthoclase and plagioclase feldspars is an important factor in the formation of clay minerals. Partial hydrolytic decomposition of feldspars may lead to the formation of mica in the fine sand and also in the silt fractions with resultant illite or expanding lattice minerals in soil calys. Under intense weathering conditions, however, complete hydrolytic decomposition leads to the formation of kaolinite in silt and clay (Datta and Das, 1972).

In Typic Haplocambids (coarse textured) in Dagala-3 series (Pedon-2) and Typic Haplocalcids in Kanyabe-1 series (Pedon-6), kaolinite was the dominant mineral, which might be due to neo formation (synthesis in sites) and inheritance from parent material *i.e.* lime stone. Sehgal (1970), while working on the pedogenesis of north-west Indian soils, observed that the presence of kaolinite in the soils can be due to inheritance and synthesis *in situ*. Sehgal (1970) also correlated the occurrence of kaolinite in Camborthids of Haryana and Punjab which are rich in calcareous materials that are inherited from the alluvium of the river 'Ghagar'.

5.5.3.2 Smectite

In the pedons-3, 9 and 12, smectite was found to be dominant clay mineral which was revealed through the X-ray diffraction peaks. This might be due to weathering of parent material *i.e.* limestone. During the process of transformation of parent rock to smectite, high amounts of exchangeable bases were released. According to Eck and Engle, (1964) montmorllonite occurs only in soils derived from calcareous materials. Tamhane and Namjoshi (1959) reported that montmorllonite was found due to weathering process of limestone. From the studies conducted on the effect of parent material and weathering environment on the genesis of clay minerals, Datta and Adhikari, (1969) indicated the presence of montmorillonite and vermiculite when the intensity of weathering was low to moderate in semi-desert to semi-arid region and the soil contained a high proportion of exchangeable alkaline earth cations like Ca^{2+} and Mg^{2+}.

5.5.3.3 Mixed layers

Interstratified layers of 1:1 mica montmoroillonite was observed in Mokhana series (Pedon-1) which might be due to the depletion of potassium from mica and fixation of aluminium and other cations between layers (Brown, 1954; Klages and White, 1957; Ragland and Coleman, 1960; Rich, 1960).

The formation of chloritised montmorillonite was observed in Typic Torriothrents of Yoginagar-2 series (Pedon-10) due to the hydroxy interlayer formation. Precipitation of hydroxy alluminium, hydroxy iron, hydroxy sesquioxides and possibly magnesium hydroxide as gibbsite like (or brucite-like) structure in the interlayer space of expandable 2:1 minerals like montmorillonite might have resulted in the chloritised montmorillonite. This observation was also in agreement with the results of Sehgal (1970) and Sehgal and De Conninck, (1971).

The pedons selected for the identification of clay minerals through XRD cover all elements of topography. It was observed that the quantity of smectite was increasing from foot slopes of hills to valley which can be attributed to the influence of topography in creating differences in external and internal drainage conditions resulting in the variation in soil properties. Biswas *et al.* (1966) emphasized the importance of topography on soil properties and observed that illite was the dominant clay mineral in soils of the upper and middle slopes while montmorillonite was dominant in soils at the base. They also reported that montmorillonite content increased while kaolinite decreased down the slope. Similar conclusions were drawn by Gawande *et al.* (1968) and Gawande and Biswas, (1972) from the studies of catenary soils on sedimentary formation in Chhatisgarh basin in Madhya Pradesh.

5.6 CLASSIFICATION

Based on the morphological characteristics and analytical results of physical, physico-chemical, chemical properties and clay mineralogical studies, the soils were classified according to "Keys to Soil Taxonomy" (Soil Survey Staff, 1998).

5.6.1 Aridisols

5.6.1.1 At order level

The pedons 2, 3, 4, 5, 6, 7, 9, 12 and 14 showed the following characteristics and hence, were classified as "Aridisols":

- An aridic soil moisture regime. Soils are dry for more than 180 cumulative days in a year
- An ochric epipedon
- Presnce of cambic and calcic horizons with the upper boundary within 100 cm of the soil surface.

5.6.1.2 At sub-order level

The pedons-4 and 6 had calcic horizon beyond 47 cm (Bw3k) and 50 cm (Bk1), respectively and hence, were classified as 'Calcids' at sub-order level. The other pedons (2, 3, 5, 7, 9, 12, and 14) were classified under 'Cambids' as they were not qualified for other sub orders due to absence of salic, gypsic, argillic (or) natric, calcic horizons, duripan and cryic soil temperature regime.

5.6.1.3 At great group level

The pedons-4 and 6 had no petrocalcic horizon, hence has not qualified as Petrocalcids and were placed under "Haplocalcids", the remaining great group of Calcids.

Similarly, the other Aridisols (Pedons-2, 3, 5, 7, 9, 12 and 14) were placed under "Haplocambids" as they are not qualified for other great groups such as Aquicambids, Petrocambids and Anthracambids due to the absence of aquic conditions for some time in normal years, duripan or petrocalcic or petrogypsic horizon and anthropic epipedon, respectively. Faroda *et al.* (1999) found Haplocambids and Haplocalcids in agro-ecological region of Kachch alluvial plain while classifying the soils in different agro-ecological zones of north-western hot arid region of India.

5.6.1.4 At sub-group level

The pedons which were classified as "Haplocalcids" (Pedons-4 and 6) at great group had fulfilled the following criteria:

- No lithic contact within 50 cm of soil surface
- No vertic properties such as cracks and slickensides
- No aquic conditions and not saturated with water any where in the profile
- Absence of xeric and ustic soil moisture regimes
- Absence of duripan and durinodes
- Absence of nodules or concretions
- Having ESP < 15
- Absence of cinders, pumice, pumice like fragments and volcanic glass

Based on the above features, these two (Pedons-4 and 6) were classifed as "Typic Haplocalcids".

The soils of Amrutanagar series (Pedon-3) exhibited cracks of more than 5 mm wide upto a depth of 40 cm and slickensides in sub-surface horizons. Therefore, they were classified as Vertic Haplocambids.

The soils of Sangnadi-1 (Pedon-12) had ESP more than 15 in B21, B22 and BC horizons within 100 cm of the soil surface and hence, these soils were grouped under "Sodic Haplocambids". Bhaskar *et al.* (2000) classified the soils of the Chitravathi river basin, Cuddapah district, Andhra Pradesh as Ustic Haplocambids and Sodic Haplocambids.

The other pedons belonging to "Haplocambids" (Pedons-2, 5, 7, 9 and 14) were named as "Typic Haplocambids" at sub group level because of the following characters:

- Absence of lithic contact within 50 cm of the soil surface
- Absence of xeric and ustic soil moisture regimes
- Absence of durinodes, nodules or concretions
- Absence of cinders, pumice, pumice like fragments and volcanic glass
- Absence of irregular decrease in organic carbon content from a depth of 25 cm either to a depth of 125 cm or to a densic, lithic, or paralithic contact if shallower.
- Have ESP of < 15 %

While generating the soil map for the soils of arid zone of Rajasthan, Dhir *et al.* (1997) reported that cambids and calcids were the dominant sub-orders present and classified the soils as Typic Haplocambids and Typic Haplocalcids at sub group level.

5.6.1.5 At family level

Particle size class

The pedons-2, 4 and 5 had more than 35 per cent rock fragments and less than 35 per cent clay. Hence they were named as "loamy skeletal" at family level.

The pedons-6 and 7 were classified as coarse loamy at family level because the clay content is less than 18 per cent and the sand fraction including coarse rock fragments is more than 15 per cent in most of the horizons.

The clay content in pedons-9 and 12 was more than 18 per cent and the coarse fraction including sand is more than 15 per cent, and hence, they were classified as 'fine loamy'.

Since the soils of pedon-14 had a texture of loamy fine sand with less than 35 per cent clay in fine-earth fraction, they were assigned the particle size class as "loamy". The soils of the pedon-3 were named as "fine" as they had more than 35 and less than 60 per cent clay (by weight).

Mineralogy class

Soils of Typic Haplocambids (coarse texture), Typic Haplocalcids, Vertic Haplocambids, Typic Haplocambids (fine texture) and Sodic Haplocambids belonging to series Dagala-3 (Pedon-2), Dhaneti-1 (Pedon-4), Amrutanagar (Pedon-3), Dagala-1 (Pedon-9) and Sangnadi-1 (Pedon-12) series were studied for mineralogy using XRD.

Typic Haplocambids (coarse texture) and Typic Haplocalcids were rich in kaolinitic mineral class whereas the remaining soils were dominant in smectitic class based on relative proportion of clay minerals present in these soils. The same mineralogy class was attributed to other soils belonging to the same subgroup and texture. Hence, the soils of Dagala-3 (Pedon-2), Dhaneti-1 (Pedon-4), Kanyabe-2 (Pedon-5), Kanyabe-1 (Pedon-6) and Dhaneti-2 (Pedon-7) were classified as "Kaolinitic" while other series *i.e.* Amrutanagar (Pedon-3), Dagala-1 (Pedon-9), Sangnadi-1 (Pedon-12) and Sangnadi-2 (Pedon-14) were classified as "Smectitic".

Soil temperature class

All the soils were termed as "hyperthermic" because the mean annual soil temperature is >22°C and the difference between mean summer and mean winter temperatures is >6°C.

5.6.1.6 At series level

The soils of the study area were classified at series level by giving the local village names to the particular soil studied in each area. In the present study, PAN + LISS-III data was used and this high resolution (5.8 m) data helped to classify the soils at pure series level. Series names for pedons and classification of soils upto family level are given in Table 40 .

5.6.2. Entisols

5.6.2.1 At order level

Pedons-1, 8, 10, 11 and 13 were classified as Entisols because these soils showed no evidence of diagnostic horizons.

5.6.2.2 At sub-order level

The soils of the pedon-11 had < 35 per cent (by volume) rock fragments and a texture of sand with an average value more than 90 per cent within the particle size control section and therefore, were classified as "Psamments" at sub-order level. The remaining soils (Pedons-1, 8, 10 and 13) were classified as "Orthents" at sub-order level as they did not qualify for other suborders based on the following conditions:

- .Absence of aquic moisture regime
- Absence of fragments of diagnostic horizons
- Has more than 35 per cent (by volume) rock fragments

- Absence of densic, lithic or paralithic contact within 25 cm of the mineral soil surface

Dhaliwal *et al.* (1996) classified the flood plain soils of north-western India under Entisols at order level and Orthents, Fluvents and Psamments at sub-order level.

5.6.2.3 At great group level

The soils of pedon–11 were classified under "Torripsamments" at great group level because of presence of aridic soil moisture regime. The other soils (Pedons-1, 8, 10 and 13), which also had aridic soil moisture regime and classified as Orthents at sub order level were classified as "Torriorthents" at great group level. Dhir *et al.* (1997) reported that Entisols and Aridisols constituted 51.84 per cent and 41.05 per cent of the total area, respectively and Torripsamments were dominant among Entisols in arid zone of Rajasthan.

5.6.2.4 At sub group level

Soils of Pedon – 11 were placed under "Typic Torripsamments" at subgroup level because, they showed the following properties:

- Absence of lithic contact within 50 cm of soil surface
- Absence of xeric and ustic soil moisture regime
- Absence of volcanic glass
- Absence of durinodes

Other soils (Pedons-1, 8, 10 and 13) were classified as "Typic Torriorthents" because of the following features:

- Absence of lithic contact within 50 cm of soil surface

- Absence of xeric, ustic soil moisture regimes and thermic, mesic (or) frigid soil temperature regimes
- Absence of aquic conditions
- Absence of durinodes
- Absence of vertic properties such as cracks and slickensides
- Absence of cinders, pumice and pumice like fragments

5.6.2.5 At family level

Particle size class

Soils of the pedons-1 and 10 were termed as coarse loamy according to particle size class because of >15 per cent of sand + rock fragments and < 18 per cent clay in the fine earth fraction. The soils of pedon-8 had 35 per cent or more rock fragments and a texture of loamy sand, and hence, they were assigned "Sandy skeletal" as particle size class.

The texture of soils of pedons-11 and 13 was sand and therefore, were grouped under particle size class as "Sandy". But for pedon-11, no particle size class was mentioned in the classification. According to Keys to Soil Taxonomy (Soil Survey Staff, 1998), neither a particle size class name nor a substitute for particle size class is used for Psamments by definition. As these taxa have sandy particle size class, this class is considered redundant in the family name.

Mineralogy class

Soils of Typic Torriorthents and Typic Torripsamments belonging to series Youginagar-2 (Pedon-10) and Dagala-2 (Pedon-11) were studied for mineralogy using XRD. Both the soils were dominant in kaolinitic class based on the relative proportions of clay minerals present in the soils. This mineralogy class was attributed to other soils belonging to the same subgroup. Hence, the soils belonging to Entisols have been classified as "Kaolinitic" mineralogical class.

Soil temperature class

All the soils were termed as "hyperthermic" because of mean annual soil temperatures >22°C and the difference between the mean summer and mean winter temperatures > 6°C.

5.6.2.6 At series level

The soils of the study area were classified at a series level by giving local village names to the particular soils found in each area. Series names for pedons and classification of soils up to family level are given in Table 40.

5.7 PEDOGENESIS

Climate is the most significant factor controlling the type and rate of soil formation. The role of climate in soil environment has been investigated by means of various indices or criteria which are based on combination of different climatic elements viz. rainfall and temperature. Soil genesis and development were influenced by soil temperature and moisture (Buol *et al.*, 1998). The study area had an arid climate with an average annual rainfall of 342.4 mm and mean annual air temperature of 26.45°C with scanty and erratic rainfall as well as extremes of temperature, resulting in high rates of evaporation. Soil temperature regime was hyperthermic whereas soil moisture regime was aridic.

Soils of the study area had on an average, weak/less profile development with low clay content, low CEC, coarse texture and accumulation of $CaCO_3$ in deeper layers upto an extent leading to the formation of calcic horizon in some pedons, sodic

Table 40: Classification of soils of the study area

Order	Suborder	Great group	Sub group	Family	Soil series	Pedon No.
Aridisols	Cambids	Haplocambids	Typic Haplocambids	Loamy skeletal kaolinitic hyperthermic Typic Haplocambids	Dagala-3, Kanyabe-2	2 5
				Coarse loamy kaolinitic hyperthermic Typic Haplocambids	Dhaneti-2	7
				Fine loamy smectitic hyperthermic Typic Haplocambids	Dagala-1	9
				Loamy smectitic hyperthermic Typic Haplocambids	Sangnadi-2	14
			Vertic Haplocambids	Fine smectitic hyperthermic Vertic Haplocambids	Amrutanagar	3
			Sodic Haplocambids	Fine loamy smectitic hyperthermic Sodic Haplocambids	Sang nadi-1	12
	Calcids	Haplocalcids	Typic Haplocalcids	Loamy skeletal kaolinitic hyperthermic Typic Haplocalcids	Dhaneti-1	4
				Coarse loamy kaolinitic hyperthermic Typic Haplocalcids	Kanyabe-1	6
Entisols	Orthents	Torriorthents	Typic Torriorthents	Coarse loamy kaolinitic hyperthermic Typic Torriorthents	Mokhana and Yoginagar-2	1 10
				Sandy skeletal kaolinitic hyperthermic Typic Torriorthents	Yoginagar-1	8
				Sandy kaolinitic hyperthermic Typic Torriorthents	Kanyabe-3	13
	Psamments	Torripsamments	Typic Torripsamments	Kaolinitic hyperthermic Typic Torripsamments	Dagala-2	11

nature in some soils, which were indicative for resultant effects of arid conditions. Thus, climate has major role in the formation of soils of the entire study area. Sehgal *et al.* (1992) and Sehgal, (1996) also made similar observations.

Sehgal *et al.* (1968) observed an interesting climosequence of soils starting from Aridisols (in the south western Punjab and Haryana) through Inceptisols and Alfisols (in the Central sections of Punjab) to Alfisols and Utisols (in north eastern Shiwaliks/lower Himalayas in Himachal Pradesh) corresponding to arid, through semi-arid and sub-humid to (per) humid climatic environments, respectively.

As climate being similar over the entire study area, variations in topography and parent material over a period of time might have also played a vital role in developing different soil taxa in the study area. The influence of topography on soil properties was clearly manifested in terms of depth, horizon, sequence, colour, texture, structure, clay content, CEC and base saturation and therefore, altogether resulted in the formation of different soil taxa. Soils located in the higher elevations (foot slopes) were shallow with coarse texture compared to the soils located in the lower elevations of the landscape (valley and nearly levelled pediplains). Dark reddish brown to strong brown colour was observed in foot slopes of hills whereas yellowish brown colour was noticed in valley portions. Comparatively well developed structure with more clay content, CEC and high base saturation was found in the soils of valley and nearly levelled pediplains than the higher elevated portions of the study area (foot slopes of hills). The role of topography was also reflected in mineralogy of soils as kaolinite, which was dominant in soils of higher elevations showed a gradual reduction in quantity down the slope with relative increase in smectite content leading to the dominance of the later in valley portion.

The combination of all these properties resulted in the formation of different types of soils falling under various physiographic units. 'Coarse loamy kaolinitic hyperthermic Typic Torriorthents', 'Loamy skeletal kaolinitic hyperthermic Typic Haplocambids' were noticed in foot slopes of hills. 'Loamy skeletal and Coarse loamy Typic Haplocalcids and Typic Haplocambids' occured in pediments followed by 'Fine loamy smectitic hyperthermic Typic Haplocambids' in pediplain and 'Fine loamy smectitic hyperthermic Sodic Haplocambids' in valley. However, 'Sandy kaolinitic hyperthermic Typic Torriorthents' in valley fringe and 'Coarse loamy kaolinitic hyperthermic Typic Torriorthents' and 'Kaolinitic hyperthermic Typic Torripsamments' in undulating pediplain with moderate to severe erosion also existed, which in turn reflects the influence of topography on soil formation. Sawhney *et al.* (1992) and Mishra and Ghosh, (1995) reported variations in soil formations with topography and noticed different types of soils in the toposequence of semi-arid and arid tracts of Punjab and mica-rich belt of Bihar, respectively.

Another important factor that influenced the soil genesis was parent material. Limestone is the parent material for most of the soils of the study area due to which calcareous nature and more saturation of exchangeable complex with Ca^{2+} exhibiting strong to violent effervescence were noticed in these soils. Calcic horizon was also observed in some pedons (Dhaneti-1, Dhaneti-2 and Kanyabe-1). Calcification might be the process contributed to the pedogenesis of these soils whereas alkalization was the pedogenic process involved in formation of Sodic Haplocambids (Sangnadi-1 series). Pal *et al.* (2003) also reported the role of these two processes for genesis of soils in the semi-arid tract of Indo-Gangetic plains, India. The role of parent material in the formation of soils was also reported by Sehgal *et al.* (1992), Subbaiah and Manickam (1992) and Khan *et al.* (2002).

The skeletal nature and shallow depths of soils located in higher elevations indicated their young age (immature nature) as compared to the soils located at lower elevations, which are relatively better developed in terms of depth, texture and structure.

The dominant natural vegetation of the study area includes shrubs such as *Alhagi pseudalnagi, Salvadora oleoides, Euphorbia caduclifolia, Salvadora persica, Maythenus emarginatus, Aristida Sp. Zizyphus sp., Calotropsis sp. Prosophis juliflora* and other *Prosophis* sp. and grasses such as *Cenchrus setigerus, C. depressus* and *Corchorus trilocularis* which can thrive well with limited moisture. The influence of natural vegetation in the formation of different types of soils was not evident as it is similar and sparse throughout the entire study area.

5.8 LAND EVALUATION

Land evaluation was done to know the capabilities/potentialities and limitations of the land by two methods viz. USDA land capability classification method and parametric method of land evaluation given by Riquier *et al.* (1970). Optimum land use was suggested based on the potentials and constraints of land.

5.8.1 Land capability classification

Soils belonging to Amrutanagar series (Pedon-3) were categorized under land capability 'Class III' and subclass 'sc' because these soils had limitations of soil (organic matter) and climate. However, climate is the limitation for the entire study area as the average annual rainfall is 342 mm. These soils can be used for the cultivation of field crops such as all pulses, millets and oilseed crops with careful management practices.

Soils belonging Kanyabe-1 (Pedon-6), Dhaneti-2 (Pedon-7) and Dagala-1 (Pedon-9) were grouped under class IV sc as these soils exhibited the limitations of coarse texture, calcic horizon from 50 cm depth onwards and low organic matter. In addition, Dagala-1 also showed limitations of coarse texture, surface stoniness and sub-surface coarse fragments. Hence, these are suitable for cultivation of limited crops and need intensive soil conservation and management practices.

Soils of pedons-1 and 2 were classified as class-VI esc and pedons-5, 12 and 14 were classified as class-VI sc. These soils of class-VI had moderate limitations of texture, surface stoniness, sub-surface coarse fragments and low organic matter. Moreover soils of Pedons-1 and 2 (Mokhana and Dagala-3 series) had the limitations of erosion with moderate to steep slopes, having shallow depth and therefore, were grouped as land capability sub class 'esc' whereas pedons-5, 12 and 14 were grouped as subclass 'sc' only. These soils are not suitable for growing crops and are only suitable for grazing (or) forestry.

Soils of Dhaneti-1 (Pedon-4), Yoginagar-1 (Pedon-8), Dagala-2 (Pedon-11) and Kanyabe-3 (Pedon-13) were classified under class-VII in which pedons-4 and 13 were kept under subclass 'sc' due to the severe limitations of texture, more surface stoniness, more subsurface coarse fragments, low organic matter, more permeability while pedons-8 and 11 were kept under sub class 'esc' because of severe erosion in addition to the above soil related constraints. These soils are fairly suitable for grazing or forestry and need careful management practices even for these purposes.

Soils belonging to Yoginagar-2 series (Pedon-10) were categorized as class-VIII sec as these soils had very severe limitations of texture (very coarse), more surface stoniness, more sub-surface coarse fragments, low organic matter, low CEC and erosion besides climate. These are suitable only for wild life or recreation purposes.

National Remote Sensing Agency (1997a) and Sharma and Kumar (2003) evaluated the potential use of land adopting this method and suggested optimum land use plan for tribal areas of Andhra Pradesh and for upper Maulkhand catchment in mid-hills zone of Himachal Pradesh respectively. Mathan *et al.* (1994), Kumar *et al.* (2002) and Venkanna Babu (2004) also adopted this method for land evaluation at Tamil Nadu, Goa and Tamil Nadu, respectively.

5.8.2 Assessment of Land productivity by Riqueir method

For Field crops

Soils of the series in Amrutnagar (Pedon-3), Dhaneti-2 (Pedon-7) and Dagala-1 (Pedon-9) were classified as average for field crops as these soils showed moderate limitations of organic matter and texture. Soils of Kanyabe-2 series (Pedon-5) were rated as poor to average class while pedons – 2, 4, 6, 8, 12, 13 and 14 were classified under poor class as these soils had the limitations of organic matter, texture and depth (< 100 cm) which reduced the rating indices. The soils of Mokhana (Pedon-1), Yoginagar-2 (Pedon-10) and Dagala-2 (Pedon-11) had the limitations of texture, organic matter, depth, low reserves of weatherable minerals in B-horizons and low base saturation/low fertility level and therefore, were classified under extremely poor to nil category.

Soil productivity can be changed from average to good and poor to average for all types of soils excluding pedons-1, 5 and 11 by adopting management practices such as addition of organic matter, improving texture by the addition of silt/clay content and by providing good irrigation facilities such as drip/sprinkler methods, besides deep tillage. No change can be brought in three types of soils *viz.,* pedons-1, 5 and 11 even after adopting improved management practices (Table 29).

For Pastures

Soils belonging to Dagala-2 (Pedon-2), Amrutanagar (Pedon-3), Dhaneti-1 (Pedon-4), Kanyabe-2 (Pedon-5), Kanyabe-1 (Pedon-6), Dhaneti-2 (Pedon-7), Yoginagar-1 (Pedon-8), Dagala-1 (Pedon-9) and Sangnadi-1 (Pedon-12) series were classified as 'poor' because of the limitations such as low organic matter and coarse texture in these soils. The other soils of Mokhana (Pedon-1), Yoginagar-2 (Pedon-10), Dagala-2 (Pedon-11), Kenyabe-3 (Pedon-13) and Sangnadi-2 (Pedon-14) series were classified under 'extremely poor to nil' category as they had constraints of low base saturation, low reserves of weatherable minerals and moderate to shallow depth in addition to the limitations mentioned above for 'poor' category of soils.

However, by correcting the above constraints through addition of organic matter as green manures/FYM, improving soil texture by the addition of tank silt, providing irrigation facilities and deep tillage, the soils of Dagala-1 and Sangnadi-1 series can be changed from 'poor' to 'good' category while other soils under 'poor' category can be changed to 'average'. No change in soils of Yoginagar-1 (Pedon-8), Yoginagar-2 (Pedon-10) and Dagala-2 (Pedon-11) can be brought about even after adopting the improved management practices.

For forest/other trees

According to actual productivity indices, all the soils were classified under 'extremely poor to nil' category. But after considering the improved management practices, no change can be observed in five types of soils (Mokhana, Yoginagar-1 and 2, Dagala-2 and Kenyabe-3 series). Three types of soils belonging to Kanyabe-1, Sangnadi-1 and Dagala-1 could be changed from 'extremely poor to nil' to 'average' category. Remaining soils could be brought from 'extremely poor to nil' class to 'poor' class indicating the potentiality of improvement.

Naidu *et al.* (1986), Diwaker and Singh, (1993), Naphade *et al.* (1994), Ratnam (2003) and Venkanna Babu, (2004) also used this method for suggesting optimum land use.

5.8.3 Suggested optimum land use plan by comparitive land evalaution

Based on the Riquier's parametric approach, the study area had three categories for cultivation of crops *i.e.* extremely poor to nil, poor and average grades. Three soil series *i.e.* pedon-1, 10 and 11 (Mokhana, Yoginagar-2 and Dagala-2, respectively) come under extremely poor to nil category, seven pedons *i.e.* pedon-2, 4, 6, 8, 12, 13 and 14 (Dagala-3, Dhaneti-1, Kanyabe-1, Yoginagar-1, Sangnadi-1, Kanyabe-3 and Sangnadi-2, respectively) come under poor category while other four pedons *i.e.* pedon –3, 5, 7 and 9 (Amrutnagar, Kanyabe-2, Dhaneti-2 and Dagala-1, respectively) fall under 'average' category.

The soils that are classified as 'average' category fell under land capability classes-III and IV, soils under 'poor' category are placed under LCC-VI and VII whereas soils under 'extremely poor to nil' category were falling under LCC-VII and VIII.

Present land use of the soils of 'average' category is cultivable land. These are used for growing bajra, sorghum and castor. But after improving the soil by managing the constraints of texture and organic matter through the addition of organic matter, tank silt and providing good irrigation facilities by means of drip (or) sprinkler these soils can be used for growing oilseeds such as groundnut, sesamum, mustard and pulses (Table 41).

The soils under 'poor' category are under land use of scrub with *Prosophis* sp. except the soils of pedons-6 and 14 which are under cultivation of castor crop. The status of the soils can be improved from actual productivity class 'poor' to potential productivity class 'average/good' by adopting management practices such as deep tillage, addition of organic manures (FYM) and by providing irrigation facilities. Therefore, it is suggested that the above soils can put to be cultivation of dryland crops such as castor and millets (*bajra and sorghum*) after adopting management practices (Fig. 23).

The pedon-12 (Sangnadi-1 series) are suffering both from sodicity and salinity due to which, the soils were not under cultivation. By applying the soil amendment *i.e.* gypsum and by improving drainage facility after giving irrigation besides following management practices as suggested for pedons-6 and 14, the soils of this series can be brought under cultivation. Salt tolerant crops like tomatoes, linseed, clusterbean, onion, cowpea, groundnut and pearl millet may also be grown.

The other pedons which come under 'poor' category (Pedons-2, 4, 8 and 13) had severe limitations of coarse fragments and surface stoniness in addition to the problem mentioned above. Hence, they were not under cultivation. These soils may be utilized for growing arid horticultural crops after providing favourable soil conditions by digging local pits and manuring with organic materials. The proposed arid horticultural crops include amla, ber etc. Bringing the potential productivity to average from that of poor class under actual productivity indicates that these soils can be used for horticultural trees/forest trees after adoption of management practices. As moisture is the limiting factor in the study area, arid horticultural crops are suggested.

Table 41: Comparative evaluation of the productivity of soils and suggested optimum land use for the study area

Soil Series	Present land use	LCC		LP1		Management practices	Suggested land use after adopting management practices
		Class	Constraints	Class	Constraints		
1) Mokhana	Scrub land (*Prosophis* sp.)	VI esc	1) Shallow depth with lithic contact 2) Coarse texture 3) More surface stoniness 4) More sub-surface coarse fragments 5) Low OC 6) Steep slope and erosion	C: Ext. Poor to Nil P: Ext. Poor to Nil T: Ext. Poor to Nil	1) Shallow depth with lithic contact 2) Coarse texture 3) Low OM	-	Recreation purpose
2) Dagala-3	Scrub land with *Prosophis* sp.	VI esc	1) Moderately shallow depth 2) Coarse texture 3) More surface stoniness 4) More sub-surface coarse fragments 5) Low OC 6) Moderately sloping land 7) Erosion	C: Poor P: Poor T: Ext. Poor to Nil	1) Low OM 2) Mod. Shallow depth. 3) Coarse textured soil	Small stone and live checks across gullies to stabilize soil scape and reduce erosion	Arid horticulture
3) Amrutanagar	Cultivated (single crop)	III sc	1) Low OC	C Average P: Poor T: Ext. Poor to Nil	1) Low OM	1) Addition of organic manures 2) Provision of irrigation facilities through drip/sprinkler methods	Cultivation of crops such as oilseeds and pulses

Table Contd…

Soil Series	Present land use	LCC		LP1		Management practices	Suggested land use after adopting management practices
		Class	Constraints	Class	Constraints		
4) Dhaneti-1	Scrub land with *Prosophis* sp.	VII sc	1) Coarse texture 2) More surface stoniness 3) More sub-surface coarse fragments 4) Calcic horizon at a depth of 47 cm 5) Low OM 6) Depth	C: Poor P: Poor T: Ext. Poor to Nil	1) Low OM 2) Depth 3) Coarse texture	1) Addition of organic manures 2) Deep tillage	Arid horticulture
5) Kanyabe-2	Partly Cultivated and partly waste land with *Prosophis* sp.	VI sc	1) Coarse texture 2) More surface stoniness 3) More sub-surface coarse fragments 4) Low OM	C: Poor to Average P: Poor T: Ext. Poor to Nil	1) Coarse texture 2) Low OM	1) Addition of organic manures 2) Provision of irrigation facilities through drip/sprinkler methods 3) Stone removal	Cultivation of oilseeds and pulses
6) Kanyabe-1	Cultivated (Single crop)	IV sc	1) Coarse texture 2) Calcic horizon from 50 cm onwards 3) Low OM	C: Poor P: Poor T: Ext. Poor to Nil	1) Coarse texture 2) Low OM	1) Addition of organic manures	Cultivation of millets and castor
7) Dhaneti-2	Cultivated (Single crop)	IV sc	1) Coarse texture 2) Calcic horizon from 50 cm onwards 3) Low OM	C: Average P: Poor T: Ext. Poor to Nil	1) Coarse texture 2) Low OM	1) Addition of organic manures 2) Provision of irrigation facilities through drip/sprinkler methods	Cultivation of crops such as oilseeds and pulses

Table Contd...

		LCC		LPI			
Soil Series	**Present land use**	**Class**	**Constraints**	**Class**	**Constraints**	**Management practices**	**Suggested land use after adopting management practices**
8) Yoginagar-1	Degraded unculturable land (or) waste land with *Prosophis* sp.	VII esc	1) Coarse texture 2) Surface stoniness 3) Sub-surface coarse fragments 4) Depth 5) Erosion	C: Poor P: Poor T: Ext. Poor to Nil	1) Coarse texture 2) Depth 3) Low OM	1) Addition of organic manures 2) Deep tillage 3) Small stone and live checks across rills to stabilize soil scape and reduce erosion	Arid horticulture
9) Dagala-1	Cultivated (Single crop)	IV sc	1) Coarse texture 2) Surface stoniness 3) Sub-surface coarse fragments 4) Depth 5) Low OC	C: Average P: Poor T: Ext. Poor to Nil	1) Coarse texture 2) Depth 3) Low OM	1) Addition of organic manures 2) Deep tillage 3) Addition of tank silt 4) Stone removal by mechanical working	Cultivation of oilseeds and pulses
10) Yoginagar-2	Waste land with *Prosophis* sp.	VIII sec	1) Very coarse texture 2) Surface stoniness 3) Sub-surface coarse fragments 4) Depth 5) Low OC 6) Low CEC	C: Ext. Poor to Nil P: Ext. Poor to Nil T: Ext. Poor to Nil	1) Very coarse texture 2) Depth 3) Low OM 4) Low reserves of weatherable minerals in B-horizon	Small stone and live checks across rills to stabilize soil scape and reduce erosion	Recreation and urban development

Table Contd...

Soil Series	Present land use	LCC		LPI		Management practices	Suggested land use after adopting management practices
		Class	Constraints	Class	Constraints		
11) Dagala-2	Scrub land	VII esc	1) Very coarse texture 2) Low fertility level 3) Low OM 4) Erosion 5) Depth 6) Low CEC	C: Ext. Poor to Nil P: Ext. Poor to Nil T: Ext. Poor to Nil	1) Very coarse texture 2) Low OM 3) Depth 4) Low base saturation/ low fertility level	Small stone and live checks across rills to stabilize soil scape and reduce erosion	Recreation and urban development
12) Sangnadi-1	Scrub land	VI sc	1) Surface stoniness 2) Low OC 3) Salinity	C: Poor P: Poor T: Ext. Poor to Nil	1) Low OM 2) Salinity/Salt content	1) Application of gypsum 2) Provision of drainage 3) Addition of organic manures	Salt tolerant crops
13) Kanyabe-3	Scrubland	VII sc	1) Very coarse texture 2) Weak profile development 3) Low fertility level 4) Low organic matter 5) More Permeability 6) More infiltration rate	C: Poor P: Ext. Poor to Nil T: Ext. Poor to Nil	1) Very coarse texture 2) Low organic matter 3) Low fertility level	1) Addition of organic manures 2) Small stone and live checks across rills to stabilize soil scape and reduce erosion	Arid horticulture
14) Sangnadi-2	Cultivated (Single crop)	VI sc	1) Coarse texture 2) Surface stoniness 3) Sub-surface coarse fragments 4) Low organic matter	C: Poor P: Ext. Poor to Nil T: Ext. Poor to Nil	1) Coarse texture 2) Low organic matter	1) Addition of organic manures, green manures 2) Stones removal by mechanical working 3) Addition of tank silt	Cultivation of millets and castor

C: Crops; P: Pastures; T: Forest/Other trees Ext.: Extremely

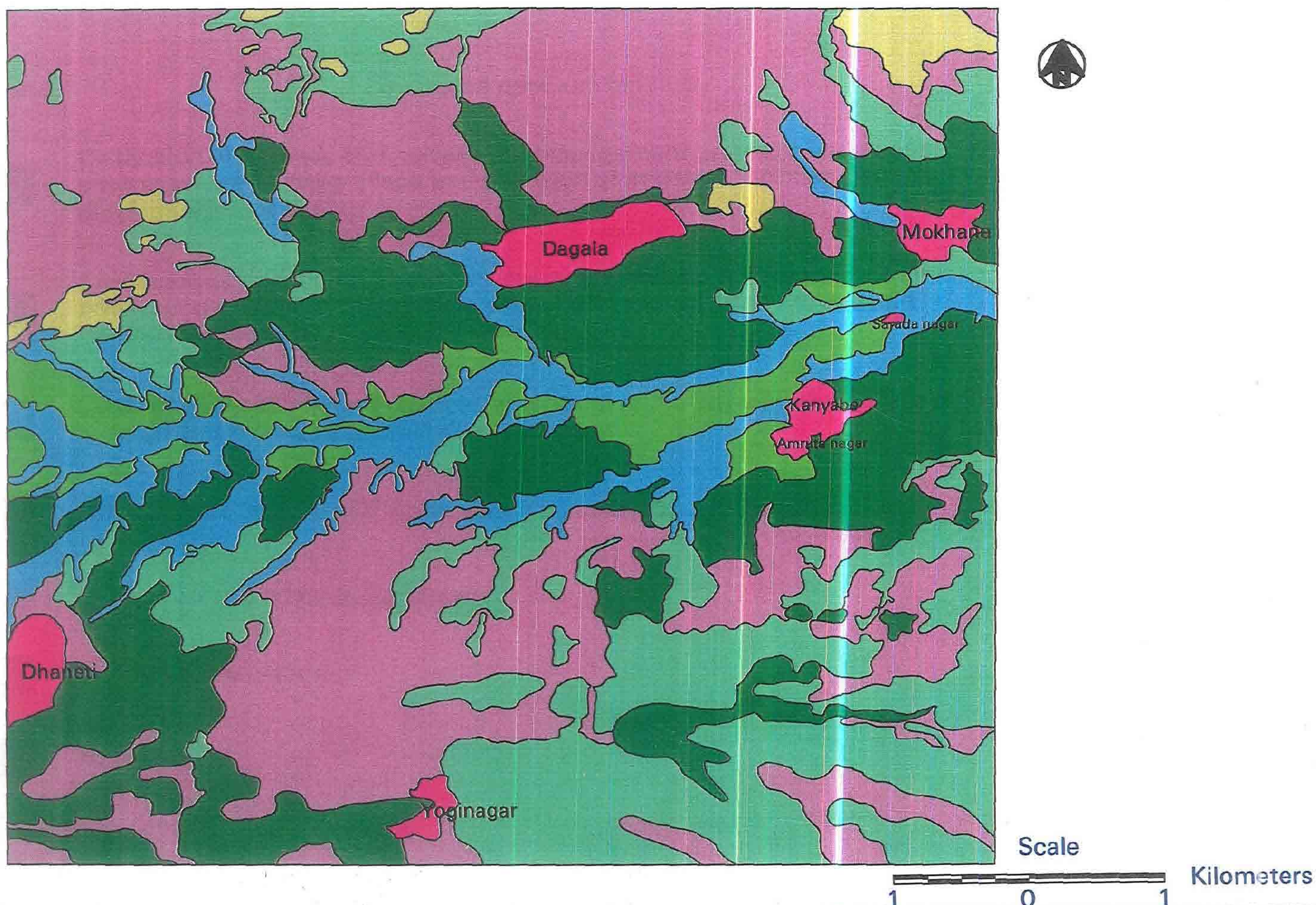

Fig. 23 : Optimum land use map of the study area

Mapunit	Suggested optimum land use	Area in ha (% to total area)
	Cultivation of oilseeds and pulses with management practices viz. addition of organic manures, deep tillage and provision of irrigation facilities through drip/sprinkler methods	1974.27 (24.96)
	Cultivation of dryland crops such as castor and millets with management practices viz. addition of organic manures and tank silt, deep tillage and removal of stones by mechanical working	375.08 (4.74)
	Cultivation of salt tolerant crops after reclaiming the soil with the adition of gypsum and providing good drainage facilities	731.09 (9.24)
	Arid horticulture with soil conservation measures to reduce soil erosion	1643.70 (20.78)
	Recreation and urban development	2809.56 (35.53)
	wild life conservation	149.21 (1.89)
	Settlements	225.72 (2.85)

Legend for optimum land use map of the study area

The pedons-1, 10 and 11 were categorized under "extremely poor to nil" class for field crops, pastures and forest/other trees. Presently they are under waste land category with *Prosophis*. They had severe limitations of texture, depth, organic matter, moisture, erosion, surface stoniness, coarse fragments and sub-surface coarse fragments. It is not economical for adoption of management practices to improve these soils and hence, they can be utilized for recreation and urban development purposes.

5. 9 SPATIAL VARIABILITY OF SOIL PROPERTIES

Spatial variability studies help in precision agriculture in matching resource application and agronomic practices with soil attributes and crop requirements as they vary across a site (Mc Bratney and Whelan, 1995). As soil serves as a growth medium for crops, its condition is a major factor affecting potential and actual yields. Traditional cropping has regarded the field as the smallest convenient unit of management. Assuming the soil is relatively homogenous, the field was generally managed by practices such as uniform sowing, fertilizer and pesticide applications, which generally ignores the spatial variability of the soil, and hence, the site-specific crop requirements.

Soil chemical and physical properties are of interest to the users of precision agriculture as their spatial variability can lead to variability in the yield. Hence, the present study was concentrated to study the spatial variability of soil chemical properties such as major nutrients, pH, salinity and organic carbon.

From the results, it was revealed that all the properties varied spatially within the field. Bouma and Finke (1993) reported that spatial variability can occur on a variety of scales, between regions, between fields or within fields. Variation in soil components can sometimes be discerned on a sub millimeter scale (Burrough, 1993). The status of K_2O showed more variability followed by OC > N > P_2O_5 > EC > pH as evidenced from the CV values of these properties (Table 36). pH showed among these, least variation.

Shi *et al.* (2000) reported more spatial variability of potassium than phosphorus in northern Ireland. In an estimation of random and spatial variability of soil properties in the semi-arid region of Punjab, Singh *et al.* (1993) showed that soil pH had least variation followed by EC, OC and available P. Courtin *et al.* (1983), Ameyan (1986) and Gupta *et al.* (1999) also found that pH is the least variable parameter and nutrients are the more variable parameters among soil chemical properties.

Soil variability naturally arises through complex interactions between time, parent material, topography, climate and organisms (Jenny, 1941). Trangmar *et al.* (1985) stated that the spatial variability of soil can be related to various factors ranging from interaction of soil forming factors to man made modifications. In the present study, the main factor inducing variability is man made modifications rather than soil forming processes as the climate, parent material are the same with slight variations in topography. Tillage operations, crop rotations, fertilizer and manure application are among the man made modifications that influenced the soil variability. These soil management practices affect the physical, chemical and biological environment of soil, hence cause spatial variation in soil properties.

Spatial variations in organic matter might be due to the differences in the application of organic manures by farmers in some fields. Jenkinson, (1988) reported that organic matter can vary according to the spatial variation of the factors that affect its accumulation and decay such as temperature, moisture content, oxygen availability, soil texture and management.

This variability in organic carbon might lead to the spatial variability in nitrogen also. The variations in nutrients might be due to the uneven use of fertilizers and manures by farmers in different cropping patterns (or) crop rotations. Method of application of nutrients might also show the impact on the variability of nutrients. Bouma and Finke, (1993) also stated that the fertilizer application can increase further the spatial variability of soil nutrients through uneven spreading patterns. Variations in application of fertilizers might have resulted in the changes in the chemical balance of soil, which ultimately lead to variability in pH. Sawyer, (1994) noticed that the combination of many factors might have contributed to the variation in soils present today i.e. soil formation, cropping history, past field delineation, crop nutrient removal and crop input applications such as fertilizers, lime, manures and pesticides.

5.9.1 Site-specific major nutrients recommendations for different crops in the study area

Application of fertilizers as per the general recommendation is based on the assumption that farm fields are homogenous units. Such a single rate of fertilizer application may lead to under fertilization or over fertilization of areas due to the existence of nutrient variability within fields. This practice reduces the fertilizer resource efficiency for farmers and deteriorates the soil quality. Hence, fertilizer resources need to be better managed for greater efficiency and soil health. This could be achieved by applying variable rates of fertilizers across the field to match the variations in soil fertility (Wollenhaupt *et al.*, 1994). Fertility maps generated through kriging can be used to divide the cultivated fields into various management zones that have variability in soil fertility (Mulla, 1993).

Site-specific nutrient recommendations for major nutrients are given by studying the spatial variability of these nutrients. The spatial variability maps of N, P_2O_5 and K_2O are being used as base for this. The crop recommendations suggested by CRIDA (Central Research Institute for Dryland Agriculture) were taken as the standard (Appendix-III). The site-specific recommendations for various zones were given to the crops such as pearl millet, sorghum, castor, cowpea, greengram and clusterbean. They are given in Table 42.

5.9.1.1 Nitrogen

CRIDA suggested an application of 80 kg nitrogen for pearl millet and sorghum, 60 kg nitrogen for castor and 20 kg nitrogen for green gram, cluster bean and cowpea per ha. Site-specific nutrients recommendation in general, reduced with the increase in soil test values. From the data presented in table 42, it can be clearly seen that for zone-6, less than half of the actual recommendation is enough. Thus, site-specific nutrient recommendations are proved to be economical and safe from ecological point of view.

5.9.1.2 Phosphorus

Similarly, 40 kg P_2O_5 ha^{-1} is recommended for pearl millet, sorghum, cowpea, greengram and clusterbean and 30 kg ha^{-1} for castor. But, according to site-specific nutrient recommendations, less than 50 per cent of nutrient application is enough for zone-6 which is evidenced from Table 42).

5.9.1.3 Potassium

General recommendations were not given for potassium to all the crops except castor. Therefore, site-specific potassium recommendations were given to the castor crop only. The actual recommendation is fixed as 30 kg ha^{-1}. However, application of

Table 42: Site-specific major nutrient recommendations for different crops in various management zones of experimental site

Zone No.	Range of property in the zone (kg ha^{-1})	Nutrient recommendations (kg ha^{-1})					
		Pearl millet	Sorghum	Castor	Cowpea	Green gram	Clusterbean
		NITROGEN					
1	103 – 144.42 (<144.42)	80	80	60	20	20.0	20
2	144.43 – 185.84 (165.13)	70	70	53	17.5	17.5	17.5
3	185.85 – 227.26 (206.55)	56	56	42	14.0	14.0	14.0
4	227.27 – 268.69 (247.98)	47	47	35	12.0	12.0	12.0
5	268.70 – 310.11 (289.40)	40	40	30	10.0	10.0	10.0
6	310.12 – 351.53 (330.82)	35	35	26	9.0	9.0	9.0
		PHOSPHORUS					
1	14.09 – 19.22 (<19.22)	40.0	40.0	30.0	40.0	40.0	40.0
2	19.23 – 24.35 (21.79)	35.0	35.0	26.0	35.0	35.0	35.0
3	24.36 – 29.48 (26.92)	29.0	29.0	21.0	29.0	29.0	29.0
4	29.49 – 34.61 (32.05)	24.0	24.0	18.0	24.0	24.0	24.0
5	34.62 – 39.74 (37.18)	21.0	21.0	15.5	21.0	21.0	21.0
6	39.75 – 44.87 (42.31)	18.0	18.0	14.0	18.0	18.0	18.0
		POTASSIUM					
1	99.75 – 171.18 (<171.18)	-	-	20.0	-	-	-
2	171.19 – 242.62 (206.91)	-	-	16.55	-	-	-
3	242.63 – 314.06 (278.35)	-	-	12.00	-	-	-
4	314.07 – 385.50 (349.78)	-	-	10.0	-	-	-

K_2O at the rate of 16.55, 12 and 10 kg ha^{-1} is recommended for zones-2, 3 and 4, respectively.

5.9.2 Inference from the soil spatial variability studies

From the results, it can be inferred that classical statistical methods include the estimation of sample mean, variance, co-efficient of variation and finding out number of samples necessary to estimate the mean within some specified confidence interval from frequency distribution data. They do not provide a complete description of the variability of a parameter because the calculated variances do not account for the distance between observations. Values of soil parameters are generally dependent on one another. There is often some degree of dependency between sample values, which is a function of the distance between samples. Classical statistical methods are inadequate for interpolation because they assume random variation and take no account of spatial correlation and relative location of sample. Therefore, expressing variability without considering the spatial dependency may not be statistically valid and thus, misleading. The geo-statistical theory enables to measure spatial dependence.

From this study, it can also be inferred that uniform fertilizer application according to the current recommendations is high compared to the site-specific recommendations based on soil spatial variability. It may lead to over fertilization of areas within a field. Hence, the site-specific nutrient recommendations rectify this and provide adequate fertilization in various management zones that vary in available nutrient status. Thus, site-specific recommendations are found to be economical and safe from ecological point of view and these would result in improved fertilizer use efficiency and soil health too.

SUMMARY

CHAPTER VI

SUMMARY

A study was undertaken with an objective to generate soil map, to suggest optimum land use plan and to prepare digital database for soil besides studying the spatial variability of the soil properties in a part of the study area for giving site-specific recommendations of major nutrients using remote sensing and GIS techniques.

The study area is part of Dagala watershed which is located in Kachch district of Gujarat. It lies between 23°15'-23°20' N latitude and 69°54'-70° E longitude with a spatial extent of 7908.64 ha. Drainage system is dendritic with irrigation tanks and intervening streams. The study area is under aridic climate with mean annual rainfall of 342 mm. Scanty and erratic rainfall as well as extreme temperatures resulting in high rates of evaporation are the characteristic features of the study area. Soil moisture regime is aridic and soil temperature regime is hyperthermic. Satellite data used for the present study was IRC-IC PAN + LISS-III. It helped to delineate the soils at 1:12,500 scale with the abstraction level of pure series.

The PAN + LISS-III merged imagery of the study area was interpreted visually after establishing the lithology. Broad physiographic units were identified and further categorization was done based on variations in slope and erosion status of the soil. Representative pedons which are confined to the physiographic units were selected. These pedons were studied for their morphological features, physical, physico-chemical, chemical properties and clay mineralogy.

Various physiographic units identified were hills, pediment-inselberg complex, pediment, pediplain and valley. Pediment was divided based on erosion. Pediplain was divided into nearly leveled and undulating based on the slope and further sub divided based on erosion status of soil. Valley portion was categorized into valley fringe, valley bottom and toe/side slopes of valley. Soils located in the higher elevations (foot slopes of hills) were shallow with coarse texture and dark reddish brown to strong brown in colour. Well developed structure with more clay, high CEC and high base saturation was found in the soils of valley and nearly levelled pediplains when compared with the soils in the higher elevated portions. Major part of the study area was occupied by undulating pediplain with moderate erosion (16.93%) followed by undulating pediplain with severe erosion (16.63%).

Based on the properties, soils were classified according to "Keys to Soil Taxonomy" (Soil Survey Staff, 1998). Later on, final soil map was generated with appropriate legend. Seventeen mapping units were identified and fourteen soil series were established in the study area.

Soils encountered in the study area belonged to orders–Aridisols and Entisols. Mokhana (Pedon-1) and Dagala-3 (Pedon-2) are the soil series identified in the foot slopes of hills, which belonged to "Coarse loamy kaolinitic hyperthermic Typic Torriorthents" and "Loamy skeletal kaolinitic hyperthermic Typic Haplocambids" respectively. Soils observed in the pediment were "Fine smectitic hyperthermic Vertic Haplocambids", "Loamy skeletal kaolinitic Typic Haplocalcids and Loamy skeletal kaolinitic Typic Haplocambids" which were placed under soil series of Amrutanagar (Pedon-3), Dhaneti-1 (Pedon-4) and Kanyabe-2 (Pedon-5), respectively. "Coarse loamy kaolinitic hyperthermic Typic Haplocalcids, "Coarse loamy kaolinitic hyperthermic Typic Haplocambids" and "Fine loamy smectitic hyperthermic Typic Haplocambids" were encountered in pediplain under Kanyabe-1 series (Pedon-6), Dhaneti-2 series (Pedon-7) and Dagala-1 series (Pedon-9), respectivley. "The other soils noticed in the pediplain belonged to Entisols and were termed as Yoginagar-1, Yoginagar-2 and Dagala-2 series. They were classified as "Sandy skeletal kaolinitic hyperthermic Typic Torriorthents" (Pedon-8), "Coarse loamy kaolinitic hyperthermic Typic Torriorthents" (Pedon-10) and "Kaolinitic hyperthermic Typic Torripsamments" (Pedon-11), respectively. Three types of soils were identified in the valley portion, which belonged to "Fine loamy smectitic hyperthermic Sodic Haplocambids" (valley bottom), "Sandy kaolinitic hyperthermic Typic Torriorthents" (valley fringe) and "Loamy smectitic hyperthermic Typic Haplocambids" (toe/side slopes of valley). Genesis of these soils is influenced by topography and parent material besides climate over a period of time.

After generating soil map, soils in each mapping unit were evaluated for their potentialities and limitations using USDA land capability method and Riquier's parametric approach. Both the methods provided reliable information. Capability classification method gave generalized classification of soils for agriculture and non-agricultural uses. Riquier's method gave accurate ratings for field crops, pastures and forest/other trees because of the weightages given to each factor. Moreover, Riquier's method was found to be useful in calculating the potential productivity based on which one can suggest the optimum land use by taking into consideration the improved management practices. Finally, optimum land use was suggested for the study area by considering the potentialities and limitations besides the present land use.

According to USDA land capability classification method, soils belonging to Amrutanagar series (Pedon-3) were categorized under LCC-IIIsc with limitations of low organic matter and climate. Soils belonging to Kanyabe-1 (Pedon-6), Dhaneti-2 (Pedon-7) and Dagala-1 (Pedon-9) series were categorized under Class-IVsc. These soils had the limitations of coarse texture, calcic horizon, surface stoniness and sub-surface coarse fragments in addition to the above limitations. Soils of pedons-1, 2, 5, 12 and 14 were classified under class-VI in which pedons-1 and 2 were placed under sub class 'esc' whereas others (Pedons-5, 12 and 14) were placed under subclass 'sc'. These soils had the moderate limitations of above mentioned features with an additional constraints of slope, erosion and depth. Soils of pedons-4, 8, 11 and 13 were classified as VII class, out of which, pedons-4 and 13 were kept under sub class 'sc' while pedons-8 and 11 were kept under sub class 'esc'. Remaining soils which were belonging to Yoginagar-2 series (Pedon-10) were grouped under class-VIIIesc.

According to Riquier's method, pedons-3, 7 and 9 were rated under average category and pedons – 2, 4, 6, 8, 12, 13 and 14 were classified under poor category while pedons-1, 10 and 11 were categorized under extremely poor to nil category for field crops. Soils of pedons – 2, 3, 4, 5, 6, 7, 8, 9 and 12 were grouped under poor class and pedons-1, 10, 11, 13 and 14 were grouped under extremely poor to nil class for pastures. All the soils were rated as extremely poor to nil class for forest/other trees.

Based on the limitations, potentialities and present land use, optimum land use is suggested after taking in to consideration the adoption of improved management practies. 24.96 per cent of the study area is suggested suitable for cultivation of oilseeds (groundnut, sesamum and mustard) and pulses. Dry land crops such as castor and millets are suggested to an extent of 4.74 per cent by adopting the management practices. The land under salt affected (9.24%) can be brought under normal cultivation of crop by reclaiming the soils with the addition of gypsum besides providing good irrigation and drainage facilities. Arid horticulture is suggested for 20.78 per cent of area while the remaining area comprising of severe limitations is being suggested for the urban development and recreation purposes.

Digital database was created for soils, which enables to study the variations in soil properties over a period of time. The derivative maps were generated from the digital database. The digital database thus created may be useful for future workers to retrieve and update the data for generating action plans over a period of time for land resource management of the study area, which is cost effective and time saving.

Part of the study area was selected to study the spatial variability of soils for site-specific nutrient management as a model to focus the importance of precision farming. Spatial variability of soil properties such as pH, EC, OC and nutrients status of N, P_2O_5 and K_2O was studied and maps were generated using geo-statistics. Among the parameters, available potassium exhibited maximum variability followed by OC while pH showed the least variation with CV value of 3.51 per cent. Site-specific nutrient recommendations are given for major nutrients based on the variability of nutrients.

FUTURE LINES OF RESEARCH

- The present study revealed that the soil properties studied using remote sensing techniques and GIS applications have given a reliable information for the study area in terms of soil productivity and site-specific nutrient management. For implementation of development plans at farm level, efforts need to be made by future workers to generate more information on soil properties and productivity which can be achieved by using the data from recent indigenous and foreign space missions viz., IRS-P5 (CARTOSAT-1) with 2.5 m spatial resolution data in panchromatic mode in conjunction with multi-spectral data with 6 m spatial resolution from IRS-P6 (RESOURCESAT), IKONOS-A and B, Quick Bird, Almaz-B etc.

- Though voluminous data on soils in form of maps and attributes (physical and chemical properties of soils, geographic location, lithology, current land use etc.) are available with various organizations, there is no organized digital database at state or national level available to users concerned. It is therefore, necessary to develop a centralized digital database. The digital soil data base created presently was pertaining to a limited area. By following the same scientific approach, digital database can be created for other areas of the country and the same can be retrieved and updated at any time in future.

- Land evaluation hitherto has been carried out mostly by conventional method involving determination of the suitability of a given piece of land for various purposes like irrigated agriculture, forestry, specific crop, urbanization etc, and categorizing the land into various classes based on its potentials and limitations. Such studies now carried out in the present investigation in a GIS environment and soil capability and productivity maps were generated using soil and terrain parameters from digital database. In future, land evaluation models can subsequently be developed, which will help in identifying alternative uses of the land in a sustainable manner.

- Emergence of new technologies such as remote sensing, GIS and GPS have opened a new era in site-specific farming by providing techniques to manage the fields at micro level units. In the present investigation, site-specific nutrient management is recommended for a part of study area which in an essential component of precision agriculture. It is receiving increasing attention internationally because fine tuning of agricultural management to the needs of plants within spatially variable fields can be attractive both from economic and ecological point of view. Little work has been carried out on Indian soils in the above angle due to many constraints. However, it will be beneficial by and large if site-specific nutrient management is practiced on Indian soils on par with advanced countries in the world.

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APPENDIX

APPENDIX - I

Soil characteristics used to determine productivity

(1) **SOIL MOISTURE CONTENT – H**

H1 Rooting zone below wilting point all the year round

H2 Rooting zone below wilting point for 9 to 11 months of the year

H2a 11 months

H2b 10 months

H2c 9 months

H3 Rooting zone below wilting point for 6 to 8 months of the year

H3a 8 months

H3b 7 months

H3c 6 months

H4 Rooting zone below wilting point for 3 to 5 months and wet below field capacity for over 6 months of the year

H4a 5 months

H4b 4 months

H4c 3 months

H5 Rooting zone wet above wilting point and below field capacity for most of the year

Note: 1. If data on actual soil moisture is not available, it is possible to use instead the number of dry months per year calculated from weather intelligence (Gaussen's ombrothermic diagramme for instance) at least for small scale maps.

2. For cold countries, the months during which frost occurs as also the months of average temperature < 10°C (threshold of productivity) are considered as dry months.

(2) DRAINAGE -D

D1a Marked waterlogging, water table almost reaches the surface all year round (Hydromorphic horizon at a depth of 0 to 30 cm)

D1b Soil flooded for 2 to 4 months of the year

D2a Moderate waterlogging, the water table being sufficiently close to the suface to harm deep rooting plants (hydromorphic horizon at a depth of 30 to 60 cm)

D2b Total waterlogging of profile for 8 days to 2 months

D3a Good drainage, water table sufficiently low not to impede crop growing (hydromorphic horizon at a depth of 60 cm below the surface)

D3b Waterlogging for brief periods (flooding), less than 8 days each time

D4 Well drained soil, deep water table (hydromorphic horizon at over 120 cm depth); no waterlogging of soil profile.

In the case see H

Note: 1. If the hydromorphic horizon is not recognizable from morphological characteristics, the height of the water table is the only point to be considered. If, on the other hand, it is fossilized, it should be ignored all together.

2. In some instances soils are both too dry in the summer and too wet in the winter, in which case the two functions H and D are combined.

(3) EFFECTIVE DEPTH OF SOIL-P

P1 Rock outcrops with no soil cover or very shallow cover

P2 Very shallow soil, less than 30 cm deep

P3 Shallow soil, 30-60 cm deep

P4 Fairly deep soil, 60-90 cm deep

P5 Deep soil, 90-120 cm deep

P6 Very deep soil, over 120 cm deep

Note: By effective depth is meant the rooting zone. The later extends to the horizon where the roots can no long penetrate, whether it be parent rock, hardpan, claypan, gypseous layer (>10-25 per cent gypsum).

(4) TEXTURE AND STRUCTURE OF ROOT ZONE-T

T1 Pebbly, stony or gravelly soil

T1a Pebbly, stony or gravelly > 60 per cent by weight

T1b Pebbly, stony or gravelly from 40 to 60 per cent

T1c Pebbly, stony from 20 to 40 per cent

T2 Extremely coarse-textured soil

T2a Pure sand, of particle structure

T2b Extremely coarse-textured soil (> 45 per cent coarse sand)

T2c Soil with non-decomposed raw humus (> 30 per cent organic matter), and fibrous structure

T3 Dispersed clay of unstable structure (often Na/T > 15 per cent)

T4 Light-textured soil, fine sand, loamy sand or light sand loam, or coarse sand and silt

T4a Unstable structure

T4b Stable structure

T5 Heavy-textured soil : clay or silty clay

T5a Massive to large prismatic structure

T5b Angular to crumb structure or massive but highly porous (e.g. soils with a high sesquioxide content)

T6 Medium-heavy soil : heavy sandy loam, sandy clay, clay loam, silty clay loam or silt

T6a Massive to large prismatic structure

T6b Angular to crumb structure (or massive but porous)

T7 Soil of average, balanced texture : loam, silt loam and sandy clay loam

Note: Texture should preferably be judged by touch in this way taking micro-aggregation into account. Otherwise reference to the texture triangle is necessary. This chart is based on the U.S. Department of Agriculture's Soil Survey Manual, but the surface "sandy loam" has been further subdivided into T4 ("light") and T6 ("heavy").

(5) AVERAGE NUTRIENT CONTENT OF A HORIZON – N

N1 Soil with base saturation V = S/T less than 15 per cent

N2 V from 15 to 35 per cent

N3 V from 35 to 50 per cent

N4 V from 50 to 75 per cent

N5 V over 75 per cent

N6 Soil excessively calcareous (> 20 to 30 per cent)

(6) SOLUBLE SALTS CONTENT-S

S1 Total soluble salts less than 0.2 per cent

S2 Total soluble salts between 0.2 and 0.4 per cent

S3 Total soluble salts between 0.4 and 0.6 per cent

S4 Total soluble salts between 0.6 and 0.8 per cent

S5 Total soluble salts between 0.8 and 1.0 per cent

S6 Total soluable salts cver 1 per cent

If sodium carbonate is present in the soils (alkali soils):

S7 Total soluble salts (including sodium carbonate) 0.1 to 0.3 per cent

S8 Total soluble salts from 0.3 to 0.6 per cent

S9 Total soluble salts over 0.6 per cent

(7) ORGANIC MATTER IN A1 HORIZON-O

O1 Very little organic matter less than 1 per cent

O2 Little organic matter, 1 to 2 per cent

O3 Average organic matter content, 2 to 5 per cent

O4 High organic matter content, over 5 per cent

O5 Very high content, but C/N over 25

Note: Place in one category lower if the organic matte is raw, of mor or moder type

(8) MINERAL EXCHANGE CAPACITY AND NATURE OF THE CLAY IN THE B-HORIZON-A

A0 Exchange capacity of clay less than 5 cmol (+). kg^{-1}

A1 Exchange capacity of clay less than 20 cmol (+).kg^{-1} (probably kaolinite and sesquioxides)

A2 Exchange capacity of clay from 20 to 40 cmol (+).kg^{-1} (probably a mixture of clays or illite)

A3 Exchange capacity of clay over 40 cmol (+).kg^{-1} (probably montmorillonite or amorphous clay)

(9) RESERVES OF WEATHERABLE MINERALS IN B-HORIZON-M

M1 Reserves very low to nil

M2 Reserves fair

M2a Minerals derived from sands, sandy materials or ironstone

M2b Minerals derived from acid rocks

M2c Minerals derived from basic or calcareous rocks

M3 Reserves large

M3a Sands, sandy materials or ironstone

M3b Acid rocks

M3c Basic or calcareous rocks

Tentative ratings of different characteristics

	FOR CROP GROWING			FOR PASTURE			FOR FOREST AND NON-FOREST TREE CROPS		
H									
H1		5			5			5	
H2	H2a10	H2b20	H2c40	20	20	30		10	
H3	H3a50	H3b60	H3c70	30	40	60	10	20	40
H4	H4a80	H4b90	H4c100	70	80	90	70	90	100
H5		100			100			100	
D	H4	H5 H2	H3						
D1		10-40			60			5	
D2		40-80			100			10	
D3		80-90			90			40	
D4		100			80			100	
P									
P1		5			20			5	
P2		20			60			5	
P3		50			80			20	
P4		80			90			60	
P5		100			100			80	
P6		100			100			100	
T									
T1a		10			30			50	
T1b		30			50			80	
T1c		60			90			100	
	H4H5H6AB	H3	H1H2		(same ratings as for crop growing)			(same ratings as for crop growing)	
T2a	10	10	10						
T2b	30	20	10						
T2c	30	30	30						
T3	30	20	10						
T4a	40	30	30						
T4b	50	50	60						
T5a	50	60	20						
T5b	80	80	60						
T6a	80	80	60						
T6b	90	90	90						
T7	100	100	100						

REMARK: Rating for H2a is 10; when the soil is irrigated the rating becomes 100

	FOR CROP GROWING		FOR PASTURE		FOR FOREST AND NON-FOREST TREE CROPS
N					
N1	40		60		80
N2	50		70		80
N3	60		80		90
N4	80		90		100
N5	100		100		100
N6	80		90		100
S		T1T2T4		T5T6T7	
S1		100		100	
S2		70		90	
S3		50		80	
S4		25		40	
S5		15		25	
S6		5		15	
S7		60		90	
S8		15		60	
S9		5		15	
O	H1H2H3	D3D4	H4H5	D1D2	AB
O1	85			70	
O2	9			80	
O3	100			90	
O4	100			100	
O5	70			70	
A					
A0		85			
A1		90			
A2		95			
A3		100			
M	H1H2H3		H4H5	AB	
M1	85		85		
M2a	85		90		
M2b	90		95		
M2c	95		100		
M3a	90		95		
M3b	95		100		
M3c	100		100		

APPENDIX – II

Land capability classification – quantification of the criteria

Characteristics	Class I	Class II	Class III	Class IV	Class V	Class VI	Class VII	Class VIII
TOPOGRAPHY (t)								
1) Slope (%)	0-1	1-3	3-8	8-15	Upto 3	15-35	35-50	> 50
2) Erosion	Nil	Slight	Moderate	Severe	Nil	Severe	V.severe	
WETNESS (w)								
3) Flooding	Nil (FO)	Nil (FO) (FO/F1)	Nil to slight (F1/F2)	Slight to mod. (F3)	Mod. To severe(F 0 /F 3)	Nil to severe (F 0 to F 4)	Nil to very severe	-
4) Drainage (I)	Well	Mod. well	Imperfect	Poor	V.poor	Excessive	Excessive	Excessive
5) Permeability	Moderate	Mod. rapid	Rapid, slow	V.rapid, very slow	-	-	-	-
6) Infiltration rate (cm hr^{-1})	2-3.5	1-2.0 3.0 – 5.0	0.5 – 1.0 5.0 – 10.0	< 0.5 > 10.0	2.0	-	-	-
PHYSICAL SOIL CONDITIONS (s)								
7) Surface texture	Loam	sil & cl	sl & c	scl	s, c(m)	ls-cl	ls,s,c	ls,s,c(m)
8) Surface coarse fragments (vol.)	1-3	3-15	15-40	40-75	15-75	75+	-	-
9) Surface stoniness (%)	< 1	1-3	3-5	5-8	8-15	15-40	40-75	>75
10) Subsurface coarse fragments (%)	<15	<15	15-35	35-50	50-75	50-75	50-75	<10
11) Soil depth (cm)	>150	150-100	100-50	50-25	-	25-10	25-10	<10

Contd . . .

12) Profile Development	Cambic/ Argillic hor. (A-(B)-C	A-B-C	Stratified A-C; A-B-C	Salic (Z)/Calcic (K) hor. A-Bz-C/A-Bk-C	Az-C, A-Bz-C	Gypsic (y) hor. A-Cy	A-C (Stony)	A-C (boundry)
FERTILITY (f)								
13) CEC (cmol(p^+ kg^{-1})	40-16	16-12	16-12	-	-	-	-	-
14) Base saturation (%)	80+	80+	80-50	50-35	50-35	35-50	<15	-
15) OC (0-15 cm) %	>1.0	0.75-1.0	0.5-0.75	<0.5	<0.5	-	-	-
16) Salinity EC (dS m^{-1})	<1.0	1-2	2-4	4-8	8-15	15-35	35-50	>50
17) Gypsum (%)	0.3 – 2.0	2-5	5-10	10-15	15-25	>25	-	-

hor. : horizon V. : very

APPENDIX - III

NUTRIENT MANAGEMENT SUGGESTED BY CRIDA FOR CROPS GROWN ON ARID SOILS OF ARID ZONE

Crop	**Dose (kg ha^{-1})**			
	N	**P_2O_5**	**K_2O**	**Method of application**
Sorghum	80	40	-	Apply 50% recommended dose of N and whole dose of P_2O_5 as basal and remaining 50% dose of N at tillering stage depending on soil moisture content.
Pearl millet	80	40	-	Apply 50% recommended dose of N and whole dose of P_2O_5 as basal and remaining 50% dose of N at tillering stage depending on soil moisture content.
Greengram Cowpea Clusterbean	20	40	-	Apply both N and P_2O_5 as basal.
Castor	60	30	20	Apply 50% recommended dose of N and whole dose of P_2O_5 and K_2O as basal and remaining dose of N in two splits at 30 and 45 days after sowing depending on soil moisture content