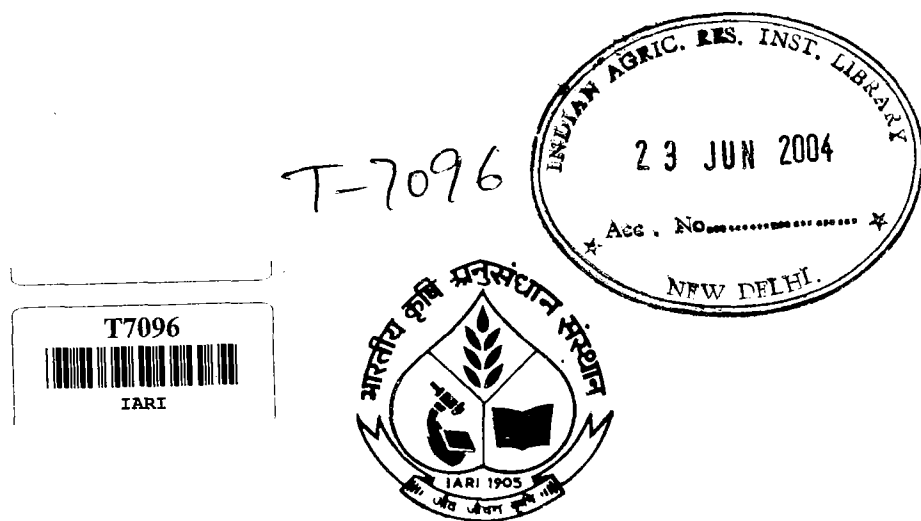


ASSESSMENT OF SOIL DEGRADATION USING REMOTE SENSING AND GIS TECHNIQUES IN MATHURA DISTRICT, UTTAR PRADESH

Fadhle Haidara Mutlaq



DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI - 110 012

2002

ASSESSMENT OF SOIL DEGRADATION USING REMOTE SENSING AND GIS TECHNIQUES IN MATHURA DISTRICT, UTTAR PRADESH

A Thesis

By

Fadhle Haidara Mutlaq

Submitted to the faculty of Post-Graduate School,
Indian Agricultural Research Institute, New Delhi
in partial fulfillment of the requirements
for the degree of

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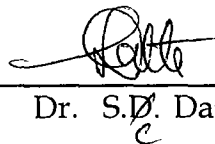
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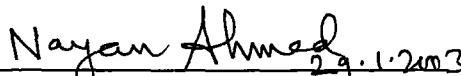

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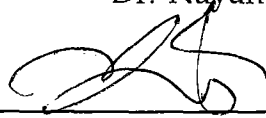
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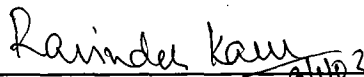
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मृदा विज्ञान एवं कृषि रसायन विज्ञान संभाग

भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली ११० ०१२

DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

Indian Agricultural Research Institute, New Delhi-110012

CERTIFICATE

This is to certify that the thesis entitled "**Assessment of soil degradation using remote sensing and GIS techniques in Mathura district, Uttar Pradesh**" submitted in partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy in Soil Science and Agricultural Chemistry**, to the Faculty of the Post Graduate School, Indian Agricultural Research Institute, New Delhi, embodies the results of *bona fide* research work carried out by **Mr. Fadhle Haidara Mutlaq**, under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma. The assistance and help received during the course of investigation has been duly acknowledged by him.

Place : New Delhi

Date : December 23, 2002


(P. K. Chhonkar) 23/12/2002
Chairman
Advisory Committee

*In the loving memories
Of my beloved father...*

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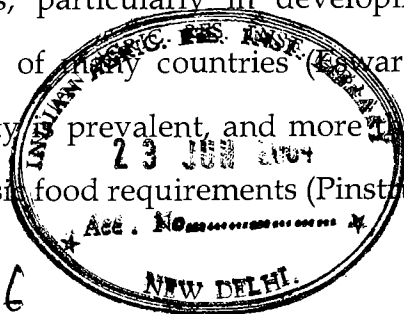
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1. INTRODUCTION

Land is a non-renewable base (Grewal and Dogra, 2000), which provides social environment in terms of shelter, communication, industries and other facilities. The land and soil profile serve as storage for water which supports plants and other living organisms as well replenishes surface and ground water. The physical, chemical and biological health of soil profile determines the ability of land to serve the socio-economic needs. Further, there is a progressive decrease in the quantity and quality of arable land due to the incipient process of land degradation (Sharma *et al.*, 2000). In this context the guiding principle of planning of land resources is to achieve self-reliance particularly in agricultural production through improved efficiency and productivity (Vijayaditya *et al.*, 2000).

The United Nations Conference on Environmental and Development (UNCED, 1992) held on Rio De Janeiro, Brazil focused the world attention on the harmful impacts of development on the Earth's life supporting system. Pressures on land are rapidly increasing due to ever increasing population competing for the finite land and water resources. The world population reached 6 billion by the turn of the century and is expected to reach about 8 billion by the year 2020 (Adams and Eswaran, 2000). Over 80% of the world's population currently lives in countries where agriculture and land are the primary sources of earning and livelihood. The rapid population increase in last five decades, particularly in developing countries, has stressed the land resources of many countries (Eswaran *et al.*, 1999 a & b) to the extent that poverty is prevalent, and more than 800 million people do not have access to basic food requirements (Pinstup



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Anderson *et al.*, 1999). Despite the impressive growth and development, India is home to one-fourth (208 million) of the world-undernourished people (800 million) (Singh, 2001). The present population of one billion, accounting for about 18 per cent of the world's population supported by only 2.4 per cent of land area, is estimated to become 1.4 billion by 2025 and 1.7 billion by 2050 AD, needing annually about 380 Mt and 480 Mt food grains respectively. This scenario along with increasing industrialization and urbanization has been visualized to place tremendous strain on shrinking land resources (Velayutham, 2000).

Barely 22% of the earth's surface is suitable for agriculture (Buring, 1992). Land resources in many tropical, subtropical and dry land regions of the world are seriously affected by land degradation (Koochafkan, 2000). The continuous degradation of production base and imbalance in soil - water - plant, human- animal systems is leading to ecological imbalance and economic insecurity (Lal, 1997). Although soil degradation is recognized as a serious and widespread problem, its geographical distribution and extent is known very roughly (Oldeman, 1994). It has been estimated that in world total loss of land through soil degradation is about 2 billion hectare, while the present arable land of the world is around 1.5 billion hectare (Dhruva Narayana *et al.*, 1997). Over 300 million hectare about the size of India is degraded to such an extent that restoration to its original productivity can be achieved only through major investment (Oldeman, *et al.*, 1990). Paradoxically, 5 to 7 million hectares of arable land of the world are lost annually through land degradation (Lal and Stewart, 1992; Dhruva Narayana *et al.*, 1997). Out of 329 Mha geographical area of India, only 264 Mha has the potential for biotic production. Land degradation has taken

place in 175 Mha, including water erosion in 111 Mha, wind erosion and aridity in 39 Mha and associated special problems of gullies and ravines, salinity and riverine and torrents in 4.0, 5.5 and 2.7 Mha respectively (Anonymous, 1990). It has been estimated about 5334 million tones of soil is being lost each year from Indian sub-continent with an average rate of soil loss as $16.4 \text{ t.ha}^{-1}\text{yr}^{-1}$ (Dhuruva Narayana and Ram Babu, 1983).

Remote sensing from satellite in conjunction with ground verification offer a potential means of surveying all the regions of globe. Satellite remote sensing can monitor much larger area than ground survey and help in targeting key ground observation. The process and extent of land degradation can be perceived better using remote sensing technique followed by verification on the ground (Anon, 2000, cited in Saini *et al.*, 2000). During 1990s, Scientists and decision makers have turned their attention to GIS to help them to study, locate and manage environmental resources (Peterson *et al.*, 1997). Remote sensing images have become primary data for Geographical Information System (GIS). These technologies are assisting us in modeling and understanding biophysical processes at all scales of enquiry (Lillesand & Kieffer, 1999). Some conventional satellites such as Landsat (TM), Spot and IRS have been used successfully to evaluate soil erosion on a regional basis. The FAO Remote Sensing unit used two scales for evaluation of world soil degradation map (1:5 million) and for national level soil degradation map (1:1 million) through Landsat imagery. Interpretation of satellite images can be effective technique for mapping and providing data for assessment of land degradation. It will be more useful if it is implemented with ground checks and thematic information, particularly where physiography is

inconspicuous. Ground testing and feed back from users of the degradation assessment methodology is vital to the evaluation and improvement of the role of remote sensing in soil degradation evaluation (Edige N and Peterse G.W., 1997). Application of remote sensing techniques becomes a handy and efficient tool for carrying out land degradation studies. In the state of Tamil Nadu (India), Elayarajan *et al.* (1994) also used Landsat STM Geocoded FCC on 1: 50,000 scale to study the kind, degree, extent and causative factors of land degradation

The western part of U.P., is extensively affected due to salinity and sodicity, waterlogging and severe soil erosion along streams and rivers. Large areas affected by these problems is lying unutilized. These lands can be put again under productive use after reclamation to increase crop production.

Land degradation mapping on 1:50,000 scale using remote sensing techniques has been done in Mathura district of U.P. by the All India Soil and Land Use Survey in 1996-1997. For visual interpretation, IRS -1B LISS -II (36.25 m ground resolution) Geocoded FCC have been used, which have limitations in delineation of different soil degradation types, degree, extent *etc.*, due to constraints of ground resolution of satellite imagery. Therefore moderately and slightly degraded soils have been excluded and considered as normal areas.

Accurate identification and assessment of the types degree, extent and causes of the soil degradation problems are prerequisite to develop suitable agricultural practice and conservation measures that will ensure safe use of the soil. From this point of view an attempt was carried out for assessment of soil degradation in part of Mathura District, Uttar Pradesh

using more finer satellite data products *i.e.* IRS 1C LISS III (Spatial resolution 23.5 m) with visual, digital image processing and GIS techniques with the following objectives:

1. To identify and assess different types of soil degradation in the study area using both visual and digital image processing techniques.
2. To generate soil resource inventory of the study area using Geographical Information System (GIS), and evaluate the soil site suitability for different crops.
3. To suggest suitable control measures for combating soil degradation problems in order to improve soil productivity and achieve sustainability.

2. REVIEW OF LITERATURE

The literature pertaining to different aspects of the study is reviewed and presented under the following heads:

- 2.1 *Soil-physiographic relationship*
- 2.2 *Soil characteristics*
 - 2.2.1 *Physical properties of soil*
 - 2.2.2 *Physico-chemical properties of soils*
 - 2.2.3 *Chemical properties of soil*
- 2.3 *Soil mineralogy*
- 2.4 *Soil classification*
- 2.5 *Land evaluation*
- 2.6 *Land degradation*
- 2.7 *Application of Remote sensing and GIS techniques in soil resource management*

2.1 **Soil physiographic relationship**

Jenny (1941) conceived the soil as an open system and made his classical statement that soil is a function of five soil forming factors namely, climate (c), organisms (o), topography (r), parent material (p) and time (t).

Topography influences the soil formation through its effects on drainage, runoff and erosion. Thus, it plays an important role in development of soils with varying characteristics.

Krishnamurthy (1975) attributed topography as the dominant soil forming factor responsible for differentiation of soils particularly with respect to their physical properties in semi-arid climate.

Gawande and Biswas (1977) also observed the influence of micro-relief on soil formation.

Pofali *et al.* (1979) reported that configuration of landscape feature follow a fairly definite soil pattern and influence soil morphology and land physico-chemical properties in the basaltic terrain.

Minhans and Bora (1982) studied the effect of altitude on the soils and reported that with increase in the altitude, the organic carbon and total available ammonical and nitrate nitrogen increase while pH and calcium carbonate of the soils decreases.

Vadivelu *et al.* (1983) reported that geomorphic units affect land use pattern through their influence on soil site and climatic characteristics. They observed that shallow soils were almost under forest with patches of rainfed crops; the pediment surface with shallow to deep soils were cultivated to sorghum, pearl-millet and safflower and the soils occurring on piedmont and flood plains, being very deep were cultivated to sorghum, cotton and safflower under rainfed condition.

Sharma and Dev (1985) reported that soils in unstable geomorphic surface are coarse textured and those in stable surfaces are relatively fine textured. The upper terrace and channel soils showed definite profile development and other such as alluvial fans, sand bars, foot-hill and flood plains showed wide spread stratification in north-east Punjab.

Gaikawad *et al.* (1986) reported that the landform and elevation affect the depth, colour, slope, erosion, physico-chemical properties of soils and their land use. It was observed that change in slope affect runoff, erosion, drainage, vegetation and land use which indirectly affect soil properties, like texture, pH, EC and base saturation.

Prasad *et al.* (1989) observed that morphological characteristics of soils were greatly influenced by topographic positions and soil depth was related to the slopes and the degree of erosion. The soil depth varies from very shallow to shallow on hill crests and convex erosional slopes through deep in mid slopes and foot slopes to very deep in the depressions/valley.

Mark and David (1993) reported that landscape position has a minimal effect on classification of pedons, but distance from source of loss appears to have influenced difference in the classification of soils in south-central Nebraska basin.

Prasad and Srivastava (1993) studied the soil physiography relationship in Dewas district to Madhya Pradesh. They reported that soils on piedmont plain and valley are deep calcareous, fine textured with swell -shrink potentials and the soils of central high lands are shallow, non calcareous, coarse to fine textured. Soils on gently to moderately sloping plain are moderately deep to deep and calcareous with vertic properties and cultivated for the sole crop of cotton or pigeonpea and their intercropping.

Singh *et al.* (1994) reported that soils on higher topographic situations were dark to brown in colour due to formation of non- hydrated compounds. The progressive yellower hue and darker chroma towards

lower topographic position were attributed to higher complexation and chelation of organic colloids on the surface of smectites, under the influence of relatively impeded drainage and stable landform. Similarly Sharma *et al.* (1999) observed that soil on moderately sloping side slope, gently sloping slope and nearly level plains were comparatively of a less redder hue than those of soils on alluvial flood plain.

Jassal *et al.* (2000) reported that the soils developed on different geomorphic units in Siwalik Hills region showed variation in morphological, physical and chemical characteristics. The soils on steep slope were relatively shallow and lacked any diagnostic horizons except an ochric horizon; the profiles were characterized by the presence of A and C-horizons only. The soils on moderate slopes were developed on alluvium derived from Siwalik rock of the catchment, showing relatively deep profile and presence of an organic sub-surface diagnostic horizon. These soils were non-calcareous in upper horizon and calcareous below lower B horizon. The terrace soils have developed on relatively younger sediments brought down and deposited by small rivulets/ choes from the upslope regions. These surfaces being at lower topographic position are subjected to periodic sedimentation and thus represent an unstable part of the landscape. These soils were characterized by the presence of cambic sub-surface diagnostic horizons.

Walia and Rao (1996) observed that some red soils in Bundelkhand region of Uttar Pradesh were deep to very deep, excessively to well drained, reddish brown to red with wide textured variations depending upon parent material and physiography.

Sen *et al.* (1997) studied eight pedons in a varying physiographic stretch across the central Assam for their characteristics and classification. They have reported that the field morphology, physical and chemical properties show variation in pedogenic development of the soils with respect to their geology and physiographic position.

Pedological development of soils occurring on different land forms of granite-gneissic landscape of Chhotanagpur plateau of West Bengal were evaluated by Dipak Sarkar *et al.* (1997). They reported that the relative profile development (RPD) ratings of the younger soils developed on unstable land forms were low and maximum values were observed in A horizon, while the values were higher in the soils developed on stable land forms and maximum values were at the B horizons.

2.2 Soil characteristics

Soil is characterized as a diverse set of chemical, physical and biological properties that have both vertical and horizontal dimensions.

The soil characteristics which influence productivity and soil quality are soil depth, texture, structure, available moisture, bulk density, pH, EC, organic carbon, calcium carbonate, exchangeable cations, cation exchange capacity etc. These important characteristics are reviewed as under:

2.2.1 Physical properties

Physical condition of a soil has direct and indirect effects on crop production and environmental quality. Well aggregated soil, if managed properly, are able to maintain a balance of air and water. So as to promote nutrient cycling and root development, while resisting erosion, surface sealing and other degradative processes.

Singh and Raje (1984) studied the relationship between soil depth and available soil moisture with growing period (in days) and concluded that as the soil depth increased, the available soil water also increases upto depth of 90 cm.

Rajkumar and Saxena (1985) reported that the lithic ustorthents have the limitation of soil depth, texture, coarse fragments for crop production and have poor productivity while the productivity of Ustochrepts and Chromusterts was found to be good and average, respectively.

Murthy *et al.* (1982) reported that the bulk density in shrink-swell soils changes with moisture content. Such soils have high (1.850 Mg m^{-3}) bulk density when dry and low (1.55 Mg m^{-3}) when wet. Depending on the soil moisture content it varies from 1 to 2 Mg m^{-3} in Vertisols.

Sharma *et al.* (1994a) characterized Soan river valley soils in lower Siwalik and suggested that higher bulk density values (1.51 Mg m^{-3}) for those soils could be attributed to coarse texture and low organic matter content within the same textural class.

Virmani *et al.* (1982) reported that there was increase of bulk density value of Vertisols alongwith the soil depth due to soil compaction.

Sharma *et al.* (1997) found the Alfisol in shallow tubewell command area in Assam varied in texture from clay loam to clay, while Inceptisols of deep tubewell command were sandy loam to clay loam. They also observed an increase in clay content with depth.

The soils of Diara land occurring in alluvial fans and flood plains of Gangetic plains of Bihar are young and stratified with AC profiles, having light colour and sand to sandy loam texture (Diwakar and Singh, 1994).

Murthy *et al.* (1995) found that forest and pasture soils had higher organic matter and mean weight diameter value than dry land and irrigated soils. Forest soils had an aggregated stability coefficient near one, which is conducive for root development.

In the soils of Majalgaon canal command area, Bharambe *et al.* (1999) found comparatively low mean weight diameter of the water stable aggregates, which decreased with depth.

Nagar *et al.* (1995) studied soil water characteristics of different soil series in Chambal command, Rajasthan, and reported that field capacity, moisture equivalent and permanent wilting point were negatively correlated with sand fraction whereas field capacity was correlated with clay, moisture equivalent and wilting point. The above correlations were found to be non-significant with silt fraction.

Sharma *et al.* (1990) reported that available water was significantly and positively influenced by clay, silt, CEC and organic carbon while negatively correlated with sand and bulk density.

Radder and Daddamani (1994) studied the moisture characteristics of major soil series of Malaprabha command in Karnataka and found that moisture content at 33 kPa tension was generally twice the moisture held at 1500 kPa in all the black soils. The mixed black and red soils and the red soils did not hold this relationship. They also reported that available

water in black soils is more (33.03 cm m^{-1}) than in mixed black and red (21.95 cm m^{-1}) and red soils (16.9 cm m^{-1}).

Siderius (1994) reported that plant available water capacity increases from sandy soils to fine loamy textured soil. Similar conclusion was given by Yadav, *et al.* (1995) that derived soil climatic parameters *viz.* Plant available water capacity (PAWC), soil effective rainfall and the length of growing period (LGP) were directly associated with soil depth and clay content.

Singh and Nayak (1999) found that water retention at various suctions correlated negatively with sand and silt and positively with clay, organic carbon, EC and pH. At any given suction, magnitude of water retention followed the order vertic Halaquepts > Typic Halaquepts > Vertic Ustochrepts > Fluventic Ustochrepts > Fluventic Ustorthents > Typic Ustorthents. The available water capacity was categorised as high in Vertic Halaquepts, Typic Halaquepts and Vertic Ustochrepts, medium in Typic Ustochrepts and lower in Fluventic Ustochrepts, Typic Ustorthents and Fluventic Ustorthents. They also observed that there was wide variation in saturated hydraulic conductivity (K_s) of the soils, the highest was observed in Typic Ustorthents and the lowest in Vertic Halaquepts.

2.2.3 Chemical properties

Stevenson (1982) stated that organic carbon has an indirect effect on nutrient availability and act as major factor regulating availability of organic forms of N, P and S in soils.

Sharma *et al.* (1994) found low content of organic carbon in river valley soils. While Chakraborty *et al.* (1984) reported high content (up to 1.12%) in Surma and Brahmaputra Valley soils.

Essiet (1986) stated that there is strong correlation of organic carbon with total nitrogen, which shows that soil nitrogen is dependent on the mineralization of organic matter.

Khargarot and Mishra (1977) noticed abrupt decrease in organic carbon content with depth, in soils of Udaipur valley. However, surface horizons (Ap or A₁) contain sufficient organic carbon for their rating of soils having high organic carbon.

Ruhal and Deo (1979) examined the distribution of inorganic phosphorus fraction in Rajasthan soils and reported that the amount of total calcium, aluminium and iron phosphate declined with depth in all the soil profiles except the hilly soils where total calcium phosphate increased.

Total phosphorus was correlated positively and significantly with the soil pH and organic carbon.

Sidhu *et al.* (1994) observed that the highest organic carbon content was in the surface horizon, and decreased down the profile. In the same time they found that organic carbon on sand dunes was very low and decrease with depth was subtle, while in some of the flood plain soils, the organic carbon content irregularly decreased with depth indicating their stratified nature.

Singh and Ahuja (1990) studied the primary nutrients in soils of the Ghaggar river basin and reported that these soils were potentially deficient

in available N, had low to medium in P status and had adequate amounts of K to meet crop requirements. Available N decreased with depth but P and K showed irregular distribution patterns.

Subbha Rao and Sekhon (1990) investigated the distribution of potassium in acidic, non-calcareous alluvial, swell-shrink and red and lateritic soils. Available (NH_4OAC extractable) K increased with depth in acidic alluvial soils from eastern India but decreased with depth in calcareous alluvial soils from Bihar and Rajasthan. In calcareous alluvial soils of Indo-gangetic plains, available K was more in top soils (0-20 cm) than in subsurface layers (20-40 and 40-60 cm).

Pandey *et al.* (2000) studied different soil associations of district Kanpur in central Uttar Pradesh and found that availability of P, in general, was significantly and positively influenced by organic matter and finer soil particles. In Typic Ustifluvents, which had pH and EC in the range of 7.2 - 8.1 and 0.35 - 0.50 respectively, available P had significant positive relationship with pH and EC.

Franzmeier *et al.* (1990) found out the relationship of CEC to clay and organic matter contents. They reported that soil pH can be used to predict base saturation with moderate accuracy. The cation exchange capacity can also be predicted from soil texture and Munsell colour designation, which can be estimated in the field.

Manrique *et al.* (1991) worked out the regression analysis to examine the relationship between CEC and clay content, organic carbon and other soil properties. They further prepared multiple regression equations, which indicated that clay, organic carbon, and soil pH accounted for about

51 per cent of the variation in CEC for all soils. For soil orders like Alfisols, Inceptisols, Mollisols and Vertisols the clay and organic carbon accounted for up to 67 per cent of the variations in CEC and for Entisols and Spodosols upto 78 per cent of the variations in CEC. Poor prediction of CEC resulted from clay for Aridisols and vertisols indicating that factors other than clay interfered with accurate prediction of CEC.

Kudrat *et al.* (1995) studied the soil of Ajay catchment in West Bengal and reported that surface layers were acidic and acidity decreased with depth. Clay content increased gradually with depth and also reported that calcium was the dominant exchangeable cation followed by Mg, Na and K.

Gajbhiye *et al.* (1989) studied the variation of available K along toposequence. He observed that available K increased from escarpment (100-150 ppm) to alluvial plain (250-300 ppm). The variation in available K along a toposequence was attributed to change in factors like texture, intensity of surface erosion affected due to slope gradient, content of organic carbon and soil depth.

Pradeep Kumar *et al.* (1996) reported an irregular depth wise distribution of total and DTPA extractable Zn, Fe, Cu and Mn in Soan river valley soils.

Vijay Kumar *et al.* (1996) observed the highest amount of DTPA extractable Zn, Cu, Fe and Mn in surface layers of soil in Northern Telangana of Andhra Pradesh.

The vertical distribution of Zn, Mn, Cu and Fe in relation to depth and important soil properties were studied by Sangwan and Kuldeep

Singh (1973). They noted irregular trend in distribution of extractable Zn, Mn, Cu and Fe in relation to depth in profiles due to alluvial nature of soils and their weak pedogenic manifestation.

Sarkar *et al.* (2000) studied the soils of Kamala and Koshi alluvial plains, Madhuvani district, Bihar and found that the highest content of DTPA extractable Zn, Cu, Fe and Mn were in surface layer in almost all the soils. DTPA extractable Cu, Fe and Mn showed decreasing tendency with depth, while Zn did not show definite trend in its distribution throughout the profile.

Chatterji (1999) reported that available Fe and Cu were significantly and negatively correlated with pH whereas available Mn showed significant negative correlation with clay in different agro-ecological sub-regions of West Bengal.

Katyal and Sharma (1991) reported that the change in pH, lime, organic matter, clay fraction and soil moisture regime had strong influence on micronutrient distribution in Inceptisols.

2.2.2 Physico-chemical properties

Tiwari *et al.* (1989) investigated the salt affected soils of central alluvial region of Uttar Pradesh. The pH values were more than 8.5 with maximum of 10.3 due to the presence of relatively larger proportion of soluble sodium carbonate and bi-carbonate. The CaCO_3 in surface soil ranged from 0.68 to 3.83 per cent. Sodium was found to be dominant cation, while carbonate was the dominant anion followed by bi-carbonate, chloride and sulphate.

Tan (1989) stated that base saturation is a property closely related to CEC and found a positive correlation between per cent base saturation and soil pH.

The results of research done by Srivastava and Srivastava (1991) supplemented these findings. They found that CEC was positively and significantly correlated with pH and furthermore stated that CEC increased at a rate of $3.7 \text{ cmol(p}^+)\text{kg}^{-1}$ per unit increased in soil pH.

Sahu and Dash (1993) observed a general increase in CEC with increasing depth ranging from 4.3 to $16.7 \text{ cmol(p}^+)\text{kg}^{-1}$ in salt affected coastal soils of Astrange, Orissa. The pH and ESP also found to be followed the same trend.

Singh and Mishra (1996) reported that pH of alluvial soil of Gandak command area of Bihar, varied between 8.0 and 8.4 and showed increasing trend with depth, whereas EC showed a reverse trend in its distribution. The soils were highly base saturated and the cations in the exchange complex were in the order $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$.

Diwakar and Singh (1993) reported that the Tal Land soils of Bihar have both lime concretions and ferruginous nodules in varying proportion. Diwakar and Singh (1994) observed slightly alkaline reaction, low CEC and high base saturation in soils of Diara land occurring in alluvial fan and flood plains of Bihar.

Elahi *et al.* (1996) noticed low base saturation per cent in soils developed in Madhupur clay in Bangladesh. Ca^{2+} and Mg^{2+} are dominant cations in the profiles, which increase with increasing depth.

Khan (1976) reported that in soils of Burner valley, bicarbonate and chloride are the dominant cations. Soils were neutral to slightly acidic, excepting soils developed on calcareous parent material in the level plains.

Kaistha and Gupta (1993) studied the soil of subhumid temperate high land of the central Himalayas and reported that the soils ranged from 6.7 to 7.7 in pH and exchangeable Ca^{2+} as dominant cation followed by Mg^{2+} .

Gupta *et al.* (1989) observed the dominance of Ca^{2+} and Mg^{2+} with Na^+ being < 15 per cent of the CEC. The CEC varies with texture and organic carbon content of the soil.

2.3 Soil mineralogy

Tomar (1985) reported that two soil pedons of Indo-Gangetic alluvial plain showed inter stratification of smectite, illite and chlorite minerals in fine clay fraction. Discrete illite and small amounts of kaolinite were also observed.

In soils of Varanasi district of Uttar Pradesh developed on Gangetic alluvium located in different physiographic positions, illite was the dominant mineral constituent over 57 per cent of clay fraction of all soils except one in which smectite also occurred in considerable amount (Singh *et al.*, 1991).

Eghbal and Southard (1993) found that smectite was the major constituent of clay fraction in soils of Aridisols on dissected alluvial fans, in western Mojave Desert of California, while mica and kaolite were less abundant.

The preponderance of mica (illite), chlorite, vermiculite and kaolinite of some soils developed in alluvium of Himachal Pradesh were reported by Gupta and Tripathi (1992).

Adhikari and Si (1993) reported the presence of mica in association with minerals like kaolinite, smectite, vermiculite, chlorite and microcline with considerable amount of amorphous material in clay fractions of some Entisols of West Bengal.

Gupta *et al.* (1989) observed the dominance of mica in some alluvium derived soils of Jammu and Kashmir.

Aba Husayn *et al.* (1980) observed that in the alluvial soils developed on lower terrace areas in Saudi Arabia, smectite was the dominant clay mineral where as kaolinite was the most abundant in soils developed on well drained highland areas. Vermiculite, mica and chlorite were the other minerals present in clay fraction.

Sangwan *et al.* (1988) found in the soils of Haryana that mica (60-80%) was the dominant clay mineral followed by Kaolinite (15-20%). Smectite, chlorite, vermiculite, quartz, and feldspar were present in minor amounts (5-10%).

Goyal *et al.* (1990) reported that in some soils of southern part of Haryana, the dominant minerals were illite and smectite. The presence of varying amounts of chlorite, chloritised vermiculite, kaolinite, quartz, feldspar and intergrades of 2 and 3 mixed layer minerals i.e., illite - chlorite, chlorite-smectite, illite-chlorite-smectite and illite-vermiculite - chloritised smectite were also observed.

Genetically the clay minerals in “Tal land” soils developed on alluvium derived from rocks like granite- gneiss, mica-schist, quartzite etc. seen to be geogenic and also pedogenic. The formation of smectite appeared to be under basic environment, impeded drainage and water logged condition for a limited period. Mica was found to be derived from micaceous parent material and feldspar. A major portion of kaolinite has been inherited from parent materials. Some of the orthoclase appear to have weathered to kaolinite (Diwarkar and Singh, 1973).

Jassal *et al.* (2000) observed relatively higher content of quartz and K-feldspar in the soils on upper terrace slopes than those soils on the lower terrace slopes due to textural difference.

Karache *et al.* (1999) reported unstable minerals in the heavy sand fraction of soils from the humid tropical region of peninsular India. The abundance of unstable minerals *viz.*, pyroxene, hornblende, and biotite are derived from nearby granitic gneisses and schists upon weathering.

2.4 Soil classification

Classification is the grouping of objects in some orderly and logical manner into compartments. It is based on the properties of objects for the purpose of studying, and identifying them. The properties are selected in accordance with the purpose of classification (Sehgal, 1996).

Gupta and Tripathi (1993) classified three rice soils and two adjacent vergin soils from north-western Himalayas as Ustic Endochrepts, Typic Haplumberts, Typic Endochrepts and Fluvaquentic Humaquepts. Toposequently, Singh *et al.* (1993) classified the soils of central Himalayas

as Typic Palendalfs (upland), Typic Hapludalfs (mid-land) and Typic Psammaquents (low land).

Diwakar and Singh (1994) classified the sedentary as well as old alluvial soils in Bihar into Udorthentic chromusterts because of presence of wide and deep cracks and sometimes gilgai micro relief on the surface.

The toposequence of alluvial fan of the Gandak command area of Bihar were classified by Singh and Mishra (1996) into Typic Ustorthents, Typic Eutrochrepts, Typic Haplustalfs and Typic Hapludalfs.

Sharma *et al.* (1994a) identified eight soil series in the Soan river valley and grouped them into Typic Ustipsamments, Typic Ustifluvents, Typic Ustochrepts and Fluventic Ustochrepts.

Walia and Rao (1996) classified some red soils in Bundelkhand region of Uttar Pradesh as Typic Ustochrepts, Dystric Ustochrepts, Ultic Haplustalfs and Udic Ustochrepts.

Singh *et al.* (1989) classified the soils of alluvial pedogenic complex of Varanasi district, UP, into Typic Ustifluvents, Vertic Ustochrepts, Fluventic Ustochrepts, Aquic and Udic Haplustalfs and Aeris Ochraqualfs.

Bhaskar and Nagaraju (1998) classified some salt affected soils of Chitravathi river basin in Andhra Pradesh occurring on a piedmont slope as Vertic Ustrophepts and Fluventic Ustrophepts and soils on basin floor as Sodic Haplusterts.

Qureshi *et al.* (1996) classified the saline and sodic soils in Bharatpur, Rajasthan, into Typic Haplustalfs, Typic Natrustalfs and Aquic Natrustalfs.

The soils of Dungarpur district, Rajasthan, were classified by Shyampura *et al.* (1993) into four different orders *viz.*, Entisols, Alfisols, Inceptisols and Mollisols. Whereas some soils of Haldi Ghati region, Rajasthan, were classified into Typic Ustorthents, Typic Ustochrepts and Typic Ustifluvents at sub group level by Sharma *et al.* (1999).

2.5 Land evaluation

Land evaluation is the assessment of the land suitability and performance for any use in culture, forestry, engineering, hydrology, regional planning, recreation etc. As such it provides a rational basis for taking land use decisions based on analysis of relations between land use and land, giving estimates of required input and projected output (FAO, 1983).

There are different methods of land estimation *viz.*, USDA land capability classification (Klingebiet and Montgomery, 1961) USBR irrigation suitability system, parametric methods for general purpose (Requier *et al.*, 1970) and the FAO frame work for land evaluation (FAO, 1976).

2.5.1 Soil-site characteristics and plant relationship

Khattar *et al.* (1988) reported that the soil characteristics such as local elevation, slope, soil drainage, profile depth, soil texture, calcium carbonate content, gravel content, soil structure, salinity and alkalinity of soils, are the limiting factors for agricultural production.

Gajbhiye and Deshmukh (1992) studied the crop response in relation to soil and site characteristics and reported that soil depth, clay content,

calcareousness and soil reaction appeared to be most striking factors influencing the crop response.

Khadse and Gaikawad (1995) evaluated yield influencing factors for different crops and reported that available water capacity appeared the most yield influencing factor followed by CEC, clay content, depth and CaCO_3 content for Sorghum, AWC and clay content for cotton and clay content followed by AWC, CEC, depth and CaCO_3 for soybean.

Bhushan and Sharma (1999) reported that the root mass density (RMD) of wheat decreased by about 20% with every 0.1 Mg m^{-3} increase in bulk density above a value of 1.36 Mg m^{-3} .

Root mass increased progressively and significantly with the increase in root-zone depth from 0.05 to 0.30 m, but decreased with the improvement in aeration status of root-zone but not in the same proportion and direction as the root growth. Hence shoot/root ratio responded differently to root zone parameter under study. Grain and straw yields of wheat increased with root-zone depth, straw yield increased almost twice as the grain yield with every 0.05 m increase in root-zone depth. Aeration status affected the grain yield, but not the straw yield.

Ahu *et al.* (1986) reported the optimum levels of soil chemical constituents for maximum paddy yield and suggested that the highest rice yields were obtained in soils having pH 6.0-6.5, 183 ppm available P, 0.40 meq/100g exchangeable K, 7.5 meq/100g exchangeable Ca, 180 ppm available Si and 18 per cent clay.

Dry matter of the rice root and grain yield were significantly higher in clay loam than in loam or sandy loam soils which may be due to its greater nutrient supplying capacity (Sharma *et al.*, 1990).

Rondal (1991) determined the variables significantly affecting the growth and development of rice by using correlation and regression analysis and reported that soil texture, CEC, soil depth, soil drainage, stoniness and relief are the significant variables affecting the rice yield.

Sharma *et al.* (1994) found that rice yield was highest in the moderately well drained, deep fine textured soils with Cambic or Argillic Horizon.

Yadav *et al.* (1999) studied soil and site characteristics in relation to yield of cotton in Vidharba region of Maharashtra. The soils site was situated in elevation of range between 465 m above msl on the summit and 320 m above msl on the valley floor. The results showed that elevation and coarse fragment did not affect the yield significantly. However, their impact was negative on the yield. The depth, clay content, PAWC and CEC significantly increased the cotton yield whereas influence of slope was observed to be negative. Furthermore, they observed that there was significant difference in cotton yield in different soils. The very fine, montmorillonitic hyperthermic Haplustepts occurring on interfluvial crest produced higher cotton yield followed by moderately well drained Typic Haplustepts of valley floor soils. The clayey lithic Ustorthents of foot slope recorded the lowest yield.

2.5.2 Soil-site suitability classification

USDA land capability classification is based on the measurements of permanent physical characteristics of the land but it does not specifically take into consideration the requirements of different kinds of land use, management levels or economics, although assumption about these are implicit.

According to FAO (1976), Land suitability classification system is the fitness of a given type of land for a defined use. The FAO soil evaluation system considers a quantitative and qualitative classification and recommends making choice between both methods according to data available. It also refers to current and potential suitability classification with the procedure as follows: (i) collection of the necessary characteristics or land qualities, (ii) determination of the land utilization requirements and (iii) matching land characteristics or land qualities with land utilization requirements.

The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. However, suitability evaluation does not necessarily identify a single form use as “best” on each land unit. Suitability class limits are defined separately for each use. Thus a particular land mapping unit might be classified as S1 for forestry and S3 for arable farming, but this does not necessarily mean that the former use will be selected (FAO, 1976).

Sehgal (1991) applied the FAO land suitability approach to the soils of Khapri watershed and found that the soil site criteria considered for suitability classes were applicable under comparable situation.

Sidhu *et al.* (1989) evaluated Vertisols and associated soils in Jalgaon district of Maharashtra for banana cultivation and found that soils of Dhupa series on the piedmont plain were suitable, while Chahardi, Bhod and Khadki series developed over piedmont plain were marginally suitable and the Bhovad series on table land were unsuitable

Vadivelu and Sys (1993) evaluated the soils of Ahmednagar district and concluded that the soils of the Sindudi, Torkewadi, Pargaon and Dargaon series are marginally suitable for growing sorghum on the basis of rating of limitation characteristics, but on the basis of the parametric method these soils are unsuitable for sorghum. Topography, depth and coarse fragments are the major limitations.

Bhaskar *et al.* (1993) reported that deeper soils of Saongi catchment, Nagpur, were highly suitable for sorghum, cotton and wheat and the shallower soils were marginally suitable or not suitable. The ranking of suitability followed the given sequence: Udic Ustochrepts > Typic Chromustepts > Typic Ustochrepts > Lithic Ustochrepts > Lithic Ustorthents. Gabour *et al.* (1994) carried out land suitability classification of El-Katta farm, Giza Governorate, Egypt. The results showed that the Typic Quartzipsamments were very suitable for carrot, potatoes and groundnuts, moderately suitable for beans, sunflowers, watermelons, tomatoes and millets and marginally suitable for wheat, maize, sorghum, onions, citrus, olives, figs, grapes and trifolium.

Das *et al.* (1997) examined the soils of Nadia, Murshidabad and Birbhum districts of West Bengal for their suitability for sugarcane cultivation and reported that soils occurring in comparatively lower landforms (Aeric Endoaquepts and Vertic Ochraqualfs) and in rugged

topography (Lithic Ustochrepts and Rhodic PaleustalFs) were marginally suitable and currently not suitable, while soils occurring on nearly level to gently sloping landform (Typic Ustochrepts, Typic HaplustalFs and Typic Ustifluvents) were moderately to highly suitable.

Vadivelu *et al.* (1983) and Bhattacharya *et al.* (1989) observed that geomorphic unit influences land use pattern through their influence on soil-site and climatic characteristics. The hill ranges with shallow soils were mostly under forest with patches of rainfed crops, the pediment surfaces with shallow to deep soils were cultivated to sorghum, pearl millet and safflower and the soils occurring on piedmont plain and the flood plain were very deep and cultivated to sorghum, cotton and safflower under rainfed condition.

Tamgadge *et al.* (1986) observed that the yield obtained from different types of soils at subgroup levels varied considerably. For wheat maximum yield was recorded from Udic Chromusterts followed by Entic Chromusterts = Typic Chromusterts > Typic Ustorthents > Vertic Ustochrepts > Lithic Ustorthents. Hajare *et al.* (1990) reported that the higher yield realisation in Typic Chromusterts and Vertic Ustochrepts over Lithic Ustorthents could be attributed to sufficiently deep solum to provide higher soil volume for nutrient and water extraction than Lithic Ustorthents. Available water capacity as well as total volume of water in the solum in former soils is higher as compared to Lithic Ustorthents

Gaikawad and Bhaskar (1988) concluded that under scientific management practices, sorghum in Typic Ustochrepts and cotton in Typic Chromusterts are highly suitable.

Anil *et al.* (1998) evaluated soil site suitability of Wunna catchment near Nagpur for major agricultural crops. They reported that Entisols which are dominant on the hill top were marginally suitable for sorghum but unsuitable for pigeon pea, while Vertisols which are dominant on toe and concave slopes of basaltic transect were very suitable for cotton, sorghum and pigeon pea. Inceptisols occurring on the toe slopes of sandstone transect were marginally suitable for sorghum and unsuitable for pigeon pea.

Tamgadge *et al.* (1999) classified the suitability of soils of Madhya Pradesh. They reported that only 12.22% of the total area is highly suitable followed by 29.51 and 9.73% moderately and marginally suitable for rice crop. For wheat, gram and cotton, the highly and moderately suitable land constitute about 12 and 5% each, respectively, but for soybean the suitability is higher (20.9 per cent moderately suitable).

Chary *et al.* (1995) studied the soils at Shesnagar, Nagpur district and reported that Typic Ustochrepts were marginally suitable for cotton, moderately suitable for sorghum, groundnut and pigeon pea. Typic Ustorthents were marginally suitable for these crops whereas Lithic Ustorthents were potentially suitable for cotton, groundnut and pigeon pea.

Singh and Mishra (1996) attempted land suitability classification of soil in a toposequence of alluvial fan of the Gandak command area of Bihar and reported that Entisols were suitable for maize, wheat and rice whereas Inceptisols were suitable for wheat and maize and moderately suitable for rice. Alfisols are suitable for rice, and moderately suitable for both wheat and maize.

2.6 Land degradation - concept and definition

The term land refers not just of soil, but to all natural resources, which contribute to agricultural production. Land degradation is a complex process in which several factors may be contributing to the loss of productivity. Land degradation is a function not only of factors of natural environments but also of land use and management.

Land Degradation is the temporary or permanent lowering of the productive capacity of land (UNEP, 1992b). Previously land degradation was recognized as a desertification processes (UNEP, 1977). Recent UNEP conference has been defined the term of desertification with a more restricted meaning.

Soil degradation is defined as a process, which lowers the current and/or the potential capability of soil to produce (quantitatively and/or qualitatively) goods or services (FAO, 1979). Soil degradation is defined as a process, which lowers the current and/or future capacity of the soils to produce goods or services (Oldeman, 1994, 1993).

In 1997, an International task force on land degradation noted that; Land degradation is a universal problem and not merely an agricultural problem but has ramifications in all aspects of society. Land degradation either natural or induced by humans is a continuous process. It has become, however, an important concern affecting the wealth of nations and food security, and impact on the livelihood of every person on earth. Food security is directly related to the ability of land to support population. The united Nations Conference on Environmental and Development (UNCED, 1992) held on Rio De Janeiro, Brazil focused the world attention

on the harmful impacts of development on the Earth's life supporting system.

Pressures on land are rapidly increasing due to ever increasing population competing for the finite land and water resources. Further, there is a systematic decrease in the quantity and quality of arable land due to the incipient process of land degradation (Sharma *et al.*, 2000). Lands are an essential means of production, which cannot be replaced if it is degraded or destroyed (Grewal and Dogra, 2000).

The continuous degradation of production base and imbalance in soil - water - plant, human- animal systems is leading to ecological imbalance and economic insecurity. Scarcity of arable land and decrease in per capita arable land area are attributed to many factors including population growth, urbanization, soil contamination and industrial pollution and soil degradation.

While the arable land is decreasing, demand for food and other agricultural products are rapidly increasing (Lal, 1997). Although soil degradation is recognized as a serious and widespread problem, its geographical distribution and the total areas being affected is very roughly known (Oldeman, 1994).

The total loss of land through soil degradation is about 2 billion hectare, while the present arable land of the world is around 1.5 billion hectare (Dhruva Narayana *et al.*, 1997). Over 300 million hectare, about the size of India, is degraded to such an extent that restoration to its original productivity can be achieved only through major investment (Oldeman, *et al.*, 1990).

The annual loss of productive lands of the whole world is about 5 to 7 million-hectare and shows an increasing trend (Dhruva Narayana *et al.*, 1997).

2.6.1 Processes and causes of soil degradation

The processes leading to soil degradation are generally triggered by the intense and increased pressure on land and water resources to meet the competing demands of the rapidly growing population for food, fibre, fuel and fodder. This lead to over exploitation and degradation of natural resources and to a partial or complete loss of the productive capacity of the soil with little consideration to maintain the eco-balance. Various anthropogenic activities, such as the introduction of large scale irrigation canals, deforestation, lead to accelerated soil degradation through salinization, flooding, drought, erosion, water-logging, etc. These processes, in turn, reduce agricultural productivity leading to social insecurity and political instability. The effects of degradation processes on the overall global environment resulting from emission of green house gases into the atmosphere, through alteration of water and energy balances, are a matter of serious concern to the global scientific community. Soil degradation is the single most destructive force diminishing the world's soil resource base and the continued degradation of productive lands is a clear threat to the survival of the human race (Sehgal & Abrol, 1994).

The interaction among the density of population, economic conditions and locality specific factors are affecting the process of land degradation.

Oldeman, L.R. (2000) reported that Overgrazing of the pastureland, mismanagement of the agricultural land, and deforestation of the forest

and woodlands are the major causes of soil degradation. Overgrazing is of particular importance in Africa and West Asia; deforestation is of serious concern in South East Asia and South America, while agricultural practices have affected the soils negatively on all continents, but particularly in large areas in South East Asia and Africa. Overexploitation of the vegetative cover is mainly a problem in West Asia and Africa. Industrial activities are of obvious importance in Europe.

Koohafkan (2000) reported that activities directly related to agriculture represent a significant factor in all human-induced land degradation in all regions except Australia. Human activities, particularly in agriculture, appear to be a major cause of land degradation.

Overexploitation of forest, other woodland area, and trees and shrubs, are the other causes of land degradation. Land degradation is also caused by selective overgrazing of grasses, shrubs and herbs.

In addition to the direct human-induced causes of land degradation, annual rainfall and rainfall-evaporation ratios are the most important micro-climatic variables affecting the lowering of the water-table, which is associated with intensive agricultural, urban and bio-industrial land use. Soil texture, hydrology, and topography play a crucial role in wind and water.

2.6.2 Impact of land degradation

Erenstein (1999) reported while most experts agree that land degradation incur costs, the magnitude of those costs is widely debated. One particular controversy revolves around the relative importance of on-site as compared to off-site costs. Land degradation and its impact on

productivity are highly variable from place to place, making generalization both difficult and controversial (Koochafkan, 2000).

Tiwari (1998) reported that in Nepal, available information on crop yield in the mountains and hills over a 25- years period (1970-1995) showed continuously declining trends of major crops such as paddy, maize and millet with loss in the productivity estimated at 17.2, 17 and 9.5% in the mountains, and 12.7, 21.7 and 8.8% in the hills respectively over this period. The total cost estimated using the productivity loss approach ranged from NRs. 395 million in 1984-85 to NRs. 283 million in 1995-96. This loss ranged from 0.89% of GDP in 1984-85 to 0.37% in 1995-96 with an average loss of 0.55% per year.

In South Africa the on-farm and off-farm, external costs of various forms of land degradation were estimated at 13% of net agriculture GDP (Winpenny, 1995). In Burkina Faso (Brown, 1994), loss of crops, livestock and fuel wood from the increased land degradation was estimated at 8.8% of GDP.

Adepteu (1994) cited in Badejo (1995) reported that continuous cultivation in the rainforest zone of Nigeria has led to decline in soil organic matter from 3.8 to 1.6% within a period of seven years. The maize yield decreased from 2.84 to 2.12 t/ha and after 18 years, the maize yield had gone down to 1.70 t/ha.

Aflsen *et al.* (1996) observed the decline in soil productivity as a result of soil erosion to be in the range of 1.2 to 2.4% in Nicaragua. The loss of productivity in cotton cultivated areas was 6.8% in 1987, 7% in 1988 and 5% in 1989 in Argentina (Pimentel *et al.*, 1995).

Redman (1977) estimated the cost of soil erosion in the United Kingdom to be 23.8 to 50.9 million pounds per year. In the United States the cost of soil erosion including impacts on the associated industry was estimated to be US \$ 4.0 thousand million for 1992 (Hrubovack, 1999).

2.6.3 Extent of land degradation

2.6.3.1 Global extent of land degradation

The global land degradation is estimated (UNEP, 1997) as 1964.4 million ha of which 38% is classified as light, 46% as moderate, 15% as strong and the remaining 0.5% as extremely degraded. As a regional percentage of global land degradation, Asia has the highest (38%) followed by Africa (25%), South America (12%), Europe (11%), North America (8%) and Australia (5%).

Some 16% of total global land area was estimated to be under risk of soil erosion (Bot *et al.*, 1999). Between 1980-1990 the global forest area has decreased by 180 million ha and from 1990 to 1995 by 56.3 million ha (FAO, 1999).

Koohafkan (2000) reported that available information shows that about 26% of total wetlands had been lost due to intensive agriculture in the past.

Scott (1993) reported the loss of wetland in Indonesia by 31%, in China by 13% and in Thailand by 22%.

Although on a global scale the proportion of agricultural land suffering from salinization is small, the problem is very serious at the national level. It is mainly a problem in semi-arid countries with 10-50%

of the irrigated areas affected, and average yield decrease of 10-25% are recorded for many crops (Umali, 1993).

Oldeman, L.R. (2000) reported that the summation of the surface areas of all GLASOD mapped units leads to a total land area of 130013 million ha, which compares favorably with FAO's estimate of 13069 Million ha. Human-induced soil degradation worldwide has affected 1965 Mha or 15% of the total land area. The total land area however includes large portions of the earth that are not influenced by men. A more realistic figure would be to consider the total area under agriculture, permanent pasture and under forest and woodland. These are the areas that are most likely affected by human-induced soil degradation. Based on FAO statistics this land surfaces is around 8735 M ha, of which 22% is degraded as a result of human intervention. Water erosion is the most important type of soil degradation (55%) followed by wind erosion (28%), nutrient decline (7%), Salinization (4%) and compaction (3%). In all continents water erosion is the most important type of soil degradation, except for West Asia and Africa, where water and wind erosion are of almost equal importance. In South America nutrient decline is more important than wind erosion. Almost 50% of the land that is affected by salinization is located in West Asia, while it occupies almost equal areas in South East Asia and Africa. Compaction is a major type of soil degradation in Europe (50% of the compacted soils worldwide). Although pollution is worldwide a type of soil degradation occupying only 22 Mha, it is important to note that 19 Mha of these polluted soils are located in Europe. Over 300 Mha globally, about the size of India, is degraded to such an extent that restoration to its original productivity can only be

achieved through major investments. This terrain has virtually lost its productive capacity. Around 40% of this strongly degraded land is located in Africa, while 25% is found in South East Asia and 20% in Africa.

2.6.3.2 Extent of soil degradation in India

Shamsher Singh *et al.* (2000) reported the extent of soil degradation in India has been assessed by various agencies. The estimates of these agencies vary widely, probably due to different approaches in defining degraded soils and adopting various criteria for delineation. All statistics available on degraded lands are either estimated or generalized information derived either using Remote Sensing Technique or GLASOD technique on very small scale. They vary widely in a nomenclature in recognizing different types of degraded lands and scale of mapping.

Soil degradation map of India scale of 1: 4.4 million was published on 1994 by NBSS & LUP (Sehgal & Abrol, 1994). It was estimated that an area of about 187 M ha (57%) of the total geographical area of India (329 M ha) is affected by various soil degradation problems, induced largely by human intervention. Water erosion is the major problem covers about 148 M ha (45%). Wind erosion is dominant in the western regions, covering 13.5 M ha (4.5%). Chemical deterioration is observed in 13.8 M ha (4.2%) with salinization occurring in 10.1 M ha. Physical deterioration, mainly water logging is observed in 11.6 M ha (3.5%) of the total area. The degree of land degradation, however, varies from slight to extreme; depending on the slope, vegetation canopy, aspect, topographic position, wind speed, velocity of rainfall etc. The dominant degree is moderate, which covered about 138 M ha. The dominant degraded area of India is under severity class "high" followed by class "medium" and a "very

high". The area under "low" class is minimum.

Sexana and Pofali (1999) prepared physiography map of India and assessed land degradation problems. They identified four physiographic regions and twenty physiographic sub-regions.

They concluded that 182.03 M ha is affected by various degradational problems. Water erosion is the major problem causing loss of topsoil and terrain deformation in 141.33 M ha representing 43 per cent of the total geographic area. Wind erosion, mostly dominated in western region, accounts for an area of 11.50 M ha (3.49%) of total geographical area. The physical degradation due to water logging and flooding affects 12.63 M ha (3.84%), chemical deterioration due to loss of nutrient and salinization was observed in 13.24 M ha (4.02%) of total geographical area.

According to department of Agriculture and Co-operation (Natural Resource Management Division), 173.64 M ha land is under problematic area. Another 40.00 M ha is flood prone. On an average 8 M ha land is affected by floods. Gullies and ravinous area occupy 3.98 M ha land. These are the lands, which are seriously degraded due to water erosion (Annon. 2000).

Wasteland Atlas of India (Annonymous, 2000) was prepared by Ministry of Rural Development, Department of Land Resources in Collaboration with National Remote Sensing Agency. A wasteland is described as "degraded land which can be brought under vegetative cover with reasonable efforts and which is currently under-utilized and land which is deteriorating for lack of appropriate soil and water management or on account of natural causes. Wasteland can result from inherent/

or on account of natural causes. Wasteland can result from inherent/imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints". About 64 M ha (20%) of total geographical area is under various categories of wastelands.

2.6.4 Assessment of soil degradation

Since soil degradation is already so widespread, there is an urgent need to conserve the productive soil remaining, and to prevent the spread of soil degradation to areas not yet affected. Only when the seriousness of the problems is recognized, and their causes properly identified, it is possible to develop agricultural practices and to design and apply conservation measures that will ensure safe use of the land. A range of methods can contribute to the assessment of soil degradation, of which the most important are direct observations and measurements [FAO, GLASOD, ASSOD] and remote sensing and GIS techniques.

A simplified approach was developed by the working group on Global Assessment of Soil Degradation (GLASOD) to assess soil degradation (Sehgal, 1996). GLASOD estimated that about 22% of the world's land area is affected by human-induced soil degradation. Water erosion is the dominant type of degradation (55%) followed by wind erosion (25%), nutrient decline (7%), Salinization (4%) and compaction (3%). Overgrazing of the pastureland, mismanagement of the agricultural land and deforestation of the forest and woodland are the major causes of soil degradation.

Human-induced soil Degradation Assessment for South and Southeast Asia (ASSOD) is a modification of GLASOD. The concepts used

in ASSOD have a more objective cartographic base, using the internationally endorsed SOTER approach and employing GIS (Oldeman & Van Lynden, 1997). The ASSOD results show a wider variance of degradation types in comparison with the GLASOD map for the same region. Water erosion still is the most widespread degradation type while agriculture and deforestation being reported as the main causative factors. Second in importance is chemical deterioration (mostly fertility decline), chiefly caused by bad agricultural practices (Oldman and Van Lynden, 1997).

2.7 Application of remote sensing and GIS techniques in land degradation Assessment

Remote sensing capabilities and their application for detecting land degradation has been explored since long time before and were extended more recently. Soil parameters, influenced by land degradation, proved to be detectable using numerical analysis of remotely sensed data (Baumgardner *et al.*, 1985).

Interpretation of satellite images can be effective technique for mapping and providing data for assessment of land degradation at small scales. It will be more useful if it is implemented with ground checks and thematic information, particularly where physiography is inconspicuous. Ground testing and feed back from users of the degradation assessment methodology is vital to the evaluation and improvement of the role of remote sensing in soil degradation evaluation (Edige and Petersen, 1997).

Present day remote sensing satellite supplies digital data with respect to the reflected solar radiation, in bands, which are specific to each satellite. Digital number (D.N) values vary accordingly. Shades of gray vary from 0 - 256. 0 indicates black whereas 256 as white. If sunlight is

completely absorbed, sensor will record zero D.N. value. Sand dunes, salt affected soils, ice covered surface (which come under degraded land) show brighter near 256 D.N. values. In waterlogged areas, D.N. value approaches to zero. In most of the cases, digital form of the satellite data is gaining importance. Digital image processing involves the manipulation and interpretation of the digital satellite data with the aid of a computer, involving procedures, which can be mathematically complex.

The pixel wise data representing consequent ground segments are fed to the computer. Through specific digital image processing software, computers help in simulating a pictorial view of the area. Since basic data is in digital form, it is possible to systematically manipulate the data through various mathematical equations - such that the derived output image gives a better visual picture about the areas degraded.

The most common data for land use analysis is satellite data. They became very popular in recent years because of their better spatial and spectral resolution and their capacity to generate multi-temporal products more cheaply than aerial photos. Besides that, land suitability analysis needs thematic maps such as soil, slope and rainfall maps. Data on crop rotation, agricultural statistics and socio-economic conditions also provide valuable background information. (Harahsheh, 1994)

The interpretation of remotely sensed data is based on the knowledge of properties and behavior of electromagnetic radiation (Edige Nizeuimana & Peterson, 1997).

In order to meet the increasing information needs of resource managers, remote sensing as well as the related technologies of digital

image processing, Global Positioning System (GPS) and Geographical Information System (GIS), will be continually depended upon to help manage and protect natural resources.

The multisensor approach has proved its capability to identify the source of pollution, accurately determine the location, extent and type of pollution. The global availability of the mobile communication further enhances our capability by enabling us to quickly locate disaster stricken groups. The utility of remote sensing has found operational application in Environmental Impact Assessment (EIA) *etc.* (Roy, Per. Comm.).

A case study was carried out by M. Elayarajan *et al.* (1999). In upper Polar-Maninuthar watershed covering an area of 29,119 ha in parts of Maduari, Dindigal, Sivaganga districts with the objective of soil map preparation in 1:50,000 scale with characterization and classification, delineation and categorization of degraded lands by employing remote sensing techniques. Satellite data (Landsat STM Geocoded FCC on 1:50,000 scale) corresponding to the Survey of India (SOI) Toposheet 58J/8 employed for the study. Eleven soil series with different morphological, physical and chemical properties were identified. The soils were grouped under Entisols, Inceptisols and Alfisols. The kind, degree, extent and consecutive factors of land degradation were investigated during ground truth collection. Four kinds of land degradation were found to occur in the study area. They included land degradation due to water erosion (6.766 ha), soil fertility and organic matter decline (0.170 ha), alkalization / salinization (6.838 ha) and soil compaction (1.70 ha). The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) has completed the soil resource mapping of different States of the country. The maps of 13

states have been prepared at a scale of 1:2,50,000 and printed at a scale of 1:5,00,000 (Velayutham, 1997).

In the state of Tamil Nadu (India), Elayarajan *et al.* (1994) also used Landsat STM Geocoded FCC on 1: 50,000 scale to study the kind, degree, extent and causative factors of land degradation. They identified four kinds of land degradation, which were land degradation due to water erosion, soil fertility and organic matter decline, alkalisations / salinization and soil compaction. Between 1986 and 1998 a soil mapping project for the states on 1:2,50,000 scale and for the country on 1:1 million scale was taken up in India by NBSS& LUP and by 2000 printing of the maps for all the states has been completed. In this exercise, 310 toposheets and 170 TM satellite imageries were used. A total of 74,400 soil profiles were studied and 99,250 soil samples were collected and analysed. The USDA soil Taxonomy has been followed with units at the level of family association (Velayutham, 2000).

Nair *et al.* (1996) used geographical information system, a tool for input, storage, analysis and display of spatial data to prepare a digital soil map of Kerala. Soil and land characteristics were organised as relational tables using general-purpose database management software. Data created included digital soil map, relational tables for site characteristics, morphology and relevant properties of the soil. A subset of database was presented with outputs like basic soil map, various thematic maps generated through reclassification and land evaluation for some specified uses.

Saini *et al.* (1999) assessed land degradation in Purulia district, West Bengal using remote sensing techniques. Analysis of satellite data (False Colour Composite in 1:50,000 scale) was carried out visually with

subsequent ground verification and translation of image interpretation units into various categories of degraded lands.

The results indicate that 31.8 per cent area of the district suffers from one or the other kind of land degradation. Water induced soil erosion is the major problem which accounts for 31.3 per cent area of the district. Land degradation due to waterlogging is limited to only 0.3 per cent area whereas 0.2 per cent area is degraded due to rock quarries, brick kiln and industrial effluents.

Gupta *et al.* (1998) studied the land degradation in Palamau district of Bihar using remotely sensed data (IRS-IA, FCC, on 1:50,000 scale). It was observed that water erosion is the main cause of land degradation affecting 6.27 per cent of district, of which 5.22 per cent is subjected to severe to very severe erosion and remaining 1.05 per cent is moderately to severely gullied land. Degradation due to rock quarries, mine spoils and dumps accounted for only 0.01 per cent of the district area. Degraded lands were mostly confined to agricultural areas (4.76%) followed by forestlands (1.10%) and open-scrub/pastures (0.42%), respectively. Sub-division-wise categorization of degraded lands was also attempted for efficient location-specific reclamation planning and easy monitoring.

Mandal *et al.* (2001) studied and mapped waterlogged areas and salt affected soils in the IGNP command area. Visual interpretation of IRS LISS-II data authenticated by ground truth was carried out for detection of waterlogged areas and characterization of salt-affected soils. The deep blue tone depicting surface ponding (stagnant ponded zone) resulted from the seepage and accumulation of irrigation water through the coarse sandy mass. Such units were mostly confined to the localized low-lying

areas. This data have also revealed that interdunal seepage lake within the buried paleo-channel of Saraswati possibly due to submerging of excess Ghaggar floodwater. Flood irrigation, sandy soils, cultivation of high water requirement crops and presence of hard gypsiferous pans in the shallow depth were responsible for development of waterlogged condition in the area. The gray to yellowish white patch around the waterlogging features represented surface salt efflorescence. The gray to grayish red represented the potential waterlogging zone. Based on the analytical data, soils were characterized as moderate to highly saline and showed the presence of significant amount of CaCO_3 (<2 mm) throughout the solum. The chemical analysis of water samples revealed the presence of high to very high quantity of soluble salt dominated by chlorides and sulfates of sodium, calcium and magnesium. Sharma *et al.* (1994) reported that crop discrimination is a basic requirement for acreage estimation and yield prediction by satellite remote sensing.

Studies were carried out in Sultanpur (Gurgaon, Haryana, India) to find out the utility of IRS I LISS II satellite data in delineation of salt affected soils, differentiation of crops grown in these soils and the effect of various soil and management factors on crop growth. Delineation of the saline and sodic soil by Maximum likelihood classification (MXL) of IRS LISS II data obtained for saline soils were differentiated from normal soils devoid of vegetation. The sodic and saline soils were, differentiated from normal soils with an overall accuracy of 78.2%. Under cropped conditions, during January, the MXL classifier could differentiate wheat, mustard, tree plantation and waste lands with classification accuracies of 74, 68.7, 87.1 and 97.0 respectively. Inclusion of additional classes *viz.*, early and

late sown wheat, irrigated and unirrigated mustard improved the classification accuracies of wheat and mustard to 77.2 and 81.2%. The poor growth of wheat and mustard attributed to salinity, irrigation and varying dates of sowing. These factors could explain 81% of the variability in Normalized Difference Vegetation Index (NDVI) values under wheat cropped conditions. With regard to mustard, salinity is the major contributor to the differences in NDVI.

Wasteland mapping in Punjab (India) using remote sensing techniques were studied by Chopra *et al.* (1994). They reported the water logged or marshy lands are distinctly seen in light to medium blue tone of varying sizes and shapes in the image. In these areas, ground water level is high especially during monsoon/post monsoon months. Poor drainage, shallow ground water level and poor soil physical condition have rendered these patches as wasteland.

Salt affected patches appear in different tones on FCC in different geographical situations. As these can be identified with white tone in alluvial plains where as it has light bluish tinge near canals. The severely salt affected soils are generally found in low-lying areas within alluvial plain. The saline-sodic soils are the result of fluctuating ground water table, prolonged use of poor quality irrigation water and flooding. This category is mostly barren and wherever cultivated, yields much below their potential capacity.

Tripathi *et al.* (1997) studied the spatial modeling of soil alkalinity in GIS Environment using IRS data and reported that in order to enhance the saline zones and suppressing the vegetation, two indices namely, Salinity Index (SI) and Normalized Difference Salinity Index (NDSI) is

proposed. SI is the ratio of red band to near infrared (NIR) band while NDSI is the ratio of the difference of the red to NIR and divided by the summation of the two. This concept has emerged from the red edge concept for vegetation vigor mapping. In red edge concept, the spectral reflectance of NIR is ratioed with red band, which gives very high values for vegetation than other features on Earth. Here if the inverse is considered then for vegetation low values will be obtained thus suppressing the vegetation and highlighting the soil. SI and NDSI are computed as follows:

$$SI = (Band3/Band4), NDSI = [(Band3-Band4)/(Band3+Band4)]$$

These are found useful than individual bands particularly in emphasizing saline soil regions.

Empirical models for soil reflectance (SR), alkalinity and NDSI *vs.* alkalinity habitat has been prepared using regression analysis:

$$\text{Alkalinity (mg/L)} = a\rho^2 + b\rho + c$$

Where a , b , c are regression coefficients and ρ is the spectral reflectance / salinity index / normalized difference salinity index. It has been observed that empirical model of spectral reflectance using band 3 *vs.* alkalinity habitat has offered a high degree of correlation, for April 1993 images. The empirical models for SI *vs.* alkalinity and for NDSI *vs.* alkalinity on similar pattern have been developed. These empirical models have been applied on the complete area, which enhanced some new areas of high salinity and the same has been confirmed from selected field verification. The similar type of empirical models are generated for November 1992 image for observing the change in alkalinity level but it

offered lesser coefficient of correlation for band 3 and for SI respectively. The NDSI model offered poor correlation for November 1992 image and it has not been considered. The reason for the decrease in the alkalinity in November period is just because of dilution of salt from the top cover of the soil due to rain. Due to these top few centimeters of the earth crust is devoid of the salt, farmers have been able to grow paddy. In November the paddy crop is prolific and offers lesser scope to record soil signatures through satellite sensing. Thus the model for NDSI in November has yielded very poor result. They concluded that in case of SI *vs.* Alkalinity, best coefficient of correlation is obtained.

Khan *et al.* (2001) mapped salt-affected soils in Punjab (Pakistan) using remote sensing with the use of GIS (IDRISI). IRS LISS-II digital data was used. For identification salt affected areas they have applied different indices *i.e.*

Salinity Index (SI): $SI = B3 / B4$

Normalized Differential Salinity Index (NDSI)

$NDSI = (B3 - B4) / (B3 + B4)$

Brightness index (BI): $BI = \sqrt{(B3^2 + B4^2)}$

Normalized differential vegetation index (NDVI) = $(B4 - B3) / (B4 + B3)$

Verma *et al.* (1994) have found that the dull tone of salt-affected soils and sandy soils have posed problems in their discrimination on TM false colour composite. The main causes of spectral confusion, masking different salinity-alkalinity degree, were: (1) the type and abundance of the vegetation cover, which control the reflectance values when the soil surface is not bare; (2) the topsoil texture, especially the presence of larger

amounts of silt-plus-clay which hinder the effects of variables: salt and sodium content (3) the mixture of topsoil properties under field conditions, where salt, particle size, organic matter, crusting and soil moisture mutually interfere (Metternicht and Zinck, 1996).

Studies on salinization using remote sensing often have concentration on severely saline soils neglecting the slightly affected areas, which must actually be just the target when dealing with the soil degradation. The detection and assessment of lower levels of salinity are difficult, mainly because of the nature of the satellite images, which do not allow getting information on the third dimension of the 3-D soil body. It is also because the impact of salinity on electromagnetic properties needs to be further explored to understand how it can be derived from remotely sensed information (Vidal *et al.*, 1997).

Considering the complexity of the salinization process and regarding its influence on different soil properties, both physical and chemical, detecting salt affected soil using remote sensing is a complex process. The reason lies on the fact that variations in the reflectance spectra of soils cannot be attributed to a single soil property (Farifteh *et al.*, 2002).

Although numerous studies have been carried out on salt-affected soil (Szilagyi and Baumgardner, 1991), there is not known study where narrow absorption bands are linked to salinity status.

Ancillary data such as spatial distribution and surface conditions of the salt-affected areas can be correlated with reflectance data. At the regional scale, use can be made of multi-spectral and multi spatial resolution space borne data, and data from previous phases, to delineate salt-affected area (Farifteh *et al.*, 2002).

Remote sensing application in soil erosion studies has been made on the Loess Plateau, northwest of China, which is one of the national projects taken on in the 7th five year plan period. A match of the results of remote sensing interpretation and experimental measurements was made, and a series of models based on the most important erosion factors were developed. Finally, the technological process of quantifying soil erosion with remote sensing information supported by Soil Erosion Information System was established. A trial small watershed was selected to test the method, and the results showed that the technological process is logically viable (Lin Pei *et al.*, 1990).

Hill and Schutt (2000) reported although the general relationship between organic matter, and soil brightness and colour has long been recognized, quantifying this has been difficult because soil reflectance is influenced by additional properties such as soil moisture, the content of iron, or mafic minerals.

Hunt (1976) has found that gypsiferous soil can be distinguished from others because of the presence of broad water absorption region from 1330 to 1650 nm due to the presence of water molecules on gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Calcareous soil has several absorption bands at 2250, 2350, 2380 and 2465 nm due to the internal vibration of the carbonate ion in CaCO_3 . The saline soil can be characterized by having 4 absorption bands near 2200, 2230 and 2440 nm.

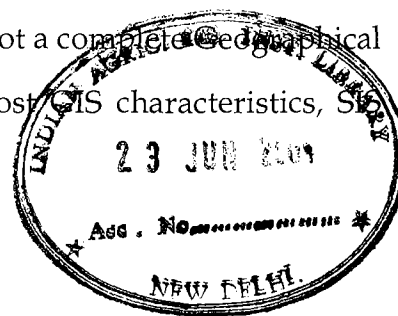
De Jong (1991) found that surface crust could not be distinguished by means of absorption features in near -infrared (NIR) and short wave infrared (SWIR). This was not to be expected because the composition of the soil surface material does not change by crust formation, that is, only

the arrangement of surface particles changes. Crust could spectrally be recognized because the overall albedo in the NIR and SWIR of a crusted soil increases approximately by 12 to 15% . Normally compacted soils are evident due to their scarce vegetation cover, which shows a typical response in the visible, near-infrared and their thermal behavior (Mulders and Girard, 1993).

Peluso *et al.* (1993) developed the Australian soil profile database. The information in the database was collected by the staff of the Western Australian Department of Agriculture and the CSIRO. It comprised point source data of site reference information soil classification, landform and land surface factors, profile morphology, vegetation, chemical and physical properties and land use capability. The data was collected using national standards (McDonald *et al.*, 1990) and soil classes were grouped according to the Australian classification (Isbell, 1989). The database had been implemented using the ORACLE relational database management system. Entity relationship modeling had been used extensively in business computing to aid development of such relationship database software. The core of the entity relationship model consisted of the site horizon relationship. As each site in the database was geographically encoded, it was possible to analyze, manipulate and retrieve this information on a spatial basis in a geographic information system (GIS). Thus the database can be queried to identify all soil sites falling within an agricultural region, district, catchment, or farmer's property.

Robert and Anderson (1991) developed a user friendly and menu-driven Soil Information System (SIS). SIS was not a complete Geographical Information System (GIS), although it had most GIS characteristics, such

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was developed for the inexperienced microcomputer user with software operating on a standard system so that anyone can use it anywhere. It was a stand alone system. It could be installed on many computer systems within a completed survey area and did not require an off site facility. SIS could also display and overlay other digitized maps such as land use ownership, vegetation cover types, roads, and drainage. To accomplish all these SSIS required detailed country soil survey reports and map polygons were labeled using interactive software. Input of soil descriptions, soil properties and soil interpretation was also executed with an interactive programme.

Reddy *et al.* (2001) conducted detailed field survey of Mohgaon watershed area of Nagpur district in an attempt to analyze terrain characteristics and generate maps of slope, geomorphology, soil depth, land use/land cover and ground water prospect thematic information using SOI topographical, remotely sensed and field survey data. The integrated analysis of slope, geomorphology, soil depth, land use/land cover and ground water prospect characteristics in GIS has generated 29 landscape ecological units with an area ranging from 0.23 to 19.20 sq. km identified in the Mohgaon watershed. Landscape ecological zones were analyzed and re-grouped into classes of ecologically stress zones which require immediate attention to maintain fragile geo-ecosystem of the area.

Soil Resource inventory of Machkund watershed, Visakhapatnam district (A.P.) were developed by Sidhu *et al.* (2000) to prepare the watershed management plan for sustainable development of the area by using remote sensing and GIS techniques. FCC prints of Geo-coded IRS-IB (bands 2, 3 and 4) acquired on 26-2-1993 were used for visual

interpretations at 1:50,000 scale to demarcate physiographic units. The soil, hydro-geomorphology and land use maps were modified and finalized on the basis of available soil survey and interpreted satellite data in conjunction with the survey of India toposheet. The watershed area was demarcated on the basis of drainage pattern of upper Machkund river and watershed atlas of All India Soil and Land Use Survey. Based on the secondary and tertiary drainage pattern, the watershed area was further sub-divided into 8 sub-watersheds. The various thematic maps *viz.* watershed and sub-watershed boundaries, transport and settlement network, hydro-geomorphology, soils, land use/land cover and slope *etc.* prepared by interpretation of satellite data and survey of India topographical maps were used for digitization and generation of data base on ARC/INFO GIS on a microvax system. The information collected from 'union' of soils, geomorphology and land use/land cover maps by adopting set of rules was used to frame the action plan for every parcel of land.

Oldeman and Van Engelen (1993) undertook at the request of UNEP and in close co-operation with the ISSS, FAO and the Land resources research center in Canada, to develop a methodology for a world soils and Terrain Digital Data base (SOTER). This land resource information system was tested in three pilot areas involving five countries (Argentina, Brazil, Uruguay, USA and Canada) using local data and training national staff in operation. A long term commitment from those agency was needed so that SOTER could rapidly provide the key soil and terrain attributes, which were needed to assess the potential productivity of the land, the status, risk and rate of soil degradation, to develop action to conserve or

rehabilitate the land and to improve our understanding in global change. Liang and Khan (1986) developed a natural resource information system for Hawaii agriculture and environment management and planning. The database contained essentially data of long-term value such as soil type and historic weather record, which remains unchanged and useful for many years. The selection of a small number of data variables for the database reduced its initial development cost and time. Therefore, its chance of being completed was enhanced and the risk of being abandoned half way was avoided. The adherence to the principle of including only the absolutely necessary variables in the database had proven to be very important in its completion.

Stoorvogel (1993) worked for optimizing land use distribution to minimize nutrient depletion by integrating information on land units and its qualities stored in geographical information system with a nutrient balance model (NUTBAL). This study showed the decrease of nutrient depletion with a slight increase of agricultural production. The re-location of land utilization types results in a decrease of erosion by locating forest and pasture on the sloping area. Leaching and denitrification on the other hand were almost not changed by the re-location of the land utilization type, but could be reduced by measures like split fertilizer applications.

A soil data base as part of a micro-computer based GIS/LIS were designed by Fernandez *et al.* (1993) to provide information in solving rural needs in Miami county. Two data models were used to provide better system efficiency and flexibility - both the EER (Extended Entity-Relationship) model for conceptual design and the relational model for implementation of the data base provided excellent results.

Change in land use pattern and over all change in biomass over a period of time using remote sensing techniques proved to a useful tool to assess the impact of land developmental projects. Transformation of Normalized Difference Vegetation Index (NDVI) by superimposition of NDVI of pre and post treated periods gives an idea of overall change in biomass. The qualitative spatial information will lead to quantitative assessment of the indicators that are instrumental for the changed status of the watershed (Anon 2001).

Information on the area extent of paddy fields is always essential for agricultural land use planning in NE Thailand. In this study, an attempt was made to investigate the feasibility of using LANDSAT-5 TM data with some common supervised classification methods, to generate information on the spatial distribution of different paddy types. To explore the extent to which various paddy types can be distinguished, four classification schemes of different levels of details for paddy classification were developed. Various statistics including histogram analysis, KAPPA analysis and Z-statistics, overall accuracy, producer's accuracy and user's accuracy were employed as the basis for this investigation. Although, the use of the data from all TM bands with the Maximum Likelihood methods appeared to be most appropriate, mapping of paddy fields based on this technique was found fairly satisfactory only when all paddy types were considered as one single class, i.e., "paddy". Distinguishing different paddy types could not be done successfully (Katawatin *et al.*, 2002).

Samant and Subramanyan (1998) attempted to quantify the change in land use of Mumbai - Navi Mumbai cities and its effect on the drainage basin and drainage network using simple map overlay techniques available

in any GIS environment. It was observed from the study that 55% reduction in forest/agricultural land, while a 300% increase in built up land had taken place in the last seventy years. This has affected the natural drainage system of the cities, causing flooding during monsoon.

Walsh (1985) developed Oklahoma Geographic Information retrieval system (OGIRS) in responding to a need for a computer based, geographically referenced natural resource information system in Oklahoma. He developed numerous models for evaluating non point source pollution and implemented best management practices to limit pollution to an acceptable level. Because of spatial variation of climate, soils and agricultural practices, no single group of control measure could be used in every region.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Location and extent

Mathura is one of the districts of Uttar Pradesh state in India and forms a part of Yamuna River basin. Administratively, the district has been subdivided into 4 tehsils *i.e.*, Chhatta, Mathura, Mat, and Sadabad, covering total area of 376432 ha.

The study area forms a part of Mathura tehsil. It is surrounded by Mat in East, Agra Canal in West, Mathura in South and Chhata in North. Geographically it lies between 27°55' to 27°65' North latitude and 77°53' to 77°71' East longitude covering (partly) the survey of India Toposheet No. 54 E/10 (1:50,000 scale). Study area is about 9581ha; location map is shown in (Fig. 3.1).

3.1.2 Physiography

Yamuna River flows through the central part of the district from north to south and divides the district into two physical units, the eastern or trans Yamuna and the western or Cis-Yamuna tract. The area under study is located in the plain terrain of the western part. The highest elevation of about 184 m above msl is located near Barauta village and the lowest elevation of 170 m above msl is situated near Sakraya and towards river. General slope is toward Yamuna River but the drop in slope from north to south is approximately 14 meter.

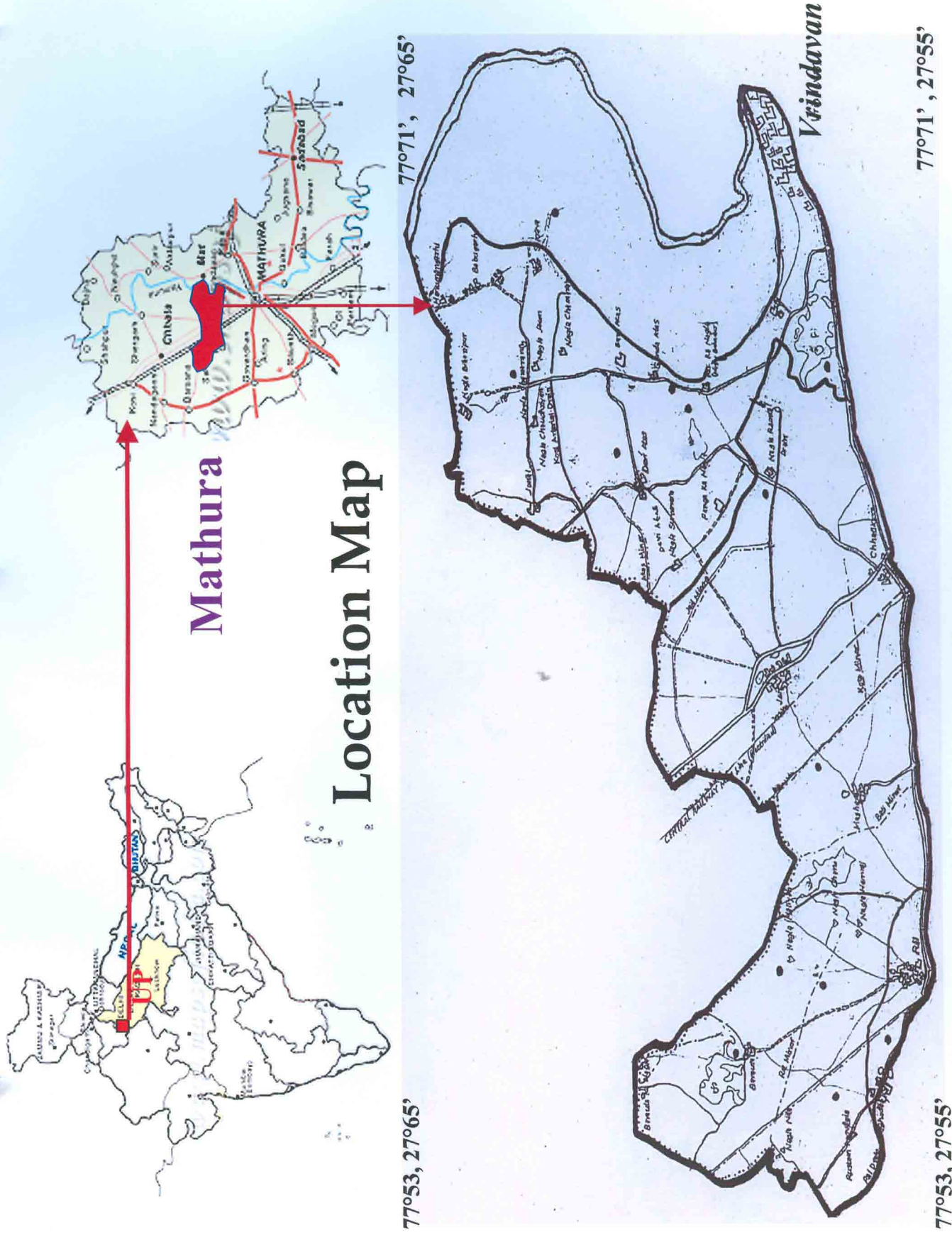


Fig. 3.1

Physiographic map of the study area

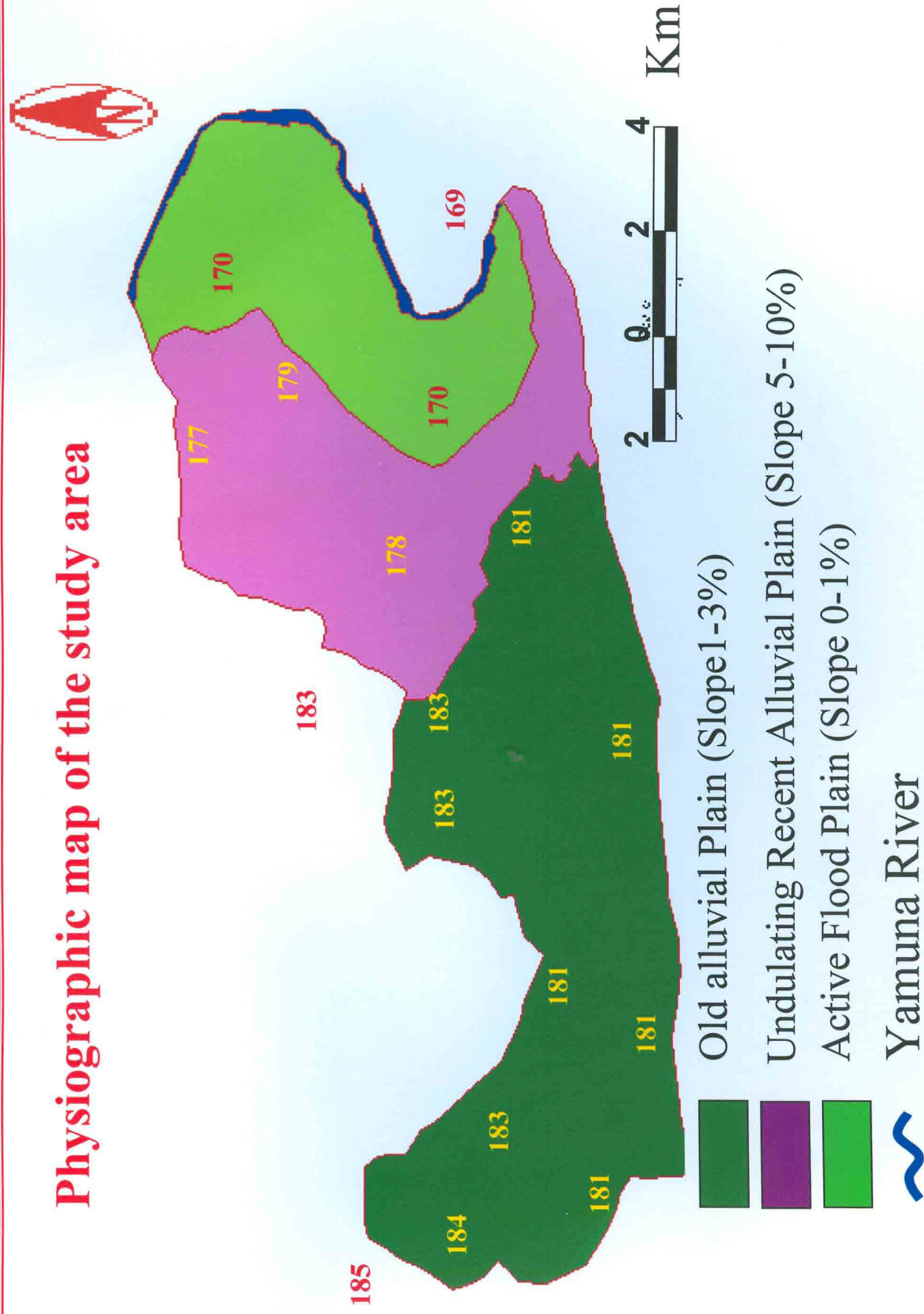


Fig. 3.2

The study area has been divided into three distinct physiographic units (Fig.3.2).

- i) Active flood plain with slope of (0-1%)
- ii) Recent alluvial plain (slope 5-10%)
- iii) Old alluvial plain (slope 1-3%)

3.1.3 Geology

The study area is a part of vast Indogangetic alluvial plain. It mainly constitutes quaternary alluvium.

The alluvium is fairly stiff. Kankars are abundant and is used for making lime and massionary work. The soil (clay) is suitable for making bricks, toys and pottery. The quaternary sediments comprise sand, silt, clay, kankar and gravels. The thickness of alluvium increases towards east of area under study.

3.1.4 Climate

The climate of the district is semi-arid. It is characterized by intense hot summer, cold winter and general dryness throughout the year except during southwest monsoon period from July to September.

The year can be divided into three seasons i.e., winter season from December to February with January being the coldest month, summer season from March to middle of June with June being the hottest month and rainy season with August the heaviest rainy month (Figure 3.3).

3.1.4.1 Rainfall

The rainy season which receives rains from south west monsoon in July continues till the end of September followed by the post monsoon

Ombrothermic Diagram, Mathura District, Uttar Pradesh

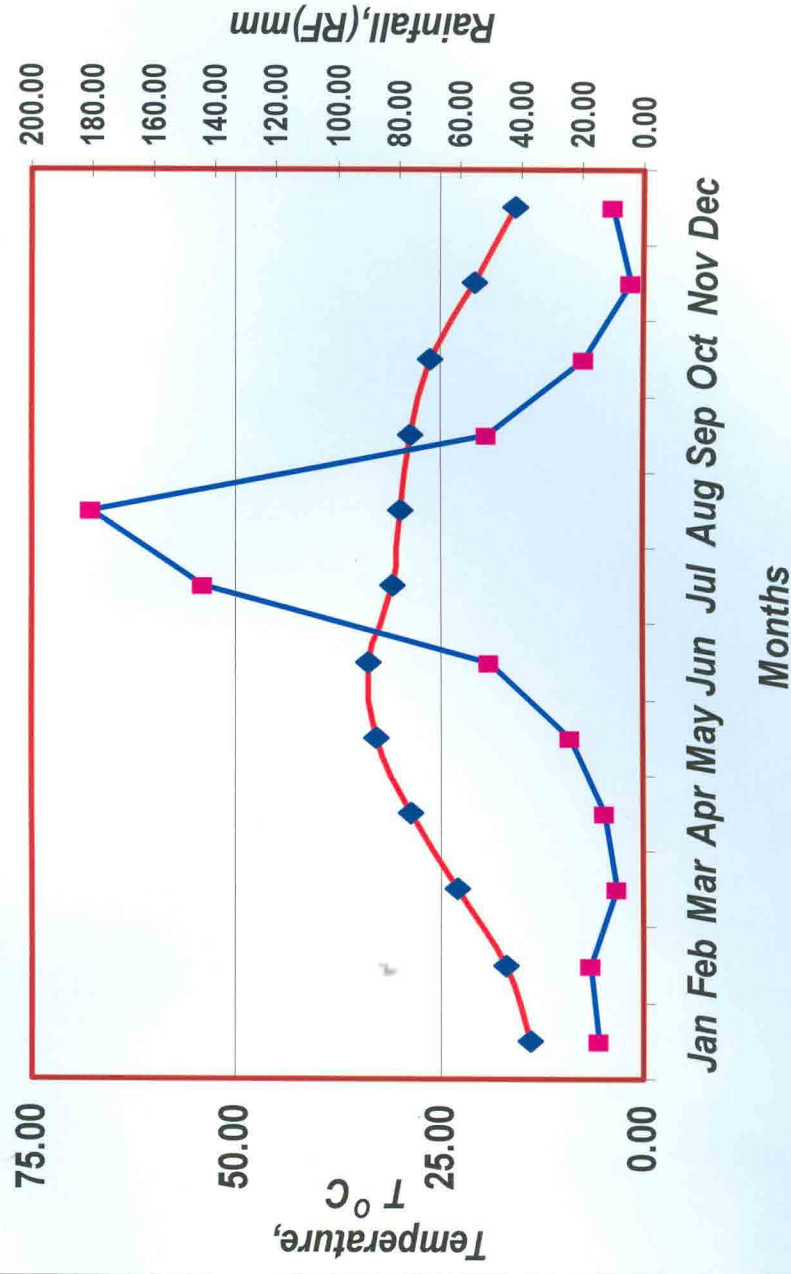


Fig.3.3

period from October to November. The mean annual precipitation is about 536 mm, around 92% per cent of which is received during south west monsoon period. Winter rainfall is very little and insufficient to meet the water requirement of Rabi crops (Table 3.1).

3.1.4.2 Temperature

The mean annual temperature is 25.0°C; maximum temperature in May goes up to 41.0°C and minimum temperature up to 6.5°C in the month of January. The mean maximum annual temperature is 34°C in June while the minimum in January goes to 14.1°C (Table 3.2, Fig. 3.4).

3.1.5 Natural vegetation

The study area is rich with deciduous types of trees and tropical scrub and thorny bushes but it does not have any extensive natural vegetation cover. The protected forest is mainly found nearby Vrindavan (Sunrakh, R.F.). The trees, shrubs and grasses found in the study area are listed in (Table 3.3)

3.2 Data used

The remote sensing data products of two seasons namely pre and post monsoon periods were acquired for the identification and mapping of degraded lands and soil resource inventory in the study area. Different time periods (pre-monsoon and post-monsoon) were chosen for visual analysis and digital image processing because of considerable variation in soil surface salinity as well as waterlogging and vegetation cover. The geocoded cloud free False Colour Composite (FCC) and corresponding digital data products were procured from National Remote Sensing Agency,

Table 3.1 : Rainfall data (mm) of Mathura district, U.P.

Month	Year											
	1979	1980	1982	1983	1984	1985	1986	1987	1988	1989	Total	Mean
January	66.40	0.00	8.60	17.40	0.70	9.80	1.80	14.80	7.00	18.00	144.50	14.45
February	56.20	0.00	19.80	8.40	0.00	0.00	49.20	5.80	8.60	23.00	171.00	17.10
March	2.80	0.00	35.00	0.00	0.00	0.20	1.20	6.00	9.60	28.60	83.40	8.34
April	2.00	0.00	37.80	19.00	0.00	13.00	0.00	0.00	20.80	34.60	127.20	12.72
May	17.80	0.00	55.00	37.20	0.00	14.40	9.80	58.00	5.00	41.70	238.90	23.89
June	61.80	0.00	39.00	35.20	52.40	28.60	156.10	11.20	71.00	38.00	503.30	50.33
July	259.20	104.90	153.40	256.60	172.70	66.90	85.90	71.60	134.60	34.70	1440.50	144.05
August	41.60	103.20	289.40	392.10	232.60	135.60	19.40	196.00	363.00	33.20	1806.10	180.61
September	0.00	55.80	4.20	48.40	67.60	72.20	119.40	85.40	25.60	32.00	510.60	51.06
October	0.00	5.70	0.00	22.40	1.80	90.80	17.40	6.80	17.00	33.00	194.90	19.49
November	0.00	0.00	9.60	0.00	0.00	0.00	0.00	0.00	0.00	28.00	37.60	3.76
December	0.00	6.00	13.40	2.60	0.00	23.80	7.80	2.30	22.00	20.20	98.10	9.81
Total	507.80	275.60	665.20	839.30	527.80	555.30	478.00	457.90	684.20	365.00	5356.10	535.61

Table 3.2 Temperature data (°C) of Mathura district, U.P.

[illegible]

Temperature curve of Mathura District, U.P.

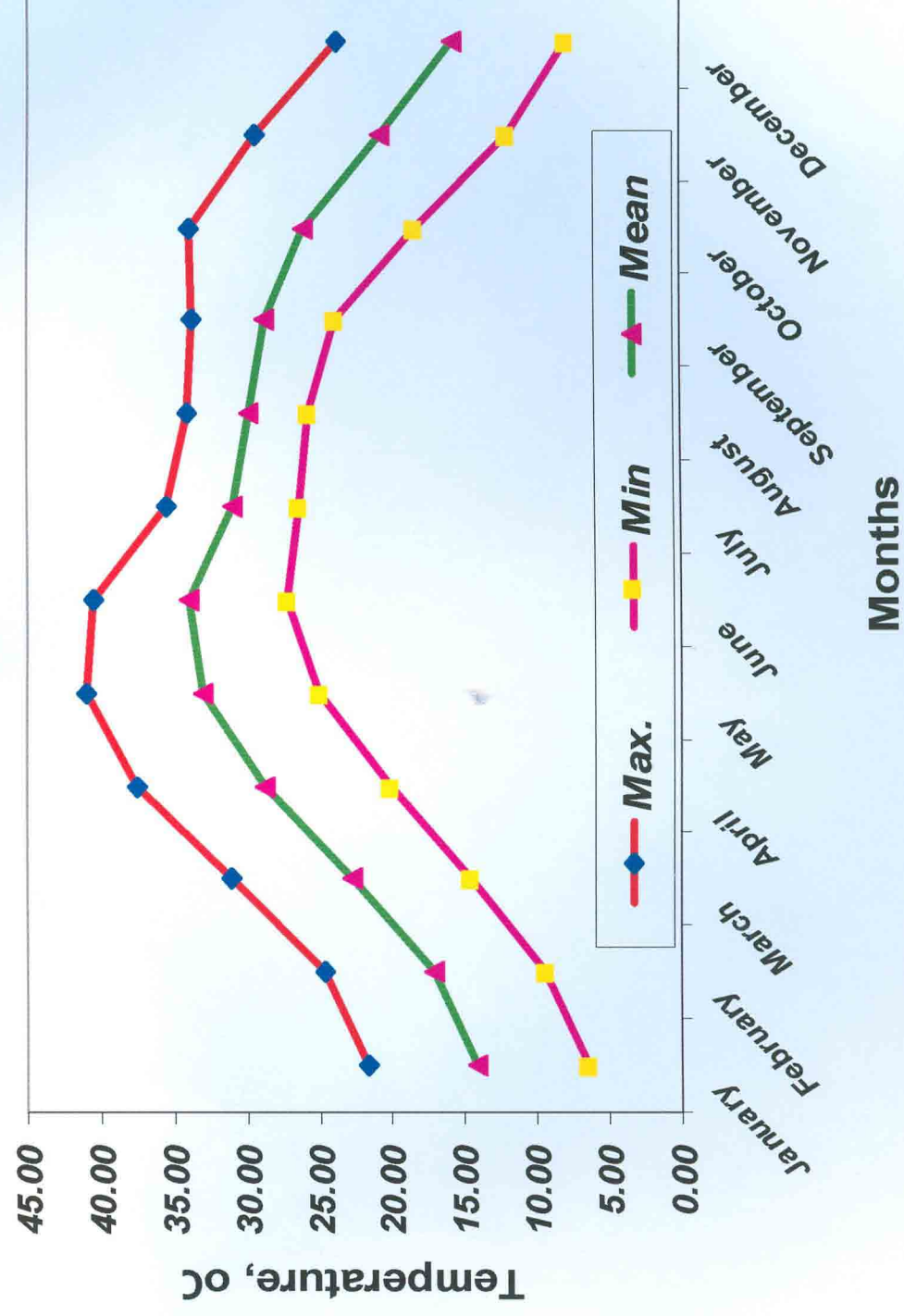


Fig.3.4

Table 3.3 Natural vegetation in the study area

Sl. No.	Common Name	Botanical Name
Trees		
1.	Neem	<i>Azadirachta indica</i>
2.	Babul	<i>Acacia arabica</i>
3.	Ber	<i>Zizyphus jujuba</i>
4.	Dhak	<i>Butea monosperma</i>
5.	Kadam	<i>Mitragyna parrifolia</i>
6.	Pilu	<i>Sadvadera eloides</i>
7.	Dhan	<i>Anogessus parifolia</i>
8.	Faras	<i>Tamarix species</i>
9.	Jamun	<i>Syzigium cermuni</i>
10.	Pipal	<i>Ficus religiosa</i>
11.	Imli	<i>Tamarindus indica</i>
Shrubs		
12.	Karil	<i>Capparis decid</i>
13.	Bansi	<i>Crotolaria species</i>
14.	Lamtana	<i>Lantana camera</i>
Grasses		
15.	Dub	<i>Cynodon dactylon</i>
16.	Cypus	<i>Cyprus camera</i>
17.	Das	<i>Desmostachya bipinnate</i>
18.	Munj	<i>Exianthus munja</i>

Hyderabad. Detail specifications about satellite, sensors and date used is given in Table 3.4 and Table 3.5 respectively.

Table 3.4 Satellite and sensor specifications

Satellite	Sensor	Bands	Spectral resolution (μm)	spatial resolution (m)	Swath width (Km)
IRS-IC (Indian Remote sensing satellite)	LISS-III (Linear image Self-scanning system)	B2	0.52-0.59	23.5	141
		B3	0.62-0.68	23.5	141
		B4	0.77-0.86	23.5	141
		B5	1.55-1.70	70.5	148

Table 3.5 Remote sensing imagery specifications

Sl No.	Data type	Scale	Path No./ Row No.	Date of satellite pass
1.	FCC (Geocoded)	1:50,000	96/52	2 nd May 2002 17 th October, 2002
2.	Digital (CD Rom/ Geocoded)	1:50,000	96/52	2 nd May 2002 17 th October,2002

Corresponding Survey of India (SOI) toposheet 54 E/10 at scale 1:50,000 was used as secondary data for delineation of test area boundary, generation of information on elevation, slope, topography, ground truth verification and registration of images.

3.3 Methods

The procedure adopted for land degradation and soil resource inventory composed of following steps:

3.3.1 Selection and acquisition of data:

- a) Procurement of satellite data products.
- b) Collection of collateral data such as topographical, geological maps and information of the area.
- c) Collection of previous reports, literature, etc. relevant to the area.

3.3.2 Pre-field visual interpretation

IRS-1C LISS-III geocoded cloud free False Colour Composite (FCC, Path No.96; Row No.52) of 2nd May and 17th October 2000 at 1 : 50,000 scale were used. Visual interpretation of image was carried out in two stages for extracting information on various degraded land units and delineation of land use and major landforms by analyzing two-season

imagery in consultation with topographical map (SOI, 54 E/10). Delineation of study area boundary, major physiographic units, land use types, soil types polygons and land degradation types were done monoscopically.

Visual interpretation technique based on image characteristics/elements i.e., colour, tone, texture, pattern, size, shape, association *etc.* enabled to identify and delineate different land degradation units and accordingly image interpretation key and legend for soil degradation mapping were developed (Table 3.6, Appendix I). Analysis of images was carried out in succession using the interpretation key. Study area was subdivided into thirteen mapping units (polygons) based on physiography, slope and image characteristics. For preparation of land use, physiography and land degradation maps following points were considered:

The different colour and gray tones on the imagery is the radiance of different objects depicted through the pixels (spatial resolution of IRS-1C L3 is 23.5 meters). That on colour composite, we can see different colors according to tone. These tones were compared with tones that is similar to a known object.

3.3.3 Ground truth verification

Field work was carried out to collect the ground information of the study area. A rapid reconnaissance survey of the study area was undertaken prior to detailed field checking to understand the broad landforms, land use, land degradation types occurring in the study area and their relationship with soil. The coordinates of more than 40 points (Appendix II) in the study area were recorded using GPS for further use in digital image processing.

Table 3.6 Interpretation key for degradation mapping of study area

S.No.	Land use	Type of soil degradation	Mapping Unit	Image Characteristics
1.	Agriculture (A)	Undulating plain affected by severe water erosion	AW ₁	Light gray to gray smooth
		Undulating plain affected by severe water erosion	AW ₂	Light gray to dark gray. Smooth with few mottles
		Plain affected by moderate salinity	ACs ₁	Gray to light gray with red mottles
		Plain affected by strong salinity	ACs ₂	Gray to yellowish white and white with red mottles
		Plain moderately affected by alkalinity	ACK ₁	Gray patches with bluish mottles
		Plain strongly affected by alkalinity	ACK ₂	Dark gray patches with bluish mottles
		Plain affected by seasonal water logging	APw ₁	Light gray to bluishgray scattered mottles
2.	Open Scrub (O)	Plain affected by permanent water logging	APw ₂	Dark blue to bluish black tone
		Normal Agriculture	AN	Light bluish and red to deep red smooth
		Plain affected by moderate salinity	OCs ₁	Gray to bluish gray with red mottles
		Plain affected by strong salinity	OCs ₂	Gray to yellowish white and white with red mottles
		Plain affected by seasonal water logging	OPw ₁	Light gray to bluish gray scattered mottles
		Plain affected by permanent water logging	OPw ₂	Dark blue to bluish black
		Normal open scrub	ON	Red to deep red
3.	Forest (F)	Undulating plain affected by sever water erosion	FW ₁	Light gray to gray. Smooth
		Normal Forest	FN	Red to deep red. Smooth
4.	Plantation (P)	Normal plantation	PN	Red to deep red. Smooth
		Water bodies (WB)	WB	Dark gray to black colour
		Habitation/Road (H)	H	Dark gray to bluish gray colour

Then ground truth verification process was started by selecting samples randomly within each delineated polygon. For each mapping unit representative soil profile, auger bores were studied and noted on the field notebook containing detailed profile site and morphological characteristics. The prefield interpreted mapping units were checked randomly throughout the whole area and corrections if necessary were made by establishing correlation between image characteristics and soil type. The samples from all soil profiles were taken for detailed laboratory analysis.

3.3.4 Post Field Interpretation

The post field interpretation involves modifications and corrections of prefield interpreted maps with help of ground observations collected. The sample points checked for ground truth were correlated with prefield interpreted maps. Necessary modifications and corrections were made in delineating the physiography, land use, soil boundaries and land degradation boundaries with the help of image characteristics, field observations and laboratory analysis. The physiography, land use, soil and land degradation maps were again traced on transparent paper using rotering pens (0.2, 0.5 and 0.8) and used further in Digital Image Processing analysis.

3.3.5 Digital image processing

3.3.5.1 Data used

The Geocoded digital products of IRS-IC, LISS-III sensor, corresponding to two dates such as 2nd May and 17th October, 2000 were procured and used (Plate 3.1 & 3.2).

*FCC covering study area as on May 2, 2000 (RGB -B432, IRS-1C,
LISS III)*



Plate 3.1

Table 3.3 Natural vegetation in the study area

Sl. No.	Common Name	Botanical Name
Trees		
1.	Neem	<i>Azadirachta indica</i>
2.	Babul	<i>Acacia arabica</i>
3.	Ber	<i>Zizyphus jujuba</i>
4.	Dhak	<i>Butea monosperma</i>
5.	Kadam	<i>Mitragyna parrifolia</i>
6.	Pilu	<i>Sadvadera eloides</i>
7.	Dhan	<i>Anogessus parifolia</i>
8.	Faras	<i>Tamarix species</i>
9.	Jamun	<i>Syzigium cermuni</i>
10.	Pipal	<i>Ficus religiosa</i>
11.	Imli	<i>Tamarindus indica</i>
Shrubs		
12.	Karil	<i>Capparis decid</i>
13.	Bansi	<i>Crotolaria species</i>
14.	Lamtana	<i>Lantana camera</i>
Grasses		
15.	Dub	<i>Cynodon dactylon</i>
16.	Cypus	<i>Cyprus camera</i>
17.	Das	<i>Desmostachya bipinnate</i>
18.	Munj	<i>Exianthus munja</i>

Hyderabad. Detail specifications about satellite, sensors and date used is given in Table 3.4 and Table 3.5 respectively.

Table 3.4 Satellite and sensor specifications

Satellite	Sensor	Bands	Spectral resolution (μm)	spatial resolution (m)	Swath width (Km)
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		B3	0.62-0.68	23.5	141
		B4	0.77-0.86	23.5	141
		B5	1.55-1.70	70.5	148

*FCC of the study area as on May 2, 2000 (RGB - B 432,
IRS-1C, LISS III)*

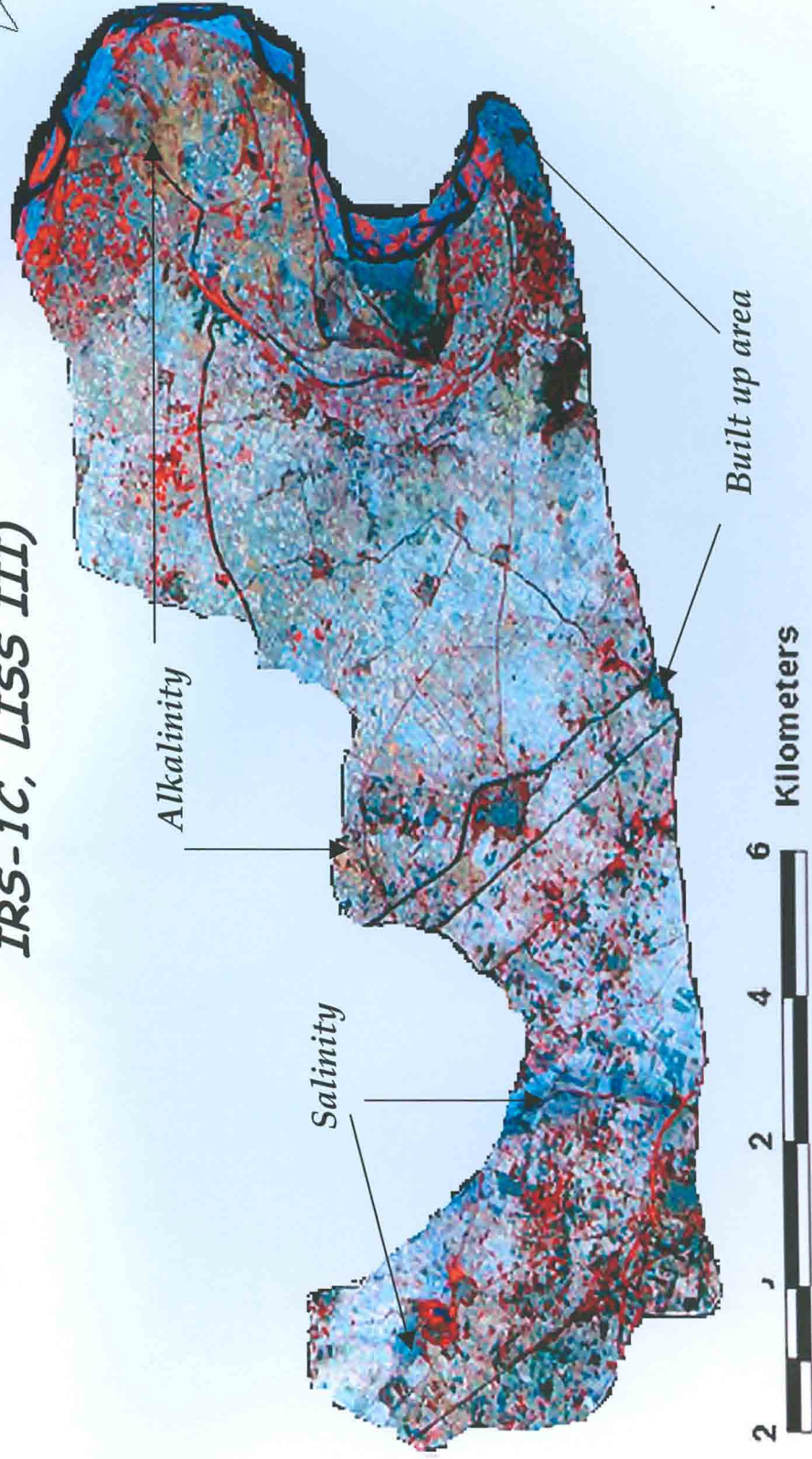


Plate 3.3

*FCC of the study area as on Oct. 17, 2000 (RGB – B 432,
IRS-1C, LISS III)*

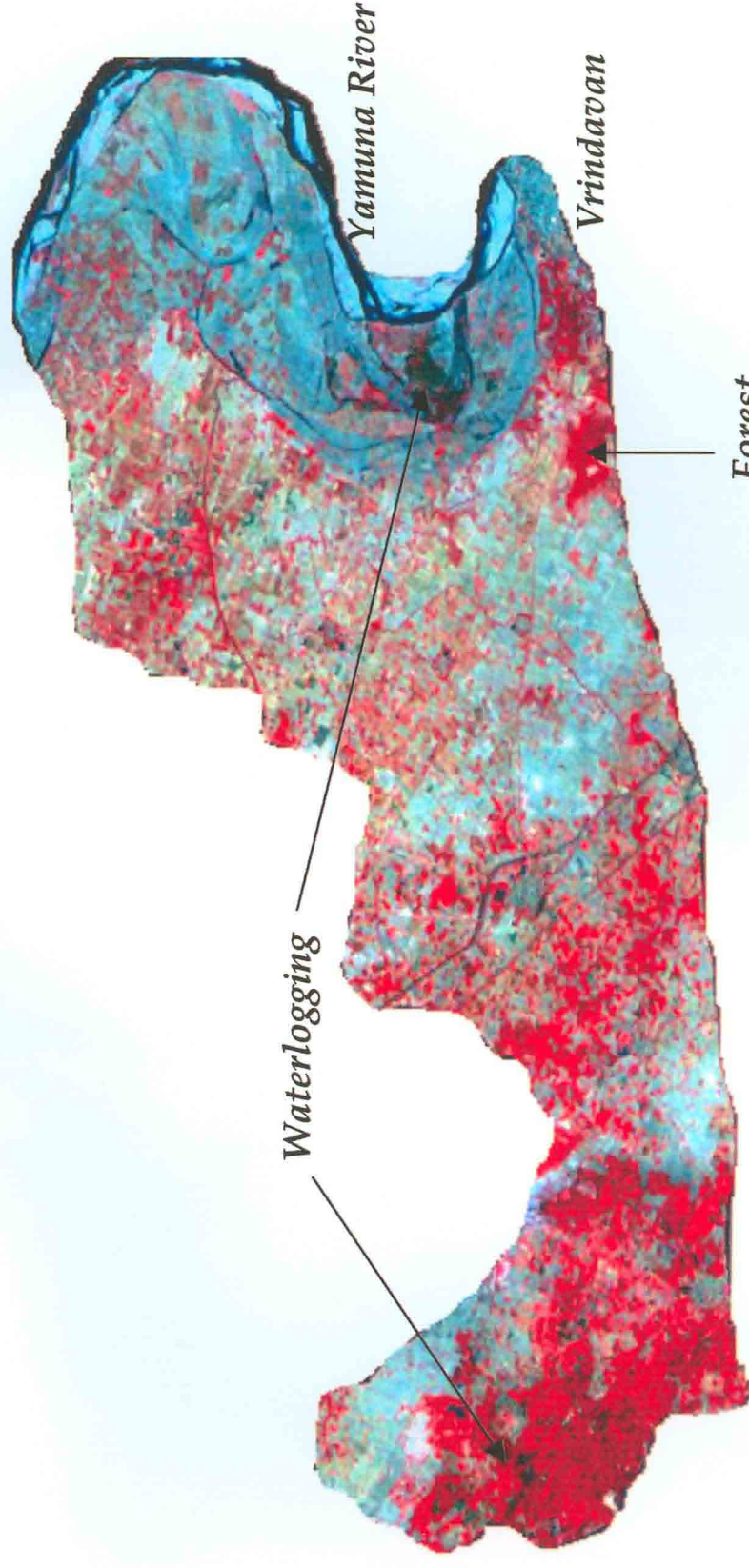


Plate 3.4

3.3.5.2 Geo-referencing

Using SOI toposheet the digital data of May 2, 2000 was registered (map to image registration) using about 40 ground control points (GCP's) that were easily recognizable on the satellite images. Similarly, October image was registered to the corrected May image (image to image registration). After completion of the registration procedure, the satellite data was ready to be used further. ERDAS IMAGINE (version 8.5) digital image processing software was used for registration and different analysis.

3.3.5.3 Sub-image extraction

The study area ($27^{\circ}55'$ to $27^{\circ}65'$ north latitude and $77^{\circ}53'$ to $77^{\circ}71'$ east longitude) was extracted from the whole images of both May and October through on screen digitization of the area of interest (AOI) and masking out using subset module of the ERDAS (Plate 3.3 and 3.4). The same area was extracted too from the toposheet in similar way. Vector layers of physiography map and soil were prepared through visual interpretation and on screen digitization.

3.3.5.4 Classification

Various forms of hybrid classification have been developed to either streamline or improve the accuracy of purely supervised or unsupervised classification. In supervised classification the analyst defines on the image a small area, called a training site, which is representative of each terrain category, or class. Spectral values for each pixel in a training site are used to define the decision space for the class. After the clusters for each training site are defined, the computer then classifies all the remaining pixels in the scene. In the unsupervised classification, the

computer separates the pixels into classes with no direction from the analyst (Sabins, F.F. 1997).

These two classification methods were attempted for delineation of various types of land degradation. Ravinous, built up and alkalinity, salinity and sand were mixed because of the similarity of tones and consequently spectral reflection. To avoid this, the image of the studied area was subdivided into three parts based on physiographic units using physiography vector layer and masking or subsetting (Plates 3.5,a, b and c).

Hybrid classifiers are particularly valuable in analysis where there is complex variability in the spectral response patterns for individual cover types present (Lillesand *et al.*, 1999). Hybrid classification (*i.e.* combination of supervised, unsupervised and knowledge based classification) is used to classify each part of the image individually or separately.

Mosaicing was done to join three parts. Nine classes were identified and mapped *i.e.* alkalinity, salinity, ravines, waterlogging, vegetation, built up area, water bodies, sand and normal land.

3.3.5.5 Rating of various degradation types

For delineation of different levels of salinity, alkalinity, waterlogging and vegetation land degradation map was **recoded** using **GIS analysis** tool of ERDAS IMAGINE to delineate salinity, alkalinity, waterlogging and vegetation maps. Then appropriate spectral indices were calculated for enhancement of each particular class and classify it into different levels. Spectral index is the mathematical expression of number of bands to

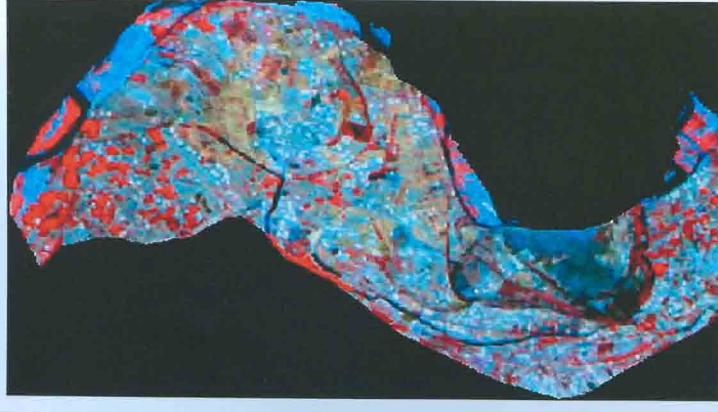
Plate 3.5 Partitions of study area



c - Old alluvial plain



*b- Undulating recent
alluvial plain*



a -Active flood plain

quantify spectral information of a feature. The various indices used to delineate and classify various features to different levels are given as below.

A) Normalized Differences Salinity Index (NDSI)

In order to enhance the saline zones and suppressing the vegetation NDSI found useful than individual bands for delineation salinity (Khan, *et al.*, 2001 and Tripathi, *et al.*, 1997). The salinity and alkalinity maps were subjected to further analysis and delineation to different levels using Normalized Differences Salinity Index (NDSI).

Mathematical expression:

$$\text{NDSI} = (\text{R}-\text{NIR})/(\text{R}+\text{NIR})$$

$$\text{i.e. } (\text{Band 3}-\text{Band 4})/(\text{Band 3} + \text{Band 4})$$

B) Normalized Differences Water Index (NDWI)

For delineation seasonal and permanent waterlogging, Normalized Differences Water Index (NDWI) was used (McFeetirs, 1996).

Mathematical expression:

$$\text{NDWI} = (\text{G}-\text{NIR})/(\text{G}+\text{NIR})$$

$$\text{i.e. } (\text{Band 2}-\text{Band 4})/(\text{Band 2} + \text{Band 4})$$

C) Normalized Differences Vegetation Index (NDVI)

For better delineation of vegetation, Normalized Differences Vegetation Index (NDVI) was used (Rouse *et al.*, 1974).

Mathematical expression:

$$\text{NDVI} = (\text{NIR}-\text{R})/(\text{NIR}+\text{R})$$

$$\text{i.e. } (\text{Ban4} - \text{Band 3})/(\text{Band 4} + \text{Band 3})$$

It was difficult to delineate water erosion using image classification. Ravinous area was subset and classified separately based on field verification and ground study. Sheet and rill erosion (slight + moderate types of water erosion) were also mapped using ground data and GIS techniques. They were compiled together and water erosion map was prepared.

3.4 Mapping of land resources using GIS

Laurini and Thompson (1992) reported that the most common method of structuring the geography of the real world on the computer is to use the layered approach. A layer map is a thematic map, which reflects either a particular use or a characteristic of the landscape (Heywood et al., 1998). Based on Morphological, physical, physico-chemical and chemical characteristics different thematic maps of study area were generated using the software ArcGIS (version 8.5). The following steps were carried out for map preparation.

3.4.1 Creation of Spatial Data Base

The soil series map prepared using ERDAS IMAGINE 8.5 version was used as spatial database. Twelve soil series and River formed thirteen polygons. Twelve representative profiles were considered as point data.

3.4.2 Creation of Non-Spatial Data Base

The attribute database comprised of soil characteristics, land use information and soil suitability classification for different crops were generated from field study, laboratory analysis and published literature. The data were stored in RDBMS. Classes and ranges of soil characteristics were also stored in RDBMS.

3.4.3 Spatial analysis

The most important part of GIS application is spatial analysis. ArcGis version 8.2 software has been used for spatial analysis. The spatial data (soil series map) and non-spatial data (attribute data) were integrated and joined to generate various thematic maps.

Arc View 3.2a was also used for generation and preparation different thematic maps. Soil suitability classification data were related to spatial data and soil suitability maps were created.

3.5 Land use/land cover

Land use/land cover map was prepared by recoding of land degradation map using ERDAS IMAGINE 8.5 software.

3.6 Soil survey and sample collection

Twelve profiles were selected in the study area representing dominant soils occurring on different physiographic units. Tentative soil boundaries were delineated based on topographic and image characteristics. Detailed-reconnaissance soil survey is used (Sehgal, 1996).

3.6.1 Morphological Examination

Morphological examination of soil profiles was carried out in the field as per procedures laid out in the Soil Survey Manual (Soil Survey Staff, 1975).

3.6.2 Soil Samples Collection

Horizon wise soil samples from each profile were collected and kept separately in plastic bags.

3.6.3 Preparation of Soil Samples

The soil samples were thoroughly air-dried in shade, grounded in wooden mortar and pestle and passed through a 2 mm sieve. The sieved soil samples were stored in stoppered plastic bottles and subsequently used for various determinations using standard methods given as under.

3.7 Soil analysis

The physical and chemical analysis of the processed soil samples were carried out as given below.

3.7.1 Physical properties

3.7.1.1 Particle size analysis

It was carried out as per International Pipette method. Soil samples (< 2 mm) were treated with NaOAc (pH 5) for removal of exchangeable divalent cations followed by several treatments with 30 % H_2O_2 for removal of organic matter. Sand (0.02 - 2.00 mm), silt (0.002 - 0.02 mm) and clay (< 0.002 mm) were separated using the procedure of Jackson (1979).

3.7.1.2 Bulk density

The bulk density of the soil was determined by Clod method using the Archimedes' principle as described by Blake (1965).

3.7.1.3 Moisture retention characteristics

The moisture retention capacity of the soils at 1/3rd and 15 bar was determined by pressure plate apparatus (Richard, 1965).

3.7.1.4 Plant available water capacity

The plant available water capacity was calculated following suggestion of Gardner *et al.* (1984) by using the formula:

$$PAWC = \sum \frac{(W_{max} - W_{dry}) D_b \times R_d \times 10}{D_w}$$

Where,

PAWC = plant available water capacity (mm),

W_{max} = gravitational water content at field capacity (33 kPa) in g g⁻¹,

W_{dry} = gravitational water content at permanent wilting point (1500 kPa) in g g⁻¹,

D_b = bulk density at W_{max} (Mg m⁻³),

R_d = rooting depth (cm) and;

D_w = density of water (≈ 1 Mg m⁻³).

3.7.2 Chemical properties

3.7.2.1 Soil reaction (pH)

Soil reaction (pH) was determined in distilled water in ratio of 1:2.5 using Control Dynamics pH meter with gel filled electrode.

3.7.2.2 Electrical conductivity

The electrical conductivity (EC) was determined in 1:2.5 soil-water suspension after settling overnight using Elico conductivity Bridge (CM 82T).

3.7.2.3 Organic carbon

Organic carbon content of the soils was determined by Walkley and Black's rapid titration method (Jackson, 1973).

3.7.2.4 Free CaCO_3

This was determined by using Collin's Calcimeter.

3.7.2.5 Cation exchange capacity (CEC)

The CEC was determined by 1N neutral NH_4OAc for non calcareous soils. Soil samples were saturated with 1N neutral NH_4OAc . The excess of ammonium acetate was removed with ethanol. The NH_4^+ in the soil sample was distilled using Kjeldahl distillation and then titrated with 1 N sulphuric acid solution.

For the calcareous soils, the Cation exchange capacity was determined by saturating the soil samples with 1 N NaOAc (pH 8.5). The excess of sodium acetate was washed with 95 per cent ethanol for 3 to 4 times until EC of the suspension comes in the range of 40 to 55 dsm^{-1} . The

adsorbed sodium was replaced by 1N neutral ammonium acetate, and the concentration of sodium in the solution was then measured with flame photometer (Jackson, 1973).

3.7.2.6 Exchangeable cations

Exchangeable cations of the noncalcareous soils were extracted with neutral normal ammonium-acetate, while exchangeable cations of the calcareous soils were extracted with 1 N KCl-Triethanolamine buffer solution (pH 8.2). The extractant was analysed for sodium and potassium using Flame Photometer (Systronics 123) and for calcium and magnesium by Atomic Absorption Spectrometer method (Lindsay and Norvell, 1978).

3.7.2.7 Base saturation

It was the sum of the bases extracted expressed as a percentage of the cation exchange capacity.

3.7.2.8 Free iron oxide

The free iron oxide was extracted by sodium dithionite-citrate-bicarbonate method. Iron was then determined by Atomic Absorption Spectrometer (Jackson, 1973).

3.7.2.9 Available nitrogen

Available nitrogen was worked out by Kjeldhal distillation with alkaline permanganate method (Subbiah and Asija, 1956).

3.7.2.10 Available phosphorus

Estimation of available phosphorus was done by extracting soil samples with Olsen's reagent of 0.5 M NaHCO_3 (pH 8.5) (Olsen, 1954) and

colour was developed by ascorbic acid method (Watanabe and Olsen, 1965). The colour intensity was read by spectrophotometer.

3.7.2.11 Available potassium

The available potassium was estimated by extracting the soil with neutral normal ammonium acetate solution and quantified by using flame photometer (Jackson, 1973).

3.7.2.12 Available micronutrients

Available micronutrients (Zn, Cu, Fe and Mn) determination was carried out by extracting the soil samples with DTPA- CaCl_2 -TEA method, and the concentration of the micronutrients were estimated by AAS (Lindsay and Norvell, 1978).

3.8 Clay mineralogy

The soil samples (<2 mm) were made free of organic matter, oxides of Fe, Al, Si and carbonate. The clay fraction was separated as per standard procedure (Jackson, 1956). Two per cent mono-ionic suspensions of potassium and magnesium saturated clays were prepared. Parallel oriented specimens were prepared on micro slides of similar dimensions by putting one ml of the 2 % suspensions and drying at room temperature. A separate micro slide with magnesium-saturated clay was glycerated by spraying 10 % glycerol solution with an TLC sprayer. X-ray diffraction analysis was done for potassium saturated clays air dried (25°C) and 550°C, and magnesium saturated air dry and glycerol solvated clay using Phillips X-ray diffractometer with Cu-K α 1 (λ 1.5405 Å) radiation at a scanning rate of 2° per minute. Interpretation of X-ray diffractograms was done according to Brown (1961) and Gjems (1967). The semi-quantitative

estimation of the minerals present in soil clay samples were carried out according to procedure of Gjems (1967) with some modification as suggested by Ghosh and Datta (1974).

3.9 Soil Classification

Morphological, physical, physico-chemical and chemical characteristics of the soils determined in the present study were used as criteria for soil classification. The soils were classified up to series level as per Soil Taxonomy (Soil Survey Staff, 1998).

3.10 Land Evaluation

The suitability of the soils for wheat, rice, sugarcane, cotton, sorghum, maize, pearl millet and barley was evaluated by comparing different land characteristics and land requirements of these crops through the limitation approach. The system of land suitability classification for specific land use suggested by FAO (1976) and Sys (1995) as modified by Sehgal (1996) was adopted.

Suitable (S) : Land on which sustained use of the kind under consideration is expected to yield benefits without unacceptable risk to land resources and management.

- S1** - Very suitable: Land unit with no or with only slight limitation(s).
- S2** - Moderately suitable: Land unit with more than four slight limitations and/or not more than 3 correctable moderate limitations
- S3** - Marginally suitable: Land unit with more than three moderate limitations and /or not more than one severe limitation.

Not Suitable (N) : Land, which has qualities that appear to preclude its sustained use of the kind under considerations.

- N1** - Actually unsuitable and potentially suitable: Land units with very severe limitations, which can be corrected; have more than one severe limitation that can be corrected.
- N2** - Actually and potentially unsuitable: Land units with very severe limitations, which cannot be corrected.

3.11 Statistical Analysis

Some of the results of soil analysis were subjected to statistical analysis to find out the correlation between different variables (App.III). They were determined following the procedure outlined by Snedecor and Cochran (1967). Various steps involved and visual interpretation techniques are illustrated in flow chart (Fig. 3.5), and digital image processing in (Fig. 3.6).

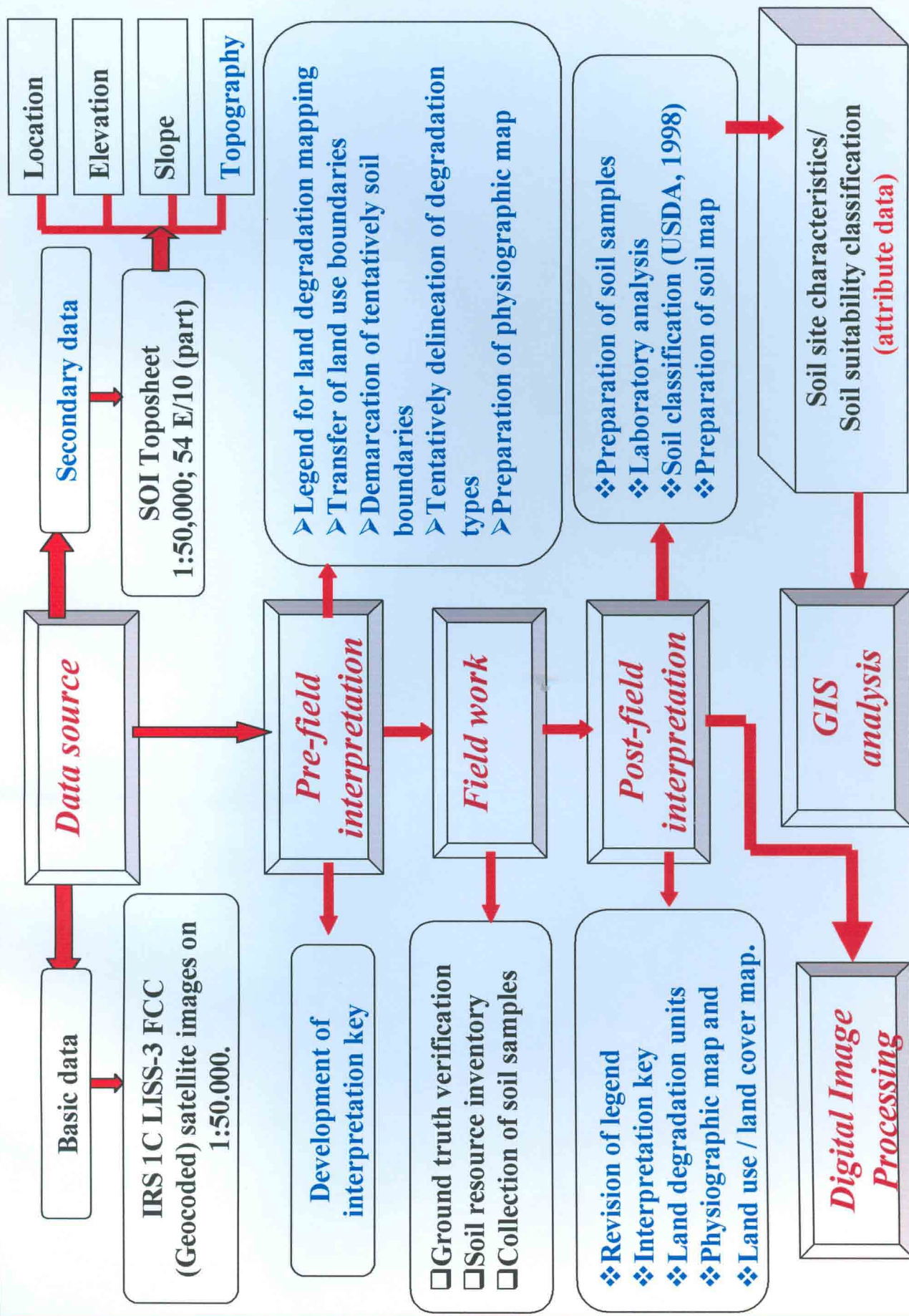


Fig.3.5 Steps involved & visual image processing

4. RESULTS AND DISCUSSION

The results obtained during the present investigations are presented under the following headings: -

- 4.1 *Soil characteristics*
- 4.2 *Soil Mineralogy*
- 4.3 *Soil classification*
- 4.4 *Soil degradation*
- 4.5 *Generation of thematic maps*
- 4.6 *Land evaluation*
- 4.7 *Land use / Land cover*
- 4.8 *Suggestive measures for reclamation of degraded soils*

4.1 Soil Characteristics

Twelve profiles representing different physiographic units of the study area were studied for their characteristics (Fig. 4.1). Twelve soil series were established. Morphological, physical, physico-chemical, chemical and fertility characteristics of the soil series are furnished below.

4.1.1 Morphological Characteristics

Morphological characteristics of the soils were studied and described by adopting the guidelines laid out in the soil survey manual (Soil Survey Staff, 1975). The detailed morphological features are furnished in Table 4.1 and their descriptions are given below.

LOCATION OF SOIL PROFILES

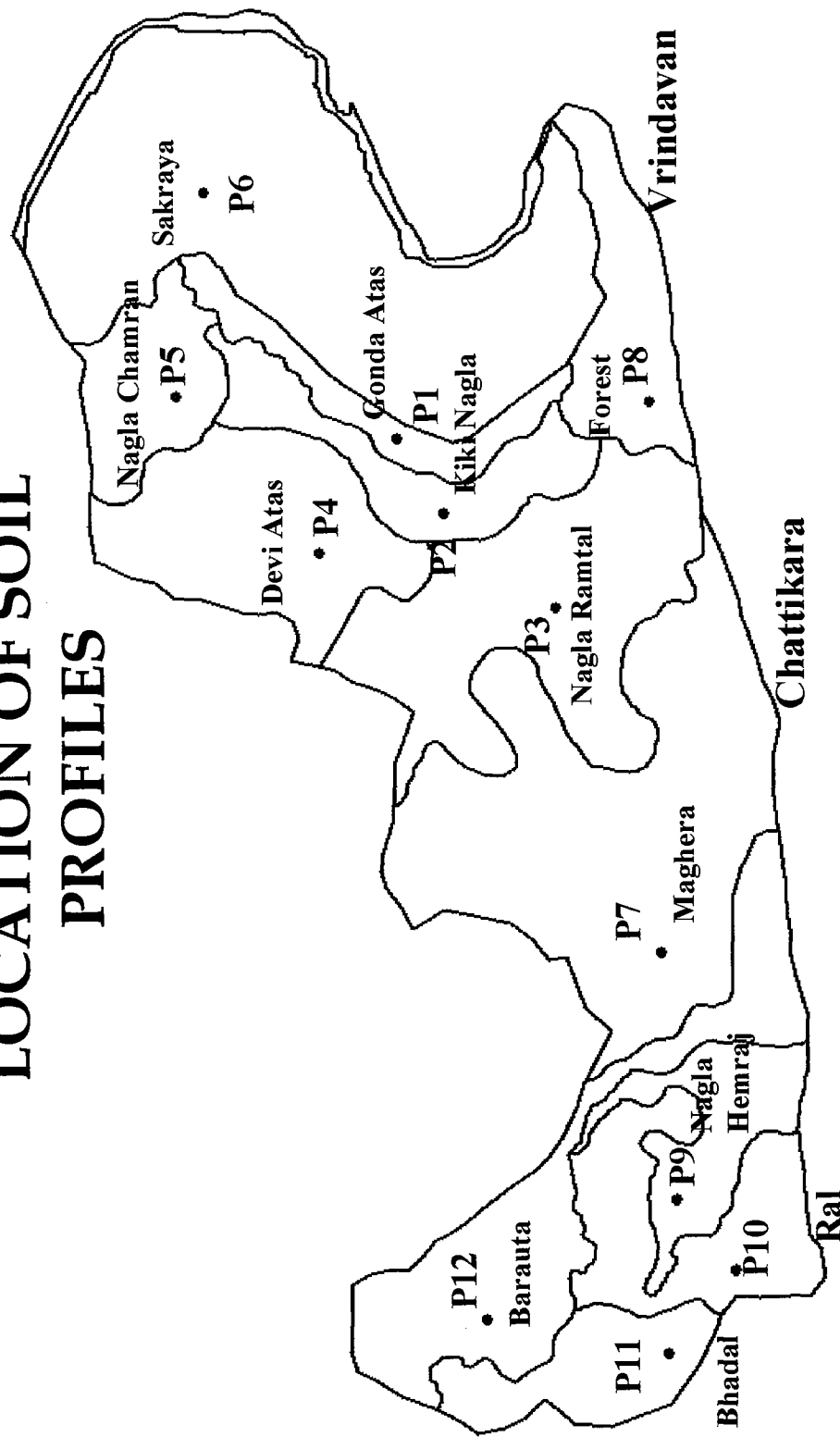


Fig. 4.1

4.1.1.1 General descriptions of the representative profiles

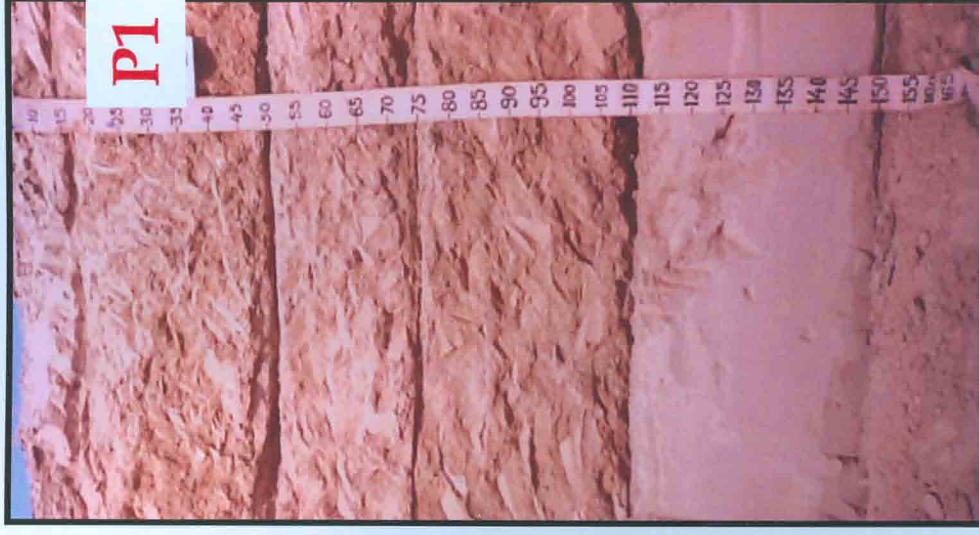
PROFILE 1 / Gonda Atas Series / Plate 1

Location	: Top of ravine, between Gonda Atas and Kiki Ka Nagla
Physiography unit	: Undulating recent alluvial plain
Slope per cent	: 5- 10 per cent
Drainage	: imperfect
Erosion	: e_3 (strong)
Stoniness	: Nil
Parent material	: Alluvial
Vegetation	: Babool, neem, kekar, etc.
Land Use	: Fallow
Classification	: Coarse loamy, calcareous, mixed hyperthermic, Typic Calciustepts

Horizon	Description
A	0-15 cm; very pale brown (10YR7/3) dry and yellowish brown (10YR5/4) moist; sandy loam; massive; slightly hard, very friable, non-sticky non-plastic; strong effervescence with dilute acid; very fine, common roots; fine and medium, common calcium carbonate concretions; clear smooth boundary.



*b – Landscape of ravineous area
(Gonda Atas)*



*a – Soil profile
(Gonda Atas series)*

Plate 4.1

- Bw1k 15-50 cm; yellowish brown (10YR5/4) moist; loam; fine, moderate, subangular blocky; friable, slightly sticky slightly plastic; violent effervescence with dilute acid; very fine, few pores; very fine, common roots; fine and medium, common calcium carbonate concretions; clear smooth boundary.
- Bw2 50 - 75; yellowish brown (10YR5/4) moist; sandy loam; fine, weak, subangular blocky; friable, non-sticky, non-plastic; strong effervescence with dilute acid; fine, common pores; fine and medium, common calcium carbonate concretions; clear smooth boundary.
- Bw3 75 - 112; yellowish brown (10YR5/4) moist; loam; fine, weak, subangular blocky; friable, non-sticky, non-plastic; strong effervescence with dilute acid; very fine, common pores; fine, few calcium carbonate concretions; clear smooth boundary.
- C 112 - 150; dark brown (10YR4/3) moist; loamy sand; massive; loose, non-sticky, non-plastic; slight effervescence with dilute acid; very fine, few pores.

PROFILE 2 / Kiki Nagla Series / Plate 2

- Location : Between Gonda Atas and Kiki Ka Nagla
- Physiography unit : Undulating recent alluvial plain
- Slope per cent : 5 - 10 per cent
- Drainage : well drained
- Erosion : e₂ (moderate)



*b – Landscape of undulating area
(Kiki Ka Nagla)*



*a – Soil profile
(Kiki Nagla series)*

Plate 4.2

Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Babool, neem, kekar, etc.
Land Use	: Agriculture
Classification	: Coarse loamy, calcareous, mixed, hyperthermic, Typic Haplustepts.

Horizon	Description
Ap	0-10 cm; light brownish gray (10YR6/2) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, friable, non-sticky, non-plastic; strong effervescence with dilute acid; fine and medium, many roots; fine and medium, few calcium carbonate concretions; clear smooth boundary.
A12	10-25 cm; pale brown (10YR6/3) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, friable, non-sticky, non-plastic; slight effervescence with dilute acid; fine and very fine, common roots; medium, common calcium carbonate concretions; clear smooth boundary.
Bw1	25-50 cm; yellowish brown (10YR5/4) moist; sandy loam; moderate, weak, subangular blocky; friable, non-sticky, non-plastic; slight effervescence with dilute acid; very fine, common pores; very fine and medium, common roots; very fine, few calcium carbonate concretions; clear smooth boundary.

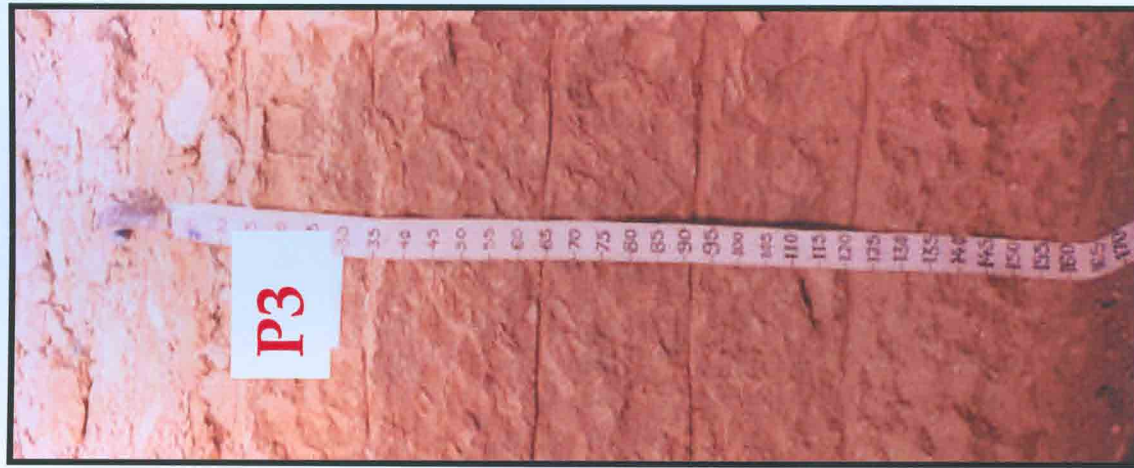
- Bw2 50-85 cm; yellowish brown (10YR5/4) moist; sandy loam; moderate, weak, subangular blocky; friable, non-sticky, non-plastic; strong effervescence with dilute acid; very fine and fine, common pores; very fine, few roots; fine, few calcium carbonate concretions; diffuse smooth boundary.
- Bc 85-115 cm; dark yellowish brown (10YR4/4) moist; sandy clay loam; moderate, weak, subangular blocky; friable, non-sticky, non-plastic; slight effervescence with dilute acid; very fine and fine, common pores; very fine, few roots; diffuse smooth boundary.
- C 115-150 cm; yellowish brown (10YR5/4) moist; massive; friable, non-sticky, non-plastic; few, common pores.

PROFILE 3 / Nagla Ramtal Series / Plate 3

- Location : 500m North-West Nagla Ramtal village
- Physiography unit : Old alluvial plain
- Slope per cent : 1 - 3 per cent
- Drainage : Moderately well drained
- Erosion : e_0 (nil)
- Stoniness : Nil
- Parent material : Alluvium
- Vegetation : Babool, neem, Deshi etc.
- Land Use : Agriculture
- Classification : Fine loamy, mixed, hyperthermic, Typic Haplustalfs



b – Landscape of Nagla Ramtal Series



*a – Soil profile
(Nagla Ramtal series)*

Plate 4.3

Horizon	Description
Ap	0-15 cm; pale brown (10YR6/3) dry and dark brown (10YR4/3) moist; sandy clay loam; massive; hard, friable, sticky, plastic; fine and medium, many pores; medium, common roots; clear smooth boundary.
AB	15-35 cm; yellowish brown (10YR5/4) moist; sandy clay loam; moderate, medium, subangular blocky; slightly hard, friable, sticky and plastic; fine and medium, many pores; very fine, few roots; clear smooth boundary.
Bt1	35-65 cm; dark brown (10YR3/3) moist; clay loam; moderate, medium, subangular blocky; friable, very sticky, plastic; few, fine, faint mottles; very fine and medium, many and common pores; very fine and fine, common roots; diffuse wavy boundary.
Bt2	55-95 cm; dark brown (10YR4/3) moist; clay loam; moderate, medium, subangular blocky; friable, very sticky, plastic; common, medium, distinct mottles; medium, few pores; very fine, common roots; diffuse wavy boundary.
Bt3	95-123 cm; dark brown (10YR3/3) moist; clay loam; moderate, medium, subangular blocky; friable, very sticky, plastic; few, medium, faint mottles; very fine, many pores; very fine, few roots; clear smooth boundary.
Bc	123-165 cm; dark brown (10YR4/3) moist; sandy clay loam; moderate, weak, subangular blocky; friable, sticky, plastic;

few, fine, faint mottles; very fine and fine, common pores;
very fine, few roots; strong effervescence with dilute acid.

PROFILE 4 / Devi Atas Series / Plate 4

Location	: 1 Km from Devi Atas towards Gonda Atas, 1/2 Km left of road
Physiography unit	: Undulating recent alluvial plain
Slope per cent	: 5 - 10 per cent
Drainage	: moderately well drained
Erosion	: e ₂ (moderate)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Babool, neem, kekar, etc.
Land Use	: Agriculture
Classification	: Fine loamy, calcareous, mixed, hyperthermic, Typic Haplustepts.

Horizon	Description
Ap	0-20 cm; pale brown (10YR6/3) dry and dark brown (10YR4/3) moist; sandy loam; massive; hard, friable, slightly-sticky non-plastic; strong effervescence with dilute acid; fine and medium, common roots; fine and medium, common calcium carbonate concretions; clear smooth boundary.

- Bw1 20-45 cm; dark brown (10YR4/3) moist; sandy clay loam; moderate, weak, subangular blocky; friable, slightly-sticky, slightly-plastic; strong effervescence with dilute acid; very fine and medium, many and few pores; very fine, common roots; very fine and fine, few calcium carbonate concretions; clear smooth boundary.
- Bw2 45-73 cm; dark brown (10YR4/3) moist; sandy clay loam; moderate, weak, subangular blocky; friable, sticky, slightly-plastic; strong effervescence with dilute acid; very fine and fine, common pores; very fine, common roots; fine, few calcium carbonate concretions; diffuse wavy boundary.
- Bw3 73-105 cm; dark brown (10YR4/3) moist; sandy clay loam; moderate, weak, subangular blocky; friable, sticky, slightly-plastic; strong effervescence with dilute acid; very fine and medium, few pores; very fine, common roots; fine, many calcium carbonate concretions; diffuse wavy boundary.
- Bc 105-140 cm; dark yellowish brown (10YR4/4) moist; sandy clay loam; moderate, weak, subangular blocky; friable, sticky, slightly plastic; violent effervescence with dilute acid; fine and medium, common pores; very fine, common roots; fine and medium, many calcium carbonate concretions; clear smooth boundary.
- C 140-165 cm; yellowish brown (10YR5/4) moist; sandy loam; massive; very friable, non-sticky, non-plastic; slight effervescence with dilute acid; very fine and fine, common



B – Landscape of Devi Atas Series



*a - Soil profile
(Devi Atas series)*

Plate 4.4

pores; very fine, common roots; fine and medium, many calcium carbonate concretions.

PROFILE 5 / Nagla Chamran Series / Plate 5

Location	: 2Km towards Behari Nagla
Physiography unit	: Undulating recent alluvial plain
Slope per cent	: 5 - 10 per cent
Drainage	: moderately well drained
Erosion	: e ₂ (moderate)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Kekar, Babool, neem <i>etc.</i>
Land Use	: Agriculture
Classification	: Fine loamy, mixed, hyperthermic, Fluventic Haplustepts.

Horizon	Description
Ap	0-15 cm; pale brown (10YR6/3) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, friable, slightly-sticky, non-plastic; fine, many pores; fine, few roots; clear smooth boundary.
Bw1	15-50 cm; dark brown (10YR4/3) moist; loam; moderate, medium, subangular blocky; friable, sticky, slightly-plastic; slight effervescence with dilute acid; fine and medium, many and few pores; fine, common roots; diffuse wavy boundary.



b – Landscape of Nagla Chamran Series



*a - Soil profile
(Nagla Chamran series)*

Plate 4.5

Bw2	50 - 76; dark brown (10YR3/3) moist; loam; moderate, medium, subangular blocky; friable, slightly-sticky, slightly-plastic; fine and medium, many and few pores; very fine, common roots; clear smooth boundary.
Bw3	76 - 110; dark brown (10YR4/3) moist; clay loam; moderate, weak, subangular blocky; friable, sticky, slightly plastic; very fine and fine, few and common pores; very fine, few roots; clear smooth boundary.
Bw4	110 - 150; dark brown (10YR4/4) moist; clay loam; moderate, medium, subangular blocky; friable, sticky, slightly-plastic; fine, common pores; very fine, few roots.

PROFILE 6 / Sakraya Series / Plate 6

Location	: 2Km from Sakraya village towards Yamuna River
Physiography	: Active flood plain
Slope per cent	: 0 - 1 per cent
Drainage	: Well drained
Erosion	: e_1 (very severe)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Neem, Kekar, etc.
Land Use	: Agriculture
Classification	: Coarse loamy, calcareous, mixed, hyperthermic, Typic Ustifluvents



*b – Landscape of active flood plain
(Sakraya series)*



*a – Soil profile
(Sakraya series)*

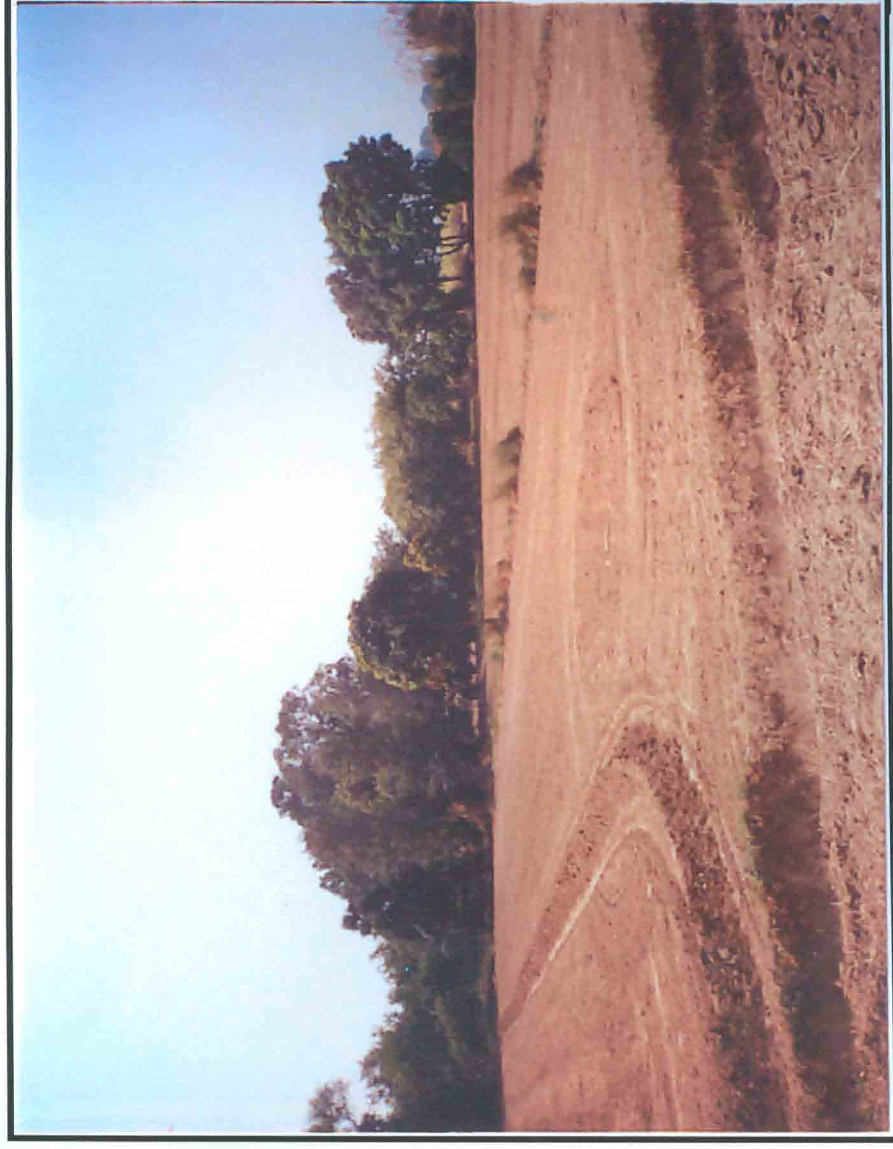
Plate 4.6

Horizon	Description
Ap	0-20cm; light brownish gray (10YR6/2) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, friable, non-sticky, non-plastic; slight effervescence; clear smooth boundary.
AC	20-60cm; pale brown (10YR6/3) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, very friable, non-sticky, non-plastic consistency; strong effervescence with dilute acid; very fine to medium common to few pores; very fine to medium common to few roots; clear smooth boundary.
1C	60-75; light gray (10YR7/1) dry and grayish brown (10YR5/2) moist; loamy sand; massive; loose, loose, non-sticky, non-plastic; no effervescence with dilute acid; fine to medium, few roots; clear smooth boundary.
2C	75-87; pale brown (10YR6/3) dry and brown (10YR5/3) moist; loamy sand; massive; slightly hard, friable, non-sticky, non-plastic; strong effervescence with dilute acid; very few coarse pores; very fine to fine common roots; clear smooth boundary.
3C1	87-110; light gray (10YR7/1) dry and grayish brown (10YR5/2) moist; loamy sand; massive; loose, loose, non-sticky, non-plastic; no effervescence with dilute acid; fine few pores; fine few roots; clear smooth boundary.

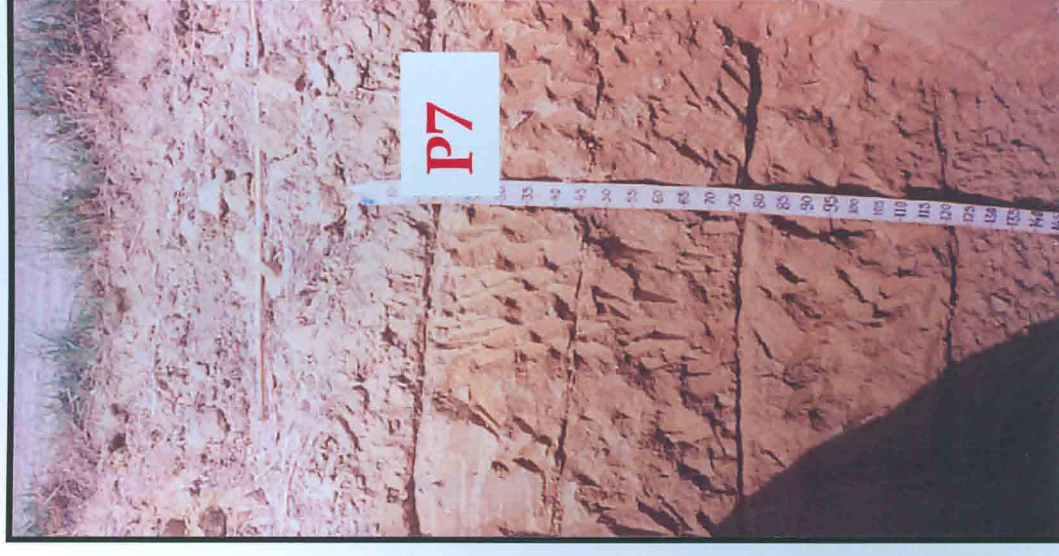
- 3C2 110-150; light gray (10YR7/1) dry and light brownish gray (10YR6/2) moist; loamy sand; massive; loose, loose, non-sticky, non-plastic; no effervescence with dilute acid; fine few roots; clear smooth boundary.
- 4C 150+; dark yellowish brown (10YR4/4) moist; sandy loam; massive; loose, friable, non-sticky, non-plastic; strong effervescence with dilute acid; very fine few pores; very fine few roots.

PROFILE 7 / Maghera series/Plate 7

- Location : 1Km from village Maghera towards canal
- Physiography unit : Old alluvial plain
- Slope per cent : 1 - 3 per cent
- Drainage : Well drained
- Erosion : e_0 (nil)
- Stoniness : Nil
- Parent material : Alluvium
- Vegetation : Babool, neem, etc.
- Land Use : Agriculture
- Classification : Fine loamy, mixed, hyperthermic, Fluventic Haplustepts.



b – Landscape of Maghera Series



*a – Soil profile
(Maghera series)*

Plate 4.7

Horizon	Description
Ap	0-20 cm; pale brown (10YR6/3) dry and brown (10YR5/3) moist; sandy loam; massive; slightly hard, friable, slightly-sticky non-plastic; fine and coarse, many and few roots; clear smooth boundary.
Bw1	20-50 cm; yellowish brown (10YR5/6) moist; sandy clay loam; medium, moderate, subangular blocky; friable, slightly sticky non-plastic; fine and medium, many and few pores; common fine roots; clear smooth boundary.
Bw2	50-82 cm; yellowish brown (10YR5/4) moist; sandy clay loam; medium, moderate, subangular blocky; friable, slightly sticky non-plastic; very fine and medium, common and few pores; common and few fine and medium roots; clear smooth boundary.
BC	82-125 cm; dark yellowish brown (10YR4/6) moist; sandy loam; medium, weak, subangular blocky; friable, slightly sticky non-plastic; very fine and fine, many pores; fine and medium, few roots; clear smooth boundary.
Ck	125 - 150cm; brown (10YR5/3) moist; sandy loam; medium, weak, subangular blocky; friable, slightly sticky non-plastic; very fine and fine, common pores; few, very fine roots; fine and coarse, many and few calcium carbonate concretions.

PROFILE 8/Sunrakh Series /Plate 8

Location	: Vrindavan Reserve Forest
Physiography unit	: Undulating recent alluvial plain
Slope per cent	: 5 - 10 per cent
Drainage	: Poorly drained
Erosion	: e ₄ (severe)
Stoniness	: Nil
Parent material	: Alluvial
Vegetation	: Kekar, etc.
Land Use	: Reserve Forest
Classification	: Coarse loamy, calcareous, mixed hyperthermic, Fluventic Haplustepts.

Horizon	Description
A	0-20 cm; light yellowish brown (10YR6/4) dry and yellowish brown (10YR5/4) moist; sandy clay loam; moderate, weak, subangular blocky; hard, friable, slightly-sticky, non-plastic; slight effervescence with dilute acid; very fine and fine pores; fine, many roots; fine and medium, few calcium carbonate concretions; clear smooth boundary.
Bw1	20-50 cm; light yellowish brown (10YR6/4) dry and yellowish brown (10YR5/4) moist; sandy loam; moderate, weak, subangular blocky; slightly hard, friable, non-sticky, non-plastic; strong effervescence with dilute acid; very fine,

b – Landscape of degraded forest (Sunrakh Series)



a – Soil profile(Sunrakh series)

Plate 4.8

- common pores; very fine, common roots; fine and medium, common calcium carbonate concretions; clear smooth boundary.
- Bw2k 50-85 cm; pale brown (10YR6/3) dry and yellowish brown (10YR5/4) moist; sandy loam; moderate, weak, subangular blocky; slightly hard, friable, non-sticky, non-plastic; violent effervescence with dilute acid; very fine, common pores; very fine, few roots; medium and coarse, many calcium carbonate concretions; clear smooth boundary.
- Bck 85-120 cm; yellowish brown (10YR5/4) dry and dark yellowish brown (10YR4/4) moist; loam; moderate, weak, subangular blocky; slightly hard, friable, slightly-sticky, non-plastic; violent effervescence with dilute acid; very fine and fine, few pores; fine, few roots; medium and coarse, many calcium carbonate concretions; clear smooth boundary.
- C 120 - 150; dark yellowish brown (10YR4/4) moist; sandy loam; moderate, weak, subangular blocky; slightly hard, friable, non-sticky, non-plastic; slight effervescence with dilute acid; very fine and fine, few pores; fine, few roots; fine and medium, few calcium carbonate concretions.

PROFILE 9 / Nagla Hemraj series /Plate 9

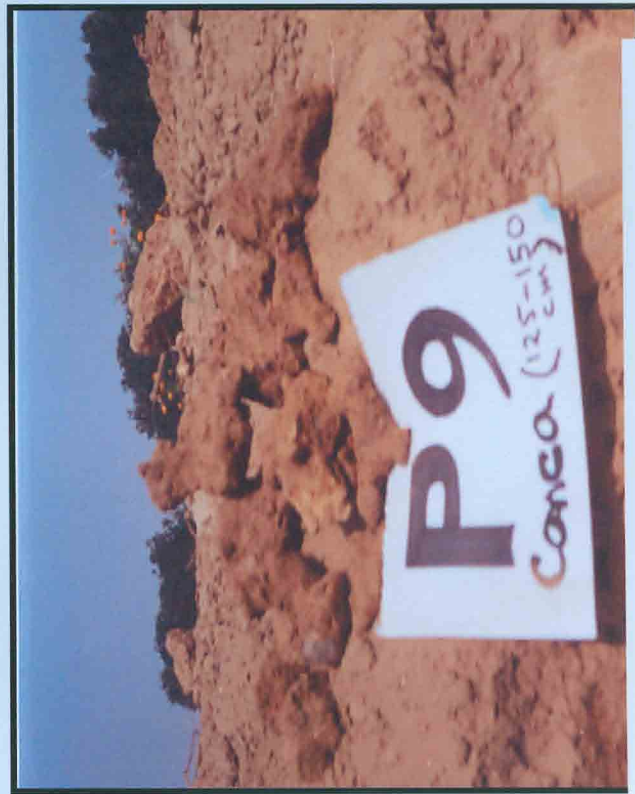
- Location : 1Km east Ral village and behind Orchard
- Physiography unit : Old alluvial plain
- Slope per cent : 1 - 3 per cent

Plate 4.9

b-
Landscape
of Nagla
Hemraj
series



a-Soil profile
(Nagla Hemraj series)



c - Calcium Carbonate concretions (conca) at
lower depth of profile 9

Drainage	: Well drained
Erosion	: e_0 (nil)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Babool, neem <i>etc.</i>
Land Use	: Agriculture/ Orchard (double crop)
Classification	: Fine loamy, calcareous, mixed, hyperthermic, Typic Haplustepts.

Horizon	Description
Ap	0-20 cm; pale brown (10YR6/3) dry and dark brown (10YR4/3) moist; sandy loam; massive; slightly hard, friable, slightly-sticky non-plastic; slight effervescence with dilute acid; fine and medium, many and few roots; clear smooth boundary.
AC	20-52 cm; yellowish brown (10YR5/4) moist; sandy clay loam; moderate, weak, subangular blocky; friable, slightly-sticky, non-plastic; slight effervescence with dilute acid; very fine and fine, common pores; very fine and fine, common roots; clear smooth boundary.
1C	52-90 cm; dark yellowish brown (10YR4/6) moist; sandy clay loam; massive; friable, slightly-sticky, non-plastic; slight effervescence with dilute acid; very fine and medium, few pores; fine and coarse, few roots; clear smooth boundary.

- 2C1 90-125 cm; dark yellowish brown (10YR4/6) moist; sandy loam; massive; friable, slightly-sticky, non-plastic; violent effervescence with dilute acid; very fine, common pores; very fine, few roots; fine and coarse, many calcium carbonate concretions; clear smooth boundary.
- 2C2k 125-150 cm; yellowish brown (10YR5/4) moist; sandy loam; massive; friable, slightly-sticky, non-plastic; violent effervescence with dilute acid; very fine, few pores; very fine, few roots; medium and coarse, many calcium carbonate concretions.

PROFILE 10/ Ral Sries /Plate 10

- Location : 1Km from village Bhadal towards village Ral
- Physiography unit : Old alluvial plain
- Slope per cent : 1 - 3 per cent
- Drainage : Moderately well drained
- Erosion : e_0 (nil)
- Stoniness : Nil
- Parent material : Alluvium
- Vegetation : Babool, Kekar, Jamun, Sesam etc.
- Land Use : Agriculture
- Classification : Fine loamy, mixed, hyperthermic, Typic Haplustepts



b – Well grown sugarcane in Ral series



*a – Soil profile
(Ral series)*

Plate 4.10

Horizon	Description
Ap	0-15 cm; pale brown (10 YR6/3) dry and dark grayish brown (10YR4/2) moist; sandy clay loam; massive; hard, friable, slightly-sticky non-plastic; fine, medium, many roots; clear smooth boundary.
Bw1	15-43 cm; dark brown (10YR4/3) moist; sandy clay loam; medium, weak, subangular blocky; friable, slightly sticky non-plastic; fine and very fine, many pores; few, fine and very fine roots; clear smooth boundary.
Bw2	43 - 80 cm; dark yellowish brown (10YR4/4) moist; sandy clay loam; medium, weak, subangular blocky; friable, slightly sticky slightly-plastic; common, fine, distinct mottles; very fine and fine, many pores; few, very fine roots; very fine, few iron concretions; diffuse smooth boundary.
Bc	80 -125 cm; brown (10YR5/3) moist; sandy clay loam; medium, weak, subangular blocky; friable, slightly sticky and slightly-plastic; many, medium, distinct mottles; very fine and fine, many pores; few, very fine roots; fine and medium, many iron concretions; diffuse smooth boundary.
C	125 - 150 cm; brown (10YR5/3) moist; sandy clay loam; massive; friable, slightly sticky and slightly plastic; very fine and fine, many pores.

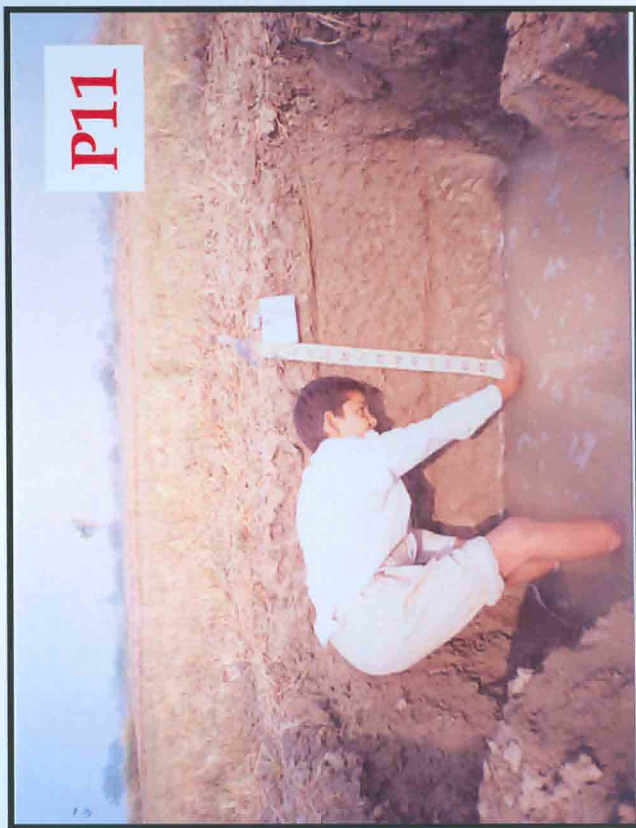
PROFILE 11/ Bhadal Sries /Plate 11

Location	: 1Km from North village Bhadal, right side of the road
Physiography unit	: Old alluvial plain
Slope per cent	: 1 - 3 per cent
Drainage	: Imperfectly drained
Erosion	: e_0 (nil)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Babool, Kekar, Jamun, Sesam etc.
Land Use	: Agriculture
Classification	: Fine silty, calcareous, mixed, hyperthermic, Typic Endoaquents

Horizon	Description
Ap	0-18 cm; dark grayish brown (2.5Y4/2) moist; silt loam; massive; very-sticky and very-plastic; fine, medium, common roots; clear smooth boundary.
A12	18-50 cm; grayish brown (2.5Y5/2) moist; silt clay; massive; very-sticky and very-plastic; very fine, few roots; clear smooth boundary.
A13	50 - 75cm; grayish brown (2.5Y5/2) moist; silty clay; massive; very-sticky and very-plastic; water table at 75 cm depth.



*b – Landscape
of Bhadal series*



*a – Soil profile
(Bhadal series)*

PROFILE 12 / Barauta Series/Plate 12

Location	: 1Km North village Barauta
Physiography unit	: Old alluvial plain
Slope per cent	: 1 - 3 per cent
Drainage	: Imperfectly drained
Erosion	: e_0 (nil)
Stoniness	: Nil
Parent material	: Alluvium
Vegetation	: Babool, Kekar
Land Use	: Agriculture (Fallow)
Classification	: Fine loamy, calcareous, mixed, hyperthermic, Typic Ustiflvents

Horizon	Description
A11	0-15 cm; dark grayish brown (10YR4/2) moist; sandy loam; massive; friable, non-sticky non-plastic; very fine and fine, common pores; clear smooth boundary.
A12	15-45 cm; dark brown (10YR4/3) moist; sandy clay loam; medium, weak, subangular blocky; friable, slightly sticky non-plastic; fine and very fine, many pores; few, fine and medium roots; clear smooth boundary.
Ck1	45-82 cm; dark yellowish brown (10YR4/4) moist; loam; massive; friable, slightly sticky non-plastic; violent



*b – Landscape of barauta series –
salt incrustation*



*a – Soil profile
(Barauta series)*

Plate 4.12

- effervescence with dilute acid; very fine and fine, common pores; few, medium and fine roots; medium and coarse, many calcium carbonate concretions; clear smooth boundary.
- Ck2 82-110 cm; brown (10YR5/3) moist; sandy clay loam; massive; friable, slightly sticky non-plastic; violent effervescence with dilute acid; very fine and fine, common pores; few, fine roots; fine and medium, common calcium carbonate concretions; fine and medium, many iron concretions; clear smooth boundary.
- Ck3 110-145 cm; brown (10YR5/3) moist; loam; massive; friable, slightly sticky slightly-plastic; violent effervescence with dilute acid; very fine and fine, common pores; fine and medium, few calcium carbonate concretions; fine and medium, many iron concretions.

4.1.1.1 Soil depth

Soil depth is an important property that directly influences the yield of crops. The deep solum provides higher soil volume for nutrient and water extraction (Hajare *et al.*, 1990). The derived soil climatic parameters *viz.* plant available water capacity (PAWC), soil effective rainfall and the length of growing period (LGP) were directly associated with soil depth and showed significant and positive 'r' values with the yield of cotton, pigeon pea, sorghum, groundnut and soybean (Yadav *et al.*, 1995).

The depth of soil series in the study area is observed to be very deep, having depth more than 100 cm. Very deep soils were developed on

stable land forms and their depth was related to the depth of alluvium in these land forms (Graham *et al.*, 1990).

4.1.1.2 Soil colour

Soil colour is one of the important basic properties that helps to identify the kinds of soil and recognize the successions of soil horizons in soil profiles. Soil colour helps also indirectly in the enhancement of chemical and biogeochemical reactions by the absorption of solar heat on the soil surface (Bhattacharjee, 1997).

All soil series in the study area having the hue of 10YR and lighter colour in the surface horizons than sub-surface horizons. In contrast, profile 11(Bhadal series) having hue of 2.5 Y and darker colour in surface horizon than subsurface horizon. Generally all the series having value of 4 to 5 and chroma 3 to 4. Sakraya series having value 6 and 7 and chroma of 1 to 3 when dry and value of 4 to 5 with chroma of 2 to 4 when moist.

The dominance of yellowish colour was indicative of the presence of sesquioxides and oxidizing conditions due to the well drained condition of the soil pedon that could be attributed to the ferruginous nature of parent material (Sharma *et al.*, 1999). In these soils, the colour was primarily inherited from the parent material, but has been somewhat modified by pedo-chemical and edaphological factors.

The darker chroma in P11 soil profile may be due to formation of non-hydrated compounds (Singh *et al.*, 1994b). The soils remain saturated during rainy season and subsequently oxidizing condition prevails. Reduction of Fe-Mn compounds takes place in dry conditions. So this soil showed colour of high chroma.

In general it was found that topography of the area has also affected the colour development, which is in agreement with the observations of Buol *et al.* (1973).

4.1.1.3 Soil structure and consistency

The soil structure refers to the aggregation of the primary soil particles into larger units known as ped and reflects the stage of soil development in different levels. It was described in terms of grade, class and type. All the soils have massive structure in surface horizons (Table 4.1). Profile 6 and 11 showed massive structure throughout the profiles. Some sub-surface horizons of other profiles have structure of fine to medium, weak to moderate sub-angular blocky. The weak structure development in these soils might be due to low clay and organic carbon content and the presence of lime concentrations as confirmed by laboratory analysis (Table 4.2; Table 4.6).

The process of eluviation and illuviation seems to have some distinctive effect in these soils. The dominance of mica type of clay (Mohanty, 1997) imparted moderate strength to bind the particles together in the formation of the medium, moderate sub angular blocky peds.

Soil consistency in all series were hard to slightly hard when dry, friable to loose when moist. Similarly consistency were varied from non-sticky non-plastic (Gonad Atas, Kiki Nagla, Sunrakh and Sakraya series), slightly sticky non plastic in Maghera and Nagla Hemraj, slightly sticky slightly plastic (Devi Atas, Nagla Chamran and Ral series) to Very sticky plastic in Nagla Ramtal series and very sticky very plastic in Bhadal series. Variation in soil structure and consistency are mainly associated with variation in amount of clay, silt, coarse fragments and free Fe_2O_3 .

Table 4.1. Morphological characteristics of soils

Hori- zon	Depth cm	Efferv- escence	Boun- dary	Matrix colour		Mottles	Struc- ture	Tex- ture	Consistency			Porosity	Roots	Conca	Conir
				Dry	Moist				D	M	W				
P1-Gonda Atas Series															
A	0-15	es	cs	10YR7/3	10YR5/4		massive	sl	sh	vfr	sopo	nil	vf c	f,m c	nil
Bw1k	15-50	ev	cs		10YR5/4		f 2 sbk	l		fr	ssps	vf f	vf c	f,m c	nil
Bw2	50-75	es	cs		10YR5/4		f 1 sbk	sl		fr	sopo	f c	nil	f,m c	nil
Bw3	75-112	es	cs		10YR5/4		f 1 sbk	l		fr	sopo	vf c	nil	f f	nil
C	112-150	e			10YR4/3		massive	ls		l	sopo	vf f	nil		nil
P2- Kiki Nagla Series															
Ap	0-10	es	cs	10YR6/2	10YR5/3		massive	sl	sh	fr	sopo	nil	f,m m	f,m f	nil
A12	10 25	es	cs	10YR6/3	10YR5/3		massive	sl	sh	fr	sopo	nil	f,vf c	m c	nil
Bw1	25-50	e	cs		10YR5/4		m1sbk	sl		fr	sopo	vf c	vf,m c	vf f	nil
Bw2	50-85	es	ds		10YR5/4		m1sbk	sl		fr	sopo	vf,f c	vf f	f f	nil
Bc	85-115	e	ds		10YR4/4		m1sbk	scl		fr	sopo	vf,f c	vf f	nil	nil
C	115-150	nil			10YR5/4		massive	sl		fr	sopo	f c	nil	nil	nil
P3- Nagla Ramtal Series															
Ap	0-15	nil	cs	10YR6/3	10YR4/3		massive	scl	h	fr	sp	f,m m	m c	nil	nil
AB	15-35	nil	cs		10YR5/4		m 2 sbk	scl	sh	fr	sp	f,m m	vf f	nil	nil
Bt1	35-65	nil	dw		10YR3/3	f 1 f	m 2 sbk	cl	fr	vsp	vf,m	m,c	vf,f c	nil	nil
Bt2	65-95	nil	dw		10YR4/3	c 2 d	m 2 sbk	cl		fr	vsp	m f	vf c	nil	nil
Bt3	95-123	nil	cs		10YR3/3	f 2 f	m 2 sbk	cl		fr	vsp	vf m	vf f	nil	nil
Bc	123-165	es			10YR4/3	f 1 f	m 1 sbk	scl		fr	sp	vf,f c	vf f	f,m m	nil

Table 4.1 contd...

Hori- zon	Depth cm	Efferv- escence	Boun- dary	Matrix colour		Mottles	Struc- ture	Tex- ture	Consistency			Porosity	Roots	Conca	Conir
				Dry	Moist				D	M	W				
P4- Devi Atas Series															
Ap	0-20	es	cs	10YR6/3	10YR4/3		massive	sl	h	fr	sspo	nil	f, m c	f, m c	nil
Bw1	20-45	es	cs		10YR4/3		m 1 sbk	scl		fr	ssps	vf, m m, c	vf c	vf, f f	nil
Bw2	45-73	es	dw		10YR4/4		m 1 sbk	scl		fr	sps	vf, f c	vf c	f f	nil
Bw3	73-105	es	dw		10YR4/3		m 1 sbk	scl		fr	sps	vf, m f	vf c	f m	nil
Bc	105-140	ev	cs		10YR4/4		m 1 sbk	scl		fr	sps	f, m c	vf c	f, m m	nil
C	140-165	e			10YR5/4		massive	sl		vfr	sopo	vf, f c	vf c	f, m m	nil
P5- Nagla Chamnan Series															
Ap	0-15	nil	cs	10YR6/3	10YR5/3		massive	sl	sh	fr	sspo	f m	f f	nil	nil
Bw1	15-50	e	dw		10YR4/3		m 2 sbk	l		fr	sps	f, m m, f	f c	nil	nil
Bw2	50-76	nil	cs		10YR3/3		m 2 sbk	l		fr	ssps	vf, m f, m	vf c	nil	nil
Bw3	76-110	nil	cs		10YR4/3		m 1 sbk	cl		fr	sps	vf, f f, c	vf f	nil	nil
Bw4	110-150	nil			10YR4/4		m 2 sbk	cl		fr	sps	f c	vf f	nil	nil
P6- Sakraya Series															
Ap	0-20	e	cs	10YR6/2	10YR5/3		massive	sl	sh	fr	sopo	nil	nil	nil	nil
Ac	20-60	es	cs	10YR6/3	10YR5/3		massive	sl	sh	vfr	sopo	vf, m c, f	vf, m c, f	nil	nil
1C	60-75	nil	cs	10YR7/1	10YR5/2		massive	ls	l	l	sopo	nil	f, m f	nil	nil
2C	75-87	es	cs	10YR6/3	10YR5/3		massive	ls	sh	fr	sopo	vf c	vf, f c	nil	nil
3C1	87-110	nil	cs	10YR7/1	10YR5/2		massive	ls	l	l	sopo	f f	f f	nil	nil
3C2	110-150	nil	cs	10YR7/1	10YR6/2		massive	ls	l	l	sopo	nil	f f	nil	nil
4C	150+	es			10YR4/4		massive	sl		fr	sopo	vf m	vf f	nil	nil

Table 4.1 contd...

Hori- zon	Depth cm	Efferv- escence	Boun- dary	Matrix colour		Mottles	Struc- ture	Tex- ture	Consistency			Porosity	Roots	Conca	Conir
									D	M	W				
				Dry	Moist										
P7- Maghera Series															
Ap	0-20	nil	cs	10YR6/3	10YR5/3		massive	sl	sh	fr	sspo	nil	f,c m,f	nil	nil
Bw1	20-50	nil	cs		10YR5/6		m 2 sbk	scl		fr	sspo	f,m m,f	f c	nil	nil
Bw2	50-82	nil	cs		10YR5/4		m 2 sbk	scl		fr	sspo	vf,m c,f	f,m c,f	nil	nil
Bc	82-125	nil	cs		10YR4/6		m 1 sbk	sl		fr	sspo	vf,f m	f,m f	nil	nil
Ck	125-150	ev			10YR5/3		m 1 sbk	sl		fr	sspo	vf,f c	vf f	f,c m,f	nil
P8- Sunrakh Series															
A	0-20	e	cs	10YR6/4	10YR5/4		massive	scl	h	fr	sspo	vf,f c	f m	f,m f	nil
Bw1	20-45	es	cs	10YR6/4	10YR5/4		m 1 sbk	sl	sh	fr	sopo	vf c	vf c	f,m c	nil
Bw2k	45-85	ev	cs	10YR6/3	10YR5/4		m 1 sbk	sl	sh	fr	sopo	vf c	vf f	m,c m	nil
Bck	85-120	ev	cs	10YR5/4	10YR4/4		m 1 sbk	l	sh	fr	sspo	vf,f f	f f	m,c m	nil
C	120-150	e			10YR4/4		m 1 sbk	sl	sh	fr	sopo	vf,f f	f f	f,m f	nil
P9- Nagla Henraj Series															
Ap	0-20	e	cs	10YR6/3	10YR4/3		massive	sl	sh	fr	sspo		f,m m,f	nil	nil
Ac	20-52	e	cs		10YR5/4		m1sbk	scl		fr	sspo	vf,f c	vf,f c	nil	nil
1C	52-90	e	cs		10YR4/6		massive	scl		fr	sspo	vf,m f	f,c f	nil	nil
2C1	90-125	ev	cs		10YR4/6		massive	sl		fr	sspo	vf c	vf f	f,c m	nil
2C2k	125-150	ev			10YR5/4		massive	sl		fr	sspo	vf f	vf f	m,c m	nil

Table 4.1 contd...

Hori- zon	Depth cm	Efferv- escence	Boun- dary	Matrix colour		Mottles	Struc- ture	Tex- ture	Consistency			Porosity	Roots	Conca	Conir
				Dry	Moist				D	M	W				
P10- Ral Series															
Ap	0-15	nil	cs	10YR6/3	10YR4/2		massive	scl	h	fr	sspo	nil	f,m m	nil	nil
Bw1	15-43	nil	cs		10YR4/3		m 1 sbk	scl		fr	sspo	vf,f m	vf,f f	nil	nil
Bw2	43-80	nil	ds		10YR4/4	c 1 d	m 1 sbk	scl		fr	ssps	vf,f m	vf f	nil	vf f
Bc	80-125	nil	ds		10YR5/3	m 2 d	m 1 sbk	scl		fr	ssps	vf,f m	vf f	nil	f,m m
C	125-150	nil			10YR5/3		massive	scl		fr	ssps	vf,f m	nil	nil	nil
P11- Bhadal Series															
Ap	0-18	e	cs		2.5Y4/2		massive	sil		vs	vp	nil	f,m c	nil	nil
A12	18-50	e	ds		2.5Y5/2		massive	sic		vs	vp	nil	vf f	nil	nil
A13	50-75	e			2.5Y5/2		massive	sic		vs	vp	nil	nil	nil	nil
P12- Barauta Series															
A11	0-15	nil	cs		10YR4/2		massive	sl		fr	sopo	vf,f c	nil	nil	nil
A12	15-45	nil	cs		10YR4/3		m 1 sbk	scl		fr	sspo	f,vf m	f,m f	nil	nil
Ck1	45-82	ev	cs		10YR4/4		massive	l		fr	sspo	vf,f c	m,f f	m,c m	nil
Ck2	82-110	ev	cs		10YR5/3		massive	scl		fr	ssps	vf,f c	f f	f,m c	f,m m
Ck3	110-145	ev			10YR5/3		massive	l		fr	ssps	vf,f c	nil	f,m f	f,m m

Table 4.2 Physical properties of soil

Horizon	Depth (cm)	Sand	Silt	Clay	Kankar	Textural class	Bulk Density, Mg m ⁻³	Moisture retention		AWC (%)
								(%)		
								33	1500	
kPa										
P1 - Gonda Atas Series										
A	0 - 15	76.15	10.77	13.08	-	Sl	1.48	14.19	3.43	10.76
Bw1k	15 -50	41.28	34.87	23.85	-	L	1.36	28.52	6.98	21.54
Bw2	50 - 75	60.26	25.12	14.62	-	Sl	1.27	27.29	3.66	23.63
Bw3	75 - 112	44.62	37.43	17.95	-	L	1.26	32.07	5.09	26.98
C	112 - 150	83.85	6.15	10.00	-	Ls	1.48	9.65	1.76	7.89
P2 - Kiki Nagla Series										
Ap	0 - 10	77.69	10.52	11.79	-	Sl	1.46	13.69	2.89	10.80
A12	10 - 25	76.67	10.00	13.33	-	Sl	1.52	10.78	2.99	7.79
Bw1	25 - 50	68.21	16.41	15.38	-	Sl	1.53	14.76	3.72	11.04
Bw2	50 - 85	62.82	18.21	18.97	-	Sl	1.55	17.79	4.84	12.95
Bc	85- 115	58.21	20.76	21.03	-	Scd	1.43	18.12	6.11	12.01
C	115 - 150	66.92	13.59	19.49	-	Sl	1.49	16.28	4.76	11.52
P3 - Nagla Ramtal Series										
Ap	0 - 15	51.79	26.42	21.79	-	Scd	1.48	20.76	5.85	14.93
AB	15 - 35	50.26	17.78	24.62	-	Scd	1.55	19.73	5.96	13.77
Bt1	35 - 65	41.54	27.18	31.28	-	Cl	1.49	21.70	8.45	13.25
Bt2	65 - 95	38.79	27.95	33.33	-	Cl	1.45	22.89	9.66	13.23
Bt3	95 - 123	36.41	30.00	33.59	-	Cl	1.46	24.15	10.59	13.56
Bc	123 - 165	54.87	21.28	23.85	-	Scd	1.37	23.23	9.56	13.67

Table 4.2 Contd.

Horizon	Depth (cm)	Sand	Silt	Clay	Kankar	Textural class	Bulk Density, Mg m ⁻³	Moisture retention		AWC (%)
								(%)		
								33	1500	
kPa										
P4 - Devi Atas Series										
Ap	0 - 20	70.00	11.54	18.46	-	SI	1.44	14.71	4.94	9.77
Bw1	20 - 45	64.62	13.33	22.05	-	Scl	1.45	15.48	5.69	9.79
Bw2	45 - 73	59.23	15.39	25.38	-	Scl	1.46	17.74	7.06	10.41
Bw3	73 - 105	60.77	13.08	26.15	-	Scl	1.43	17.65	7.92	9.73
Bc	105 - 140	65.13	13.59	21.28	18.00	Scl	1.42	15.93	6.96	8.97
C	140 - 165	77.69	6.93	15.38	-	SI	1.35	10.53	4.05	6.4
P5 - Nagla Chamran Series										
Ap	0 - 15	65.64	18.72	15.64	-	SI	1.46	19.55	3.50	16.05
Bw1	15 - 50	43.83	31.28	24.62	-	L	1.41	24.83	10.26	14.5
Bw2	50 - 76	37.95	34.61	27.44	-	L	1.33	26.38	11.15	15.23
Bw3	76 - 110	26.41	40.00	33.59	-	Cl	1.36	28.63	12.49	16.14
Bw4	110 - 150	32.56	33.34	34.10	-	Cl	1.39	26.47	13.88	12.59
P6 - Sakraya Series										
Ap	0 - 20	76.67	11.79	11.54	-	SI	1.33	18.66	3.57	15.09
Ac	20 - 60	75.13	13.84	11.03	-	SI	1.33	17.37	3.53	13.84
1C	60 - 75	88.72	4.10	7.18	-	Ls	1.34	3.41	1.32	2.09
2C	75 - 87	82.82	7.95	9.23	-	Ls	1.36	11.05	2.35	8.07
3C1	87 - 110	88.97	3.34	7.69	-	Ls	1.39	4.70	1.45	3.25
3C2	110 - 150	89.23	7.36	6.41	-	Ls	1.50	5.05	1.50	3.55
4C	150+	66.67	19.48	13.85	-	SI	1.29	23.52	5.39	18.13

Table 4.2 Contd.

Horizon	Depth (cm)	Sand	Silt	Clay	Kankar	Textural class	Bulk Density, Mg m ⁻³	Moisture retention		AWC (%)
								(%)		
								33	1500	
kPa										
P7 - Maghera Series										
Ap	0 -20	60.00	22.82	17.18	-	Sl	1.34	19.78	5.41	14.37
Bw1	20 - 50	58.46	18.72	22.82	-	Scl	1.39	18.03	6.87	11.16
Bw2	50 - 82	59.49	17.43	23.08	-	Scl	1.38	19.05	7.61	11.44
Bc	82 - 125	62.31	18.20	19.49	-	Sl	1.36	18.55	6.89	13.38
Ck	125 - 150	57.95	25.39	16.66	19.00	Sl	1.26	19.88	4.86	15.02
P8 - Sunrakh Series										
A	0 - 20	52.31	25.64	22.05	-	Scl	1.32	19.58	6.66	12.92
Bw1	20 - 45	58.21	24.87	16.92	-	Sl	1.38	18.85	5.17	13.68
Bw2k	45 - 85	72.56	15.90	11.54	17.00	Sl	1.34	24.39	5.64	18.75
Bck	85 - 120	42.31	34.10	23.59	20.00	L	1.36	26.24	9.72	16.52
C	120 - 150	71.54	13.59	14.87	-	Sl	1.40	16.69	6.25	10.44
P9 - Nagla Henraj Series										
Ap	0 - 20	67.44	17.18	15.38	-	Sl	1.25	18.25	5.25	13.00
Ac	20 - 52	62.05	16.92	21.03	-	Scl	1.32	17.58	6.30	11.28
1C	52 - 90	57.44	20.00	22.56	-	Scl	1.35	19.24	8.32	10.92
2C1	90 - 125	67.95	14.87	17.18	-	Sl	1.41	17.44	5.45	11.99
2C2k	125 - 150	78.72	9.23	12.05	18.00	Sl	1.24	13.45	2.85	10.60

Table 4.2 Contd.

Horizon	Depth (cm)	Sand	Silt	Clay	Kankar	Textural class	Bulk Density, Mg m ⁻³	Moisture retention		AWC (%)
								(%)		
								33	1500	
kPa										
P10 - Ral Seriesm										
Ap	0 - 15	66.67	11.02	22.31	-	Scl	1.36	16.62	6.85	9.77
Bw1	15 - 43	62.56	11.80	25.64	-	Scl	1.42	17.64	7.43	10.21
Bw2	43 - 80	59.74	13.85	26.41	-	Scl	1.40	20.67	9.38	11.29
Bc	80 - 125	51.79	19.24	28.97	-	Scl	1.45	21.25	10.60	10.65
C	125 - 150	65.64	10.51	23.85	-	Scl	1.51	18.15	7.50	10.65
P11 - Bhadal Series										
Ap	0 - 18	43.59	29.75	26.66	-	Sil	1.39	25.30	9.28	16.02
A12	18 - 50	30.77	28.46	40.77	-	Sic	1.34	26.79	14.63	12.16
A13	50 - 70+	12.82	30.77	56.41	-	Sic	1.37	28.46	18.78	9.68
P12 - Barauta Series										
A11	0 - 15	69.49	15.64	14.87	-	SL	1.26	18.63	4.60	14.03
A12	15 - 45	50.51	23.08	26.41	-	Scl	1.39	24.58	9.46	15.12
Ck1	45 - 82	48.46	24.87	26.67	46.00	L	1.34	31.46	9.66	21.80
Ck2	82 - 110	51.79	25.90	22.31	12.00	Scl	1.29	29.15	8.35	20.80
Ck3	110 -145+	38.46	34.36	27.18	10.00	L	1.32	29.50	11.41	18.09

4.1.2 Physical Properties

4.1.2.1 Soil texture and particle size distribution

The texture of the soil is perhaps one of the most important characteristics and it has great influence on physical and physico-chemical properties of soils. The interaction of organic and inorganic substances such as carbonates, oxides of iron, silicon, and aluminium *etc.* act to bind the soil particles together. The variation in proportions of soil separates contribute towards variation in soil texture. As can be seen in Table 4.1 and 4.2, textural classes of the soils in the study area ranged from loamy sand to silt clay through sandy loam, sandy clay loam and clay loam.

Soil on the active flood plain (Sakraya series) was relatively higher in sand content (ranged from 75.13 to 89.23 percent) and sandy loam textural class was found in top soil while the loamy sand class was found throughout the control section up to 150 cm depth. The texture in Gonda Atas, Kiki Nagla and Sunrakh series found to be sandy loam to loam with dominance of sandy loam textural class. Nagla Ramtal series (Profile 3) shows increase in clay content from 21.8 per cent in Ap and 24.6 per cent in AB horizons to 31.3, 33.3 and 33.6 per cent in Bt1, Bt2 and Bt3 horizons respectively. The increase in clay content has been observed to be more than 1.2 per cent and mottles have been observed in these horizons so that it was qualified for Argillic horizon.

Bhadal series shows much difference in texture comparing to all others. The clay content was increased from 26.6 per cent in surface horizon to 40.7 and 56.4 per cent in sub-surface horizons (the highest between all surface and sub-surface horizons). The textural class was

Particle size distribution (Texture)

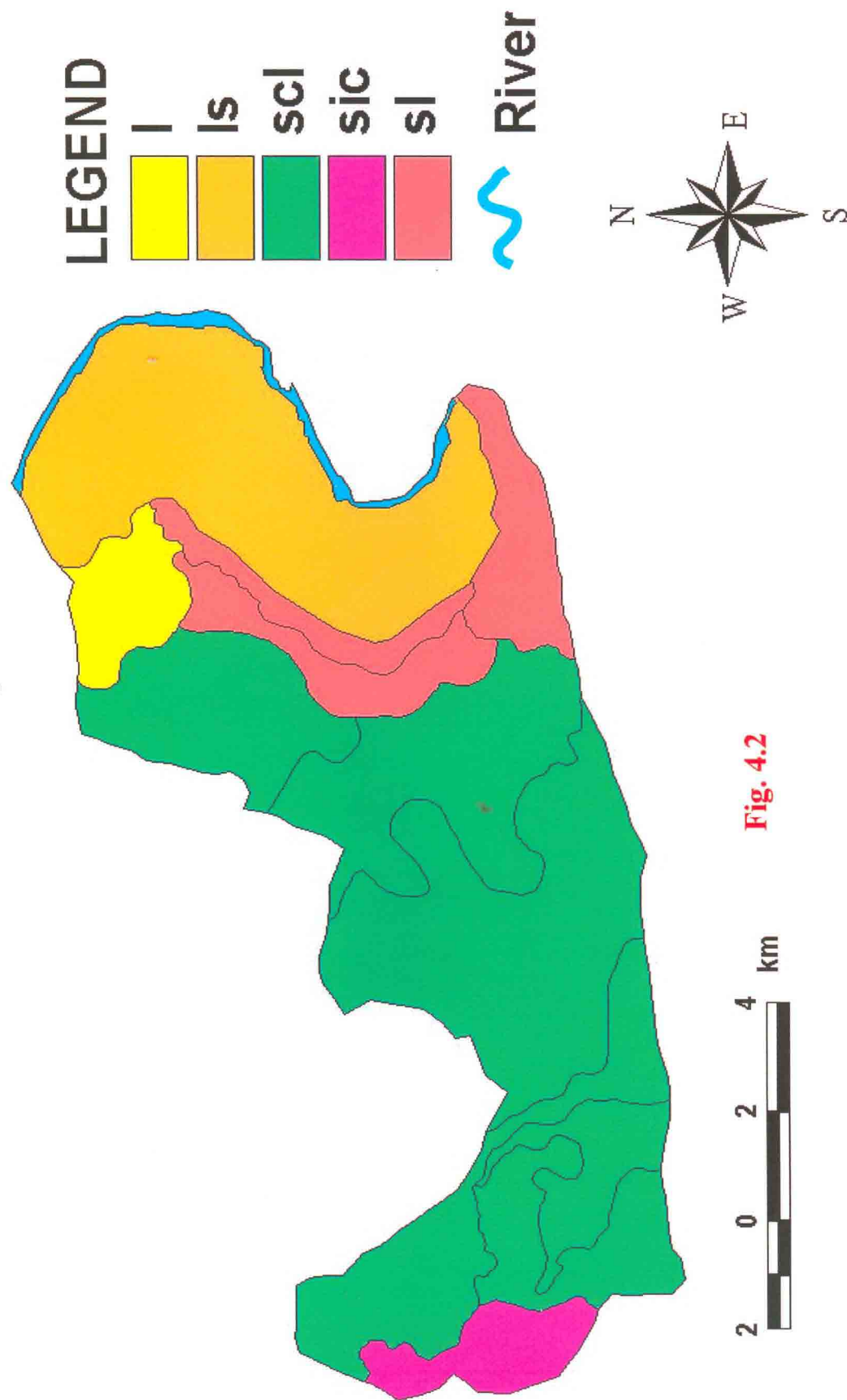


Fig. 4.2

observed to be silt loam and silt-clay in surface and sub-surface horizons respectively.

It has been recorded that Ral series had sandy clay loam textural class throughout the soil profile (P10). The textural classes in all other soil series were ranged between sandy loam to sandy clay loam.

The weighted averages of texture (Sys, 1985) were calculated (Table 4.5) and fitted to GIS for mapping. Five textural classes were mapped in the study area that are loam, loamy sand, sandy clay loam, sandy loam and silt clay. Their distribution throughout the study area is shown in Fig. 4.2.

It was observed that sand content of different soil series were significantly and negatively correlated at 1% level to silt ($r = -0.8658$), clay ($r = -0.9012$), CEC ($r = -0.7999$), Ca ($r = -0.5028$), Mg ($r = -0.7468$), Na ($r = -0.4243$) and K ($r = -0.4924$) whereas the silt content was positively correlated with the clay ($r = 0.5850$), CEC ($r = 0.5086$), Ca ($r = 0.3238$), Mg ($r = 0.4874$), Na ($r = 0.2108$) and K ($r = 0.4556$). Similarly the clay content of the all soil series was significantly and positively correlated at 1% level with CEC ($r = 0.8980$), Ca ($r = 0.5963$), Mg ($r = 0.8440$), Na ($r = 0.5510$) and K ($r = 0.4179$) (Appendix III).

These correlations suggest that sand fraction was directly transformed into silt as well as clay. Such relationship was also observed by Karmakar (1985).

4.1.2.2 Bulk density

Bulk density is the mass of soil per unit of volume including pore spaces (Hillel, 1980). Variation in the size, concentration and composition

of gravelly material in soil mass and relative proportion of the soil separates influence the bulk density value. The data on bulk density is presented in Table 4.2. In surface horizons it varied from 1.25 to 1.48 Mg m⁻³ and in sub-surface horizons ranged from 1.23 to 1.55 Mg m⁻³. The soils do not have definite pattern of distribution in the profiles, except Sakraya series (P6), where it increased with depth (1.33 to 1.50 Mg m⁻³) due to high content of sand fraction (82.82 % to 89.23 %) and decreased in 4C horizon to 1.29 Mg m⁻³ due to clay migration from surface to lower horizon.

Although statistically not significant, sand and organic carbon positively correlated with bulk density ($r = 0.1663$ and 0.0315) respectively.

4.1.2.3 Soil moisture retention

The data on soil moisture content is furnished in Table 4.2.

Moisture content at 33 kPa.

It ranged from 3.41 to 32.07 per cent and in general not much difference in distribution pattern, in all the soil series was observed. The highest value was recorded in Gonda Atas (P1) followed by Barauta (P12). Although Nagla Chamran (P4) and Sakraya (P6) have comparatively low value of moisture content, but the distribution pattern was quite different. Silt and clay as well as organic carbon content play dominant role in controlling soil moisture content at this suction.

Moisture content at 1500 kPa

The moisture content at 1500 kPa ranged from 1.32 to 18.78 per cent. Soils of Bhadal (P11), Devi Atas (P5), and Ral (P10) have comparatively high values of moisture content at this suction. In general, water retention of all the soil series in the study area was low possibly due to lighter

texture and dominance of unexpandable clay minerals as well as low organic carbon content (Virmani *et al.*, 1982).

4.1.2.4 Available water capacity

Available water capacity (AWC) of soils generally considered as amount of water held between soil-water tension corresponding to field capacity (33 kPa) and permanent wilting point (1500 kPa). It is estimated gravimetrically.

As transpired by the data (Table 4.2) that the AWC of the soils has wide variation from 2.09 per cent in Sakraya series to 26.98 per cent in Gonda Atas series. Depth wise distribution of AWC tends to follow particle size distribution in profiles. Moreover, it was observed that AWC has highly significant and negative correlation with sand ($r = -0.4988$) and positive correlation with silt content ($r = 0.7060$) both at 1 % level. Although statistically not significant, clay and organic carbon positively correlated with AWC ($r = 0.1927$ and 0.1284).

4.1.2.5 Plant available water capacity of the soils

Although the moisture held between field capacity (33 kPa) and permanent wilting point (1500 kPa) is considered available to plant, but it may not be actually available to crops. Gardner *et al.* (1984) suggested the concept of plant available water capacity (PAWC), which is calculated by using formula as mentioned in chapter 3.

The data regarding PAWC of the soil series was presented in Table 4.3. In general, all the soil series in study area had relatively higher PAWC (ranged from 183.06 in Sakraya series to 362.70 mm in Gonda Atas series), which could be due to the depth of soils. Soil depth ranged from

Table 4.3 Plant available water capacity of soils (PAWC)

Horizon	Depth (cm)	Moisture retention (%)		BD max (Mg m ⁻³)	Available water capacity			Average (mm m ⁻¹)	PAWC (9)*(2)/100
		33 kPa	500 kPa		(3)-(4)	(6)*(5)	(7)*10		
P1 - Gonda Atas Series									
A	0 - 15	14.19	3.43	1.48	10.76	15.92	159.25		
Bw1k	15 -50	28.52	6.98	1.36	21.54	29.29	292.94		
Bw2	50 - 75	27.29	3.66	1.27	23.63	30.01	300.10	241.80	362.70
Bw3	75 - 112	32.07	5.09	1.26	26.98	33.99	339.95		
C	112 - 150	9.65	1.76	1.48	7.89	11.68	116.77		
P2 - Kiki Nagla Serimes									
Ap	0 - 10	13.69	2.89	1.46	10.80	15.77	157.68		
A12	10 - 25	10.78	2.99	1.52	7.79	11.84	118.41		
Bw1	25 - 50	14.76	3.72	1.53	11.04	18.89	168.91		
Bw2	50 - 85	17.79	4.84	1.55	12.95	20.07	200.73	164.85	247.28
Bc	85- 115	18.12	6.11	1.43	12.01	17.17	171.74		
C	115 - 150	16.28	4.76	1.49	11.52	17.18	171.66		
P3 - NaglaRamtal Series									
Ap	0 - 15	20.76	5.85	1.48	14.93	22.10	220.96		
AB	15 - 35	19.73	5.96	1.55	13.77	21.34	213.44		
Bt1	35 - 65	21.70	8.45	1.49	13.25	19.74	197.43		
Bt2	65 - 95	22.89	9.66	1.45	13.23	19.18	191.84	201.49	332.46
Bt3	95 - 123	24.15	10.59	1.46	13.56	19.80	197.98		
Bc	123 - 165	23.23	9.56	1.37	13.67	18.73	187.28		

Table 4.3 Contd.

Horizon	Depth (cm)	Moisture retention (%)		BD max (Mg m ⁻³)	Available water capacity			Average (mm m ⁻¹)	PAWC (9)*(2)/100
		33 kPa	500 kPa		(3)-(4)	(6)*(5)	(7)*10		
P4 - Devi Atas Series									
Ap	0 - 20	14.71	4.94	1.44	9.77	14.07	140.69		
Bw1	20 - 45	15.48	5.69	1.45	9.79	14.20	141.96		
Bw2	45 - 73	17.74	7.06	1.46	10.41	15.20	151.99	131.44	216.88
Bw3	73 - 105	17.65	7.92	1.43	9.73	13.91	139.14		
Bc	105 - 140	15.93	6.96	1.42	8.97	12.74	127.37		
C	140 - 165	10.53	4.05	1.35	6.48	8.75	87.48		
P5 - Nagla Chamran Series									
Ap	0 - 15	19.55	3.50	1.46	16.05	23.43	234.33		
Bw1	15 - 50	24.83	10.26	1.41	14.57	20.54	205.44		
Bw2	50 - 76	26.38	11.15	1.33	15.23	20.26	202.56	207.37	311.06
Bw3	76 - 110	28.63	12.49	1.36	16.14	21.95	219.50		
Bw4	110 - 150	26.47	13.88	1.39	12.59	17.50	175.00		
P6 - Sakraya Series									
Ap	0 - 20	18.66	3.57	1.33	15.09	20.07	200.70		
Ac	20 - 60	17.34	3.53	1.33	13.84	18.41	184.07		
1C	60 - 75	3.41	1.32	1.34	2.09	2.80	28.01	122.12	183.18
2C	75 - 87	11.05	2.35	1.36	8.07	10.98	109.75		
3C1	87 - 110	4.70	1.45	1.39	3.25	4.52	45.18		
3C2	110 - 150	5.05	1.50	1.50	3.55	5.33	53.25		
4C	150+	23.52	5.39	1.29	18.13	23.89	233.88		

Table 4.3 Contd.

Horizon	Depth (cm)	Moisture retention (%)		BD max (Mg m ⁻³)	Available water capacity			Average (mm m ⁻¹)	PAWC (9)*(2)/100
		33 kPa	500 kPa		(3)-(4)	(6)*(5)	(7)*10		
P7 - Maghera Series									
Ap	0 -20	9.78	5.41	1.34	14.37	19.26	192.56		
Bw1	20 - 50	18.03	6.87	1.39	11.16	15.61	156.12		
Bw2	50 - 82	19.05	7.61	1.38	11.14	15.79	157.87	175.35	263.03
Bc	82 - 125	18.55	6.89	1.36	13.28	18.20	181.97		
Ck	125 - 150	19.88	4.86	1.26	15.02	18.93	189.25		
P8 - Sunrakh Series									
A	0 - 20	19.58	6.66	1.32	12.92	17.05	170.54		
Bw1	20 - 45	18.85	5.17	1.38	13.68	18.88	188.78		
Bw2k	45 - 85	24.39	5.64	1.34	18.75	25.13	251.25	196.28	294.42
Bck	85 - 120	26.24	9.72	1.36	16.52	22.47	224.67		
C	120 - 150	16.69	6.25	1.40	10.44	14.62	146.16		
P9- Nagla Hemraj Series									
Ap	0-20	18.25	5.25	1.25	13.00	16.25	162.50		
Ac	20-52	17.58	6.30	1.32	11.28	14.89	148.90		
1C	52-90	19.24	8.32	1.35	10.92	14.74	147.42	151.86	227.79
2C1	90-125	17.44	5.45	1.41	11.99	16.91	169.06		
2C2k	125-150	13.45	2.85	1.24	10.60	13.14	131.44		

Table 4.3 Contd.

Horizon	Depth (cm)	Moisture retention (%)		BD max (Mg m ⁻³)	Available water capacity			Average (mm m ⁻¹)	PAWC (9)*(2)/100
		33 kPa	500 kPa		(3)-(4)	(6)*(5)	(7)*10		
P10 - Ral Series									
Ap	0 - 15	16.62	6.85	1.36	9.77	13.29	132.87		
Bw1	15 - 43	17.64	7.43	1.42	10.21	14.50	144.98		
Bw2	43 - 80	20.67	9.38	1.40	11.29	15.81	158.08	150.23	225.35
Bc	80 - 125	21.25	10.60	1.45	10.65	15.44	154.43		
C	125 - 150	18.15	7.50	1.51	10.65	16.08	160.82		
P11- Bhadal Series									
Ap	0 - 18	25.30	9.28	1.39	16.02	22.27	222.66		
A12	18 - 50	26.79	14.63	1.34	12.16	16.29	162.94	172.75	120.93
A13	50 - 70+wet	28.46	18.78	1.37	9.68	13.26	132.62		
P12 - Barauta Series									
A11	0 - 15	18.63	4.60	1.26	14.03	17.68	176.78		
A12	15 - 45	24.58	9.46	1.39	15.12	21.02	210.17		
Ck1	45 - 82	31.46	9.66	1.34	21.80	29.21	292.12	237.23	343.98
Ck2	82 - 110	29.15	8.35	1.29	20.80	26.83	268.32		
Ck3	110 -145	29.50	11.41	1.32	18.09	23.88	238.79		

145 to 165 cm. However, Bhadal soil series had the lowest PAWC (120.93 mm) but does not reflect the real situation because of high water table at 75 cm and soil depth is considered for calculation of PAWC. Yadav *et al.* (1995) reported that PAWC directly associated with soil depth and clay content.

4.1.3 Physico-chemical properties

The physico chemical properties of soils are closely related to the soil texture, mineralogy and various pedogenic processes, which affect soil development. Details regarding physico-chemical properties of soils in study area were obtained through laboratory examinations. The results of the examination were presented in Table 4.4 and weighted averages in Table 4.5.

4.1.3.1 Soil reaction

The pH determination is very important for characterizing soils from the standpoint of nutrient availability and physical condition. It provides information on the potency of toxic substances present in the soil. Ascertaining the soil pH provides the most rational bases for managing soil for selective agricultural crops, pasture cultivation, forestry *etc.*

The soil reaction (pH) was measured in water in the ratio of 1:2.5. Table 4.4 shows pH in surface soil of different soil series ranged from 7.7 to 9.0 i.e. from mildly alkaline to strongly alkaline and that of subsurface soil ranged from 7.4 to 9.6. The weighted averages data (Table 4.5) shows that pH value for Sunrakh soil series ranges from 7.7 to 8.3, that for the Bhadal series ranges from 7.8 to 7.9, that for Barauta soil series ranges from 8.0 to 8.8 and for Nagla Ramtal series ranges from 7.4 to 8.8. The

Table 4.4 Physico-chemical characteristics of soils

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm ⁻¹)	CEC	Cmol(p ⁺)kg ⁻¹					Σ Exch. Bases	Ca/Mg ratio	Base Saturation %	ESP
					Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
P1 - Gonda Atas Series													
A	0 - 15	8.5	0.90	5.21	2.59	0.52	1.09	0.31	4.51	4.98	86.56	20.92	
Bw1k	15 -50	9.2	3.60	12.65	3.25	1.00	3.78	0.32	8.35	3.25	66.01	29.88	
Bw2	50 - 75	9.0	4.30	7.38	3.32	1.07	2.34	0.23	6.96	3.10	94.31	31.71	
Bw3	75 - 112	8.9	3.30	9.61	3.67	1.45	2.27	0.24	7.63	2.53	79.40	23.62	
C	112 - 150	9.6	1.50	5.24	2.61	0.93	0.78	0.13	4.45	2.81	84.92	14.89	
P2 - KiKi Nagla series													
Ap	0 - 10	8.9	0.33	8.47	3.68	1.06	0.78	0.31	5.83	3.47	68.83	9.21	
A12	10 - 25	8.8	0.53	8.41	3.27	1.02	2.02	0.19	6.52	3.21	77.53	24.02	
Bw1	25 - 50	9.2	1.60	8.41	4.30	2.34	1.36	0.17	8.17	1.84	78.60	16.17	
Bw2	50 - 85	8.8	1.30	10.32	4.86	2.97	1.34	0.17	9.34	1.64	90.50	12.98	
Bc	85- 115	8.6	1.90	12.30	5.81	2.97	1.45	0.18	10.41	1.96	84.63	11.79	
C	115 - 150	8.1	1.10	11.29	6.68	2.11	1.76	0.21	10.76	3.17	95.31	15.59	
P3 - Nagla Ramtal Series													
Ap	0 - 15	8.2	1.15	12.60	3.89	6.02	1.80	0.21	11.92	0.65	94.60	14.29	
AB	15 - 35	8.2	1.45	14.50	3.13	6.25	2.11	0.19	11.68	0.50	80.55	14.55	
Bt1	35 - 65	8.0	1.35	18.24	5.41	7.78	2.52	0.22	15.92	0.70	87.28	13.82	
Bt2	65 - 95	7.4	0.80	20.63	5.76	8.22	2.99	0.26	17.22	0.70	83.47	14.49	
Bt3	95 - 123	7.8	0.37	21.29	5.36	7.05	2.02	0.23	14.61	0.76	68.62	9.49	
Bc	123 - 165	8.8	0.35	18.73	6.37	7.45	1.49	0.27	15.58	0.86	83.18	7.96	

Table 4.4 Physico-chemical Contd.

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm ⁻¹)	Cmol(p ⁺)kg ⁻¹					Σ Exch. Bases	Ca/Mg ratio	Base Saturation %	ESP
				Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
P4 - Devi Atas Series												
Ap	0 - 20	8.9	0.91	3.64	1.68	1.94	0.22	7.48	2.17	76.95	19.96	
Bw1	20 - 45	9.1	0.59	3.21	2.97	2.13	0.17	8.48	1.08	67.30	16.90	
Bw2	45 - 73	8.6	1.20	9.17	2.62	1.87	0.16	13.82	3.50	92.57	12.53	
Bw3	73 - 105	8.3	1.50	9.70	2.22	1.52	0.19	13.62	4.37	85.40	9.69	
Bc	105 - 140	8.3	0.90	7.74	2.13	1.47	0.20	11.54	3.63	69.23	8.82	
C	140 - 165	8.6	0.58	5.33	1.53	1.21	0.12	8.19	3.48	81.09	11.98	
P5 - Nagla Chamran Series												
Ap	0 - 15	9.0	0.30	3.07	2.36	1.42	0.23	7.08	1.30	79.02	15.85	
Bw1	15 - 50	8.7	0.71	5.19	7.15	2.31	0.23	14.88	0.73	92.59	14.37	
Bw2	50 - 76	8.4	0.83	5.52	7.15	2.24	0.25	15.17	0.77	85.71	12.66	
Bw3	76 - 110	8.0	0.82	6.88	7.32	2.62	0.32	17.14	0.94	91.51	13.99	
Bw4	110 - 150	7.8	0.81	7.33	8.91	2.31	0.40	18.95	0.82	97.23	11.85	
P6 - Sakraya Sries												
Ap	0 - 20	8.7	0.27	4.75	2.46	0.44	0.25	7.90	1.93	92.61	5.16	
Ac	20 - 60	8.8	0.31	4.25	2.23	0.78	0.09	7.30	1.91	95.30	10.18	
1C	60 - 75	8.8	0.10	2.10	1.29	0.37	0.04	3.84	1.63	96.97	9.34	
2C	75 - 87	8.8	0.10	3.60	1.10	0.47	0.08	5.25	3.27	95.80	8.58	
3C1	87 - 110	8.7	0.10	2.03	0.98	0.35	0.05	3.41	2.07	97.99	10.06	
3C2	110 - 150	8.7	0.10	2.23	1.00	0.34	0.06	3.63	2.23	95.53	8.95	
4C	150+	8.6	0.20	5.73	1.16	0.46	0.16	7.51	4.94	76.87	4.71	

Table 4.4 Physico-chemical Contd.

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm ⁻¹)	Cmol(p ⁺)kg ⁻¹						K ⁺	Σ Exch. Bases	Ca/Mg ratio	Base Saturation %	ESP
				Ca ²⁺	Mg ²⁺	Na ⁺								
P7 - Maghera Series														
Ap	0 -20	0.50	8.7	5.45	3.56	1.10			0.17	10.28	1.53	92.78	9.93	
Bw1	20 - 50	0.14	8.7	6.64	4.97	1.20			0.11	12.92	1.34	79.56	7.39	
Bw2	50 - 82	0.09	8.6	7.04	5.41	1.51			0.10	14.06	1.30	66.23	7.11	
Bc	82 - 125	0.16	8.9	7.22	6.16	1.69			0.09	15.16	1.17	83.34	9.29	
Ck	125 - 150	0.13	9.2	7.13	4.35	1.57			0.08	13.13	1.64	92.66	11.08	
P8 - Sumrakh Series														
A	0 - 20	0.25	7.7	8.75	2.12	0.12			0.17	11.16	4.13	87.12	0.94	
Bw1	20 - 45	0.11	7.9	4.28	1.65	0.13			0.11	6.17	2.59	74.25	1.56	
Bw2k	45 - 85	0.03	8.1	6.37	1.68	0.46			0.12	8.63	3.79	94.01	5.01	
Bck	85 - 120	0.06	8.1	17.16	2.54	0.15			0.18	13.57	4.21	67.42	0.87	
C	120 - 150	0.09	8.3	12.49	1.68	0.28			0.18	12.14	5.95	97.20	2.24	
P9 - Nagla Hemraj Series														
Ap	0 - 20	0.25	8.4	6.54	2.08	0.23			0.32	9.17	3.14	81.95	2.06	
Ac	20 - 52	0.11	8.9	5.75	2.25	1.71			0.14	9.85	2.56	94.44	16.40	
1C	52 - 90	0.03	9.0	5.42	4.31	2.86			0.12	12.71	1.26	90.40	20.34	
2C1	90 - 125	0.06	9.3	5.53	1.57	2.47			0.09	9.66	3.52	88.54	22.64	
2C2k	125 - 150	0.09	9.5	4.59	1.35	2.46			0.06	8.46	3.40	91.96	26.74	

Table 4.4 Physico-chemical Contd.

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm ⁻¹)	Cmol(p ⁺)kg ⁻¹					Σ Exch. Bases	Ca/Mg ratio	Base Saturation %	ESP
				Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
P10 - Ral Series												
Ap	0 - 15	8.5	0.80	12.50	5.47	3.12	3.28	0.19	12.06	1.75	96.48	26.24
Bw1	15 - 43	8.4	0.50	15.48	5.94	2.76	3.10	0.10	11.90	2.15	76.87	20.03
Bw2	43 - 80	8.5	0.40	18.73	6.69	3.87	3.32	0.11	13.99	1.73	74.69	17.73
Bc	80 - 125	8.6	0.40	20.25	6.86	4.58	3.45	0.11	15.00	1.50	74.07	17.04
C	125 - 150	8.8	0.37	13.79	5.48	3.87	1.78	0.10	11.23	1.42	81.44	12.91
P11 - Bhadal Series												
Ap	0 - 18	7.9	6.60	18.88	9.24	6.53	1.22	0.44	17.43	1.42	92.32	6.46
A12	18 - 50	7.8	2.85	22.43	9.03	8.78	1.43	0.33	19.63	1.03	87.52	6.38
A13	50 - 70	7.9	3.10	26.77	12.16	10.50	1.87	0.39	24.92	1.16	93.09	6.99
P12 - Barauta Series												
A11	0 - 15	8.0	25.50	5.54	2.29	1.66	0.45	0.40	4.80	1.38	86.64	8.12
A12	15 - 45	8.3	4.20	12.98	2.07	7.88	1.22	0.36	11.53	0.26	88.83	9.40
Ck1	45 - 82	8.8	4.10	13.47	4.27	1.74	0.20	0.16	6.37	2.45	47.29	1.48
Ck2	82 - 110	8.7	4.30	10.59	4.19	1.62	1.93	0.10	7.84	2.59	74.03	18.22
Ck3	110 -145	8.8	4.10	12.71	4.49	1.75	0.15	0.14	6.53	2.57	51.38	1.18

Table 4.5 Physical and physico-chemical properties of soils (weighted means)

Soil series	Sand, %	Silt, %	Clay', %	Textural class	PAWC mm m ⁻¹	pH 1:2.5	EC dsm ⁻¹	CEC cmol(p ⁺)kg ⁻¹	BS %	ESP %
Gonda Atas (P1)	52.09	29.46	18.45	Sl	363	8.8	3.3	10.40	78	22.4
Kiki Nagla (P2)	63.69	16.13	16.79	Sl	247	8.8	1.3	8.42	74	15.00
Nagla Rantal (P3)	45.18	25.56	29.26	ScI	332	8.7	1.3	15.10	89	14.4
Devi Atas (P4)	63.15	13.48	23.37	ScI	217	8.9	1.1	11.70	75	19.4
Nagla Chamran (P5)	41.49	32.35	26.16	I	311	8.9	0.6	13.90	84	15.3
Sakraya (P6)	77.85	12.25	9.90	Is	183	8.7	0.3	8.00	89	9.74
Maghera (P7)	59.79	19.03	21.18	ScI	263	8.1	0.3	14.20	90	9.42
Sunrakh (P8)	60.39	22.82	16.79	Sl	294	7.7	8.9	10.20	85	2.71
Nagla Hemraj (P9)	61.96	17.94	20.10	ScI	228	8.9	0.49	10.73	85	15.65
Ral (P10)	59.98	13.93	26.09	ScI	225	8.5	0.7	15.00	89	23.80
Bhadal (P11)	28.94	29.45	41.61	Sic	121	7.8	5.6	21.20	91	6.60
Barauta (P12)	52.83	23.13	24.04	ScI	344	8.1	17.0	10.80	88	7.87

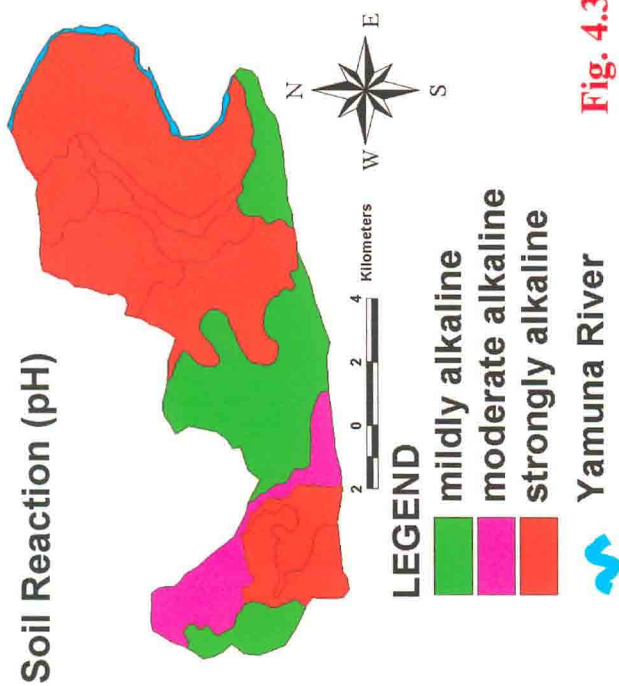


Fig. 4.3

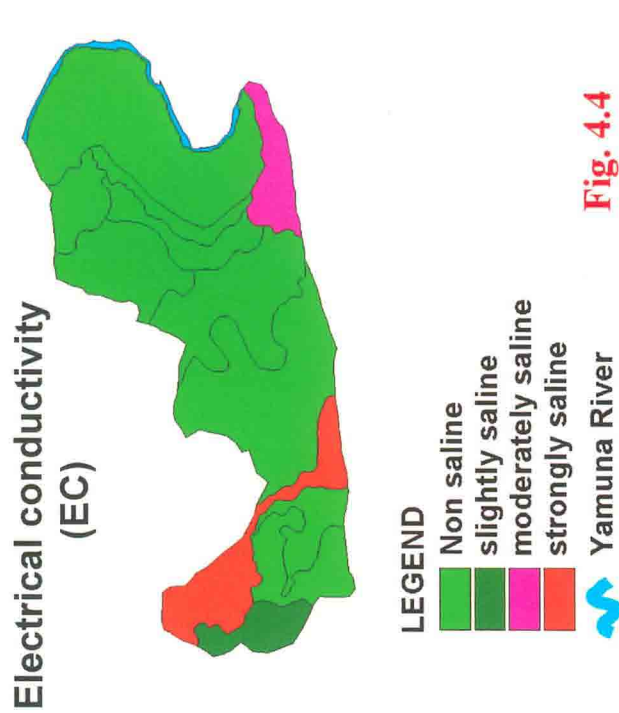


Fig. 4.4

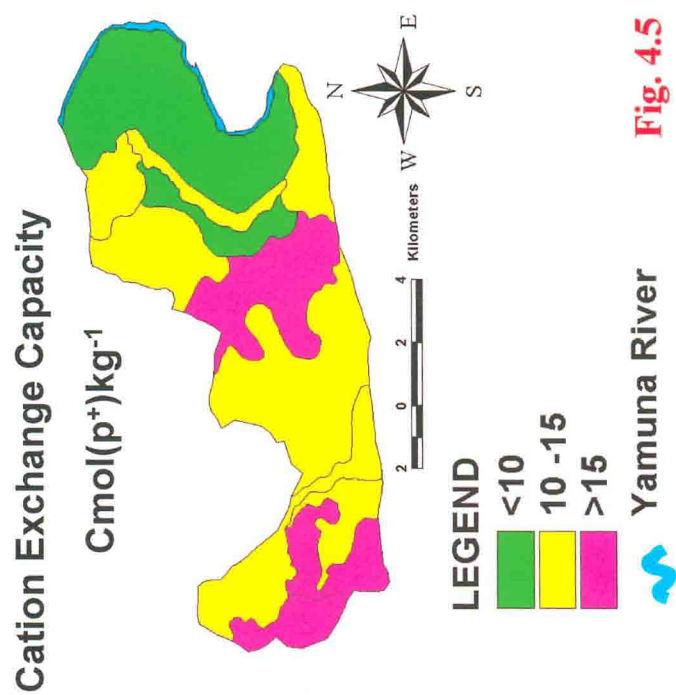


Fig. 4.5

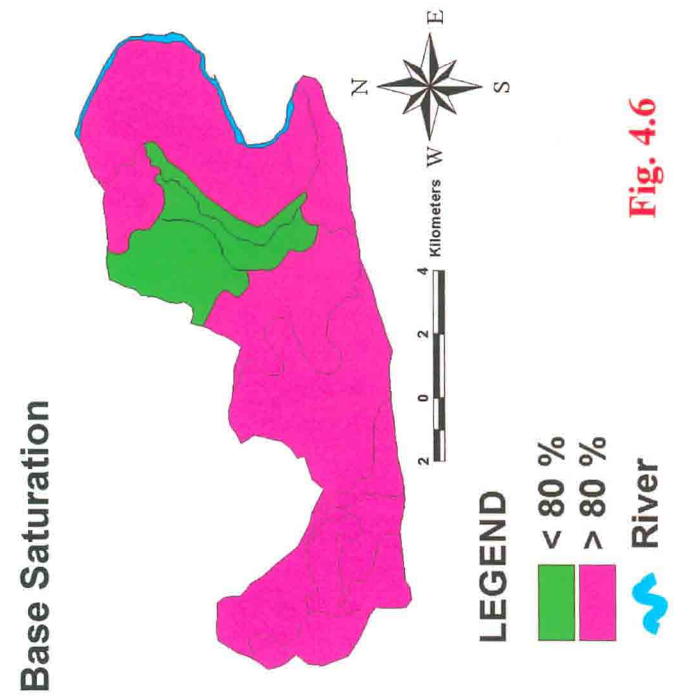


Fig. 4.6

other soil series showed pH 8.5 and higher. Total three pH classes were found in the study area i.e. mildly alkaline, moderately alkaline and strongly alkaline (Fig. 4.3).

The correlation analysis (Appendix III) shows that the pH of different soil series positively and significantly correlated with exchangeable sodium percentage ESP ($r = 0.4161$), sand content ($r = 0.5072$) at 1% level and the same at 5% level with the calcium carbonate percentage ($r = 0.3187$).

4.1.3.2 Electrical conductivity

Soils in the study area have electrical conductivity (EC) ranging from 0.27 to 25.50 in surface layers and from 0.1 to 4.8 dSm^{-1} in sub-surface layers. The electrical conductivity of Gonda Atas series ranged from 0.9 to 4.3 dSm^{-1} with weighted average of 3.3 dSm^{-1} . Similarly the electrical conductivity of Sunrakh series ranged from 3.0 to 10.0 dSm^{-1} with weighted average of 8.9 dSm^{-1} . Bhadal series emerging as slightly saline with electrical conductivity value ranging from 2.85 to 6.6 dSm^{-1} and weighted average of 5.6 dSm^{-1} . Barauta series emerged as the strongest saline soils in the study area with electrical conductivity values ranging from 4.1 to 25.50 dSm^{-1} and weighted average of 17.0 dSm^{-1} . The electrical conductivity of Kiki Nagla series ranged from 0.33 to 1.90, Nagla Ramtal series from 0.35 to 1.45 and Devi Atas series from 0.50 to 1.50 dSm^{-1} , with weighted averages of 1.3, 1.3 and 1.1 dSm^{-1} respectively. Other soil series have electrical conductivity value less than 1.0 dSm^{-1} . The distribution of salinity within study area is shown in Fig. 4.4.

4.1.3.3 Cation exchange capacity

The cation exchange capacity (CEC) of soil is defined as the capacity of the soil to sorb or hold and to exchange cations in reversible chemical reactions. It is possibly the most important property for both soil genesis and fertility studies.

The CEC of the soil series were generally low which ranged from 5.21 to 18.88 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in surface horizons and from 3.48 to 26.77 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in sub-surface horizons.

The CEC in the study area revealed considerable variations among and within profiles depending on clay content of different layers and different profiles. However, CEC of Kiki Nagla series (P2) and Sakraya series (P6) was the lowest in CEC content. It ranged from 8.41 to 12.30 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ and from 3.48 to 9.77 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ with averages of 8.42 and 8.0 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ respectively.

The CEC of the soil series of Nagla Ramtal (P3), Ral (P10) and Bhadal (P11), have the highest content of clay so also the highest content of CEC. It ranged from 12.60 to 21.29, 12.50 to 20.25 and 18.88 to 26.77 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ with weighted averages of 15.1, 15.00 and 21.2 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ respectively. The other soil series have CEC values ranging from 10.2 to 14.2 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$.

Statistical analysis revealed a high and positive correlation between clay content and CEC ($r = 0.8980^{**}$). It shows also significant and positive correlation between CEC and Ca^{2+} ($r = 0.7073$), Mg^{2+} ($r = 0.8440$), Na ($r = 0.5510$), Mn^{2+} ($r = 0.4662$) and Zn^{2+} ($r = 0.3066$). Manrique *et al.* (1991) reported that the clay and organic carbon accounted for up to 67 per cent

of variation of CEC in soil orders like Alfisols, Inceptisols and Vertisols, while in Entisols and Spodosols up to 78 per cent.

Generally the soils that are low in clay content show low CEC values. The low CEC in these soils could be due to low clay and organic carbon contents and also type of clay mineral present in these soils. The X-ray studies (Tables 4.8, 4.9) confirmed that these soils contain low contents of smectite and vermiculite and relatively more of illite and kaolinite. Area wise distribution of different CEC values is shown in Fig. 4.5.

4.1.3.4 Exchangeable cations

The exchangeable cations present in a pedon are sensitive indicators of changes caused by operation of soil formation. Exchangeable Ca^{2+} was observed to be the dominant base followed by Mg^{2+} , Na^+ and K^+ in all of soil series in the study area except Gonda Atas (P1), Nagla Ramtal (P3) and Nagla Chamran (P5). In Gonda Atas exchangeable Ca^{2+} was also the dominant cation followed by Na^+ , Mg^{2+} and K^+ . The dominant cation in Nagla Ramtal (P3) and Nagla Chamran (P5) was Mg^{2+} followed by Ca^{2+} , Na^+ and K^+ .

In surface horizons of all soil series the exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 2.29 in Barauta series to 8.75 in Sunrakh series, 0.52 in Gonda Atas series to 6.53 in Ral series, 0.12 in Sunrakh series to 3.28 in Ral series and from 0.17 in Sunrakh series to 0.44 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in Bhadal series respectively, whereas that in sub-surface horizons it ranged from 2.03 in Sakraya series to 12.16 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in Bhadal series, 0.98 in Sakraya series to 10.50 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in Bhadal series, 0.34 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in Sakraya series to 3.78 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in Gonda Atas series and from 0.04

cmol(p⁺)kg⁻¹ in Sakraya series to 0.40 cmol(p⁺)kg⁻¹ in Nagla Chamran series respectively.

Exchangeable Ca²⁺ increased with depth indicating leaching of Ca²⁺ to lower horizons in Kiki Nagla, Nagla Ramtal, Nagla Chamran, Maghera, Bhadal and Barauta series, while it tends to increase to certain depth and then reduce in lower layers in Gonda Atas, Devi Atas, Sunrakh and Ral series. Exchangeable Ca²⁺ decreased with depth in Nagla Hemraj series while it was irregularly distributed down the profile in Sakraya series.

Exchangeable Mg²⁺ was the dominant cation in Nagla Ramtal (P3) and Nagla Chamran (P5). It shows the tendency to increase with depth. However, variations of Na⁺ and K⁺ with depth was found to be inconspicuous.

Ca²⁺: Mg²⁺ ratio tends to follow the trend of Ca²⁺ distribution in the profiles. The values are relative high, ranging from 0.65 to 4.98 in surface horizons and from 0.26 to 5.95 in subsurface horizons, indicating that soils in the study area are low in degree of weathering. The higher value of Ca²⁺: Mg²⁺ ratios are observed in Gonda Atas, Kiki Nagla, Devi Atas, Sakraya, Sunrakh, and Nagla Hemraj series.

In general, the exchangeable cations followed the order Ca²⁺ > Mg²⁺ > Na⁺ > K⁺ which is in consonance with the report of many workers (Gupta *et al.*, 1989; Singh and Mishra, 1996). Statistical analysis shows a high significant and positive correlation between exchangeable cations Ca²⁺, Mg²⁺, Na⁺, K⁺ and clay content of soils ($r = 0.5963$), ($r = 0.8440$), ($r = 0.5510$) and ($r = 0.4179$) respectively. Exchangeable Ca²⁺ is also significantly and positively correlated with CEC, Mg²⁺, silt and Fe₂O₃.

($r = 0.7073$), ($r = 0.4268$), ($r = 0.3238$), ($r = 0.5100$) respectively. It is also significantly and negatively correlated with pH ($r = -0.4411$) and sand content ($r = -0.5028$). Mg^{2+} and Na^+ also followed the similar trend.

4.3.1.5 Base saturation

The per cent base saturation indicates the degree of leaching of soil, which is used as diagnostic criteria for classifying the soil into order level.

Soils of the study area were highly base saturated with values ranging from 68.83 to 96.48 per cent in surface horizons and from 51.38 to 97.99 per cent in sub-surface horizons. The weighted average values show that all the soil series have more than 80 per cent base saturation except three series i.e. Gonda Atas, Kiki Nagla and Devi Atas that have less than 80 per cent saturation with bases (Fig. 4.6).

No depth wise trend was observed. The high base saturation of these soils indicates the low degree of leaching in the study area.

4.1.4 Chemical Properties

Some of the chemical properties of soils relevant to present study (organic carbon, free $CaCO_3$, Free Fe_2O_3 available macro and micronutrients) are presented in Table 4.6.

4.1.4.1 Organic carbon

Organic carbon (O.C) content is an important and distinguishing diagnostic criteria. Soils of the study area, except surface horizon of Maghera series (P7), contained low organic carbon, i.e. less than 0.50 per cent. It ranged from 0.08 to 0.43 per cent in surface horizons and from 0.02 to 0.28 per cent in sub-surface horizons. However, surface horizons of P7

Table 4.6 Chemical characteristics of soils

Horizon	Depth (cm)	O.C.	Free	Free	Fe Fe ₂ O ₃	Available macronutrients (kg ha ⁻¹)			DTPA-Extractable micronutrients, (mg Kg ⁻¹)				
			CaCO ₃	(%)		N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu	
P1 - Gonda Atas Series													
A	0 - 15	0.11	8.40		0.38	97.22	5.60	323.90	1.16	3.27	0.31	0.28	
Bw1k	15 -50	0.09	15.75		0.58	50.18	7.18	326.59	1.5	1.90	0.17	0.32	
Bw2	50 - 75	0.06	9.70		0.45	34.50	4.90	236.54	1.25	1.16	0.25	0.21	
Bw3	75 - 112	0.14	11.00		0.55	25.09	6.21	252.67	1.89	1.69	0.19	0.25	
C	112 - 150	0.06	2.00		0.34	12.54	5.40	131.71	0.98	1.01	0.13	0.19	
P2 - Kiki Nagla series													
Ap	0 - 10	0.24	2.76		0.29	213.25	35.71	317.18	1.71	5.91	0.36	0.42	
A12	10 - 25	0.24	2.25		0.32	159.94	3.35	198.91	1.72	3.83	0.25	0.48	
Bw1	25 - 50	0.22	1.25		0.37	156.80	4.44	172.03	1.15	3.46	0.22	0.56	
Bw2	50 - 85	0.12	1.60		0.44	144.26	2.65	176.06	2.33	3.65	0.07	0.58	
Bc	85- 115	0.09	2.25		0.52	166.21	2.66	189.50	2.81	4.04	0.11	0.69	
C	115 - 150	0.09	1.50		0.44	109.76	4.40	213.70	2.42	3.27	0.07	0.52	
P3 - Nagla Ramtal series													
Ap	0 - 15	0.39	0.00		0.49	216.38	24.60	215.04	8.24	10.25	0.44	1.50	
AB	15 - 35	0.32	0.00		0.58	178.75	4.91	198.91	5.02	7.67	0.17	0.89	
Bt1	35 - 65	0.14	0.00		0.72	163.07	4.90	228.48	4.82	7.01	0.09	0.72	
Bt2	65 - 95	0.16	0.00		0.80	144.26	4.45	266.11	5.56	10.52	0.18	0.72	
Bt3	95 - 123	0.13	0.00		0.80	172.48	5.60	244.61	6.52	11.45	0.21	0.89	
Bc	123 - 165	0.06	3.00		0.74	112.90	3.35	288.24	4.91	5.10	0.13	0.75	

Table 4.6 Contd

Horizon	Depth (cm)	O.C.	Free		Available macronutrients (kg ha ⁻¹)	DTPA-Extractable micronutrients, (mg Kg ⁻¹)						
			CaCO ₃ (%)	Fe ₂ O ₃		N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu
P4 - Deve Atas Series												
Ap	0 - 20	0.25	2.25	0.39	219.52	13.10	227.14	1.94	4.41	0.33	0.54	
Bw1	20 - 45	0.22	0.50	0.45	144.26	7.25	180.10	1.92	3.39	0.13	0.69	
Bw2	45 - 73	0.16	1.50	0.52	141.12	7.70	172.03	1.94	3.72	0.14	0.65	
Bw3	73 - 105	0.11	3.00	0.58	125.44	5.45	197.57	2.47	4.27	0.08	0.66	
Bc	105 - 140	0.09	8.60	0.52	94.08	5.60	208.32	1.92	3.97	0.18	0.64	
C	140 - 165	0.04	2.76	0.45	37.63	8.00	126.34	1.61	3.04	0.13	0.25	
P5 - Nagla Chamran Series												
Ap	0 - 15	0.08	0.10	0.35	185.02	32.10	237.89	6.01	8.27	0.39	0.98	
Bw1	15 - 50	0.13	0.10	0.72	144.26	14.90	236.54	7.08	7.27	0.13	0.90	
Bw2	50 - 76	0.28	0.10	0.83	166.21	23.30	259.39	9.59	6.63	0.29	0.91	
Bw3	76 - 110	0.22	0.10	0.97	141.12	53.60	331.97	13.41	10.08	0.35	1.30	
Bw4	110 - 150	0.27	0.10	0.98	119.17	104.10	416.64	10.46	7.41	0.37	1.10	
P6 - Sakraya Series												
Ap	0 - 20	0.35	1.75	0.48	244.61	28.70	254.02	4.28	5.77	0.37	0.81	
Ac	20 - 60	0.19	1.25	0.51	169.34	4.40	87.36	4.78	3.41	0.15	0.77	
1C	60 - 75	0.11	0.00	0.41	47.04	3.85	44.35	1.92	1.73	0.17	0.19	
2C	75 - 87	0.13	1.25	0.53	72.13	11.80	81.98	2.84	2.25	0.16	0.47	
3C1	87 - 110	0.03	0.00	0.36	37.63	3.36	47.04	1.81	1.69	0.06	0.19	
3C2	110 - 150	0.03	0.00	0.34	28.22	5.74	56.45	2.58	1.57	0.12	0.19	
4C	150+	0.14	2.30	0.65	18.82	7.20	161.28	4.85	3.31	0.26	1.27	

Table 4.6 Contd

Horizon	Depth (cm)	O.C.	Free CaCO ₃ (%)	Free Fe ₂ O ₃	Available macronutrients (kg ha ⁻¹)			DTPA-Extractable micronutrients, (mg Kg ⁻¹)				
					N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu	
P7 - Maghera Series												
Ap	0 -20	0.50	0.30	0.59	206.98	17.70	180.10	6.26	8.25	0.28	0.87	
Bw1	20 - 50	0.14	0.00	0.88	147.39	6.75	114.24	2.95	4.62	0.17	0.47	
Bw2	50 - 82	0.09	0.00	0.92	109.76	3.38	100.80	2.49	4.98	0.08	0.35	
Bc	82 - 125	0.16	0.00	0.88	103.49	6.24	88.70	2.36	4.18	0.06	0.29	
Ck	125 - 150	0.13	9.20	0.64	50.18	2.66	84.67	1.86	1.61	0.15	0.24	
P8 - Sunrakh Series												
A	0 - 20	0.25	2.30	0.81	159.94	8.50	177.41	1.16	3.28			
Bw1	20 - 45	0.11	4.75	0.64	103.49	9.00	116.93	1.04	2.07	0.20	0.44	
Bw2k	45 - 85	0.03	10.00	0.74	53.31	5.60	123.65	1.16	1.72	0.07	0.30	
Bck	85 - 120	0.06	5.75	0.66	65.86	7.70	189.50	1.17	1.38	0.18	0.22	
C	120 - 150	0.09	1.50	0.41	31.36	7.70	184.13	1.92	0.94	0.17	0.37	
P9 - Nagla Hemraj Series												
Ap	0 - 20	0.25	0.75	0.45	288.51	50.00	327.94	4.97	5.60	0.74	1.16	
Ac	20 - 52	0.11	0.25	0.69	128.58	4.45	141.12	2.74	4.90	0.15	0.53	
1C	52 - 90	0.09	0.75	0.80	109.76	2.64	122.30	2.31	4.56	0.09	0.54	
2C1	90 - 125	0.06	9.75	0.68	90.94	5.45	91.39	2.04	3.74	0.15	0.41	
2C2k	125 - 150	0.03	15.00	0.44	31.36	5.42	63.17	0.60	.95	0.08	0.18	

Table 4.6 Contd

Horizon	Depth (cm)	O.C.	Free		Free Fe ₂ O ₃	Available macronutrients (kg ha ⁻¹)			DTPA-Extractable micronutrients, (mg Kg ⁻¹)			
			CaCO ₃	(%)		N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu
P10 - Ral series												
Ap	0 - 15	0.27	0.50	0.50	0.57	235.20	26.20	192.19	6.29	8.78	0.40	1.05
Bw1	15 - 43	0.06	0.00	0.00	0.70	122.30	7.45	98.11	3.77	6.99	0.30	0.69
Bw2	43 - 80	0.05	0.00	0.00	0.79	116.03	6.48	112.90	3.98	9.02	0.26	0.60
Bc	80 - 125	0.02	0.00	0.00	0.82	106.62	7.76	118.27	3.27	7.54	0.22	0.62
C	125 - 150	0.05	0.00	0.00	0.84	47.04	15.10	100.80	2.07	4.23	0.22	0.28
P11 - Bhadal Series												
Ap	0 - 18	0.43	1.75	0.50	0.50	260.29	31.80	456.96	15.01	7.56	0.61	3.58
A12	18 - 50	0.24	0.10	0.76	0.76	175.62	8.20	341.38	4.19	7.91	0.24	1.34
A13	50 - 70	0.25	0.25	0.94	0.94	172.48	7.45	397.82	3.50	8.04	0.13	1.41
P12 - Barauta Series												
A11	0 - 15	0.19	0.25	0.30	0.30	112.90	46.40	413.95	3.09	1.73	0.40	0.83
A12	15 - 45	0.11	0.00	0.68	0.68	125.44	10.00	369.95	2.67	4.86	0.20	0.82
Ck1	45 - 82	0.14	8.50	0.77	0.77	84.67	11.00	165.31	1.62	2.49	0.22	0.79
Ck2	82 - 110	0.14	25.00	0.73	0.73	47.04	4.60	107.52	1.40	2.00	0.13	0.39
Ck3	110 -145	0.14	21.25	0.78	0.78	47.04	12.80	139.78	1.97	2.09	0.20	0.38

Table 4.7 Chemical properties of soil (weighted means)

Soil series	O.C.	Free	Free	N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu
		CaCO ₃	Fe ₂ O ₃							
		%								
		kg ha ⁻¹								
Gonda Atas (P1)	0.1	12.00	0.46	78.34	6.23	324.98	1.30	2.72	0.25	0.30
Kiki Nagla (P2)	0.24	2.45	0.31	181.26	16.29	246.22	1.72	4.67	0.29	0.46
Nagla Ramtal (P3)	0.36	0.0	0.53	201.33	16.72	208.59	6.95	9.22	0.33	1.26
Devi Atas (P4)	0.24	2.25	0.40	204.47	11.93	172.30	1.94	4.21	0.29	0.57
Nagla Chamran (P5)	0.1	0.10	0.50	168.72	25.22	237.35	6.44	7.87	0.29	0.95
Sakraya (P6)	0.32	1.65	0.49	229.56	18.10	169.88	4.38	5.30	0.33	0.80
Maghera (P7)	0.43	0.00	0.65	195.06	15.51	166.93	5.60	7.52	0.26	0.79
Sunrakh (P8)	0.22	6.51	0.78	147.65	8.60	165.32	1.14	3.04	0.17	0.41
Nagla Hemraj (P9)	0.22	1.38	0.50	256.52	40.84	290.58	4.52	5.46	0.62	1.03
Ral (P10)	0.20	0.00	0.62	190.04	18.70	154.56	1.51	8.06	0.36	0.91
Bhadal (P11)	0.37	1.75	0.57	236.58	25.19	424.60	11.98	7.66	0.51	2.95
Barauta (P12)	0.16	7.68	0.33	117.92	31.84	396.35	2.92	2.98	0.32	0.83

contained 0.50 per cent. The organic carbon content in all the soils were found to be the highest in epipedons and decreased along with depth except Nagla Chamran series (P5) which showed high O.C content in the lower horizons. It varied from 0.08 per cent in surface horizon to 0.27 per cent at 110-150 depth. It's probably because of human disturbance of soil during leveling. The weighted averages of O.C values shows that all soil series are having O.C less than 0.5 per cent and varies from 0.1 to 0.43 per cent. In order to differentiate between soil series they were grouped into three groups based on O.C contents i.e. <0.2, 0.2 - 0.3, 0.3 - 0.5 per cent as very low, moderately low and low respectively (Fig. 4.7). It is clearly seen that Bhadal, Maghera, Nagla Ramtal and Sakraya series are the best in the study area regarding organic carbon content (0.3 - 0.5%). Ral, Nagla Hemraj, Devi Atas, Kiki Nagla, and Sunrakh are classified as moderately low and Barauta, Nagla Chamran and Gonda Atas are classified as very low in organic carbon content.

Poor organic carbon content of the study area could be due to low accumulation of organic matter and because of prevailing climatic conditions, low rainfall and high temperature which is conducive for rapid decomposition of organic matter. Their irregular distribution pattern in the profiles could be due to different cycles of alluvial deposition (Sharma *et al.*, 1999).

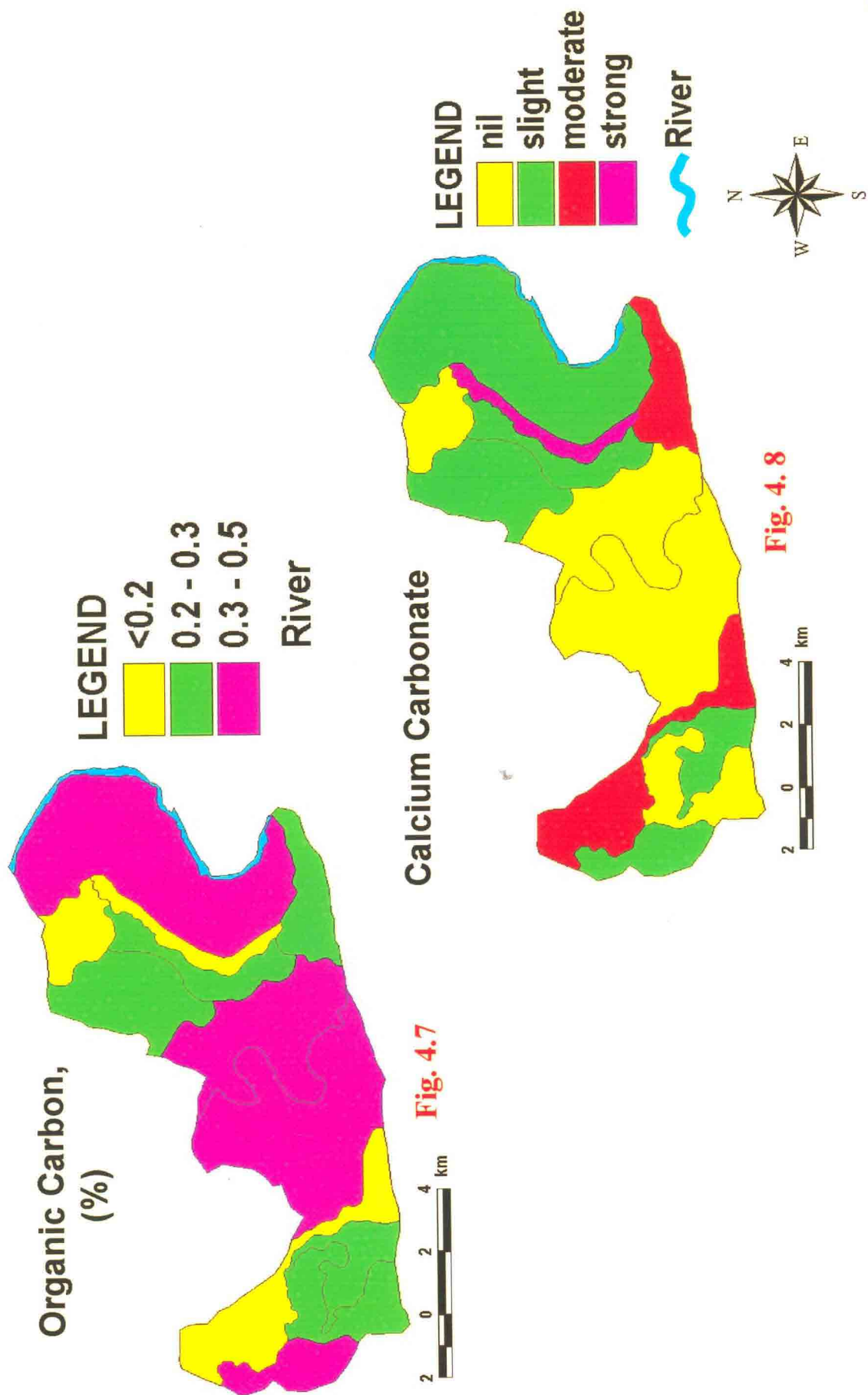
Statistical analysis (Appendix III) shows high significant and positive correlation between organic carbon and N, P_2O_5 , K_2O , Fe, Mn, Zn and Cu with values of ($r = 0.7160$), ($r = 0.4416$), ($r = 0.4740$), ($r = 0.5671$), ($r = 0.4654$), ($r = 0.4244$), ($r = 0.6171$) respectively.

4.1.4.2 Free calcium carbonate

The free CaCO_3 was observed in all the soil series. The percentage ranged from 0.10 to 8.40 in surface horizons to 25.00 per cent in sub-surface horizons. The soils in the study area have high amount of bases, as calcium and magnesium that might have reacted with CO_2 and H_2O under high temperature to precipitate as calcium bicarbonate which on desiccation resulted in CaCO_3 . The distribution of CaCO_3 may be either uniform throughout the profile or may increase in the lower horizons. The depth of CaCO_3 enriched horizon depends on percolating rainwater, ground water depth, amount of rainfall and texture of the soils. The highest percentage was found in Gonda Atas (P1) followed by Barauta (P12) and Sunrakh (P8) with the weighted average values of 12.00, 7.68 and 6.51 per cent respectively. It has been classified as strong (Gonda Atas), medium (Barauta and Sunrakh), slight (Sakraya, Kiki Nagla, Devi Atas, Nagla Hemraj and Bhadal series) and non-calcareous (Nagla Chamran, Nagla Ramtal, Maghera and Ral series) (Fig. 4.8).

The precipitation of CaCO_3 forming Calcic horizon at some depth in the regolith was observed in Gonda Atas series (P1) which is directly related to the extent of leaching *vis-à-vis* seasonal cycles of the pedoclimate (Bhattacharjee, 1997).

The calcareous nature of soils in the study area is due to deposition of recent alluvium enriched with CaCO_3 by Yamuna River. It is also present in the form of "kankars" of varying shapes and sizes (Plate 4.9). It could also be due to semi-arid climate of the area, which is quite congenial for carbonate formation, besides deposition of CaCO_3 bearing alluvium. Statistical analysis (Appendix III) shows highly significant and positive



correlation at 1% level between calcium carbonate content and available water capacity (AWC) ($r = 0.4810$).

4.1.4.3 Free iron oxides

The free Fe_2O_3 content ranged from 0.29 to 0.59 per cent in surface horizons and from 0.34 to 0.98 per cent in sub-surface horizons. The highest in Fe_2O_3 content was in Maghera followed by Nagla Chamran, Ral, Bhadal and Nagla Ramtal series with the mean values of 0.78, 0.77, 0.74, 0.73 and 0.69 per cent and the least was Kiki Nagla followed by Gonda Atas, Sakraya and Devi Atas series with mean values of 0.40, 0.46, 0.47 and 0.79 per cent respectively. The other series have Fe_2O_3 content between 0.61 to 0.66 per cent. It has been observed that Fe_2O_3 content is low in epipedon which increased in B horizon indicating advanced weathring stage and then slightly decreased in lower horizons. However, in Devi Atas, Bhadal, Ral and Barauta series it regularly increased with depth. In Sakraya series, it was irregularly distributed with depth.

Statistical analysis shows high significant and positive correlation between Fe_2O_3 content an DTPA-extractable Mn ($r = 0.3701$) and significant but negative correlation with pH ($r = -0.3513$)

4.1.4.4 Available nitrogen

From the results obtained (Table 4.6), it is observed that all soil series in the study area are low in nitrogen content. It ranged from 97.22 to 288.51 kg ha^{-1} in surface horizons and from 12.54 to 178.75 kg ha^{-1} in sub-surface horizons. It is observed that in all soil profiles the surface layers are having higher amount of available nitrogen than sub-surface

layers which is attributed to the trend of organic carbon distribution and also mineralization. The distribution in the profiles tends to decrease with depth in all profiles.

The weighted means (Table 4.7) shows that Nagla Hemraj was the highest in available nitrogen followed by Bhadal series, Sakraya series, Devi Atas and Nagla Ramtal with values of 256.5, 236.6, 229.6, 204.5 and 201.3 kg ha⁻¹ respectively. The lowest available nitrogen was found in Gonda Atas followed by Barauta and Sunrakh with values of 78.3, 117.9 and 148.6 kg ha⁻¹ respectively. These soils are affected by different types of soil degradation i.e. ravines with alkalinity (Gonda Atas), erosion and salinity (Sunrakh) and salinity/alkalinity and waterlogging (Barauta). The distribution of available nitrogen in the study area is shown in Fig. 4.9.

The available nitrogen seems to be controlled by organic carbon, silt and clay content. Correlation studies showed highly significant and positive correlation between available nitrogen and organic carbon with $r = 0.7160^{**}$. The significant and positive correlation between available nitrogen and organic carbon content was also reported by Kumar *et al.* (1995). It also shows highly significant and negative correlation between available nitrogen and calcium carbonate content with $r = -0.4565^{**}$.

In general the soils are low in available nitrogen that could be due to low total nitrogen, organic matter and high temperature regime (Dasog and Hadimani, 1980; Goyal and Singh, 1987)

4.1.4.5 Available phosphorus

The available phosphorous content in all the studied soils is low to medium and ranges from 5.60 to 70.30 kg ha⁻¹ in surface horizons and

from 3.35 to 104.10 kg ha⁻¹ in sub-surface horizons. The weighted means show that the highest in available phosphorous content (in terms of P₂O₅ kg ha⁻¹) is Nagla Hemraj followed by Barauta, Nagla Chamran and Bhadal with values 40.9, 31.8, 25.2 and 25.2 kg ha⁻¹ respectively and the lowest is in Gonda Atas followed by Sunrakh with values 6.2 and 8.6 kg ha⁻¹ respectively. The low content of available phosphorous in the study area may be due to high removal than replenishment and also due to high fixing capacity of waterlogged and paddy soils, where the major part of applied P remains fixed in the form of Al, Fe and Ca-P after the harvest of paddy crop. It could be also due to low organic carbon and total P content and at the same time high pH value and CaCO₃ content causing the conversion of soluble P into insoluble form of calcium phosphate (Ruhal and Dev, 1979).

The highest values are observed in surface horizons (Ap) in all soils except Nagla Chamran series (P5), which could be due to management practices (addition of fertilizers to plough layer) and decreasing trend with depth may be due to fixation of phosphorous either by sesquioxides or by calcium carbonate. However Nagla Chamran series shows different trend of increasing available phosphorous with depth from 32.10 kg ha⁻¹ in surface to 104.10 kg ha⁻¹ in Bw4 horizon. That is can be due to turning over and leveling (churning) of the soil.

Statistical analysis of the data on available P (in term of P₂O₅ kg ha⁻¹) of the soils showed that soil reaction and CaCO₃ content influenced negatively the amount of available P with r values = -0.2994* and -0.1886 respectively. In contrast, organic carbon content influenced positively

with $r = 0.4416^{**}$. The levels and distribution of available phosphorous in study area is shown in Fig. 4.10.

4.1.4.6 Available potassium

The available potassium (in terms of K_2O kg ha⁻¹) of the soils ranged from 177.41 to 456.96 kg ha⁻¹ in surface horizons and from 44.35 to 416.64 kg ha⁻¹ in sub-surface horizons. Most of the soil series did not show any distribution pattern with depth except Maghera and Nagla Hemraj, which showed the tendency of decreasing available K with depth whereas Nagla Chamran showed the tendency of increasing available K with depth similar to that as available phosphorous. The same distribution pattern was found in soils of Ghaggar river basin as reported by Singh and Ahuja (1990).

Weighted mean values shows that Bhadal series was found to be the highest in available K followed by Barauta with values of 424.6 and 396.3 kg ha⁻¹ respectively.

Considering the criteria of <136, 136-337.5 and > 337.5 K_2O kg ha⁻¹ as low, medium and high respectively (Baruah and Barthakur, 1999), soil series in the study area in general could be grouped into medium in available K except Bhadal series and Barauta which could be grouped into high in available K.

Correlation studies showed a positive and highly significant relation between available K and organic carbon, silt and clay with ($r = 0.4740^{**}$), ($r = 0.4618^{**}$) and ($r = 0.4200^{**}$) respectively. This is in agreement with the reports of Deshmukh *et al.* (1991).

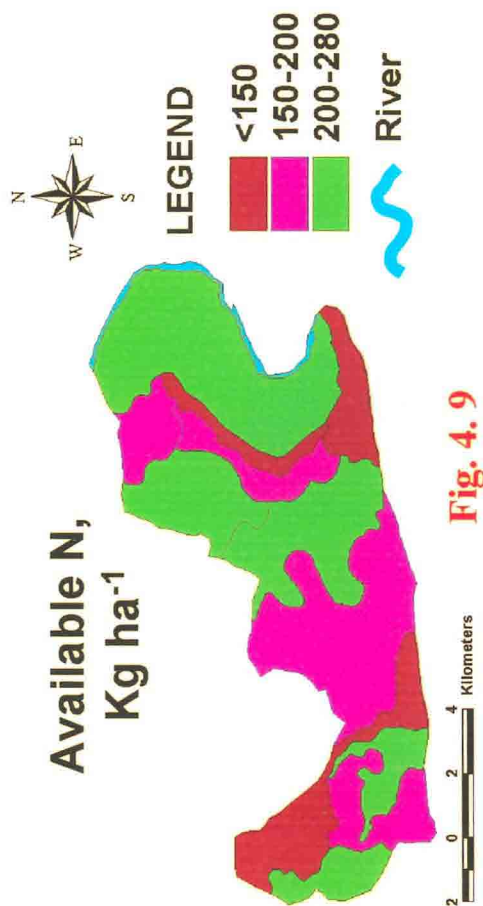


Fig. 4.9

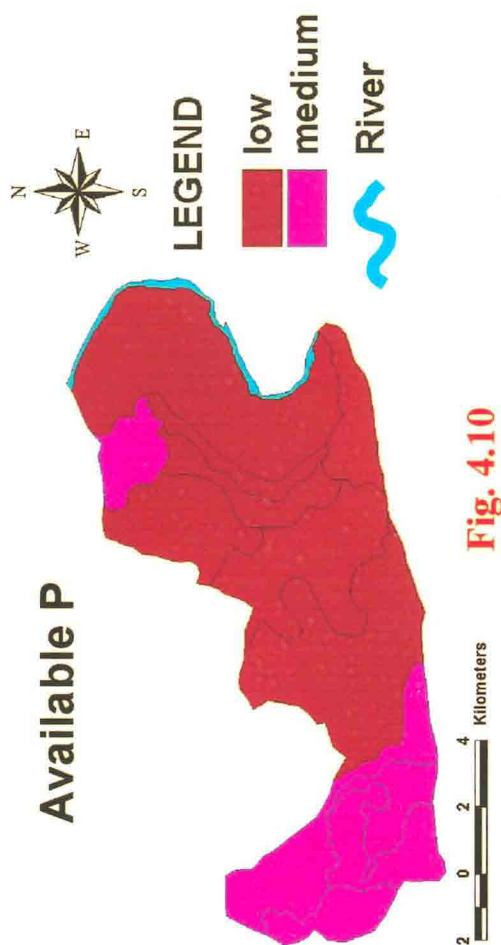


Fig. 4.10

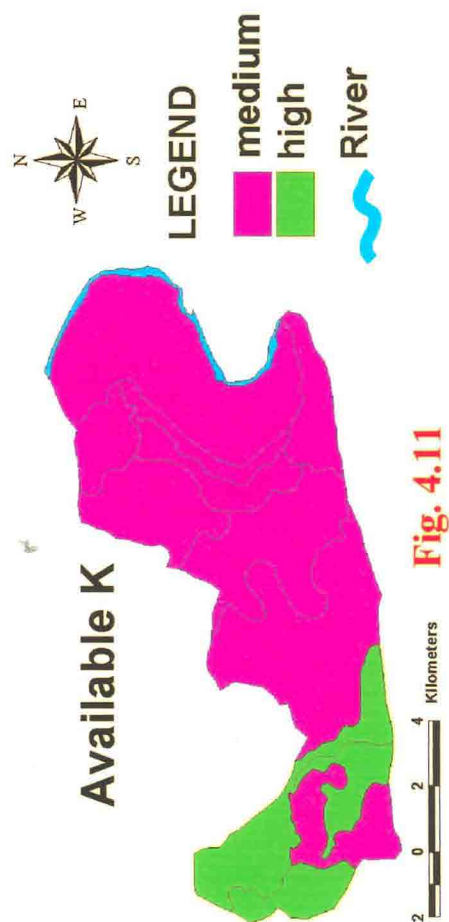


Fig. 4.11

The levels and distribution of available potassium in study area is shown in Fig. 4.11.

4.1.4.7 DTPA extractable micronutrients

The weighted mean data of Diethylene Triamine Penta Acetic Acid (DTPA) extractable micronutrients (Table 4.7) showed that Mn was the highest available micronutrient in all the soils except Bhadal series where the Fe is the highest one. The availability of the micronutrients followed the order $Mn > Fe > Cu > Zn$.

DTPA extractable-Fe

The DTPA-Fe content of the soils (Table 4.6) varied from 1.16 to 15.01 mg kg⁻¹ in surface horizons to 1.04 to 13.41 mg kg⁻¹ in sub-surface horizons. The distribution of available Fe showed decreasing trend in Maghera, Nagla Hemraj, Bhadal, Ral and Barauta series and increasing trend in Nagla Chamran series. Other profiles showed an indefinite trend. Bhadal series contained relatively higher amount of available Fe when compared to other soils followed by Nagla Ramtal, Nagla Chamran, Maghera and Nagla Hemraj series with weighted averages values 11.9, 6.9, 6.4, 5.6, and 4.5 kg ha⁻¹ respectively. On the other hand it was found that Gonda Atas and Sunrakh were the lowest in available Fe content with values 1.30 and 1.14 kg ha⁻¹ respectively, which may be due to the highest CaCO₃ content in these soils.

The high DTPA-Fe in Bhadal, Nagla Ramtal, Nagla Chamran, Maghera and Nagla Hemraj may be due to high clay and organic carbon content, while the low content of available Fe in Gonda Atas and Sunrakh

series is most probably due to presence of CaCO_3 coupled with high pH value as reported by Yelvikar *et al.* (1996) and Prasad and Gajbhiye (1999).

Statistical analysis confirmed that organic carbon, silt and clay showed highly significant and positive correlation with DTPA-Fe content with r values = 0.5671**, 0.4199** and 0.3166* respectively, while pH, CaCO_3 and sand have negative correlation with the DTPA-Fe content with r = -0.4205**, -0.3440** and -0.4195** respectively. The positive correlation between available Fe and organic carbon was also reported by Sarkar *et al.* (2000).

On the basis of critical limit of 4.5 mg kg^{-1} (Lindsay and Norvell, 1978), Bhadal, Nagla Ramtal, Nagla Chamran, Maghera and Nagla Hemraj soil series could be grouped as adequate in available Fe content while the others were found to be deficient (Fig. 4.12).

DTPA extractable-Mn

The DTPA-Mn of the soils was adequate in general which ranged from 1.73 to 10.25 mg kg^{-1} in surface horizons and from 0.95 to 11.45 mg kg^{-1} in sub-surface horizons. There was a tendency of available Mn to increase with depth in Bhadal series only, while in Maghera, Sunrakh and Nagla Hemraj it tends to decrease. The others show irregular distribution with depth. Weighted average values show that Nagla Ramtal series recorded the highest in available Mn with the value of 9.22 mg kg^{-1} followed by Ral, Nagla Chamran, Bhadal and Maghera series with values of 8.1 , 7.8 , 7.7 and 7.51 mg kg^{-1} respectively. These soil series occurring on alluvial plain with slope gradient of 0 to 1 per cent (except Nagla Chamran) have relatively high clay, CEC and very less CaCO_3 content.

Gonda Atas had the lowest content of available Mn followed by Barauta series with values of 2.72 and 2.98 mg kg⁻¹ respectively. These are degraded soils occurring on ravinous areas and salt affected old alluvial plains with slope gradient of 3-5 and 0-1 per cent respectively and having the highest CaCO₃ content among others soil series in the study area.

Correlation studies had shown that available Mn is significantly and positively correlated with clay content and CEC with ($r = 0.5040^{**}$) and ($r = 0.4662^{**}$) whereas, it is significant but negatively correlated with CaCO₃ and pH ($r = -0.4425^{**}$) and ($r = -0.4342^{**}$) respectively.

On the basis of critical limit of 3.5 mg kg⁻¹ (Lindsay and Norvell, 1978), Gonda Atas, Sunrakh and Barauta soil series could be grouped as deficient in Mn content while others were found to be adequate (Fig. 4.13).

DTPA extractable-Zn

The DTPA-Zn of the soils was found to be deficient in general. It ranged from 0.2 to 0.74 mg kg⁻¹ in surface horizons whereas in sub-surface horizons it varied from 0.06 to 0.37 mg kg⁻¹. There was not much variation in available Zn among and within the profiles. All the soils showed high Zn content in surface horizons and decreasing trend with depth. Weighted average values show that Nagla Hemraj series recorded the highest in available Zn with the value of 0.62 mg kg⁻¹. All the other series showed values of available Zn less than critical level.

Considering 0.60 mg kg⁻¹ as critical limit of Zn (Lindsay and Norvell, 1978), it can be inferred that Nagla Hemraj series is the only one series adequate in available Zn. All the other series were found to be deficient in available Zn (Fig. 4.14).

The low available Zn content is possibly due to high soil pH and CaCO_3 content which might have resulted in the formation of insoluble compound of zinc or insoluble calcium zincate (Sarkar *et al.*, 2000). Correlation studies indicated that available Zn is highly significantly and positively correlated with organic carbon, clay content and CEC with ($r = 0.4244^{**}$), ($r = 0.3615^*$), and ($r = 0.3066^{**}$) while it is significant and negatively correlated with pH and non significant but negatively correlated with CaCO_3 content ($r = -0.3370^*$) and ($r = -0.1130$) respectively.

DTPA extractable-Cu

DTPA-Cu content of surface horizons of the soils ranged from 0.28 to 3.58 mg kg^{-1} and in sub-surface horizons it ranged from 0.19 to 1.41 mg kg^{-1} . Maghera, Nagla Hemraj, Ral and Barauta series showed the tendency to decrease in available Cu with depth whereas Kiki Nagla, Nagla Ramtal, Devi Atas and Nagla Chamran series had the tendency to increase in available Cu with depth. Available Cu distributed unevenly and its availability more or less followed the presence of clay and CaCO_3 in the profiles of Gonda Atas, Sakraya, Sunrakh and Bhadal series. In general, soils on the upper slopes had higher available Cu than those on lower parts. Weighted average values show that Bhadal series recorded the highest in available Cu followed by Nagla Ramtal and Nagla Chamran with values of 2.95, 1.26 and 0.95 mg kg^{-1} respectively. Gonda Atas had the lowest content of available Cu followed by Kiki Nagla series with values of 0.30 and 0.46 mg kg^{-1} respectively.

Correlation studies showed that clay and organic carbon content are highly significant and positively correlated with available Cu

Available Fe

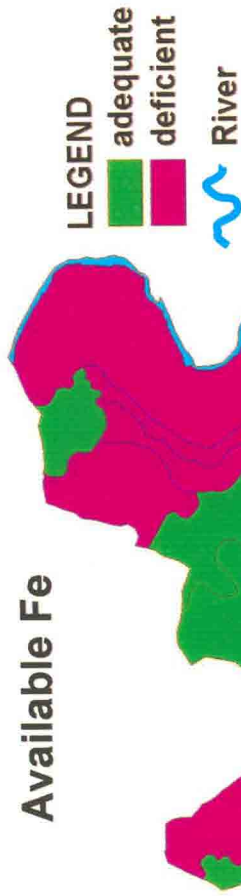


Fig. 4.12

Available Mn



Fug.4.13

Available Zn



Fig. 4.14

Available Cu

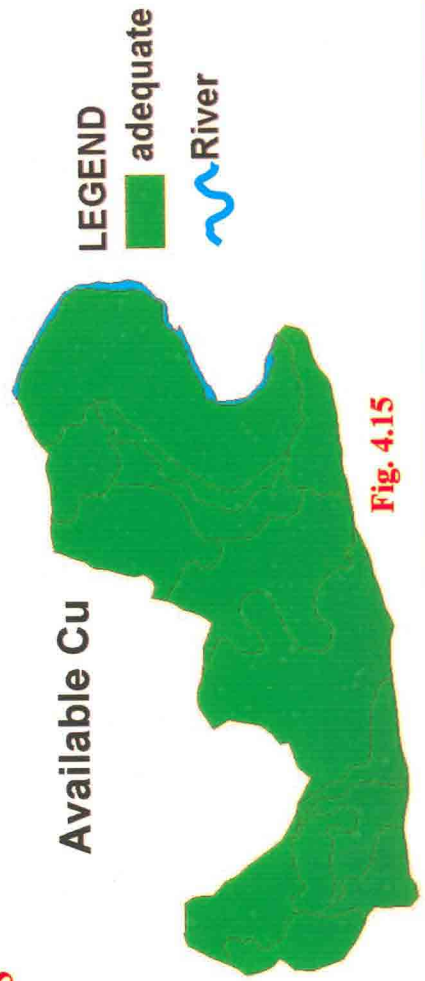


Fig. 4.15

($r = 0.3903^{**}$ and $r = 0.6171^{**}$ respectively), while CaCO_3 and pH are highly significant but negatively correlated with it ($r = -0.2822^{**}$ and $r = -0.6171^{**}$ respectively). Similar observation, particularly correlation between available Cu and Organic carbon as well as available Cu and clay content, was reported by Siddhamalai *et al.* (1999) and Sarkar *et al.* (2000).

Considering 0.20 mg kg^{-1} as critical limit of Cu (Lindsay and Norvell, 1978), all soils in the study area have sufficient available Cu (Fig. 4.15).

4.2 Soil Mineralogy

Layer aluminosilicate clays constitute the major portion of the clay fraction in most of the soils. This information helps in understanding the properties of soils and also used as a differentiating character at family level in soil taxonomy.

4.2.1 X-ray Differentiation (XRD)

Identification of various minerals in clay fraction ($< 2 \mu\text{m}$) from selected profiles and horizons was done on the basis of strongest peaks from basal planes. The clay minerals were subjected to different treatments *viz.* Mg- air; Mg-glycerol solvated, K-air and K-550°C and X-ray diffractograms were obtained by X-ray diffractometer. The X-ray diffractograms are given in Appendix IV.

Smectite was observed in all the samples. The presence of this mineral was indicated by the presence of peak at $17.65 \text{ \AA}$ to about $22.06 \text{ \AA}$ in Mg glycerol solvated clay.

Vermiculite was observed in some samples. The presence of this mineral was confirmed by the presence of a peak at 14.24 Å that disappeared in K-550 °C treated samples. Chlorite was also observed almost in all the soils except Maghera series. Indication of the existence of chlorite was identified with the presence of peak at 1424 Å in Mg-glycerol solvated sample and its persistence on K-heated at 550 °C clay. All the samples contained mica and kaolinite. The presence of mica was indicated by the appearance of peak at 10.27 Å, while kaolinite was indicated by the peak of 7.13 Å, which collapsed on K-500 °C.

4.2.2 Semi-quantitative composition of soil clay

The semi quantitative composition of soil clay was estimated on the basis of relative peak area corrected for scattering at low angles recorded in X-ray diffractogram. The data on semi-quantitative composition of soil clay is presented in Table 4.8. This data showed that mica (illite) was the dominant mineral in almost all the soils, with the range of 39 to 75 per cent in surface horizons and from 42 to 76 per cent in sub-surface horizons. Mean averages (Table 4.9) show that Nagla Chamran series is the highest in illite content 76 per cent, followed by Maghera and Ral (P10) with mean averages 66 and 65 per cent respectively while Gonda Atas was the lowest (44 per cent) followed by Devi Atas and Sakraya series with 45 and 48 per cent respectively.

Next to mica were kaolinite and chlorite. Kaolinite was found to be next dominant mineral in all soil series with the range of 11 to 24 per cent in surface horizons and from 14 to 25 per cent in sub-surface horizons. Mean averages show that Ral is the highest in Kaolinite content 25 per cent followed by Barauta, Devi Atas, Nagla Ramtal and Kiki Nagla with

Table 4.8 Semi-quantitative composition of soil clay of selected horizons

Horizon	Depth, (cm)	Minerals (%)				
		Smectite	Vermiculite	Chlorite	Illite	Kaolinite
P1 - Gonda Atas Series						
A	0 - 15	6	-	29	45	20
C	112 - 150	6	-	37	42	15
P2 - Kiki Nagla Series						
Ap	0 - 10	4	-	24	51	21
Bc	85- 115	8	2	16	56	18
P3 - Nagla Ramtal Series						
Ap	0 - 15	3	-	24	52	21
Bc	123 - 165	9	2	14	57	18
P4- Devi Atas Series						
Ap	0 - 20	6	-	36	39	19
Bc	105 - 140	8	2	18	51	21
P5 - Nagla Chamran Series						
Ap	0 - 15	3	-	11	75	11
Bw4	110 - 150	5	-	5	76	14
P6 - Sakraya Series						
Ap	0 - 20	8	-	33	46	13
4C	150+	14	-	19	49	18
P7- Maghera Series						
Ap	0 -20	10	7	-	65	18
Ck	125 - 150	11	5	-	67	17
P8 - Sunrakh Series						
A	0 - 20	8	-	18	57	17
Bw2k	45 - 85	9	-	13	58	20
P9 - Nagla Hemraj						
Ap	0 - 20	4	-	21	60	15
2C2k	125 - 150	8	3	9	63	17
P10 - Ral Series						
Ap	0 - 15	4	2	3	67	24
C	125 - 150	5	1	7	62	25
P11 - Bhadal Series						
Ap	0 - 18	4	-	22	56	18
A13	50 - 75	7	2	14	63	14
P12 - Barauta Series						
A11	0 - 15	4	-	13	62	21
Ck3	110 -145	10	-	19	49	22

Table 4.9 **Semi-quantitative composition of soil clay of selected horizons (Average means)**

Series	Minerals (%)				
	Smectite	Vermiculite	Chlorite	Illite	Kaolinite
Gonda Atas	5	0	33	44	18
Kiki Nagla	5	1	20	54	20
Nagla Ramtal	5	1	19	55	20
Devi Atas	7	1	27	45	20
Nagla Chamran	4	0	8	76	12
Sakraya	11	0	26	48	15
Maghera	11	6	0	66	17
Sunrakh	9	0	15	58	18
Nagla Hemraj	6	1	15	62	16
Ral	4	1	5	65	25
Bhadal	6	1	18	60	15
Barauta	7	0	16	55	22

22, 20, 20 and 20 per cent respectively. Nagla Chamran series was the lowest (12 per cent) followed by Bhadal and Nagla Hemraj with average of 15 and 16 per cent respectively.

Chlorite was found in all soil series except Maghera. It ranged from 3 to 27 per cent in surface horizons and from 7 to 37 per cent in sub-surface horizons. It was observed to be highest in Gonda Atas followed by Devi Atas and Sakraya series with averages of 33, 27 and 26 per cent. Bhadal series was observed to be the lowest in Chlorite content followed by Nagla Chamran with averages of 5 and 8 per cent respectively.

The next mineral observed was Smectite in all the series with ranges from 3 to 10 per cent in surface horizons and from 5 to 14 per cent in sub-surface horizons. It was observed to be highest in Sakraya followed

by Maghera and Sunrakh with averages of 11, 10 and 8 respectively while Nagla Chamran and Ral was found to be the lowest in Smectite content followed by Bhadal with averages of 4, 4 and 6 per cent respectively.

Vermiculite was observed to be the least mineral of the soils in the study area. It was absent totally in Gonda Atas, Nagla Chamran, Sakraya, Sunrakh and Barauta series and was observed in lower depths of Kiki Nagla, Nagla Ramtal, Devi Atas, Nagla Hemraj and Bhadal series.

Leaching condition in Barauta, Ral and Devi Atas series caused the depletion of exchangeable and soluble base cations such as Ca^{2+} , Mg^{2+} , K^{+} and Na^{+} and also enriched in H^{+} concentration. This situation was conducive for formation of 1:1 type of mineral such as kaolinite. Whereas basic cations in alluvium derived soils as a result of deposition of leached products, enabled the soils to increase soil reaction, which in turn increased the solubility of Si. This condition led to formation of 2:1 type of minerals such as smectite, vermiculite, mica and also 2:1:1 type of mineral such as chlorite (Barshad, 1964; Ameryckx, 1985; Hardjowigeno, 1993).

4.3 Soil Classification

Soil classification is a method of organizing and communicating knowledge and perception about the attributes of soils. Based on morphological, physical, physico-chemical and chemical properties, the soils of study area were classified up to soil family level under soil taxonomy system (Table 4.10). Particle size distribution (broad textural class), mineralogy and soil temperature regimes were applied as criteria for grouping the soils into different families. The dominant soils of study area belong to soil orders Inceptisols, Entisols and Alfisols. Based on

Table 4.10 Classification of soils of study area

Profile	Order	Suborder	Great group	Subgroup	Family
P ₁	Inceptisols	Ustepts	Claciustepts	Typic calciustepts	Coarse loamy, calcareous, mixed, hyperthermic
P ₂	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Coarse loamy, calcareous, mixed, hyperthermic
P ₃	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Fine loamy, mixed, hyperthermic
P ₄	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy, calcareous, mixed, hyperthermic
P ₅	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Fine loamy, mixed, hyperthermic
P ₆	Entisols	Fluvents	Ustifluvents	Typic Ustifluvents	Coarse loamy, calcareous, mixed, hyperthermic
P ₇	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Fine loamy, mixed, hyperthermic
P ₈	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Coarse loamy, calcareous, mixed, hyperthermic
P ₉	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy, calcareous, mixed, hyperthermic
P ₁₀	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy, mixed, hyperthermic
P ₁₁	Entisols	Aquents	Endoaquents	Typic Endoaquents	Fine silty, calcareous, mixed, hyperthermic
P ₁₂	Entisol	Fluvents	Ustifluvents	Typic Ustifluvents	Fine loamy, calcareous, mixed, hyperthermic

textural classes, calcareousness, erosion, salinity and alkalinity features of different families they were classified into 12 soil series (Fig. 4.16). All the soils are mineral soils as they have less than 1.0 per cent organic matter. The mean annual soil temperature of study area is 25.12°C , with mean maximum and minimum values of 33.84 and 14.06°C respectively. Since the difference between mean annual summer and winter is more than 5°C , the soils are grouped into Hyperthermic temperature regime.

4.3.1 Entisols

Soil profiles P6, P12 and P11 were classified as Entisols with no diagnostic horizons other than Ochric epipedon. The distinct feature of Entisols is a very slight degree of soil formation either because of limited available time for development or because of unfavorable pedo-environment. The P6 soil was situated in active flood plain of Yamuna River that influenced by seasonal flooding. P12 and P11 soils are situated in the lower left part of old alluvial plain and influenced by high water table, waterlogging and salinity. Intense surface soil erosion, waterlogging may have caused retardation of profile development and soil horizonation. This may be the reason why these soils have not developed well.

The P11 soil had water table at 75 cm depth, three months saturation and redox depletion with a colour value of $2.5\text{Y}4/2$ in surface and $2.5\text{Y}5/2$ in sub-surface. It meets the requirements for Aquents suborder. It has not met the requirements for Sulfic, Lithic, Sodic, aeric, Humaqueptic and Mollic Endoaquents great groups, therefore it has been classified as Typic Endoaquents. The laboratory data indicates the silty clay textural class, morphological studies indicated effervescence throughout the profile and mineralogy studies showed the presence of

mixed type of minerals. These factors led the placement of P11 under *Fine silty, calcareous, mixed, Hyperthermic Typic Endoaquents* at family level. This soil profile was unique in the study area therefore it was placed as separate soil series. It is located near by Bhadal village, so that series has been given the name of *Bhadal series*.

Organic carbon content in P6 and P12 soils decreased irregularly along with depth, and the soil moisture regime is Ustic. Hence this soil met the requirements for Fluvent, Ustifluvent and Typic Ustifluvent at suborder, great group and subgroup, respectively. Laboratory and morphological studies show presence of calcium carbonate and mixed mineralogy in clay fraction of soil in control section in both soils. P6 soil had loamy sand, while P12 had sandy clay loam textural class so that P6 was placed under *Coarse loamy, calcareous, mixed, Hyperthermic Typic Ustifluvent* while P12 was placed under *Fine loamy, calcareous, mixed, Hyperthermic Typic Ustifluvent* at family level. Due to the difference in textural classes, physiography and drainage conditions P6 was placed under Sakraya series and P12 under Barauta series after the names of villages Sakraya and Barauta respectively.

4.3.2 Inceptisols

The P1, P2, P4, P5, P7, P8, P9 and P10 soils have been undergoing soil formation processes but they are in initial stage of soil development. The indication of soils development in these soils are one or combination of these: alteration of colour, soil structure development and accumulation of clay in subsurface horizons. This development led to formation of cambic horizon, and the soils has been classified as Inceptisols. Since

moisture regime of these soils is ustic, these soils were grouped into Ustepts at suborder.

P1 soil has 15.75 percent CaCO_3 within 15 - 50 cm depth that is 5% or more high than that of any underlying horizon. So that it meets the requirements of Calcic horizon and therefore the soil was placed under Calciustepts great group and Typic Calciustepts subgroup. As the textural class was sandy loam, the soil was classified as *Coarse loamy, calcareous, mixed, Hyperthermic Typic Calciustepts*. It is named as Gonda Atas series after the name of Gonda Atas village where it is located.

P2, P4, P9 and P10 soils did not meet the criteria that are required for Durustepts, Calciustepts and Dystrustepts at great group level and were classified as Haplustepts. They were placed under Typic Haplustept at subgroup level, because it represents the central concept of Haplustept. The organic carbon of this soil decreased regularly between depth of 25 cm and 100 cm below the mineral soil surface and had base saturation more than 60 per cent in all its horizons. Since P2 soil had sandy loam textural class, more than 2% CaCO_3 and mineralogical study showed the presence of mixed minerals, it was classified under family of *coarse loamy, calcareous, mixed, Hyperthermic Typic Haplustept*. It has given a name of Kiki Nagla as soil series after the name of Kiki Ka Nagla village. P4 and P9 soils have sandy clay loam textural class, effervescence throughout the profiles and mixed mineralogy so that they are placed under *Fine loamy, calcareous, mixed, Hyperthermic Typic Haplustept*. Since P4 soil is located on undulating recent alluvial plain with 5-10 % slope with moderately well drainage and moderate erosion that affect the potential land use of this soil while P9 soil is located on very gently

sloping old alluvial plain with slope 1 - 3 % with well drainage and not affected by soil erosion they were placed as Nagla Hemraj and Nagla Chamran series after the names of their locations. P10 soils have sandy clay loam textural class, no evidence of CaCO_3 , moderately well drainage and very gently sloping physiography so that it is placed under Ral soil series after the name of Ral village.

Soils of P5, P7 and P8 had organic carbon decrease irregularly between 25 cm and 100 cm depth below mineral soil surface. This led the soils to be grouped into Fluventic Haplustepts. Since the P5 and P7 soils had broad textural class (fine loamy) and mixed mineralogy in clay fraction of soils in control section these soils were placed under *Fine loamy, mixed, Hyperthermic Fluventic Haplustepts*. P5 Soil had loamy textural class, moderate erosion, and moderately well drainage so that it was placed as Nagla Chamran series, while P7 had sandy clay loam textural class and well drainage so that it is keyed as Maghera series after Maghera village. P8 soil had sandy loam textural class (coarse loamy), 6.5 % CaCO_3 and effervescence throughout the profile, affected by severe erosion and poor drainage. It was classified as *coarse loamy, calcareous, mixed, Hyperthermic Fluventic Haplustepts* and placed under Sunrakh soil series after the name of Sunrakh reserve forest where it is located.

4.3.3 Alfisols

P3 soil is very deep having light coloured surface horizon (Ochric horizon) over a clay-enriched, argillic sub-surface horizon with base saturation of more than 35 percent throughout the solum. It is placed at order level of Alfisols. The moisture regime is Ustic because in most part

of the year this soil remains dry for more than 90 cumulative days but less than 180 days and accordingly these soils are placed under Ustalfs suborder. The pedon is devoid of Natric sub-surface horizon, duripan, plinthite, cracs, lithic or paralithic contact within 50 cm and also do not have colour redder than 5YR. Based on these characteristics, this pedon is qualified for Haplustalfs at great group level and this soil do not have any other aberration towards any other soils and hence placed under Typic Haplustalfs at sub-group level. The soil has sandy clay loam textural class and mixed mineralogy and hence classified at family level as *Fine loamy, mixed, Hyperthermic, Typic Haplustalfs*.

4.3.4 Extent of soil orders and series

The area under different soil orders in the study area is given in table 4.11 and illustrated in figure 4.17. It was found that Inceptisols are the dominant soils followed by Entisols and Alfisols with area of 5664.23 ha (59.12%), 2632.30 ha (27.47%) and 1134.65 ha (11.84%) respectively. It was found that Sakraya series is the largest followed by Maghera, Nagla Ramtal, Barauta and Devi Atas with area of 2257.04 ha (23.56 %), 1768.56 ha (18.46 %), 1134.65 ha (11.84%), 829.08 ha (8.65 %) and 781.37 ha (8.16%) respectively. Gonda Atas was found to have the least one followed by Bhadal, Nagla Hemraj and Nagla Chamran with area of 125.73 ha (1.31%), 366.61 ha (3.83%), 373.08 ha (3.89%) and 374.87 ha (3.91%) respectively. Area under different soil series in the study area is given in Table 4.12 and figure 4.18.

Soil Series Map

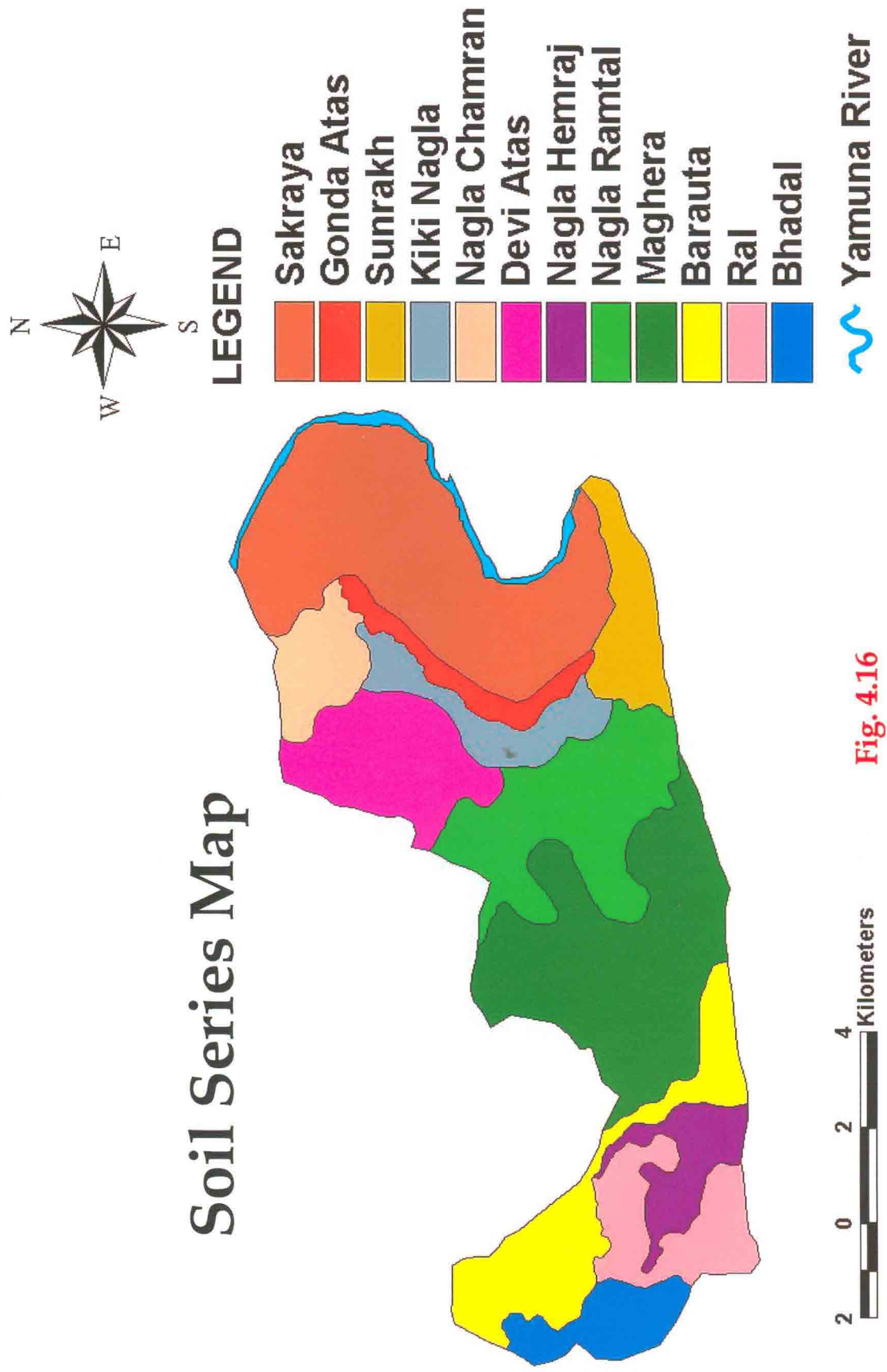


Fig. 4.16

Legend of soil map

Series name	Legend Description	Taxonomy
Sakraya	Very deep, well drained, loamy sand, calcareous, brown to grayish brown soils occurring on nearly level active flood plain with sheet erosion and seasonal flooding	Typic Ustifluvents
Gonda Atas	Very deep, imperfectly drained, sandy loam, calcareous soils occurring on undulating moderately sloping recent alluvial plain with severe erosion and moderate alkalinity	Typic Calcustepts
Sunrakh	Very deep, moderately well drained, sandy loam, calcareous, yellowish brown, occurring on undulating moderately sloping recent alluvial plain with severe erosion and moderate salinity	Fluventic Haplustepts
Kiki Naglh	Very deep, well drained, sandy loam, calcareous, brown to yellowish brown soils occurring on undulating moderating sloping recent alluvial plain with moderate erosion and moderate alkalinity	Typic Haplustepts
Nagla Chamran	Very deep, moderately well drained, loamy, brown to dark brown soils occurring on undulating moderately sloping recent alluvial plain with moderate erosion and moderate alkalinity	Fluventic Haplustepts
Devi Atas	Very deep, well drained, sandy clay loam, calcareous, yellowish brown to dark brown soils occurring on old alluvial plain with moderate erosion and moderate alkalinity	Typic Haplustepts
Nagla Hemraj	Very deep, well drained, sandy clay loam, calcareous, yellowish brown to dark brown soils occurring on very gently sloping old alluvial plain with moderate alkalinity	Typic Haplustepts
Nagla Ramtal	Very deep, moderately well drained, sandy clay loam, dark brown soils occurring on very gently sloping old alluvial plain with slight alkalinity	Typic Haplustepts
Maghera	Very deep, well drained, sandy clay loam soil occurring on very gently sloping old alluvial plain	Typic Haplustepts
Barauta series	Very deep, imperfectly drained, sandy clay loam, calcareous, dark grayish brown to dark brown soils occurring on very gently sloping old alluvial plain with strong salinity	Typic Ustifluvents
Ral	Very deep, moderately, well drained, sandy clay loam soil, occurring on very gently sloping old alluvial plain with moderate alkalinity and seasonal waterlogging	Typic Haplustepts
Bhadal	Very deep, imperfect drained, silty clay, calcareous, gray to dark gray soils occurring on very gently sloping old alluvial plain with moderate salinity, high water table and water logging	Typic Endoaquents

Table 4.11. Extent of soil orders in study area

Soil order	Soil series	Area	
		ha	%
Alfisols	Nagla Ramtal	1134.65	11.84
Entisols	Sakraya, Bhadal and Barauta	2632.30	27.47
Inceptisols	Gonda Atas, Kiki Nagla, Devi Atas, Nagla Chamran, Maghera, Sunrakh, Nagla Hemraj and Ral	5664.23	59.12
Others	Yamuna River	150.17	1.57

Table 4.12. Extent of soil series in study area

Soil series		Area		
Name	Representative profile	sq m	ha	%
Sakraya	P6	21048105	2257.04	23.56
Gonda Atas	P1	2666478	125.73	1.31
Sunrakh	P8	4375581	437.56	4.57
Kiki Nagla	P2	4189417	418.94	4.37
Nagla Chamran	P4	3748684	374.87	3.91
Devi Atas	P5	7813703	781.37	8.16
Nagla Hemraj	P9	3730789	373.08	3.89
Nagla Ramtal	P3	11346494	1134.65	11.84
Maghera	P7	17685603	1768.56	18.46
Barauta	P13	8290803	829.08	8.65
Ral	P12	5636880	563.69	5.88
Bhadal	P11	3666136	366.61	3.83
River		1623236	150.17	1.57
Total		95821913	9581.35	100.00

Extent of soil orders

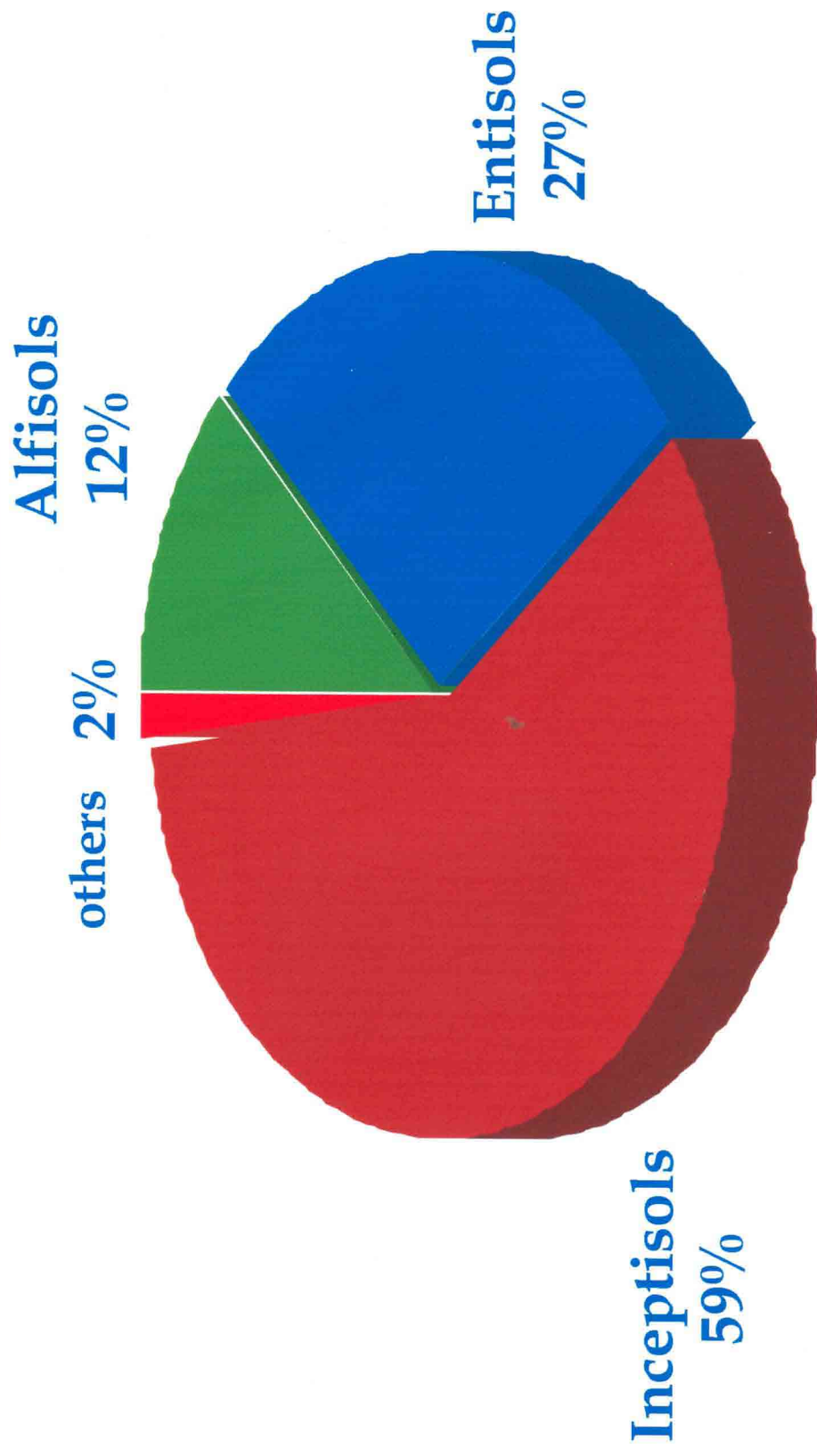


Fig. 4.17

Extent of soil series

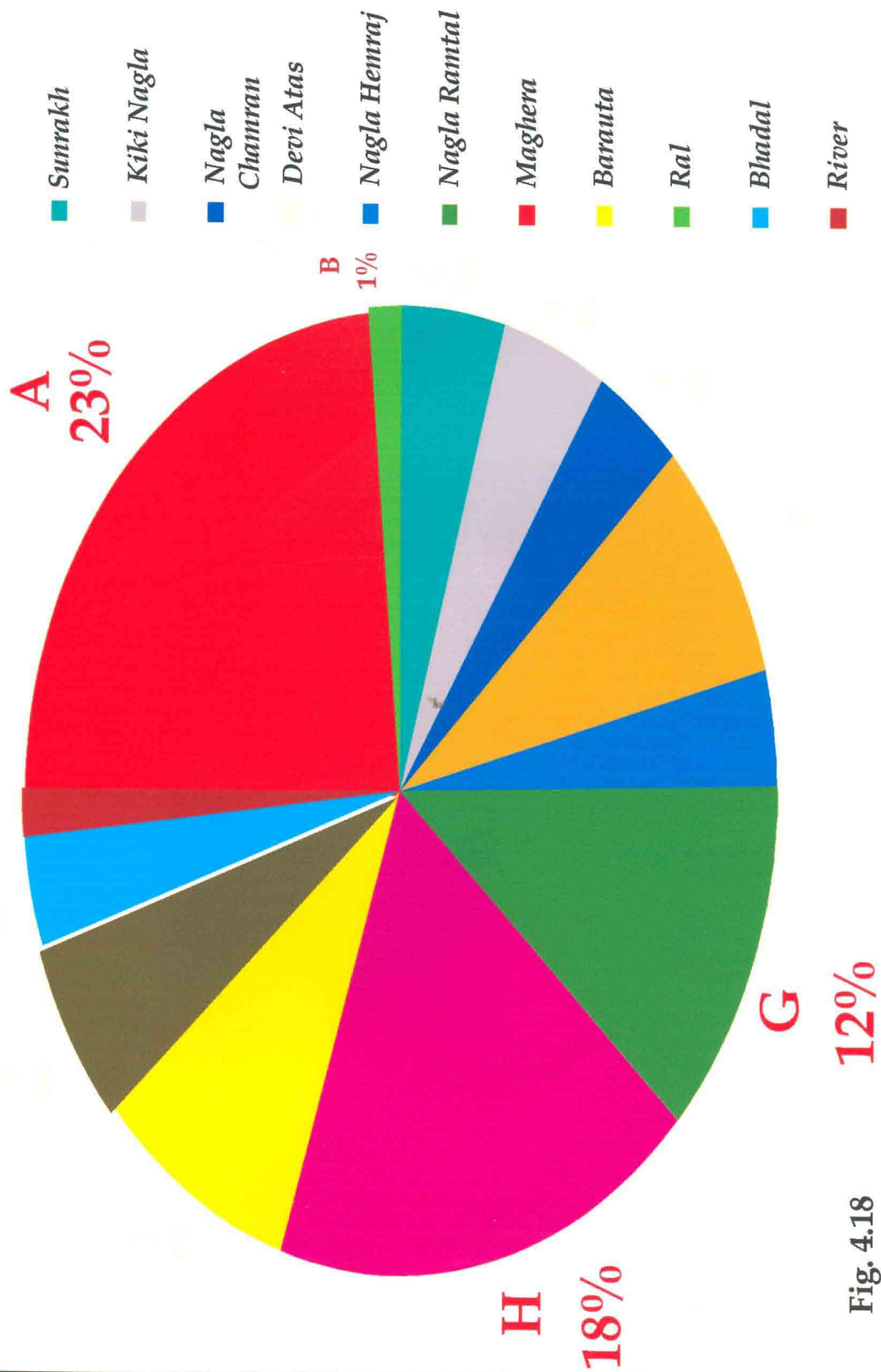


Fig. 4.18

4.4 Soil degradation assessment

With the advancement of information technology, the use of remote sensing data has become very important tool for soil resource studying and mapping. In this study an attempt has been made to carry out visual as well as digital image processing to extract required information about various land degradation types.

4.4.1 Visual image interpretation

IRS-1C LISS III Geocoded cloud free False Colour Composite (FCC, Path No.96; Row No.52; of 2nd May and 17th October 2000) at 1:50,000 scale were procured and used.

It was found that gullied and/or Ravinous land shows a light gray-to-gray or dark gray tone, smooth with view mottles texture and irregular shapes. It occurs along the curve line from Vrindavan to Sakraya and Nagla Chamran villages and it is severe to very severe in Sunrakh, Gonda Atas and Kiki ka Nagla series. The area is either barren or occasionally/ marginally cultivated.

Permanent waterlogging areas appear in dark blue to bluish black tone of varying sizes and shapes in the image while seasonal waterlogging shows light gray to bluish gray scattered mottles.

This problem mostly occurred in low-lying areas of Bhadal, Ral, Barauta besides of active flood plain due to accumulation of Yamuna river's floodwater. It was found also that soils in these areas are having imperfect drainage, shallow ground water level and affected too by salinity and alkalinity. The extent and distribution of waterlogging was found to be higher in October (Post-monsoon) data.

Salt affected areas appear in different tones and shapes. Strongly saline areas show gray to yellowish white and white with red mottles while moderately saline areas appear in gray to light gray with red mottles. It occurs mostly in Barauta, Bhadal and Ral series.

The dark gray and/or gray patches with bluish mottles represented alkalinity as strong and medium degree of severity. It was found as the major problem in the study area.

Healthy vegetation, forest and plantations appeared in red to deep red smooth tone.

4.4.2 Digital image processing (DIP)

4.4.2.1 Data Used

The IRS-IC LISS III digital data in the form of CD - Room (Path No.96; Row No.52; of 2nd May and 17th October 2000) at 1:50,000 scale were procured and used for DIP. Land degradation in the study area was assessed for its types, degree, extent, rate and causative factors as per methodology mentioned in chapter 3. The results found are furnished bellow:

4.4.2.2 Type, degree and extent of Soil degradation

It was found that three major types of land degradation occurred in the study area such as water erosion, chemical deterioration and physical deterioration (Fig. 4.19).

The dominant one was observed to be water erosion followed by chemical and then physical deterioration with extent of 4395.51, 3597.15 and 1370.76 ha respectively (Table 4.13). Figure 4.20 shows that they covered 46, 38 and 14 % of the total study area respectively.

Fig.4.19: LAND DEGRADATION MAP

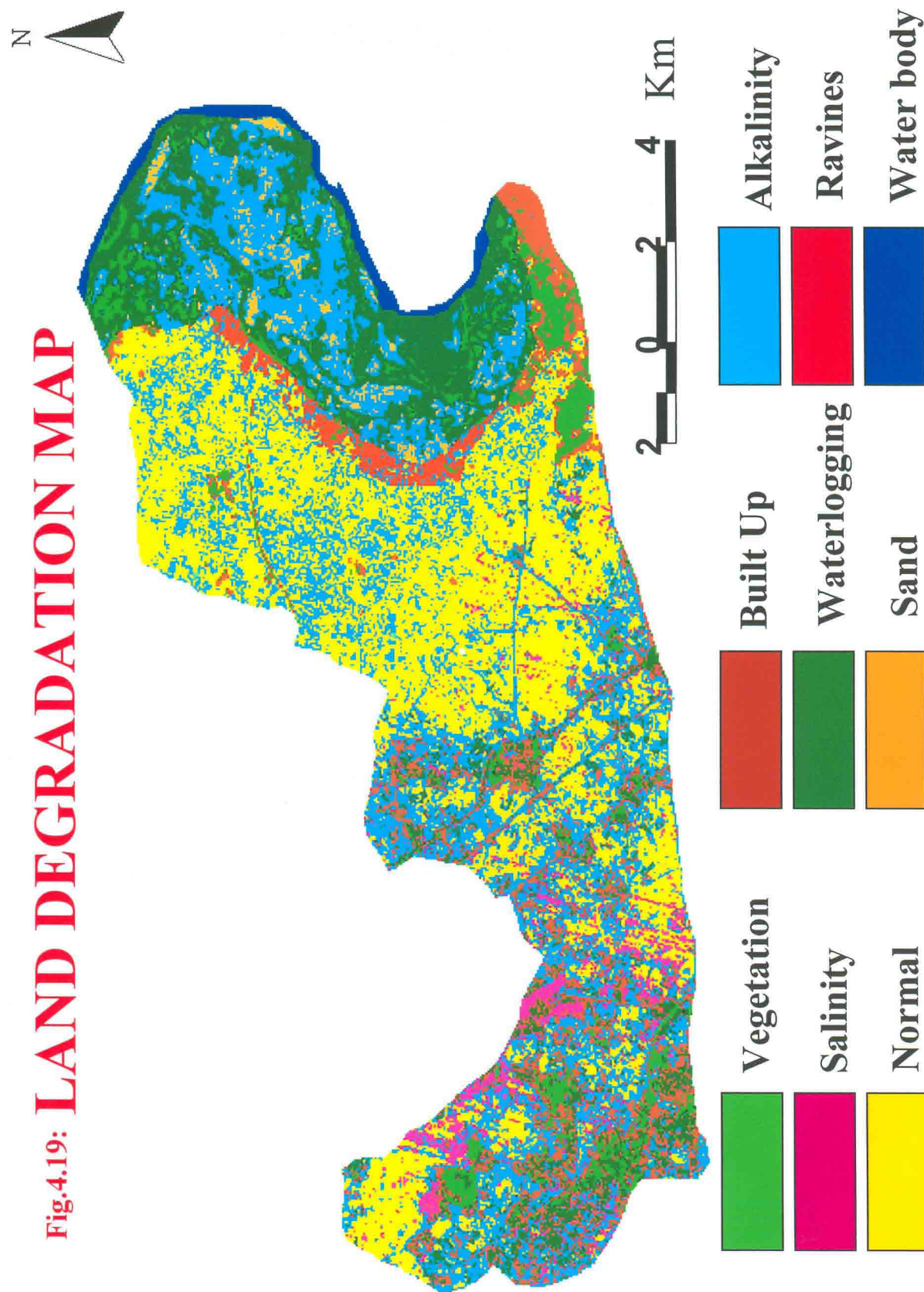


Table 4.13 Type and extent of land degradation

Sl. No.	Type	Extent	
		ha	% of total area
1.	Water erosion (W)	4395.51	45.88
2.	Chemical deterioration (Ck/Cs)		
	Alkalinity (Ck)	3075.04	32.09
	Salinity (Cs)	522.11	5.45
3	Physical degradation		
	Waterlogging (Pw)	1370.76	14.31
	Total degraded area	9363.42	97.73
4.	Others (Normal area)	217.93	2.27
	Total area	9581.35	100.00

A. Water erosion

Water erosion was observed mainly in undulating recent alluvial plain and active flood plain. Severe water erosion i.e. deep gullies or ravines with combination of salinity and flooding which are beyond restoration stage are in Sunrakh (Vrindavan Reserve Forest) area. Strong water erosion i. e. moderately deep gullies (plate 4.13) was found in Gonda Atas. Rill erosion (plate 4.14) was found in Kiki Nagla, Nagla Chamran and Gonda Atas. Slight water erosion was observed in Sakraya and Devi Atas (Fig. 4.21). It was observed that slight water erosion is the dominant degree of severity with area coverage of 3038.41ha, equivalent to 31.71% of total area followed by moderate (793.81ha; 8.28%) and severe (437.56ha; 4.57%) (Table 4.14; Figure 4.22).

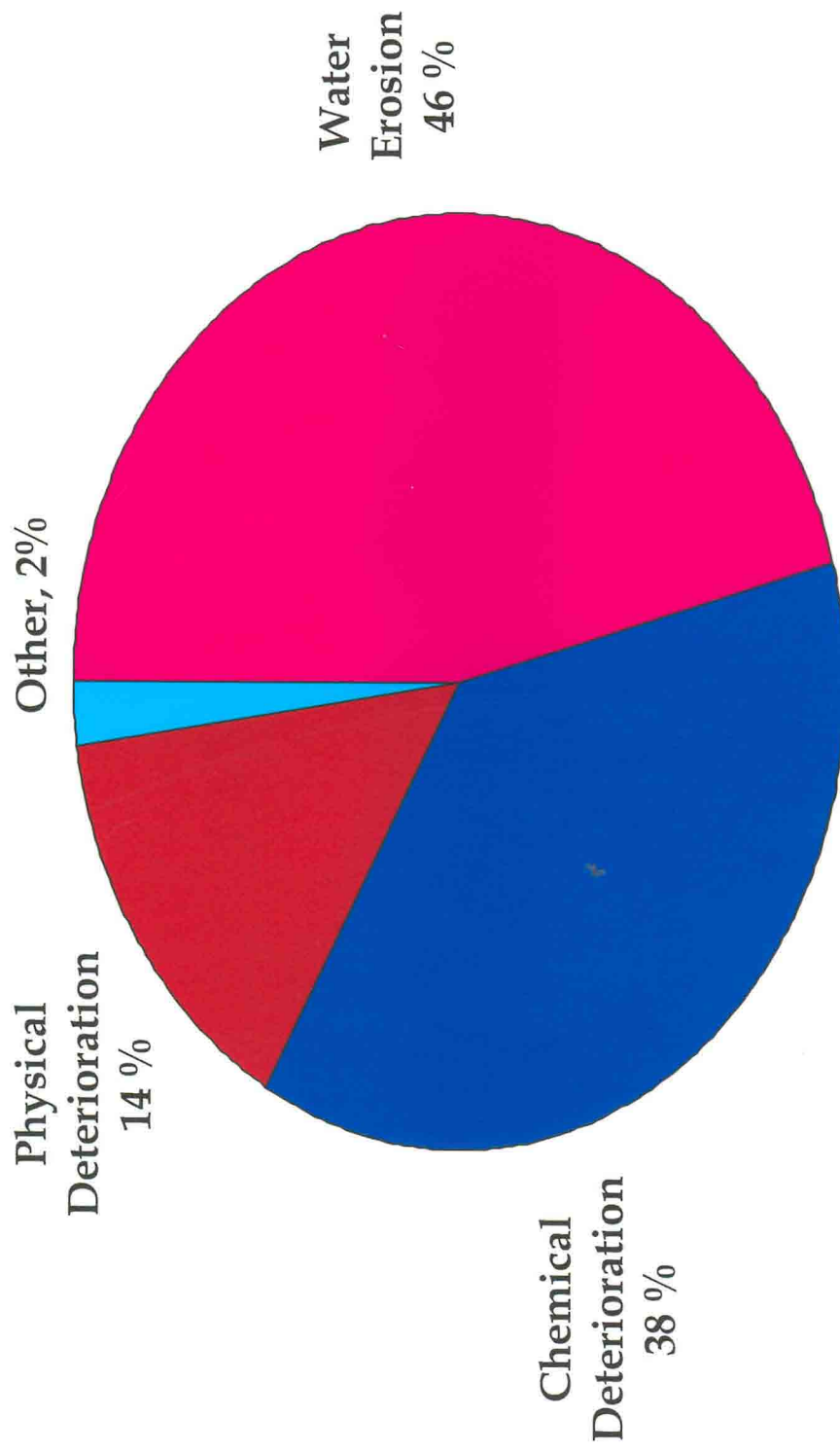


Fig. 4.20 Type and extent of soil degradation



Plate 4.13 - Gully erosion

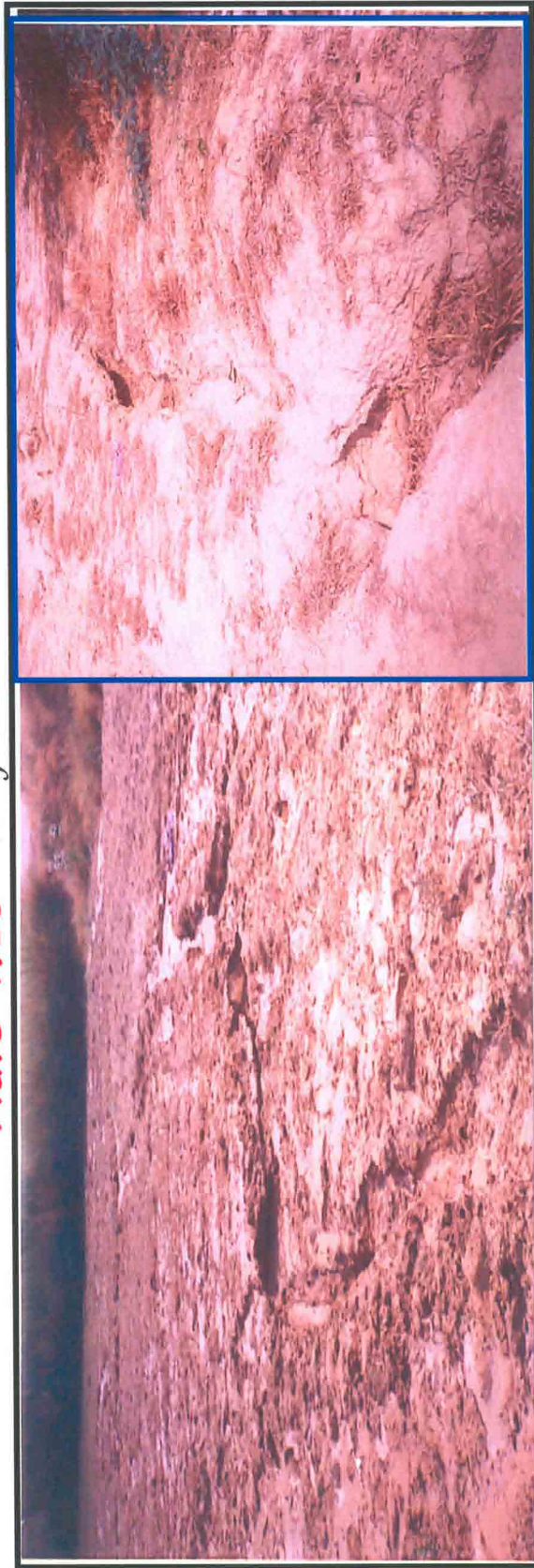
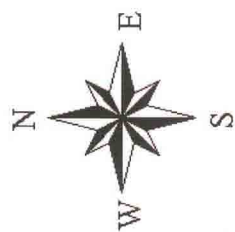


Plate 4.14 — Sheet & Rill erosion

Water erosion map



LEGEND

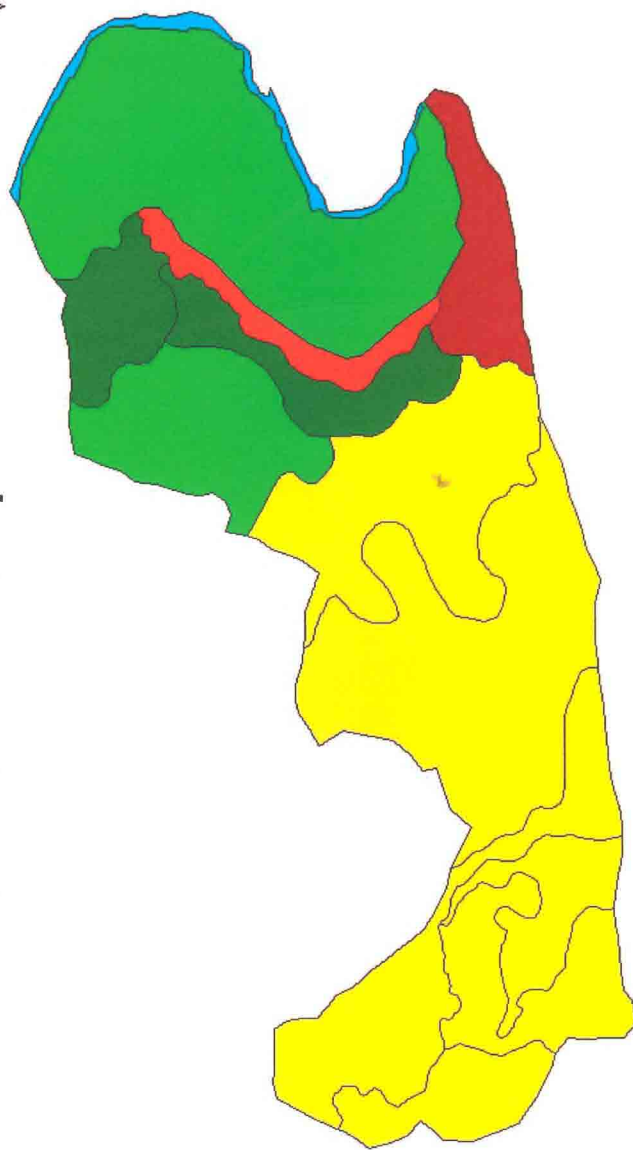
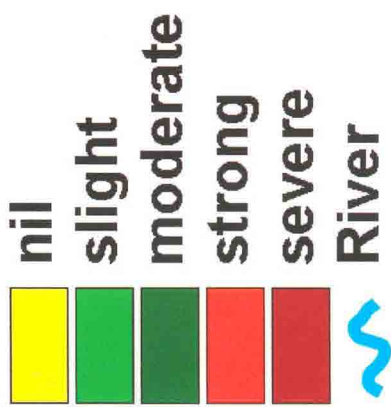
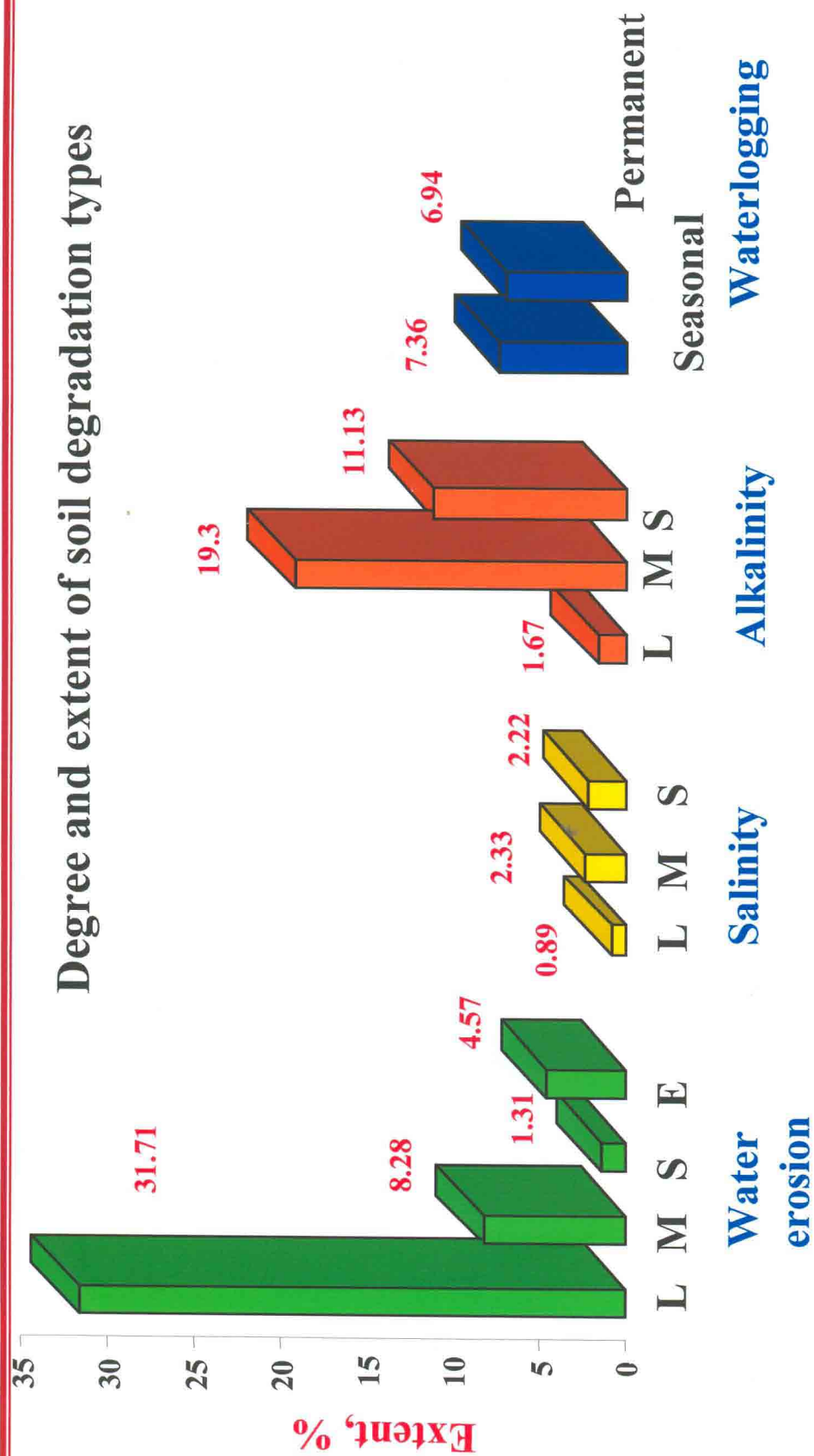


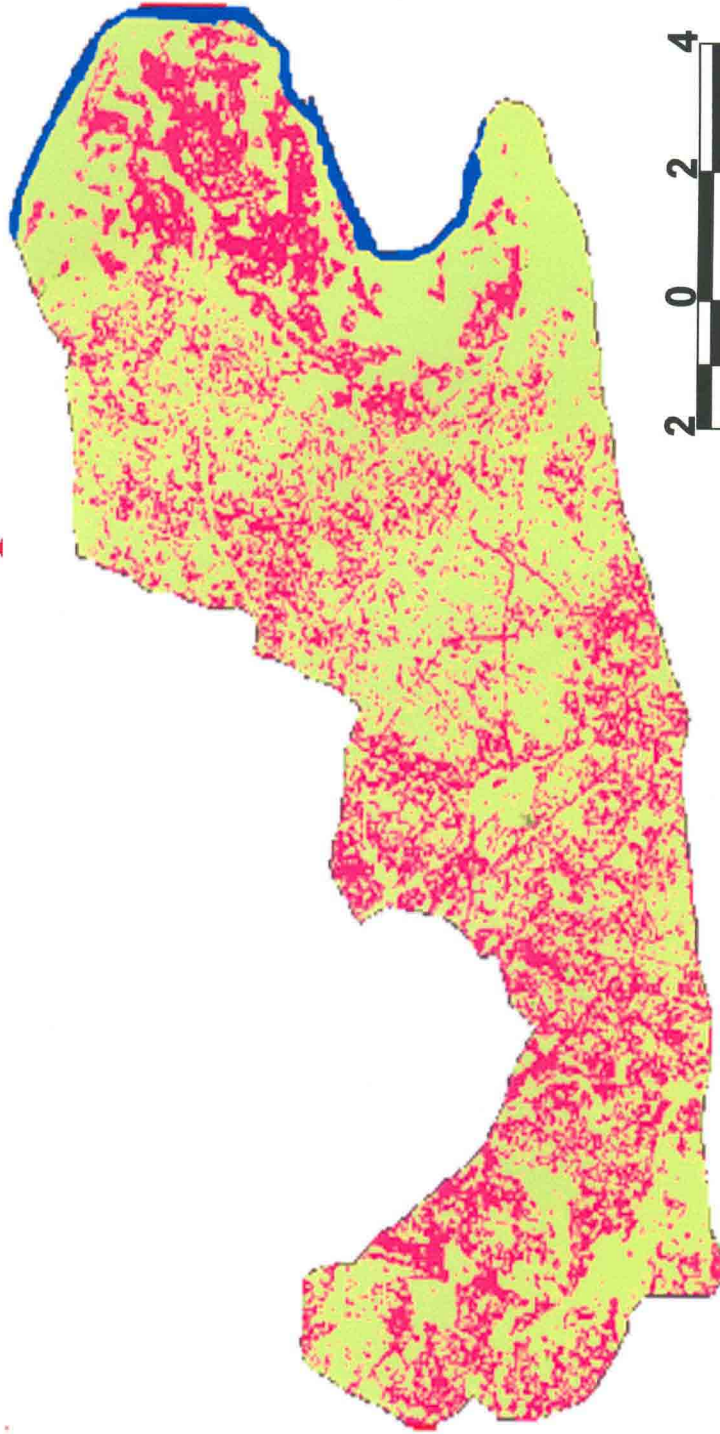
Fig. 4.21



Types and degree

Fig.4.22

Chemical Deterioration Map



Salinity / alkalinity



Non saline / Non alkaline



Yamuna River

Fig. 4.23

Table 4.14 Degree, Extent, Rate and Causative factors of soil degradation in the study area

Kind	Degree	Extent		Rate	Cause
		ha	%		
Water erosion (W)	Slight	3038.41	31.71	-1	a, n
	Moderate	793.81	8.28	-1	a, n
	Strong	125.73	1.31	-1	a, n
	Severe	437.56	4.57	-1	a, n
	Total	4395.5	45.88		
Salinization (Cs)	Slight	85.56	0.89	-1	a, n
	Moderate	223.51	2.33	-1	a, n
	Strong	213.04	2.22	-1	a, n
	Total	522.11	5.45		
Alkalinization (Ck)	Slight	159.83	1.67	-1	a, n
	Moderate	1849.22	19.30	-1	a, n
	Strong	1066	11.13	-1	a, n
	Total	3075	32.09		
Waterlogging (Pw)	Seasonal	705.46	7.36	-1	a, n
	Permanent	665.3	6.94	-1	a, n
	Total	1370.8	14.31		
	Total area	9581.4	100.00		

B. Chemical deterioration

Chemical deterioration is represented mainly by salinity / alkalinity and which occupied about 38% of total area (Fig. 4.23).

Salinity (plate 4.15; Fig. 4.24) was found mainly in Barauta, Bhadal, Ral, Sunrakh and Gonda Atas with area coverage of 522.11 ha representing 5.45 % of total area. Strong salinity with surface incrustation was found in Barauta soil series with area coverage of 213.04 ha representing 2.22% of total area. Generally this area is barren or occupied by natural trees and



Plate 4.15 - Salinity



Plate 4.16 - Salinity/alkalinity

Fig. 4.23 Chemical degradation map

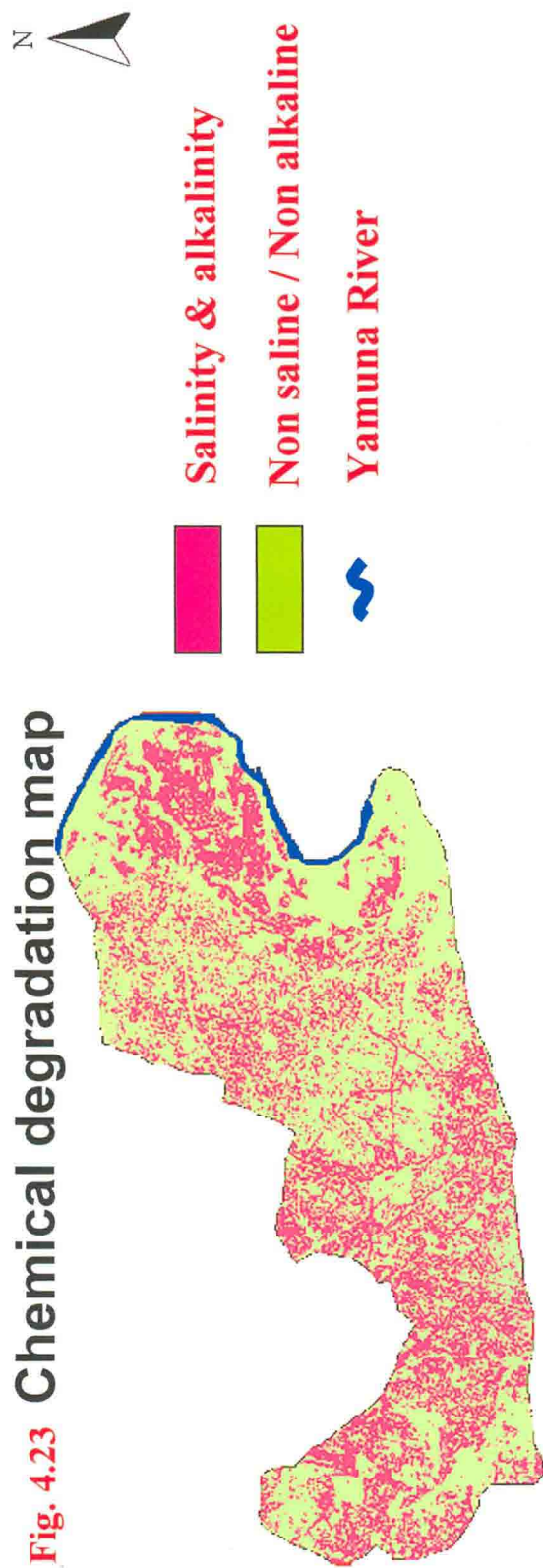


Fig. 4.25 Alkalinity Map (NDSI)

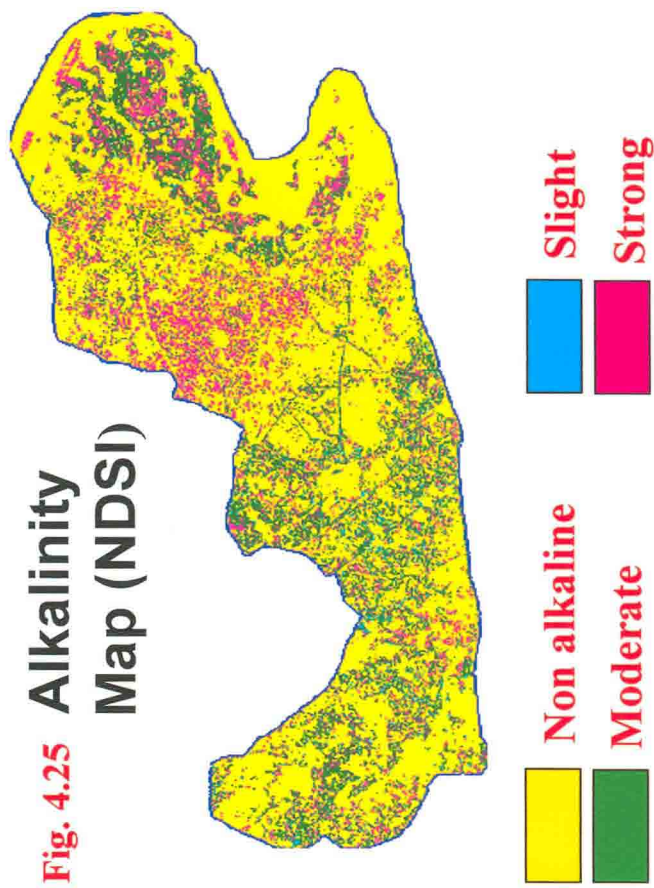
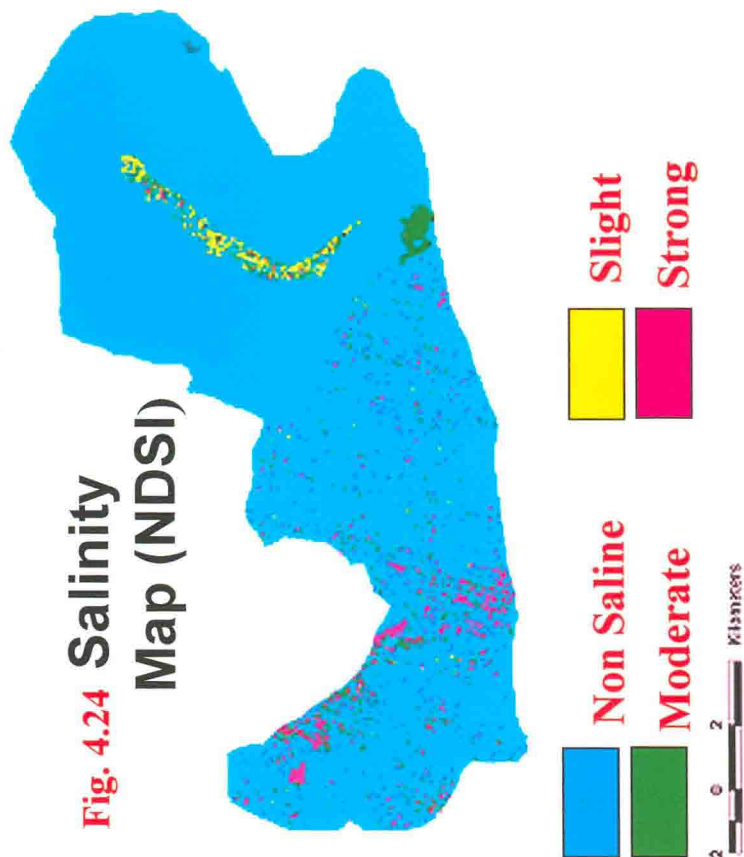


Fig. 4.24 Salinity Map (NDSI)



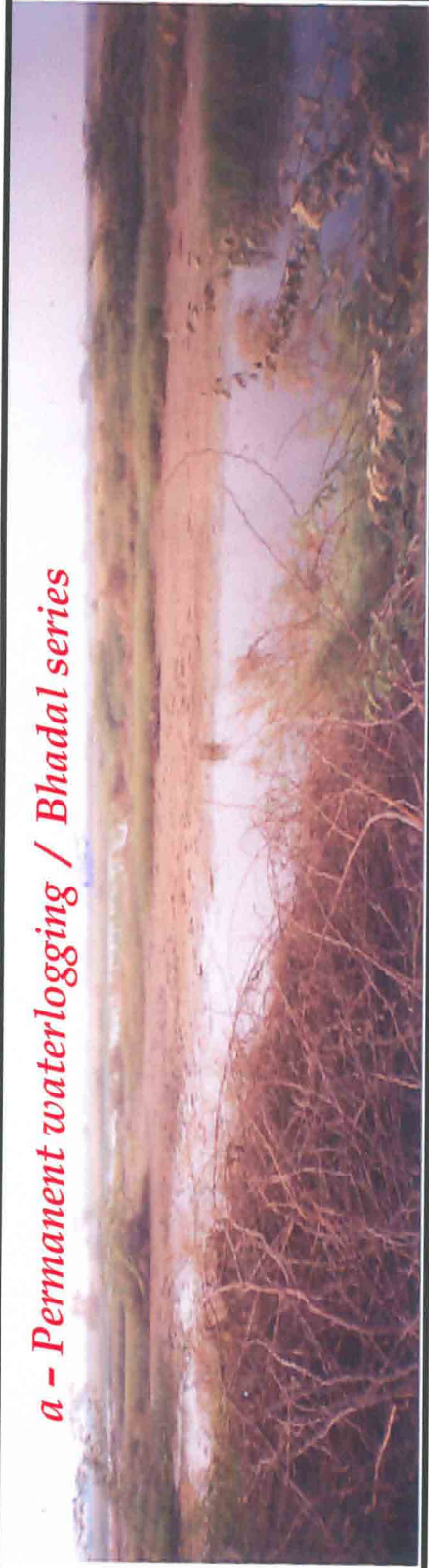
shrubs. Moderate salinity was found mainly in western part of study area covering 223.51 ha representing 2.33% of total area. Slight salinity was observed in Bhadal, Gonad Atas and scattered throughout the study area. The area under this class is found to be 85.56 ha representing 0.89 % of total area. It was found that moderate degree of severity is the dominant class followed by strong and slight (Fig. 4.22).

Alkalinity was found to be the second dominant degradation problem after water erosion. It was observed everywhere in the study area (Fig. 4.25; Plate 4.16) with area coverage of 3075.00 ha representing 32.09% (Table 4.14). The moderate degree of severity is found to be the dominant followed by strong and slight (Fig. 4.22) with area coverage of 1849.22, 1066.00 and 159.83 ha representing 19.30, 11.13 and 1.67 per cent respectively.

C. Physical deterioration

The common type of physical deterioration occurring in the study area is found to be waterlogging which cover an area of 1370.80 ha representing 14.31 % of total area (Table 4.14; Fig. 4.26). This problem mostly occurred in low-lying areas, near by irrigation canals and rice fields of Bhadal, Ral and Barauta series (Plate 4.17 a, b, c) and it is also found in active flood plain (Sakraya series) due to accumulation of Yamuna river's floodwater. It was also found that soils in these areas are having imperfect drainage, shallow ground water level and affected too by salinity and alkalinity. Classification of waterlogging was done using both summer (May) and post-monsoon (October) data. Permanent waterlogged areas was extracted from May data while seasonal waterlogged areas was extracted from October data. The extent and distribution of

a - Permanent waterlogging / Bhadal series



b- Fallow land due to waterlogging problem



c - Waterlogging in nearby rice fields / Ral series

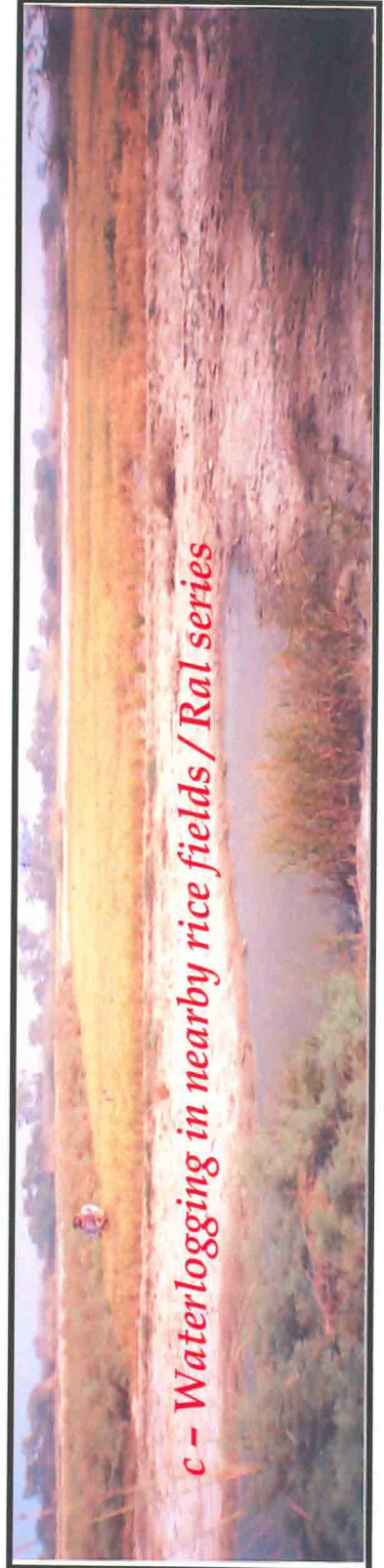


Plate 4.17 - Waterlogging

Plate 4.18—
Waterlogging
during May (Pre)
and Oct. (Post)
monsoon

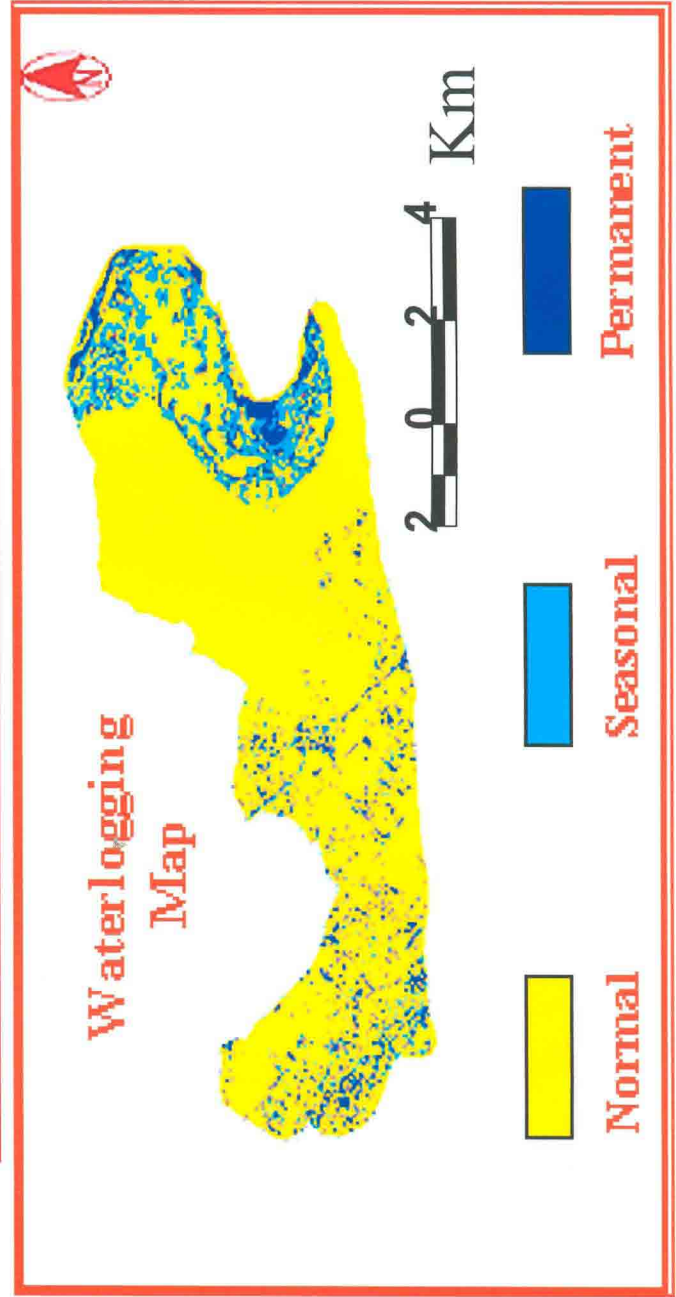
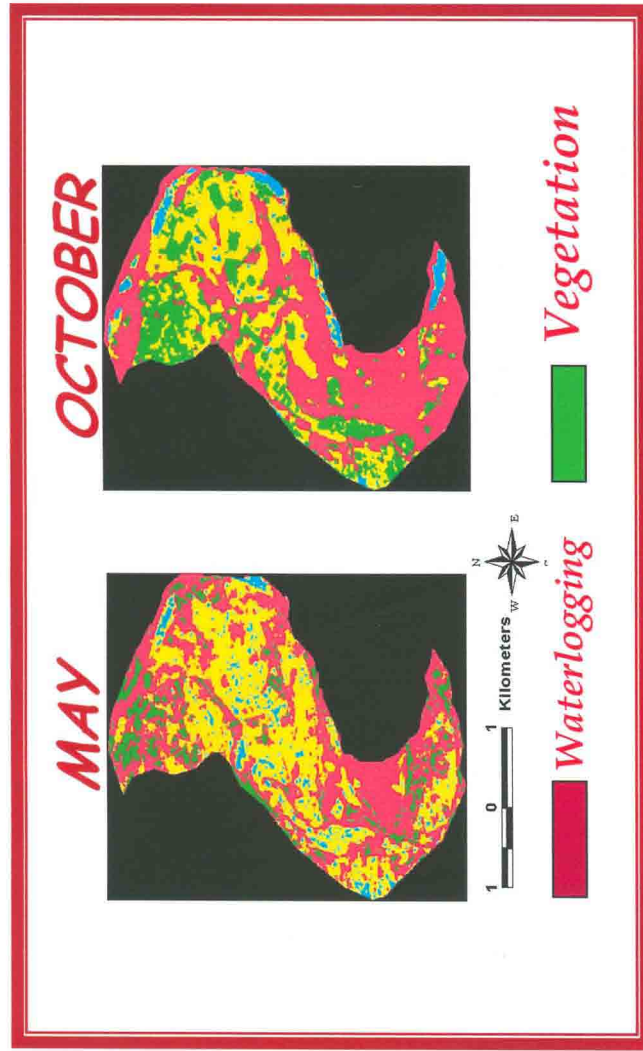


Fig. 4.26

waterlogging was found to be higher in the October (Post-monsoon) data than May (Plate 4.18; Figure 4.22). It was found that permanent waterlogging covers 665.3 ha representing 6.94 % of total area while seasonal waterlogging covers 705.46 ha representing 7.36 % of total area.

4.4.2.3 Rate and Causative factors

The causative factors of water erosion in this area is found to be natural due to periodical flooding whenever the river water table raises during monsoons and also because of the slope gradient and light texture of soils. It is also human induced because of increasing agricultural activities and improper management practices. Subsequently, the rate of degradation was found to be slowly increasing (-1) as there is no soil protection measures. Salinity may be caused naturally due to parent material, high level of ground water and its salinity and also may be due to irrigation, impeded drainage and improper management. This also causes waterlogging problem besides salinity/ alkalinity. It was found that major soils found in the study area were calcareous in nature due to calcareous alluvium. This indicates the natural cause of alkalinity beside human induced factor, which is related to improper management of soil resources.

4.5 Generation of thematic maps

The growing availability of computer based Geographical Information System (GIS) is enabling large volume storage, analysis and integration of multiple land resource data sets. GIS provides a means of taking different kinds of information, processing them into compatible data sets, combining them and displaying the results on a map (Nair *et al.*, 1996).

For the purpose of generation of thematic maps soil data was partitioned into two components i.e. spatial data, representing the aerial dimension and attribute data describing the properties of soils occurring in each map unit. The soil series map of the study area (Fig. 4.16) was imported in the GIS environment and used as spatial data. The attribute data comprised of soil site characteristics, soil morphology, land use information and soil suitability classification for different crops generated from field study and laboratory analysis were related to spatial data and stored in RDBMS (Table 4.15; 4.16). Classes and ranges of different soil characteristics were also stored in RDBMS. Therefore a number of single theme maps were prepared by reclassification of the basic soil map using appropriate attribute data sets.

4.5.1 Slope

Using the slope information collected during the course of soil survey and incorporated in the visual and digital image processing, the digital soil series map was reclassified to yield the slope map of the study area (Fig. 4.27). It was found that major portion of the study area falls in very gently sloping class with 1-3% slope, followed by level to nearly level with 0-1% slope and moderately sloping class with 5-10% slope.

Slope has direct influence on land use as the slope classes impose certain management, which have to be economically justified. All agricultural operations favored by a level to nearly level and very gently sloping topography. Major portion of the study area falls in this range. Most of recent alluvial plain falls in moderately sloping class where the risk of erosion is also observed.

Table 4.16 Soil suitability classes for different crops

Soil series	Annual crops							
	Rabi				Kharif			
	Wheat	Rice	Sugarcane	Cotton	Maize	Pearl Millet	Sorghum	Barley
Soil suitability classes								
Sakraya	S2	S3	S3	N1	S3	S2	S3	S3
Gonda Atas	N1	N1	N1	N2	N1	N1	N1	S3
Sunrakh	N2	N2	N2	N2	N2	N2	N2	N2
Kiki Nagla	S2	S3	S3	N1	S2	S3	S2	S2
Nagla Chamran	S2	S3	S3	S3	S2	S3	S2	S2
Devi Atas	S2	S3	S3	S3	S2	S3	S2	S2
Nagla Hemarij	S2	S2	S2	S2	S2	S2	S2	S2
Nagla Ramtal	S2	S2	S2	S2	S1	S2	S2	S2
Maghera	S2	S2	S1	S2	S1	S1	S2	S2
Barauta	S3	N1	N1	S3	N1	N1	N1	S2
Ral	S2	S2	S2	S2	S2	S2	S3	S2
Bhadal	S2	S2	S2	S2	S2	S3	S2	S2

S1- Very suitable to suitable

S2- Moderately suitable

S3- Marginally suitable

N1- Almost non suitable

N2- Non suitable

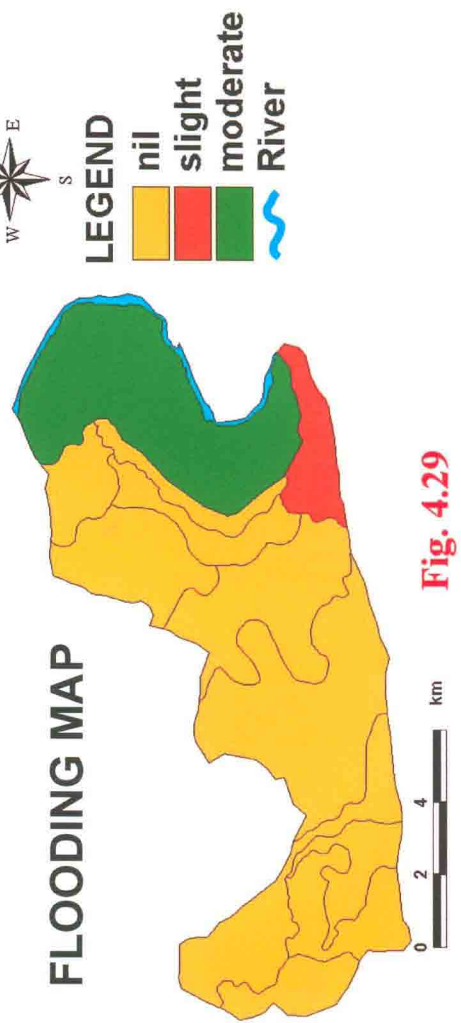
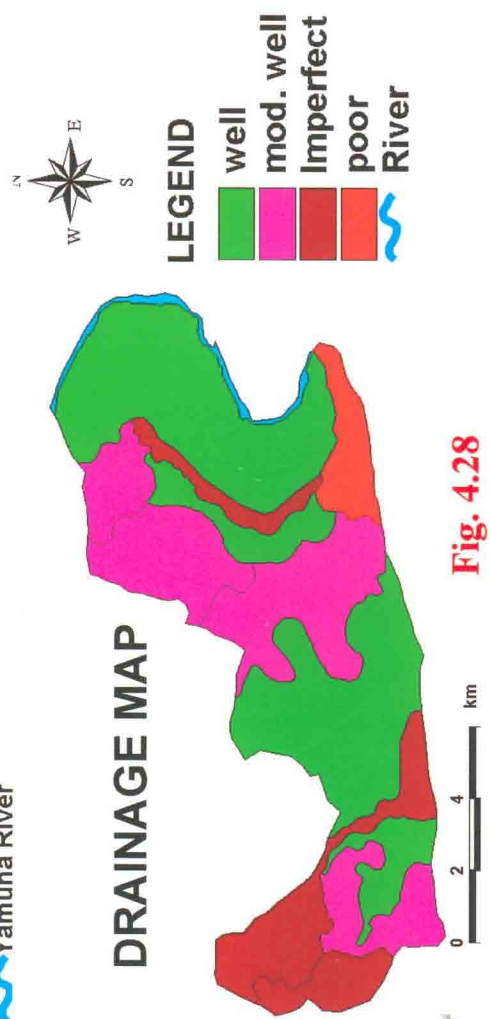
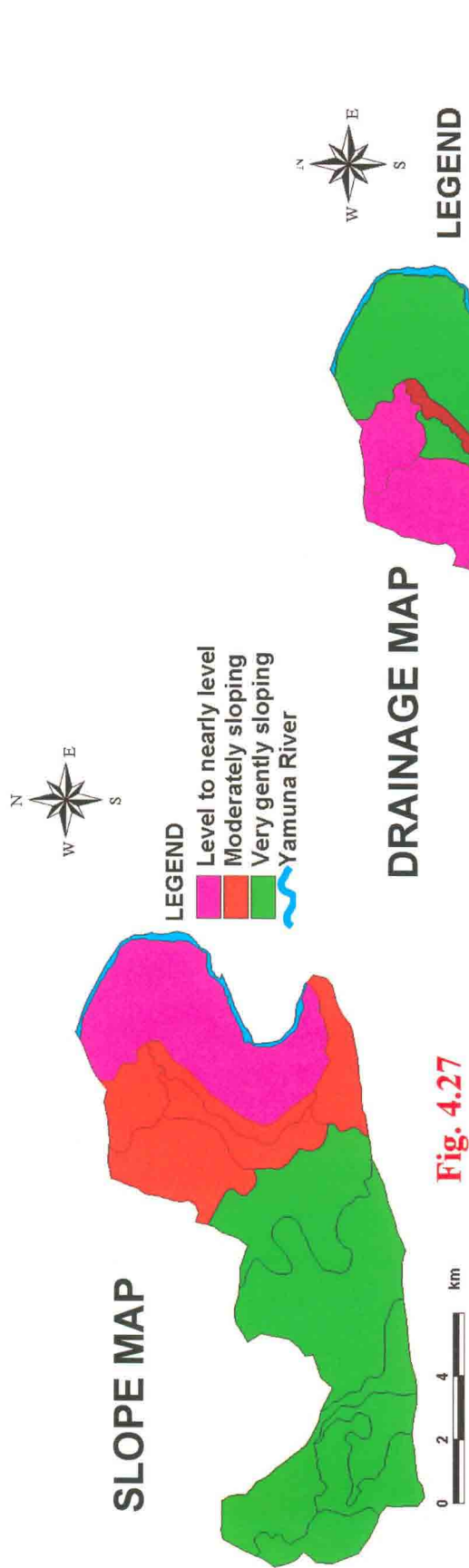
Drainage

Soil drainage refers to the removal of water added to the soil through precipitation or irrigation and by flow through the soil to the underground storage and/or runoff. Poorly drained soil either has to be left in natural condition or can be used only for rice cultivation. Using defined drainage classes the soil series map was reclassified to obtain drainage map (Fig. 4.28). Four drainage classes were found in the study area. Imperfect drainage was found in Gonda Atas, Barauta and Bhadal series. Gonda Atas and Barauta are affected by strong water erosion and salinity respectively and are almost barren soils, while most of Bhadal series is used for rice cropping system. Poor drainage was found in Sunrakh series (Forest area). Moderately well drainage was observed in Nagla Chamran, Devi Atas and Ral soil series. Major portion of the study (Sakraya, Kiki Nagla, Maghera and Nagla Hemraj series) area have well drainage class.

Flooding

Flooding is the serious limitation for land use, especially in lands with little slope gradient. Using defined flooding classes the soil series map was reclassified to obtain flooding map (Fig. 4.29). It was observed that Sakraya soil series with slope of 0-1 % is moderately affected by flooding while Sunrakh series is slightly affected. Major portion of Sakraya series is flooded during monsoon causing waterlogging problem which restricts its cultivation.

Other theme maps depicting pH, EC, CEC, BS, OC, CaCO_3 , available N, P and K, available micronutrients Fe, Mn, Zn and Cu were prepared and discussed above.



4.6 Land evaluation

The information obtained through soil survey was used in the recent past for the general appraisal of land by using land capability classification. Recently the data based on soils and other site conditions are being increasingly used for land suitability evaluation of a particular crop or a set of crops. Identification of suitable crops for different regions will help the development agencies in land use planning and suggest alternate land use for farmers for optimum utilization of soil resources. Land suitability evaluation is the process of assessing the suitability (present or potential) of land for specific use. The subsequent step is to prepare soil resource maps. It involves interpretation of data on climate, soil, vegetation and quality of land. The determination of land use requirements is the most important step in the land evaluation procedure. Once the land use requirements are determined these need to be matched with the soil-site characteristics of a map unit(s) and limitations in respect of different parameters are to be quantified. In the present study the limitation method was followed and each of the land characteristics was evaluated on a relative scale of limitations. Limitations are imposed when land characteristics deviated from the optimal conditions. The guidelines used for determining the degree of limitations (FAO, 1976) are in table 4.17. Five levels of limitations are given, ranging from no limitation (0), slight limitation (1), moderate limitation (2), severe limitation (3) and very severe limitation (4). The method defines land classes with regard to number and intensity of limitations. In the present study, the soil site suitability criteria for different crops as outlined by FAO (1976) and Sys (1995) and modified by Sehgal (1996) is followed.

Table 4.17 Guidelines for use of degree of limitations

Level of limitation	Degree of Limitation	Guidelines for setting level of limitation
0	No	The range of conditions for the land quality are those highly suited to the specific land use.
1	Slight	Conditions which may have small but detectable adverse effect on the land use.
2	Moderate	Conditions which will have substantial adverse effect on the land use, but are unlikely to cause it to be impracticable or uneconomic.
3	Severe	Conditions which will probably cause the land use to be impracticable or uneconomic unless other circumstances are especially favorable.
4	Very severe	Conditions which will certainly cause the land use to become impracticable or uneconomic.

In order to construct a knowledge base by using deductive reasoning which may lead to ranking of land units into different classes, the present attempt was made to evaluate the suitability of soil series in the study area in terms of their characteristics and limitations. The climatic characteristics of study area and the weighted means of soil-site characteristics (Table 4.15) were matched with climatic and soil-site requirements for wheat (Table 4.18), rice (Table 4.20), sugarcane (Table 4.22), cotton (Table 4.24), maize (Table 4.26), sorghum (Table 4.28), pearl millet (Table 4.30) and barley (Table 4.32) to find out the suitability classes of the soils.

The suitability of climate and soil site characteristics of each mapping unit along with the kind and degree of limitations for wheat (Table 4.19), rice (Table 4.21), sugarcane (Table 4.23), cotton (Table 4.25), maize (Table 4.27), sorghum (Table 4.29), pearl millet (Table 4.31) and barley (Table 4.33) are generated and furnished bellow.

In order to computerise the data and link to GIS environment, soil suitability classification attribute data (Table 4.16) were Prepared by taking suitability classes from the above mentioned tables and related to spatial data (Fig. 4.16) so that soil suitability maps, current and potential land use maps were created.

4.6.1 Suitability for wheat

Wheat is one of the major crops grown in the study area in *rabi* season with yield of low to medium. Hence, evaluation on suitability of the land for wheat has become more important, so that proper measures can be taken in order to increase and sustain the productivity.

Climate characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for wheat (Table 4.18) to evaluate the suitability of soil for this crop. Results are presented in (Table 4.19), which shows kind and degree of limitation and suitability of soils as well. Climate characteristics contribute slight limitation for optimum wheat growth due to rainfall, while soil site characteristics varies in degree of limitation from slight to very severe. Suitability map for wheat (Fig. 4.30) shows that Gonda Atas and Sunrakh series are having severe and very severe limitations for growing wheat respectively due to severe and very severe erosion, alkalinity and wetness limitations while Barauta series shows a marginally suitable class due to very severe limitation of salinity, moderate alkalinity and drainage limitations. The other soil series are moderately suitable for growing wheat.

Table 4.18 Climatic and soil-site suitability criteria for wheat

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c), <i>Unirrigated conditions</i>					
Summer dominant	> 1000	750-1000	500-750	< 500	-
Rainfall (mm)	> 750	500-750	250-500	< 250	-
Topographic (Slope %) (t)					
Plain, irrigated	0-1	1-3	3-8	> 8	others
Hilly, unirrigated	0-3	3-8	8-15	15-25	> 25
Sprinkler irrigated	0-8	8-15	15-25	> 25	-
Wetness (w)					
Flooding	Nil	Slight	Slight	Mod. Poor	Severe
Drainage classes	Well	Mod. Well	Imperfect excessive	Poor, v. Excessive	V. poor
Physical characteristic (s)					
Texture	scl, cl, sil	sc(s), scl, l	sic, c, ls+ sl+, sic(s)	ls (coarse)	s (coarse)
Available water-holding capacity	> 200	150-200	100-150	50-100	< 50
(rainfed area)					
Depth (cm)	> 80	50-80	20-50	< 20	-
CaCO ₃ (%)	3-15	0-3, 15-25	25-50	50-75	> 75
Gypsum (%)	0.3-0.2	< 3.0; 2-5	5-10	10-25	> 25
Stoniness (vol.%)					
Surface	< 3	3-15	15-40	40-75	> 75
Subsoil	< 15	15-40	40-75	-	-
Soil fertility characteristics (f)					
(NPK) Rating	HHM	MMM	MLL	LLL	-
O.M (0 - 20 cm)	HHM	MMM			-
Base saturation	> 80	50 - 80	35 - 50	< 35	-
Salinity/ Sodicty (n)					
ECe (dSm ⁻¹)	< 2	2-4	4-8	8-15	> 15
Fine, mod-fine texture	< 4	4-8	8-15	15-25	> 25
Coarse; medium texture					
ESP					
Coarse & medium texture	< 2	< 8	8-15	125-25	> 40
Fine texture		2-4	4-8	8-15	> 15

Table 4.19 Soil site suitability for Wheat

Soil Series	Climate	Erosion	Slope	Drainage	Flooding	Limitations levels for soil site characteristics					NPK Rating	Suitability Class
						Texture	CaCO ₃	BSP	ESP	EC dSm ⁻¹		
Sakraya	1	1	0	0	3	2	0	0	2	0	1	S2wsn
Gonda Atas	1	3	2	2	0	2	0	1	3	1	2	S3nw
Sunrakh	1	4	2	3	1	2	0	0	2	3	2	N2tnw
Kiki Nagla	1	2	2	0	0	2	0	1	2	0	1	S2tsn
Nagla Chamran	1	2	2	1	0	1	0	0	2	0	1	S2tn
Devi Atas	1	2	2	0	0	1	0	1	3	0	2	S2tn
Nagla Hemraj	1	0	1	0	0	1	0	0	3	0	1	S2 n
Nagla Ramtal	1	0	1	1	0	1	0	0	2	0	1	S2nts
Maghera	1	0	1	0	0	1	0	0	2	0	1	S2n
Barauta	1	0	1	2	0	1	0	0	2	4	1	S3nw
Ral	1	0	1	1	0	1	0	0	3	0	1	S2n
Bhadal	1	0	1	2	0	2	0	0	2	2	1	S2wsn

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate; t = Topography ; s = Physical Characteristics; n = Salinity/alkalinity ; w = Wetness

In general the sources of limitations are low rainfall during the growing season, low NPK, salinity / alkalinity, texture and erosion. The management practices need to be adopted is to provide additional irrigation with a good quality of water at the time of critical stage of crop growth and integrated nutrient management.

4.6.2 Suitability for rice

Climate characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for rice (Table 4.20) to evaluate the suitability of soil for this crop. Results are presented in (Table 4.21), which shows kind and degree of limitation and suitability of soils as well. Climatic characteristics contribute slight limitation for optimum rice growth due to rainfall, while soil site characteristics varies degree of limitation from slight to very severe. Suitability map for rice (Fig. 4.31) shows that Sunrakh soil series is not suitable for rice due to very severe limitation of erosion and salinity while Gonda Atas and Barauta are currently non suitable but potentially suitable because of very severe limitations of erosion and salinity respectively and moderate limitations of texture for both. Sakraya soil series shows marginal suitability for rice due to severe limitations of texture (ls) and moderate limitations of drainage and erosion. Kiki Nagla, Nagla, Chamran and Devi Atas are marginally suitable for rice too because of severe limitations of erosion and moderate limitations of slope and texture. Bhadal series shows good conditions for growing rice except the severe limitation of salinity which makes it moderately suitable. It can improve to S1 class by correcting salinity limitation by providing artificial drainage and leaching with good water or by flooding during rainy

Table 4.20 Climatic and soil-site suitability criteria for Rice

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c)					
Total rainfall (mm)	>1500	100-1500	750-1000	<750	
Rainfall during growing season (mm)	>750	550-750	450-550	<450	
Length of growing period (days)					
Topography (t)					
Slope (%)	0-1	1-3	3-8	>8	Others
Erosion	e0	e0	e1	e2	e3 e2
Wetness (W)					
Drainage					
Flooding					
Physical characteristic (s)					
AWC (mm m ⁻¹)	Imperfect	Mod. well	Well, excessive	excessive	Very excessive
Stoniness (surface) (%)	Moderate	Poor strong	severe	---	---
Texture	<3	3-15	15-40	40-75	>75
Depth (cm)	sic, c	sic, cl, lsc	l, sl, scl, sil	ls	S
CaCO ₃ (%)	>80	50-80	25-50	<25	---
	3-15	15-25	25-50	50-75	---
Soil fertility characteristics (f)					
(NPK) rating	HHH	MMM	MLL	LLL	
CEC (soil) [cmol(p ⁺)kg ⁻¹]	>16	16-10	10-5	<5	
BS (%)	>80	80-50	50-35	<35	
OC (%) (surface horizon)	<0.75	0.75-0.5	0.5-0.2	<0.2	
Salinity-sodicity (n)					
ECe (dSm ⁻¹)	0.1	1-2	2-4	4-6	>6
ESP (%)	8-15	15-25	25-40	>40	
PH (1: 2.5)	6.5-7.0	7.0-8.2	8.2-8.5	8.5-9.0	>9.0

Table 4.21 Soil site suitability for rice (irrigated)

Soil Series	Climate	Erosion	Slope	Drainage	Limitations levels for soil site characteristics							NPK Rating	Suitability Class
					Flooding	Texture	CaCO ₃	BSP	ESP	EC dSm-1			
Sakaraya	1	2	0	2	1	3	0	0	0	0	1	S3 swt	
Gonda Atas	1	4	2	0	0	2	0	1	1	2	1	N1ntsw	
Sunrakh	1	4	2	0	0	2	0	0	0	4	1	N2tnws	
Kiki Nagla	1	3	2	2	0	2	0	1	1	1	1	S3tsn	
Nagla Chamran	1	3	2	1	0	2	0	0	1	0	1	S3tn	
Devi Atas	1	2	2	1	0	2	0	1	1	0	1	S3n	
Nagla Hemraj	1	0	1	2	0	2	0	0	1	0	1	S2ws	
Nagla Ramtal	1	0	1	1	0	2	0	0	1	0	1	S2SW	
Maghera	1	0	1	2	0	2	0	0	0	0	1	S2SW	
Barauta	1	0	1	0	0	2	0	0	0	4	1	N1nw	
Ral	1	0	1	1	0	2	0	0	1	0	1	S2n	
Bhadal	1	0	1	0	0	0	0	0	0	3	1	S2wn	

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate; t = Topography ; s = Physical Characteristics; n = Salinity/alkalinity ; w = Wetness

season. Other soil series are moderately suitable for rice culture due to limitations of texture, slope, drainage and climate conditions.

4.6.3 Suitability for sugarcane

Climatic characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for sugarcane (Table 4.22) to evaluate the suitability of soil for this crop. Results are presented in Table 4.23, which shows kind and degree of limitation and suitability of soils as well. Climatic characteristics contribute slight limitation for optimum wheat growth due to rainfall, while soil site characteristics varies degree of limitation from slight to very severe. Suitability map for sugarcane (Fig. 4.32) shows that Sunrakh soil series is not suitable for sugarcane due to very severe limitation of erosion, drainage and salinity while Gonda Atas and Barauta are currently non suitable but potential suitable because of very severe and severe limitations of alkalinity, slope and erosion and moderate limitations of drainage and texture for Gonda Atas and very severe limitation of salinity for Barauta. Sakraya, Kiki Nagla, Nagla Chamran and Devi Atas soil series are marginally suitable for sugarcane due to severe limitations of slope and moderate limitation of texture. Nagla Ramtal, Nagla Hemraj, Ral and Bhadal are moderately suitable with slight to moderate limitations of slope, drainage, texture, alkalinity and nutrient status. Maghera soil series found to be the best for growing sugarcane with no considerable limitations.

Table 4.22 Climatic and soil-site suitability criteria for sugarcane

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Topography (t)					
Slope (%)	0-1	1-2	2-4	4-6	>6
Erosion	e0	e1	e2	e3	e4
Flooding	F0	---	---	F1	F2
Wetness (W)					
Drainage	Good	Moderate	Imperfect	Poor	Poor
Physical characteristic (s)					
AWC (mm m ⁻¹)	>200	200	200-150	150-100	<50
Stoniness (surface) (%)					
Texture	Sic, sil, cl, si, sicl	Sc, l, scl	Sl, ls, lfs	Fs, ls	sics
Depth (cm)	>125	125-80	80-50	50-25	<25
CaCO ₃ (%)	0-12	12-25	25-35	35-50	>50
Soil fertility characteristics (f)					
(NPK) rating					
CEC (soil) [cmol(p ⁺) kg ⁻¹]	>24	24-16	<16 (-)	<16 (+)	
BS (%)	>80	80-50	50-35	<35	
OC (%) (surface horizon)	>8.0	8.0-4.0	<3.0		
Salinity-sodicity (n)					
ECe (dSm ⁻¹)	0-2	2-5	5-8	8-10	>14
ESP (%)	0-5	5-10	10-15	15-20	>20
PH (1: 2.5)	>6.0	6.5-6.0	6.0-5.5	5.5-5.0	<4.5

Table 4.23 Soil site suitability for Sugarcane

Soil	Limitations levels for soil site characteristics											
Series	Climate	Erosion	Slope	Drainage	Flooding	Texture	CaCO ₃	BSP	ESP	EC dSm ⁻¹	NPK Rating	Suitability Class
Sakraya	1	1	0	0	3	3	0	0	1	0	0	S3ws
Gonda Atas	1	3	3	2	0	2	0	1	4	1	1	N1nt
Sunrakh	1	4	3	3	1	2	0	0	0	3	1	N2twn
Kiki Nagla	1	2	3	0	0	2	0	1	3	0	1	S3tn
Nagla Chamran	1	2	3	1	0	1	0	0	3	0	1	S3tn
Devi Atas	1	1	3	1	0	1	0	1	3	0	1	S3tn
Nagla Hemraj	1	0	1	0	0	1	0	0	2	0	1	S2n
Nagla Ramtal	1	0	1	1	0	1	0	0	2	0	1	S2n
Maghera	1	0	1	0	0	1	0	0	1	0	1	S1
Barauta	1	0	1	2	0	1	0	0	1	4	1	N1nw
Ral	1	0	1	1	0	1	0	0	4	0	1	S2n
Bhadal	1	0	1	2	0	0	0	0	1	2	1	S2wn

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics; n = Salinity/alkalinity ; w = Wetness

4.6.4 Suitability for cotton

The suitability of climate and soil site characteristics of study area for cotton along with the kind and degree of limitations is presented in Table 4.25. Total rainfall of study area is 536 mm in which major portion is received during growing season. Hence, it limits moderately for optimum growth of cotton and additional irrigation during the critical stage of plant growth is needed. Moreover, limitations due to soil characteristics vary from slight to very severe mainly due to difference in texture and slopes.

Suitability map of cotton (Fig. 4.33) shows that Gonda Atas and Sunrakh series are unsuitable for cultivation of cotton due to very severe limitation of texture, severe and very severe limitation of erosion, severe limitation of slope, moderate and severe limitation of drainage respectively. Sakraya and Kiki Nagla are currently non suitable but potentially suitable. Sakraya having very severe limitation of texture and flooding while Kiki Nagla has very severe limitation of texture and severe limitations of slope and erosion. Nagla Chamran, Devi Atas and Barauta are marginally suitable for cotton. The reasons behind that are severe limitation of slope, moderate limitation of climate, erosion, texture and alkalinity for Nagla Chamran; severe limitation of slope and alkalinity, moderate limitation of climate and texture for Devi Atas and severe limitation of salinity and moderate limitation of climate, drainage and texture for Barauta series.

Although the soils showed marginal suitability for cotton, it is not impossible to grow this crop in this area with optimum yield. Major area comprises of Nagla Ramtal, Maghera, Nagla Chamran, Ral and Bhadal is moderately suitable for cotton with moderate limitations of climate, texture and alkalinity. However, some management practices such as providing

Table 4.24 Climatic and soil-site suitability criteria for cotton

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c)					
Total rainfall (mm)	850-1050	700-850	550-700	<550	-
Rainfall during growing season (mm)	750-950	600-750	450-600	<450	-
Length of growing period (days)	>150	135-150	120-135	<120	-
Mean temp. Growing season ($^{\circ}\text{C}$)	22-28	28-32	>32	-	-
Mean max. temp. Growing season ($^{\circ}\text{C}$)	-	-	<32	-	-
Mean min. temp. Growing season ($^{\circ}\text{C}$)	-	-	-	>36	-
Mean R.H. Growing season (%)	60-80	80-90	-	<50	-
Topography (t)					
Slope (%)	<1	1-3	3-5	>5	-
Erosion	e0	e1	e2	e3	-
Wetness (w)					
Drainage	Well	Mod. well	imperfect	Poor & excessive	-
Flooding	F0	-	-	F1	F2+
Physical characteristics (s)					
AWC (mm m^{-1})	>200	150-200	100-150	50-100	-
Stoniness (surface) (%)	<15	<15	15-40	>40	-
Texture	sic, sicl, c	cl	scl, sil, l, sc	sl	s, sl
Depth (cm)	>100	75-100	50-75	25-50	<25
CaCO_3 (%)	<5	5-10	10-20	>20	-
Soil fertility characteristics (f)					
(NPK) rating					
CEC (soil) [$\text{cmol (p}^+ \text{) kg}^{-1}$]	>30	20-30	<20	-	-
BS (%)	>80	50-80	35-50	<35	-
OC(%) (surface horizon)	2.0	2.0-1.2	1.2-0.8	<0.8	-
Salinity-sodicity (n)					
ECe (dSm^{-1})	<2	<2	2-4	>4	-
ESP (%)	<5	5-10	10-15	>15	-
pH (1:2.5)	6.5-7.5	7.5-8.5	8.5-9.0	>9.0, <6.5	-

Table 4.25 Soil site suitability for Cotton

Soil	Limitations levels for soil site characteristics											
Series	Climate	Erosion	Slope	Drainage	Flooding	Texture	CaCO ₃	BSP	ESP	EC dsm ⁻¹	NPK Rating	Suitability Class
Sakraya	2	1	0	0	4	4	0	0	1	0	-	N1sw
Gonda Atas	2	3	3	2	0	4	2	1	3	2	-	N2stn
Sunrakh	2	4	3	3	3	4	1	0	0	3	-	N2twn
Kiki Nagla	2	2	3	3	0	4	1	1	2	0	-	N1stn
Nagla Chamran	2	2	3	1	0	2	0	0	2	0	-	S3stn
Devi Atas	2	1	3	1	0	2	0	1	3	0	-	S3tns
Nagla Henraj	2	0	1	0	0	2	0	0	3	0	-	S2sn
Nagla Ramtal	2	0	1	1	0	2	0	0	2	0	-	S2sn
Maghera	2	0	1	0	0	2	0	0	1	0	-	S2nt
Barauta	2	0	1	2	0	2	1	0	1	3	-	S3nsw
Ral	2	0	1	1	0	2	0	0	3	0	-	S2ns
Bhadal	2	0	1	2	0	0	0	0	1	3	-	S2nw

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics; n = Salinity/alkalinity ; w = Wetness

Suitability map for Wheat

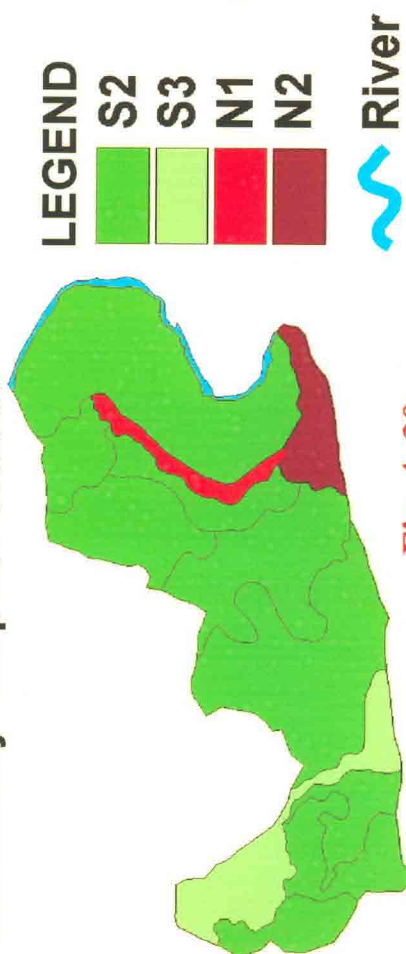


Fig. 4.30

Suitability map for Rice

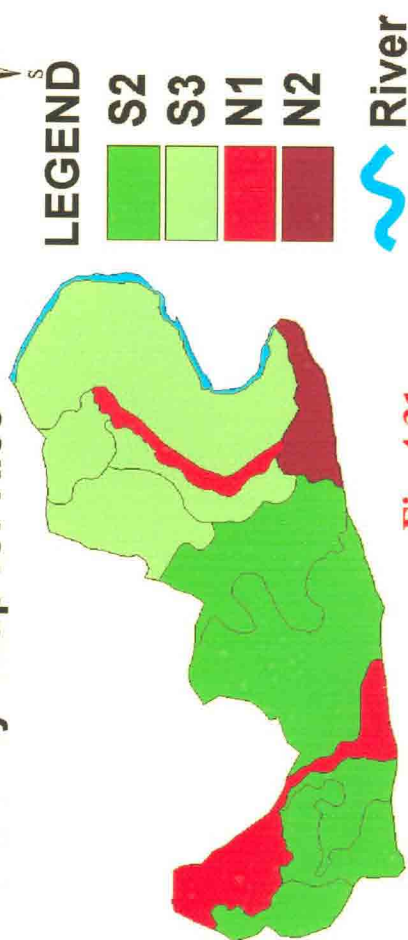


Fig. 4.31

Suitability map for Sugarcane

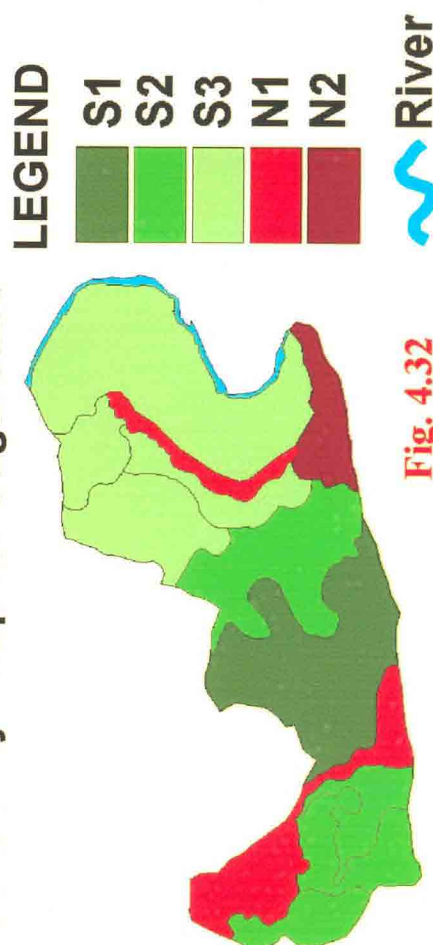


Fig. 4.32

Suitability map for Cotton

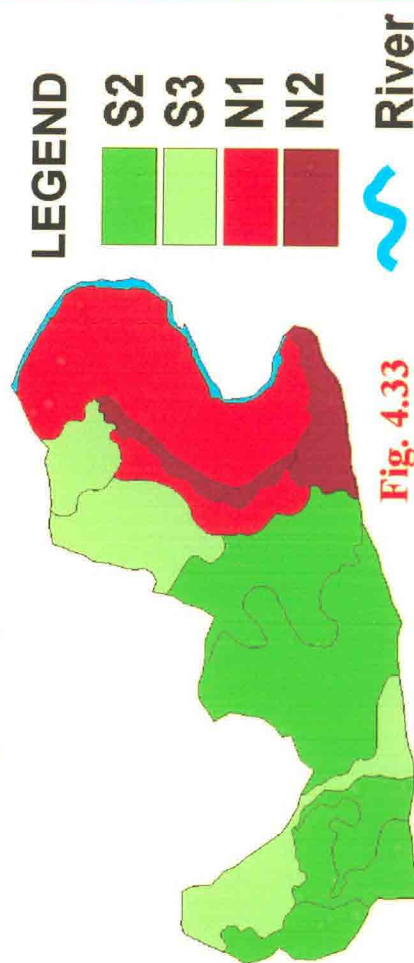


Fig. 4.33

additional irrigation during critical stage of growth and applying organic manure/FYM need to be done. Organic manure/FYM, besides providing chemical nutrients to plant, also helps soil in increasing water retention capacity and in long term helps in modifying soil texture by developing soil structure.

4.6.5 Suitability for Maize

Climate characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for Maize (Table 4.26) to evaluate the suitability of soil for this crop. Results are presented in Table 4.27, which shows kind and degree of limitation and suitability of soils as well. Climate characteristics contribute slight limitation for optimum Maize growth due to rainfall, while soil site characteristics varies in degree of limitation from slight to very severe. Suitability map for Maize (Fig. 4.34) shows that Sunrakh series occupied by forest is not suitable for growing maize due to very severe limitations of erosion and salinity, severe limitations of drainage and moderate limitations of texture. Gonda Atas and Barauta are currently non suitable but potentially suitable with suitability classes (N1tsw and N1nw). The first one because of severe limitations of erosion and alkalinity and moderate constraints due to drainage and texture. The second one is because of very severe salinity constraints and moderate limitations of drainage. Kiki Nagla, Nagla Chamran, Devi Atas, Nagla Hemraj, Ral and Bhadal are evaluated as moderately suitable for Maize due to constraints of erosion, alkalinity, texture and slope. The suitability classes assigned to them are S2tsn, S2tn, S2n, S2n, S2s and S2wn respectively. It was found that Nagla Ramtal and Maghera are the best soils for growing maize with no considerable limitations S1.

Table 4.26 climatic and soil-site suitability criteria for Maize

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c)					
Total rainfall (mm)	750 -900	900 - 1200	1200 - 1600	1600	
Rainfall during growing season (mm)	750 - 600	600 - 500	500 - 400	400 - 300	< 300
Length of growing period (days)					
Mean temp. Growing season (°C)	24 - 22	22 - 18	18 - 16	16 - 14	< 14
Topography (t)					
Slope (%)	04-4	4-8	8-16	16-30	30-50 > 50
Erosion	F 0 e0	F 0 e1	F 0 e2	F 1 e3	F 2+ e4
Wetness (W) flooding	No flooding	moderate	Imperfect	Poor but drainable	Poor, not drainable
Physical characteristic (s)					
AWC (mm m ⁻¹)					
Stoniness (surface) (%)					
Texture					
Depth (cm)					
CaCO ₃ (%)	sic, sicl, si, scl, cl	l, sc, scl	sl, lfs, ls	fs, s, lcs	cs
	>100	100-75	75-50	50-20	< 20
	0-6	6-15	15-25	25-35	>35
Soil fertility characteristics (f)					
(NPK) rating	HHH	MMM	MLL	LLL	---
CEC (soil) [cmol(p ⁺) kg ⁻¹]	>24	24-16	<16 (-)	<16 (+)	---
BS (%)	>80	80-50	50-35	35-20	<20
OC (%) (surface horizon)		>0.8	0.8-0.4	0.4-0.2	<0.2
Salinity-sodicity (n)					
Ece (dSm ⁻¹)	0-2	2-4	4-6	6-8	>8
ESP (%)	0-8	8-15	15-20	20-25	>25
PH (1: 2.5)	6.6-7.0	7.0-7.8	7.8-8.1	8.2-8.5	>8.5

Table 4.27 Soil site suitability for Maize

Soil	Limitations levels for soil site characteristics											
Unit	Climate	Erosion	Slope	Drainage	Flooding	Texture	CaCO ₃	BSP	ESP	EC dsm ⁻¹	NPK Rating	Suitability Class
Sakraya	1	1	1	0	4	3	0	0	0	0	-	S3ws
Gonda Atas	1	3	1	2	0	2	1	1	3	1	-	S3tswN
Sunrakh	1	4	1	3	1	2	1	0	0	4	-	N2 tnws
Kiki Nagla	1	2	1	0	0	2	0	0	2	0	-	S2tsn
Nagla Chamran	1	2	1	1	0	1	0	0	2	0	-	S2 tn
Devi Atas	1	1	1	1	0	1	0	0	2	0	-	S2 n
Nagla Hemraj	1	0	0	0	0	1	0	0	2	0	-	S2n
Nagla Ramtal	1	0	0	1	0	1	0	0	1	0	-	S1
Maghera	1	0	0	0	0	1	0	0	1	0	-	S1
Barauta	1	0	0	2	0	1	1	0	0	4	-	N1nw
Rai	1	0	0	1	0	1	0	0	3	0	-	S2s
Bhadal	1	0	0	2	0	0	0	0	0	2	-	S2wn

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics; n = Salinity/alkalinity ; w = Wetness

4.6.6 Suitability for sorghum

The suitability classes of the study area for sorghum is presented in table 4.29 and Fig. 4.35. Climate characteristics cause slight limitation for this crop while soil characteristics varies degree of limitation for each series. It was found that Sunrakh, Gonda Atas and Barauta series could be classified as N1twsn, N1nst and N1nsw respectively while Sakraya and Nagla Chamran will fall into marginally suitable classes S3s and S3ns. Others are found to be moderately suitable for growing sorghum mainly due to limitations of texture, salinity, alkalinity, slope, erosion and fertility constraints. With proper management practices the suitability of these soils can be improved. The recommended management practices are providing additional irrigation, applying organic manures and controlling soil pH.

4.6.7 Suitability for pearl millet

Climate characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for pearl millet (Table 4.30) to evaluate the suitability of soil for this crop. Results are presented in Table 4.31, which shows kind and degree of limitation and suitability of soils as well. Climate characteristics contribute slight limitation for optimum pearl millet growth due to rainfall, while soil site characteristics vary degree of limitation from slight to very severe. Suitability map for pearl millet (Fig. 4.36) shows that Sunrakh series is not suitable for growing pearl millet; it has N2twns class with three very severe limitations of erosion, drainage and salinity and moderate limitations due to slope and texture. Gonda Atas and Barauta were classified under currently not suitable but potentially suitable N1twsn

Table 4.28 Climatic and soil-site suitability criteria for sorghum

Soil-site characteristics	Degree of limitation and Suitable class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c)					
Total rainfall (mm)	750-850	650-750	650-550	450-550	<450 >850
Rainfall during growing season (mm)	500-600	500-600	400-500	300-400	<300
Length of growing period (days)	150-120	120-105	105-90	<90	-
Mean temp. Growing season ($^{\circ}\text{C}$)	32-26	26-24	24-22	22-20	<20
Mean max. Temp. Growing season ($^{\circ}\text{C}$)	31	31-33	33-35	>35	-
Mean min. temp. Growing season ($^{\circ}\text{C}$)	>22	22-18	18-15	<15	-
Mean R.H. growing season (%)	70-60	60-50	50-40	<40	-
Topography (t)					
Slope (%)	<1	1-3	3-5	5-8	>8
Erosion	e1	E1	e2	e3	-
Wetness (w)					
Drainage	Well	Mod. Well	Imperfect & somewhat excessive	Poor & excessive	-
Physical characteristics (s)					
AWC (mm m-1)	>200	150-200	100-150	50-100	<50
Stoniness (surface) (%)	<15	<15	15-40	40-60	>60
Texture	sic, sicl, cl	c, l, sc	sil, scl	sl	s, ls
Depth (cm)	>100	75-100	50-75	<50	-
CaCO ₃ (%)	<5	5-10	10-25	>25	-
Soil fertility characteristics (f)					
CEC (soil) [cmol(p ⁺)Kg ⁻¹]	>30	30-20	20-10	<10	-
BS (%)	>80	80-50	50-35	<35	-
O.M (%)	>0.75	0.75-0.50	0.50-0.20	<0.20	-
(surface horizon)					
Salinity/sodicity (n)					
ECe (dSm ⁻¹)	2	2-4	4-8	8-10	>10
ESP (%)	<5	5-10	10-15	>15	-
PH (1:2.5)	6.5-7.5	6.5-5.5 7.5-8.0	5.5-5.0 8.0-8.5	<5.0 8.5-9.0	>9.0

Table 4.29 Soil site suitability for Sorghum

Soil		Limitations levels for soil site characteristics										
Series	Climate	Erosion	Slope	Drainage	Flooding	Texture	CaCO ₃	BSP	ESP	EC dSm ⁻¹	NPK Rating	Suitability Class
Sakraya	1	1	0	0	-	3	0	0	1	0	1	S3s
Gonda Atas	1	3	3	2	-	3	0	1	4	1	1	N1 nst
Sunrakh	1	4	3	3	-	3	1	0	0	3	1	N1 twsn
Kiki Nagla	1	2	2	0	-	3	0	1	2	0	1	S2 st
Nagla Chamran	1	2	2	1	-	1	0	0	2	0	1	S2 tn
Devi Atas	1	1	2	1	-	2	0	1	3	0	1	S2 nts
Nagla Hemraj	1	0	1	0	-	2	0	0	3	0	0	S2 ns
Nagla Ramtal	1	0	1	1	-	2	0	0	2	0	1	S2 sn
Maghera	1	0	1	0	-	2	0	0	1	0	1	S2 sn
Barauta	1	0	1	2	-	2	1	0	1	4	1	N1 nsw
Rai	1	0	1	1	-	2	0	0	4	0	1	S3 ns
Bhadal	1	0	1	2	-	0	0	0	1	2	1	S2 wn

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics ; n = Salinity/alkalinity ; w = Wetness

Table 4.30 Climatic and soil-site suitability criteria for pearl millet

Soil-site characteristics	Degree of limitation and Suitability class			
	0	1	2	3
	None	Slight S1	Moderate S2	Severe S3
				Very severe N1 N2
Climatic characteristics (c)				
Rainfall (mm)	600-750	500-600, 750-850	400-500, 850-950	250-400, 950-1100
Rainfall-growing period (mm)	550-600	450-550	300-450	200-300
Length of growing season (days)	100-110	90-100, 110-120	80-90, 120-130	70-80, 130-150
Mean temp. Growing period ($^{\circ}\text{C}$)	25.0-27.5	22.5-25.0	20-22.5, 27.5-30	17.5-20.0 30-32
Mean max. temp. Growing season ($^{\circ}\text{C}$)	30-32	32-34, 28-30	>34, <28	-
Mean min. temp. Growing Season ($^{\circ}\text{C}$)	22-24	20-22, 24-26	<20, >26	-
Mean R.H. during growing season (%)	70-75	65-70, 75-80	60-65, 80-85	<60, >85
Topography (t)				
Slope (%)	0-1	1-3	3-8	8-15
Erosion	e0	E0	e1	e2
Wetness (w)	well	Well	mod. well	imperfect, excessive
Drainage				poor v. poor
Physical characteristics (s)				
Texture (family class)	fine loamy	fine, v. Fine	c. loamy	-
Coarse fragments (vol. %)	<3	3-15	15-35	-
Soil depth (cm)	>75	50-75	25-50	>50
CaCO_3 (%)	0-10	10-25	25-35	<10
Gypsum (%)	0-3	3-5	5-10	>50
Salinity/sodicity (n)				>15
ECe (mmhos cm^{-1})	<1	1-2	2-4	>8
ESP				-
Med. to coarse soils	<10	10-15	15-25	>40
Fine soils	<5	5-10	10-15	-
				>25

Table 4.31 Soil site suitability for Pearl Millet

Soil	Limitations levels for soil site characteristics											
Series	Climate	Erosion	Slope	Drainage	Flooding	Texture	CaCO ₃	BSP	ESP	EC dsm ⁻¹	NPK Rating	Suitability Class
Sakaraya	1	2	0	0	-	2	0	0	0	0	-	S2 ts
Gonda Atas	1	4	2	3	-	2	1	0	2	2	-	N1 twsn
Sunrakh	1	4	2	4	-	2	0	0	0	4	-	N2 twns
Kiki Nagla	1	3	2	0	-	2	0	0	2	0	-	S2tsn
Nagla Chamran	1	3	2	2	-	0	0	0	2	0	-	S2twm
Devi Atas	1	2	2	2	-	1	0	0	2	0	-	S3 twm
Nagla Hemraj	1	0	1	0	-	1	0	0	2	0	-	S2n
Nagla Ramtal	1	0	1	2	-	1	0	0	1	0	-	S2 w
Maghera	1	0	1	0	-	1	0	0	0	0	-	S1
Barauta	1	0	1	3	-	1	0	0	1	4	-	N1 nw
Ral	1	0	1	2	-	1	0	0	2	0	-	S2 wn
Bhada	1	0	1	3	-	1	0	0	0	3	-	S3 wn

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics; n = Salinity/alkalinity ; w = Wetness

and N1nw respectively. The major constraints of Gonda Atas series are erosion, drainage, slope, texture and alkalinity while for Baruta series salinity and drainage are the major constraints for growing pearl millet. Kiki Nagla, Nagla Chamran, Devi Atas and Bhadal were found to be marginally suitable for pearl millet with suitability classes of S3tsn, S3twn, S3twn and S3wn respectively. The constraints are due to severe limitations of erosion and moderate of slope, texture and alkalinity for Kiki Nagla; severe limitations of erosion and moderate of slope, drainage and alkalinity for Nagla Chamran; moderate limitations of erosion, slope, drainage and alkalinity for Devi Atas and severe limitations of drainage and salinity for Bhadal. Sakraya, Nagla Ramtal, Nagla Hemraj and Ral were classified as moderately suitable for growing pearl millet with S2ts, S2w, S2n and S2wn classes respectively. Maghera soil series was found to be the best suitable soil for growing millet in the study area with no considerable limitations.

4.6.8 Suitability for barley

The climate characteristics of the study area along with soil site characteristics (Table 4.15) were matched with climate and soil site requirements for barley (Table 4.32) to evaluate the suitability of soil for this crop. Results are presented in Table 4.33, which shows kind and degree of limitation and suitability of soils as well. Soil site characteristics vary in degree of limitation from slight to very severe. Suitability map for barley (Fig. 4.37) shows that Sunrakh series is found to be not suitable for pearl millet cultivation and is classified as N2twS due to very severe limitation of erosion and drainage and severe limitation of texture; Sakraya and Gonda Atas were found to be marginally suitable with classes of S3ws

Suitability map for Maize

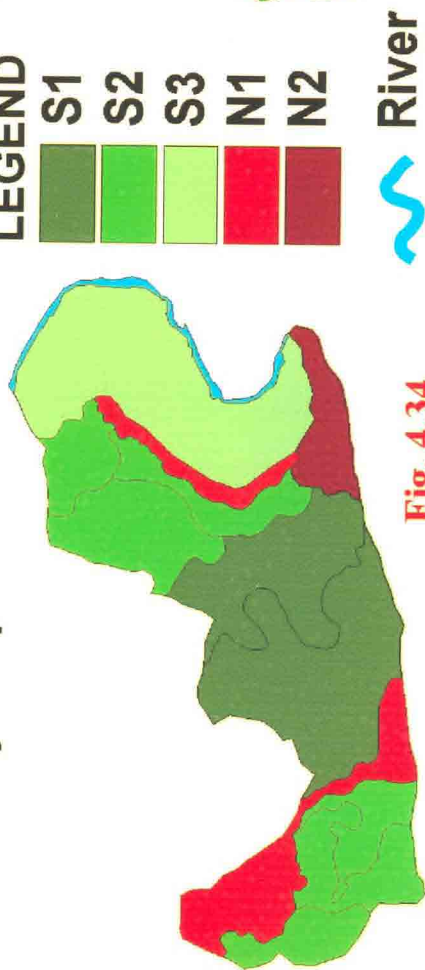


Fig. 4.34

Suitability map for Sorghum

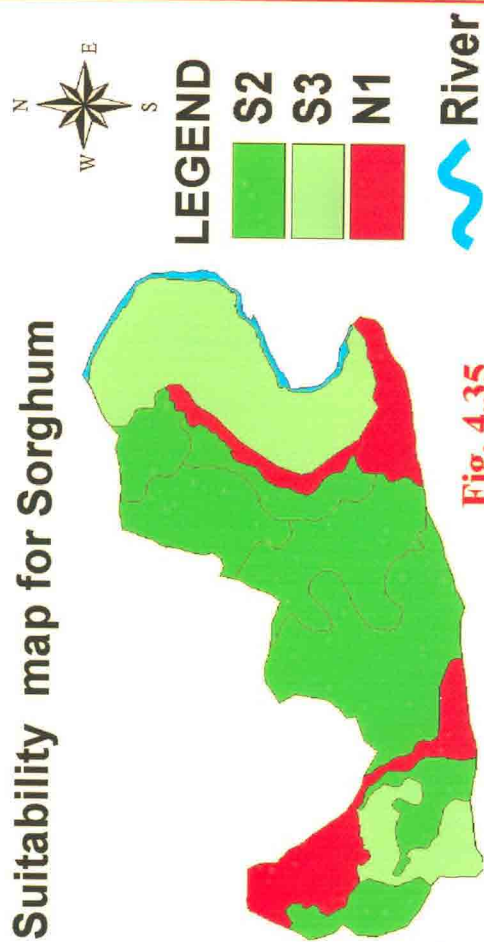


Fig. 4.35

Suitability map for Pearl millet

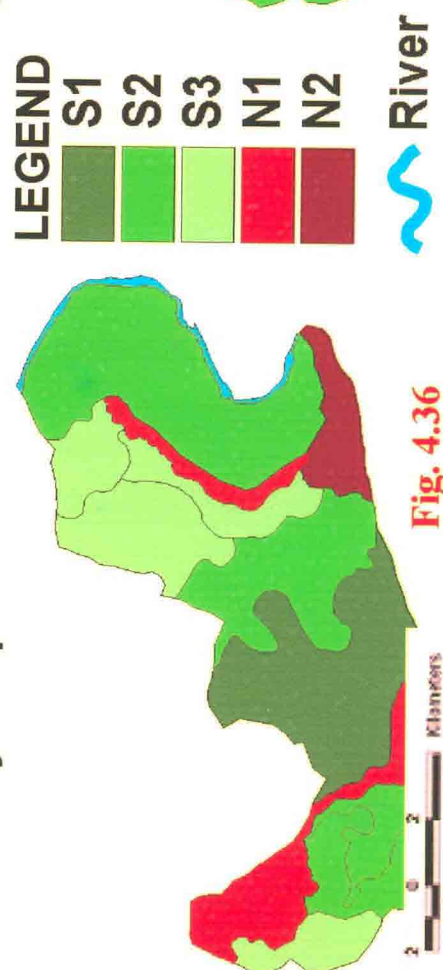


Fig. 4.36

Suitability map for Barley

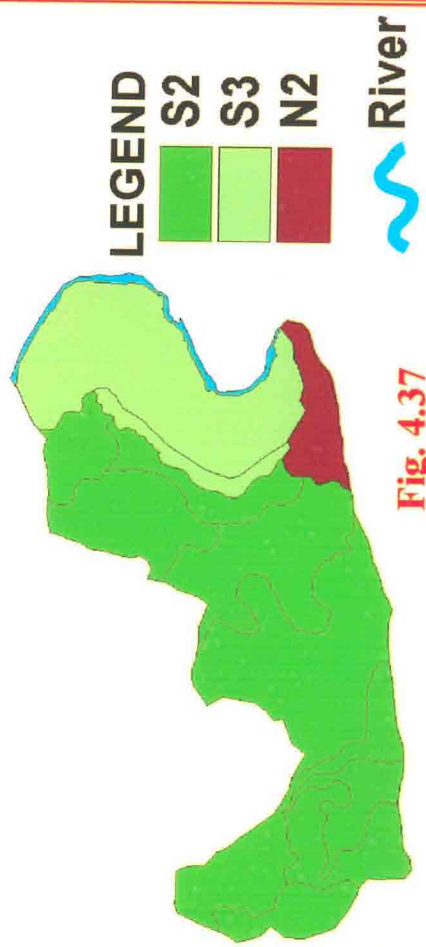


Fig. 4.37

Table 4.32 Climatic and soil-site suitability criteria for barley

Soil-site characteristics	Degree of limitation and Suitability class				
	0	1	2	3	4
	None	Slight S1	Moderate S2	Severe S3	Very severe N1 N2
Climatic characteristics (c)	650-400	400-300	300-200	200-150	<150
Total rainfall (mm)	-	-	-	-	-
Rainfall during growing season (mm)	-	-	-	-	-
Length of growing period (days)	-	-	-	-	-
Mean temp. Growing season ($^{\circ}\text{C}$)	-	-	-	-	-
Mean Max. Temp. Growing season ($^{\circ}\text{C}$)	-	-	-	-	-
Mean Min. Temp. Growing season ($^{\circ}\text{C}$)	-	-	-	-	-
Mean R.H. Growing season (%)	-	-	-	-	-
Topography (t)	0-1 e0	1-2 e1	2-4 e2	4-6 e3	>6 e4
Slope (%)					
Erosion					
Wetness (W)	Well F0	Moderate	Imperfect F1	poor F2	Poor F3
Drainage					
Flooding					
Physical characteristic (s)					
AWC (mm m^{-1})					
Stoniness (surface) (%)	sic, si, cl, sil, cl	sc, l	scl, 50-20	sl, lcs 20-10	s <10
Texture	>90	90-50	30-40	40-60	>60
Depth (cm)	3-20	20-30			
CaCO_3 (%)					
Soil fertility characteristics (f)					
(NPK) rating	>24	24-16	<16 (-)	<16 (+)	---
CEC (soil) [$\text{cmol}(\text{p}^+) \text{kg}^{-1}$]	>80	80-50	50-35	<35	
BS (%)	2.0	2.0-1.2	1.2-0.8	<0.8	
OC (%) (surface horizon)					
Salinity-sodicity (n)					
ECe (dS m^{-1})	0-8	8-12	12-16	16-20	>25
ESP (%)	0-15	15-25	25-35	35-45	
PH (1: 2.5)	>8.0	8-5	5.0-3.5	3.5-2.0	<2.0

Table 4.33 Soil site suitability for Barley

Soil Series	Climate	Erosion	Slope	Drainage	Flooding	Limitations levels for soil site characteristics					NPK Rating	Suitability Class
						Texture	CaCO ₃	BSP	ESP	EC dSm ⁻¹		
Sakraya	0	1	0	0	3	3	0	0	0	0	-	S3ws
Gonda Atas	0	3	2	2	0	3	0	0	1	0	-	S3tsw
Sunrakh	0	4	2	4	1	3	0	0	0	1	-	N2tws
Kiki Nagla	0	2	2	0	0	3	0	0	0	0	-	S2st
Nagla Chamran	0	2	2	1	0	1	0	0	0	0	-	S2t
Devi Atas	0	1	2	1	0	2	0	0	1	0	-	S2ts
Nagla Hemraj	0	0	1	0	0	2	0	0	1	0	-	S2 n
Nagla Ramtal	0	0	1	1	0	2	0	0	0	0	-	S2 s
Maghera	0	0	1	0	0	2	0	0	0	0	-	S2 s
Barauta	0	0	1	2	0	2	0	0	0	2	-	S2wsn
Ral	0	0	1	1	0	2	0	0	1	0	-	S2s
Bhadal	0	0	1	2	0	0	0	0	0	0	-	S2w

Key : S1 = Very suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1 = Currently non suitable but potentially suitable, N2 = Non suitable,

Small letters = Constraints (subclass)

c = Climate ; t = Topography ; s = Physical characteristics ; n = Salinity/alkalinity ; w = Wetness

and S3tsw respectively, because of severe limitations of texture and flooding for Sakraya and severe limitations of texture and erosion for Gonda Atas. All other areas were found to be moderately suitable for growing barley with slight to moderate limitations mainly due to texture, drainage and slope. However barley was found to be the adequate crop for cultivation in the study area and it is mainly recommended to cultivate under saline/ alkaline soils due to its good tolerance for salinity/alkalinity.

4.7 Land use/Land cover

The study area lies in cis-Yamuna part, which is under intensive cultivation with irrigation facilities from canals and wells. Generally, two crops namely Kharif and Rabi are taken in the study area. Rice, Wheat, Sugarcane are generally grown in Rabi season (Fig. 4.38). Pearl millet, and Sorghum are sown in Kharif season (Fig. 4.36). According to land use/land cover results obtained the dominant land use in the area under study is agriculture, which occupied 6854.28 ha representing 71.64%.

Out of total area of 9581.35 ha only 331.78 ha (3.46%) is under forestland, about 1496.48 ha (15.62%) is under wasteland (waterlogged + Ravines), about 738.64 (7.71%) is under built up area. Details of the present land use/land cover is given in Table 4.34; and illustrated in fig. 4.40.

4.7.1 Potential land use

An analysis of the current land use pattern revealed that large area is under fallow or wasteland and the area under forest is rather low. To achieve better ecological balance part of fallow or waste land should be converted into forest, part of saline area (Barauta) can be used to cultivate

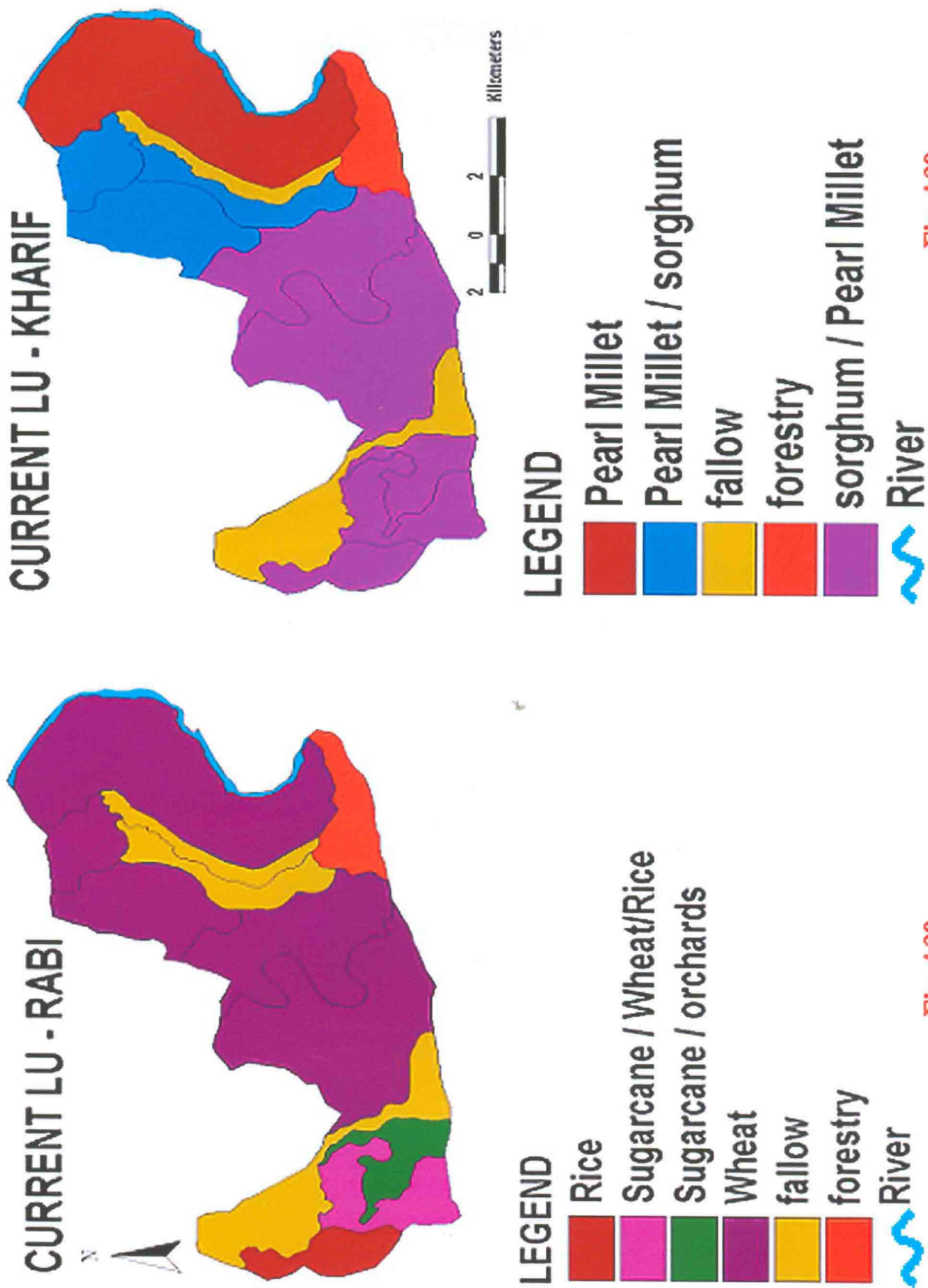


Fig. 4.38

Fig. 4.39

Table 4.34 Present land use/land cover statistics

Sl. No.	Land use	Area, ha	% of total area
1.	Agriculture	6864.28	71.64
2.	Forest and shrubs	331.78	3.46
3.	Built up area	738.64	7.71
4.	Water logged area	1370.76	14.31
5.	Ravines	125.72	1.31
6.	Water bodies	150.17	1.57
	Total	9581.35	100.00

salt tolerant crops such as barely and cotton while soil conservation measures can be applied to ravinous areas to bring it back under cultivation. Maize was suggested also for cultivation in the study area because of high potentiality and suitability of large area for its cultivation. For the preparation of potential land use map for both Rabi and kharif seasons (Fig. 4.41 and 4.42 respectively) the following points were taken into consideration:

1. Suitability classes of soils for different crops
2. Allocation of sufficient area for crop production to meet needs of food production
3. Adding some crops which having good potentiality for cultivation in the study area.
4. Preservation of existing forest lands.
5. Rehabilitation and conservation of degraded lands.
6. Multiple choices of crops are given for a map unit so that selection of crops can be made depending on the prevailing socio-economic conditions.
7. Maintenance of ecological balance.

Land use/Land cover Map

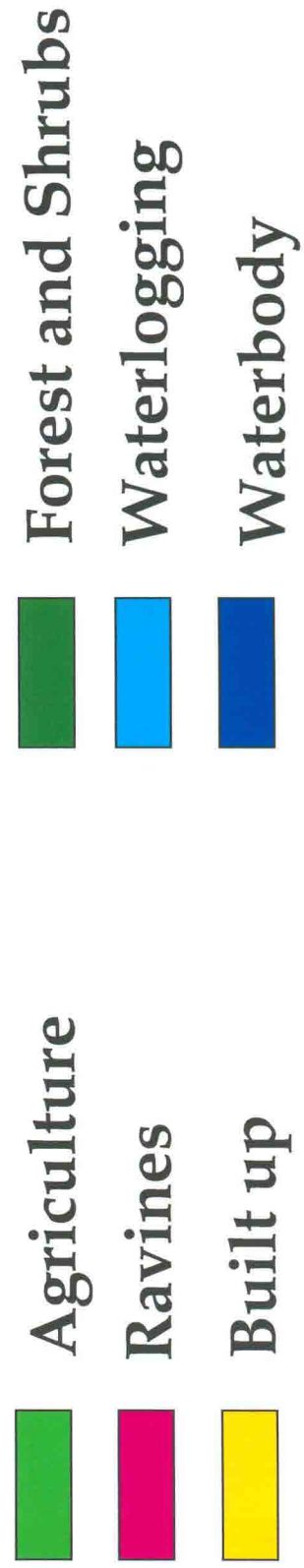
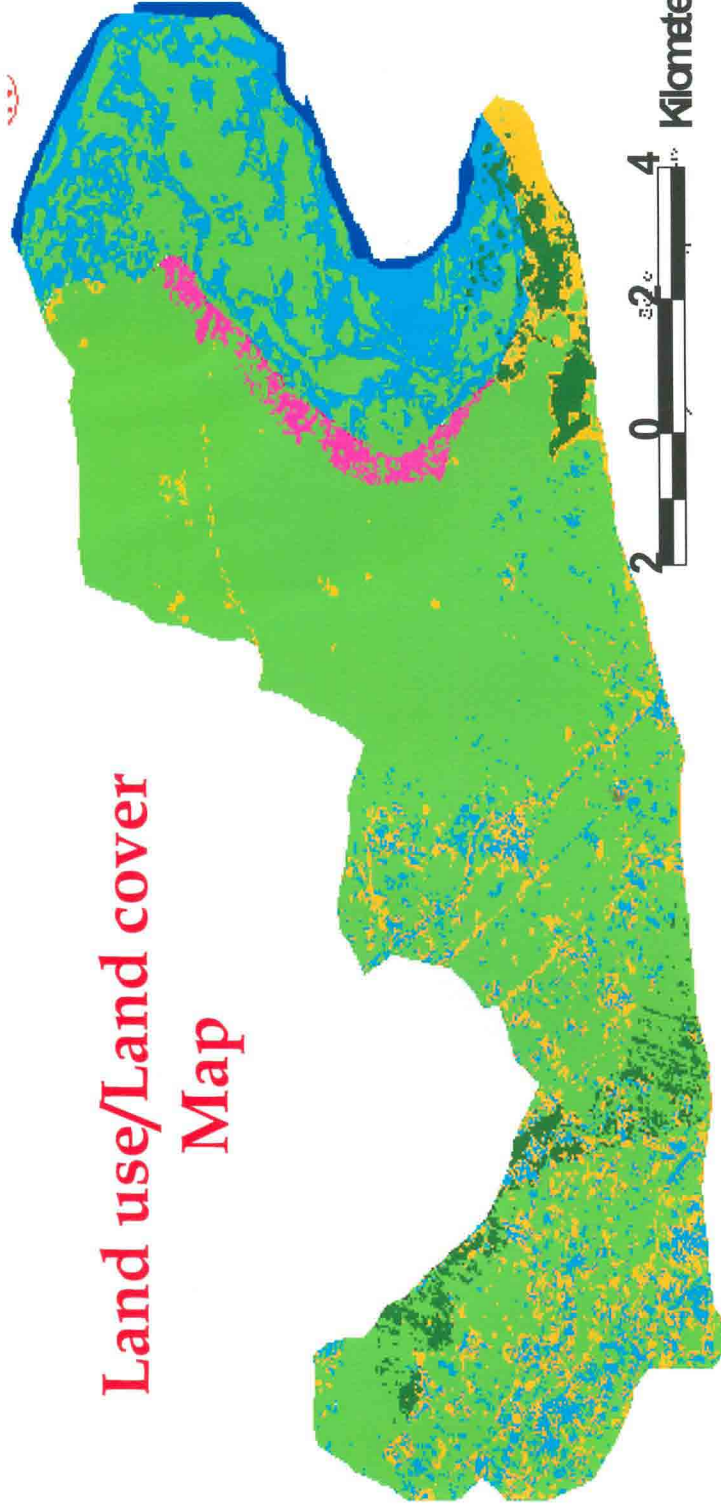


Fig. 4.40

POTENTIAL LAN USE RABI

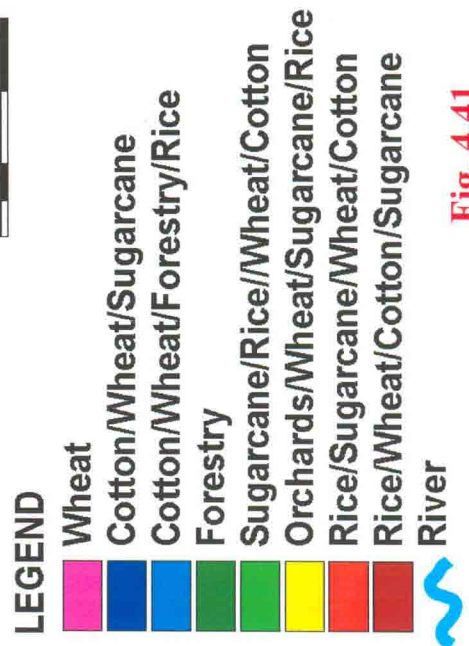
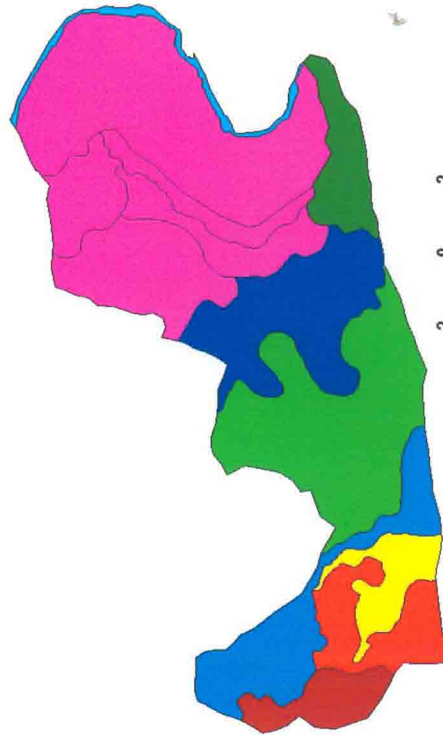
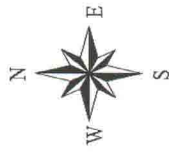


Fig. 4.41

POTENTIAL LAND USE KHARIF

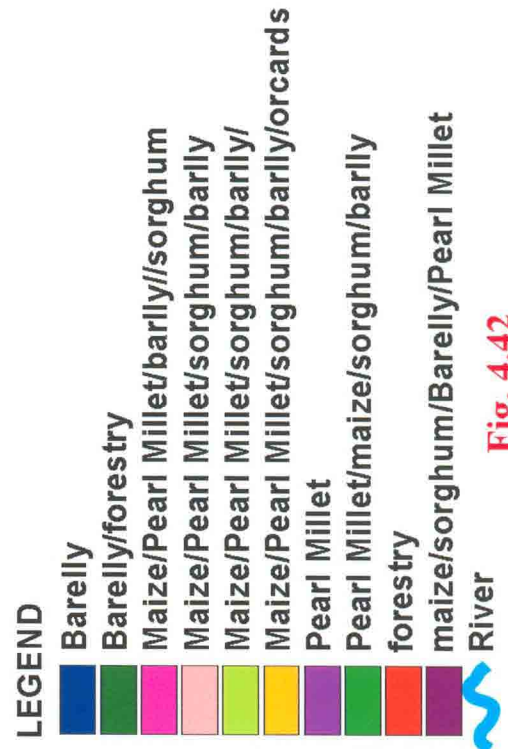
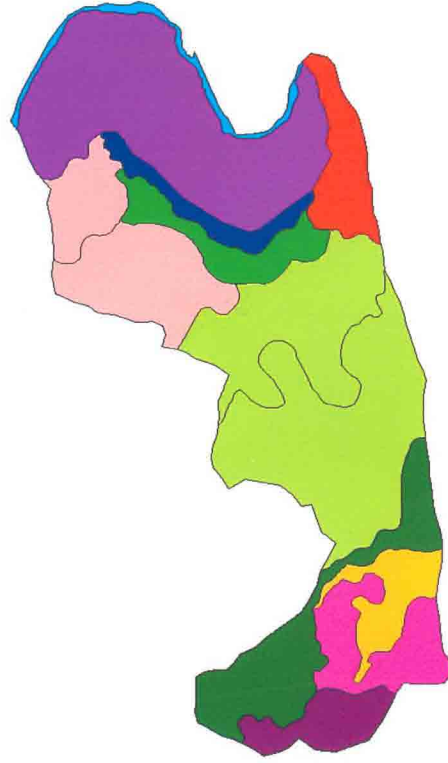


Fig. 4.42

4.8 Suggestive measures for reclamation of degraded soils

To rehabilitate degraded lands management units are formulated based on landscape characteristics, limitations of land and its use. Suggestive measures of broad nature to restore lost potential of various degraded lands identified are given here under.

4.8.1 Water eroded/ gullied land

These lands are under different degree of severity of water erosion ranging from slight to severe and very severe erosion. They are having low fertility status, coarse texture and low water holding capacity and are subjected to improper land use and faulty cultivation. The water erosion problem was found in Gonda Atas, Sunrakh, Kiki Nagla, Devi Atas, Sakraya and Nagla Chamran series. To check the water erosion problems following measures are generally adopted:

- Bunding and leveling of land
- Stream bank should be properly grassed and afforested
- Reclamation of some of the eroded patches by leveling and bench terracing
- Adoption of suitable grass and forest tree species to check the advancement of gully formation
- Land shaping, field bunding should be adopted to arrest the erosion
- Application of manures to improve physical characteristics of soils

4.8.2 Salt affected land

These lands are subjected to accumulation of salt in soil profile and on the surface and are occurring in Barauta, Bhadal, Sunrakh and Gonda Atas series. These soils are characterized by low fertility status, imperfect to poor drainage, and have kankar layer in the profile. Following measures are need to be adopted to reclaim these lands:

- Salt resistant crops like paddy, barley, cotton, wheat etc. should be grown.
- Saline patches should be flooded with good quality canal water to wash out the excess salts from the surface as well as the sub soil.
- Disposal of saline water through surface and sub-surface drainage.
- Construction of more irrigation canals to reduce the use of saline ground water.
- Development of micro watersheds to mitigate the problem of utilizing saline ground water.
- Surface salts can be removed by scraping the surface.
- Sodic soils can be reclaimed through application of soil amendments like gypsum, pyrite, organic manures and acid forming fertilizers.
- Saline ground water should be avoided for irrigation

4.8.3 Waterlogged land

Both seasonal and permanent waterlogging exists in Sakraya, Bhadal, Ral and Barauta series. Reclamation of waterlogged land can be achieved trough adopting the following measures:

- Introduction of proper drainage outlets.
- Provision of suitable water outlets for removal of water.
- The permanent waterlogged area can be used for fisheries, while seasonally waterlogged areas can be cultivated for rice.

5. SUMMARY AND CONCLUSIONS

Land is a non-renewable natural resource, which provides social environment in terms of shelter, communication, industries and other facilities. The rapid population increase in last five decades, particularly in developing countries, has stressed the land resources of many countries to the extent that poverty is prevalent, and more than 800 million people do not have access to basic food requirements. Paradoxically, 5 to 7 million hectares of arable land of the world is lost annually through land degradation. While arable land is decreasing, demand for food and other agricultural products are rapidly increasing. The continuous degradation of production base and imbalance in soil - water - plant, human- animal systems is leading to ecological imbalance and economic insecurity.

Remote sensing from satellite in conjunction with ground verification offers potential means of surveying all the regions of globe. The process and extent of land degradation can be perceived better by using remote sensing and GIS techniques followed by verification at test sites on the ground. Recent awareness in information technology, especially in the digital format holds the opportunity for better organization of land and soil data by facilitating its storage, retrieval and processing of voluminous data sets. With the background information, an attempt is made to prepare an inventory of soil resources, to identify and assess soil degradation, and to suggest suitable control measures for combating soil degradation problems using remote sensing and GIS techniques.

The present study is undertaken in Part of Mathura Tehsil, Mathura District, Uttar Pradesh that forms a part of Yamuna River basin, Indo-Gangetic alluvial plain. The climate of the district is semi-arid. It is characterized by intense hot summer, cold winter and general dryness throughout the year except during southwest monsoon period from July to September.

The remote sensing data products of two seasons namely pre (May) and post-monsoon (October) periods were acquired from National Remote Sensing Agency, Hyderabad for the identification and mapping of degraded lands and soil resource inventory in the study area. The procedure adopted for land degradation and soil resource inventory consisted of selection and acquisition of data, pre-field visual interpretation, ground truth verification and post field Interpretation including laboratory analysis of soils and digital image processing. IRS-1C LISS-III geocoded cloud free False Colour Composite (FCC) and digital format (CD-ROM) data products (Path No.96; Row No.52; of 2nd May and 17th October 2000) at 1:50,000 scale were used. Corresponding Survey of India (SOI) Toposheet 54 E/10 at scale 1:50,000 was used as secondary data for delineation of area boundary, generation of information on elevation, slope, topography, ground truth verification and registration of images.

Twelve representative profiles from three different physiographic units of study area were described as per guidelines laid out in the Soil Survey Manual (Soil Survey Staff, 1975). Horizon wise soil samples were collected for detailed analysis of physical, physico-chemical, chemical and mineralogical properties. Based on these characteristics, the soils were then classified up to series level according to Soil Taxonomy (Soil Survey

Staff, 1998). Twelve soil series were identified. The soil site suitability for wheat, rice, sugarcane, cotton, maize, sorghum, pearl millet and barley were also evaluated as per FAO guidelines (1976) as modified by Sehgal (1996). ERDAS IMAGINE (version 8.2), Arc GIS (version 8.2) and ArcView (version 3.2a) software were used for image processing and generation of different thematic maps of the study area. The summary of the results of the investigations is given below.

The depth of soil series in the study area is related to the thickness of alluvium in this landform and observed to be very deep, having range from 145 to 165 cm.

All soil series in the study area have the hue of 10YR and lighter colour in the surface horizons than sub-surface horizons. In contrast, profile 11(Bhadal series) has hue of 2.5 Y and darker colour in surface horizon than sub-surface horizon. Generally all the series have value of 4 to 5 and chroma of 3 to 4 but Sakraya series is having value of 6 and 7 and chroma of 1 to 3 dry and value of 4 to 5 with chroma of 2 to 4 moist. The colour was primarily inherited from the parent material, but has been somewhat modified by pedo-chemical and edaphological factors. The darker chroma in P11 soil profile may be due to formation of non-hydrated compounds. The soils remain saturated during rainy season and subsequently oxidizing condition prevails. Reduction of Fe-Mn compounds takes place in dry conditions. So this soil showed colour of high chroma.

All the soils have massive structure in the surface horizons. Profiles 6 and 11 showed massive structure throughout the depth. Some sub-surface horizons of other profiles have structure of fine to medium, weak to moderate sub-angular blocky. Soil consistency in all series was hard to

slightly hard when dry, friable to loose when moist. Similarly stickyness and plasticity were varied from non-sticky non-plastic (Gonda Atas, Kiki Nagla, Sunrakh and Sakraya series), slightly sticky non plastic in Maghera and Nagla Hemraj), slightly sticky and slightly plastic (Devi Atas, Nagla Chamran and Ral series) to very sticky and plastic in Nagla Ramtal series and very sticky and very plastic in Bhadal series. Variation in soil structure and consistency are mainly associated with variation in amount of clay, silt, coarse fragments and free Fe_2O_3 . The weak structural development in these soils might be due to low clay and organic carbon content and the presence of lime concentrations. Variation in soil structure and consistency are mainly associated with variation in amount of clay, silt, lime concentrations and free Fe_2O_3 .

It has been recorded that Ral series had sandy clay loam textural class throughout the soil profile (P10). The textural classes in all other soil series ranged between sandy loam to sandy clay loam. Variation in soil texture are mainly associated with variation in CEC, amount of clay, silt, sand and lime concentrations.

Bulk density of the study area varied from 1.25 to 1.48 Mg m^{-3} in surface horizons and from 1.23 to 1.55 Mg m^{-3} in sub-surface horizons. The soils did not have definite pattern of distribution, except Sakraya series (P6), where it increased with depth (1.33 to 1.50 Mg m^{-3}) due to high content of sand fraction (82.82 % to 89.23 %) and decreased in 4C horizon to 1.29 Mg m^{-3} due to clay migration from surface to lower horizon.

The moisture content at 33 kPa ranged from 3.41 to 32.07 per cent and in general there was not much difference in distribution pattern in all the soil series. The moisture content at 1500 kPa ranged from 1.32 to 18.78

per cent. In general, water retention of all the soil series in the study area is low possibly due to lighter texture and dominance of unexpandable clay minerals as well as low organic carbon content.

The AWC of the soils has wide variation from 2.09 per cent in Sakraya series to 26.98 per cent in Gonda Atas series. Depth wise distribution of AWC tends to follow particle size distribution in profiles. In general, all the soil series in study area have relatively higher PAWC (183.06 in Sakraya to 362.70 mm in Gonda Atas series), which could be due to the depth of soils.

pH in surface soil of different soil series ranged from 7.7 to 9.0 i.e. from mildly alkaline to strongly alkaline and that of sub-surface soils ranged from 7.4 to 9.6. Three pH classes were mapped in the study area i.e. mildly alkaline, moderately alkaline and strongly alkaline. Alkalinity in the study area is due to the calcareous nature of parent material.

Soils in the study area have electrical conductivity (EC) ranging from 0.27 to 25.50 in surface layers and from 0.1 to 4.8 in sub-surface layers. Barauta series emerged as the strongest saline soil in the study area with electrical conductivity values ranging from 4.1 to 25.50 dSm^{-1} with weighted average of 17.0 dSm^{-1} . This is related to poor drainage, high water table and waterlogging occurring in this area.

The CEC of all the soil series were generally low and ranged from 5.21 to 18.88 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in surface horizons and from 3.48 to 26.77 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in sub-surface horizons. The CEC in the study area revealed considerable variations among and within profiles depending on clay content of different layers and different profiles.

Exchangeable Ca^{2+} was observed to be the dominant base followed by Mg^{2+} , Na^+ and K^+ in all of the soil series in the study area except Gonda Atas (P1), Nagla Ramtal (P3) and Nagla Chamran (P5). In Gonda Atas exchangeable Ca^{2+} was also the dominant cation but it followed by Na^+ , Mg^{2+} and K^+ . The dominant cation in Nagla Ramtal (P3) and Nagla Chamran (P5) was Mg^{2+} followed by Ca^{2+} , Na^+ and K^+ . In general, the exchangeable cations followed the order $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$.

Soils of the study area are highly base saturated with values ranging from 68.83 to 96.48 per cent in surface horizons and from 51.38 to 97.99 per cent in sub-surface horizons. The weighted average values show that all soil series have more than 80 per cent base saturation except three i.e. Gonda Atas, Kiki Nagla and Devi Atas series.

Soils of the study area contained low organic carbon less than 0.50 per cent except surface horizon of Maghera series. It ranged from 0.08 to 0.43 per cent in surface horizons and 0.02 to 0.28 percent in sub-surface horizons. However, surface horizons of Meghera series contained 0.50 per cent organic carbon. Poor organic carbon content of the study area could be due to low accumulation of organic matter and because of prevailing climatic conditions of low rainfall and high temperature which is conducive for rapid decomposition of organic matter

The Free CaCO_3 was observed in all the soil series. The percentage ranged from 0.10 to 8.40 in surface horizons to 25.00 percent in sub-surface horizons. Calcic horizon at some depth in the regolith was observed in Gonda Atas series (P1) due to precipitation of CaCO_3 .

The free Fe_2O_3 content ranged from 0.29 to 0.59 per cent in surface horizons and from 0.34 to 0.98 percent in sub-surface horizons. It has been observed that Fe_2O_3 content is low in epipedon and invariably increased in B horizon indicated weathering stage and then slightly decreased in lower horizons.

All soil series in the study area are low in nitrogen content. It ranged from 97.2 to 288.5 kg ha^{-1} in surface horizons and from 12.5 to 178.8 kg ha^{-1} in sub-surface horizons. In general the soils are low in available nitrogen that could be due to low total nitrogen, low organic matter and also high temperature.

The available phosphorous content in all the studied soils is low to medium and ranges from 5.60 to 70.3 kg ha^{-1} in surface horizons and from 3.35 to 104.1 kg ha^{-1} in sub-surface horizons.

The available potassium (in term of $\text{K}_2\text{O kg ha}^{-1}$) of the soils ranged from 177.41 to 456.96 kg ha^{-1} in surface horizons and 44.35 to 416.64 kg ha^{-1} in sub-surface horizons. Considering the criteria of <136, 136-337.5 and > 337.5 $\text{K}_2\text{O kg ha}^{-1}$ as low, medium and high respectively (Baruah and Barthakur, 1999), all the soil series in the study area in general could be grouped into medium in available K except Bhadal (P11) and Barauta series (P12) which could be grouped into high in available K.

The weighted mean data of Diethylene Triamine Penta Acetic Acid (DTPA) extractable micronutrients showed that Mn has the highest content in all the soils except Bhadal series (P11) where the Fe is the highest one. Iron was found to be the second largest followed by Cu, and Zn.

The DTPA-Fe content of the soils varied from 1.16 to 15.01 mg kg^{-1} in surface horizons and from 1.04 to 13.41 mg kg^{-1} in sub-surface

horizons. On the basis of critical limit of 4.5 mg kg^{-1} (Lindsay and Norvell, 1978), Bhadal, Nagla Ramtal, Nagla Chamran, Maghera and Nagla Hemraj soil series could be grouped as adequate in Fe content while others were found to be deficient

The DTPA-Mn of the soils was adequate in general, ranged from 1.73 to 10.25 mg kg^{-1} in surface horizons and from 0.95 to 11.45 mg kg^{-1} in sub-surface horizons. On the basis of critical limit of 3.5 mg kg^{-1} (Lindsay and Norvell, 1978), Gonda Atas, Sunrakh and Barauta soil series could be grouped as deficient in Mn content while others are adequate in available Mn.

The DTPA-Zn of the soils was deficient in general. It is ranged from 0.2 to 0.74 mg kg^{-1} in surface horizons whereas in sub-surface horizons it varied from 0.06 to 0.37 mg kg^{-1} . Taking 0.60 mg kg^{-1} as critical limit of Zn (Lindsay and Norvell, 1978), it can be inferred that only soils of Nagla Hemraj series is adequate in available Zn. All other soils are deficient in available Zn.

DTPA-Cu content of surface horizons of the soils ranged from 0.28 to 3.58 mg kg^{-1} and in sub-surface horizons ranged from 0.19 to 1.41 mg kg^{-1} . Considering 0.20 mg kg^{-1} as critical limit of Cu (Lindsay and Norvell, 1978), all soils in the study area are sufficient in available Cu.

The X-ray diffraction study of clay fraction showed that Smectite was observed in all soils. Vermiculite was observed only in some soils. Chlorite was also observed almost in all the soils except Maghera series. All the samples contained mica and kaolinite. Data showed that mica (illite) was the dominant mineral in almost all the soils, with the range of

39 to 75 per cent in surface horizons and from 42 to 76 per cent in sub-surface horizons. Kaolinite was found to be next dominant mineral in all soil series with the range of 11 to 24 per cent in surface horizons and from 14 to 25 per cent in sub-surface horizons.

Chlorite was found in all soil series except Maghera. It ranged from 3 to 27 per cent in surface horizons and from 7 to 37 per cent in sub-surface horizons. The next mineral observed was Smectite in all series ranging from 3 to 10 per cent in surface horizons and from 5 to 14 per cent in sub-surface horizons. Vermiculite was observed to be the least mineral of the soils in the study area.

The dominant soils of the study area belonged to soil orders Inceptisols, Entisols and Alfisols. Based on textural classes, calcareousness, erosion, salinity and alkalinity features of different families they were classified into 12 soil series. It was found that Inceptisols are the dominant soils followed by Entisols and Alfisols. Sakraya series is the largest followed by Maghera, Nagla Ramtal, Barauta and Devi Atas with areas of 2257.04 ha (23.56 %), 1768.56 ha (18.46 %), 1134.65 ha (11.84%), 829.08 ha (8.65 %) and 781.37 ha (8.16%) respectively. Gonda Atas was found to be the least one followed by Bhadal, Nagla Hemraj and Nagla Chamran with areas of 125.73 ha (1.31%), 366.61 ha (3.83%), 373.08 ha (3.89%) and 374.87 ha (3.91%) respectively.

An attempt was made to carry out visual as well as digital image processing to extract required information about various land degradation types.

Visual interpretation of images showed that gullied and/or ravinous

land shows a light gray-to-gray or dark gray tone, smooth with view mottles texture and irregular shapes. Permanent waterlogging areas appear in dark blue to bluish black tone of varying sizes and shapes in the image while seasonal waterlogging shows light gray to bluish gray scattered mottles. Salt affected areas appear in different tones and shapes. Strongly saline areas show gray to yellowish white and white with red mottles while moderately saline areas appear in gray to light gray with red mottles. The dark gray and/or gray patches with bluish mottles represented alkalinity with strong and medium degree of severity. Healthy vegetation, forest and plantations appeared in red to deep red smooth tone. Land degradation in the study area was assessed for its types, degree, extent, rate and causative factors. It was found that three major types of land degradation occurred in the study area such as water erosion, Chemical and Physical deterioration. The dominant one was observed to be water erosion followed by chemical and then physical deterioration with extent of 4395.5 ha (46%), 3597.2 ha (38%) and 1370.8 ha (14 %) respectively.

The causative factors of land degradation in the study area were found to be both natural and human induced. Subsequently, the rate of degradation was found to be slowly increasing (-1).

Using Geographical Information System (GIS) a number of single theme maps such as pH, EC, CEC, BS, OC, CaCO_3 , Available N, P and K, Available micronutrients Fe, Mn, Zn and Cu, Slope, drainage and flooding were prepared by reclassification of the basic soil map using appropriate attribute data sets.

The thematic maps generated in the GIS environment provides the spatial distribution pattern of several physical and physico-chemical

properties which will be highly useful for Farmers, researchers and planners in the study area as a soil information database for future studies.

Suitability of the soil for wheat, rice, sugarcane, cotton, maize, sorghum, pearl millet and barley has been evaluated by matching soil site characteristics with soil site requirements of crops under study. Soil suitability data were linked to GIS and suitability maps for different crops were generated.

It was found that Sunrakh series is non suitable for all the evaluated crops due to severe and very severe erosion, salinity and poor drainage.

Gonda Atas was found to be marginally suitable for growing barley and currently non-suitable but potentially suitable for all other evaluated crops.

Barauta series shows marginal suitability for cotton and wheat, moderate for barley and currently non-suitable but potentially suitable for all other evaluated crops due to very severe limitation of salinity, moderate alkalinity and drainage limitations.

Sakraya soil series was found to be moderately suitable for growing wheat and pearl millet; marginally suitable for sugarcane, maize, barley, rice and sorghum and currently non suitable but potentially suitable for cotton due to severe limitations of texture (ls) and moderate limitations of drainage and erosion.

Maghera series was found to be the best for growing maize and pearl millet (S1), and it is moderately suitable for all other evaluated crops. Nagla Ramtal was found to be highly suitable for maize but

moderately suitable for all other crops. The remaining soil series are moderately to marginally suitable for growing the evaluated crops.

According to land use/land cover analysis the dominant land use in the area under study is agriculture (71.64%), followed by wasteland (15.62%), built up area (7.71%) and forestland (3.46%).

From the present study, the following conclusions can be drawn:

- ❖ Remote sensing and Geographical Information System (GIS) techniques were found to be valuable tools for studying and mapping of soil resources and land degradation assessment.
- ❖ Digital Image Processing techniques are much better than visual interpretation in delineation of types, degree and extent of land degradation. Many a times two or more different objects appear alike in tone leading to wrong inference. However, knowledge based and hybrid classification helped to discriminate such objects.
- ❖ Three major types of soil degradation were found in the study area i.e. water erosion, chemical deterioration (alkalinity, salinity) and physical deterioration (waterlogging). The dominant degradation type was found to be water erosion followed by alkalinity, waterlogging and salinity. The most degraded soil was found to be Sunrakh, Gonda Atas and Barauta series.
- ❖ Three soil orders were found in the study area and twelve soil series were identified. Sandy clay loam was found to be the dominant among the five textural classes observed. All the soils have low organic carbon and nitrogen; low to medium P; medium to high K; mild to strong in soil reaction; slight to strong in soil salinity; low

to medium CEC; slight to strong in calcium carbonate content; adequate to deficient in available iron, Mn and adequate in Cu but deficient in Zn (except Ral series) content.

- ❖ The dominant clay mineral was found to be Illite followed by kaolinite, chlorite, vermiculite and smectite.
- ❖ Degraded soils (Sunrakh, Gonda Atas and Barauta) were found to be the least suitable for growing crops while the Maghera and Nagla Ramtal were found to be the best suitable followed by Nagla Hemraj and Ral soil series.

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APPENDICES

APP.I: Legend for soil degradation mapping.

APP. II :Ground truth verification, using GPS, FCC and Toposheet.

APP. III : Correlation matrix between the variables.

APP. IV : X-RAY diffractograms of selected horizons of representative profiles.

APPENDIX - 1

Legend for soil degradation mapping

Appendix 1.1 - Types of soil degradation

Degradation Type	Degradation Type's name
W	Water erosion
E	Wind erosion
Cs	Salinization
Csk	Saline/alkali
Ck	Alkalinisation
Cn	Fertility decline
Pw	Waterlogging
Dc	Complex degradation
N	Normal land
X	Wasteland

Appendix 1.2. - Degree of severity of soil Degradation

Sl. No.	Type of Degradation	Degree of Severity	Description	Symbol
1	Water erosion (W)	Nil	No erosion	0
		Slight	Sheet erosion	1
		Moderate	Rill erosion	2
		Strong	Sallow to moderately deep gullies 1-3 m deep)	3
		Severe	Very deep gullies (>3m deep)	4
2	Wind erosion (E)	Severe	Active plain and sand dunes	1
		Very severe	Active and shifting dunes and sand casting	2
3	Waterlogging (Pw)	Seasonal	Affecting one crop; 4-6 months submergence	1
		Permanent	Affecting two crops; 6 months submergence	1
4	Salinity afflictions (Cs)	Nil	EC (dSm ⁻¹) <4	0
		Slight	EC (dSm ⁻¹) 4-8	1
		Moderate	EC (dSm ⁻¹) 8-15	2
		Strong	EC (dSm ⁻¹) 15-25	3
		Severe	EC (dSm ⁻¹) >25	4
	Alkalinity (Ck)	Nil	PH < 7.5 ESP 5 - 10	0
		Slight	PH 7.5-7.8 ESP 10-15	1
		Moderate	PH 7.9-8.4 ESP 15-30	2
		Strong	PH 8.5-9.0 ESP 30 - 50	3
		Severe	PH >9.0 ESP >50	4

Appendix 1.3 - Extent of soil degradation

Class	Description	Symbol
Common	Affected area 5-10%	1
Very Common	Affected area 10-25%	2
Frequent	Affected area 25-50%	3
Dominant	Affected area >50%	4

Appendix 1.4 - Classes of Degradation Rate

Degradation rate-class	Degradation rate's name
-3	Rapidly increasing degradation
-2	Moderately increasing degradation
-1	Slowly increasing degradation
0	No change in degradation
1	Slowly decreasing degradation
2	Moderately decreasing degradation
3	Rapidly decreasing degradation

Appendix 1.5 - Classes of Degradation Cause

Degrad. Cause class	Degradation Cause name
a	Agricultural activities
e	Over-exploitation of vegetation for domestic use
f	Deforestation and removal of natural vegetation
l	Industrial activities
n	Natural causes
o	Overgrazing

Appendix 1.6 - Major landscape classes (Landforms) and % slope range

Symbol	Class	Landscape description	% Slope
I.	Active river flood plain	Level to nearly level seasonally flooded area	0.0-1.0
II.	Recent alluvial plain	Undulating moderately sloping	5-10
III.	Old alluvial plain	Very gently sloping	1.0-3.0

Appen. 1.7 Major Land Use Classes

Land Use Class	Remarks	Symbol
Agriculture	All types of agriculture excepting orchards/fruit crops, plantation etc.	A
Forest	All types of forest i.e. P.F., R.F. and other forests shown on Toposheet.	F
Plantation	All types of plantation crops, fruit drops, tea, coffee, rubber, orchards etc.	P
Others (including open scrub, Pastures, etc.	All other lands under scrub	O
Habitations	Cities, Villages etc.	H
Water bodies	Ponds....etc	WB

Appendix II

Ground truth verification, Using GPS, FCC and Toposheet

Sl.	No. of	Suggested profile	Coordinates	Ground features, Remarks
1.	1		270 38/ 20.9// 770 33/ 24.0//	Akbarpur, 196, railway-road crossing
2.	2		270 38/ 1.5// 770 33/ 7.5//	Salt encrustation
3.	3		270 37/ 44.5// 770 33/ 0.9//	Ploughed soil with gray assay color
4.	4		270 36/ 47.8// 770 32/ 20.9//	Microwave station, sugarcane, saline water
5.	5		270 32/ 32.7// 770 32/ 41.4//	Barauta ka Nagla, Sugarcane
6.		P1	270 36/ 04.6// 770 32/ 47.3//	Ploughed before cultivation
7.		P2	270 34/ 37.9// 770 32/ 57//	Salt encrustation, left hand side
8.		P3	270 34/ 10.9// 770 32/ 15.2//	Right hand side- salt encrustation Left hand side - rice field, waterlogging
9.		P4	270 34/ 35.7// 770 31/ 42.4//	Waste land (RHS)
10.		P5	270 37/ 34.4// 770 38/ 20.6//	Saline, Degraded land, LH of road
11.		P6	270 37/ 34.4// 770 38/ 20.6//	River side, ½ km to Sakraya
12.		P7	270 35/ 58.7// 770 39/ 20.9//	Plantation area
13.	6		270 35/ 30.9// 770 32/ 55.3//	Water body surrounding by shrubs
14.	7		270 34/ 39.4// 770 33/ 18.4//	Canal, road crossing
15.	8		270 33/ 43.6// 770 33/ 41.1//	Ral drain, road crossing

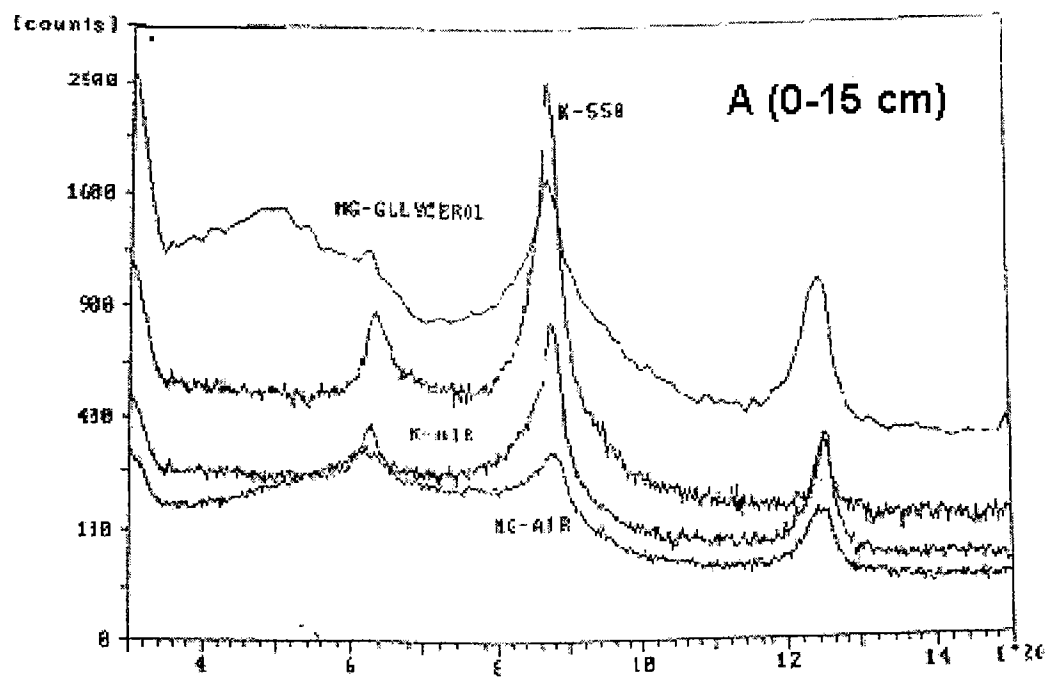
Sl.	No. of	Suggested profile	Coordinates	Ground features, Remarks
16.	9		270 33/ 33.4// 770 33/ 36.5//	Ral village
17.	10		270 33/ 50.4// 770 32/ 43.9//	Water body before Bhadal, (RHS)
18.	11a		270 33/ 00.2// 770 32/ 30.1//	Canal and road crossing after Bhadal, Paddy field (RHS)
19.	11b	P8	270 34/ 06.8// 770 22/ 22.2//	Paddy field
20	11c		270 34/ 10.9// 770 32/ 15.3//	Paddy field, water logging.
21	11d	P9	270 34/ 38.9// 770 31/ 43.2//	Waterlogging
22	12		270 34/ 38.5// 770 31/ 44.8//	Road to Kaunhi
23	13		270 35/ 05.7// 770 30/ 56.7//	Water body near Pelkhu village, No drinking water (saline water)
24	14		270 34/ 00.6// 770 38/ 26.9//	Kaunhi canal + road crossing Paddy LH, Barren RH
25	15		270 33/ 32.9// 770 30/ 32.4//	RHS saline encrustation with sugarcane from Pelkhu. to Kaunhi.
26	15a		270 33/ 20.5// 770 30/ 49.3//	Kaunhi village (Arhar, Sugarcane, Babool)
27	16		270 32/ 58.1// 770 31/ 21.1//	Open scrub (LH). Barren land (RH)
28	17	P10	270 32/ 43.7// 770 31/ 24.5//	Salt encrustation
29	17a		270 33/ 15.0// 770 33/ 17.9//	Sugarcane
30	19		270 33/ 17.9// 770 33/ 31.1//	Canal to Ral
31	20		270 33/ 19.4// 770 34/ 30.5//	Ral drain- main road cross. LH sugarcane
32	21		270 33/ 28.1// 770 38/ 57.2//	Road crossing, Ral

Sl.	No. of	Suggested profile	Coordinates	Ground features, Remarks
33	22		270 33/ 29.3// 770 37/ 20.01//	Railway-road crossing. Chatta
34	25		270 35/ 51.3// 770 37/ 49.8//	Road crossing.
35	26		270 36/ 18.7// 770 38/ 22.3//	Devi atas, Pond water LH
36	27a		270 37/ 6.3// 770 38/ 13.0//	Kosi atas, artificial drain and road cross
37	27b	P11	270 37/ 34.4// 770 38/ 20.6//	Jute crop, near Devi Atas village towards Sakraya.
38	28		270 37/ 34.4// 770 38/ 20.6//	Cross road
39	29	P12	270 37/ 34.4// 770 38/ 20.6//	S8
40	30		270 36/ 45.4// 770 39/ 30.5//	Bari Atas S10

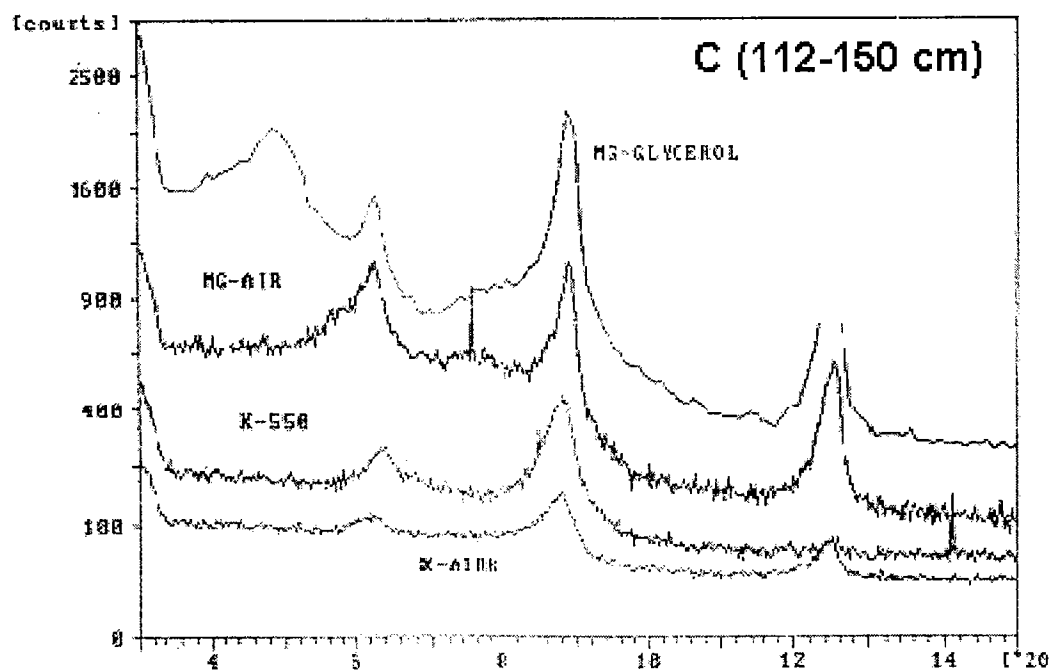
Characters	OC	pH	EC	CaCO ₃	Fe ₂ O ₃	Sand	Silt	Clay	CEC	Ca	Mg	Na
K	0.4742**	-0.4581**	0.2969*	-0.1235	0.0181	-0.4924**	0.4556**	0.4179**	0.2659	0.1546	0.3796**	0.0641
BS	0.1865	-0.1281	-0.0649	-0.3380*	-0.1991	0.2058	-0.1940	-0.1802	-0.2155	0.0337	0.0740	0.0055
ESP	-0.1367	0.4161**	-0.1717	0.1786	-0.1830	0.0664	-0.0853	-0.0500	-0.1060	-0.3529*	-0.1011	0.7266**
N	0.7160**	-0.3389*	-0.1175	-0.4565**	-0.0415	-0.2169	0.1137	0.2468	0.2470	0.1295	0.3580*	0.1180
P2O5	0.4416**	-0.2994*	0.1369	-0.1886	0.0355	-0.1753	0.2623	0.0812	0.0477	0.0090	0.2211	-0.0292
K2O	0.4740**	-0.4616**	0.2977*	-0.1203	0.0196	-0.4971**	0.4618**	0.4200**	0.2703	0.1574	0.3826**	0.0656
Fe	0.5671**	-0.4205**	-0.1557	-0.3440*	0.2602	-0.4195**	0.4199**	0.3166*	0.3205*	0.1658	0.3826**	0.0656
Mn	0.4654**	-0.4342**	-0.2529	-0.4425**	0.3701**	-0.4470**	0.2356	0.5040**	0.4662**	0.1915	0.5399**	0.3254**
Zn	0.4244**	-0.3370*	0.0873	-0.1130	0.0456	-0.4470**	0.2460	0.3615*	0.3066**	0.2813	0.3320*	0.0496
Cu	0.6171**	-0.4243**	-0.0378	-0.2822**	0.1106	-0.4170**	0.3549*	0.3903**	0.3461*	0.2957*	0.4375**	0.0384
AWC	0.1284	-0.0481	0.2447	0.4810**	0.2660	-0.4988**	0.7060**	0.1927	0.1593	0.0233	0.0923	0.1278
Bulk	0.0315	-0.0437	-0.2407	-0.2899*	-0.2096	0.1663	-0.3094*	-0.0541	-0.1202	-0.1739	-0.0645	-0.0308

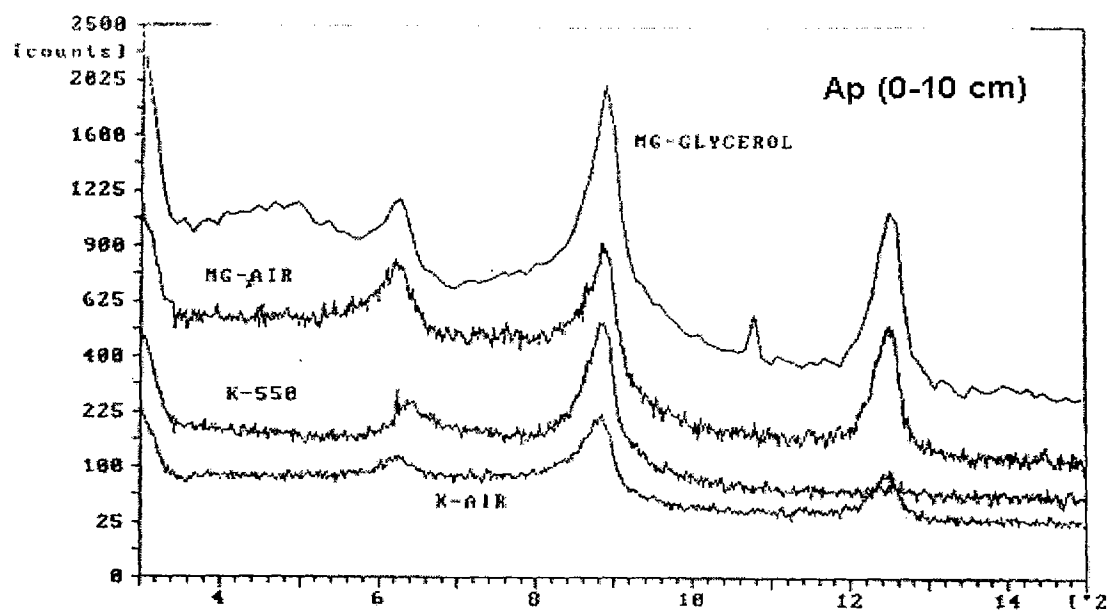
Appendix III Contd.

[illegible]

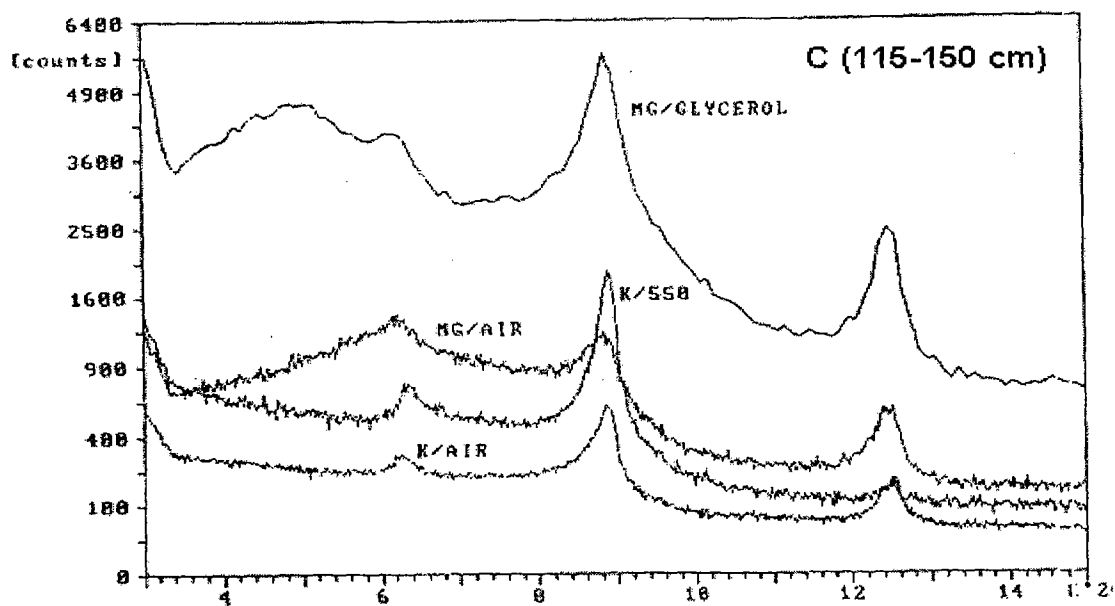


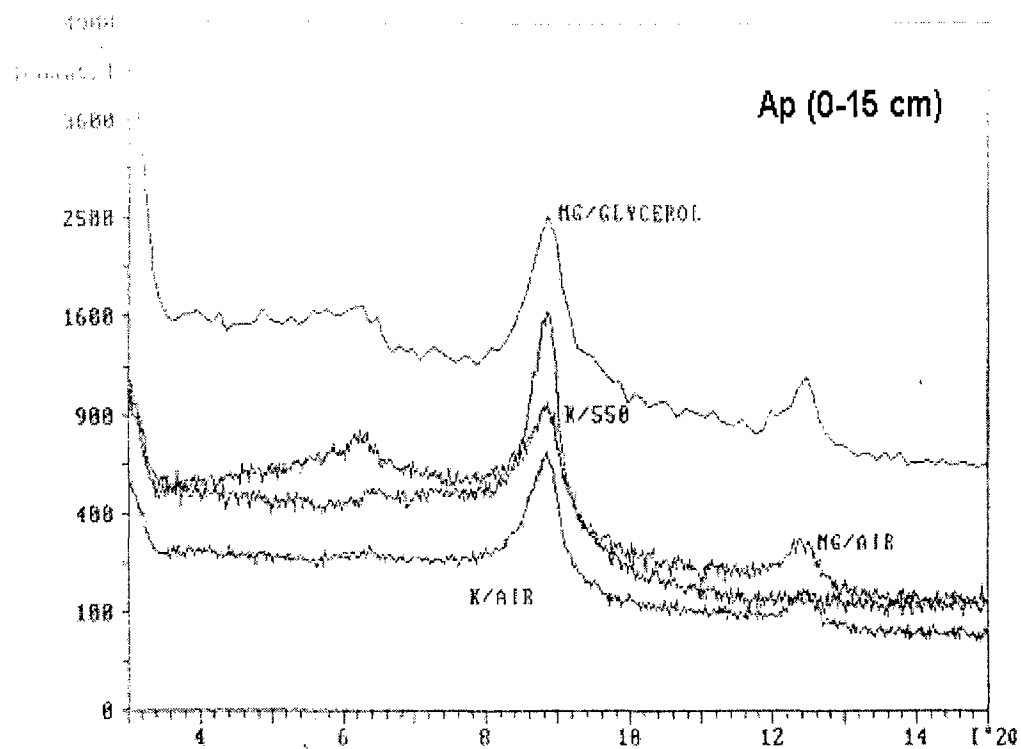
App. 4.1 X-ray diffractogram of Gonda Atas series



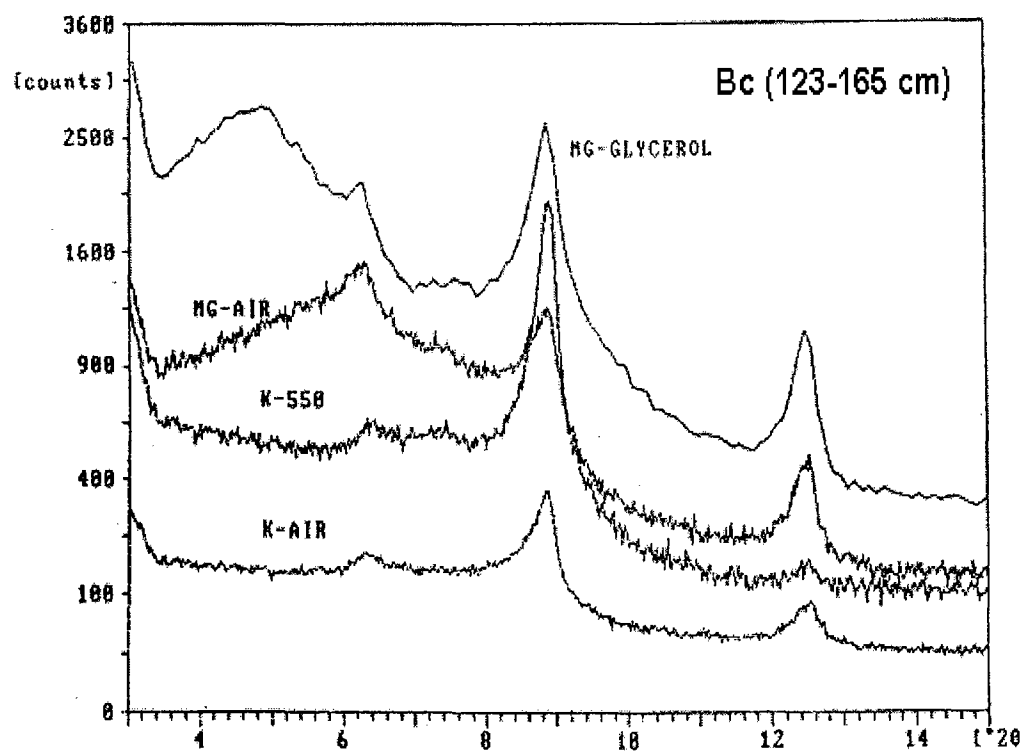


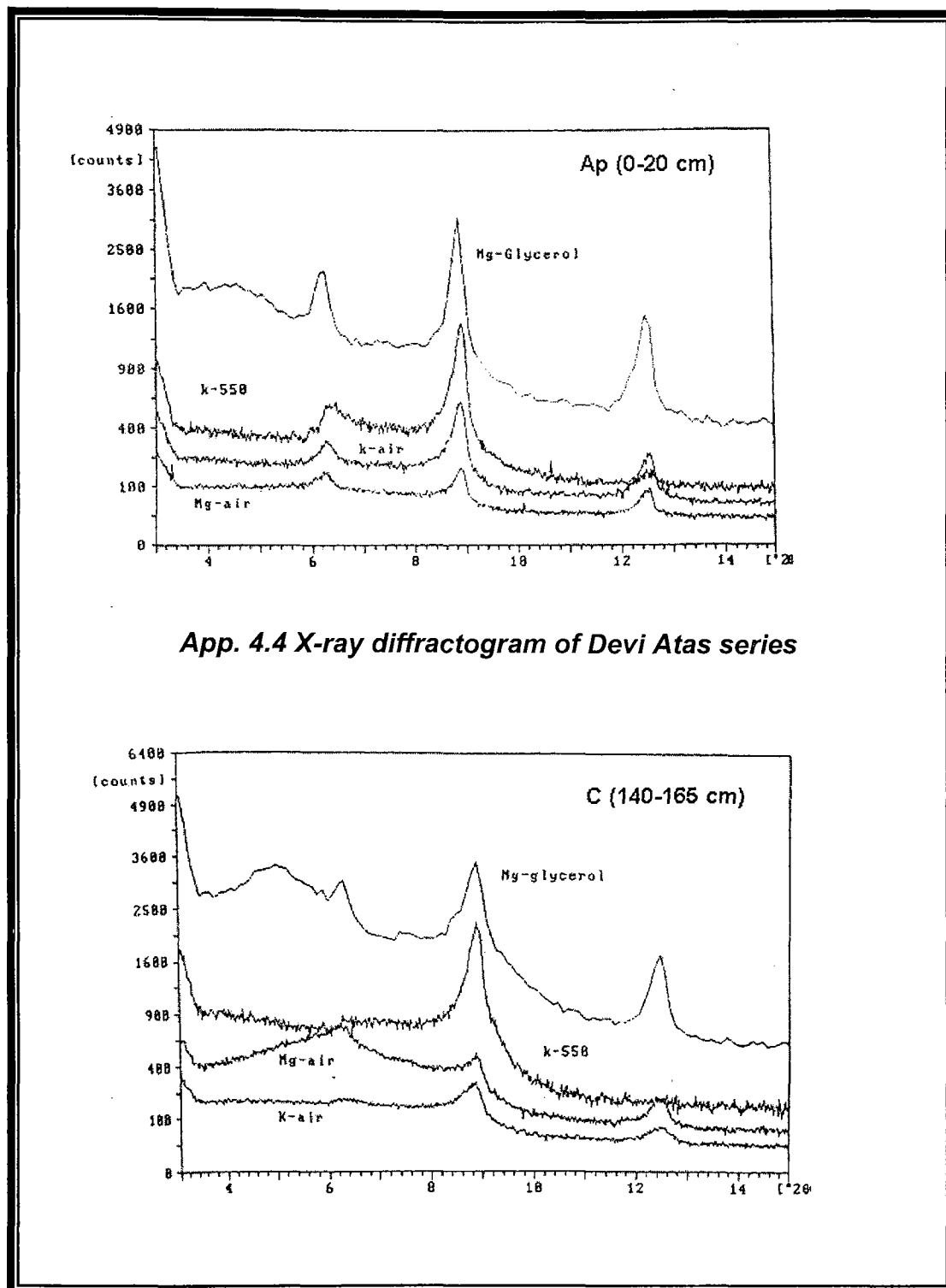
App. 4.2 X-ray diffractogram of Kiki Nagla series



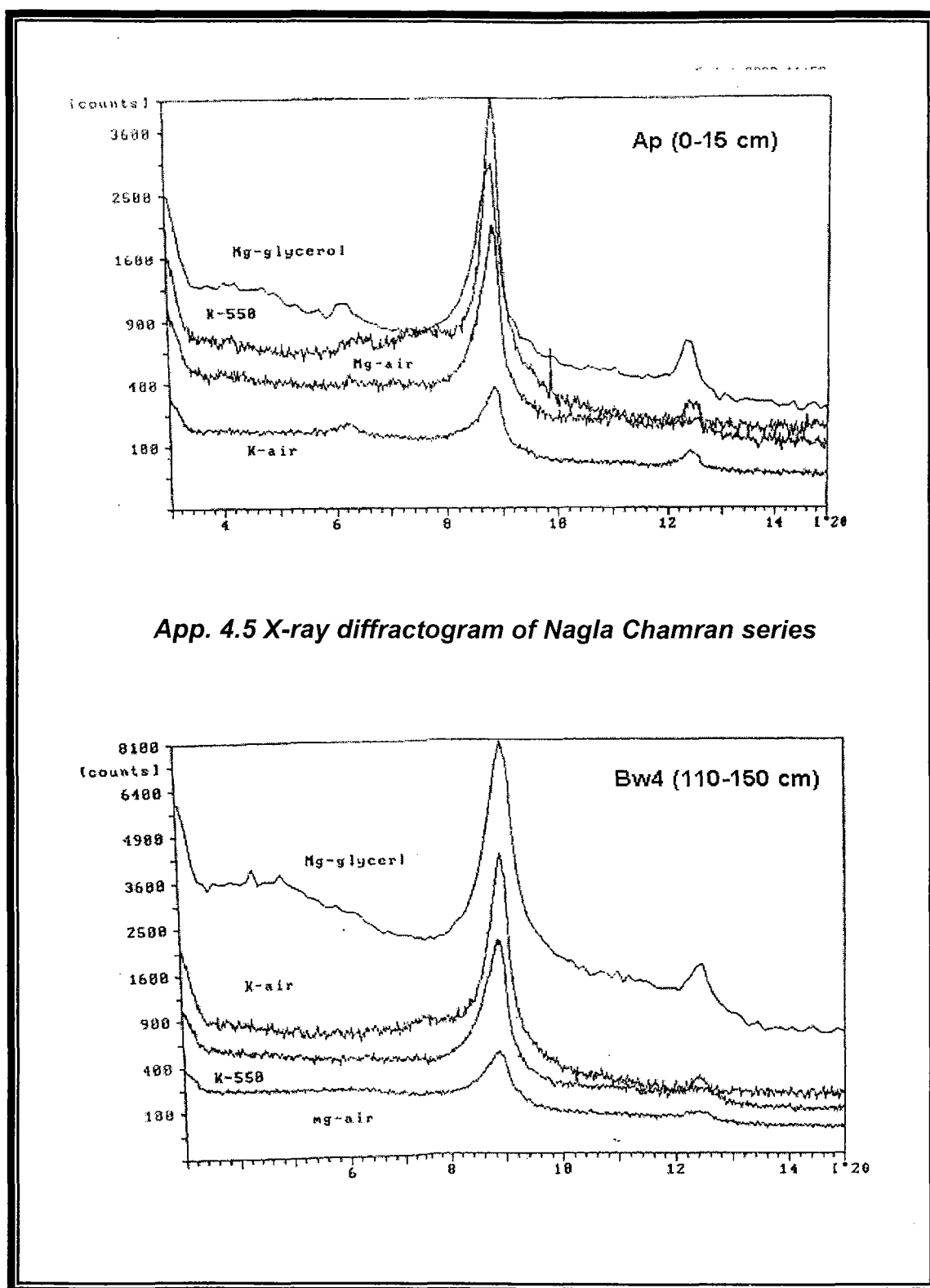


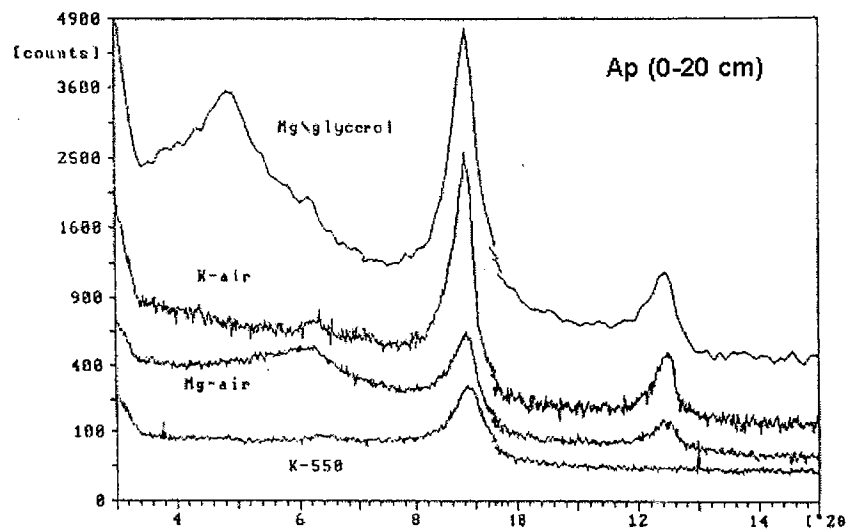
App. 4.3 X-ray diffractogram of Nagla Ramtal series



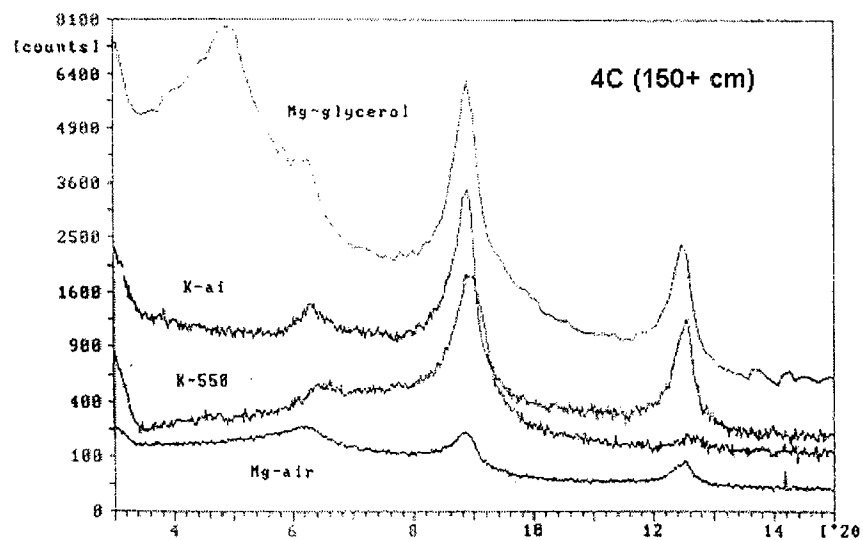


App. 4.4 X-ray diffractogram of Devi Atas series

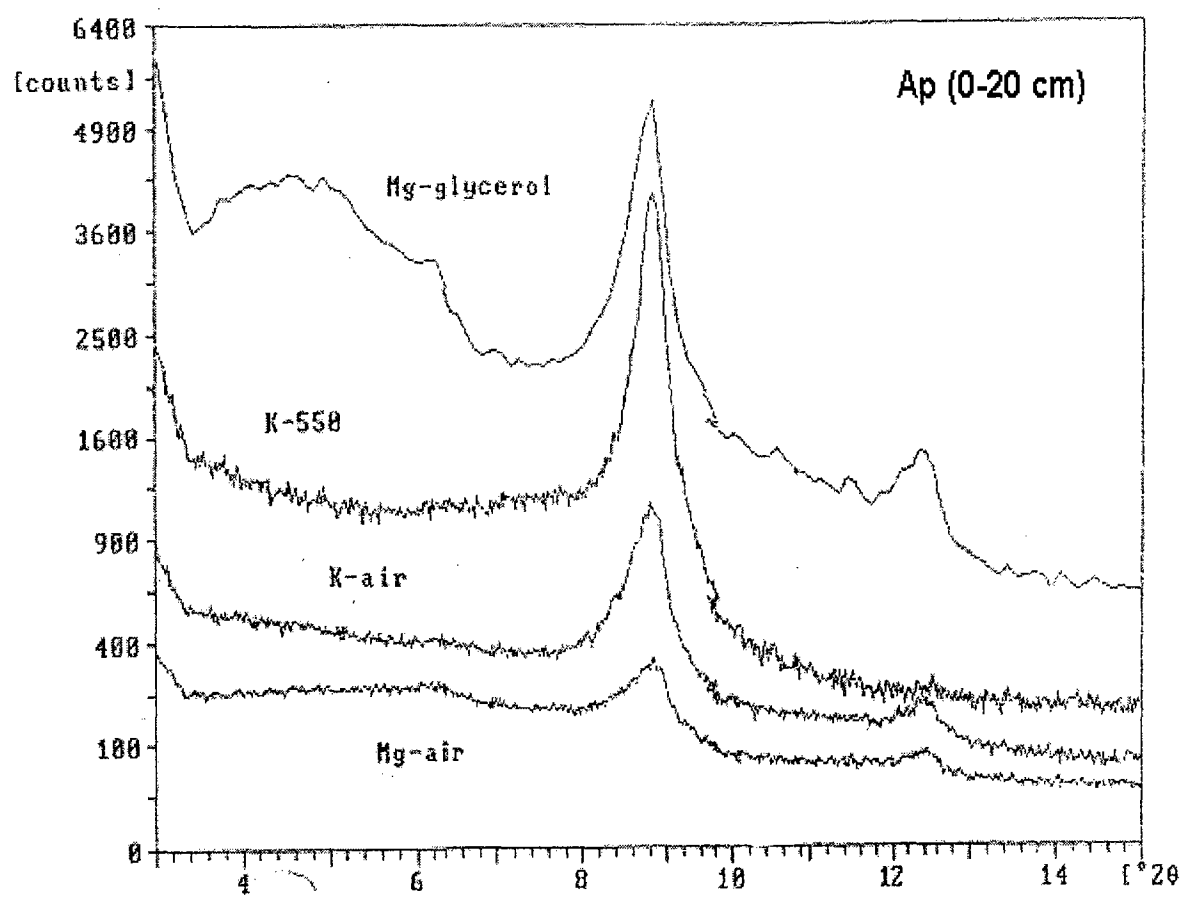


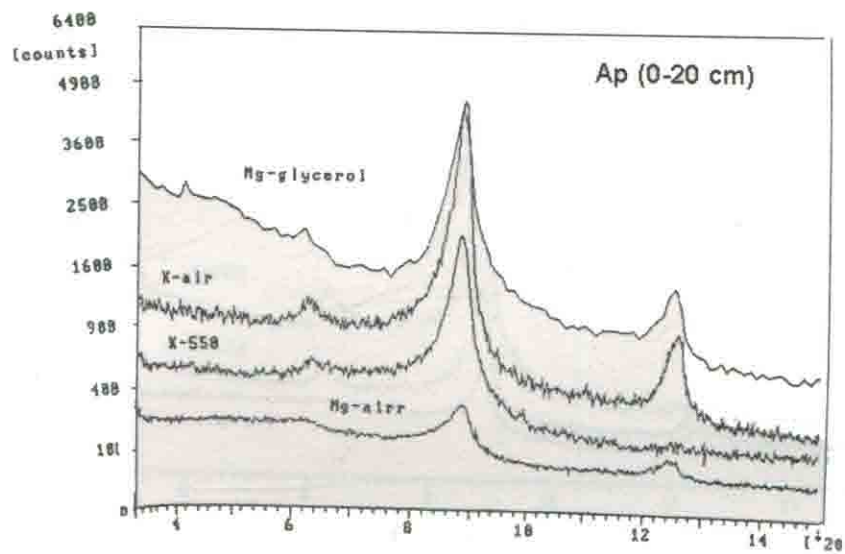


App. 4.6 X-ray diffractogram of Sakraya series

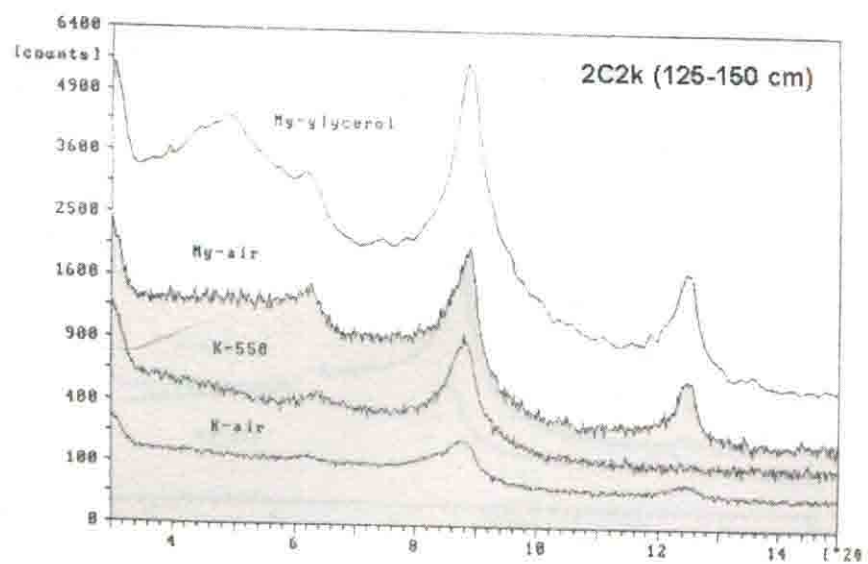


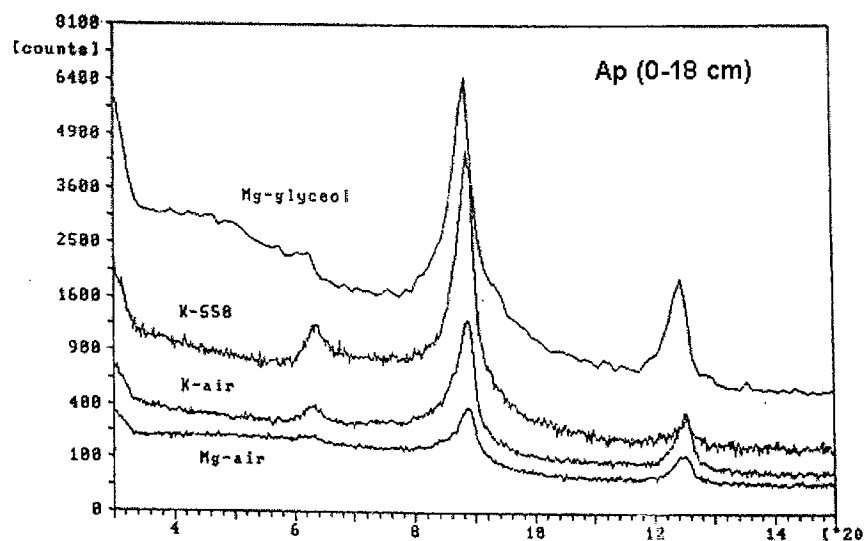
App. 4.7 X-ray diffractogram of Maghera series



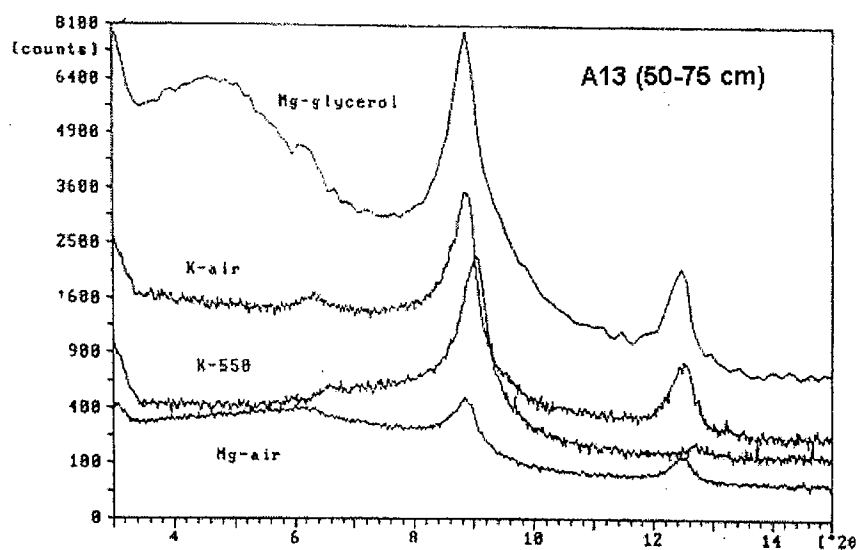


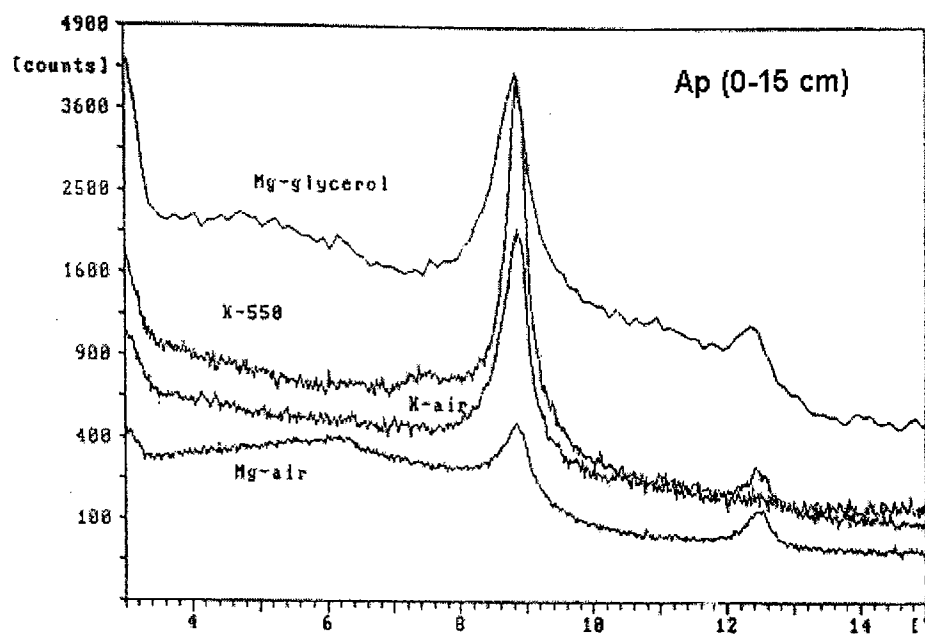
App. 4.9 X-ray diffractogram of Nagla Hemraj series



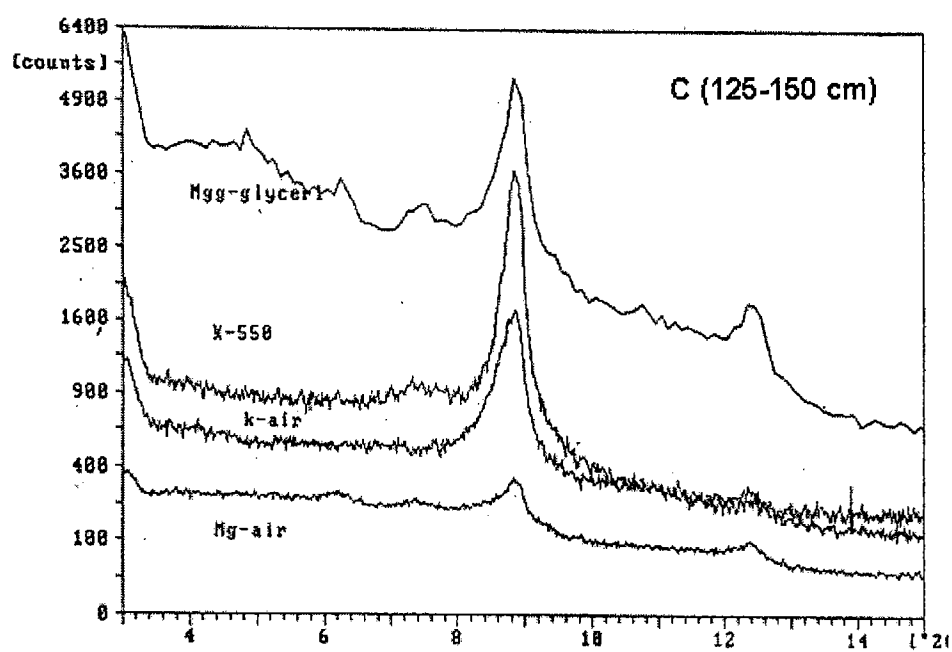


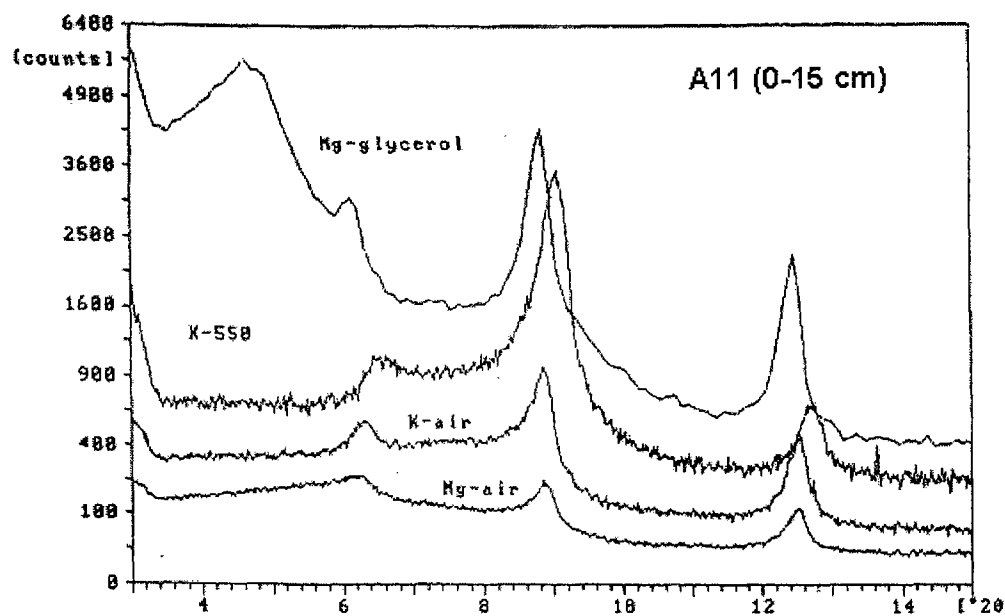
App. 4.11 X-ray diffractogram of Bhadal series



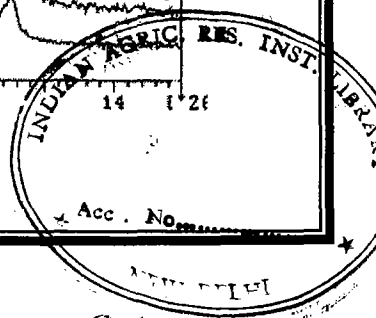
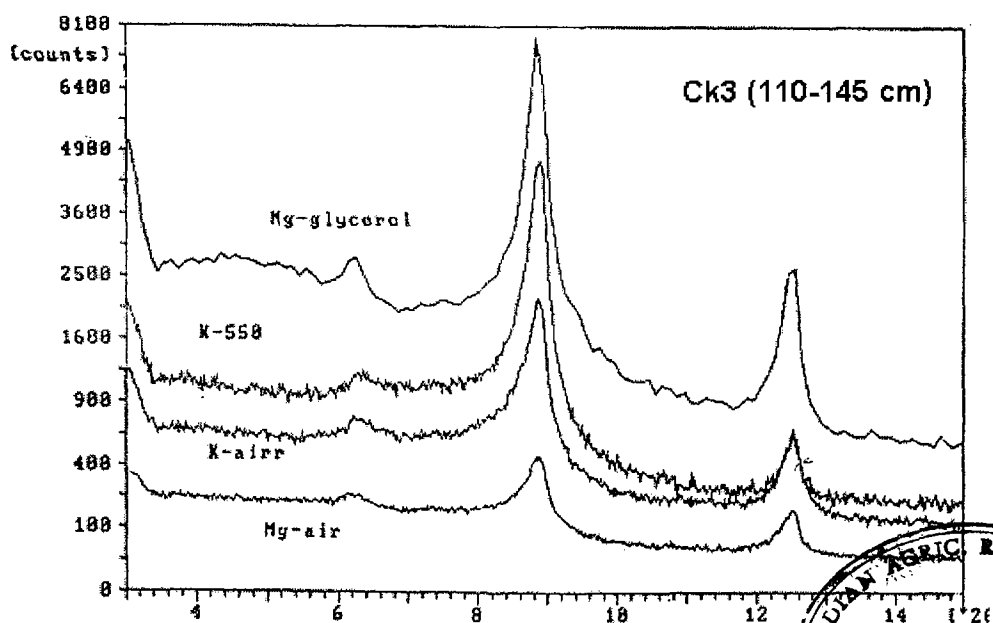


App. 4.10 X-ray diffractogram of Ral series





App. 4.12 X-ray diffractogram of Barauta series



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