SYNERGISTIC LAND USE STUDY IN PIEDMONT ZONE BETWEEN GANGA-YAMUNA, RIVERS, INDIA

A THESIS

Submitted in fulfilment of the requirements for the award of the degree

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DOCTOR OF PHILOSOPHY

in

EARTH SCIENCES

By

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the thesis, entitled "**Synergistic Land Use In Piedmont Zone Between Ganga-Yamuna, Rivers, India** " in fulfillment of requirement for the award of the degree of Doctor of Philosophy and submitted in the Department of Earth Sciences, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during a period from February 1998 to July 2003 under the supervision of **Dr. A. K. Awasthi, Professor**, Department of Earth Sciences, Indian Institute of Technology, Roorkee and **Dr. Sri Niwas Pandey, Professor**, Department of Earth Sciences, Indian Institute of Technology, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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(Om Prakash Dubey)

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SYNOPSIS

On the southern foot of the Himalayas, lies a very prominent east west running geomorphic feature, commonly known as Piedmont. Sediments in this zone range from boulders to sand, silt with little clays. The rugged topography, fragile ecological set up, gravelly soil has discouraged human settlements in this terrain which has poor connectivity to the neighboring areas. Nevertheless, with increase in population this region has attracted the local populace for their needs of food, fodder and fire wood. Accordingly the area is being used, wherever inhabited, without proper planning in unscientific manner. Therefore, there is a need to evaluate this geomorphic unit for better use of this land in environment friendly way. Thus a part of the piedmont lying between rivers the Ganga and the Yamuna covering an area of about 2000 km sq. has been taken up for investigation as a model study of development of these areas for agricultural land use.

Preliminary field investigations indicated that the land use in the area is influenced by the land elevation, land slope, drainage, rainfall, temperature, soil type, erosion, surface and groundwater. In this study these parameters have been evaluated through synergistic use of remotely sensed data, field investigations, laboratory studies and analysis of existing data.

GEOMORPHIC FEATURES

Based on satellite images, IRS _ LISS II, False Colored Composite (FCC), and Topographic Maps at 1:250,000 and 1:50000 scales along with field surveys the area was classified in to four major geomorphic units, namely, the northern most, Upper Regime Piedmont (UP), Middle Regime Piedmont (MP), to the south the Inter Channel Plainer Area (IC), and Channel Braid Bars(CB).

The northern most geomorphic unit (UP) which is in direct contact with the exposed Himalayan hill slope is characterized by undulating topography, with average elevation more than 350 m above mean sea level (m s l) and ground slope of more than 3^0 (5.3%). South of UP geomorphic unit, where ground elevation ranges between 300 m and 350 m above m s l, ground slope between 2^0 (3.5%) and 3^0 (5.3%) has been designated as MP geomorphic unit. The southern most unit that is characterized by near flat, non undulated topography, slope less than 2^0 (3.5%), ground elevation between 250 m and 300 m above msl has been designated as Inter Channel Plainer Area (IC) unit. The fourth unit is designated as Channel Braid Bars (CB). The geographical area of UP, MP, IC, and CB geomorphic units are about 17.4%, 12.6%, 63.4% and 6.6% of the total (about 2000 sq. km) area. The Inter Channel Plainer Area (IC) unit is further subdivided in to three subunits namely:

(i): I_1: characterized by frequent flooding;

(ii): I_2: experiences occasional flooding; and,

(iii): I_3: is relatively free from flooding

Geographical areas of these subunits are 19.6%, 14.4%, and 29.4% totaling to 63.4% of the total study area (about 2000 sq km)

SOIL CHARACTERISTICS

In order to assess the soil characteristics of the area, 250 soil samples collected from various geomorphic units, were analyzed to determine the soil texture , mineralogical composition , salinity , alkalinity , hydraulic conductivity and hydrologic soil classification.

Field investigations indicate that the UP geomorphic unit is characterized mainly by coarse gravely sediments _ gravels (boulders, cobbles, pebbles, granules), and coarse sand. The MP geomorphic unit contains mainly gravely sands _ finer gravels with occasional cobbles, pebbles, granules, rich in coarse grained to medium grained sand, silts and clays. Grain size analysis of sandy components of the UP geomorphic units indicates that d_{50} of the component which is about 50 cm thick is more than 1.0 mm. The sandy component of the MP soil is about 15cm to25 cm thick and d_{50} is 1.0 mm to 0.5 mm. The soils in the IC geomorphic unit is characterized by relatively finer sediments, mainly sand, silt and clays, d_{50} of the soil is less than 0.025 mm. Soil thickness is more than 25 cm. d_{50} of soils in the channel braid bars (CB) is varying between 1.0 mm and 0.025 mm.

Petrographic investigations, indicate that the boulders, cobbles, pebbles and sand are of heterogeneous nature with various types of rocks mainly quartzite with small amount of sand stone, phyllites and limestone. The sand and silt are made up of mainly quartz with mica and feldspar. X – Ray investigations indicate that the clay minerals are mainly Kaolinite, Illite with some Vermicullite and montmorillonite. From mineralogical considerations the soils can support a variety of crops.

Electrical conductivity of the soil samples indicates that, the electrical conductivity of the UP geomorphic unit soils is about 0.04 dsm^{-1}, in the MP geomorphic unit it is 0.20 dsm^{-1} and in IC unit it is 0.25 dsm^{-1}. The $_pH$ value of the soils in the UP is 7.8, in the MP it is 7.7 and in the IC unit it is 7.1. These values indicate that electrical conductivity is showing an increasing trend from north to south, whereas, $_pH$ is showing a reverse trend as it is decreasing from north towards south. Spatial variation of electrical conductivity and $_pH$ indicate that the soil in the area is neither saline nor alkaline.

Hydraulic conductivity of the soil samples determined by falling head method indicates that in the UP geomorphic unit it is 80 cm/hr while in the MP geomorphic unit it is 70 cm/hr and in the IC geomorphic unit it is 20 cm/hr. Field measurement of infiltration capacity indicates that in the UP geomorphic unit it is 16 cm/hr. In the MP geomorphic unit it is 12 cm/hr and in the IC geomorphic unit it is 2 cm/hr. From the spatial variation of hydraulic conductivity and infiltration capacity it is inferred that both hydraulic conductivity and infiltration capacity is showing an increasing trend from north towards south. From soil investigations it is inferred that soils in the north are coarse grained, highly permeable and highly aerated as compared to the soils in south. Further soils in the north are difficult to work with. Such a soil can support a variety of crops.

WATER RESOURCES

The area is bounded by two perennial rivers the Ganga and the Yamuna. In between these two rivers, the area is traversed by a number of seasonal streams namely, Hindon, Solani and Ratmau etc, which forms the tributaries of these two rivers. Besides these the area has three canal systems, namely, Upper Ganga Canal, Eastern Yamuna Canal and Khara Canal. Except in the area close to canals and streams groundwater is the major source of water.

Groundwater Resources

Based on the ground water level measured during the period 1984 -2001 it is found that in the UP geomorphic unit the depth of the groundwater table is about 33m below ground level (bgl) and fluctuation in this unit is about 2.8 m bgl. In the MP geomorphic unit it is about 20 m bgl and fluctuation is about 2.0 m. In the IC unit the depth of the water table is about 5 m bgl and fluctuation is about 1.5. The chemical analysis of water indicates that it is fresh and useable for domestic and agricultural purposes.

The groundwater resource in the area was estimated using Groundwater Estimation Committee (GEC, 1997, Govt. of India) norms. The study indicated that the major source of the groundwater in the area is rainfall recharge; canal seepage and irrigation return flow. About 85% of the rainfall occurs during June and September. On annual basis rainfall recharge in the area is about 33%, whereas GEC recommended norm is 20% to 25% and computed by empirical relation is about 10%. Hence, empirical formula (Chaturvedi , 1947) was modified as :

$$R_r = a\,(R - b)^{0.5}$$

Where R_r is rainfall recharge, R is rainfall, and a & b are constants. The numerical values of these constants were determined in least square sense. Based on 1984 -1995 data, numerical value of the constants was worked out to be 4.0 for UP and MP geomorphic unit; it is 3.3 for sub geomorphic units I_1 & I_2; whereas for sub geomorphic units I_3 & CB it was found to be 3.2.

The numerical value of the constants b was worked out to be 25 for UP geomorphic unit, 30 for MP geomorphic unit, 35 for I_1 & I_2 geomorphic sub unit, 38 for I_3 and CB geomorphic sub unit. After this modification efficiency of the prediction was found to be about 82%

In order to determine the period when the rainfall recharge is available for pumping, cross correlation studies between rainfall and depth of groundwater table were carried out. It is observed that the coefficient of correlation is showing an increasing trend with time and after achieving a maximum value it starts decreasing.

In the UP geomorphic unit, rainfall takes minimum time (10 - 20 days) to recharge the groundwater. In the MP geomorphic unit it is 20 days, whereas in the IC geomorphic unit it takes about 40 to 50 days to recharge the groundwater. Such studies have further indicated that in the UP and MP geomorphic unit the recharged water is available for about 20 to 40 days, whereas in the IC geomorphic unit it is available for longer duration, about 8 months in the shallow regimes.

It was found that, in spatial domain, the rainfall recharge is influenced by land cover in addition to amount of rainfall. Hence, a simple model, **G = AP**, where G is a column vector as rainfall recharges per unit rainfall; A is land cover system operator matrix and P is the rate of rainfall recharge. Land cover input to the model was determined from analysis of IRS LISS II; FCC .The model was calibrated and tested. Model efficiency was found to be about 85%.

Surface Water Resources

Surface water resources were estimated using the Soil Conservation Society (SCS) model. The model was found to yield values of stream flow which is about 35% higher than the observed values. Thus, the SCS model was modified for this area and is presented below.

$Q = (P - 0.3\ S)^2 / P + 0.7\ S;$

Where Q is stream flow in mm, P is rainfall in mm, and S is defined by following relation.

$S = (25400/CN) - 254$

Where, CN is popularly known as Curve Number, a constant which depends upon land cover soil complex of the area.

In the study the numerical value of the curve number, CN, for different land cover _ soil complex was determined in the Least Square Sense. After these modifications the model was found to be yield results with in ± 15% error.

Keeping in view the fact that the piedmont area is poorly monitored and studied for the estimation of stream flow a simple model using only two parameter, namely the rainfall and land cover was developed. The model is, q = AC, where q is stream flow vector per unit rainfall, A is land cover system operator matrix and C is run off coefficient vector for different land cover. System operator matrix, A, was extracted from the analysis of IRS LISS II, FCC. The model was calibrated and tested. The efficacy of this model was found that the model yields results with in ± 15 %.

Available Water Resources

As mentioned earlier except rivers Ganga and Yamuna streams are flashy in nature. Field investigations indicated that stream flow in the flashy river is available for short duration, less than a day or two and hence the direct use of stream flow for agricultural purposes is very limited. Further groundwater is the only dependable source of water for irrigation. The study indicated that on an average about 270 x 10^2 ha m recharged water is available annually. Water availability in the UP and MP geomorphic unit is much lower as compared to the IC geomorphic unit. Further conjunctive use of surface and groundwater is essential for growing a variety of crops.

OPTIMAL LAND USE

In the area more than 80% of the land is used for agricultural use. Field surveys indicate that wheat, sugarcane, paddy, maize and masoor are the main crops grown in the area. At existing land use, total food production (288270 T/year) is found to be more than the local demand (147278 T/year);whereas the total fodder production is (1472072 T/year) is less than the local demand (1500000 T/year). The total fire wood production is (52781 T/year) which is less than the demand (91250 T/year).

Thus, the total food grain production is not only sufficient for the local demand but is a source of income. On the other hand the fodder and fire wood production is less than the local demand, thereby leading to encroachment over forest land resulting into continual environmental degradation. Thus, there is a need for optimal use of land aiming at fulfilling the local needs of food grain, fodder, fire wood and improving economic conditions along with maintaining the environmental balance.

In view of above Linear Programming (LP) approach was made to allocate land for different uses. Input to the LP model was determined through field surveys and investigations of different geomorphic features. Based on this approach the food grain production can be increased to four times. The current deficit in fodder and fuel wood production can be made over. This will help in improving the economic condition of the villagers and maintaining the environmental balance

Crop Suitability Vis-à-vis Geomorphic Unit

With a view to develop a simple methodology for crop suitability assessment detailed field investigations were carried out. It was found that crop yield varies from one geomorphic unit to another. To study the spatial variation in crop yield, concept of Bench Mark Unit - a unit having highest yield of a particular crop, and a Productivity Index (PI) - ratio of crop field from an investigation area to the Bench Mark Land Unit was introduced. It was found that the PI for the area is low (0.46 to 0.82). PI for UP and MP geomorphic units are low as compared to IC geomorphic units. PI for maize, groundnut and urd crop is relatively higher (0.76) in the UP and MP geomorphic units. PI for wheat, sugarcane and paddy is higher (0.70) in the I_1 and I_2 subunits. For all the crops in the I_3 subunits, PI remains more or less close to 0.60 to 0.68. In the CB units, PI is lowest (0.46 to 0.56) for each crop and may come down to zero if affected by flood erosion.

Correlation study between terrain parameters and PI indicate that terrain parameters are highly related (coefficient of correlation, $\rho = 0.87$ to 1.00). Land slope is negatively related with soil thickness ($\rho = -0.87$). It is directly related with soil texture, d_{50} ($\rho =$ 0.997. It is is directly related with depth of groundwater table ($\rho = 0.992$). It is inversely related with productivity index ($\rho = -0.958$). This indicates that terrain characteristics control the intensity of agriculture. Each geomorphic unit has its own terrain characteristics. The impact of simultaneous affect of terrain characteristics on crop yield has been assessed through multivariate approach - the Principle Component Analysis (PCA).

PCA indicated that the first largest eigen value is 4.79.The second largest eigen value is 0.2 and other eigen values are negligible and hence ignored. The first principal component corresponding to the largest eigen value which accounts for about 99 % variation in the data is heavily loaded (0.961 to 0.992). In view of multivariate relationship of Productivity Index (PI) with terrain characteristics, namely, land slope (L_s), soil thickness (S_t), grain size (d_{50}), depth of the groundwater table (d_w) taking in to account the first principal component has been worked out as:

$$PI = 0.6213 - 0.000979\ L_s + .000961\ S_t - .000985\ d_{50} - .0000992\ d_w$$

This relationship can be utilized to assess the crop PI, for various geomorphic units which may help in use of a given terrain for a crop.

Use of land for various crops vis _ a _ vis geomorphic units has been presented in the form of a map. It is inferred that the northern geomorphic units, namely, the upper and middle regime piedmonts are more suitable for maize, groundnut and urd (a variety of pulse) crops. However, wheat, sugarcane and paddy are the most suitable crops in the plainer areas, namely, I_1 and I_2 which are close to streams. In the geomorphic units I_3 and the channel braid bars (CB), any crop can be grown but with risk of crop damage due to stream erosion especially during rainy season. It is expected that if piedmont land is used as suggested above it will enhance the food production by four times and make up the fodder and fire wood demand, which will help in improving the economic condition of the populace and development in environmental friendly way.

1

INTRODUCTION

1.0 Background

Availability of per capita land in India is decreasing gradually from 0.90 hectare in 1951 to 0.50 hectare in 1980, to 0.17 hectare in 1990. Prognostic modeling revealed that by 2020 it would become 0.09 hectare i.e. a square plot of 90-m size (Biswas, et.al., 1985; Narayanan, 1986; 1996; Planning Commission, 1989; Sehgal et.al, 1996; Dubey, 1997; Khanna et.al., 1998; Abdul Kalam et. al. 2002; Joshi, 2003). This is very grim situation and, calls for looking out additional land, which is not in optimal use currently. These studies have indicated that till eighteenth century people were living close to highly cultivable and useful land and were able to fulfill their agricultural, domestic, industrial and other needs. However, with increasing population in recent years demand for land is increasing at a faster rate in order to fulfill the requirements leading to prosperous life style.

In India about 50 million hectare area may be classified as Piedmont province (Bhumbla et.al., 1986; Reddy, 2003). Earlier this area was considered inhospitable and difficult to work on due to its geographical location, physiographic characteristics, climatic conditions and hydrological constraints, such as, frequent floods, droughts, undulating rough terrain and lack of infrastructure. Up to middle of nineteenth century in general piedmont areas were virgin and in natural state of balance. The population pressure on piedmont has been increasing at a progressively faster rate with remarkable changes in land use and land cover. Human interventions with an objective to get maximum return from these lands have increased the ecological problems.

Thus the piedmont areas are put to stresses in order to meet the demand of the growing population. Until recently there has been a general lack of economic development in these areas. The current and anticipated rate of industrial, economic and agricultural developments of these landforms demands an optimal use of land so as to minimize the losses and maximize the gains on sustained basis (French, 1993; Dubey, 1997). In the absence of a balanced land use policy unplanned development are taking place in these areas spurting the environmental degradation. Therefore, there is a need to manage and conserve natural resources base with adoption of appropriate technology in such a way that the activities are environmental friendly, technically feasible, economically viable, and socially acceptable (TAC 1988).

Keeping this in mind the present study has been carried out in the piedmont zone between the rivers Ganga and Yamuna with an objective to work out a model for development based on available resources.

1.1 Study Area

The salient features of the study area are being described below.

1.1.1 Location

Covering about 2000 km^2, Ganga Yamuna Piedmont lies in the parts of districts Hardwar (Uttranchal State) and Saharanpur (Uttar Pradesh state), India. The area is bounded between the latitudes, 29 ^{0} 50' north to 30 ^{0} 20' north, and longitude 77 ^{0} 15' east to 78 ^{0} 15' east. It is a part of the area lying at the foot of the east- west running Siwalik hill range between the two holy rivers the Ganga in the east and the Yamuna in the west (Fig. 1.1).

Roorkee and Hardwar are important towns in the area. The width of this area varies from 5 km to 30 km. The foothill zone ranges up to an elevation of about 450 m above mean sea level (m s l) with a southerly slope. The piedmont zone has an elevation of about 400-m above m s l in the north, and about 250 m above m s l in the south. It becomes nearly flat towards Roorkee and forms a part of Gangetic plains.

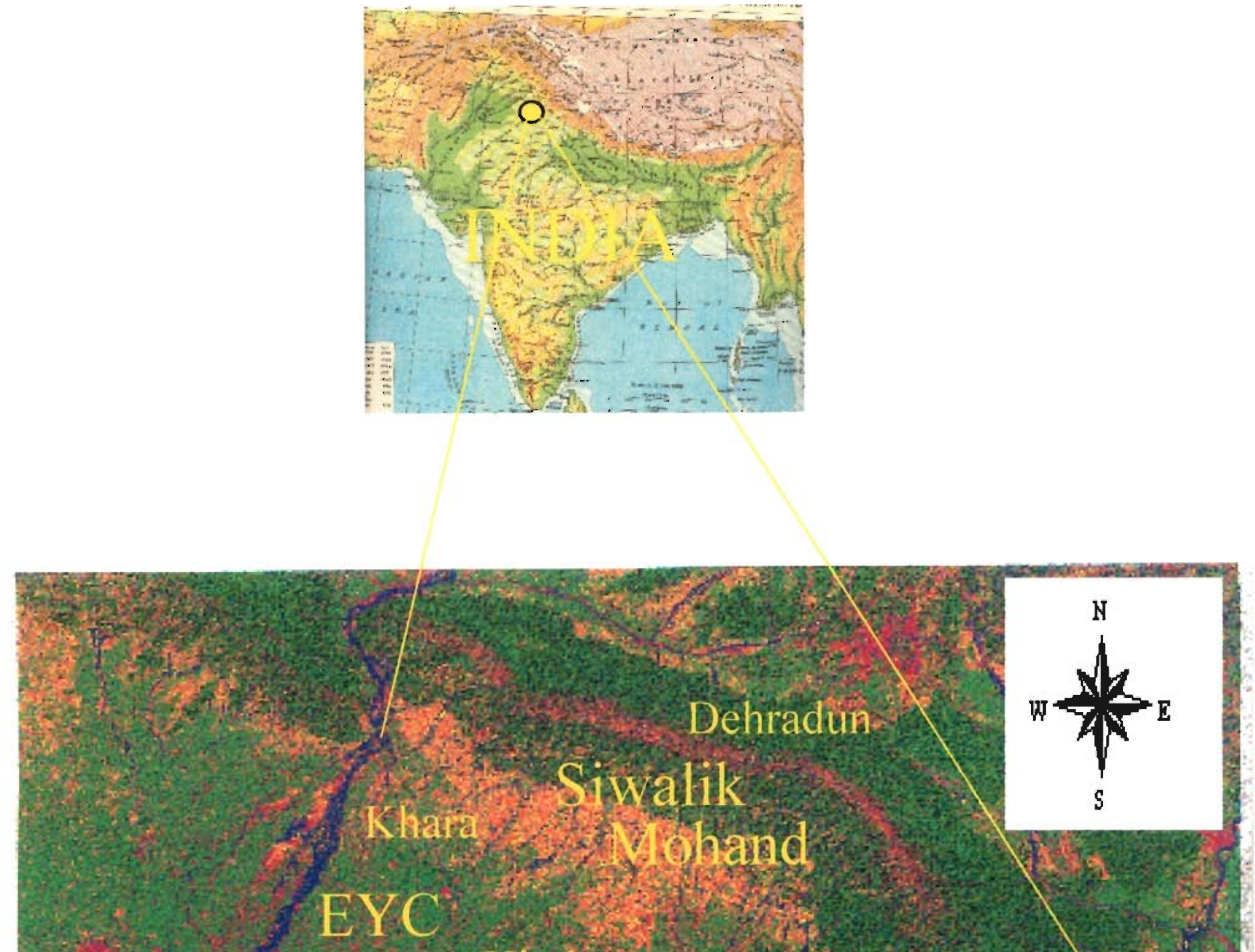


Fig. 1.1 Location Map

1.1.2 Drainage

Besides perennial rivers Ganga and Yamuna, the area is crisscrossed by a number of small streams such as, Budhi Yamuna, Mashkara Rao, Paondhoi, Dhamola, Nagdeo, Chachahi, Hindon, Kali, Solani, Ratmau,Pathri rao and Ranipur rao. These rivers bring flash floods every monsoon and remain dry during rest of the year (Fig 1.1). In addition to these natural systems, three canal systems, namely, the Upper Ganga Canal, the Western Yamuna Canal, and the Khara Canal pass through the area. The Upper Ganges Canal and the Eastern Yamuna Canal systems are more than a century (1845) old (Fig 1.1).

1.1.3 Flora and Fauna

In the area besides the agricultural crops and tree plantations, the important nursery plantations are Mango, Guava, and Papaya etc. The area in general is devoid of thick forest. Clusters of bushes and shrubs are found in pockets where soil is rich in clays. Natural vegetation is found in areas close to the streams, ponds and canals. Along with domestic animals, Tiger Leopard, Elephant, Barking Deer, Sambhar, Blue Bull, Peacock and Fowls represent the general fauna in the area.

1.1.4 Climate

The winter season in the area begins towards the end of October and extends up to March. The peak summer months are May and June. The minimum and maximum temperature touches - 2^0 C and 46^0 C respectively. Rainy season extends from middle of June to end of September. In general, as compared to plains the area presents inconsistent climate in spatial and temporal domain except for the hot months of May and June.

1.1.5 Geological Setup

Ganga and Yamuna rivers flow through the weak zones (probable faults) in lower Himalayan zone (Agoes, 1956; Mithal et. al., 1959; Krishnan, 1960; Agarwal et.al., 1960; Gansser, 1964). The geological map (Fig. 1.2) shows that near Hardwar, the southeastern limit of the Mohand anticlines is thursted over the northeastern part. This is probably continuing in to alluvium and passes between Ganeshpur and Ismailpur villages. Drilling at these sites indicated the presence of Tertiary rocks named as Siwaliks, at a depth of about 80 m and complete absence of the same down 250 m. These rocks dipping northerly at angles 20^0 - 30^0, form southern limb of Mohand anticlines. The rocks constituting the foothills belong to the Tertiary and further south they are of Quaternary age (Fig. 1.3). The general succession of the formations is tabulated in the Table 1.1.

The Quaternary sediments of the area are made up of gravel, sand, silts with little clays. The gravels consisting of boulders, cobbles, pebbles, granules, sand and silts with little clays are of heterogeneous nature and made up mainly of various types of rocks such as, quartzite, basic rocks, gneiss, and granite. The size of the boulder ranges from 15 cm to 150 cm. The southern part of the area consists mainly of clay, sandy clay, and occasionally thin beds or lenses of gravel. The clay of this belt is usually gray to brown and some times mottled. The granular beds occur mostly as lenses and some times inter finger with clayey and non- clayey sediments. The thickness of these boulder sediments is about 100m to 150m.

According to the seismic surveys carried out by Oil and Natural Gas Corporation (India) the thickness of the alluvium in and around Roorkee varies from 350 m to 500 m. Alluvium is generally made up of older and younger horizons. The sediments are sand, silt and clays with occasional gravel beds and lenses of peaty organic matter. The older alluvium is generally differentiated by the younger one by its darker tone in color and richness in kankar (impure calcium carbonate).

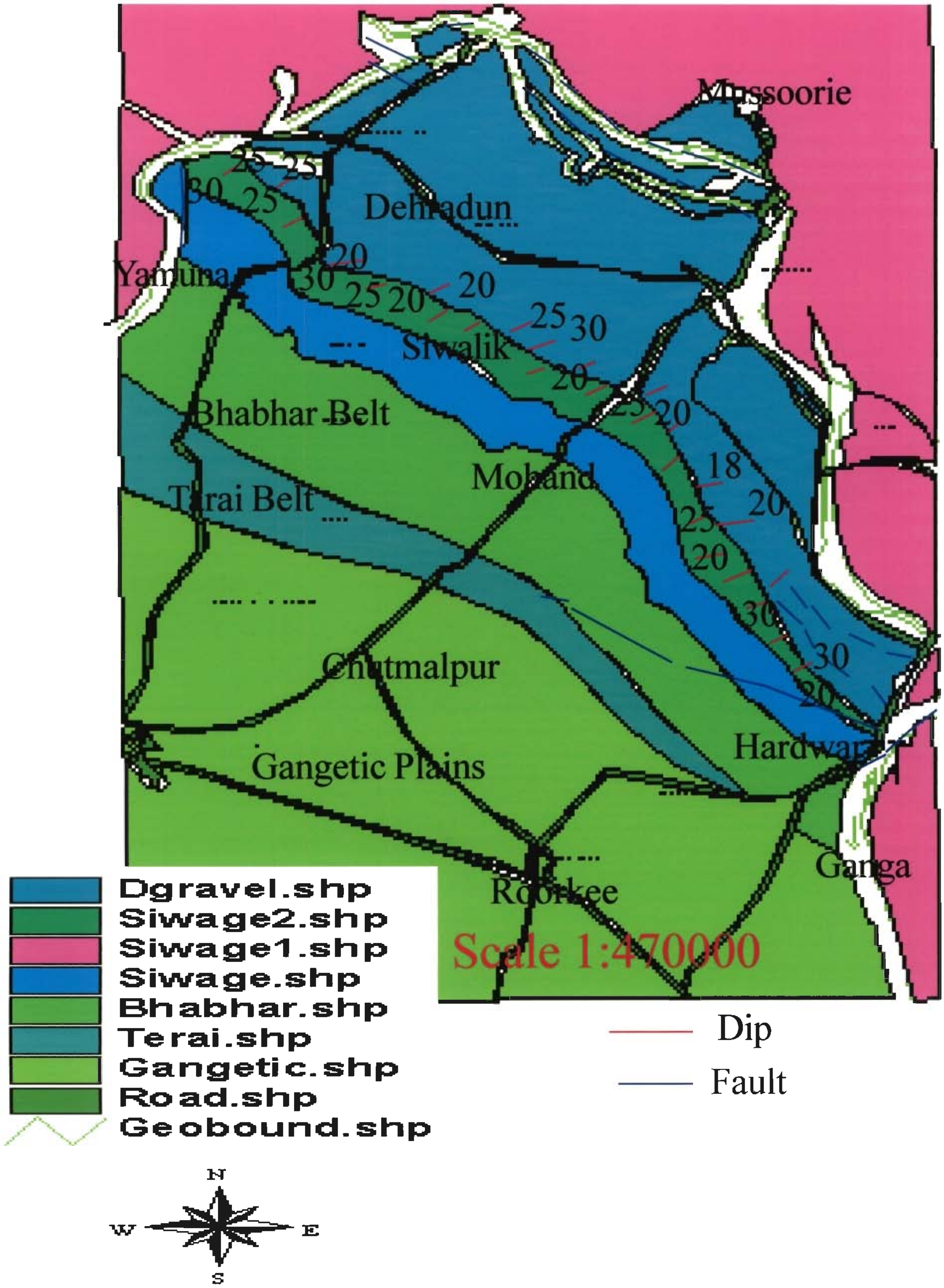


Fig.1.2 Geologic Map (Modified After Rao,1965)

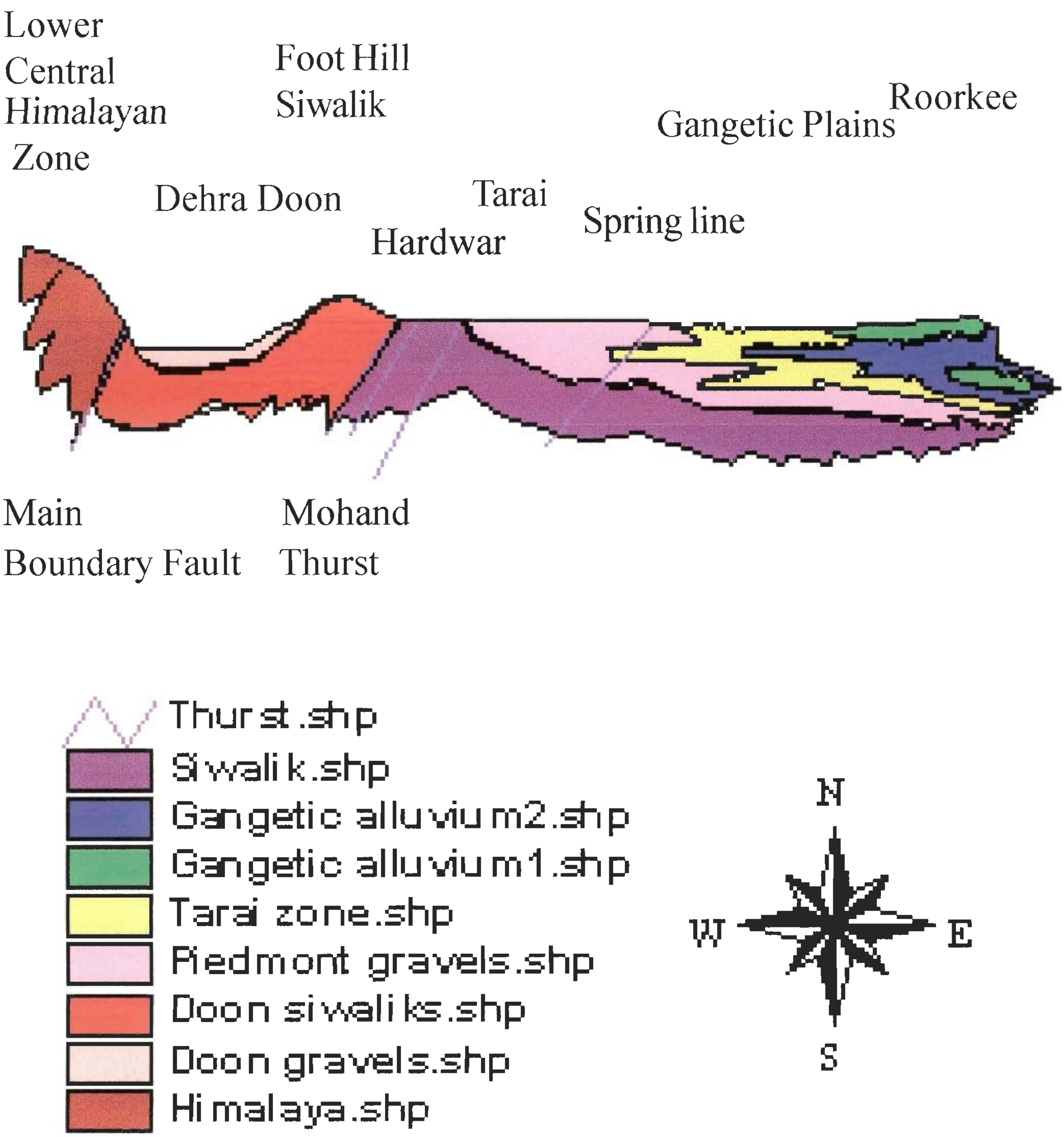


Fig.1.3 Geologic Section

Table 1.1 Successions of Formations

Age	Units	Lithology
Quaternary	Piedmont deposits Alluvium	**Piedmont**: Integrated alluvial fan deposits consisting of Sand, Boulder, Clay - boulder beds with Gravel-Clay, Sandy Clay, and Sand with gravel and Pebbles. **Alluvium**: Sand, Silt, Clay and kankar with occasional gravel beds and lenses of peat organic material.
Tertiary	Siwalik : Upper Siwalik (US) MiddleSiwalik (MS) Lower Siwalik (LS)	**US**: Pebble, Boulder, Conglomerate, Sand rocks and Clay. **MS**: Massive Sand rocks, light gray Sandstone resembling fly ash deposits associated with Clay and Calcareous beds. **LS:** Hard massive gray and brownish Sandstone, gray to maroon Clays and Sand beds

1.2 Review of Previous Works.

Review of literature indicated that limited work has been carried out in the Ganga Yamuna piedmont. However, some work related to its geology and groundwater availability has been carried out in the areas close to the present one.

Area lying on eastern, southern, and western side of the Ganga Yamuna piedmont has attracted many investigators since 1930. A brief review of some of the investigations is being described below.

As a part of the field investigations under 'Ganga Valley State Tube well Irrigation Scheme', Mackenzie, during 1935, conducted field experiments (Taylor et. al., 1936) to study the transmissivity of the water bearing formations in a part of Gangetic Alluvium lying south of the present study area. Based on extensive field work he concluded that in these alluvial areas tube wells of 0.04 m^3/sec capacity spaced about 1 km apart can safely be operated without any appreciable depletion in the regional water table.

Auden (1935) carried out field investigations in the alluvial areas lying south of the present one and submitted to the then government of the then United Provinces a number of technical reports containing the feasibility of ground water utilization through tube wells. For the first time (Stampe, 1936) an effort was made to utilize the ground water resource in the areas south of the Ganga Yamuna piedmont. During this period a large number of tube well schemes were introduced in the alluvial area.

Nautiyal, (1945), carried out field investigations to asses the groundwater availability in an area laying about 150 km in the NE direction of the present study area. In the same area Shah, (1961) conducted some exploratory drilling operations. His investigations indicated that the difference in land slope and the slope of the water bearing granular beds are more or less same towards south. From the study he also inferred that the Tarai aquifers connected with the Bhabhar deposits, in the north and maintains hydraulic continuity. Dwivedi and Gupta (1961) based on field experiments in an area south of the present study area, the Ganga Yamuna Doab, studied the ground water regime and estimated the ground water potential of the area for potential utilization.

The then, Exploratory Tube Wells Organization, Ministry of Food and Agriculture, Government of India, conducted groundwater explorations in the Doon valley, lying north of the Ganga Yamuna piedmont. They studied the suitability of aquifers in that area for construction of irrigation wells. Their study indicated that the wells in the Tarai regions are not utilizing the full capacity of the confined aquifers, particularly in the Saharanpur region (Pandey et.al., 1962). Chaturvedi and Mithal (1963) studied the groundwater regime in Ganges – Ramganga Doab of Bijnor area, Uttar .Pradesh State. This area is about 100 km south east of the present study area. Their study was largely devoted to the suitability of ground water for irrigation purpose from quality considerations. Bhattacharya (1963) studied the regional depletion of the water table in a part of the Ganga – Yamuna interfluves lying south ward to the present study area. He presented empirical formulae for estimating the rainfall penetration to the ground water table in the western part of the Uttar .Pradesh State.

Rao (1962; 1965) studied the geological set up and the ground water availability in a part of alluvium area lying south of the present study area. He studied the geology and structure of the rock – soil formation of the area, computed the rate of ground water recharge and discharge. He developed relationships between the water yields from well and the terrain characteristics of the areas. For a part of area he has also used aerial photographs for interpreting paleo channels.

Mithal et. al. (1973) and Rao (1973) studied the ground water regime of a part of the area lying south of the Ganga Yamuna piedmont. Bhatnagar et. al. (1973) conducted the hydro geological mapping of Bhabhar zone in the upper Yamuna Basin. Their study area is about 200 km west of the present one. Meijerink (1974) carried out hydrogeological study of area around Roorkee using aerial photographs. Kansakar (1988) studied the hydrogeology of Roorkee area. Musampa (1994) studied the hydrogeology of Roorkee town. Agarwal (1994) estimated the aquifer parameters in an area, about 150 km south of the Ganga Yamuna piedmont. Ground water quality in a part of Saharanpur district, about 50 km south of the present study area was investigated by Seth et.al. (1994), NIH (1999) made an attempt to study the groundwater quality of a part of the Hardwar district. Rao et. al. (2002) made an attempt to delineate the recharge and discharge areas using environmental isotope technique in apart of Hardwar district.

Above descriptions though very limited indicates that little work has been carried out in the Ganga Yamuna piedmont. However, there is not a single study devoted to the optimal use of land in and around this area. Few geological and hydrological investigations have been carried out in areas south of Ganga Yamuna piedmont. Therefore, it is expected that the present study will be able to plan the road map for achieving the objectives of the Antodaya.

1.3 Methodology and Scope of The Present Study

The present study has been carried out in synergistic manner using available data, remotely sensed data, field surveys and laboratory studies. The investigation program is shown in Table 1.2.

In this chapter, the introductory aspects and the existing literature have been briefly described. The chapter II deals with the geomorphic, drainage, meteorological and land cover characterization of the area.

In Chapter III, an endeavor has been made to assess the soil resources, covering soil texture soil mineral, salinity, alkalinity, and specific yield.

Chapter IV deals with the assessment of water resources in the area. Formulation and testing of simple models for the estimation of surface water and ground water based on input from remote sensing data has been described.

Chapter V deals with the formulation and application of optimal land use model for the Ganga and Yamuna piedmont.

Conclusions based on the present study highlighting optimal use of land in this piedmont area have been presented in the chapter VI.

Table 1.2 Investigation Program

S.No.	Module	Date Used	Information Derived
1.	Introduction	Literature Survey	Literature Components of Study
2.	Terrain Evaluation (a)Topographic Map (b)Drainage Network Map (c)Geomorphic Map (d)Land Cover Map (e) Hydrometeorological Study	Survey of India Topographic Sheet (25) Aerial Photograph (200) Satellite Data Product (20) Field Survey (10 Field Traverse)	45 Primary Control Point 1000 Secondary Control Point Topographic Map, Drainage Network Map Geomorphic Map, Land Cover Map, Monthly Average Statistics pertaining to Rainfall, Temperature, Humidity, Evapotranspiration, Wind Speed, Sun shine duration
3.	Soil Resources (a) Surface Soil Investigation (b) Subsurface Soil Investigation	Existing Records NATMO Maps Aerial Photograph (200) Satellite Data Product (20) Field Survey (10 Field Traverse) Experimental Sites (250) Experiments (1250) Litho Charts (100) VES (45) Aquifer Samples (50)	Geologic Sections Soil Texture Map Hydrologic Soil Classification map Agricultural Map Soil Properties, for Example, Soil grain Size distribution, Soil minerals, Soil permeability etc.
4.	Water Resources Assessment of water Resources (a) Ground Water (b) Surface Water	Existing Records Meteorological Characteristics(1975-2000) Land Characteristics Soil Characteristics Observed Stream Flow (1975-2000) Groundwater Fluctuation in Observation wells (1975-2000)	Water Balance Land Based Stream Flow Model Land Based Groundwater Recharge Model Land Based Evapotranspiration Model Groundwater Resources
5.	Crop Suitability Analysis of Geomorphic Units (a) Optimal Land Use Pattern	Existing Records Land Characteristics Soil Characteristics Land Use Requirement Land Use Economics Field Surveys	Optimal Land Use Model Crop Water Requirement Suggested optimal Land Use.
Numbers in parentheses represents the number of data sets			

2

TERRAIN EVALUATION

2.0 Background

Land use relates to the human activity or economic function associated with a specific piece of land. Land cover, on the other hand, is related to the type of feature present on the surface of the earth. Land cover of an area influences more or less all the components of the land water and air system (Kanwar, 1972, Meijerink, 1974; Sokolov et.al., 1974; Wischmeier et.al., 1978; Zachar, 1982; Van Diepen et. al., 1991; Verheye, 1992; Dubey, 1997; Sombroek et.al., 1996; Vincent, 1997; Foddy, 2000; Singh, 2001; Singh et.al., 2001; Kar et.al., 2002).

Field reconnaissance revealed that in the study area terrain characteristics are highly variable in spatial domain. Land Use of an area depends upon its terrain characteristics. (Mc Cormack, 1974; Twidale, 1976; Townshend, 1981; Mandal, 1982; Srivastava et.al., 2002). In the present study terrain characteristics, namely, Geomorphic (land elevation, land slope), drainage, land cover dynamic, and meteorologic (rainfall, temperature, relative humidity, sunshine duration, wind velocity and evapotranspiration) have been considered as most influential terrain parameters.

Preliminary study of the available terrain data indicated that these are not suitable or sufficient due to a variety of reasons. For example, either these are outdated, or have short memory, or their configuration, accuracy or trustworthiness is inadequate. Topographic sheets (Fig. 2.1) from Survey of India (SOI) are based on field surveys conducted during 1966-1967 without being updated. Hence, the available maps are generally outdated and hence not suitable from the scale and information content consideration

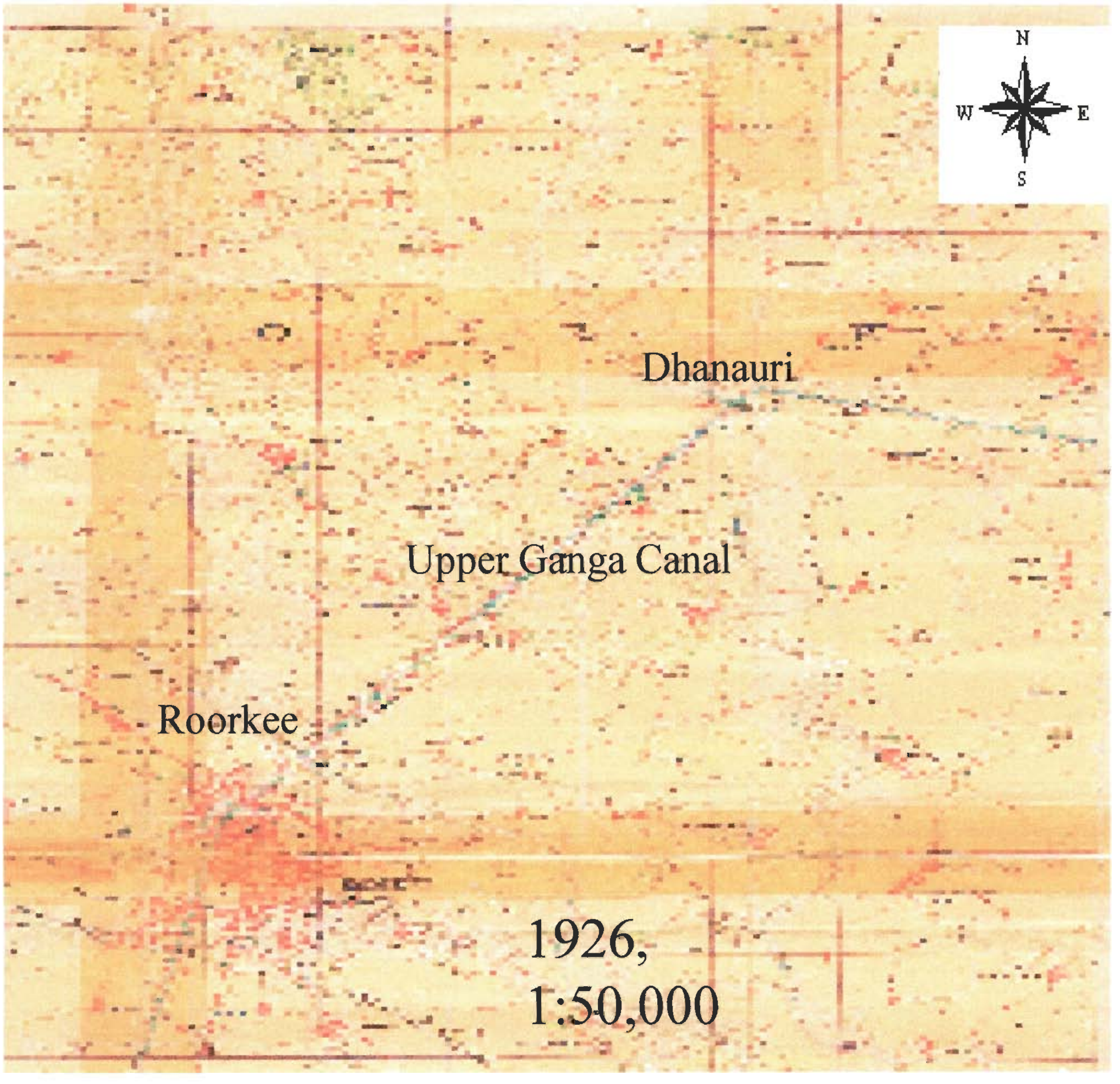


Fig. 2.1 Topographic Map (Part of Area)

On the contrary, remote sensing techniques have proven their capability for terrain characterization (Verstappen, 1977; Reves, 1987; Avery et.al., 1992; Barret et.al., 1992; Rao, 1995; Revees, 1999; Goswami et.al., 1996; Suresh Babu et.al., 1999; Singh, 2001; Huque et. al., 2002; Yang et. al., 2002). In view of this, in the present study synergistic use of remotely sensed data, available ancillary data and field survey have been made for terrain evaluation.

It is worth mentioning that the geomorphic units are indicator of earth processes that influences the land use. For example, the earth processes - surface runoff, groundwater recharge, soil erosion and sediment yield that influence the land use varies from one geomorphic unit to another (Biswas et. al., 1985; Frezer, 1971; Meijerink, 1974; Biswas et. al., 1997; Vincent, 1997). Hence, in the present study, geomorphic unit has been assumed as a base for analysis. The terrain evaluation program is shown in Table 2.1.

Table 2.1 Terrain Evaluation Program

<table>
<tr><th>Sl. No.</th><th colspan="2">Terrain Characteristics</th><th>Data used</th><th>Data Analysis Approach</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">Geomorphic</td><td>Land Unit</td><td>Topographic sheet (25)*
Aerial Photographs (200), FCC (10)</td><td>Map and Image analysis Field Surveying (10)</td></tr>
<tr><td>Land Elevation</td><td rowspan="2">Topographic Sheet (25)
Aerial Photographs (200)</td><td rowspan="2">PCP(45)
Photogrammetric Techniques
SCP(1000)</td></tr>
<tr><td>Land Slope</td></tr>
<tr><td>2.</td><td colspan="2">Drainage</td><td>Topographic Sheet (25)
FCC (10)</td><td>Map and Image Analysis
Field Surveying (10)</td></tr>
<tr><td>3.</td><td colspan="2">Land Cover</td><td>Topographic sheet (25)
Aerial Photograph (200)
FCC (10)</td><td>Map and Image Analysis
Field Traversing (10)</td></tr>
<tr><td>4.</td><td colspan="2">Meteorological</td><td>Observed Data
(during 1970-2000)</td><td>Meteorological impact on land use</td></tr>
<tr><td colspan="5">(Topographic sheet at 1:50,000 Scale, Aerial Photograph at 1: 32,000 Scale, FCC – False Colored Composite, PCP – Primary Control Point, SCP – Secondary Control Point, *Number in the bracket represent the number of data set used in the analysis)</td></tr>
</table>

2.1. Geomorphic Feature

Visual analysis of IRS – LISS II, F.C.C. (Fig.2.2), aerial photographs (Fig 2.3) and field visit indicated that area is geomorphologically heterogeneous. Thus,the area was classified in to four geomorphic units, namely, the Upper Regime Piedmont (U.P.), the Middle Regime Piedmont (M.P.), the Inter Channel Plainer Area (IC), and the channel Braid Bar (CB). The IC unit is further categorized in to three sub units namely, I_1, I_2, and I_3 on the basis of topographic variation and risk of flooding.

These units were delineated by synergistic use of remotely sensed data, False Colored Composite (FCC IRS-LISS II), topographic map and field survey, using the approach proposed by Mejerink (1974). On the FCC (Fig. 2.1), geomorphic units were identified using image elements. The image interpretation key, that was prepared through field survey and checks, is shown in Table 2.2. Geomorphic units were interpreted and delineated on F.C.C .using the image interpretation key (Table 2.2) and finally registered on the topographic sheet (Fig. 2.4). Area of various geomorphic units is also tabulated in Table -2.2.

A perusal of Table 2.2 indicates that the area of the four geomorphic units namely the UP, MP, IC and the CB are 348 km^2, 252 km^2, 1268 km^2, and 132 km^2 respectively totaling to 2000 km^2. They constitute about 17.4%, 12.6 %, 63.4 % and 6.6% of the total area. Geographical area of I_1, I_2, and I_3 sub units are, 392 km^2, 288 km^2 and 588 km^2. Thus these sub units constitute about 14.4%, 19.6% and 29.4% which is 63.4% in total that is the area of the IC unit.

2.2 Physiographic Characteristics

Physiographic characteristics of a land unit that is represented by its elevation and slope influences the local earth process and hence its land use. As mentioned 'earlier the

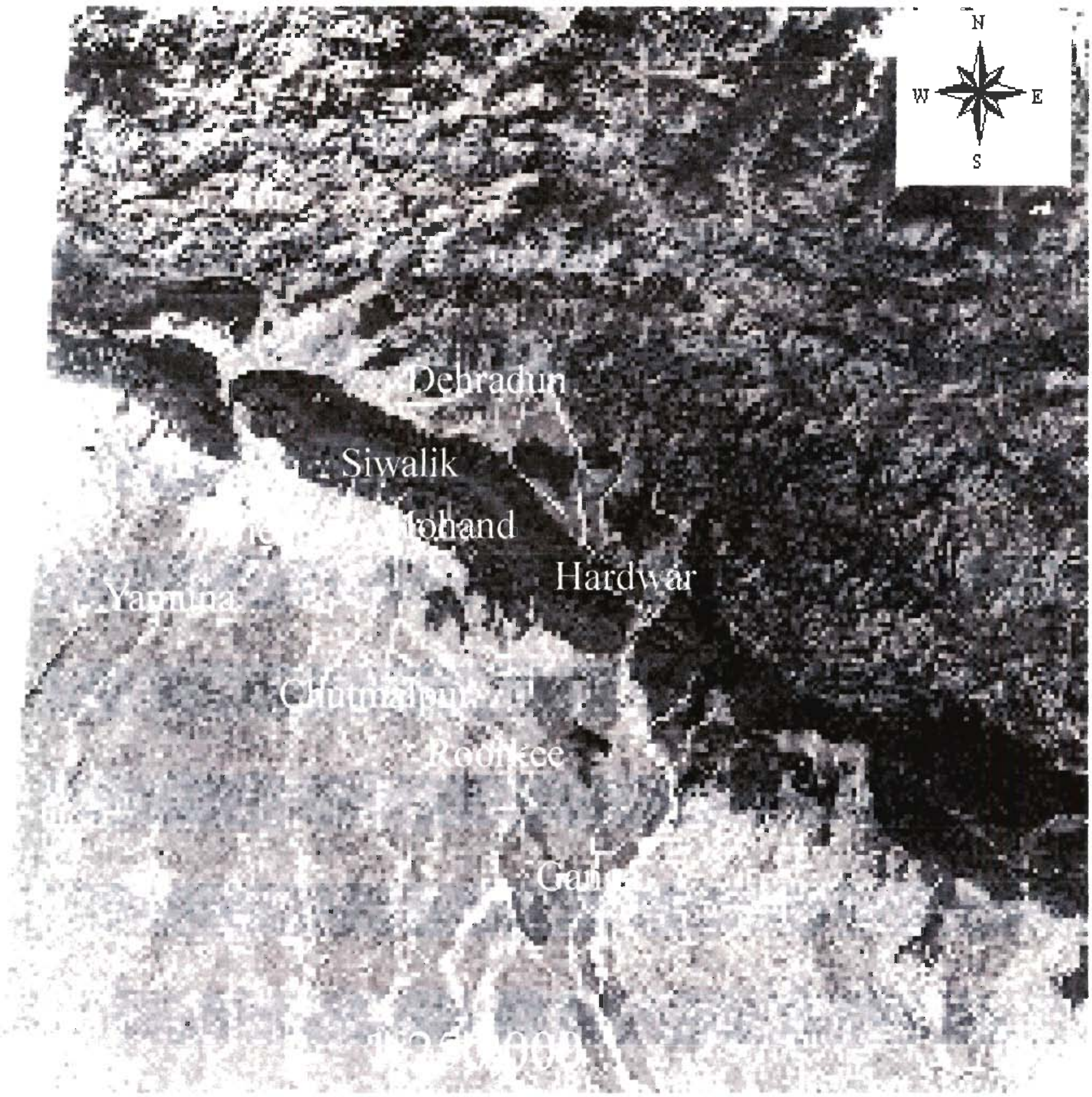


Fig. 2.2 (a) Landsat Imagery (Band 5)

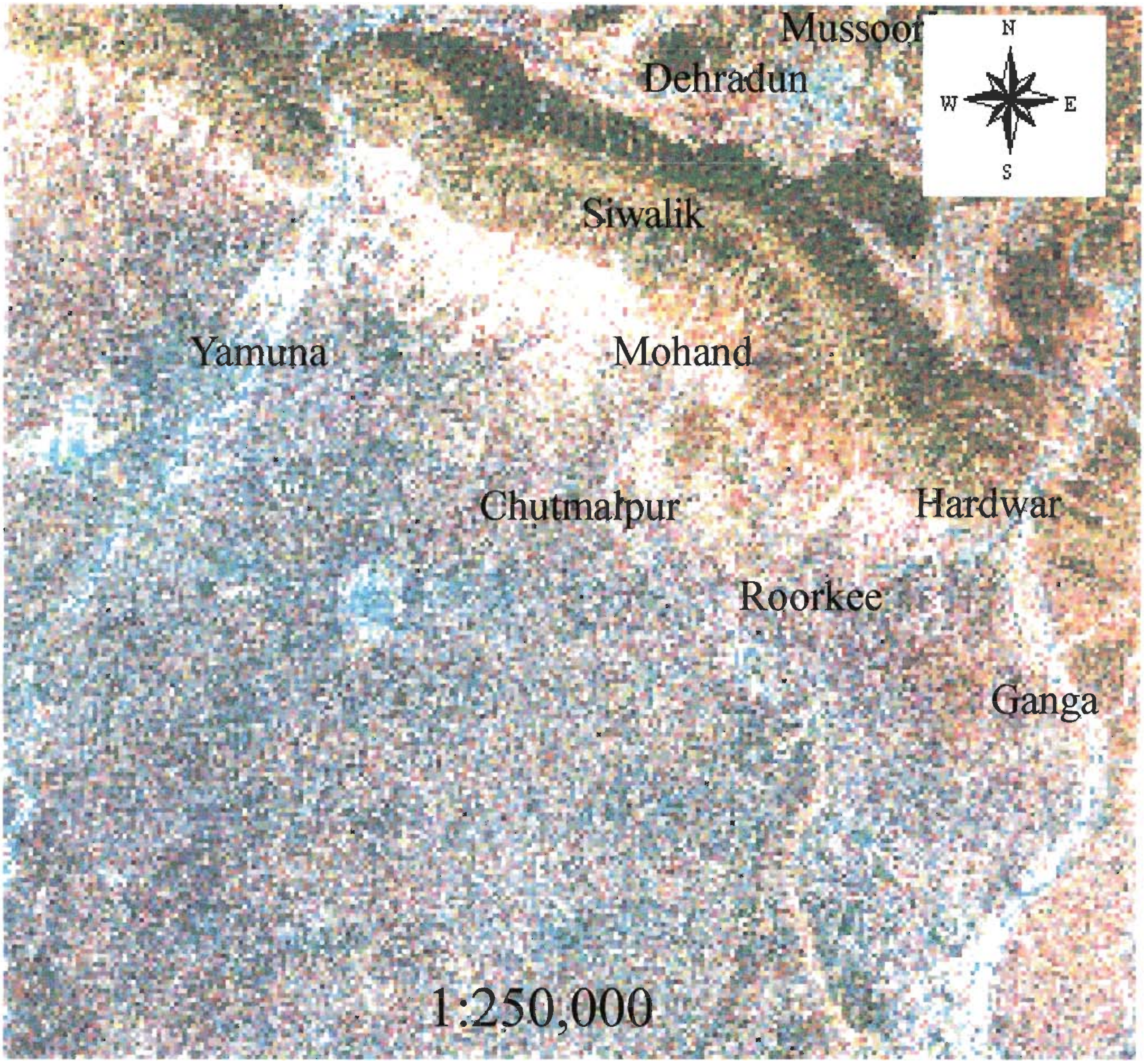


Fig. 2.2(b) I R S-L I S S-II, F C C (Band 2, 3, 4)

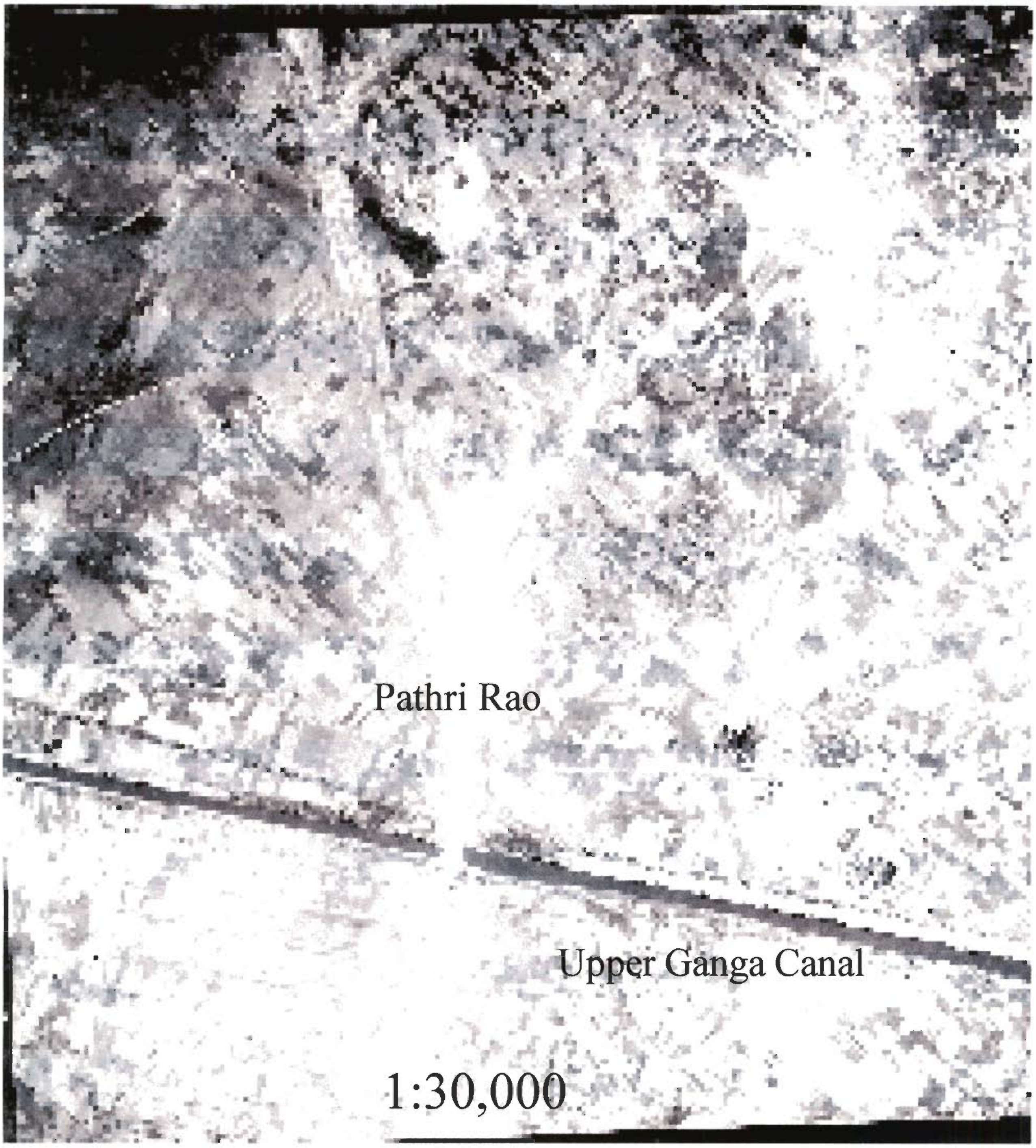
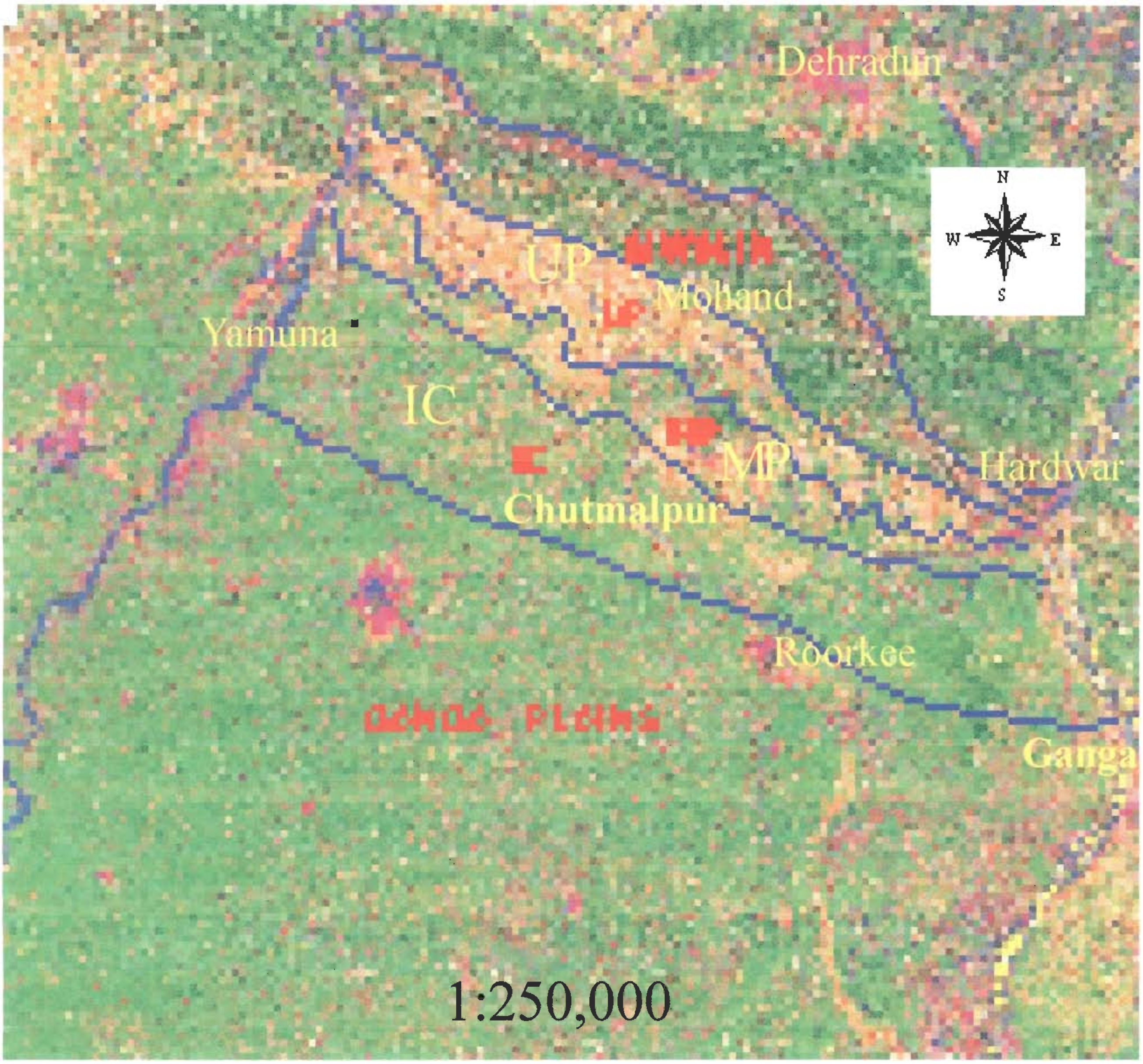
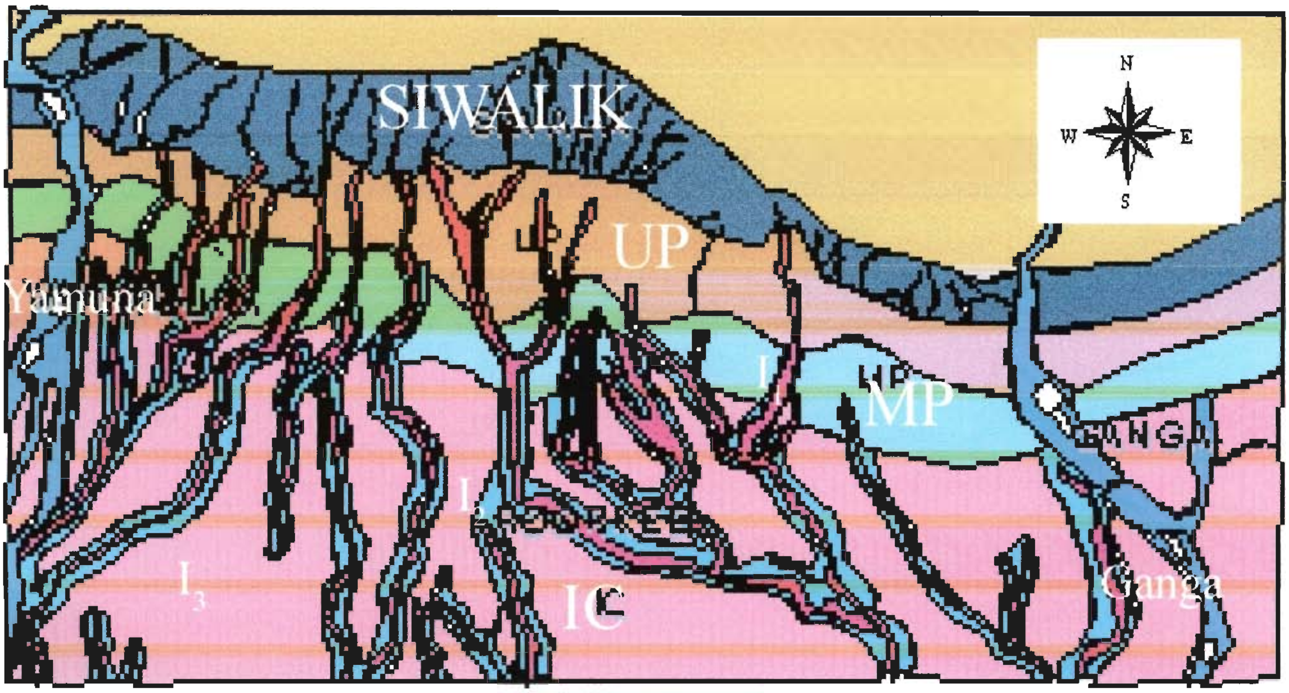


Fig. 2.3 Aerial Photograph (Part of Area)



UP: Upper Regime Piedmont
MP: Middle Regime Piedmont
IC: Inter Channel Plainer Area

Fig. 2.4(a) Geomorphic Classification



River12.shp
River1.shp
Upp1.shp
Siwalik.shp
Mp.shp
Upp.shp
Boundarygi3.shp
Boundarygi2.shp
Boundarygi1.shp
Boundaryg5.shp
Boundaryg4.shp
Boundaryg3.shp
Boundaryg2.shp

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

I_1 : Characterized by Frequent Flooding

I_2 : Characterized by Occasional Flooding

I_3 : Relatively Free From Flooding

Fig. 2.4(b) Geomorphic Classification

information interpreted from topographic sheets is not sufficient. Hence, it was decided to update these maps by synergistic use of the remotely sensed data, IRC-LISS II, FCC (Fig.2.2), aerial photographs (Fig.2.3), ancillary data, along with fresh field surveys wherever required. From the available topographic maps at 1: 50,000 scales, ground elevation contours along with the spot heights were extracted and traced on a tracing paper. In the area, State Irrigation Department, Public Works Departments have established some Bench Marks (BM). From these departments geographical coordinates of these benchmarks along with their spot elevation were collected and complied.

Table 2.2 Salient Features of Geomorphic Units

S. No.	Geomorphic Unit		Diagnostic Features	Area (km^2)
	Name	**Code**		
1	**Upper Regime Piedmont**	**UP**	Parallel to foot hill, highly undulated and sloppy towards south, loose and very coarse materials, frequent stream migration.	348 (17.4)[x]
2	**Middle Regime Piedmont**	**MP**	Large fan shaped area, south of the unit UP, moderately undulated mixture of coarse materials, frequent stream migration.	252 (12.6)
3	**Inter Channel Plainer Area (IC)**	I_1	Low land along banks of rivers, subjected to frequent flooding, river meander.	392 (19.6)
		I_2	High land along both banks of rivers, subjected to periodic or occasional flooding, paleo channels.	288 (14.4)
		I_3	Triangular area lying between two streams, mixtures of coarse and fine materials.	588 (29.4)
4	**Channel Braid Bar**	**CB**	Channel Braid Bars.	132 (6.6)

*Number in bracket represent the area as percentage of the total study area (2000 km^2)

These BM, 45 in number were referred as principal control point. These are generally located close to canals and roads. Their density is low in remote areas. Hence generating secondary control points was felt in these areas. Generation of these secondary control points by land surveying, through triangulation, triliteration, traversing and leveling, was found time consuming and costly.

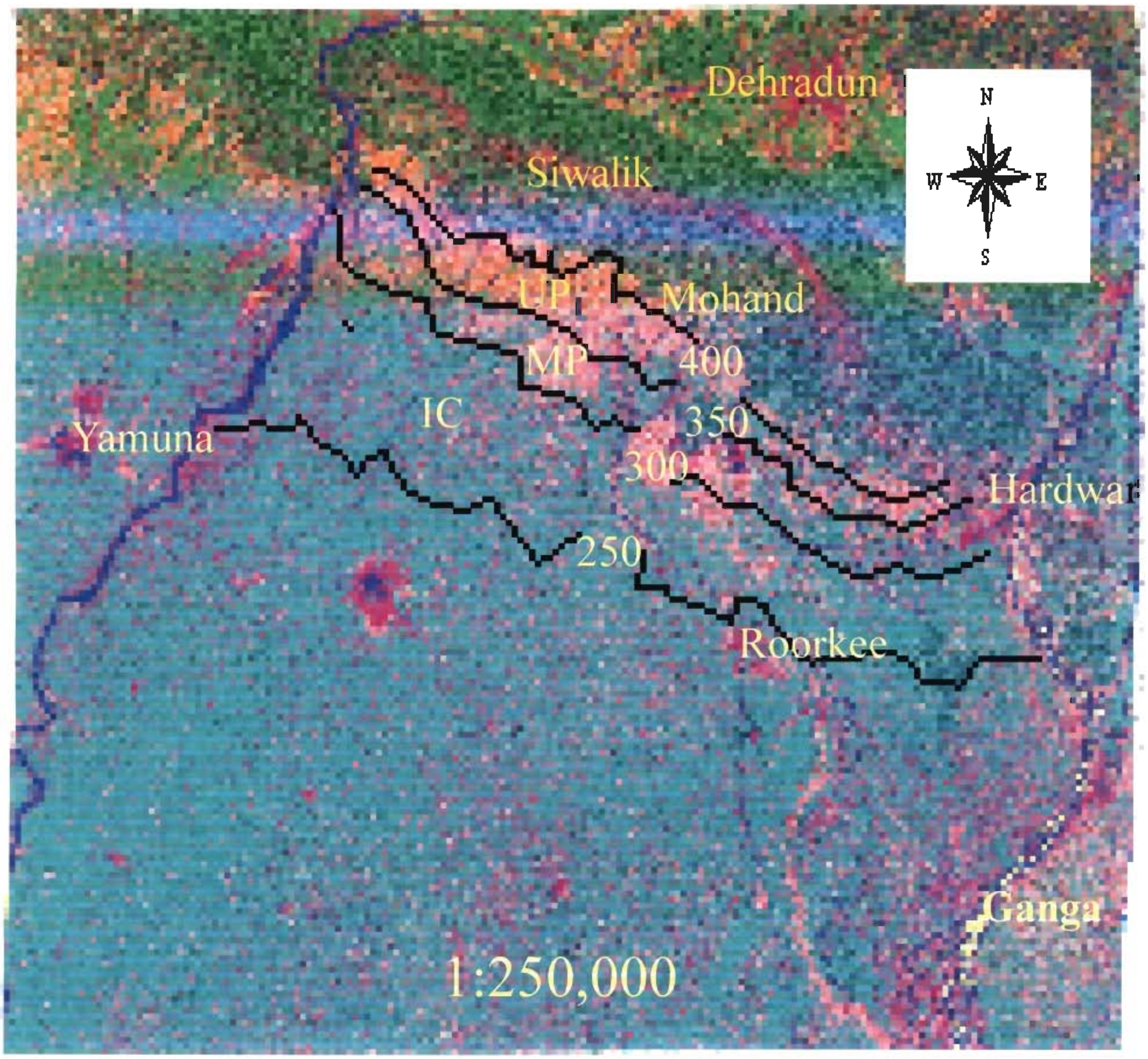
Therefore, these secondary control points were generated through photogrammetric techniques (Moffitt et.al., 1980; Wolf, 1983; Vincent, 1997) supported by limited field survey. In all 1000 secondary control points were generated. Finally ground elevation contour map (Fig 2.5) has been prepared.

The slope map of the area was prepared by carrying out slope analysis. Slope analysis has been carried out on the contour lines (Fig 2.5). For slope analysis several sections were marked on the contour map.

On these sections the horizontal distance or the horizontal equivalent was measured and then after land slope it was determined. Finally, a slope facet map (Fig 2.6) has been prepared. Contour map (Fig. 2.5) and slope facet map (Fig. 2.6) was analyzed to assess the physiographic characteristics.

Perusal of Fig.2.5 and 2.6 indicates that in the area the ground elevation range from 250 m to about 400 m whereas its slope ranges from 0^0 to 6^0. Distribution of area in different elevation zone is shown in (Fig. 2.7) .Further, about 63.4% of the total area lies between 250 m above mean sea level (m s l) and 300 m above m s l.

The remaining, 36.6 % of the area, lying above 300 m ground elevation is undulated. Cumulative area in different elevation zones follows a linear trend (Fig. 2.7). From above it is inferred that the major part of the area is suitable for a variety of uses.

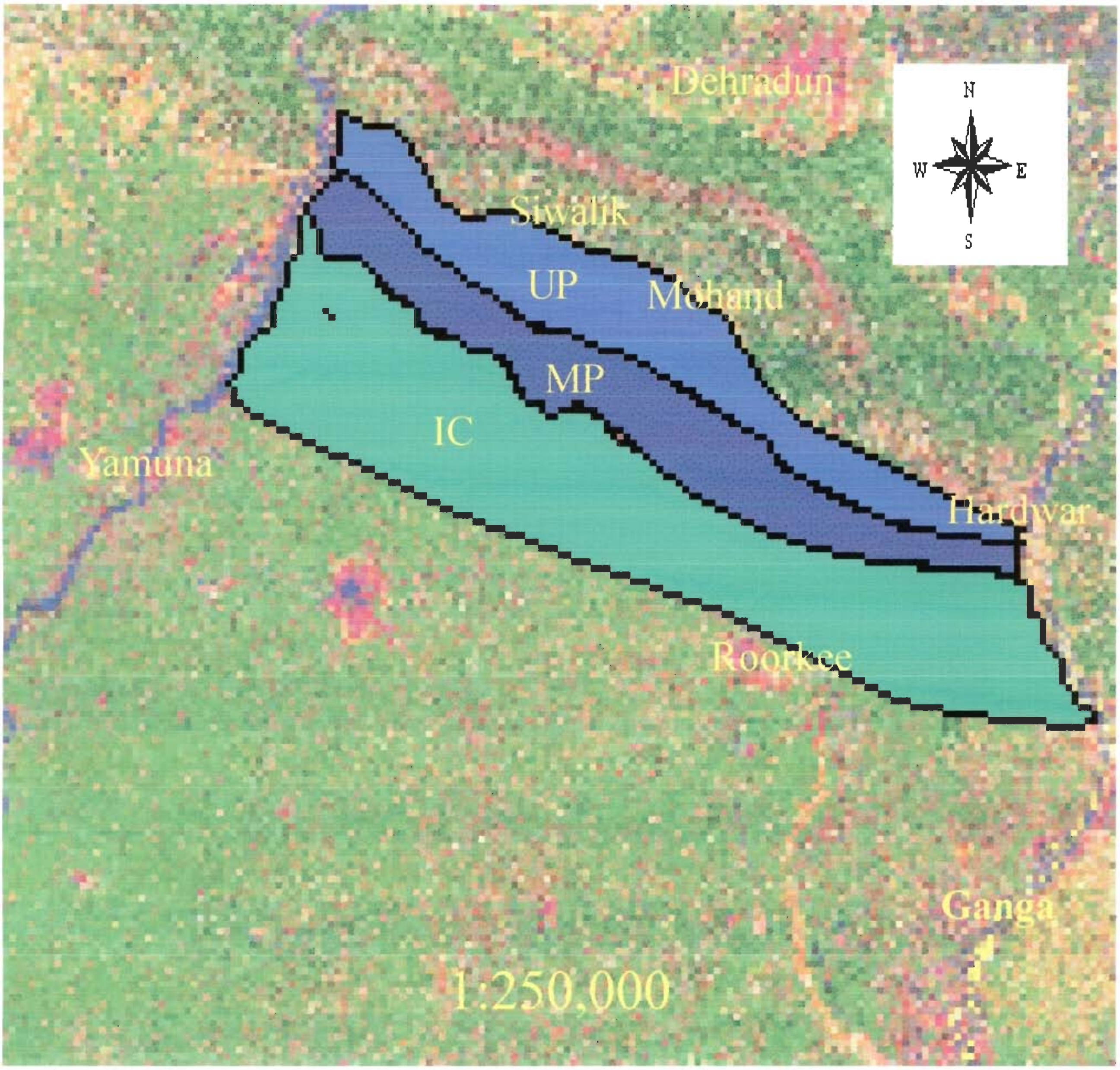


UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.2.5 Contour Map



Land Slope (degrees)

< 2

2 - 3

> 3

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.2.6 Slope Facet

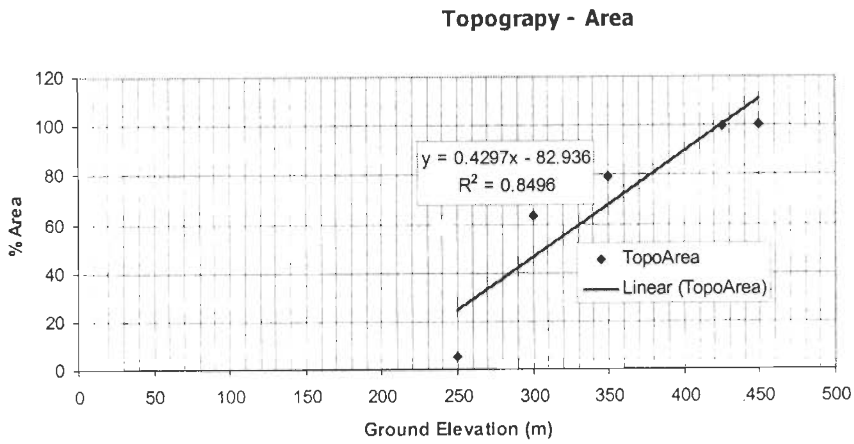


Fig. 2.7 Topographic Variation of Land Use

2.3 Drainage

Drainage characteristics of an area influence the local hydrologic processes, for example, surface run off, ground water storage, and available moisture (Calver et al., 1972; Gurnell, 1978; Leopold et al., 1956; Rogers, 1971; Thomas et. al., 1970; Trainer, 1969; Siegal et. al., 1980). These processes in their own way influence the land use. The drainage characteristics have been evaluated through drainage network analysis. The drainage network map for the area was prepared through synergistic use of topographic map, remotely sensed data, IRC-LISS II, FCC and field surveys.

Drainage networks were delineated through the visual analysis of the remotely sensed data, namely, the IRC-LISS II, FCC (Fig.2.2) and the aerial photograph (Fig.2.3). The drainage network was delineated using the image elements (Avery et.al., 1992; Mather, 1999; Singh, 2001). On the FCC, drainage lines are appearing in bluish black color. Aerial photographs were analyzed under stereoscope for delineating additional drainage lines in difficult areas. Drainage lines delineated on FCC and aerial photographs were registered and integrated on the drainage map traced from topographic map. The final drainage network thus worked out is shown in Fig. 2.8.

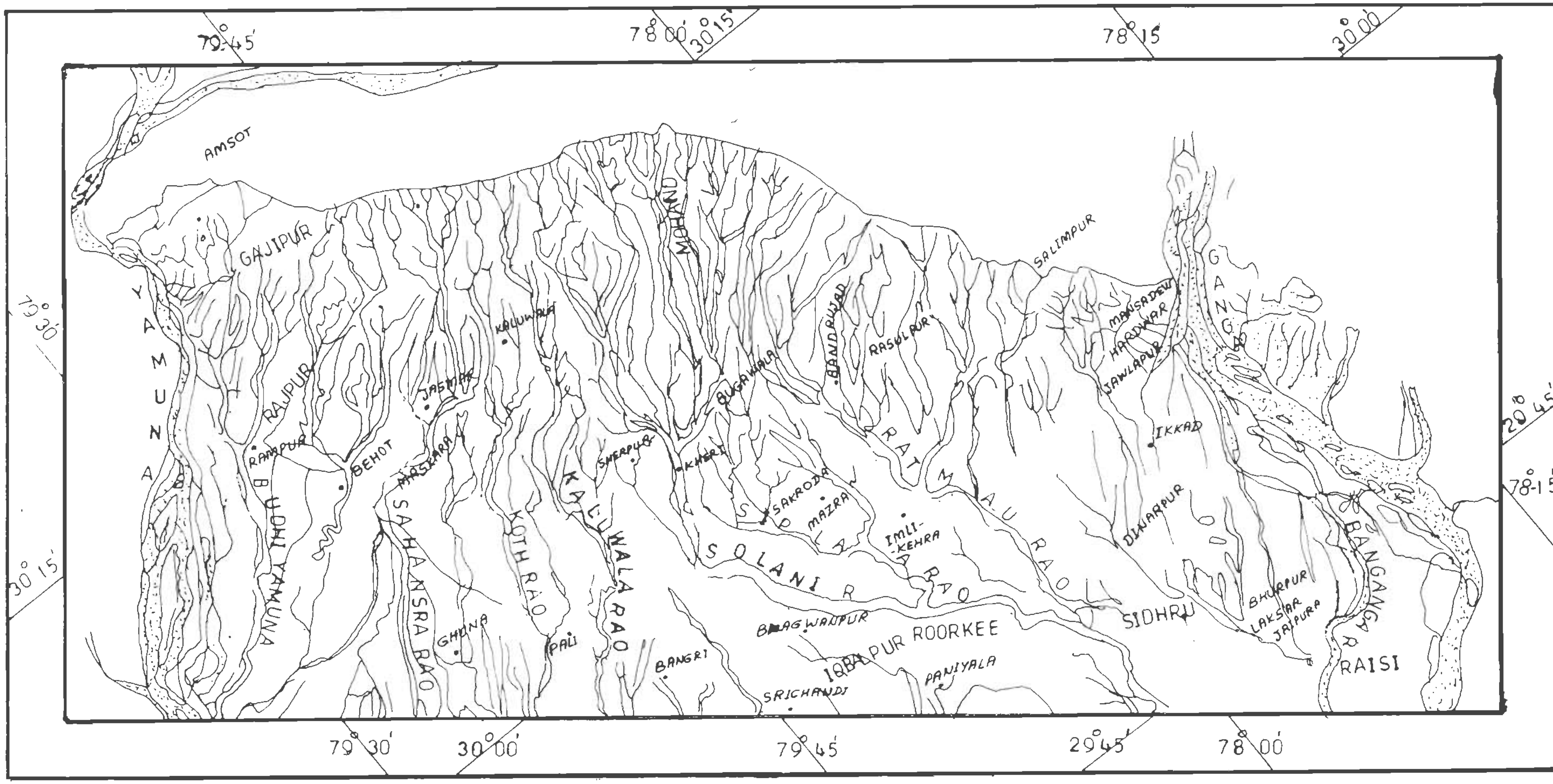


Fig. 2.8 Drainage Map

Visual analysis of the drainage network map reveals that in addition to the rivers Ganga and Yamuna the area is knitted with many flashy streams, namely Solani, Ratmau, and Hindon. In the upper reaches most of these streams are flowing towards south.

These rivers after traveling about 5 km towards south have a tendency towards east or west to join river Ganga or river Yamuna subsequently. River Hindon runs more or less straight and acts as a divide line. River Solani shows a peculiar trend, traveling southward up to village Amanatgarh,, and suddenly tending towards east.

Ratmau stream a tributary of river Solani follows more or less the same trend. In the Siwaliks the drainage pattern is close to dendrite. In the UP and MP geomorphic unit it is generally braided. In the IC unit the numbers of drainage lines are few. In this unit the braiding pattern gradually disappears and number of stream segments increases as compared to the other geomorphic units.

For the sake of simplicity the study area was divided into 50 sub basins. Drainage network analysis was carried out following the Hortonian concept (Chow 1964, Schiedegger, 1973, Williams, 1978, Singh 1989, Nag 1998, Nautiyal 1994). A summary of drainage parameters is presented in Table 2.3.

Table 2.3 indicates that in the area maximum order of the stream is four. The numerical value of the bifurcation ratio falls within 1.0 - 5.0. Hence, it is inferred that the geological factors have not distorted the drainage pattern. Circularity ratio for the streams varies between 0.36 and 0.62, whereas the elongation ratio, have been found to range from 0.40 to 0 .97 and form factor varies between 0.12 and 0.62.

These values indicate that in general the sub basins are elongated. The time of concentration for the sub basins have been found to vary between 5 hr and 12.4 hr. Drainage density varies between 1.348 and 4.175

Table 2.3 Drainage Parameters

Sl. No.	Drainage Parameters: Description	Data Range: Max	Data Range: Min	Broad Inference
1.	**Stream order**	4	2	4th order basin
2.	**Number Of Streams – I order**	66	4	Number of stream follows Horton's Law
	II order	15	1	
	III order	5	1	
	IV order	1	1	
4.	**Total Stream length (km)**	54.15	3.80	Basins are elongated
4.	**Length of overland Flow(km)**	0.22	0.13	
5.	**Drainage Area (km^2)**	16.662	1.950	
6.	**Basin Perimeter (km)**	17.63	5.18	
7.	**Basin Dimensions**			Basins are elongated
	Length (Km)	8.2	2.15	
	Width (km)	4.8	0.79	
8.	**Basin Centroid (km)**	4.13	0.864	Basins are narrow and elongated and free from distortions
9.	**Form Factor**	0.62	0.12	
10.	**Circularity ratio**	0.62	0.36	
11.	**Elongation Ratio**	0.97	0.40	
12.	**Unity Shape Factor**	2.77	1.15	
13	**Bifurcation Ratio**	5.0	1.0	
14.	**Total Relief (m)**	434	280	Relief is low to medium
15.	**Relative Relief**	0.14	0.003	
16.	**Relief Ratio**	0.1485	0.03	
17.	**Ruggedness number**	1.973	0.331	Rocks are weak to medium resistance
18.	**Drainage frequency**	2.1	0.4	
19.	**Drainage density**	4.175	1.348	
20.	**Length of main stream (m)**	8100	1750	
21.	**Length of main basin (m)**	9500	1350	
22.	**Average slope (%)**	60.04	9.314	Large variation in land slope
23	**Time of Concentration (Hr)**	12.4	4.9	

Synergistic study of the drainage map along with contour map and slope facet map reveals that the first and second order streams are characterized by steep slopes. In general, the northern portion, which is in contact with Siwaliks has high relief (of the order of 434 m). In this region the ground slope is also high, of the order of about 6 %. Most of the basins are elongated in shape. Further in general, stream segments are short having average length of 3 km. Length of over flow ranges from 0.13 km to 0.22 km. This indicates that rainwater travels about 200 m before the formation of well defined channel. These conditions are favourable for quick runoff and heavy sediment yield. This indicates that the northern portion of the area is characterized by low moisture holding capacity with high risk of floods and erosion.

During field traversing it was found that the piedmont channels though shallow (1.0 to 2.0 m deep) occupy about 25% of the area. These channels, except during rainy season remain dry for most part of the year. Encroachments for agriculture and infrastructure developmental activities have of late spurted in these areas. Therefore, it became an inevitability to study the geometry of these channels.

Five streams, Solani, Ratmau, Pathri, Gaughat and Ranipur Rao have been selected with a view to work out the extent to which these stream regimes can be suitably used. On each stream 10 representative sections have been selected based on proximity and accessibility.

Channel parameters namely, bed width, cross section area, channel depth corresponding to the bank full discharge and bed slopes were measured at these sections. The length of the main channel and corresponding drainage area was measured from topographic maps at 1:50,000 and FCC.

At few sections the ground measurement was difficult. Relevant data for these sections were generated from analysis of aerial photographs. The depth of the channel was calculated from parallax readings on stereo photographs. The generated data set consisting of 1200 samples was analyzed. Best fit relations between various parameters have been worked out and tabulated in the Table 2.4.

Perusal of Table 2.4 indicates that both the channel width and cross sectional area are positively related with length of the main channel and corresponding drainage area. This is in conformity with the general trend in case of alluvial rivers (Leopold et. al., 1964;).

Table 2.4 Relationship Between Stream Parameters

S.N.	Stream Parameters (Variable)		Relationship($y=ax^b$)		R^2
	Dependent (y)	Independent(x)	a	b	
1.	Slope (S)	Length (L)	0.0305	-0.469	0.935
2.	Slope S)	Area (A)	0.0194	-0.330	0.923
3.	Width (B)	Area (A)	6.415	0.736	0.909
4	Depth (D)	Length (L)	1.165	0.328	0.750
5.	Depth (D)	Area (A)	0.785	-0.183	0.649
6.	X-sectional Area (a)	Length (L)	8.060	.5815	0.795
7.	X-sectional Area (a)	Area (A)	6.307	0.301	0.82579
8.	Discharge (Q)	Width (B)	0.010	2.000	0.780
9.	Discharge (Q)	Depth (D)	5.900	3.000	0.750

S is stream bed slope (m / m), L is stream length (km), A is drainage area (km^2), B is stream width (m), a, is cross sectional area (m^2), D is the stream depth (m) and Q is bank full discharge in cumec.

However the channel depth follows a decreasing trend with increase in both drainage area and length of the main channel, which is contrary to the behavior of alluvial rivers. The channel bed slope has been found to decrease exponentially with increase in both drainage area and channel length. This is also in accordance with the trends in alluvial rivers (Leopold et. al., 1964).

Bank full discharges are positively related to the channel width as well with the channel depth. From above descriptions it is inferred that the piedmont channels are wide, braided and their behavior is different from the alluvial channels. Unplanned human endeavors in these channel areas may surge risk to flooding, land erosion and ultimately environmental degradation in these areas.

2.4 Land Cover

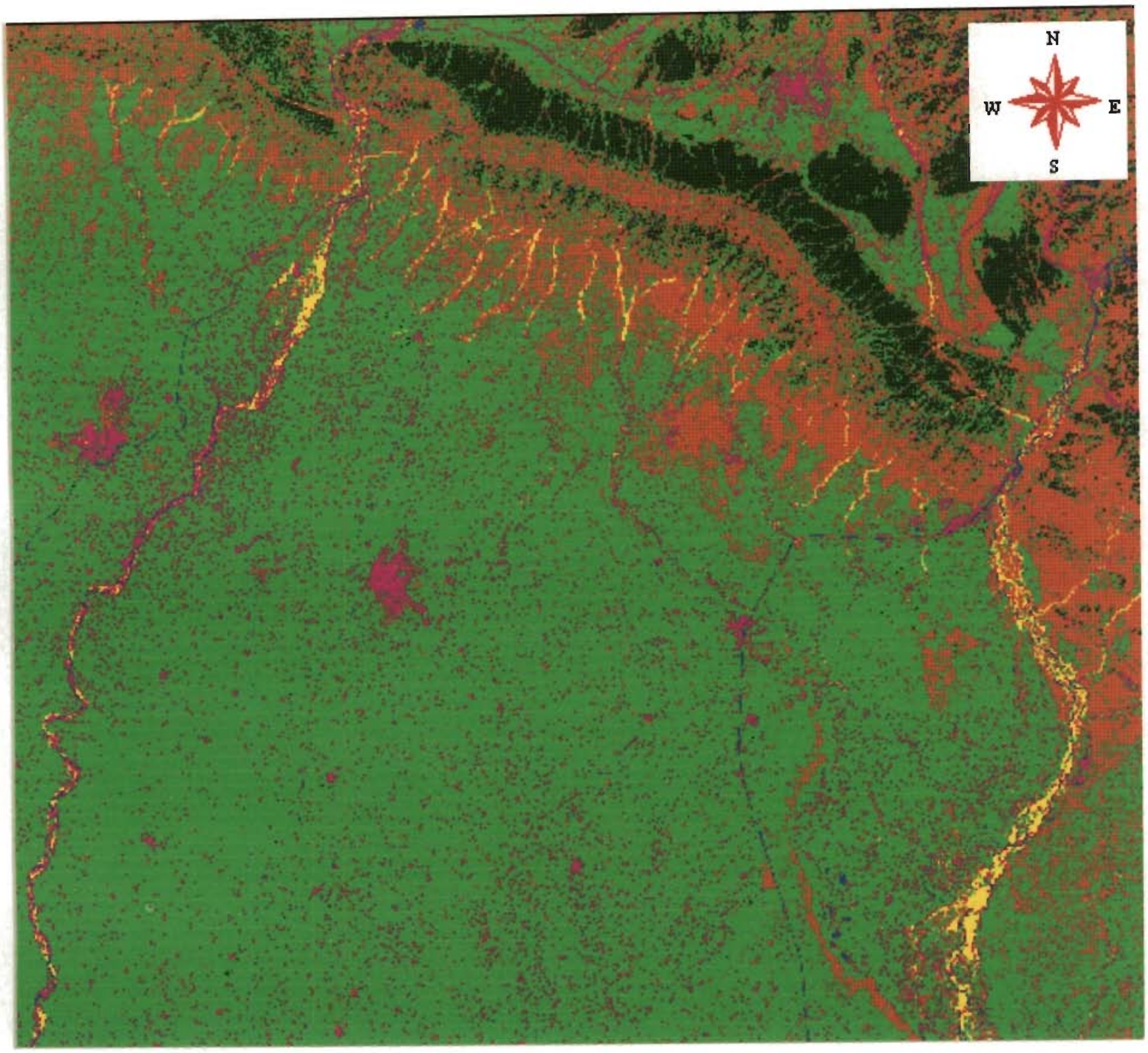
The term land cover relates to the type of feature present on the surface of earth (Lillesand and Kiefer, 1999). Knowledge of land cover is important for many planning and management activities and is considered an essential element for modeling and understanding the earth as a system. Temporal changes in land cover reflects the cumulative influence of all the causative factors. Therefore, study of land cover characteristics helps in deciding the possible use of a land unit. Many workers, (Mc Cormack, 1974; Anderson, 1976; Bergasma, 1983; Nagraja, 2002) have proposed Land cover classification schemes.

For this study the land cover classification prevalent in India (NRSA, 1992), which incorporates the United State Geological Survey land cover classification scheme (Anderson, 1976) has been used. It was decided to classify the land cover of the area in to build up land, agricultural areas, forest land, water bodies, and waste land.

Conjunctive use of Visual and digital analysis of remotely sensed data yields sufficiently accurate results (NRSA, 1989; Atkinson and Curran, 1997; Samant and Subramanyan, 1998; Campbell, 1996; Foddy et.al., 1996; Mather, 1999; Verma et.al., 2001; Krishnan, 2002; Singh et.al., 2002) and hence used for land cover classification. The method of integrating static and dynamic image interpretation elements proposed and advanced by Hilwig, (1980) has been adopted.

Land cover map (Fig. 2.9) of the area was prepared for the years 1926, 1972, 1975, 1985, 1986, 1990 and 2000 through synergistic use of topographic map, False Colored Composite (IRS-LISS II FCC), digital data and field traversing.

In order to test the accuracy of land cover map, 10 field traversing were conducted to cover about 20% of the total area. Accuracy of these maps was found to be about 82%. Land cover statistics during period 1926 to 2000 is shown in the Table 2.5 and Fig.2.10.



Legend

Forest Area
Water
Barren Land
Agriculture
Urban Area
Sandy Area

Fig. - 2.9 Land Cover Map

Table 2.5 Percent Area under Land Use

S. N	Land Use	Year						
		1926	1972	1975	1985	1990	2000	2002
1.	**Forest**	14.65	13.62	16.54	15.4	14.95	14.50	12.5
2.	**Plantation**	5.15	4.58	4.25	5.25	5.25	3.85	3.85
3.	**Agriculture**	15.0	36.73	48.2	66.82	72.25	76.01	79.36
4.	**Sandy/Bare**	64.23	43.72	29.46	10.58	5.45	3.24	1.54
5.	**Urban Area**	0.97	1.35	1.55	1.95	2.1	2.40	2.75

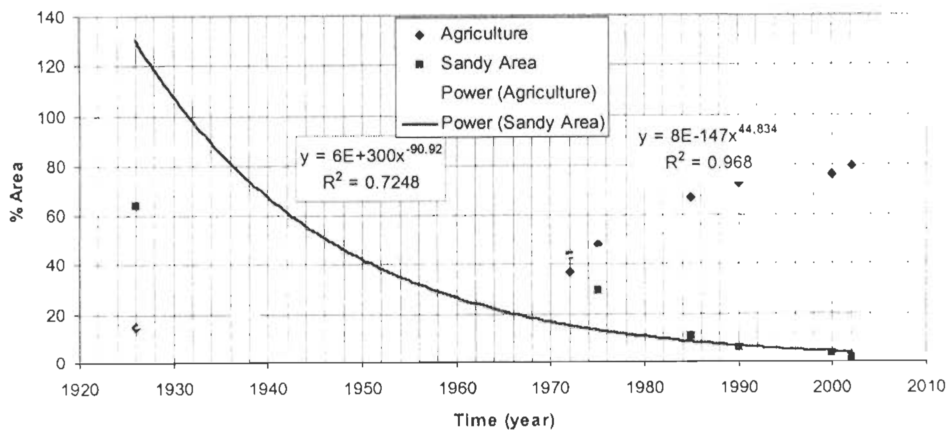


Fig. 2.10 Temporal Variation of Land Use

Conjunctive study of Table 2.5 and Fig.2.9 and 2.10 reveals that, the percentage of land covered both by forest and plantation is showing a gradual decreasing trend. The percentage area of sandy and bare land is also showing a decreasing trend by the faster rate. Percentage area of both rural settlements and agricultural area is showing an increasing trend. Increase in agricultural area has followed the power law. At present the percentage area of agricultural land is about 80%.

Above mentioned inferences followed by field visits goad to infer that in the area to meet out the requirements, the same land is being put to different use in temporal domain. Thus the area is witnessing a very complicated land transformation from one use to another influenced by its terrain, social and economic factors. Land use transformation matrix was hypothesized and shown in Table 2.6

Table 2.6 Land Use Transformation Matrix

From Land Use	To Land Use			
	F	P	C	S
Forest (F)		IC	IC,MP	UP,MP
Plantation(P)	IC		IC,MP	UP,MP
Cultivation	IC	IC		UP,MP
Sandy &Fallow	MP	MP	IC	
UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC)				

From the above table it has been inferred that even though the land use transformation in the area is complex, however, some general trend exists. For example, in the UP geomorphic unit, land transformation is between forests and agricultural activities. The MP unit and the IC units have witnessed large-scale land use transformation. Inter and intra land use transformation took place between forest, fallow, bare, and rural settlements. Further, field traversing confirmed that land utilization in the area is not proper and there is wide scope for improvement.

2.5 Meteorological Characteristics

Meteorological characteristics influence the soil-water-plant system. Therefore, study of meteorological characteristics of an area is essential for deciding its land use. Indian Meteorological Department (IMD), State Government Departments – Irrigation Department, Forest Department, and Indian Institute of Technology, Roorkee, is collecting meteorological data in the study area.

Meteorological data is being collected at Bahadrabad, Dholkhand, Kalsia, Mayapur, Mohand, Muzaffarabad, and Roorkee stations. The available data from different sources was collected, compiled and found to be sufficient. Rainfall, Antecedent Moisture condition (AMC), Rainfall erosion index (EI_{30}), temperature, relative humidity, period of sunshine, wind velocity, potential evapotranspiration are the major meteorological factors influencing the land use. These characteristics of the area are described below:

(a) Rainfall

Rainfall in an area influences the land use in a variety of ways, for example, irrigation requirement, soil erosion, drainage and finally crop suitability. In the area rainfall data is collected at Bahadrabad, Dholkhand, Kalsia, Mayapur, Mohand, Muzaffarabad and Roorkee stations.

For the Bahadrabad station, continuous data is available since 1955 while at other stations data are generally irregular and have gaps. Therefore, the Bahadrabad station is assumed to be the base station and functional relationships between the rainfall at the base station, Bahadrabad, and the rainfall at other stations have been developed (Fig 2.11).

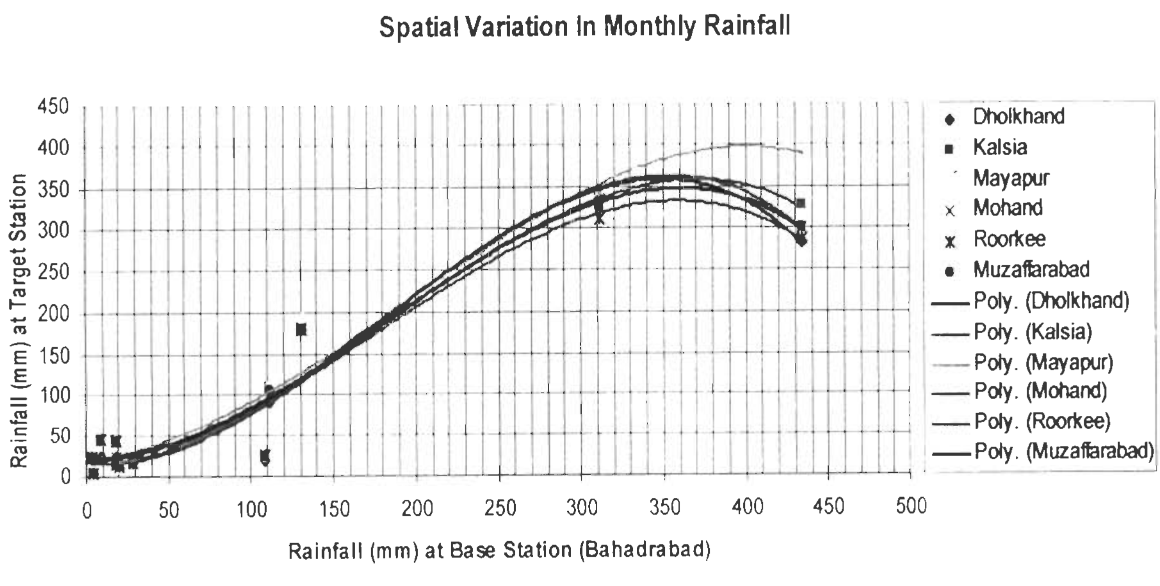


Fig. 2.11 Spatial Variation of Rainfall

From (Fig 2.11) it is inferred that there is a strong correlation between the rainfall at Bahadrabad station and other stations. On monthly basis the coefficient of correlation between rainfall at Bahadrabad and other stations was found to vary from 0.915 to 0.999. This plot (Fig. 2.6) was used to fill up the gaps in the data. Based on observed data during 1955 to 2002 for the Bahadrabad station and for the other stations during 1970 to 2002, average monthly rainfall is tabulated in Table 2.7.

Perusal of Table 2.7 indicates that in the area the average minimum and maximum monthly rainfall is 3.5 cm and 390 cm respectively.

Table 2.7 Average Monthly Rainfall

Month	Average Monthly Rainfall (Cm) At Station						
	Bah	Dhol	Kal	Map	Moh	Roo	Muz
Jan	18.8	24.2	46.5	47.2	25.2	43.2	42.5
Feb	9.4	23.5	46.0	48.8	25.1	45.5	44.5
Mar	4.0	21.5	24.1	26.2	22.3	23.1	22.1
Apr	20.6	11.5	10.4	11.2	12.4	13.5	12.2
May	28.4	16.5	15.2	23.6	18.4	18.5	16.5
Jun	111.6	92.5	108.7	116.3	100.2	98.0	105.7
Jul	312.1	340.5	328.7	345.2	342.4	311.4	324.5
Aug	435.1	282.5	326.4	390.9	300.2	287.3	300.2
Sep	131.2	179.5	181.9	194.6	182.5	180.9	178.4
Oct	108.9	20.4	24.9	25.1	24.2	25.9	24.5
Nov	4.5	3.5	4.3	5.3	4.0	4.3	3.9
Dec	18.5	17.2	18.5	16.5	15.5	16.0	15.5
Annual	1207.3	1033.3	1135.6	1250.9	1072.4	1067.6	1090.5

Bah: Bahadrabad, Dhol: Dholkhand, Kal: Kalsia, Map: Mayapur, Moh: Mohand, Roo: Roorkee, Muz: Muzaffarabad

The distribution of the rainfall is skewed towards higher side. Further, more than 85% of the total annual rainfall occurs during June to September. During this period available rainfall is much higher than the demand. In the remaining period, September to June, the rainfall is much lower than the demand. During this period additional water is required that is to be fulfilled by artificial means.

(b) Antecedent Moisture Conditions (AMC)

Antecedent Moisture Condition (AMC), an indicator of available moisture controls the land use through influencing water-soil-plant system. Three numbers of discrete AMC classes, namely AMC1, AMC2, and AMC3, are defined (Table 2.8).

As per Soil Conservation Service (SCS) criteria (Table 2.8), AMC1 represents dry condition, AMC2 represents the moderate condition and AMC3 corresponds to the wet condition.

Table 2.8 AMC Criteria

AMC Class	**5 days Antecedent Rainfall (mm)**	
	Dormant Season	**Growing Season**
AMC1	< 12.7	< 35.6
AMC2	12.7 - 27.9	35.6 - 53.3
AMC3	> 27.9	> 53.3

In a year the number of days corresponding to each AMC class was counted. The process was repeated to all the seven rain gauge stations. For the area, the number of days corresponding to each AMC level was calculated as spatial average. Average, based on 1970 – 2002 data, AMC level on seasonal basis has been worked out and tabulated in the Table 2.9.

Table 2.9 Seasonal Variation of AMC

Period		Prevalent AMC (days) (Based on 1975– 2001)		
Duration	days	AMC1	AMC2	AMC3
Summer (Mar - Jun)	122 days	85	12	25
Monsoon (Jul – Sep)	92 days	22	15	55
Winter (Oct - Feb.)	151 dyas	133	9	9

From Table 2.9 it is inferred that during summers (March-June) and winters (October-February), the AMC 1, condition prevails for about 70% duration. Whereas during monsoon period (July-September) the AMC2 condition prevails for about 31% and the AMC3 conditions prevails for about 51% duration. These inferences indicate that during the monsoon period available water in the area is more than the demand and during summers the area experiences shortage of water.

(c) Rainfall Erosion Index (EI_{30})

Rainfall induces soil erosion and hence, rainfall erosion index, influences the use of land through risk to crop damage. Rainfall Erosion Index (EI_{30}), is the greatest average rainfall intensity experienced in any 30-minute period, during a storm (Foster et.al, 1977; Wischmeier et.al.1978, Kenneth et.al., 1991; Narain et.al., 1994). EI_{30} is calculated from the following relation.

$$EI_{30} = \frac{KE \times I_{30}}{100} \qquad (2.1)$$

Where, KE= 210.3 + 89 $\log_{10}$ I, is the kinetic energy gained by the raindrops. I, is the intensity of the rainfall in cm/hr, and I_{30}, is the maximum amount of rainfall in 30 minute duration. Calculation of I_{30}, requires rainfall charts showing the temporal variation in rainfall. For this automatic rain gauge is required. In the area rainfall charts are available for Bahadrabad and Roorkee stations only. For these stations first of all individual storms were identified and corresponding EI_{30} , was calculated using equation (1). Average EI_{30} on monthly basis was calculated and tabulated in Table 2.10. Keeping in view the non-availability of rainfall chart an attempt has been made to investigate the relationship between the annual rainfall and EI_{30}. Relationship, in least square sense, having goodness of fit 0.88 is:

$$EI_{30\,a} = 340 + 0.36\, I_y \qquad (2.2)$$

Where $EI_{30,}$ also known as rainfall factor, R, is in ton/hectare/year and I_y is the annual rainfall in mm. On monthly basis above relationship (Fig. 2.12) between $EI_{30.}$ and I is:

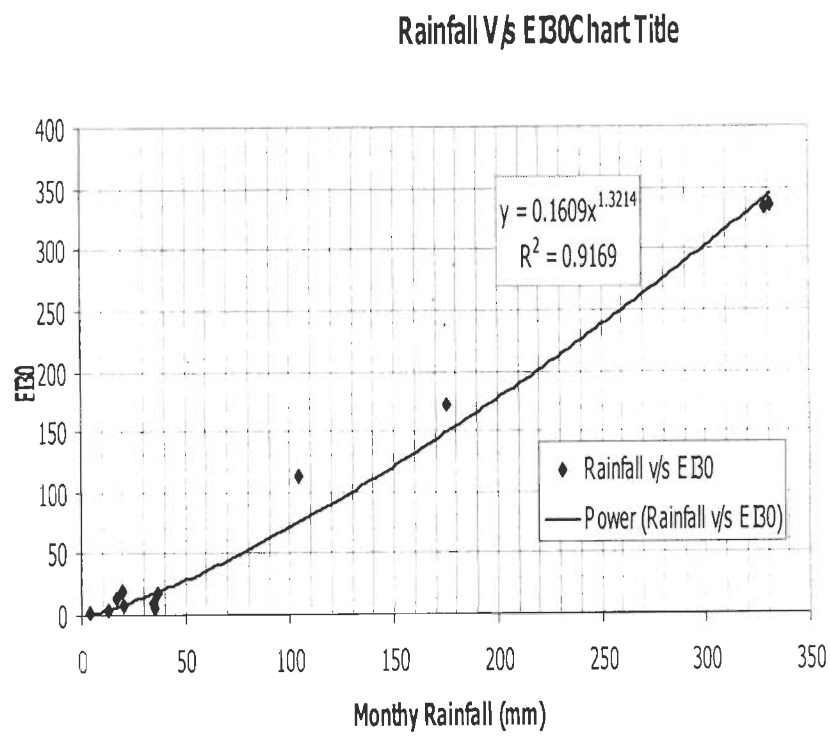


Fig.2.12 Relationship between Rainfall and EI_{30}

$$EI_{30\,m} = 0.169\, I_m^{\;1.3214} \qquad (2.3)$$

Where, $EI_{30\,m}$, is the monthly rainfall erosion Index factor and I_m is the monthly rainfall in mm. In the area, on the annual basis rainfall erosion index varies between 370 and 450. In general it is higher in the north as compared to south. This indicates that upper regime piedmont is more prone to rainfall erosion, restricting its use for agricultural activities.

(d) Air Temperature

Air temperature of an area influences evaporation, transpiration, crop water requirement and other related processes and hence the suitability and land use. For the area daily (1955 to 2000) temperature data is available solitary for Bahadrabad and Roorkee stations. Average temperature on monthly basis is tabulated in Table 2.10.

Table 2.10 Average Meteorological data

Month	Temperature (^{0}C)	Relative humidity (Rh in %)	Sunshine duration (Hours/day)	Wind velocity (Km/ hr)	ET_0 (mm/day)	EI_{30}
Jan	13.4	91.5	9.5	3.0	1.54	5.9
Feb	15.5	88.5	10.4	3.7	2.53	10.1
Mar	19.85	79.0	10.3	5.6	3.92	8.7
Apr	25.13	60.0	12.0	4.5	6.56	3.6
May	29.9	47.0	12.3	5.8	8.95	19.8
Jun	31.15	70.5	10.2	4.5	5.49	113.8
Jul	29.03	84.5	10.2	3.6	3.38	334.4
Aug	29.35	90.5	10.6	2.6	3.45	335.4
Sep	27.23	90.0	10.2	2.7	3.98	171.0
Oct	21.35	89.5	10.7	2.2	3.45	17.1
Nov	13.9	89.5	10.1	2.1	2.49	1.0
Dec	10.48	94.5	9.1	2.6	1.78	14.1

Analysis of Table 2.10 indicates that on an average basis air temperature range from 10^0 C to 31^0 C. Monthly average temperature was found to be minimum (10.48^0 C) in December whereas, it is maximum (31.15 ^{0}C) during June. Ever minimum and maximum temperatures of $-1.7\ ^0$C and 45.6^0 C were recorded on Jan 29, 1964 and June 17, 1958 respectively.

In the summers the average monthly temperature 29^0 C and 31^0 C. The maximum temperature during this period varied from 30.3^0 C to 45.6^0 C while the minimum temperature varied from 4.2^0 C to 22.7^0 C. The above values varied from 21.6^0 C to 36.4^0C and -1.7^0 C to 15.6^0 C respectively in winters. March, April and May were the months of largest diurnal variation of temperature when nights were cooler and days were comparatively hotter.

In the rainy season, the monthly maximum and minimum temperature varied from 33.6 C to 41.3^0 C and 15.0^0 C to 26.6^0 C respectively. During the period from July to September the monthly average temperature fluctuated between 27.2^0 C and 31.5^0 C. The above description infers that the area witnesses a large variation in temperature. Thus, the area can support a variety of crops from the rainfall considerations.

(e) Relative Humidity

Relative humidity (Rh) influences the soil-water-plant system and hence the land use. Observed data indicate that in general, the relative humidity was found to be higher in antemeridian hours than the hours of post meridian. During rainy days when the sky remained cloudy through out the day, relative humidity showed almost no variation. Average monthly relative humidity data for the area is tabulated in Table 2.10.

Average relative humidity is maximum (94.5%) during December, whereas it is minimum (47.0%) during May. During July to February, the average relative humidity remains more than 84.0%. During the period of March to June average relative humidity varies between 47.0% and 79.0%. Its ever maximum and minimum values were 100 % and 45 % respectively. April and May months were comparatively dry months when the value of maximum and minimum relative humidity was of the order of 60 % and 47 % respectively. The ever minimum humidity of only 2 % was observed on April 24, 1969. Above inferences goad to conclude that during the monsoon period relative humidity is comparatively higher as compared to the non monsoon period. Thus during non monsoon period the crop water requirement will be higher. Hence water demand is to meet by artificial methods.

(f) Sunshine Duration

Sunshine duration influences the soil-plant-water system and hence the land use. Average monthly sunshine duration for the area is tabulated in Table 2.10. Perusal of this table indicates that on an average for whole of the year sun shines for 8 hours a day. The average maximum sunshine duration is highest (12.3 hours) during May, where as it is least (9.1 hours) during December. During the period June to October, and February to March, it is more than 10 hours.

There were several days in a year when sun was not seen at all due to clouds. On the contrary sun was seen for more than 12 hours on many days in the months of May and June. Sun was perceived for a maximum period of 12.9 hours on May, 20, 22, and 24, 1963, and May 24 and 25, 1964. From above it can be inferred that from sunshine duration point of view, the area can sustain a variety of crops.

(g) Wind velocity

Wind velocity have an effect on the soil-plant-water system and hence the land use. Average monthly wind velocity for the area is tabulated in Table 2.10. Wind velocity is maximum (5.8 Km/hr) during May, whereas it is minimum (2.1 Km/hr) during November. During January and February months the wind velocity was more than 3.0 Km/hr, whereas during March to June it is more than 4.5 Km/hr. For the remaining period it is more than 2.1 Km/hr. Wind velocity of more than 12 Km/hr was observed on several days during the month of May. The ever maximum instantaneous maximum velocity of the order of 115 Km/h with its direction west-northwest was observed on May 27, 1971 at 2.50 am.

(h) Potential Evapotranspiration (ET_0)

Potential evapotranspiration (ET_0) influences soil-water-plant system. It influences the water requirement for crop and hence the suitability of a precise crop in a precise area. Temporal variation of potential evapotranspiration is tabulated in Table 2.10. Perusal of this table indicates that the maximum value of ET_0 , is 8.95 mm /day during the May, whereas its minimum value is 1.54 mm/day during January.

During summers (April, May and June) its value is highest (between 5 mm/day and 9 mm/day) while in winters it is about 2 mm/days. In remaining months it ranges between 3 mm/day and 4 mm/days.

It indicates that water requirement of crop will be minimum during winters and maximum during summers. Therefore, for crop growth additional water through artificial means is required during summers.

2.5.1 Interrelationship Between Meteorological Parameters

From above description it is clear that air temperature (T), relative humidity (Rh), sunshine duration (S), wind velocity (w), rainfall (R), potential evapotranspiration (ET_0), number of rainy days (n) and rainfall erosion index (ET_{30}) all individually and collectively influence the soil water plant system.

Table – 2.11 Meteorological Parameters – Correlation Matrix

Parameters	**T**	**Rh**	**S**	**w**	**R**	**ET_0**	**n**	**EI_{30}**
Temperature (T^0 C)	1							
Relative Humidity (Rh %)	-0.54	1						
Sunshine Duration (S)	0.57	-0.85	1					
Wind Velocity (w)	0.4	-0.82	0.56	1				
Rainfall (R mm)	0.6	0.24	-0.1	-0.21	1			
Evapotranspiration (ET_0)	0.7	-0.96	0.88	0.72	-0.10	1		
Rainy Days (n)	0.6	0.19	-0.41	-0.05	0.96	-0.08	1	
Rainfall Erosion Index EI_{30}	0.6	0.20	-0.08	-0.20	0.99	-0.05	0.96	1

These meteorological parameters are interrelated in complex manner. Correlation matrix between various meteorological parameters is tabulated in Table - 2.11. A perusal of Table 2.11 indicates that the meteorological parameters are interrelated with varying degree of strength is reflected by the coefficient of correlation (ρ) that range between 0.05 and 0.96. Further air temperature and rainfall are highly related with other meteorological parameter.

Therefore, rainfall and temperature can be assumed to be representative of the meteorological regime of the area, and these are easily available parameter. Further potential evapotranspiration is an indicator of crop water requirement. Observation of this parameter is difficult and costly affair. In lack of observed data it is generally estimated from observed data.

2.5.2 Estimation of Evapotranspiration – A New Approach

Review of the literature (Chow 1964, Singh 1989) indicates that for the estimation of evapotranspiration the most commonly used methods are Blaney Criddle method, Radiation method, and Penman method. For the areas where measured data on temperature, humidity, wind and sunshine hours are available, modified Penman equation is in wide use (Singh 1989). Therefore in this study modified Penman equation has been used. A comparison of numerical values of ET_0 as obtained from evaporation data and meteorological data has been made in the Table 2.12.

A close look of the above table reveals that though the numerical values of ET_0 by the two approaches are comparable, however, there is a large deviation in few months. This deviation may be attributed to the assumed value of the surface reflection coefficient (α). In absence of reliable data generally the numerical value of the surface reflection coefficient is assumed to be 0.25.

Table 2.12 Comparison of Evapotranspiration

(Based on 1980-2000)

Month	Evapotranspiration (ET_0) in mm/day	
	Observed	α **= 0.25**
Jan	1.54	.96
Feb	2.35	1.71
Mar	3.92	2.67
Apr	6.56	5.5
May	8.95	9.21
Jun	5.49	6.34
Jul	3.38	5.3
Aug	3.45	4.53
Sep	3.98	4.35
Oct	3.45	3.16
Nov	2.49	1.26
Dec	1.78	1.37

An effort has been made to work out the surface reflection coefficient and then after numerical values of ET_0 was revised. Surface reflectance of earth features was observed by Reflectance Spectra Radiometer. The average surface reflection coefficient was computed from the observed reflectance data.

Field experimentation was carried out and surface reflection coefficient was determined for some of the prevalent land use in the area. On the basis of the 450 field observations on different land use, average surface reflection coefficient was computed and tabulated in Table 2.13.

Analysis of the Table 2.13 indicates that the surface reflectance is minimum (0.08) for the water bodies, whereas, it is maximum (0.32) for the green grasses. These (Table 2.13) average surface reflection coefficient (α) was used as input to the Modified Penman equation and evapotranspiration was calculated. For this the MS Excel software was customized. The revised, computed values of evapotranspiration along with the observed values are tabulated in Table 2.14 and graphically shown in Fig. 2.13.

Table 2.13 Surface Reflection Coefficient

Sn.	Land Cover Feature	Surface Reflection Coefficient (α)		
		Minimum	Maximum	Average
1	Water Surface	.06	.10	.08
2	Dry Sand	.25	.35	.30
3	Moist Sand	.09	.18	.10
4	Clay	.05	.15	.10
5	Plants	.15	.30	.20
6	Wheat	.10	.15	.15
7	Sugarcane	.05	.18	.20
8	Potato	.15	.27	.2
9	*Barseem*	.19	.25	.2
10	Vegetables	.20	.25	.22
11	Meadow	.15	.26	.2
12	Dry grass	.30	.35	.32
13	Green Grass	.25	.27	.25
14	Forest	.10	.15	.10

Table 2.14 Observed and calculated Evapotranspiration

(Based on 1980-2000)

Months	Average Surface albedo	Evapotranspiration (ET_0) in mm/day		
		Observed	Calculated based on surface *Albedo* (α)	
			α = 0.25	Spatial average α
Jan	.1242	1.54	.96	1.30
Feb	.1259	2.35	1.71	2.10
Mar	.1360	3.92	2.67	3.70
Apr	.1470	6.56	5.5	6.45
May	.1510	8.95	9.21	9.00
Jun	.1880	5.49	6.34	5.60
Jul	.2087	3.38	5.3	3.50
Aug	.2071	3.45	4.53	3.60
Sep	.2131	3.98	4.35	4.00
Oct	.1670	3.45	3.16	3.50
Nov	.1885	2.49	1.26	2.35
Dec	.1240	1.78	1.37	1.60

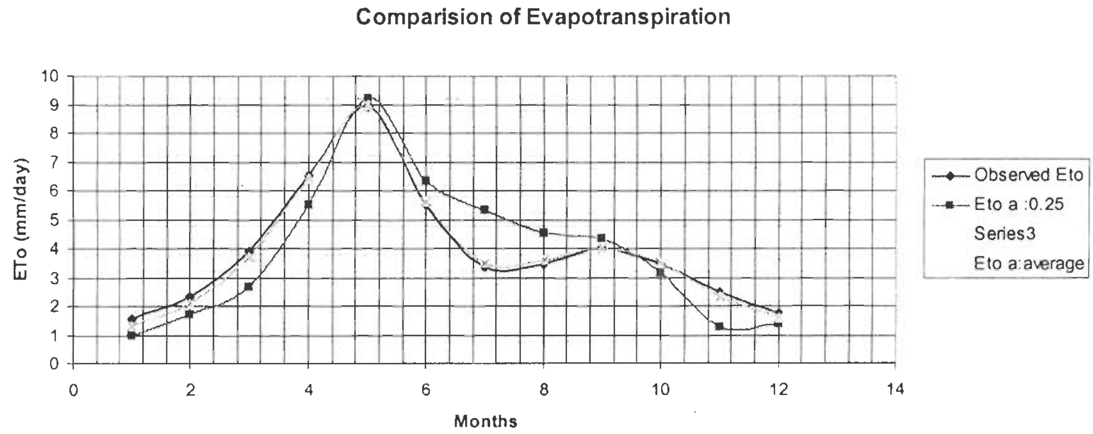


Fig. 2.13 Comparison of Evaopotranspiration

Conjunctive analysis of Table 2.14 and Fig. 2.13 reveals that the revised results are found to match (Fig.2.13) very well with the observed values. Further, temperature data are generally available; hence relationship between temperature and ET_0 has developed in least square sense. A simple relationship to estimate the ET_0 from temperature is shown in Fig. 2.14.

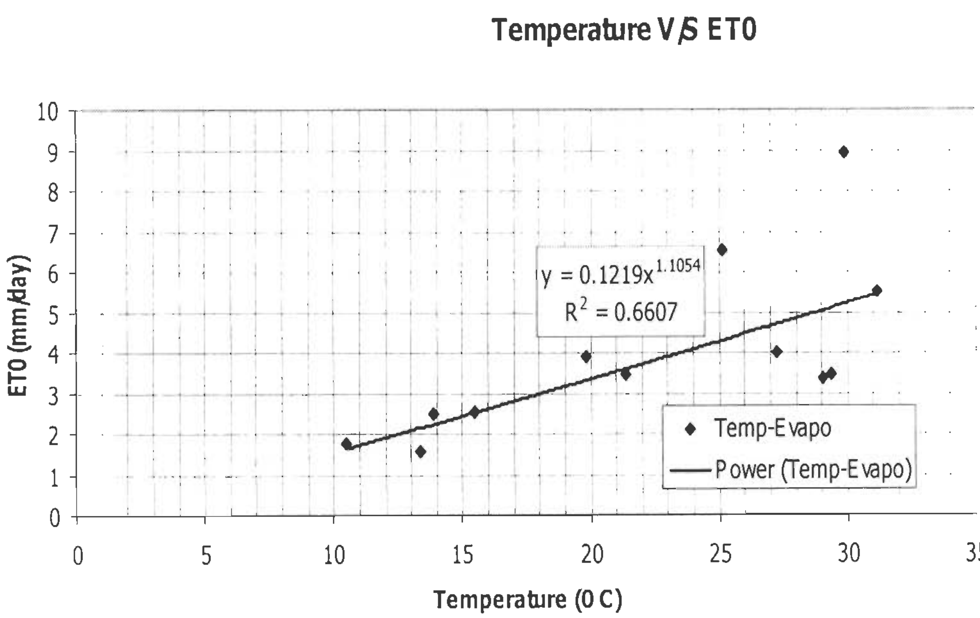


Fig. 2.14 Relationship Between Temperature and ET_0

2.5.3 Trend Analysis

From above description it is inferred that the land use of an area heavily banks on temperature and rainfall regime of the area. Hence, temperature and rainfall data were put to the trend analysis. The result of the study indicate that in general during the period 1955 to 2000, annual maximum and minimum temperature are showing a gradual rising trend. However, on seasonal basis pattern is found to be erratic. During the period March to November, the maximum temperature is showing a rising trend, whereas, the minimum temperature is showing a declining trend. During, December to February, the maximum temperature is showing a decreasing trend, whereas, the minimum temperature is showing a rising trend.

On annual basis, average temperature is showing an increase of about 0.190^0 C. This trend is found to show a seasonal movement being, about 0.2^0 C in the pre-monsoon season and about 0.15^0 C during monsoon and about 0.3^0 C after post monsoon. Monthly rainfall data does not show any significant trend. It is inferred that the rainfall in the area shows an erratic behavior.

Table 2.15 Terrain Characteristics of Geomorphic Units

Parameters	UP	MP	Geomorphic Unit			CB
			IC			
			I_1	I_2	I_3	
Area (%)	17.4	12.6	19.6	14.4	29.4	6.6
Elevation (m)	> 350	300-350	250-300	250-300	250-300	200-300
Slope (degree)	> 3	2=3	< 2	< 2	< 1	< 1
Drainage	Braided	Braided	Sub Parallel	Sub Parallel	Sub Parallel	
Annual Rainfall (mm)	1110	1200.1	1050	1050	1050	1050 - 1200
EI_{30}	742	773	724	724	724	724-773

2.6 Closing Interpretation

Land use of an area relates to the human activity or economic function. Whereas land cover relates to the type of feature present on the surface of the earth. Besides other factors the land use of an area depends upon its terrain characteristics. Preliminary analysis of the available data indicated that these are not adequate. Synergistic use of remotely sensed data, aerial photographs, topographic sheets and field surveys for updating and augment the existing database was found cost-effective.

From Geomorphic considerations the area has been classified in to four geomorphic units. The Upper Regime Piedmont (UP) that is in contact with the Siwaliks. This unit is characterized by highly undulated and steep land sloping south ward and frequent stream migration. The Middle Regime Piedmont (MP) lying south of the UP Geomorphic unit, is characterized by moderate undulation, moderately sloping southward and frequent stream migration.

The third geomorphic unit, the Inter Channel plainer area (IC) lying south of the MP geomorphic unit has been sub divided in to three sub units namely, I_1, I_2, and I_3, on the basis of topographic variation and risk to flooding. The sub unit I_1, is low land along banks of streams, subjected to frequent flooding and river meandering. The sub unit, I_2 is characterized by high land along both banks of streams, subjected to periodic or occasional flooding and stream migration, whereas the sub unit I_3 is relatively free from flooding. This sub unit is triangular area lying between two streams. Channel braid bars (CB) are high lands in the stream course made up of heterogeneous mixtures of sand and loam.

In addition to the perennial rivers Ganga and Yamuna the area is traversed by three major seasonal streams, namely, Hindon , Solani and Ratmau. These rivers flow from southern face of Siwaliks down south ward. In general the sub basins are elongated which are characterized by quick runoff and high sediment yield. Braided drainage pattern in the UP and MP unit are indicative of high permeability. Parallel to sub parallel drainage pattern in the IC geomorphic unit indicates low permeability and influence of topography.

Agriculture is the major (about 80%) land use in the area. Besides agriculture the area is covered by forest, plantation, and rural settlements. During the period 1926 to 2002, in general, agricultural activities and rural settlements are increasing, whereas the bare and barren land is shrinking. In meet out the requirements some units are under going frequent land transformation.

In the area, meteorological data are being collected at Bahadrabad and Roorkee, Mayapur, Dholkhand, Muzaffarabad, Mohand and Kalsia stations. Rainfall at Bahadrabad station is strongly related with Rainfall at other stations (correlation coefficient more than 0.85). On long-term (1955-2002) basis annual rainfall in the area varies from 1050 mm to 1200 mm. About 80% of the total annual rainfall occurs during June to September, On annual basis, AMC1 condition prevail for about 50% of time, AMC2 condition for about 11% of time and AMC3 condition for about 39% of time. Average temperature during summers is about 30^0 C and during winters it is 15^0 C. Average Humidity ranges from 70% to 90%. Average sunshine duration ranges from 9 hrs to 12 hrs. Wind speed ranges from 2 Km/hr to 5.8 Km/hr. Monthly Evapotranspiration varies from 1.7 mm/day to 8.95 mm/day.

As such the terrain characteristics of the area suggest that the area can support a variety of land use.

3

SOIL RESOURCES

3.0 Background

Workability, drainage and water retain ability of the loose surface deposits, the soils, influences its use. These factors act and interact among themselves and ultimately affect the growth of natural vegetation and crops. Literature survey indicates that few studies have been carried out to estimate the soil characteristics for land use in this area. The soil maps available from National Thematic Mapping Organization, are of general nature, on scales smaller than 1:1,000,000. For the land use planning, detailed maps at scale, 1:50,000 or larger depicting the soil properties are required.

Soil properties influencing the land use are its thickness, texture, structure and chemical composition. Preliminary field survey indicated that soils in the area mainly the gravel sand along with some silt and clay. In general, soil grain size is decreasing from gravelly in the north to sandy silt in the south.

This pattern closely follows the spatial pattern of geomorphic units. The UP and the MP geomorphic unit are largely covered by coarse grained sandy soil. The IC unit is covered by sandy loam or loam sand soil.

Keeping in view the data required and their scarcity in this study an attempt has been made to assess the soil properties of the various geomorphic units with a view to assess and evaluate the land use of the area. The details of the investigations are given below.

3.1 Soil Texture

The relative proportions of different sized soil grains determine the texture of deposits. Field investigation indicate that the soil in this area has grains ranging from gravel (more than 2 mm), sand (2 mm to 1/16 mm), silt (1/16 mm to 1/256 mm) to clay (less than 1/256 mm) occurring in different proportions. The northern part of the area is rich in gravels, ranging from pebbles (4 mm – 64 mm), cobbles (64 mm – 256 mm), to boulders (> 256 mm) up to 1500 mm.

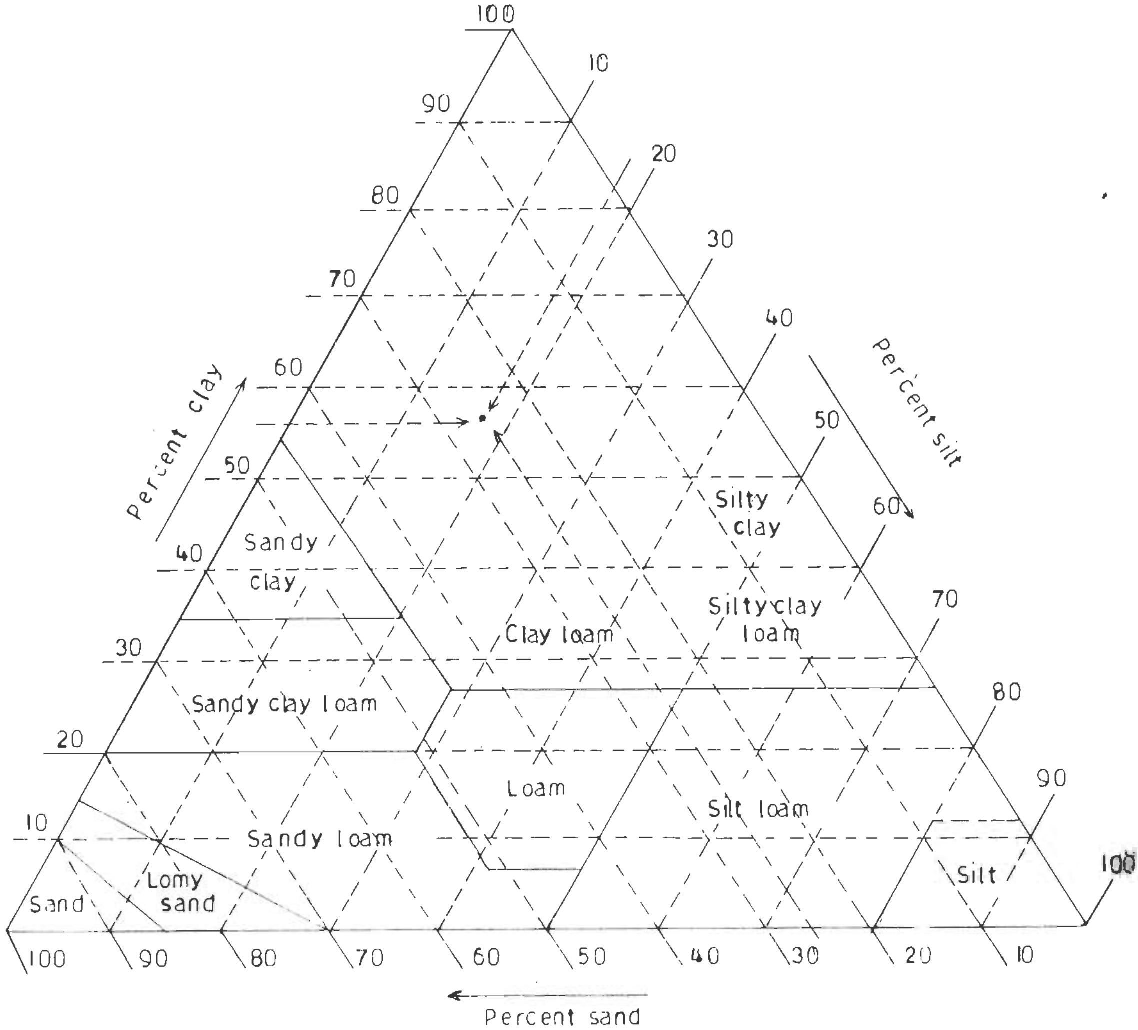
However, in this gravel rich regime, lenses of relatively finer sediments namely finer-granules (2 mm – 4 mm), sand, and silt with little clay are also found. The gravel rich soil is of little use for the agriculture. The relatively fine grained soils are the one that support agriculture.

In this study the textural soil classification scheme for the agriculture (Fig.3.1), proposed by United States Department of Agriculture (USDA, 1960) has been used. The basis of this classification scheme is the percentage of sand, silt and clay in the soil. Hence grain size analysis of soil was attempted.

A total of 250 field sites were selected and care was taken that these field experimentation sites are well distributed throughout the area representing the soil character of the geomorphic units present in the area.

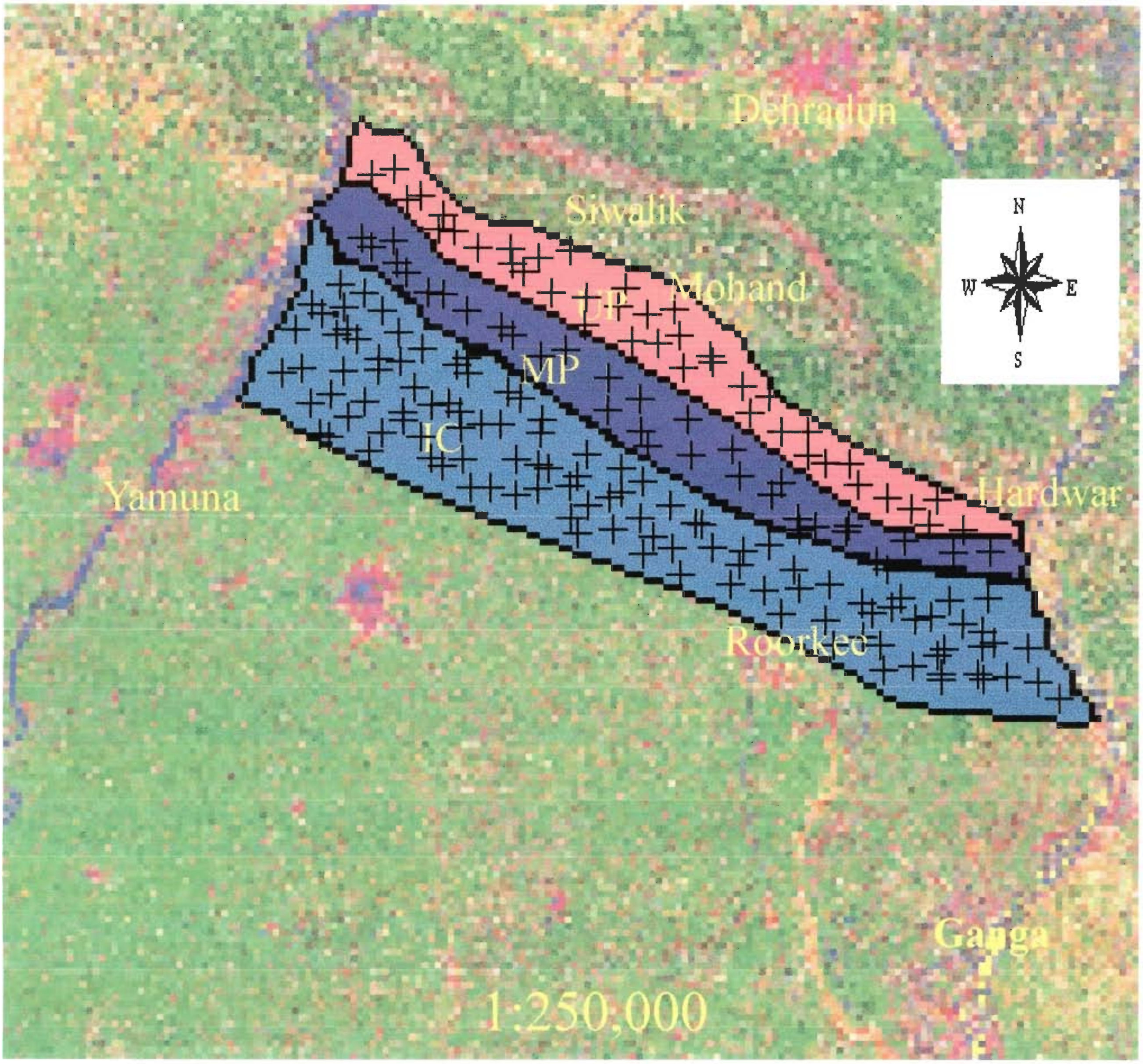
Thus, 40 site in the UP, 30 sites in the MP, 80, 30 and 50 sites respectively in the I_1, I_2, and I_3, and 20 sites in the CB geomorphic units were selected (Fig.-3.2). For grain size and other laboratory analysis about 2 kg soil samples were collected from these sites. In the UP and the MP geomorphic units the soil samples collected were from locations where lenses of fine grained soil are available.

The soil samples were subjected to Sieve Analysis in the laboratory. This analysis was carried out according to the recommendations of IS 1498 – 1970. For each sample a grain size distribution curve (Fig.-3.3) was prepared.



The use of the textural triangle is demonstrated by dashed arrows. The intersection Of these arrows represents a clay soil that is 26% sand, 56% clay, and 18% silt.

Fig. 3.1 Textural Soil Classification (USDA, 1960)



+ Sampling Sites

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.3.2 Soil Sampling Sites

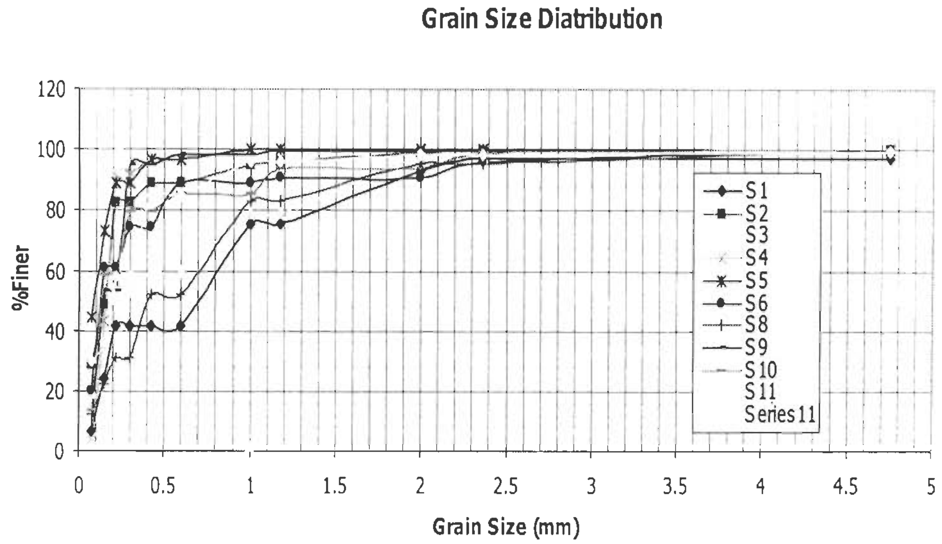


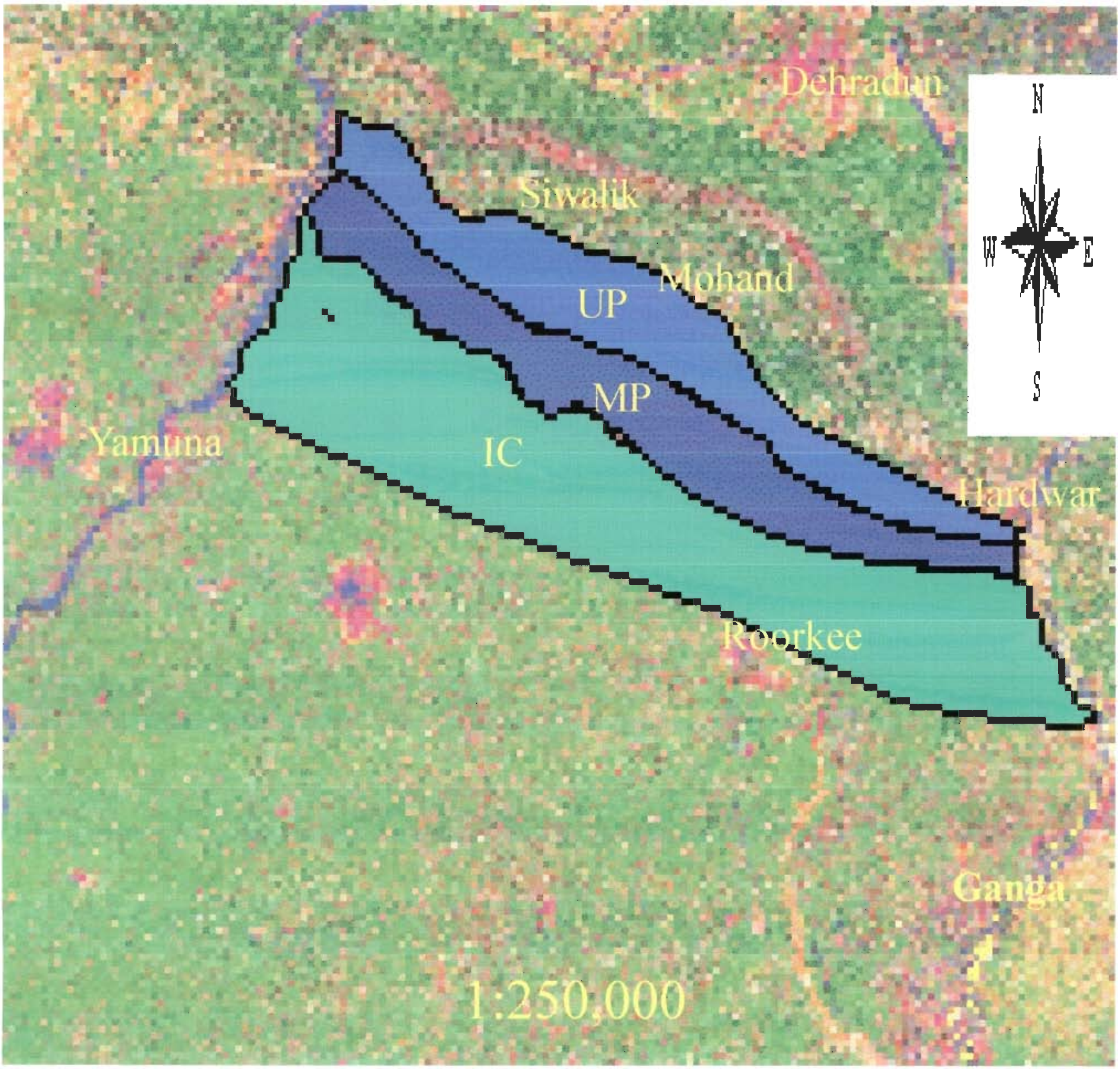
Fig.3.3 Grain Size Distribution Curves

From these curves percentage of sand, silt and clay along with mean grain size d_{50} was estimated. Synthesis of laboratory and field experimentation was done and result is tabulated in Table -3.1. Spatial distribution of soil texture in the area is shown in Fig. 3.4.

Table -3.1 Soil Textures of Geomorphic Units

Geomorphic Unit		Grain Size Spectrum (%)			Soil Texture	d_{50} (mm)	
		Sand	Silt	Clay		Range	Average
UP		>85	<15	<10	**Coarse Gravel**	1.0 – 2.0	1.5
MP		>85	<15	<10	**Medium Sand**	1.0 – 0.5	0.8
IC	I_1	50 - 80	<50	<20	**Sandy Loam**	1 – .025	0.6
	I_2	70 -80	<50	<20	**Loamy Sand**	1 – .025	0.3
	I_3	50 - 80	<50	<20	**Sand Loam**	1 – .025	0.3
CB		>85	<15	<10	**Sand**	1.0 – 0.5	0.8

A perusal of Table -3.1 and analysis of Fig. 3.4 indicates that, the soil in the UP geomorphic unit is coarse textured. This is reflected by their higher percentage (. 85%) of coarse grained sand and low percentage (< 15%) of silt clay fraction and d_{50} (2.0 mm -1.0 mm) of the soil. Soil in the MP geomorphic unit is also coarse grained, d_{50} (1.0mm -0.5



Soil Texture

	Sand - Loam
	Medium Sand
	Coarse Gravel

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig. 3.4 Spatial Distribution of Soil Texture

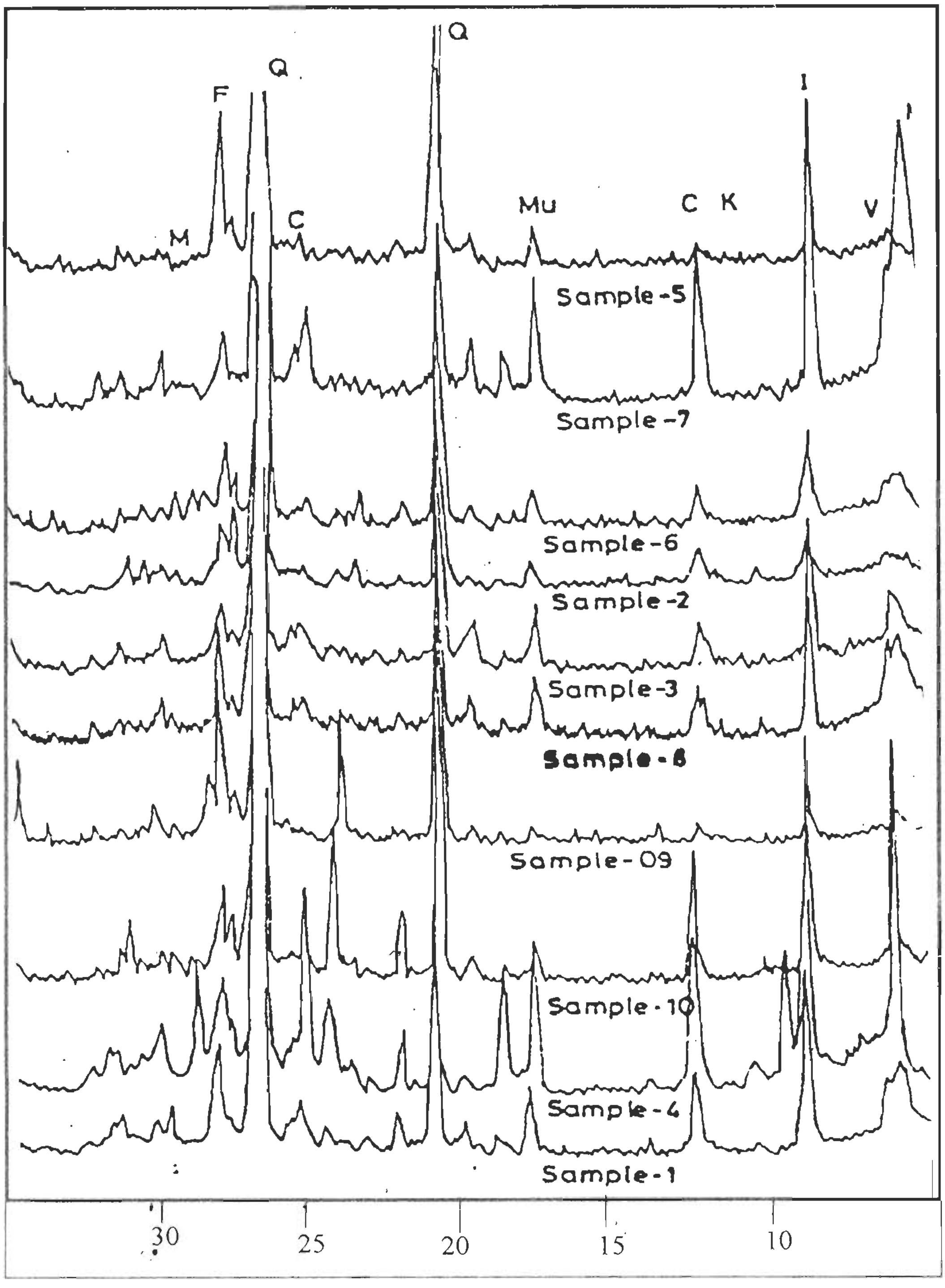
mm) but comparatively finer than the soils of the UP geomorphic unit. In the sub unit I_1 the soil are finer (d_{50}, 1.0mm -0.025mm) than the soil in the MP geomorphic unit. It is generally sandy loam in nature. Soil in the sub unit I_2 is finer as compared to the soil of I_1. This trend continues in the sub unit I_3 , as well. Soil in the CB geomorphic unit shows a large variation (d_{50} 0.5-3.5) in the soil grain size and hence the soil texture.

Thus, the grain size spectrum indicates that in the area, soil properties show a large variation in spatial domain. Soils both in the UP and MP geomorphic units are coarser having large volume of non capillary pore spaces, which ensures good drainage and aeration. Soils in this area are generally loose and non – cohesive and have a low water holding capacity.

In these geomorphic units some isolated patches of relatively finer soil are also seen. Soil in sub units I_1, I_2, and I_3 contain more or less equal amounts of sand and silt. Soils in IC geomorphic unit, are finer and clay rich than those of MP geomorphic unit. These soils are favorable for holding water, easy to work and aerated. Braided bars of the channels show a large variation in their behaviors from north to south. From above it has been inferred that in the north soils are coarser and it is finer towards south. Further, it can be grossly concluded that IC geomorphic unit is comparatively more suitable for agricultural activities.

3.2 Soil Minerals

Mineralogical composition of soil influences the crop growth and hence its use. Petrographic investigations indicate that the boulders, cobbles, pebbles and sand are of heterogeneous nature with various types of rocks mainly quartzite with small amount of sand stone, hyalites and lime stone. The sand and silt are made up of mainly quartz with mica and feldspar. Mineralogical composition of the clay fraction was determined by X – ray diffraction obtained using Philips diffractrometer with Nickel filtered radiation. The soil samples were scanned over a range of 5 to 35 degrees and X – ray diffraction patterns (Fig. 3.5) were obtained.



C- chlorite, F-Feldspar, Q-Quartz, I-illite, K-Kaolinite, M-Montmorillonite, Mu-Muscovite, V-Vermicualite

Fig. 3.5 X-Ray Difractograms of the powder of soils

Analysis of these diffraction patterns indicates that the soils of the study area are responsive at 6^0, 9^0, 17^0, 21^0, 26^0, and 28^0. Further, clay minerals in the soils of the study area are mainly Kaolinite, Illite with same Vermicullite and Montmorillonite. Spatial variation in the mineralogical composition may be attributed to their gneiss. From mineralogical considerations it is inferred that the soils of the area can support a variety of crops.

3.3 Soil Salinity and Alkalinity

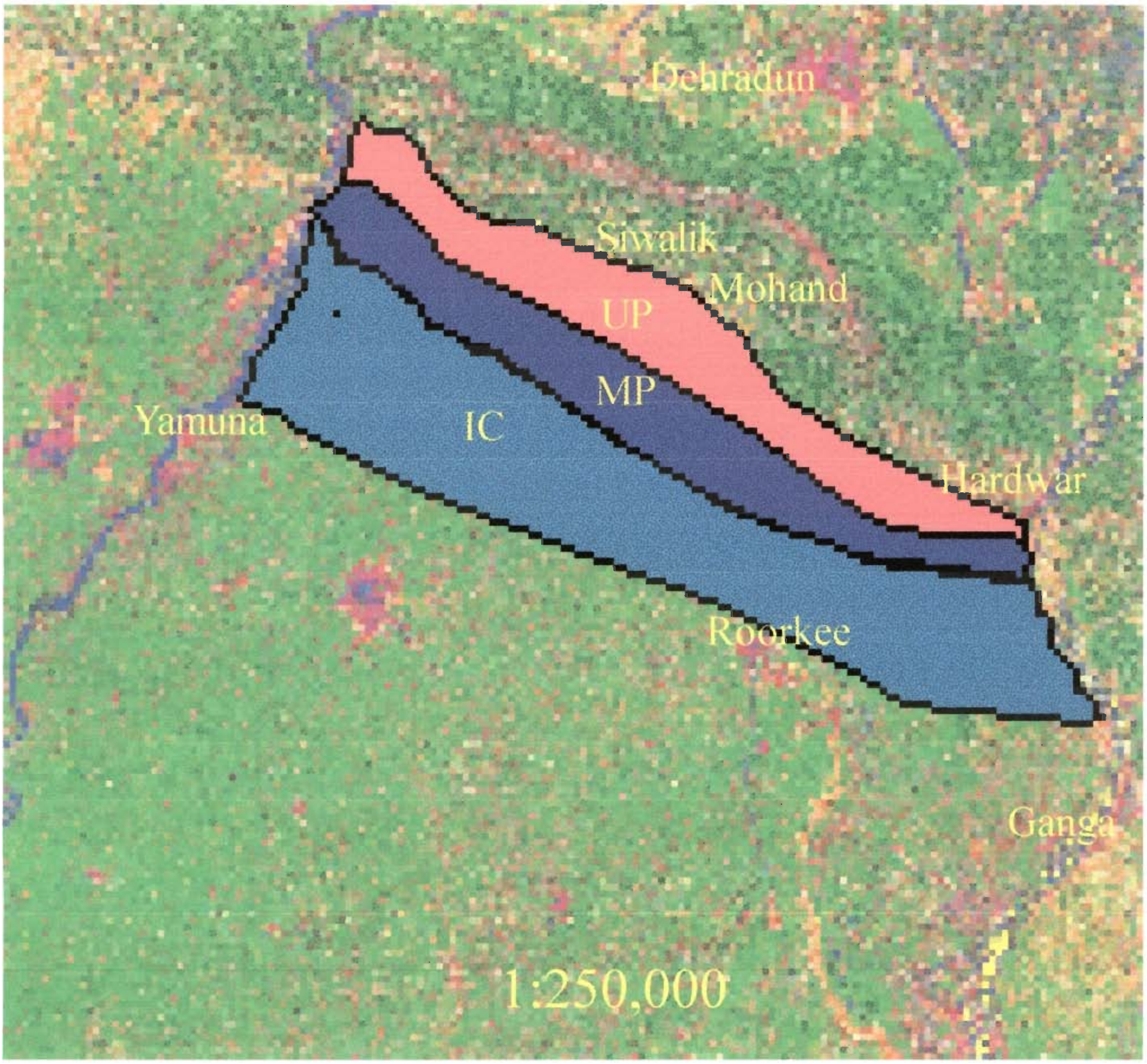
Soil salinity and alkalinity in addition to its texture and structure influence crop growth and hence the land use. The soil salinity is measured as its electrical conductivity. The electrical conductivity (EC) of soil was measured with the help of a conductivity meter whereas; soil alkalinity is measured as its pH that was measured by pH meter. The electrical conductivity and pH of soils in different geomorphic units were assessed. Thus soil samples from 8 sites in the UP, 6 sites in the MP, 16, 6 and 10 sites respectively from the, I_1, I_2 and I_3 and 4 sites in CB geomorphic units were selected, tested and the test results are tabulated in Table -3.2, and graphically shown in Fig.3.6.

Table -3.2 Electrical Conductivity and pH of Soils

Geomorphic Unit		Electrical Conductivity (ds m^{-1})		pH	
		Range	Average	Range	Average
UP		0.04 – 0.08	0.06	7.5 – 8.0	7.8
MP		0.08 – 0.20	0.15	7.4 – 7.9	7.7
IC	I_1	0.15 – 0.25	0.21	7.1 – 7.4	7.3
	I_2	0.15 – 0.25	0.21	7.1 – 7.4	7.3
	I_3	0.15 – 0.25	0.21	7.1 – 7.4	7.3
CB		0.04 – 0.12	0.08	7.3 -- 7.9	7.8

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars.

Conjunctive analysis of Table -3.2 and Fig.3.6 indicates that the numerical value of the electrical conductivity in the UP unit is lowest (0.04 dsm^{-1}); in the MP unit it is 0.08 dsm^{1} – 0.2 dsm^{-1}, and is highest, 0.25dsm^{-1}, in the IC unit. The CB geomorphic unit shows maximum variation (0.04 – 0.12 dsm^{-1}) in the conductivity. This indicates that in the



EC (0.15-0.25)
EC (0.08-0.20)
EC (0.04-0.08)

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.3.6 Spatial Variation Of Soil Salinity north electrical conductivity is lowest (0.04 dsm^{-1}) and towards south it is showing an increasing pattern and attains highest value (0.25 $d\ s\ m^{-1}$).

The spatial variation of pH is showing a reverse trend as compared to electrical conductivity. In the UP geomorphic it is highest (7.8), in the MP geomorphic unit it is 7.7, whereas in the IC unit it is lowest (7.1). The CB geomorphic unit shows maximum variation in the pH (7.3 – 7.9). In the north it is highest and towards south it is decreasing.

From above it is inferred that in the area electrical conductivity of soil varies from 0.04 to 0.25 $d\ s\ m^{-1}$ indicating that soils are free from salinity hazard. The pH of the soil varies from 7.1 to 8.0, indicating that soils are slightly alkaline but close to neutral. Hence the area is suitable for a variety of agricultural practices.

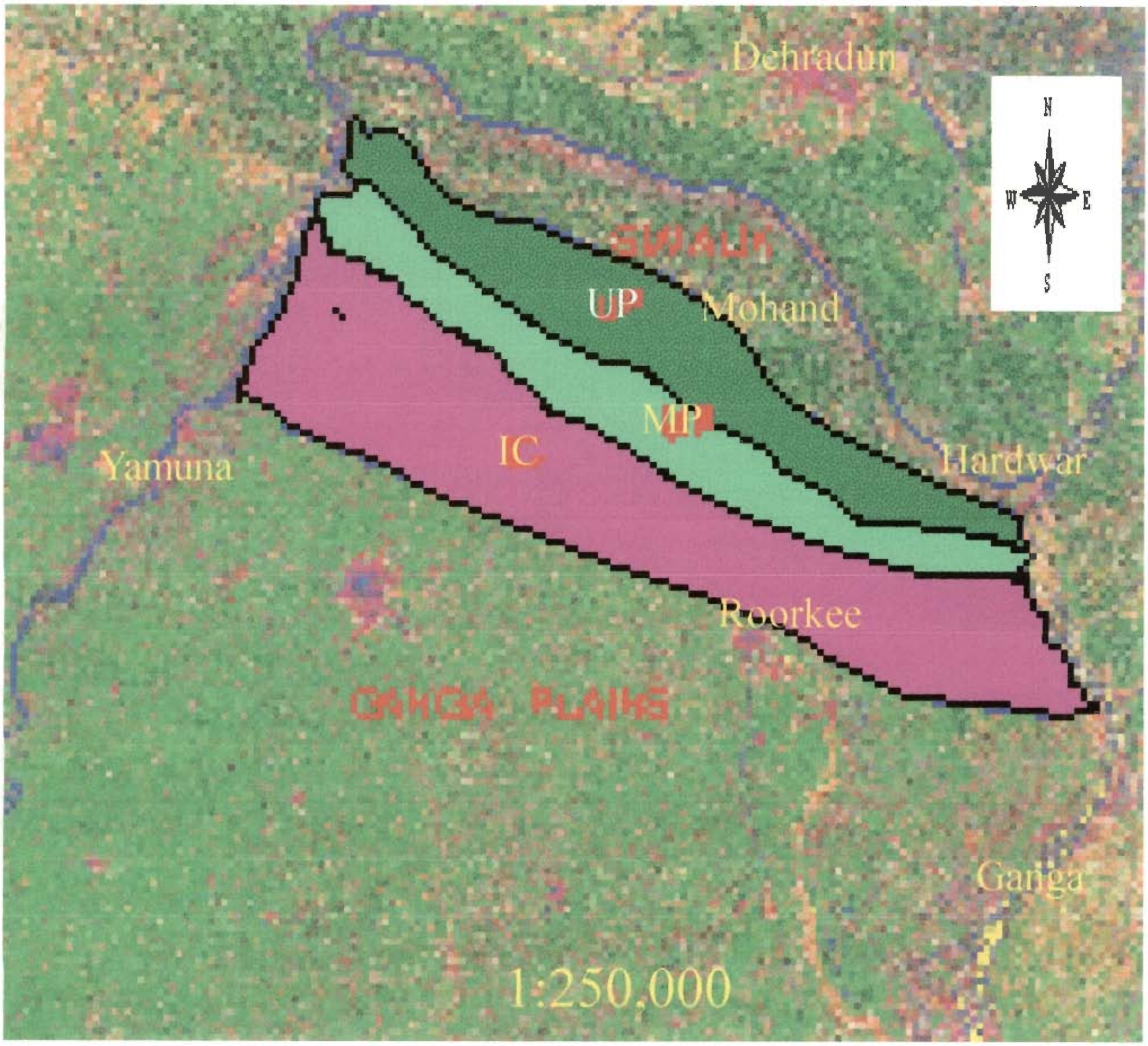
3.4 Soil Structure

The packing and arrangement of individual soil particles with respect to each other form a pattern known as soil structure. Soil structure pronouncedly affects its physical properties. These properties act and interact with themselves and finally influence the suitability of soil for their specific use. In this study an attempt has been made to assess the hydraulic conductivity, infiltration capacity, specific yield and erosion capacity of the soils in different geomorphic units. These are described below.

(1) Hydraulic Conductivity

Hydraulic conductivity of the soil samples was determined in the laboratory by falling head method. The soil samples from different sites were subjected to laboratory analysis. The result of laboratory analysis is tabulated in Table -3.3.Spatial variation of hydraulic conductivity is shown in Fig. 3.7.

A perusal of Table -3.3 and Fig. 3.7 reveals that the hydraulic conductivity of the UP geomorphic unit is highest (80 cm / hr), in the MP geomorphic unit it is 70 cm /hr,



Hydraulic Conductivity (cm/hr)

- 0.03-40
- 40-70
- 70-80

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.3.7 Variation Of Hydraulic Conductivity whereas in the IC geomorphic unit it is lowest (10.5 cm/hr). Hydraulic conductivity in the I_1 sub unit is 25.8 cm/hr, in the I_2 it is 15.9 and in the I_3 it is 10.5 cm/hr.

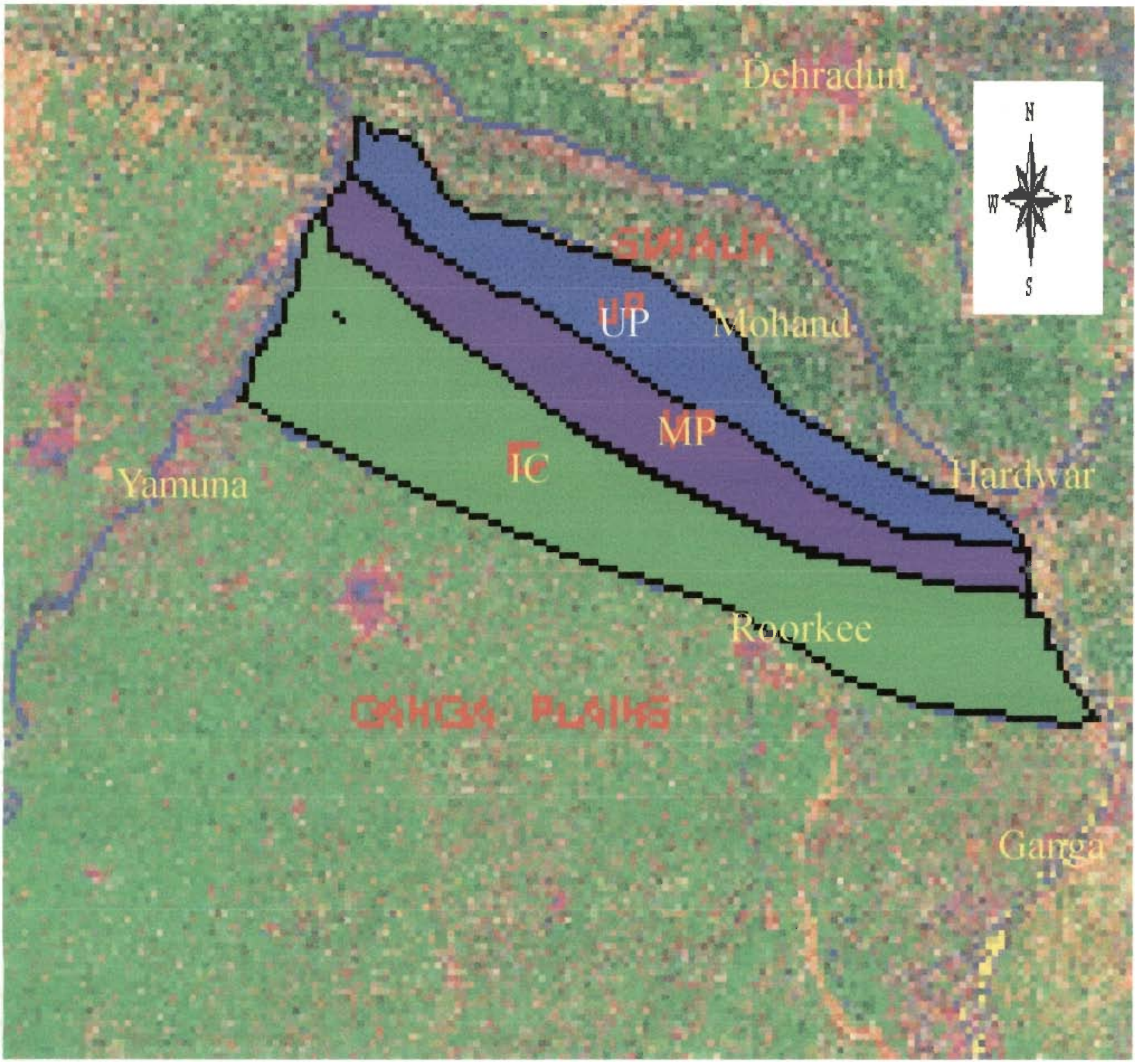
Table -3.3 Hydraulic Conductivity of Soils

<table>
<tr><th colspan="2" rowspan="2">Geomorphic Unit</th><th colspan="2">Hydraulic Conductivity (cm/hr)</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td colspan="2">UP</td><td>70 – 80</td><td>75.5</td></tr>
<tr><td colspan="2">MP</td><td>40 – 70</td><td>55.4</td></tr>
<tr><td rowspan="3">IC</td><td>I_1</td><td>0.3 – 40</td><td>25.8</td></tr>
<tr><td>I_2</td><td>0.3 – 40</td><td>15.9</td></tr>
<tr><td>I_3</td><td>0.3 – 40</td><td>10.5</td></tr>
<tr><td colspan="2">CB</td><td>0.3 – 70</td><td>30.2</td></tr>
<tr><td colspan="4">UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars.</td></tr>
</table>

The CB geomorphic unit shows largest variation (0.3 – 70) in the numerical value of the hydraulic conductivity. In the north it is highest (more than 70 cm/hr) and in the south it is lowest (about 0.3 cm/hr). These values indicate that in both the UP and MP units soils are coarse grained, highly permeable, highly aerated and have low water holding capacity as compared to I_1, I_2 and I_3 sub units. Further soils in the north are difficult to work with as compared to south. In the south, the braid bars have comparatively high water holding capacity as compared to that in the north.

(2) Water Infiltration Capacity

Infiltration capacity of soil influences the water retain ability thereby the water requirement of a crop and hence the crop suitability. Infiltration capacity is influenced by initial soil moisture content, condition of the soil surface, hydraulic conductivity of the soil profile, texture and structure of the soil and land cover. In this study, an attempt has been made to assess the water infiltration capacity of soil in different geomorphic units. Thus, 8 sites in the UP, 6 sites in MP, 16, 6 and 10 sites in the IC unit (I_1, I_2 and I_3 sub units) and 4 sites in CB units were selected. Water infiltration tests were carried out using double ring cylindrical infiltration meter. The result of the test is tabulated in the Table -3.4 and Fig. 3.8.



Infiltration Capacity (cm/hr)

- 2.0-8.0
- 8.0-12.0
- 12.0-16.0

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.3.8 Variation Of Infiltration Capacity

Table -3.4 Infiltration Capacities of Soils

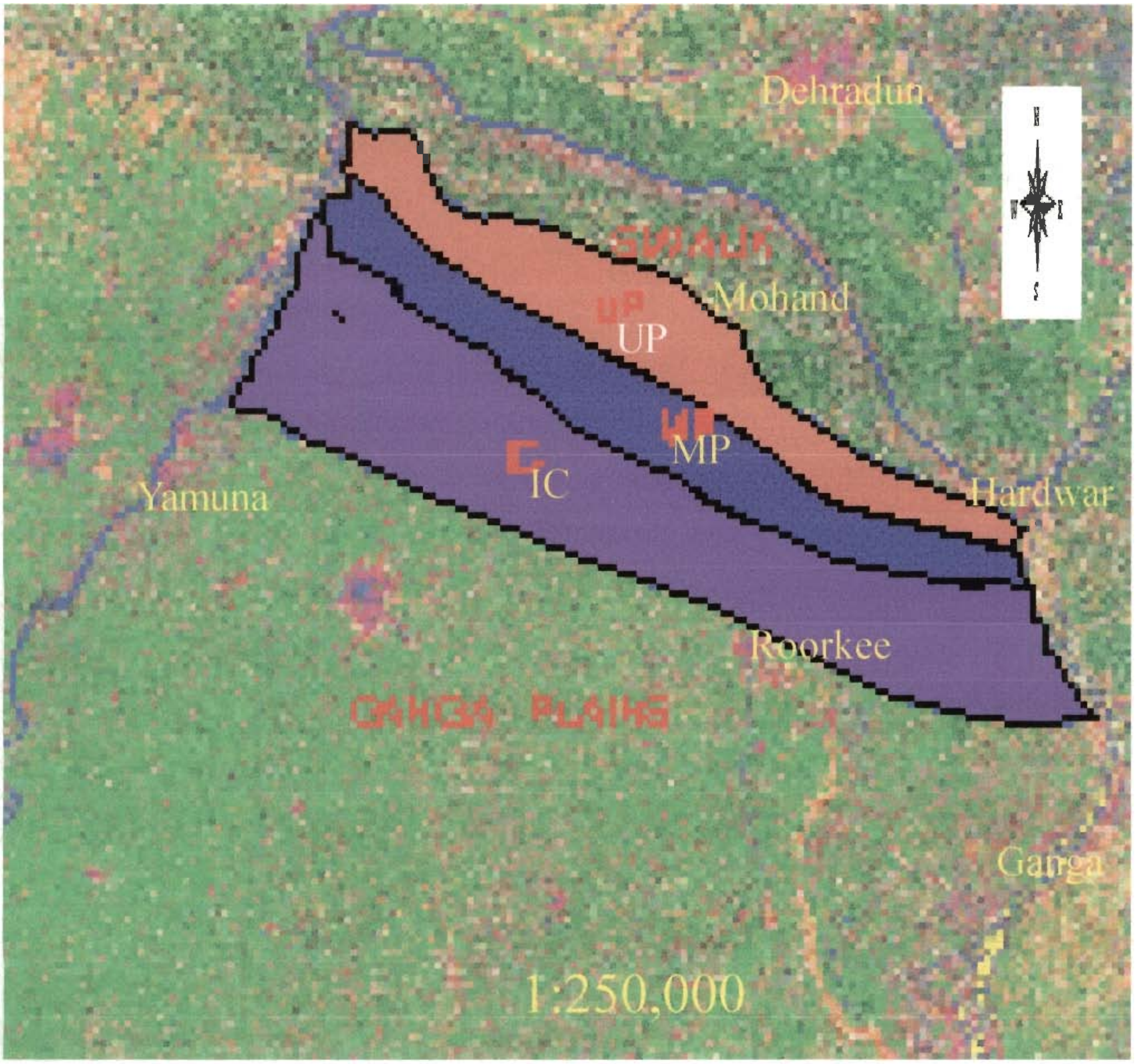
Geomorphic Unit		Infiltration Capacity (cm / hr)	
		Range	Average
UP		12 – 16	14.5
MP		8 – 12	10.6
IC	I_1	5 – 8	6.8
	I_2	4 – 6	5.5
	I_3	2 – 4	3.6
CB		2 – 8	5.8

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars.

A perusal of Table -3.4 and Fig. 3.8 indicates that water infiltration capacity of the UP unit is highest, (16 cm / hr) in the MP unit it is 12 cm/hr and lowest (6 cm/hr) in the IC unit. In the I_1 sub unit it is 8.0 cm/hr, in the I_2 sub unit it is 6.0 cm/hr whereas in the I_3 sub unit it is 4.0 cm/hr. The channel braid bar geomorphic unit shows largest variation (2 cm/hr – 8 cm/hr) in the infiltration capacity. From above it is inferred that in the north the infiltration capacity is highest (more than 8.0 cm/hr) and towards south it is lowest (about 2.0 cm/hr). These inferences indicate that both UP and MP units have low water holding capacity as compared to I_1, I_2 and I_3. Thus as compared to other units, the IC unit is more suitable for agricultural activities.

(3) Specific Yield

Specific yield of aquifers soil represents its drain ability. It influences groundwater recharge and discharge; the crop water requirement, and hence the crop suitability of an area. In this study the specific yield in different geomorphic units have been evaluated by the column drainage method. Thus aquifer samples from 4 sites from the UP geomorphic unit, 3 sites in the MP geomorphic unit, 8, 3 and 5 sites respectively from the IC unit (I_1, I_2 and I_3 sub units) and 2 sites from the CB were selected. From each site, aquifer samples were collected from the zone of water table fluctuation. Soil sample were put to column drainage test. Specific yield in various sites have been calculated and tabulated in Table -3.5. Spatial variation of Specific yield is shown in Fig. 3.9.



Specific Yield
(%)

10.0-210
8.0-10.0
6.0-9.0

UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

Fig.3.9 Variation Of Specific Yield

Table -3.5 Specific Yield in Geomorphic Units

Geomorphic Unit		Specific Yield (%)	
		Range	Average
UP		6- 9	8
MP		8 – 10	9
IC	I_1	10 – 18	13
	I_2	12 – 18	15
	I_3	15 – 21	18
CB		8 – 20	12
UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars.			

A perusal of Table -3.5 and Fig 3.9 indicates that the numerical value of the specific yield is lowest (8.0%) in the UP, in the MP it is 9.0%. In the IC unit the specific yield in the sub units I_1 I_2 and I_3 are 13.0%, 15.0% and 18.0% respectively. The CB geomorphic unit shows maximum variation (8.0% - 20.0%) in the specific yield. From above it is inferred that in the south the specific yield is 20.0% and towards north it is decreasing 8.0%.

Thus IC geomorphic unit have highest water holding and yielding capacity as compared to other units. Hence, this unit is more suitable for agricultural activities.

3.5 Hydrologic Soil Classification

Soil characteristics of a geomorphic unit control its hydrological behavior. This behavior in turn influences the crop water requirement, crop damage and ultimately the land use. From hydrologic considerations (Victor, 1969) soils are classified in to four groups - A, B, C, and D.

Group A, soils are associated with low runoff potential and high Infiltration rate. Group B is associated with moderately low runoff potential and high infiltration rate. Group C is associated with moderately high runoff potential. Group D is associated with high runoff potential (Victor, 1969).

Considering the soil characteristics -texture, hydraulic conductivity (K) and infiltration capacity (Ic) hydrologic responses of the soil in various geomorphic units were assessed following the SCS guide lines (SCS,1972). Finally hydrologic soil group was assigned to each unit and tabulated in Table 3.6. Spatial distribution of hydrologic soil groups is shown in Fig. 3.10.

Analysis Table 3.6 indicates that the soils of the geomorphic unit UP are characterized by low runoff potential. Soils of the geomorphic unit MP and CB geomorphic units are characterized by moderately low runoff potential. The IC geomorphic unit is characterized by the moderately high runoff potential.

Table -3.6 Hydrologic Soil Classifications of Geomorphic Units

Geomorphic Unit		Soil Characteristics			Runoff Potential	Hydrologic Soil Group
		Texture	K	Ic		
UP		Coarse Gravel	75.5	14.5	Low	A
MP		Medium Sand	55.4	10.6	Moderately Low	B
IC	I_1	Sandy Loam	25.8	6.8	Moderately high	C
IC	I_2	Loamy Sand	15.9	5.5	Moderately high	C
IC	I_3	Sand Loam	10.5	3.6	Moderately high	C
CB		Sand	30.2	5.8	Moderately Low	B

A: Low runoff Potential, B: moderately low runoff potential , C: moderately high runoff potential, K: Hydraulic Conductivity, Ic: Infiltration Capacity, UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars.

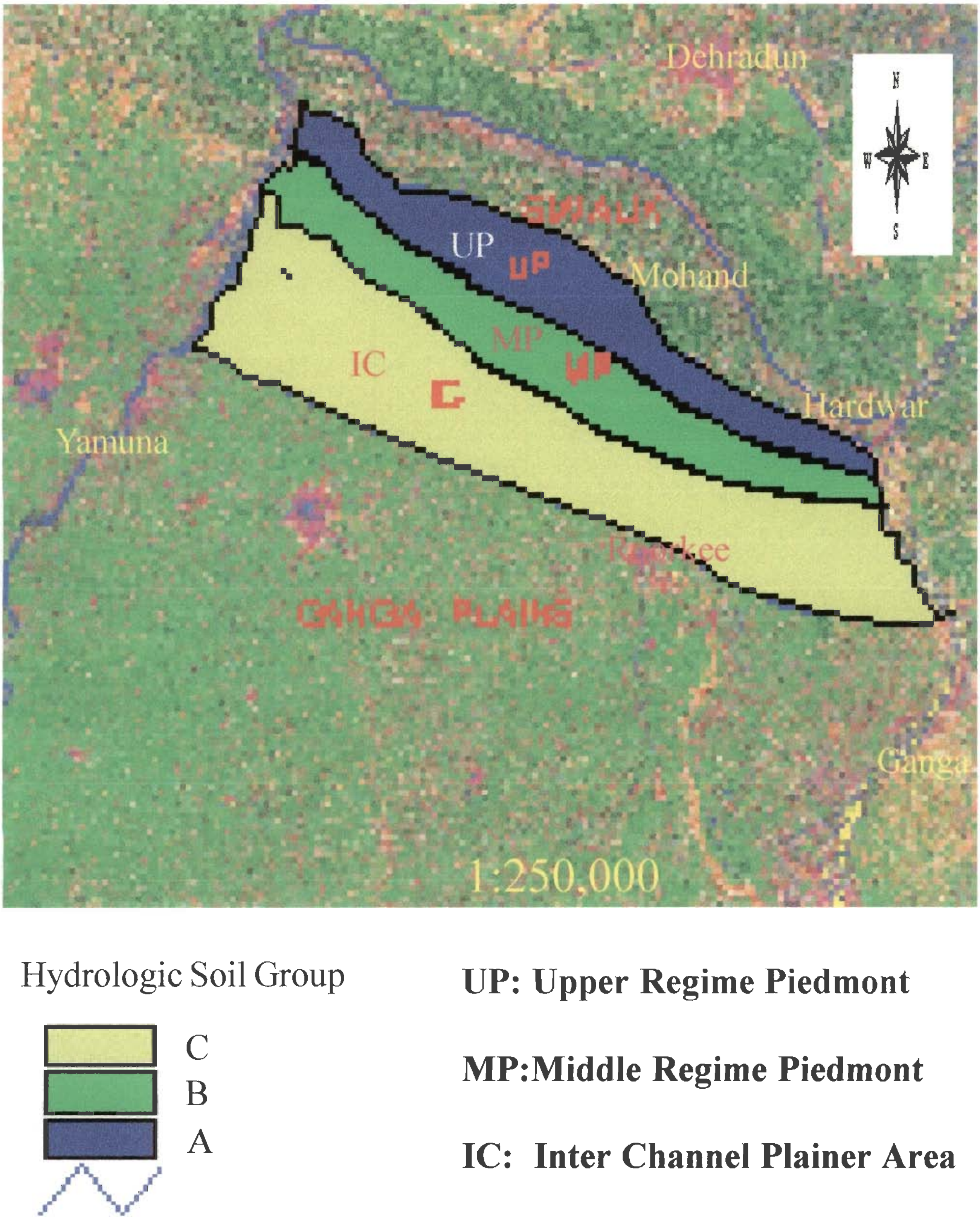


Fig.3.10 Hydrologic Soil Classification

As such, soils of the geomorphic units UP and MP have low water retention as compared to the IC unit. Hence, land use in the UP and MP units is to be determined cautiously. The Soil characteristics of the various geomorphic units is tabulated in Table 3.7

Table 3.7 Soil Characteristics of Geomorphic Units

Parameters	UP	MP	IC			CB
			I_1	I_2	I_3	
Soil Composition	Coarse Gravel with Sand	Fine Gravel Sand	Sand Silt	Fine Sand Silt Clay	Very fine Sand, Silt Clay	Gravel, Sand
Sand – d_{50} (mm)	>1	1.00 0.50	1.00-.025	1.00-.025	1.00-.025	1.00-.50
Petrographic Composition	G*,S,C	G,S	S,C	S,C	S,C	G,S
Average Hydraulic Conductivity (cm/hr)	75.5	554	25.8	15.9	10.5	30.2
Infiltration Capacity (cm/hr)	14.5	10.6	6.8	5.5	3.6	5.8
Specific Yield (%)	8	9	13	15	18	12
Electrical Conductivity (dsm^1)	0.06	0.15	0.21	0.21	0.21	0.08
pH	7.8	7.7	7.3	7.3	7.3	7.8
Hydrologic Soil Group	A	B	C	C	C	B

* G: Coarse Gravel-Quartzite, Phyllite, Gneiss, Sandstone Limestone; S: Sand Silt-Quartz, Feldspar, Mica, C:clay- Kaolinite, Illite,Vermicullite, Montmorrilonite,

3.6 Closing Interpretation

For land use studies detailed soil map are required. The available soil data was augmented through synergistic use of available data, remotely sensed data, field survey and laboratory experiments. In order to assess the soil characteristics of the area 250 soil samples collected from various geomorphic units were analyzed to determine the soil texture , mineralogical composition , salinity , alkalinity , hydraulic conductivity and hydrologic soil classification.

UP geomorphic unit is characterized mainly by coarse gravely sediments _ gravels and coarse sand. Grain size analysis of sandy components of the UP geomorphic units, about 15cm thick, indicates that d_{50} of these soil is more than 1.0 mm. The MP geomorphic unit contains mainly gravely sands with occasional cobbles, pebbles, granules, rich in coarse grained to medium grained sand, silts and clays. The sandy component of the MP soil is about 15cm to25 cm thick and d_{50} is 1.0 mm to 0.5 mm. The soils in the IC geomorphic unit is characterized by relatively finer sediments, mainly sand, silt and clays, d_{50} of the soil is less than 0.025 mm. Soil thickness is more than 25 cm. d_{50} of soils in the channel braid bars (CB) is varying between 1.0 mm and 0.025 mm.

Petrographic investigations, indicate that the boulders, cobbles, pebbles and sand are of heterogeneous nature with various types of rocks mainly quartzite with small amount of sand stone, phyllites and limestone. The sand and silt are made up of mainly quartz with mica and feldspar. X – Ray investigations indicate that the clay minerals are mainly Kaolinite, Illite with some Vermicullite and montmorillonite. From mineralogical considerations the soils can support a variety of crops.

Electrical conductivity of the UP geomorphic unit soils is about, 0.04 dsm^{-1}, in the MP geomorphic unit it is 0.20 dsm^{-1} and in IC unit it is 0.25 dsm^{-1}. The $_{p}H$ value of the soils in the UP is 7.8, in the MP it is 7.7 and in the IC unit it is 7.1. These values indicate that electrical conductivity is showing an increasing trend from north to south, whereas, $_{p}H$ is showing a reverse trend as it is decreasing from north towards south. Spatial variation of electrical conductivity and pH indicate that the soil in the area is neither saline nor alkaline.

Hydraulic conductivity of UP geomorphic unit it is 80 cm/hr while in the MP geomorphic unit it is 70 cm/hr and in the IC geomorphic unit it is 20 cm/hr. Field measurement of infiltration capacity indicates that in the UP geomorphic unit it is 16 cm/hr. In the MP geomorphic unit it is 12 cm/hr and in the IC geomorphic unit it is 2 cm/hr. From the spatial variation of hydraulic conductivity and infiltration capacity it is inferred that both hydraulic conductivity and infiltration capacity is showing an increasing trend from north towards south. From soil investigations it is inferred that soils in the north are coarse grained, highly permeable and highly aerated as compared to the soils in south. Further soils in the north are difficult to work with. Such a soil can support a variety of crops.

4

WATER RESOURCES

4.0 Background

For any land use, more so far agricultural purposes water is a crucial resource. As mentioned earlier the area is bounded by two perennial rivers Ganga and Yamuna (Fig-1.1) to the east and west respectively. In between these two rivers, a number of seasonal streams namely, Budhi Yamuna, Mashkara Rao, Paondhoi, Dhamola, Nagdeo, Chachahi, Hindon, Kali, Solani, Ratmau,Pathri rao and Ranipur rao, which from tributaries of these two rivers, flow through the area. Besides this, the area has three canal systems namely, Upper Ganga canal, Eastern Yamuna canal and Khara canal. Except in the areas close to canals and rivers groundwater is the major source of water in absence of perennial surface water source, in most of the areas. In this study an endeavor has been made to assess the water resources potential in various geomorphic regimes of the area for their better use. Groundwater being the major resource its estimation is being described below

4.1 Ground Water Resource Estimation

The useable groundwater resource is a space-dynamic resource. Ground water resource can be evaluated by the groundwater level fluctuation method. This method considers the response of ground water level to ground water input and output components. As such this approach appears more scientific, realistic and directly measurable, unlike other approaches where assumptions need to be made for most of the input and output components. This however, requires adequately spaced set up of observation wells and water level records for a sufficiently long period. It is desirable that there should be at least three spatially well distributed observation wells per 100 sq km. For composite units at least 5 observation wells are required such that at least two observation wells are available in each type of sub area. Also, water level observations must be available for a minimum period of 5 years, along with corresponding rainfall data in the unit. Regarding frequency of water level data, pre and post monsoon observations preferably in successive years, are the minimum requirement. It would be ideal to have monthly water level.

Thus, evaluation of groundwater resource at a given point of time involves extensive network of data collection system. This will require huge capital investment, skilled human resource and time. However, in areas of little scientific development, where adequate data on ground water level fluctuations are not available as specified above, ground water recharge may be estimated using rainfall infiltration factor method. These approaches are accepted and prevalent in India (GEC 1997). Estimation of groundwater resource by groundwater fluctuation method is being described below.

4.1.1 Groundwater Level Fluctuation Methods

The ground water level fluctuation method is one of the most appropriate tools for groundwater recharge assessment in the monsoon season. For non-command areas, recharge in the non-monsoon season is a small component and may be estimated empirically. In applying the groundwater level fluctuation method, two alternate approaches are possible:

(a): Based on observed value of specific yield:

This approach is suitable when base flow data in the dry season is not available.

(b): Groundwater balance equation:

It is applied separately for the dry season to estimate specific yield and then this value of specific yield is used in the groundwater balance equation for the monsoon season to estimate recharge. This approach provides more reliable assessment of recharge in areas where adequate information about base flow in the dry season is available, or the base flow in the dry season is practically negligible.

Approach (a):

In this approach, specific yield value is obtained from pumping tests or from norms for different hydro geological areas. In using pumping tests to obtain specific yield value, it is worth mentioning that unless the tests are of sufficiently long duration (minimum pumping duration of 16 hrs), proper assessment of specific yield value is difficult. In situations where specific yield value cannot be estimated by other means, the norms recommended by GEC, 1997, may be used

Recharge for the Monsoon Season:

The water level fluctuation method is applied for the monsoon season to estimate the recharge. The groundwater balance equation for the monsoon season in non-command area is given by,

$$R_G - D_G - B + I_s + I = S \quad (4.1)$$

Where

R_G = gross recharge due to rainfall and other sources including recycled water

D_G = gross groundwater draft

B = base flow into streams from the area

I_s = recharge from streams into ground water body

I = net groundwater inflow into the area across the boundary (inflow-outflow)

S = Change in groundwater storage

All quantities in the equation 4.1 refer to the monsoon season only. In the equation (4.1), if the area under consideration is a watershed, the net groundwater inflow term, I may be taken as zero. If there is inflow and outflow across the boundary in theory, the net inflow may be calculated using Darcy law, by delineating the inflow and outflow sections of the boundary. Besides such delineation, the calculation also requires estimation of transmissivity and hydraulic gradient across the inflow and outflow sections. For the groundwater assessment as prescribed in these recommendations, the net inflow term, I, may be dropped.

There are similar difficulties in estimating the base flow and recharge from streams in equation. (4.1), if the unit of assessment is a watershed in hard rock area. A single stream gauge monitoring station at the exit of the watershed can provide the required data for the calculation of base flow. Since such data is generally not available, it is recommended that the base flow term and recharge from stream in equation. (4.1) may also be dropped.

After deleting net inflow, recharge from streams and base flow terms in equation. (4.1), the resultant recharge term now refers to the possible recharge under the present recharge minus the natural discharges in the area during the monsoon season. To signify this, the R_G term in equation (4.1) is rewritten as R. equation. (4.1) is now rewritten as,

$$R = S + D_G \qquad (4.2)$$

Where, R is the possible recharge, which is gross recharge minus the natural discharges in the area in the monsoon season (R_G - B+ I+ Is). Substituting this expression for storage, S, in terms of water level fluctuation and specific yield, equation. (4.2) becomes

$$R = h \times S_y \times A + D_G \qquad (4.3)$$

Where,

h = rise in water level in the monsoon season

A = area for computation of recharge

S_y =specific yield

The recharge calculated from equation. (4.3) gives the available recharge from rainfall and other sources for the particular monsoon season. For non-command areas, the recharge from other sources may be recharged from recycled water from groundwater irrigation, recharge from tanks and ponds and recharge from water conservation structures, if any. The recharge from rainfall is given by

$$R_{if} = R - R_{gw} - R_{wc} - R_t$$

$$= h \times S_y \times A + D_G - R_{gw} - R_{wc} - R_t \tag{4.4}$$

Where,

R_{if} = recharge from rain fall

R_{gw} = recharge from groundwater irrigation in the area

R_{wc}= recharge from water conservation structures

R_t = Recharge from tanks and ponds

The estimation of recharge from (R_{gw}), (R_{wc}) (R_t) may be made based on the GEC 1997 norms. The recharge from rainfall estimated as per equation. (4.4) is for a particular monsoon season.

Approach (b):

In this approach, the specific yield is estimated from ground water balance in the dry season. Then after, based on this specific yield; recharge is estimated from ground water balance in the monsoon season. The approach is suitable in areas where data regarding base flow in the dry season is available or base flow in the dry season is practically zero. The period January to May (5 months) is suitable for dry season balance. Ignoring the net inflow term due to subsurface flow and assuming that the recharge from rainfall during the dry season is zero, the ground water balance in the dry season is given by:

$$h \times Sy \times A = D_G - R_{gw} + B \tag{4.5}$$

Where

h = decrease in groundwater level

D_G = gross groundwater draft

R_{gw} = recharge recycled from groundwater irrigation

B = base flow from the area

All quantities in equation (4.5) refer to the dry season only, as defined in this section. The estimation of recharge from groundwater irrigation (R_{gw}) may be made based on the norms presented by the GEC. In equation.(4.5), the recharge term from water conservation structures and from tanks and ponds are not included, because it is expected that these recharge effects would have become negligible by the time the dry season commences. The specific yield value can now be calculated from equation. (4.5) as follows:

$$S_y = \frac{D_G - R_{gw} + B}{h \times A} \tag{4.6}$$

Once specific yield value is determined from the water level fluctuation data in the dry season, the recharge in the monsoon season can be calculated from equation. (4.3), applying the water level fluctuation method.

The corresponding recharge from rainfall is obtained from equation. (4.4), where the terms $R_{gw,}$ R_{wc} (recharge from groundwater irrigation and water conservation structures in the monsoon season) and R_t (recharge from tanks and ponds) can be obtained from the GEC, 1997, norms. Estimation of groundwater resource is being described below. In the study the groundwater fluctuation method has been used to estimate the groundwater resources. For this Ms Excel, easily accessible software has been customized

4.2 Available Groundwater Resources

As mentioned earlier sufficient data are not available for the area and hence field survey was conducted for collecting the relevant data. For this in the area open wells were selected to cover various geomorphic regimes and in these wells the depth of the groundwater table during pre monsoon (May / June) and post monsoon (October /

November) periods for each year during 1975 – 2002 were collected. From the observed data, occurrence of groundwater table in terms of its depth below ground level and fluctuation is synthesized and tabulated in Table –4.1

Table4.1 Spatial Variations in Groundwater Table

Geomorphic Unit		Groundwater Table Depth (m)				
		Pre monsoon		Post monsoon		Fluctuation
		Range	Avg	Range	Avg	
UP		30 - 35	32.5	27.2-32.2	29.7	2.8
MP		18 -22	20.0	16-20	18.0	2.0
IC	I_1	4 0– 6.4	5.2	2.5-4.9	3.7	1.5
IC	I_2	6.8 – 9.8	8.3	5.2-8.2	6.7	1.6
IC	I_3	8.8 – 12.0	10.4	7.4-10.6	9.0	1.8
CB		5.0 – 7.0	6.0	3.5-5.5	4.5	1.5

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC) - I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars, Avg: Average

A perusal of Table 4.1 indicates that the upper regime piedmont is characterized by relatively deeper (30 – 35 m) groundwater table associated with large (2.8 m) fluctuation in the groundwater table. This characteristic is followed in the middle regime piedmont and the IC unit in decreasing order of magnitude both in the depth of the groundwater table and its fluctuation. In the channel braid bars, in the north, depth and fluctuation of the groundwater table is more as compared to south.

Another, input to this method is the groundwater draft from irrigation wells. Estimation of this is being described below.

4.2.1. Groundwater Draft

Field survey was carried out in each geomorphic regime to collect the data on groundwater draft. In the area groundwater draft takes place through shallow tube wells (about 20 m deep) and deep tube wells (50 m deep). Withdrawal through open wells and hand pumps contribute very little. Survey was carried out to assess the number of shallow and deep tube wells as well as their average annual withdrawal. Results are tabulated in Table -4.2

Table 4.2 Groundwater Draft

		Deep Tube Wells		Shallow Tube Wells	
		Number	**Average Draft* (ha m / Year)**	**Number**	**Average Draft* (ha m / Year)**
UP		5	10	45	1.1
MP		12	15	230	1.0
IC	**I_1**	5	16	20	1.2
	I_2	50	18	510	1.6
	I_3	180	20	2012	1.6

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC) - I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding,, *: Average Annual Draft in ha m / year

Table 4.2 indicates that both the number of deep tube wells and shallow tube wells in the UP geomorphic unit is lowest (5 and 45 respectively). Whereas in the IC geomorphic unit ,the sub unit I_3, it is maximum (180 and 2012 respectively) The average annual draft of both deep tube wells and shallow tube wells in the IC geomorphic unit - I_3 sub unit is maximum (20 ham/year and 1.6 ham/year respectively), followed by in the I_2 sub unit (18 ham/year and 1.6 ham/year), the I_1 sub unit (16 ham/year and 1.2 ham/year), the MP geomorphic unit (15 ham/year and 1.1 ham/year) and the UP geomorphic unit (10 ham/year and 1.0 ham/year). Deep tube wells are characterized by deeper penetration, higher discharge and running hours as compared to shallow wells.

For the estimation of other components of the groundwater resource GEC, 1997, has laid down generalized norms which may be used in areas where adequate data is not available. In this study these norms have been used for the estimation of canal seepage, rainfall recharge, seepage from surface water bodies, irrigation return flow, net draft and developable recharge. These are tabulated in Table 4.3. Various components of the groundwater resource as worked out are tabulated in Table 4.4

Table 4.3 Groundwater Estimation Norms

Groundwater Balance Parameter	Value
Canal Seepage (Cumec / 10^6 m^2)	3.5
Rainfall Recharge (% of rain fall)	25
Seepage from Ponds (Cm / ha)	40
Irrigation Return Flow (% of applied water)	55
Net Draft (% of gross draft)	85
Developable Recharge (% of total recharge)	70

Table -4 4 Groundwater Resource Components

Source and Recharge	% of total annual Rainfall
Rainfall	33.0
Canal	16.0
Irrigation	5.0
Ponds, Flooded area	10.8
Developable Recharge	46.0

Table -4 4 indicates that in the area the major source of groundwater is rainfall recharge (33%) and canal seepage (16%). The available groundwater for development is 46% of the total rainfall. Total rainfall recharge to groundwater works out to be 33% of the total annual rainfall. This is higher (33%) than the recommended value (20% to 25%) by GEC, 1997, as well as estimated value (10%) using the Chaturvedi (1947) formula. These findings indicate that the Chaturvedi formula tends to underestimate the available groundwater water resources. This approach though in use is highly conservative in nature. Therefore, there is a need to look and refine this approach so as to make it applicable in this area.

4.2.2 Modified Chaturvedi (1947) Formula

Only a fraction of the annual rainfall percolates downwards, while a major portion runoff on the surface or is lost by evapotranspiration. Downward percolation of the rainfall to the groundwater reservoir depends upon the intensity, duration and seasonal distribution of rainfall, topography, land cover, humidity and the characteristics of the soil cover. Further, every rainfall event is not able to contribute to the groundwater reservoir. As mentioned earlier, the rainfall recharge work out by the Chaturvedi formula is only 10% of the total rainfall. However, the recharge from rainfall as worked out from the fluctuation method is 33% of the rainfall. It is closer (20% to 25%) to the norms given by GEC (1997). It implies that the Chaturvedi formula underrate the rainfall recharge in this area. The constants 1.2 and 36 of the Chaturvedi formula are area specific. In view of this an attempt has been made to modify the Chaturvedi formula:

$$R_r = 1.26\,(R - 36)^{0.5} \tag{4.7}$$

Where R_r is rainfall recharge in cm, R, is rainfall in cm. The Chaturvedi formula is modified as:

$$R_r = a\,(R - b)^{0.5} \tag{4.8}$$

Where, both a, and b, are constants to be evaluated. Numerical values of the constants have been worked out in least square sense. Based on, 1986 - 2000, data. These values along with goodness of fit for various geomorphic regimes are tabulated in Table -4.5.

Table -4.5 Rainfall Recharge Parameters

Geomorphic Unit		Rainfall Recharge { $R_r = a(R-b)^{0.5}$ } Parameters		
		a	B	Goodness of Fit
UP		4	25	0.90
MP		4	30	0.89
IC	I_1	3.3	35	0.91
	I_2	3.3	35	0.90
	I_3	3.2	38	0.89
CB		3.2	38	0.85
UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC) – I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding,				

Table -4.5 indicates that the proposed modification in the Chaturvedi formula is statistically robust, having goodness of fit more than 0.85. Numerical values of constants collectively suggest that rainfall recharge is higher for UP and MP geomorphic unit as compared to the IC geomorphic unit. Efficiency of the model works out to be about 80%.

4.2.3. Temporal Availability of Rainfall Recharge

From pervious section it is inferred that in the area about 33% of the rainfall goes as recharge to the groundwater reservoir. The occurrence of rainfall is not uniformly distributed through out in a year. Hence the quantity of available recharged water during a year also varies in temporal domain. For effective development of an area in addition to quantity, the time of availability of groundwater is equally important. Therefore, an attempt was made estimating the time, when the percolated rainfall is available for withdrawal. This has been worked out through cross – correlation study (Chow, 1964)

Cross correlation coefficients and ground water level were calculated at time interval of 10 days, 20 days, 30 days, 40 days, 50, 100, 150, 200, 250 and 300 days. Temporal variation of cross-correlation coefficient is shown in Fig.4.1. Time interval at which the correlation coefficient between rainfall and groundwater level is maximum in various geomorphic regimes is tabulated in Table -4.6.

Table -4.6 Lag Time for Recharge from Rainfall

Sl. No.	Geomorphic Unit		Lag time in days
1.	UP		10
2.	MP		20
3.	IC	I_1	40
		I_2	40
		I_3	50
4.	Channel Braid Bar (CB)		20

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC) - I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding

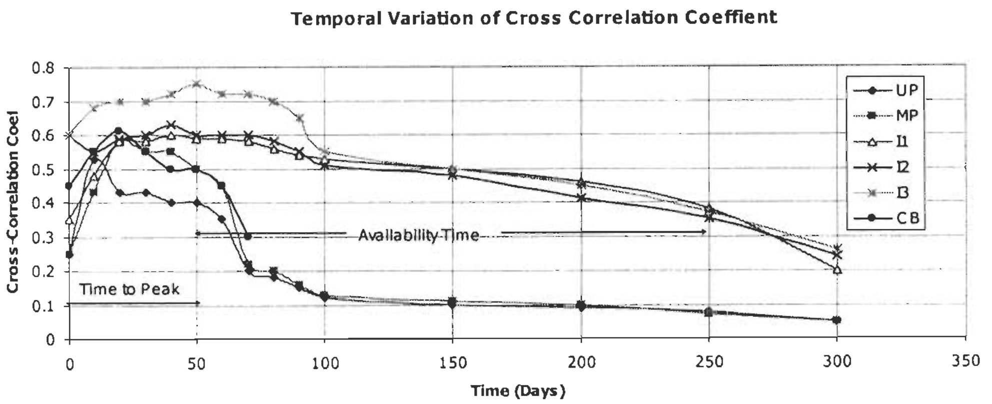


Fig. 4.1 Temporal Variation Of Cross Correlation Coefficient

Table -4.6 indicates that in the UP geomorphic unit rainfall takes about 10 days to recharge the groundwater, and it is quickest. In the IC unit time gap is about 40 - 50 days. As the general groundwater flow is from north to south, therefore, in the UP and MP geomorphic units the percolated rainfall is to be utilized within a month, else this percolated rainfall will move towards the IC unit. In the IC geomorphic unit recharged water is available after a month but for an extended period

These finding along with the prevailing conditions of the data scarcity and proven capacity of remote sensing techniques for providing terrain characteristics goad to conclude that there is need to develop a simple model to evaluate the rainfall recharge.

4.2.4. Rainfall Recharge Estimation - A New Approach

It is worth to mention here that the Chaturvedi (1947) formula considers only the rainfall as source. But the two areas getting the same rainfall but possessing a different land cover will have different recharge; therefore, there is a need to take in to account the land cover characteristics in the estimation of the rainfall recharge.
In this section an endeavor has been made in this direction. In the present study the strategy adopted for ground water recharge estimation was first of all to determine the recharge rate for different types of land cover complex, and then to predict ground water recharge and finally the groundwater resource.

Rainfall, R_f and land over L_c are space dynamic parameters and their effect on the recharge can be quantitatively represented as modeled in the following manner (Dubey et. al. 1984, Dubey 1996, Dubey 1999) Recharge in an area can be represented as:

$$Rn = a_i h_i S_{yi} \qquad (4.9)$$

Where, R_r is the rainfall recharge in an arbitrary station i, h_i is the difference between maximum and minimum ground water level at this station, S_{yi} is the average specific yield in the influencing zone of the station in the zone of water table fluctuation. Rainfall recharge can also be written as:

$$Rn = \square\ aij\ di\ pj \qquad (4.10)$$

Where, a_{ij} is area of the j^{th} type of land cover in the influencing zone of the station i, d_i is total rainfall in a given period; p_j is the coefficient of recharge for j^{th} type of land cover. From equation comparing equation (4.9) and (4.10)

$$a_i h_i S_{yi} = \sum_j a_{ij} d_i P_j$$

$$\frac{a_i h_i S_{yi}}{R_i} = \sum_J a_{ij} p_j = \frac{R_{ri}}{R_i}$$

Or

$$G_i \frac{R_{ri}}{di} = \sum_j a_{ij} P_j = Gi = \frac{Rri}{di}$$

Above equation it can be written in a matrix operator form as

$G = A \, . \, P$

Where, G is nx1 Column Vector having its element as ratio of rainfall recharge to rainfall. A is n x m system operator matrix representing the values as land cover in a particular area as its element, P is mx1 column vector representing the rate of recharge corresponding to different land cover. The ideal situation for a unique solution of the system is when A is a square non singular matrix, which is having a classical inverse, as A^{-1} and the solution of the system operator equation is written as:

$$P = A^{-1} G \tag{4.12}$$

But in solving real world problem the operator, A is rectangular matrix. Then the system fails to admit unique solution. In these circumstances Least Square, Minimum Norm or combination or both may be obtained and solution of system operator equation (4) may be written as:

$$P = A^*.\, G \tag{4.13}$$

Where, A* is the Generalized Linear Inverse of A (Moore, 1920). Once recharge rate P and land cover operator matrix A, is known at any other time or place, groundwater table fluctuations can be predicted again using the system operator equation.

Model Calibration and testing

The calibration and testing of the developed groundwater recharge model was carried out for the Solani stream basin. The Solani stream basin was selected for two reasons; firstly it touches Roorkee, which helps in experimenting and secondly, it is a representative stream. The developed model requires rainfall, land cover, and fluctuations in the ground water table, and specific yield for its calibration. In the present study the observed rainfall data for the area was collected and compiled. The details are given earlier.

The compiled rainfall data have been used. Land cover statistics have been estimated from the analysis of the Satellite data product. The details for these are given in previous chapters. Specific yield of the aquifer was determined as described in earlier chapter. The groundwater fluctuation data have been observed, collected and compiled. The model was calibrated for the years 1984, 1985, 1986 and 1998. The salient features of the input data are tabulated in Table -4.7.

Table 4.7 Input Data for Groundwater Recharge model

S.N.	Data	Data Source	Data range
1	Land cover	Interpretation of Satellite data	Forest, Agriculture, Bare Land
2	Groundwater fluctuation	Field observation	1.7 m to 2.5 m
3	Specific Yield	Field data	0.1 to 0.25
4	Rain fall	Observed data	20 mm to 400mm(monthly)

The results of the calibration are tabulated in the Table -4.8.

Table 4.8 Groundwater Recharge model Calibration

S.N.	Land cover	System Response Factor (P)				
		1984	1985	1986	2000	Average
1	Forest	25.06	23.82	23.73	24.1	24.2
2	Agriculture- Intense	36.25	34.94	36.10	36.9	37.4
3	Agriculture- Moderate	65.17	68.32	60.40	62.5	64.6
4	Barren Land	72.65	79.38	60.39	72.4	70.8

The model testing was done for the period 1988 to 2000. It was found that the prediction efficiency of the model is 86.5 %. Keeping in view this value of prediction efficiency it was inferred that the developed model can be used to assess the groundwater recharge.

4.2.5 Groundwater Balance

As mentioned earlier, a part of the groundwater total inflow to the various geomorphic unit moves out and as such only a part of it is available as a balance for use. From this balance a part of the groundwater is being withdrawn. The remaining groundwater is the resource that can be pumped out to meet the requirements. Groundwater resource has been estimated and tabulated in Table 4.9.

Perusal of Table 4.9 indicates that the on annual basis total groundwater resource available in the area is 493 x 10^2 ham, out of this about 222 x 10^2 ham is withdrawn. As such about 271 x 10^2 ham is still available for future use. Available water resources in various geomorphic units are tabulated in Table 4.9. Hence it is inferred that the area possesses a huge amount of developable groundwater resource.

Table -4.9 Groundwater Resource

Geomorphic Unit		Groundwater Resource (10^2 ham)				
		Inflow	Out flow	Balance	Draft	Resource
UP		139.45	107.05	32.35	1.75	30.5
MP		92.93	42.33	50.60	14.87	35.73
IC	I_1	88.58	6.27	82.31	52.18	36.4
	I_2	106.39	10.7	95.69	3.66	92.02
	I_3	222.80	25.5	197.3	147.14	50.16
CB		35.82	7.32	28.5	2.66	25.84
Total				**492.92**	**222.26**	**270.66**

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area (IC) - I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB: Channel Braid Bars

4.3 Surface Water Resources

As mentioned earlier the groundwater is the major resource. Nevertheless, the flows in the rivers Ganga and Yamuna and canals also form water resource. This resource potential i.e. surface water resource potential has been evaluated in this section. There are a number of models proposed by various workers and organizations. All these approaches have been developed for the areas which have been very well studied and have well tested parameters required in these models. In the poorly investigated area, these approaches are difficult to use. Hence, in areas as the present one, initial assessment of surface water resource needed to be assessed is based on limited available field data. An effort has been made in this regard. Estimation of stream flow using the SCS model is being described below.

4.3.1. Soil Conservation Society (SCS, 1972) Model

Soil Conservation Society (SCS) model developed by the USDA (Chow 1964; Singh, 1989) is reproduced below.

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \qquad (4.14)$$

Where Q is runoff in mm, p is rainfall in mm, S is initial abstraction defined as:

$$S = \frac{25400}{CN} - 254 \tag{4.15}$$

Where CN is Curve Number, a dimensionless coefficient describing the soil – land cover complex of the watershed. This ranges from 0 to 100. It is obtained by relating hydrologic soil groups with land use. In addition, CN depends upon Antecedent Moisture condition (AMC). It is an index of the watershed wetness.

In this study SCS criteria (Table 2.8) of 5 day rainfall have been used to flag AMC level (Table 2.9). For the experimental basin, Solani, runoff computed by SCS model, using initial abstraction as 0.2 S and 0.25 S along with observed stream flow are tabulated in Table 4.10.

Table 4.10 Stream Flow Prediction

Month (1996)	**Rainfall (mm)**	**Stream Flow (mm)**		
		Observed	**SCS - Initial Abstraction**	
			0.2 S	**0.25 S**
January	20	9.6		
February	0	0		
March	0	0		
April	15.3	7.34		
May	7.8	3.74		
June	75.1	36.0		
July	494.5	207.36	248.76	236.23
August	452.0	216.96	319.59	313.08
September	126.9	48.91	54.43	50.5
October	8.0	3.84		
November	0	0		
December	52.4	25.15		

A perusal of Table 4.10 indicates that the recommended value of initial abstraction as 0.2 S in SCS model yields stream flow which is about 35 % higher than the observed value and hence it is not suitable for this area.

Further, initial abstraction as 0.2 S as well as 0.25 S is also not reasonable. This observation is in line with results of the previous chapter that in space time domain the area is generally dry. Therefore, it was decided to slightly modify the SCS model to suit this area.

It was thought to adopt the initial abstraction as 0.3 S. This necessitated developing a new set of value of CN values corresponding to the prevalent land cover-soil complexes in the area. From the available historical records (1984-2000) of rainfall and runoff records, CN values for different months were calculated in least square sense.

The CN values as computed above are the weighted CN value for the whole basin. Keeping in view the spatial-temporal variation of land use / land cover in different hydrologic soil group, CN values has been allocated for various soil-land cover complex. The final CN values are shown in the Table 4.11(a) and 4.11(b).

Table 4.11(a)CN for Soil – Land Cover Complexes (June-September)

Land Cover	CN Values											
	Month											
	June			July			August			September		
	Hydrologic Soil Group											
	A	B	C	A	B	C	A	B	C	A	B	C
Dense Forest	13	22	38	26	40	58	44	60	76	44	60	78
Open Forest	14	25	40	28	44	60	48	64	78	48	64	78
Scrub/Sandy/Barren	12	21	37	25	39	57	43	59	75	48	59	75
Agriculture	42	53	60	42	53	60	62	72	78	79	86	90
Town area/Urban	59	72	80	77	86	91	89	94	97	89	94	97

Table -4.11 (b) CN for Soil - Land Cover Complexes (Oct – May)

Land Cover	CN Values											
	Months											
	October			Nov, Dec, Jan			Feb, Mar			Apr, May		
	Hydrological Soil Group											
	A	B	C	A	B	C	A	B	C	A	B	C
Dense Forest	59	78	88	59	78	88	59	78	88	21	41	55
Open Forest	65	82	89	65	82	89	65	82	89	26	46	59
Scrub/Sandy/Barren	58	78	87	58	78	87	58	78	87	21	40	54
Agriculture(Int)	67	78	85	83	90	94	47	60	70			
Agriculture (Mod)	72	81	88	96	92	96	53	64	75	48	62	72
Town area/Urban	89	94	97	89	94	97	89	94	97	59	72	80

Using above mentioned tailored values of CN and initial abstraction as 0.30 S stream flows has been calculated and tabulated in Table 4.12 and Fig. 4.1, as an example for comparison.

Table 4.12 Stream Flow Comparison

Month (1995)	Rainfall (mm)	Stream Flow (mm)			
		Observed	SCS - Initial Abstraction		
			0.2 S	0.25 S	0.3 S
January	20	9.6			
February	0	0			
March	0	0			
April	15.3	7.34			
May	7.8	3.74			
June	75.1	36.0			
July	494.5	207.36	248.76	236.23	213.49
August	452.0	216.96	319.59	313.08	206.58
September	126.9	48.91	54.43	50.5	46.79
October	8.0	3.84			
November	0	0			
December	52.4	25.15			

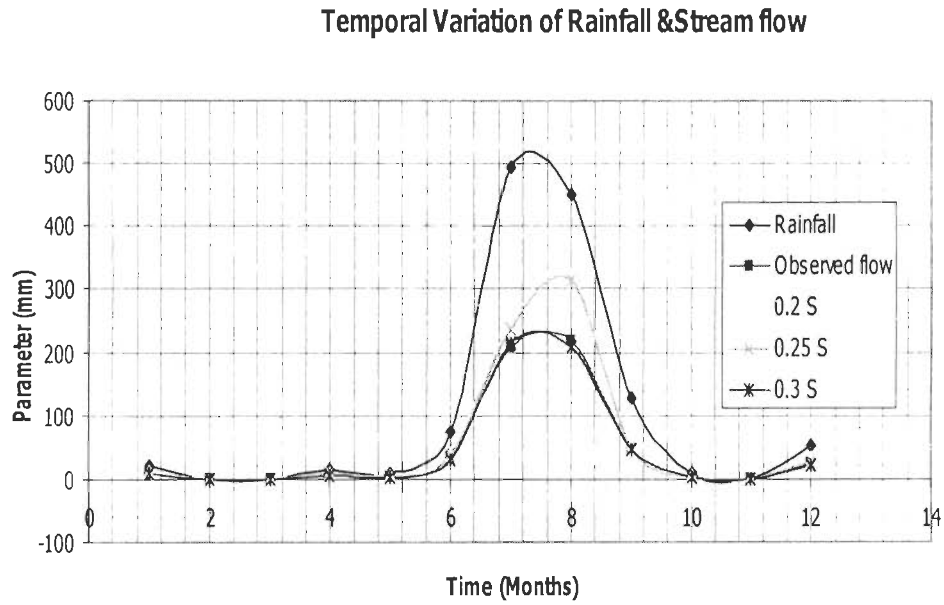


Fig.4.2 Temporal Variation of Stream Flow

Conjunctive analysis of table 4.12 and Fig. 4.2 indicates that the initial abstraction of 0.3 S yield stream flow comparable to the observed value. It was found that this modification have improved the prediction efficiency of SCS model in this area by about 90 %. Hence for the area the SCS Model having initial abstraction Ia = 0.30S may be used to compute the Stream flow.

Keeping in view the fact that the piedmont area is poorly monitored and poorly studied, for the estimation of stream flow a simple model using only two parameters, namely the rainfall and land cover is developed.

4.3.2. Land Based Stream Flow Model

Review of the existing literature (Singh, 1989; Engman and Gurney, 1991; Chow, et.al.1998) it can be inferred that the stream flow depends upon the above surface, surface and sub surface characteristics of the area under investigation. The approaches available to estimate stream flow can be grouped into two classes:

(1) Empirical approaches

(2) Simulation Models

A close study of the available physically based models (Chow et.al, .1998; Kite and Pietroniro, 1995; Seth, 1999; Todini, 1988; Singh, 1989; Dubey, 1996; Dubey, 1999) reveals that, for calibration and validation of these models, a large data set is needed. The Stream flow (Q) can be functionally expressed as:

Q = f (Climatic Characteristics, Physiographic Characteristics), or

Q = f (Rainfall, Interception, Evaporation, Transpiration, Basin Characteristics and Channel Characteristics)

There are 11 parameters defining rainfall variability, 5 parameters defining interception, 6 parameters to define evaporation, 13 parameters to define basin characteristics and 7 parameters to define channel characteristics (Chow, 1964; Todini, 1988; Singh, 1989), totaling to 47 parameters. An estimator of Q can be defined with which 47 dimensional spaces are mapped to a set of Q values. In a poorly investigated area it would be difficult and costly to evaluate all the 47 parameters. Thus, in the present study, rainfall, land cover, land slope and permeability of the soil has been assumed to be the most influential parameter (Dubey, 1996; 1999). As it has been assumed that the total 47 data can be mapped in to 4. An estimator, f can be defined as:

$$(R, A, S, K) - f_1 \rightarrow Q$$

Where, R is the rainfall, A is the area of a particular land cover, S is the land slope, and K is the soil permeability. Rainfall, R, and land cover, A, are the most influential parameters. Further information related to these is easily available from meteorological and satellite data products. Therefore in order to obtain fast and simple estimation of stream flow it is desirable that the stream flow is estimated from these two parameters only. This will also help in estimating the hydrologic consequences of land use changes (Dubey, 1996; 1999). An estimator f_2 may be defined as:

$$(R,\ A) - f_2 \rightarrow Q \tag{4.16}$$

The strategy adopted for Stream Flow prediction was to first determine the runoff coefficient for different types of land cover, and then utilize these in prediction of stream flow. It is assumed that other parameters are represented by the R, A couplet. This appears to be a valid assumption as rainfall is the major source of the stream flow. The land slope and the permeability influence the land cover in the area (Dubey et.al, 1984). Quantitatively above mapping may be expressed as:

$$\frac{q_i}{R_i} = \sum_{j=1}^{M} a_{ij}\ C_j \tag{4.17}$$

Where, q_i is the runoff from i^{th} area. R_i is the runoff from i^{th} area. A_{ij} is the area of the j^{th} type of land cover in the i^{th} area. C_j is the runoff coefficient for j^{th} type of land cover.

$$Q = \sum_{i} \frac{q_i}{R_i} = \sum_{I=1}^{N} \sum_{J=1}^{M} R_i\ a_{ij}\ C_{ij}$$

Stream flow from an area basin may be written as as above.

Where N is the total number of sub areas in a basin, M is the total number of Land Cover classes. In matrix form above mentioned system operator equation may be written as:

$$\underset{N\times 1}{G} = \underset{N\times M}{A} \cdot \underset{M\times 1}{C} \tag{4.19}$$

Where G is an n x 1 column vector, A is an n x m land operator matrix, C is an m x 1 column vector representing runoff coefficient for different types of land cover.

The ideal situation, for a unique solution of the system, is when A is a square non singular matrix, which is having a classical inverse, as A^{-1} .Under these circumstances the solution of above equation is written as:

$$C = A^{-1} G \tag{4.20}$$

However in solving real world problem the operator A is rectangular. This type of system fails to admit unique solution. In these circumstances Least Square, Minimum Norm or combination or both may be obtained and solution of the system operator equation (4.20) may be written as:

$$C = A^{*}.\,G \tag{4.21}$$

Where, A* is Generalized Linear Inverse of A. Stream flow can be easily predicted once runoff coefficient land cover operator matrix and rainfall is known at any other time or place using the above-mentioned system operator equation

Calibration and Testing of Stream Flow Model

The calibration and testing of the developed Stream Flow Model was carried out for the Solani stream. The developed model requires rainfall, land cover and stream flow for its calibration. For this the observed rainfall data for the area have been used. Land cover statistics have been estimated from the analysis of the satellite data product. The details of these studies are given earlier.

In the area the stream flow data is not available. Further, stream flow measurement is a difficult and costly task. Measurement of gauge of a stream is comparatively simple task. Therefore an effort was made to develop relationship between Gauge and Discharge, commonly known as Gauge –Discharge curve. The Gauge –Discharge curve of the Solani stream and Ratmau stream is shown in Fig 4.3. .Later on this Gauge - Discharge was used to estimate the stream flow from observed Gauge.

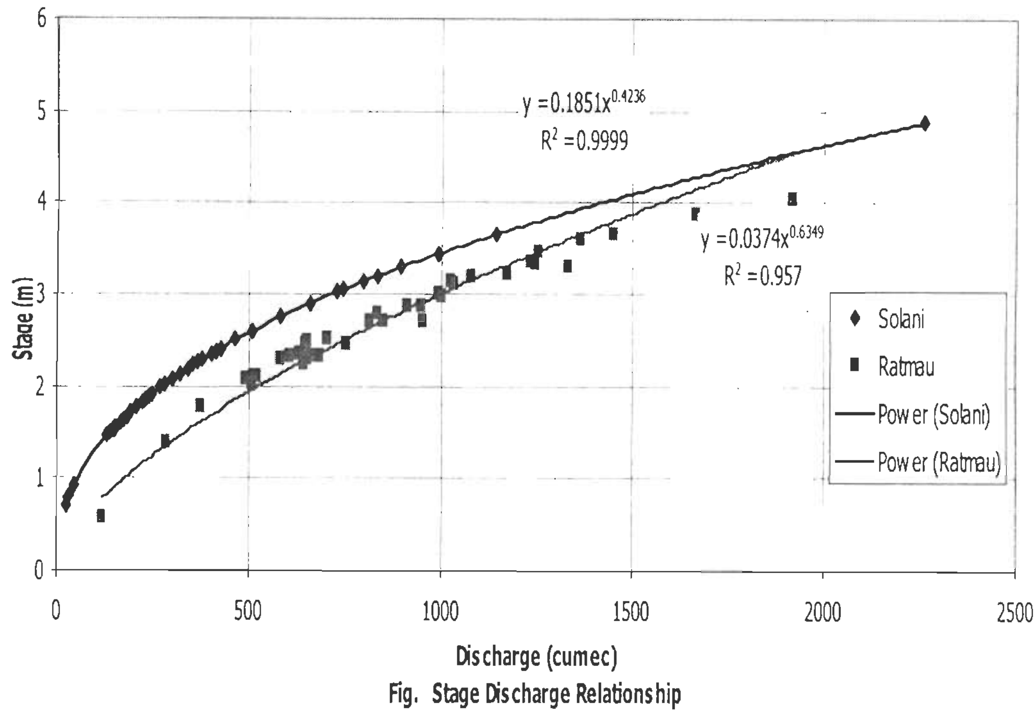


Fig. 4.3 Stage Discharge Curve

Gauge measurements were taken during the years 1975,1984,1985,1986,1989,1990,1995, and 2000. The model was calibrated for the period 1984-2000. The detail of the input data is tabulated in Table 4.13. The result of the calibration is tabulated in the Table 4.14.

Table -4.13. Input Data for Stream Flow Model

S.N.	Data	Data Source	Data range
1	**Land Cover Statistics**	Interpretation of Satellite data	Forest, Agriculture, Bare Land
2	**Stream flow**	Field observation	0 to 128 x 10^6 m^3
3	**Rain fall (mm)**	Observed data	20 mm to 400mm

Table 4.14 Stream Flow Model Calibration

S.N.	Land cover	System Response Factor (C)				
		1984	1985	1986	2000	Average
1	**Forest**	10.3	9.8	10.2	10.1	10.1
2	**Intensively Agricultural**	50.4	49.9	49.8	49.9	50.0
3	**Moderately Agricultural**	55.8	54.9	56.0	55.8	55.5
4	**Barren Land**	5.0	5.2	5.1	51.5	5.1

The model testing was done for the period 1985, 1990 and 2000. It was found that the prediction efficiency of the model is 86.58 %.

Water samples from tube wells in various geomorphic units were collected and analyses. Water quality of these samples in terms of pH and SAR is tabulated in Table 4.15. It is found that the water in the area is suitable for domestic and agricultural use.

Water resources characteristics of the various geomorphic Units is tabulated in Table 4.15

4.4 Closing Interpretation

Above analysis indicated that except in the area close to canals and streams groundwater is the major source of water. The depth of the groundwater table in the UP geomorphic unit is about 33m below ground level (bgl) and fluctuation is about 2.8 m bgl. In the MP geomorphic unit it is about 20 m bgl and fluctuation is about 2.0 m. In the IC unit the depth of the water table is about 5 m bgl and fluctuation is about 1.5. The chemical analysis of water indicates that it is fresh and useable for domestic and agricultural purposes.

Table 4.15 Water Resources Characteristics of Geomorphic Units

Land Parameters	UP	MP	IC			CB
			I_1	I_2	I_3	
Major Source Of Water	GW	GW	GW	GW	GW	GW
Average Depth Of Water Table (1975-2001)						
Pre Monsoon (m)	32.5	20.0	3.7	8.3	10.4	6.0
Post Monsoon (m)	29.7	18.0	1.5	6.7	9.0	4.5
Average water Level Fluctuation (m)	2.8	2.0	1.5	1.6	1.8	1.5
Number of Wells						
Deeper	5	12	20	50	180	
Shallow	45	230	20	510	2012	
Average Draft From a Well (10^2 ham)						
Deeper	10	15	1.6	18	160	
Shallow	1.0	1.1	1.6	1.6	1.2	
Annual Rainfall (mm)	1110	1200.1	1050	1050	1050	1050 - 1200
Rainfall-Recharge Time (days)	10-20	10-20	40-50	40-50	50-60	10-20
Availability- recharged Groundwater (days)	20-30	20-30	240-260	240-260	240-260	20-30
Groundwater Resource						
Inflow (10^2 ham)	139.45	92.93	88.58	106.39	222.80	35.82
Out flow (10^2 ham)	107.05	42.35	6.27	10.7	25.50	7.32
Balance (10^2 ham)	32.35	50.60	82.31	95.69	197.30	28.50
Draft (10^2 ham)	1.75	14.87	52.18	3.66	147.14	2.66
Resource	30.50	35.73	36.4	92.02	50.16	25.84
Water quality						
pH	8.0	7.9	7.1	7.2	7.2	7.7
SAR	0.6	0.6	0.2	0.3	0.3	0.4

Major source of the groundwater is the rainfall recharge. About 85% of the rainfall occurs during June and September. On annual basis rainfall recharge in the area is about 33%, whereas GEC recommended norm is 20% to 25% and computed by empirical relation is about 10%. Hence, empirical formula (Chaturvedi , 1947) was customized for this area with about 82% prediction efficiency.

In the UP geomorphic unit, rainfall takes minimum time (10 to20 days) to recharge the groundwater. In the MP geomorphic unit it is 20 days, whereas in the IC geomorphic unit it takes about 40 to50 days to recharge the groundwater. Such studies have further indicated that in the UP and MP geomorphic unit the recharged water is available for about 20 to 40 days, whereas in the IC geomorphic unit it is available for longer duration, about 8 months in the shallow regimes.

For the estimation of rainfall recharge a simple 2 parameter, rainfall and land cover, model has been developed. Land cover input to the model was determined from analysis of IRS LISS II; FCC .The model efficiency was found to be about 85%.

Available surface water resource was estimated using the Soil Conservation Society (SCS) model. The computed values were found to be about 35% higher than the observed stream flow. Thus, the SCS model was customized for this area with higher prediction efficency

For the estimation of stream flow, a simple 2 parameter, rainfall and land cover model have been developed. Land cover input to the model was determined from analysis of IRS LISS II; FCC .The model efficiency was found to be about 85%. The efficacy of this model was found that the model yields results with in ± 15 %.

Field investigations indicated that stream are flashy as such stream flow is available for short duration, less than a day or two and hence the direct use of stream flow is very limited. Further groundwater is the only dependable source of water for irrigation. The study indicated that on an average about 270 X 10^2 ha m recharged water is available annually. Water availability in the UP and MP geomorphic unit is much lower as compared to the IC geomorphic unit. Further conjunctive use of surface and groundwater is essential for growing a variety of crops.

5

CROP SUITABILITY ANALYSIS OF GEOMORPHIC UNIT

5.0 Background

The Ganga and Yamuna piedmont terrain is mainly governed by agricultural activities. This activity spreads over 79% of the area. However, it is being practiced over the years in poorly planned manner. With the increasing population, the demand of agricultural product is mounting. Thus there is need for optimal use of this land according to its sustained agricultural capacity (FAO, 1991; Sys et.al.,1993; Dubey, 1997; Naidu et. al., 2001). In this chapter, an effort is made to work out and suggest optimal use of various geomorphic units of this terrain for agricultural purposes.

Literature survey indicates that various approaches have been proposed to assess crop suitability of any type of terrain. These approaches evolved over a period of time and may be broadly categorized to three periods, namely, pre- 1949 period, from 1949 to 1970 period and post 1970 period. During the pre-1949 the approaches were based on qualitative assessment of crop yield. During 1949 to 1970 the agricultural soil capability concept was added to the crop production and soil damage was given paramount importance. In the post 1970 period, the concept of land capability, soil characteristics, soil hazard, available water resources were incorporated step by step for crop suitability assessment (Requier et.al., 1970; Kassam, 1980; Robiniv et.al., 1981; Beek, 1981; Singh, 1989; Sehgal et. al., 1990; Dubey, 1997).

Currently available methods are by and large, general in nature and useful on regional scale. Hence, in areas where the terrain characteristics are varying in small spatial domains as the present one, there is a need to take in to account local terrain parameters influencing the crop suitability and its production. This piedmont zone is located on a geologically active terrain adjoining the southern part of the Himalayan mountain system and is characterized by six geomorphic units. In view of these special features of this terrain between the rivers Ganga and Yamuna an attempt has been made to develop a multivariable analytical approach taking into account the parameters associated with various geomorphic units of the areas for crop suitability assessment for the terrain.

5.1 Current Land Use Scenario

As mentioned earlier the prevalent land use in the area is agriculture based. Twenty types of land use categories including crops are prevalent. However wheat, sugarcane, paddy, maize and masoor are the major crops grown. The prevalent area of various land uses along with production and demand of food grains, fodder, and fire wood beside net economic turn over is shown in Table 5.1.

A perusal of Table 5.1 indicates that the total food grain demand, as worked out on the basis, is 807 gm/capita/day (ICMR) is about 147278 T annually and the total production is about 2882707 T annually which is in much excess of the demand. The total annual fodder demand is 1500000 T. This total demand is based on sample survey conducted in the area. It is 0.01 T/ day / animal for cows and horses, whereas for buffalo it is 0.02 T / day / animal. The total annual fodder production is about 1472072 T. This indicates shortage of fodder production in the area.

Further, the total fire wood demand is 91250 T / year. This is based on sample survey conducted in the area. Fire wood requirement in the area is 0.5 kg/capita/day. The total production of fire wood in the area is 52781 T/year. This indicates an acute shortage of fire wood in the area.

Total annual return in the area worked out to be Rs. 1118 /head/year.

Table 5.1 **Current Land Use Scenario (Based on 2001**

Sl.No.	Land Cover		Production (T/Year)			Net Benefit
	Type	Area (hectare)	Food Grain	Animal Feed	Fire Wood	Rs.(x 10^5)
1.	Wheat	50570	68269.5	202280		788.6
2.	Paddy	19575	21336.8	39150		391.5
3.	Barley	503	362.2	1006		5.0
4.	Jawar	61	1.9	122		0.6
5.	Bajra	1089	250.5	1633.5	1089	10.9
6.	Maize	17587	18994		17587	562.8
7.	Arhar	104	119.6		104	2.1
8.	Gram	3946	315.8			118.4
9.	Moong	119	27.4			1.2
10.	Urd	192	38.4			1.9
11.	Masoor	5709	1313.1			85.6
12.	Pea	156	142			3.7
13.	Potato	620	91592			49.6
14.	Groundnut	300	480			14.7
15.	Sugarcane	29466	132212.5	1177840		3533.5
16.	Cherry	150	3000	3000		3.
17.	Barseem	600	12000	12000		24.0
18.	Vegetables	130	5200	1040		6.5
19.	Oil Seed	150	210			4.5
20.	Plantation	425	34000.0	34000.0	34000.0	12.8
Total Production			**288269.7**	**1472071.5**	**52781.0**	**5590.9**
Demand			**147277.5**	**1500000.0**	**91250.0**	**1118.2/Head/ hect..**
Balance (Production. – Demand)			**(+)40991.5**	**(-)27928.5**	**-38469**	

From above description it is inferred that though there is adequate food grain to meet the local demand but there is shortage of fodder and fire wood. In this connection this is to mention that in spite of overall higher food grain production than demand, field investigations indicate that there are many families who face food scarcity. This situation is responsible for poor quality of domestic animals and poor socio-economic conditions of many families, particularly the woman folk. Villagers, of late, have started land grazing practices and encroachment on forest land leading to further environmental degradation of the area. These findings goad the need for optimal use of land aiming towards achieving self sufficiency and improving the economical conditions together with maintaining the environmental balance.

5.2 Mathematical Model for Optimal Land Use

The land use is constrained mainly by available land, soil mass, water resources and human resources to fulfill the requirements of food grains, food for bovine population, fire wood and improvement in economic and environmental conditions. The area has a variety of resources. It receives more than 1000 mm rainfall annually leading to about 270 MCM of developable water resources and a variety of soil cover and sizeable human resources willing to work during winter, summers and rainy season. The current land use scenario as mentioned above indicates deficiency in fodder and fuel leading to encroachment of the forest areas which is causing continual environmental degradation with little financial benefits. To work out optimal land use a model has been formulated and described below.

5.2.1. Model Formulation

As mentioned earlier the optimal land use of the area is desirable to maximize the return benefit from the area. For this Linear Programming (LP) approach has been followed. The model incorporates 20 types of land cover (Agricultural – wheat, paddy, barley, jawar, bazra, maize, arhar, gram, moong, urd, masoor, pea, potato, groundnut, sugarcane, cherry, barseem, vegetables, oilseeds and plantation), during three seasons (Kharif - Rabi and Summer), with two irrigation conditions (irrigated and non irrigated), and 6 domestic animals, totaling 31 decision variables for the said purpose.

The optimal solution is obtained under the shadow of resource constraints. The solution was obtained with objective to maximize the net excess benefit from the system. The over all benefit, Z_B, is total benefit from the land cover system. Z_B, has been mathematically represented as:

$$Z_B = \sum_{i=1}^{20} \sum_{j=1}^{3} \sum_{k=1}^{2} B_{ijk} \, x_{ijk} + \sum_{l=1}^{6} B_l \, x_l \qquad (5.1)$$

Where, Z_B is the function to be maximized, B_{ijk} is the net benefit per unit area from the i^{th} land cover class during j^{th} season under k^{th} irrigation condition; x_{ijk} is the areal coverage of i^{th} category of land cover during j^{th} season, under k^{th} irrigation condition. B_l is the net benefit per unit from i^{th} category of animal and x_l is the number of the i^{th} category of animal. For the known B_{ijk} and B_l the model yields optimal x_{ijk}, B_l and z_B. The above model runs under the shadow of following constraints of modeling.

(i) Physical Constraints

The total study area is constant and therefore, at a particular instant of time the total area of all land cover has to be less than the total area. Mathematically, it is expressed as:

$$\sum_{i}^{20} \sum_{j}^{3} \sum_{k}^{2} x_{ijk} < A \qquad (5.2)$$

Where, x_{ijk} is the area of i^{th} category of land cover during j^{th} season under k^{th} irrigation condition A is the total study area equal to 2000 km^2.

(ii) Human Resources Constraint

The total man power in the area is constant the paying capacity of land users is low, therefore, the required man power in a particular season should not exceed the available man power. Mathematically it is represented as:

$$\sum_{I}^{20} \sum_{j}^{3} \sum_{k}^{2} h_{ijk}\, x_{ijk} + \sum_{l=1}^{6} h_l\, x_l < H \qquad (5.3)$$

Where, h_{ijk} is the human resources required on unit area basis for the i^{th} category of land cover during j^{th} season under k^{th} irrigation condition, h_l is the human resources required on per unit basis for the l^{th} category of domestic animals, and H is the total human resources available. H is equal to 350000. x_{ijk} and x_l are defined earlier.

(iii) Water Resources Constraints

Water is an important input to land and livestock system. Total water resources consisting of surface water and groundwater are constant. At a particular instant of time, land cover and live stock should be managed in such a way that water required to meet out the crop and live stock demand is less than or equal to the available water resources.

$$\sum_{I}^{20} \sum_{j}^{3} \sum_{k}^{2} w_{ijk}\, x_{ijk} + \sum_{I=1}^{6} w_l\, x_l \leq W \qquad (5.4)$$

Where, w_{ijk} is the water requirement on unit area basis for the i^{th} category of land cover during j^{th} season under k^{th} irrigation condition, w_l is the water resources required on per unit basis for the l^{th} category of the domestic animal and w is water resources available. W is equal to 270. MCM x_{ijk} and x_l are defined earlier.

(iv) Food Grain Requirement Constraints

Cereals, pulses, oil seeds and vegetables have been considered as a food grain requirement. Total production of these should meet the actual requirement. This is a social requirement and mathematically expressed as:

$$\sum_{i}^{20} \sum_{j}^{3} \sum_{k}^{2} f_{ijk} \; x_{ijk} \geq F \qquad (5.5)$$

Where, f_{ijk} is r^{th} food grain yield on unit area basis from the i^{th} category of land cover during j^{th} season under k^{th} irrigation condition and F is the total food grain requirement. F, the total food grain requirement has been assessed as per Indian council of Medical Research (ICMR) guidelines. It is 807 gm/capita/day. Total food grain demand is 147277.5 T/Year.

(v) Animal Feed Requirement Constraint

In synergistic land use, dairy and poultry are linked with the agricultural sector. The requirements of domestic animals in terms of green fodder and dry straw have been considered. This constraint is mathematically expressed as:

$$\sum_{i}^{20} \sum_{j}^{3} \sum_{k}^{2} a_{ijk} \, x_{ijk} > A_f \qquad (5.6)$$

Where, a_{ijk} is the animal yield on unit area basis from i^{th} category of land cover, during j^{th} season under k^{th} irrigation condition and A_f is the total animal feed requirement. Total animal feed requirement is based on sample survey. It is 0.01 T/day/animal for cows and horses, whereas for buffalo it is 0.02 T/day/animal. Total feed requirement is 1500000 T.

(vi) Fire Wood Requirement Constraint

In the study area, a majority of inhabitants depends on land for their fire wood requirement. Based on sample survey it has been found that fire wood requirement in the study area is 0.5 kg/capita/day. In order to fulfill the fire wood requirement it is important that its production is more than the requirement. This is mathematically expressed as:

$$\sum_{i}^{20} \sum_{j}^{3} \sum_{k}^{2} g_{ijk} \; x_{ijk} > F_w \qquad (5.7)$$

Where, g_{ijk} is the fire wood production on unit area basis from i^{th} category of land cover during j^{th} season under k^{th} irrigation condition, F_w is the total fire wood demand. Total fule demand is 91250 T/Year.

(vii) Social Constraints

Land users have strong affinity for wheat, therefore, it is expected that at least 25% of the total cultivable area will be used for growing wheat.

(viii) Financial Constraints

As mentioned earlier, in the study area, agriculture is the back bone of economy. Any proposed land use system should be able to provide at least the present economical status.

5.2.2 Model Input

The inputs to the model are constraints to the characteristics of the geomorphic unit. These are physical constraints, namely, human resources, available water resources, food grain requirement, animal feed requirement, fire wood requirement and financial requirements. The model aims to allocate available land for different uses in such a manner so as to get maximum net return and at the same time satisfying all the imposed constraints. Model input, B_{ijk} , is the net benefit from a particular crop, h_{ijk} is human resources, w_{ijk} is water requirement for growing a particular crop, f_{ijk} is food grain yield, a_{ijk} is animal feed yield, and g_{ijk} is the fire wood production from a particular crop/ land use.

In order to acquire these inputs, field survey was concluded. Field survey indicated that in the study area crop yield under rain fed and irrigated conditions remains more or less equal. This similarity in crop yield may be attributed to a variety of factors namely, poor economic conditions of farmers, use of low quality of seeds, low dozes of fertilizers and above all irregular supply of irrigation water.

Table 5.2 (a) Model Input Data – Land Cover Sector (As on 2002)

Sl. No.	Land Cover	Net Benefit/ha (Bijk) Rs./ha	Human Resource No./ha (hijk) mandays/ha	Water Requirement (Wijk) (mm/ha)	Food Grain Yield (fijk) T/ha	Animal Feed Yield T/ha (aijk) T/ha	Fuel Wood Production T/ha (gijk)	Existing Land Cover ha
1.	**Wheat**	1500	100	160.57	1.35	4.0		50570
2.	**Paddy**	2000	100	2100.00	1.09	2.0		19575
3.	**Barley**	1000	45	26.24	.72	2.0		503
4.	**Jawar**	1000	45	60.40	.03	2.0		61
5.	**Bajra**	1000	45	26.24	.23	1.5	1.0	1089
6.	**Maize**	3200	50	38.30	1.08	1.0	1.0	17587
7.	**Arhar**	2000	50	62.50	1.15	1.0	1.0	104
8.	**Gram**	3000	50	26.24	.08	1.0		3946
9.	**Moong**	1000	50	182.66	.23	1.0		119
10.	**Urd**	1000	50	26.24	.20	1.0		192
11.	**Masoor**	1500	50	26.24	.23	1.0		5709
12.	**Pea**	2400	50	83.83	.91	10.0		156
13.	**Potato**	8000	285	263.89	147.73			620
14.	**Grounnut**	4900	175	429.00	1.60			300
15.	**Sugarcane**	12000	200	642.28	4.49	40.0		29446
16.	**Cherry**	2000	50	26.24	20.00	20.0		150
17.	**Barseem**	4000	100	253.34	20.00	20.0		600
18.	**Vegetables**	5000	250	386.40	40.0	10.0		130
19.	**Oil Seed**	3000	100	263.20	1.4	15.0		150
20.	**Plantation**	3000	50	642.28	80.00	80.0	80.0	425

However crop yield in the command area of tube well is distinctly higher as compared to rain fed cultivation. Input to the model has been categorized in to two sectors, namely, land cover sector and domestic animal sector. Inputs to the model pertaining to land cover sector is tabulated in Table 5.2 (a). Model inputs were estimated on average basis based on field survey.Inputs to the model pertaining to bovine population are tabulated in Table 5.2 (b).

Table 5.2 (b) Model Input Data – Bovine population (As on 2002)

Sl.No.	Domestic Animal	Net Benefit Rs./Unit (Bijk)	Human Resource (Mandays/Unit) (hijk)	Water Requirement (MCM/Year) (Wj)	Number	Animal Feed Requirement (T/Year)
1.	**Cow**	3000	0.10	0.0018	148707	542780
2.	**Buffalow**	2500	0.10	0.0190	124642	1455819
3.	**Polletry Unit**	100	0.05	0.0010	41313	
4.	**Sheep & Goat**	100	0.05	0.0010	34311	
5.	**Horse**	100	0.05	0.0010	1879	6858
6.	**Boar**	100	0.05	0.0010	8316	

Field investigations and perusal of Table 5.2 (a) and Table 5.2 (b) indicates that net benefit from various crops varies from rupee 1000 T / ha to 12000 T / ha. In general net benefit is low approximately of the order of 1000 T / ha. Human resources requirement for growing crops varies from 45 man days / ha to 285 man days / ha. General human resource requirement is 50 man days / ha.

Water resources requirement for varies crops have been calculated as per revised FAO approach. It varies from 26.24 mm to 2100 mm. General requirement for various crops in the area is 100 mm. Food grain yield varies from 0.08 T / ha to 147.0 T / ha. In general it is 1 T / ha. Animal feed yield from various crops varies from 1 T / ha to 40 T / ha. In general it is of the order of 1 T / ha. Fire wood production in general is 1 T / ha. Major source of fire wood is plantation.

5.2.3 Model Out put

The model allocates the land to be used for growing different crops. The optimal aerial coverage for different crops is given in the Table 5.3, which indicates that most of the area should be used mainly for wheat, sugarcane, maize and paddy.

Table 5.3 Model Output – Allocated Land Cover

Sl.No.	Land Cover	Area x_{ijk} (ha)
1.	Wheat	54550
2.	Paddy	22580
3.	Barley	400
4.	Jawar	20
5.	Bazra	500
6.	Maize	26755
7.	Arhar	350
8.	Gram	3850
9.	Moong	100
10.	Urd	150
11.	Masoor	6789
12.	Pea	245
13.	Potato	1225
14.	Groundnut	300
15.	Sugarcane	30558
16.	Cherry	265
17.	Berseem	800
18.	Vegetables	300
19.	Oil Seed	250
20.	Plantation	800

Knowing the optimal (allocated) land cover area, the food grain, animal feed and fire wood production based on average yield have been assessed and tabulated in Table 5.4.

Analysis of Table 5.4 reveals that:

(a) In optimal use of land the total production could be more than the demand. Food grain production can be increased to nearly four times than the demand. Further the current deficits of animal food and fire wood can also be made up and can become in surplus than the local demand.

Table 5.4 Optimal Land Cover characteristics (As on 2001)

Sl.No.	Land Cover		Production (T/Year)			Net Benefit Rs. (x 10^5)
	Type	Allocated Area x_{ijk} (ha)	Food Grain	Animal Feed	Fuel Wood	
1.	**Wheat**	54550	81825	218200		818.25
2.	**Paddy**	22580	33870	45160		451.60
3.	**Barley**	400	400	8		4
4.	**Jawar**	20	0.8	40		0.20
5.	**Bajra**	500	150	750	500	5
6.	**Maize**	26755	32106		26755	856.16
7.	**Arhar**	350	420		420	7.00
8.	**Gram**	3850	385			115.50
9.	**Moong**	100	26			1.00
10.	**Urd**	150	34.5			1.50
11.	**Masoor**	6789	2036.7			101.84
12.	**Pea**	245	245.0			5.88
13.	**Potato**	1225	208127.5			98
14.	**Groundnut**	300	540			14.70
15.	**Sugarcane**	30558	152790	1222320		3666.96
16.	**Cherry**	265	6095	5300		5.30
17.	**Barseem**	800	18400	16000		32
18.	**Vegetables**	200	11000	200		15
19.	**Oil Seed**	250	500			7.50
20.	**Plantation**	800	64000.0	64000.0	64000.0	24
	Total	**150687**	**612951.9**	**1571978**	**91675.0**	**6231.39**
Production			**548951.5**	**1571978**	**91675.0**	
Demand			**147277.5**	**1500000**	**91250**	1246.28/Head /Year
Production –Demand			**(+)401674**	**(+)71978**	**(+)425**	

(b) As compared to existing land use it is inferred that, area coverage for wheat, paddy, maize, arhar, masoor, peas, potato, sugarcane, charry barseem, vegetables and plantation may be increased and for the remaining crops - barley, jawar, bazraa, moong and urd is to be reduced.

© The surplus food grains, fodder and fire wood can help to improve the economic benefits of the populace through business transactions with others in need of these. This would also help to reduce grazing and encroachment of the forest land and thus help in preventing natural environment vis-a vis developed area in some part of the area. They found encouraging results. However the difficulty for them to use the model is that they are not equipped with the needed guidance to understand and use that model. Realizing this attempt has been made to translate this model to a simple model with inputs that could be easily understood by the users.

5.3 Geomorphic Approach for Crop Suitability

In a given climatic condition, crop suitability in a land unit depends upon a variety of terrain parameters. Field survey in the study area revealed that the terrain parameters influencing the crop suitability are, land slope, soil characteristics (soil type, soil thickness, soil drainage) and depth of the groundwater table. FAO (1989) has classified crop suitability in to five classes, namely, most suitable, highly suitable, moderately suitable, slight suitable and not suitable on the basis of certain terrain characteristics. For the wheat crop (the principal crop of the area) these suitability conditions has been assessed based on relevant terrain characteristics of the area as given in Table 5.5.

Table 5.5 Terrain Suitability for Wheat Suitability

S.No	Terrain Characteristics	Crop Suitability				
		Most	Highly	Moderate	Slight	NS
1	Land Slope (deg)	< 0.5	0.5 – 1.0	1.0 – 2.0	2.0 – 3.0	3.0 – 5.0
2	Soil Type	Sandy Loam	Loamy Sand	Coarse Sand	Sand Pebbles	Sand Pebbies Boulders
	Soil Thickness (cm)	> 90	50 – 90	25 – 50	10 – 25	< 10
	Soil Drainage	Well	Moderate	Imperfect	Poor	Excessive
3	Depth of Ground water (m)	< 2	2 – 5	5 -10	10 – 15	>15

An analysis of the approach and the results indicates that for preliminary semi quantitative assessment, the approach appeared useful. While implementing to an unknown area it was found that approach has some inherent drawbacks. For example, a land unit may be classified as most suitable from the land slope consideration, but from other considerations it may not be so. This brings an element of quandary in terms of crop suitability assessment. Further through this technique, the entire Ganga and Yamuna piedmont is classified as slightly suitable for cropping. However within this terrain, field investigations indicate variation in crop yield from one geomorphic unit to another. In view of this, an attempt has been made to classify this terrain for crop suitability on the basis of geomorphic variations. The details of the approach are being given below.

5.3.1 Bench Mark Land and Productivity Index

In this geomorphic approach a concept of 'Bench Mark Land Unit' for a given crop has been first introduced. A land unit that gives the highest yield of a particular crop is defined as Bench Mark Land Unit for that crop. Bench Mark Land Unit is the result of all characteristics of the terrain that have contributed interactively in optimal manner to give highest yield of a particular crop. In addition, with a view to assess the yield of a crop from an investigated land unit as compared to that of the bench mark land unit, a parameter, Productivity Index (PI) has been introduced and defined as

$$\mathrm{Pr}\,oductivityIndex(PI) = \frac{Yield\ per\ hectare\ from\ an\ area}{Yield\ per\ hectare\ from\ Bench\ Mark\ Unit}$$

Field survey was conducted to delineate the bench mark land unit and estimate the crop yield. For this, a few major crops, namely, wheat sugarcane, paddy, maize, groundnut and urd were selected. Crop yield from Bench Mark Land Unit and other geomorphic units are tabulated in Table 5.6.

Table 5.6 Crop Yield from Bench Mark Land Unit

Geomorphic Unit		Crop Yielf (T/ha)					
		Wheat	Sugarcane	Paddy	Maize	Groundnut	Urd
U P		1.1	3.4	0.9	1.1	1.8	0.22
MP		1.1	3.5	1.1	1.2	1.7	0.23
IC	I_1	1.4	5.0	1.3	1.1	1.6	0.22
	I_2	1.5	4.5	1.2	1.0	1.5	0.21
	I_3	1.2	4.0	1.1	0.9	1.5	0.18
CB		1.0	3.4	0.9	0.8	1.0	0.15
Bench Mark Unit		1.8	6.2	1.6	1.5	2.2	0.30

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars

Based on the yield of a crop from a geomorphic unit and yield of the same crop from the bench mark land unit, the productivity index as defined above has been calculated. The process is repeated for each crop and for each geomorphic unit and given in Table 5.7.

Table 5.7 Productivity Indices for Various Crops

Geomorphic Unit		Crop Productivity Index (PI)					
		Wheat	**Sugarcane**	**Paddy**	**Maize**	**Groundnut**	**Urd**
UP		0.55	0.54	0.56	0.73	0.81	0.73
MP		0.60	0.56	0.62	0.80	0.77	0.76
IC	**I_1**	0.70	0.80	0.81	0.66	0.72	0.73
	I_2	0.82	0.73	0.75	0.67	0.68	0.70
	I_3	0.66	0.65	0.68	0.61	0.68	0.60
CB		0.55	0.55	0.56	0.53	0.46	0.50

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars

On the basis of productivity index and their variation from one geomorphic unit to another, the major crops grown in the area may be categorized in to two groups namely, C_1 group, consisting of wheat, sugarcane and paddy. The second group C_2 , consisting of maize, groundnut and urd. A perusal of Table 5.7 indicates the following.

(a) The UP and the MP geomorphic units have relatively higher productivity index for maize, groundnut and urd crops, as compared to wheat, sugarcane and paddy crops.

(b) The IC geomorphic unit – I_2 and I_3 subunits have relatively higher productivity index for wheat, sugarcane and paddy crops as compared to maize, groundnut and urd.

© The productivity index of I_1 remains more or less same but at lower values as compared to the I_2 & I_3.

(d) In the CB unit the productivity index is least for each crop.

Thus on the basis of above, following inferences may be drawn.

Both in the UP and MP unit maize, groundnut and urd is a preferable crop. However in the IC – I_2 and I_3, wheat, sugarcane and paddy are preferable crop. In the flood plain A_3, any crop can be grown. In the CB unit the crop yield would be lower for every crop and may go down to zero, if affected by floods and channel erosion.

5.3.2 Relationship between Terrain Characteristics and Crop Yield

The crop suitability in a terrain is related to its land characteristics. Integrated study of geomorphic terrain characteristics, productivity index and discussions with the villagers revealed that, land slope, depth of the soil, soil texture, depth of groundwater table and intensity of agriculture are the governing factors for crop selection in a particular land unit. Therefore, an attempt has been made to investigate the relationship between various terrain parameters and productivity index. Coefficient of correlation among various pairs of geomorphic parameters were determined and tabulated in Table 5.8.

Table 5.8 Geomorphic Correlation Matrix

Parameter	L_s	S_t	d_{50}	D_w	A_i	PI
Land Slope (L_s %)	1.0					
Soil Thickness (S_t Cm)	(-)0.866	1.0				
d_{50} (mm)	0.997	(-)0.899	1.0			
Depth of Groundwater (d_w, m)	0.992	(-)0.921	0.994	1.0		
Intensity of Agriculture (A_i %)	(-)0.914	0.996	(-)0.926	(-)0.945	1.0	
Productivity Index (PI)	(-)0.958	0.997	(-)0.966	(-)0.978	0.991	1.0

From the study of the geomorphic correlation matrix (Table 5.8) following inferences have been drawn.

(a) Various terrain parameters appear to be highly interrelated as shown by significant high coefficients of correlation which range from 0.866 to 0.997.

(b) Land slope and soil thickness are negatively correlated with coefficient of correlation as (-) 0.866 and thus have inverse relationship.

© Land slope and soil texture, d_{50} of the soil are positively correlated and have coefficient of correlation as 0.997. It is also positively related with the groundwater table with coefficient of correlation as 0.992. This indicates that land slope is directly related to d_{50} and the depth of groundwater table.

(d) Land slope is negatively correlated with intensity of agriculture and productivity index. Its coefficient of correlation is (-) 0.914 with intensity of agriculture, (-) 0.958 with productivity index.

(e) Productivity index and intensity of agriculture show nearly perfect (0.991) correlation. This is indicative of direct relation.

Above inferences indicate that the terrain parameters are interrelated. They act and interact among themselves to produce a typical geomorphic unit. It indicates that productivity index takes in to account simultaneously all these parameters. Therefore, each geomorphic unit should be expected to have its own productivity index for a given crop if other facilitating factors remain the same.

5.4 Multivariate Relationship Between Terrain Parameters And Productivity Index

Studies in the previous section indicate that when considered individually, various terrain parameters affect the productivity of a given crop. In view of this it is desirable to work out the impact of their simultaneous roles in production of a crop. Hence a multivariate approach using principal component analysis was applied. For this the correlation matrix (Table 5.7) was spectrally decomposed to determine the eigen values. The first, eigen values was found to be 4.789. The second largest value was found to be 0.202. Other eigen values were very small. Numerical value of eigen values represent the information content. Keeping this in mind only first and second eigen values have been retained and used in the study. Other eigen values have been ignored. Corresponding to these two eigen values, eigen vectors have been calculated and tabulated in Table 5.8. These eigen vectors are popularly known as variable loadings to yield components. The component corresponding to the largest eigen values is known as first component, and corresponding to the second largest eigen values is the second component.

Table 5.9 Variable Loading

Variable	Variable Loading	
	I Component (C_1)	**II Component (C_2)**
Land Slope (deg)	0.979	0.119
Soil Thickness (cm)	(-)0.961	0.227
d_{50}	0.958	0.169
Depth of Ground water Table (m)	0.992	0.112
Intensity of Agriculture (%)	(-)0.997	0.212

From Table 5.9 following inferences have been drawn.

(a) The first component is heavily loaded with all the variables. This is heavily loaded with depth of ground water table, followed by d_{50} of the soil land slope, soil thickness and intensity of agriculture in decreasing order of loading.

(b) The second component is lightly loaded with all the variables. These inferences goad that the first component accounts for about 95% variation in the data. As such this factor has about 95% information density.

An effort was made to investigate the relationship between productivity index and first component scores. This component explains maximum variation in the data; as such it is a simple one composite representing the terrain characteristics. As shown earlier that the productivity index depend terrain characteristics, namely, land slope, soil thickness, d_{50}, depth of groundwater table and intensity of agriculture. As first component is representative of these characteristics, hence productivity index and first component must be related. Relationship between productivity index and first component (PC_1) in least square sense is found to be

$$PI = -0.01C1 + 0.6213 \quad (5.8)$$

Where,

$$C1= 0.979\ L_s\ -.961\ S_t\ +.985\ d_{50}\ +\ .992\ d_w\ -.997\ A_c \quad (5.9)$$

Finally the relationship between productivity index (PI) and terrain parameters is:

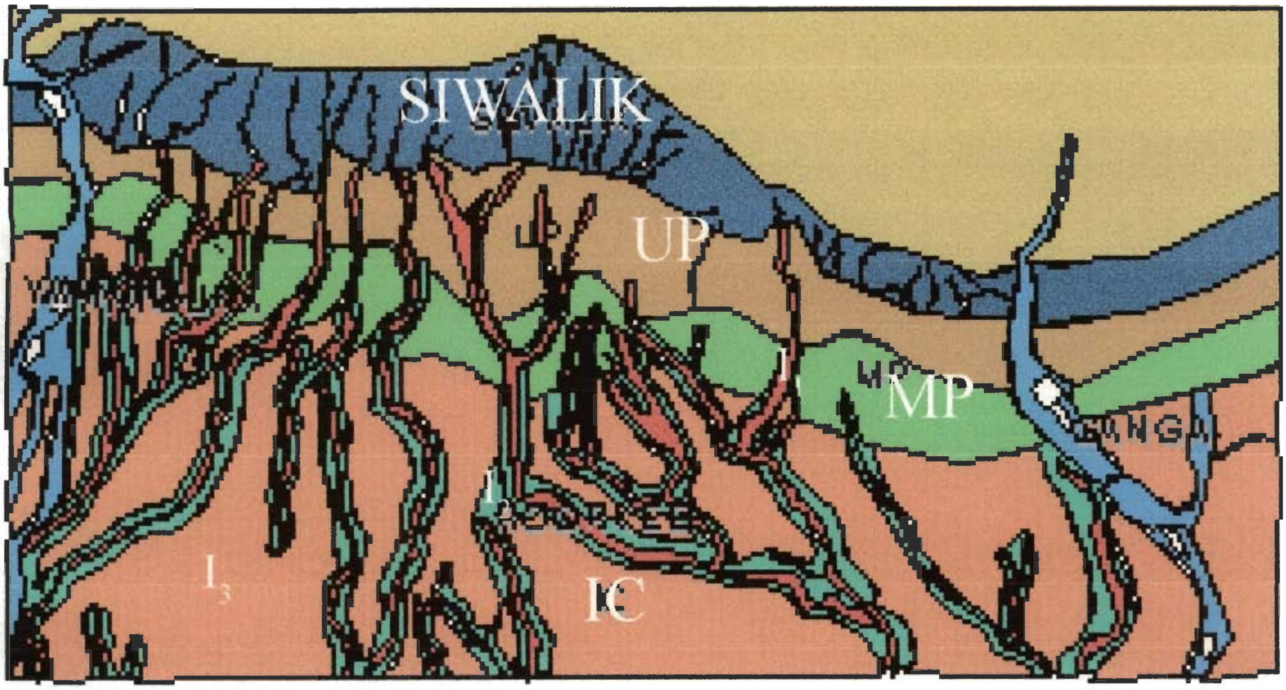
$$PI = 0.6213 - 0.000979\ L_s + .000961\ S_t - .000985\ d_{50} - .0000992\ d_w \quad (5.10)$$

Where, L_s is land slope in degrees, S_t is soil thickness in cm, d_{50} is the soil grain size in mm, d_w is depth of the groundwater table in m.

5.5 Suggested Land Use

In a new area, terrain parameters can help to work out the principal component score (equation 5.9). Thereafter this component score can be used to estimate the productivity index (PI) using equation 5.8. However, equation (5.10) can be directly used to estimate the PI from terrain parameters. This relationship can be utilized to assess the PI from the geomorphic attribute and then to decide the appropriate land use.

Keeping in view the poor literacy of the villagers, optimal land use of the area has been suggested in the form of a map and a table. Based on computed PI, optimal crops for each geomorphic unit has been worked out and tabulated in Table 5.10. For the local populace a map depicting the optimal land use has been prepared and shown in Fig. 5.1



UP: Upper Regime Piedmont

MP:Middle Regime Piedmont

IC: Inter Channel Plainer Area

I_1 : Characterized by Frequent Flooding

I_2 : Characterized by Occasional Flooding

I_3 : Relatively Free From Flooding

UP: Suitable For Maize, Groundnutand Urd

MP: Suitable For Maize, Groundnut Urd, Wheat, Sugarcane, Paddy

IC: Suitable For Wheat, Sugarcane, Paddy, Maize, Groundnut Urd, Wheat

CB: Suitable For Maize, Groundnutand Urd

Fig. 5.1 Suggested Land Use

Table 5.10 Suggested Land Use

Geomorphic Unit		Suggested Major Land Use
UP		Maize, Groundnut and Urd
MP		Maize, Groundnut and Urd
IC	I_1	Maize, Groundnut and Urd, Wheat Sugarcane, Paddy
	I_2	Wheat Sugarcane, Paddy, Maize, Groundnut and Urd
	I_3	Wheat Sugarcane, Paddy, Maize, Groundnut and Urd
CB		Maize, Groundnut and Urd, Wheat Sugarcane, Paddy

UP-Upper Regime Piedmont, MP- Middle Regime Piedmont, IC-Inter Channel plainer area, I_1: areas prone to frequent flooding, I_2: areas prone to occasional flooding, and I_3 : areas relatively free from flooding, CB : Channel Braid bars

From above table and map it is inferred that the upper regime piedmont (UP) and middle regime piedmont (MP) , that are characterized by high to medium land slope, low soil thickness, coarse gravely soil, deep ground water table and low water storage capacity are relatively more suitable for maize, groundwater and urd crops. This unit is showing generally whitish to light pink color on IRS _ LISS _II, F.C.C.

The inter Channel Plainer Area (IC) unit that is characterized by moderate to near flat ground slope, moderate and high soil thickness, medium to fine soil texture, moderate to shallow groundwater table and moderate and high water storage capacity is relatively more suitable for wheat, sugarcane, paddy, maize, groundnut and urd crops. However, it is worth mentioning here that the area close to streams has advantage of easily available water resources but has major disadvantages of stream bank erosion and flooding. The Channel Braid Bars (CB) unit is suitable for a variety of crops with low productivity that may go down to zero, if affected by soil erosion and flooding.

Land use characteristics of the area is tabulated in Table 5.11. In a new piedmont area, in absence of better observed data the PI as given in Table 5.7 may be used as a guide. Thereafter, optimal land use can be decided. It is worth mentioning here that optimal land use is space and time dependent and hence requires regular updating. It was observed that working with hard copy map is difficult, costly and time consuming. Thus, a soft copy processing of data becomes essential.

Therefore an effort was also made to customize the geographical Information system (GIS) software, Arc View, to carry out the entire analysis in this environment (Fig.5.2). This will help in monitoring the land use changes and suggesting the optimal land use in changed scenario.

Table 5.11 Land Use Characteristics of Geomorphic Units

Land Parameters		UP	MP	IC			CB
				I_1	I_2	I_3	
Major Land Use		Thin Agriculture	Thin Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Crrent Production (T/Ha)	**Wheat**	1.	1.1	1.4	1.5	1.2	1.0
	Sugarcane	3.4	3.5	5.0	4.5	4.0	3.4
	Paddy	0.9	1.1	1.3	1.2	1.1	0.9
	Maize	1.1	1.2	1.1	1.0	0.9	0.8
	Groundnut	1.8	1.7	1.6	1.5	1.5	1.0
	Urd	0.22	0.23	0.22	0.21	0.18	0.15
Productivity Index	**Wheat**	0.55	0.60	0.7	0.82	0.66	0.55
	Sugarcane	0.54	0.56	0.80	0.73	0.65	0.55
	Paddy	0.56	0.62	0.81	0.75	0.68	0.56
	Maize	0.73	0.80	0.66	0.67	0.61	0.53
	Groundnut	0.81	0.77	0.72	0.68	0.68	0.46
	Urd	0.73	0.76	0.73	0.70	0.60	0.50
Proposed Land Use		C2	C2, C1	C1	C1	C1	C1, C2

C1: Wheat, Sugarcane, Paddy; C2: Maize Groundnut, Urd

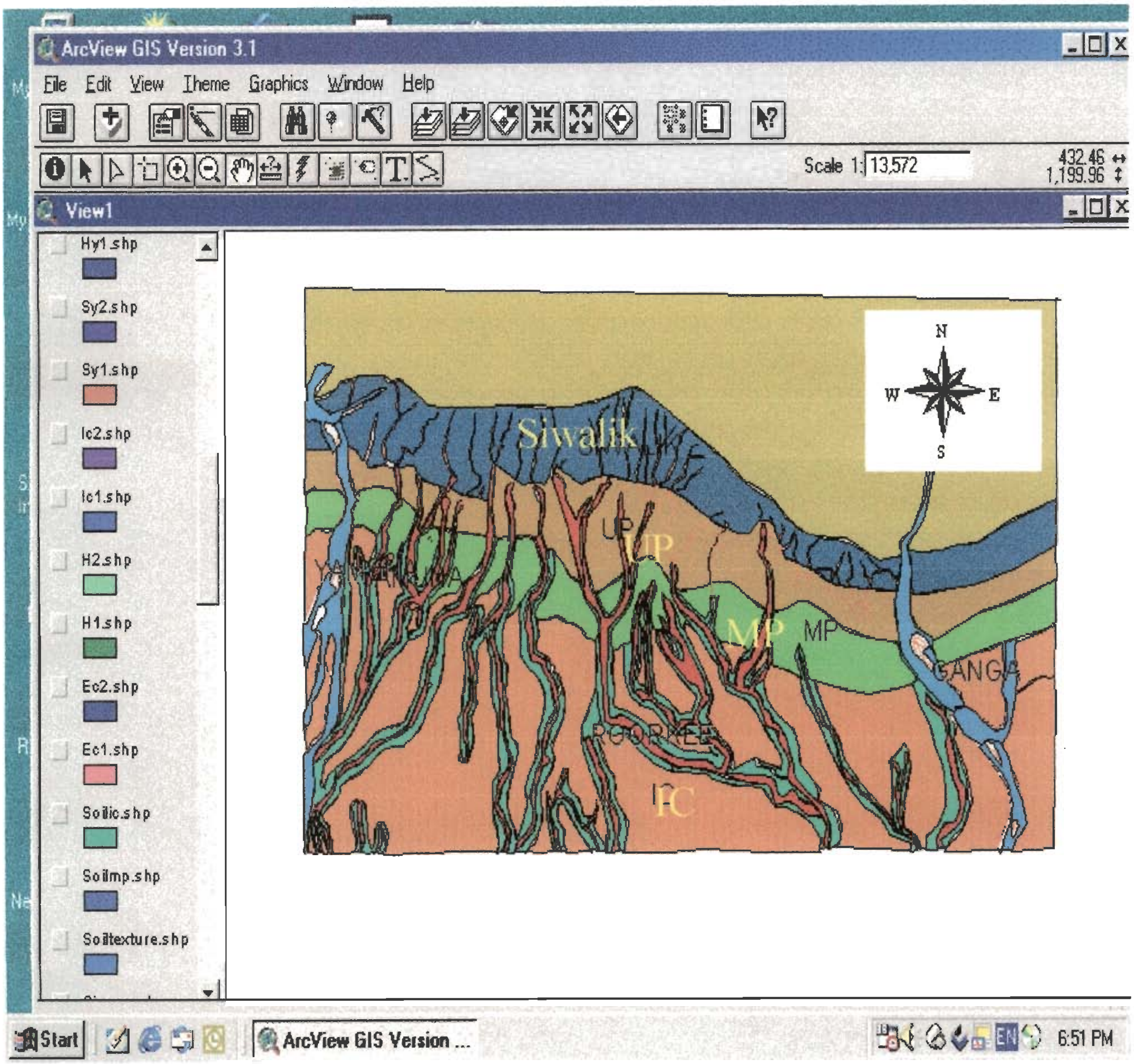


Fig.5.2 Data Analysis In GIS Environment

6

SUMMARY & CONCLUSION

To the south, on the foot of the Himalayas, conspicuous, east - west running geographic feature, commonly known as piedmont, occurs in the form of alluvial deposits. These deposits are characterized by sediments ranging in size from boulders to sand, silt with little clays.

Till the middle of last century, this difficult terrain had poor human settlement mainly due to its fragile ecological set up in terms of climate, water availability, soil characteristics, rugged topography, poor accessibility and connectivity to neighboring areas .However with increasing population, these areas have attracted the populace to make use of these poorly inhabited and developed areas for there well-beings. Accordingly, agricultural and allied activities have spurted in unscientific and unplanned use of land which is causing environmental degradation of the area.

There is, thus a need to evaluate this geomorphic terrain for better and optimal use in an environment friendly way. Accordingly, a part of piedmont spreading between rivers the Ganga and the Yamuna has been taken up for investigation as a model of development of these areas for land uses. This terrain has an area of about 2000km. sq.The annual rainfall varies between 1033 mm and 1200mm of which about 85% rainfall takes place between June and September every year.

Preliminary field survey indicated that the land use in the area is influenced by its terrain characteristics, namely, physiography (land elevation, land slope, drainage), climate (rainfall, temperature), soil (soil type, soil erosion etc.), and water resources (groundwater and surface water).

In view of this, these parameters have been determined and evaluated on the basis of synergistic use of remotely sensed data, field investigations, laboratory studies and analysis of existing data.

Geomorphic Features

Based on synergistic use of aerial photographs at about 1:30000 scale with stereoscopic coverage, Indian Remote Sensing Satellite (LISS II) geo-coded False Colored Composite (FCC) of bands 2, 3 and 4 on 1:50000 scale, topographic maps at 1:50000 scale and field surveys, the area was classified in to four major geomorphic units, namely, Upper Regime Piedmont (UP), Middle Regime Piedmont (MP), Inter Channel Plainer Area (IC) and Channel Braid Bars (CB).The IC unit is further categorized into three sub units namely, I_1, I_2 and I_3 on the basis of topographic variations and risk of flooding.

The Upper Regime Piedmont (UP), geomorphic unit occurs in the northern most part of the study area and is in direct contact with the hill slope. This geomorphic unit is characterized by undulating topography, relatively higher elevation averaging more than 350 m above mean sea level (m s l) and exhibits general ground slope of more than 3^0.It consists mainly of very coarse gravel sediments. This unit forms about 17.4% of the total study area.

To the south of this unit , lies a geomorphic feature designated as Middle Regime Piedmont (MP).The MP unit is characterized by relatively low relief with average ground elevation between 300 m and 350 m above m s l and relatively gentler slope of about 2^0-3^0.Its sediments are mainly gravel-sands. This geomorphic unit forms about 12.6% of the total piedmont area under study.

In the southern most, the third geomorphic unit, designated as, Inter Channel Areas (IC), exhibits slope less than 2^0 with relatively plainer-non undulated topography with elevation between 250 m and 300 m above mean sea level. These plainer areas are characterized by relatively finer sediments, mainly sand, silt and clays. This IC unit is the largest geomorphic unit in terms of area and forms about 63.4%of the total piedmont area under study.

All these three major geomorphic units are cut across by southerly flowing streams and their tributaries namely, Hindon, Solani, Ratmau, Pathri and Ranipur. These streams and their tributaries cause floods during the rainy season. Considering drainage characteristics, the following four geomorphic sub- units have been delineated mostly in the IC unit:

(i): I1: characterized by frequent flooding;
(ii): I2: experiences occasional flooding; and,
(iii): I3: is relatively free from flooding

The sub unit, I_1, is characterized by frequent flooding, that is to say, the area experiences flooding more or less every year. The sub unit I_2 is characterized by occasional flooding, that is to say, the area experiences flooding once in about eight to ten years. The geomorphic sub-unit I_3 is relatively free from flooding. These areas are relatively higher so that flood water is not able to touch these lands. Area of sub units, I_1, I_2 and I_3 are 19.6%, 14.4% and29.4% of the total area respectively. Relatively higher patches within the channels have been designated as Channel Braid Bars-CB. The Channel Braid Bar (CB) area spreads over 6.6% of the total area. It has been found that about that about 63.4% of the total study area spreads between 250 m and 300 m above m .s l and is mostly plainer. About 30%of the area lies above 300 m above m.s.l. and shows undulating topography.

Drainage

The area is traversed by a number of seasonal and flashy streams in addition to the river Ganga in the east and Yamuna in the west. These streams systems emerge from the southern face of the Siwaliks .In the Siwaliks, the drainage system is more or less denderatic. In the piedmont, drainage pattern is generally sub parallel. These channels follow Hortonian law. In general; streams are shallow and relatively wider in the MP geomorphic unit. They show a decreasing trend in depth with increase in drainage area. In general, drainage density is low, 1.35 km/km^2.Bifurcation ratio of the stream system lies between 2 and 5. These results indicate that the sub basins are generally elongated and induce quick and higher run off associated with the higher sediment yield.

Soil Characteristics

The superficial deposits made up of relatively loose unconsolidated sediments play an important role in cropping practices. Soil of an area influences the agricultural practices by its workability; drainage and water retain ability in a given climatic condition. Based on field investigations and 250 soil samples collected from various condition geomorphic units, the soil texture , mineralogical composition, salinity, geomorphic units were analyzed to determine the soil texture, mineralogical composition, salinity, alkalinity, hydraulic conductivity and hydrological soil classification as proposed by USDA were determined. The sediments of the UP unit are coarse gravels sediments – gravels with boulders, cobbles, pebbles, granules, mainly coarse sand with little clay. Soils in the MP geomorphic unit are fine gravels (with occasional cobbles, pebbles and granules) to coarse to medium sands, silts and clays. Soil in the IC geomorphic unit is relatively finer and consists of sand silt and clays.

The sandy component of soil which is about 15 cm thick in the UP unit has more than 85% sand width less than 15% silt-clay fraction. Wherever present the sandy soil in this geomorphic unit is very coarse grained (d_{50}, more than 1.0 mm). The soil in the MP geomorphic unit is medium grained sand (d_{50}, between 1.0 mm and 0.5 mm) but is finer than the soils in the UP unit. Soils in this unit are about 15 cm -20 cm thick. The soils in the IC geomorphic unit are finer (d_{50}, less than .025 mm) than the soils in the MP unit. Soils in this unit are mainly sandy loam, containing comparable amount of sand, silt and clay. Soils in the CB geomorphic unit found mainly in the I_1 are sandy in nature. It shows large textural variation (d_{50} varies between 1.0 mm and 0.025 mm).

The mineralogical composition of the soil has pronounced influence on the land use. Petrographic investigations indicated that the boulders, cobbles, pebbles and sand are of heterogeneous nature with various types of rocks mainly quartzite with small amount of sand stone, phyllites and limestone. The sand and silt are made up of mainly quartz with mica and feldspar. X - Ray investigations indicate that the clay minerals are mainly Kaolinite, Illite with some Vermicullite and Montmorillonite. From mineralogical considerations the soil can sustain a variety of crops.

Based on 50 electrical conductivity tests it is inferred that the electrical conductivity varies from 0.04 dsm^{-1} to 0.25 dsm^{-1}.It shows increasing trend from UP (0.04 dsm^{-1}) through MP (0.15 dsm^{-1}) to IC (0.25dsm^{-1}).The pH worked out on the basis of 50 soil samples varies from 7.1 to 8.0.The pH is maximum (8.0) in the UP geomorphic unit. It shows a decreasing trend through MP unit as, 7.7 to IC (7.1). Thus electrical conductivity and pH follows a reverse trend in spatial domain. Thus, the soils are neither saline nor alkaline and hence not detrimental to the crop growth.

Hydraulic conductivity of the soil samples collected from various geomorphic units was worked out in the laboratory by Falling Head Method. It varies between 80cm/hr and 0.3cm/hr. Average value of the hydraulic conductivity is highest (80 cm/hr) in UP unit and lowest (about 20 cm/hr) in the IC unit. It is 55 cm/hr in the MP unit.

Field measurement of infiltration capacity of the soil at well distributed 50 sites was carried out by double ring infiltration meter. Infiltration capacity for various geomorphic units varies from 2 cm/ hr to 16 cm/hr. The average value of infiltration capacity is highest (about 15 cm/hr) in the UP unit, intermediate (about 11 cm/hr) in the MP unit, and lowest (about 5cm/hr) in the IC unit.

The hydraulic conductivity and infiltration capacity indicate that the relatively coarser soil in the UP and MP geomorphic units are characterized by high drainage, high aeration and low water holding capacity as compared to relatively finer soils in IC. The short soils in the IC are more suitable for agricultural activities as compared to UP and MP.

Water Resources

For any land use, more so for agriculture, water is an essential resource. The area is bounded by two perennial rivers the Ganga and the Yamuna. In between these two rivers a number of seasonal streams, Hindon, Solani, Ratmau and Ranipur which form tributaries of these two rivers flow through the area. Also, the area has three canal systems, namely, Upper Ganga Canal, Eastern Yamuna Canal and Khara Canal. In the area groundwater is the main source of water. In this study an attempt has been made to assess the water resources potential in various geomorphic regimes of the area.

Based on field survey, 25 open wells distributed in various geomorphic units were selected. In these wells depth of the groundwater table during pre-monsoon (May/June) and post monsoon (Oct/Nov) measured for during 1975 to 2001 indicates that maximum depth of the groundwater table varies between 33 m below ground level (b g l) to about 2.0 m b g l. The minimum depth varies between 1 m b g l and 30 m b g l. Average depth of the ground water table is showing a decreasing trend from UP (more than 30 m) through MP (15 m) to IC (less than 5 m b g l). The average fluctuation in the groundwater level during pre-monsoon and post-monsoon shows a decreasing trend from UP (about 2.8 m) through MP (2.0 m) to IC (about 1.5 m).

The groundwater withdrawal is mainly through tube wells. In the UP, the number of deeper tube wells owned by the State Government is 5 and the number of shallow tube wells owned by villagers is 45. The number of deeper as well as shallow tube wells is showing an increasing trend through MP to IC. In the MP the number of deeper tube wells is 12 and shallow tube wells are 230. In the IC the number of deeper and shallow tube wells is 235 and 2542 respectively.

The average withdrawal from deeper tube wells is least (10 ham/year) in the UP. In MP it is 15 ham/year and is higher, (about 20 ham/year) in IC. The average withdrawal from shallow tube wells is also following this trend, but their average withdrawal is about one tenth of the deeper wells. This variation in the average withdrawal is attributed to the fact that deeper wells are capable of higher pumping and has more running hours as compared to shallow tube wells. Further field survey indicated that withdrawal from other sources is negligible.

The groundwater resource estimation was done using the Ground Water Estimation Committee (GEC 1997, Government of India) norms. Groundwater balance study indicated that the major source of groundwater is rainfall recharge, canal seepage and return flow from irrigation. The annual rainfall in the area varies between 1033 mm and 1200 mm. About 85 % of this rainfall is between June and September. The groundwater budget analysis indicated that on annual basis about 33% of the rainfall recharge to groundwater. The rainfall recharge as worked out by empirical relationship, Chaturvedi Formula, is about 10 % of the annual rainfall. It is worth mentioning here that as per GEC 1997, norms rainfall contribution to groundwater is about 20% to 25 %. This indicates that the rainfall recharge as worked out by the groundwater budget analysis is closer to the GEC 1997 norm. The Chaturvedi formula grossly underestimates the amount of rainfall recharge.

These finding indicates that rainfall recharge behavior of this area is different from the alluvial regions, for which empirical relation was developed by Chaturvedi. In view of this the Chaturvedi (1971) formula was customized for this area. The

Chaturvedi formula in terms of annual rainfall, R in cm, and rainfall recharge Rr, in cm is:

$$Rr = 1.26(R-36)^{0.5}$$

In this formula, the constants, 1.26 and 0.5 are location specific. Therefore, the rainfall recharge for this area is written as:

$$Rr = a\,(R-b)^{0.5}$$

The numerical value of the constants, a, and b, were determined in least square sense. The numerical value of a, for UP and M P is 4.0. For IA and Channel Braid Bar (CB) it is 3.2.The numerical value b, for UP is worked out as 25, for MP it is 30, for unit I_1 & I_2 it is 35, for I_3 and CB it is 38. When these values were used it was found that the prediction efficiency of rainfall recharge is about 85 %.

Further the rain fall recharge is influenced by the spatial variations in the geomorphic characteristics namely, physiography – land slope, soil type. Land cover of an area is a good indicator of terrain characteristics. Therefore an attempt was made to incorporate land cover in addition to rainfall in the estimation of rainfall recharge. Land cover data for the area were extracted through visual analysis of IRS LISS II FCC of the area, remotely sensed data and field checks. Accuracy of the land cover map, thus, prepared was more than 85%. A simple model has been worked out, calibrated and tested for the estimation of rainfall recharge. The model in matrix form is:

$$G=AP$$

Where, G is n x 1, column vector, having its elements as ratio of rainfall recharge to groundwater, A is n x m land cover system operator matrix representing the values as land cover of a particular type in a particular area, P is a m x 1 column vector representing rainfall recharge corresponding to different land cover. Efficiency of the model was found to be about 85 %. This model can be used to assess the rainfall recharge in changed scenario of land cover.

Current utilization of ground water resource is less than 50% of the available resource. It is found that about 270 x 10^2 ham extractable additional groundwater is available. This additional resource can be sensibly utilized for further development.

Cross correlation study between rainfall and groundwater level indicate that in the UP unit, rainfall takes minimum time (10 to 20 days) to recharge the groundwater. Whereas in the MP it takes 20 to 30 days, and in IC unit, it takes about 40 to 50 days to recharge the groundwater. In view of fast subsurface drainage the rainfall recharge component of the groundwater is to be utilized within a period of about 20 days in UP. Such studies have also indicated that in the IC, percolated rainfall is available after a month but for a longer duration of about 8 months.

Besides groundwater, surface water through canals and the seasonal flow in the streams also forms the additional resource. Though a number of models are available to estimate the stream flow, they require a lot of input data. These models are suitable for well instrumented and well studied areas. In the inadequately studied area such as the piedmont areas, all the input parameters are generally not available and at the same time are difficult and costly to collect.

An effort was made to estimate the surface water resources using the Soil Conservation Society (SCS) model. The model was found to yield values of stream flow which is about 35% higher than the observed values. Thus, the SCS model was modified for this area and is presented below.

$Q = (P - 0.3\ S)^2 / P + 0.7\ S;$

Where Q is stream flow in mm, P is rainfall in mm, and S is defined by following relation.

$S = (25400/CN) - 254$

Where, CN is popularly known as Curve Number, a constants which depends upon land cover soil complex of the area.

In the study the numerical value of the curve number, CN, for different land cover _ soil complex was determined in the Least Square Sense. After these modifications the model was found to be yield results with in ± 15% error.

Keeping in view the fact that the piedmont area is poorly monitored and studied for the estimation of stream flow a simple model using only two parameter, namely the rainfall and land cover was developed. The model is, q = AC, where q is stream flow vector per unit rainfall, A is land cover system operator matrix and C is run off coefficient vector for different land cover. System operator matrix, A, was extracted from the analysis of IRS LISS II, FCC. The model was calibrated and tested. The efficacy of this model was found that the model yields results with in ± 15 %.

As mentioned earlier except rivers Ganga and Yamuna streams are flashy in nature. Field investigations indicated that stream flow in the flashy river is available for short duration, less than a day or two and hence the direct use of stream flow for agricultural purposes is very limited. Further groundwater is the only dependable source of water for irrigation. The study indicated that on an average about 270 X 10^2 ha m recharged water is available. Water availability in the UP and MP geomorphic unit is much lower as compared to the IC geomorphic unit. Further conjunctive use of surface and groundwater is essential for growing a variety of crops.

Optimal Land Use – Crop Suitability

Agriculture is the governing vocation in the area. About 80% of the total land is used for this purpose. It is been carried out over the years in an unplanned manner. Field survey indicates that the land use in the area is agriculture based - mostly for crops, fodder and fire wood. Though, 20 types of agriculture based land use prevalent in the area but, wheat, sugarcane, paddy, maize and masoor are the main crops. The total food grain production is 288270T/year, whereas its local demand is 1472782 T/year. The total fodder production is 1472072 T/year and its demand is 1500000 T/year. The total fire wood production is 52781 T/year, whereas its demand is 91250 T/year. Thus, food production is not only sufficient to meet local requirement but forms a source of income. However, there is a shortage of fodder and fire wood which leads to encroachment of forest land, resulting into continual environmental degradation. Therefore, there is need for optimal use of land aiming to achieve self sufficiency in the domestic needs and improving the economic conditions of the populace together with maintaining the environmental balance through synergistic development of the area.

The land use is constrained mainly by available land; soil mass, water and human resources. The area receives more than 1000 mm annual rainfall and at present 270 x 10^2 ha-m of water resources is for overall development of the area. It has a variety of soil cover, and sizeable human resources. Thus, the area has a variety of resources. Hence, optimal land use of this area is desirable to maximize the benefits from the area. In this regard, linear programming (LP) approach has been followed. The LP model incorporated 20 types of land cover, during three seasons, with irrigated and rained cultivation, along with six types of domestic animals, totaling to 31 decision variables through which the over benefit, Z_B, as given below is maximized:

$$Z_B = \sum_{i=1}^{20} \sum_{j=1}^{3} \sum_{k=1}^{2} B_{ijk}\, x_{ijk} + \sum_{l=1}^{6} B_l\, x_l$$

Where, Z_B is the function to be maximized, B_{ijk} is the net benefit per unit area from the i^{th} land cover class during j^{th} season under k^{th} irrigation condition; x_{ijk} is the areal coverage of i^{th} category of land cover during j^{th} season, under k^{th} irrigation condition. B_l is the net benefit per unit from i^{th} category of animal and x_l is the number of the i^{th} category of animal. For the known B_{ijk} and B_l the model yields optimal x_{ijk}, B_l and z_B. The above model runs under the shadow of following constraints of modeling.

The model is constrained by variations in terms of geomorphic features, soil characteristics, water resources, food grain requirement, animal fodder requirement, fire wood requirement and human resources. The model allocates the available land for different uses in such a manner so as to get maximum benefit in a given set of conditions. If this model is applied it is estimated that the food grain production can be increased to nearly four times the current production (288270 T/year).Further, the current deficits of animal fodder and fire wood can be made over and can be produced in surplus. The surplus food grains, fodder and fire wood would help in improving the economic conditions of the populace through business transactions with others in need of these. In addition this would reduce grazing and encroachment of forest land and thus help in improving the natural environment vis-à-vis development of the area.

Encouraged by above inferences, detailed field investigations were carried out with a view to develop a methodology for assessment of crop suitability and its yield. These investigations indicate that crop yield varies with geomorphic features. Accordingly, new concept of 'Bench Mark Land Unit' – a ;land unit that gives highest yield of a particular crop, and 'Productivity Index' – ratio of crop yield from an area as compared to the yield from bench mark land unit have been introduced.

For the major crops in the area, productivity index of various geomorphic unit for various crops have been assessed. In general PI for the entire geomorphic unit is low. Numerical value of PI varies between 0.46 and 0.82. In general, PI, for the IC,

unit is higher (more than 0.70).On the basis of variation of PI, in spatial domain, the crops grown in the area have categorized into two groups; group C1 – wheat, sugarcane and paddy; group C2 – maize, groundnut and urd. The UP and MP units have relatively higher PI (more than 0.76) for maize, groundnut and urd.I1 & I_2 subunits have relatively higher (more than 0.70) PI for wheat, sugarcane and paddy crops. In the I3 subunit, PI remains more or less same (0.60 to 0.68) for each crop but at lower values as compared to subunits I_1 & I_2 .In the channel braid bars (CB) , PI is least (0.46 to 0.56) for each crop. Thus, both in the upper and middle regime piedmont i.e. (UP & MP) maize, groundnut and urd is a preferable crop. However, in the subunits I_1 & I_2, wheat, sugarcane and paddy are a preferable crop. In the subunit A3, any crop can be grown , whereas in the CB subunit the crop yield would be lower and may go down to zero if effected by channel erosion.

Correlation studies between terrain parameters and PI indicate that the terrain parameters are highly related. Coefficient of correlation ranges between 0.87 and 1.00.Land slope and soil thickness is negatively related (r = -0.87).Land slope and soil texture, d^{50}, is directly related (r = 0.997).Land slope and depth of the groundwater is directly related (r = 0.958).

Productivity index and intensity of agriculture show a near perfect relation (r = 0.991). These findings indicate productivity index takes in to account simultaneously all the terrain parameters. When considered individually, various terrain parameters affect the productivity of a given crop. However, the impact of their simultaneous affect on crop yield has been assessed through multivariable approach using Principle Component Analysis (PCA).

For the PCA, the correlation matrix was decomposed spectrally to evaluate the eigen values. The largest eigen value is 4.79 and the second largest eigen value is 0.20.The remaining eigen values are very small and hence ignored. The first component is highly loaded with all variables, the variables loading varies between 0.979 and 0.997.The second component is lightly loaded _ between 0.112 and 0.212. Graphical analysis indicated that PI and the scores of the first component (C1) are highly related.

The relationship in least square sense is:

PI = -0.01C1 + 0.6213

Where,

C1 = [0.979-.961 .985 .992 -.997] [L_s , st , d_{50} , d_w , A_c]

This relationship can be utilized to assess the PI from the geomorphic attribute and then to decide the appropriate land use. Keeping in view the poor literacy of the villagers, optimal land use of the area has been suggested in the form of a map and Table .The inferences from the study area:

The upper regime piedmont (UP) and middle regime piedmont (MP) , that are characterized by high to medium land slope, low soil thickness, coarse gravely soil, deep ground water table and low water storage capacity are relatively more suitable for maize, groundwater and urd crops. This unit is showing generally whitish to light pink color on IRS _ LISS _II, F.C.C.

2-The inter Channel Plainer Area (IC) unit that is characterized by moderate to near flat ground slope, moderate and high soil thickness, medium to fine soil texture, moderate to shallow groundwater table and moderate and high water storage capacity is relatively more suitable for wheat, sugarcane, paddy, maize, groundnut and urd crops. However, it is worth mentioning here that the area close to streams has advantage of easily available water resources but has major disadvantages of stream bank erosion and flooding. The Channel Braid Bars (CB) unit is suitable for a variety of crops with low productivity that may go down to zero, if affected by soil erosion and flooding.

Table 6.1 Terrain Characteristics of Geomorphic Units And Proposed Land Use

Parameters	UP	MP	IC			CB
			I_1	I_2	I_3	
Area (%)	17.4	12.6	19.6	14.4	29.4	6.6
Elevation (m)	> 350	300-350	250-300	250-300	250-300	200-300
Slope (degree)	> 3	2=3	< 2	< 2	< 1	< 1
Drainage	Braided	Braided	Sub Parallel	Sub Parallel	Sub Parallel	
Annual Rainfall (mm)	1110	1200.1	1050	1050	1050	1050 - 1200
EI_{30}	742	773	724	724	724	724-773
Soil Composition	Coarse Gravel with Sand	Fine Gravel Sand	Sand Silt	Fine Sand Silt Clay	V fine Sand, Silt Clay	Gravel, Sand
Sand – d_{50} (mm)	>1	1.00 0.50	1.00-.025	1.00-.025	1.00-.025	1.00-.50
Petrographic Composition	A*,B,C	A,B	B,C	B,C	B,C	A,B
Average Hydraulic Conductivity (cm/hr)	75.5	554	25.8	15.9	10.5	30.2
Infiltration Capacity (cm/hr)	14.5	10.6	6.8	5.5	3.6	5.8
Specific Yield (%)	8	9	13	15	18	12
Electrical Conductivity (dsm^1)	0.06	0.15	0.21	0.21	0.21	0.1
pH	7.8	7.7	7.3	7.3	7.3	7.8
Hydrologic Soil Group	A	B	C	C	C	B
Major Source Of Water	GW	GW	GW	GW	GW	GW
Average Depth Of Water Table (1975-2001)						
Pre Monsoon (m)	32.5	20.0	3.7	8.3	10.4	6.0
Post Monsoon (m)	29.7	18.0	1.5	6.7	9.0	4.5

Average water Level Fluctuation (m)	2.8	2.0	5	1.6	1.8	1.5
Number of Wells						
Deeper	5	12	20	50	180	
Shallow	45	230	20	510	2012	
Average Draft From a Well (10^2 ham)						
Deeper	10	15	1.6	18	160	
Shallow	1.0	1.1	1.6	1.6	1.2	
Annual Rainfall (mm)	1110	1200.1	1050	1050	1050	1050 - 1200
Rainfall-Recharge Time (days)	10-20	10-20	40-50	40-50	50-60	10-20
Availability-recharged Groundwater (days)	20-30	20-30	240-260	240-260	240-260	20-30
Groundwater Resource						
Inflow (10^2 ham)	139.45	92.93	88.58	106.39	222.80	35.82
Out flow (10^2 ham)	107.05	42.35	6.27	10.7	25.50	7.32
Balance (10^2 ham)	32.35	50.60	82.31	95.69	197.30	28.50
Draft (10^2 ham)	1.75	14.87	52.18	3.66	147.14	2.66
Available Resource	30.50	35.73	36.4	92.02	50.16	25.84
Water quality						
pH	8.0	7.9	7.1	7.2	7.2	7.7
SAR	0.6	0.6	0.2	0.3	0.3	0.4
Crrent Production (T/Ha) — **Wheat**	1.	1.1	1.4	1.5	1.2	1.0
Sugarcane	3.4	3.5	5.0	4.5	4.0	3.4
Paddy	0.9	1.1	1.3	1.2	1.1	0.9
Maize	1.1	1.2	1.1	1.0	0.9	0.8
Groundnut	1.8	1.7	1.6	1.5	1.5	1.0
Urd	0.22	0.23	0.22	0.21	0.18	0.15
Productivity Index — **Wheat**	0.55	0.60	0.7	0.82	0.66	0.55
Sugarcane	0.54	0.56	0.80	0.73	0.65	0.55
Paddy	0.56	0.62	0.81	0.75	0.68	0.56
Maize	0.73	0.80	0.66	0.67	0.61	0.53
Groundnut	0.81	0.77	0.72	0.68	0.68	0.46
Urd	0.73	0.76	0.73	0.70	0.60	0.50
Proposed Land Use	C2	C2, C1	C1	C1	C1	C1, C2

* A: Coarse Gravel-Quartzite, Phyllite, Gneiss, Sandstone Limestone; B:, C1: Wheat, Sugarcane, Paddy; C2: Maize Groundnut, Urd

• REFERENCES

- **Abdul Kalam A. P. J.** and Rajan Y. S. 2002, India - 2020 - A Vision for New Millennium, Penguin Books, New Delhi.
- **Agarwal, G.C**. and Srivastava, J. P., 1960, Geological investigations of Mohund Anticline between Mohund and Badshahibagh, Dehradun and Saharanpur Districts; U.P." O.N.G.C., Progress Report 1959-60.
- **Agarwal, C.S**.; 1994, Quantitative Analysis of Aquifer Parameters in Part of Western Uttar Pradesh, for groundwater Estimation, IAH-Jnl of Hydrology.
- **Agoes, W.B**.;1956, Report on Airborne magnetometer Survey in Indo-Gangetic Plains, India. Government Of India Publication.
- **Anderson,J.R**.; Hardy E.E.; Roach, J.T., and Witmer, R.E.;1976, A Land Use and Land Cover Classification for use with Remote Sensor data. U.S. geological Survey, Prof. Paper, 964, Washington, D.C. U.S.Governemnt Printing Press.
- **Atkinson, P. M**.; and Curran P. J.; 1997, Choosing An Appropriate Spatial Resolution for Remote Sensing Investigation. Photogrammetric Engineering and Remote Sensing, 63 (12): pp 1345-1351.
- **Auden, J. B**.; 1935, Report on "Possible Lowering of Water Table in U.P. as a Result of Tube well Pumping" U.P. Govt. Publication.
- **Avery T. E**.; and Berline G. L.; 1992, Fundamentals of Remote Sensing and Air photo Interpretation. Mac Milan Publishing Company. New York 201-224.
- **Barrett, E. C**.; and Curtis, L. F.; 1992, Introduction to Environmental Remote Sensing. Chapman and Hall New York.
- **Beek, K.J**.;1981, From Soil Survey Interpretation to Land Evaluation.Part1 and 2. Soil Survey Land Evaluation 1, 6-12and 23-30.
- **Bergsma Elko**.1983, Rainfall Erosion Surveys For Conservation Planning. ITC. Pp-166-174.

* **Bhatnagar, N.C.**; Agashe R.M. and Nautiyal M.D.; 1983, Hydrogeology Mapping Of Bhabhar Zone in Upper Yamuna Basin. Tech. Report No.3, CGWB, Faridabad, India
* **Bhattacharya, A.P.**;1963, Recharge of Under Groundwater. IRI, Roorkee, Annual Report.pp 135-141.
* **Bhumbla, D. R.**; Khare, Arvind; 1986, Estimate of Wastelands in India. Society For Wasteland Development. New Delhi, 16pp.
* **Biswas, A. K**; 1997, Water Development and Environment. Water Resources Development, 13(2) 141-167.
* **Calver. A.**; Kirby, M. J.; and Weyman, D. R.; 1972, Modeling hill slope and Channel Flows. In. Chorley, R.J. Spatial Analysis in Geomorphology, Mchuen & Co. Ltd., 197-218.
* **Campbell, J. B.**; 1996, Introduction to Remote Sensing. Taylor and Francis, London.
* **Chaturvedi, R. S.**; 1947, Technical Memorandum No.17 And 18.Irrigation Research Institute, Roorkee.
* **Chaturvedi, R. S.**; and Mittal R.S.; 1963, Groundwater Studies in Ganges – Ramganga Doab of Bijnor District, Uttar Pradesh. Groundwater Symposium, G.S.I., Calcutta.
* **Chow Ven Te**; 1964, Hand Book of Applied Hydrology. Mc Graw Hill Book Company.
* **Chow, V.T.**; Maidment, D. R. And Mays, L.W.;1998, Applied Hydrology, Mc Graw Hill, Singapore.
* **Dubey, O. P**, Sri Niwas, Awasthi, A. K., 1984, Analysis of Remotelysensed Data for Ground Water Studies of Piedmont Zone, Proc. Asian Conference on Remote Sensing, Kathmandu. Pp- E-6-1 to E-6-4.

- **Dubey, O. P.**; Sharma, K. P.; 1984, Stream Flow forecasting Using Remote Sensing Techniques. Proc. National Seminar on Water Resources Management, K.N.I.T., Sultanpur.
- **Dubey, O. P.**; 1997, LACS – A Programme for Land Arability Classification. International Conference on Civil Engineering For Sustainable Development. Roorkee. Pp:897-910.
- **Dubey, O. P.**; 1996, DMBR-A Digital Map Based Rainfall- Runoff Modeling System. Jnl. IWRS, 2(3) pp 59-64.
- **Dubey, O.P.**, 1999, A Land Based Groundwater Table Fluctuation Model For Piedmont Areas.Jnl.IWRS, 19 (2) pp64-99.
- **Dwivedi, N.K.**; and Gupta P.N.; 1961, Behavior of Groundwater Table In Ganga Yamuna Doab, Uttar Pradesh. Irrigation Research Institute, Roorkee. T.M. No.31, RR (G-42)
- **Engman, E. T.**; Gurney R. J.; 1991, Remote Sensing In Hydrology. Chapman and Hall, Publishers, N.Y.
- **FAO**, 1991, Guidelines for Land Use Planning. Inter departmental Working Group on Land Use Planning. Rome.
- **Foody,G**. and P.Curran(eds).1996, Environmental Remote Sensing From Regional To Global Scales.Wiley,New York.
- **Foster, G.R.**; Meyer, L.D. and Onstand, C.A.; 1977, An Erosion Equation Derived from Basic Erosion Principle. Trans. Of The ASAE 20(4):678-682.
- **French, R.H.**; 1993, Alluvial Fan: Proposed new Process Oriented Definitions for Arid South West. Jnl. Water Resources Planning and management. 119(5):588-598.
- **Frezer, F.** 1971, Photo Interpretation Applied to Geomorphology- A Review. Photogrammetria, 27:7-53.

- **Gansser, Augusto**; 1964, Geology of The Himalayas. Interscience Publisher, London.
- **GEC**; 1997, Report of the Ground Water Resource Estimation Committee. Ministry Of Water Resources, Government of India. pp: 33-70
- **Gurnell**, A. M.; 1978, The Dynamics of a Drainage Network. Nordic Hydrology, 9: 293-306.
- **Hilwig, F.W.**;1980, Visual Interpretation of Multi Temporal Landsat Data for Inventories of Natural resources. ITC(2):297-327.
- **Huque, I.**; R. Rahman 2002, ADSS for land use stratergies in the s- w region of Bangladesh. ISPRS & SIS ; wl 34 , part 7 , Resource and environmental monitoring , Hyderabad , pp - 529 _ 530
- **Joshi, A.P.**; 2003, Degenerating Sustainability. Kurukshetra- A Journal On Rural Development. Government of India. 51(9):26-28
- **Kansakar S.B.S.**; 1988, Hydrogeological Studies of Roorkee Area with Special Reference to University Campus. M.E. Dissertation Dept. Of Hydrology, University Of Roorkee ,Roorkee,India.
- **Kanwar, J.S.**; 1972, Optimal Cropping Pattern. Proc. Optimal Cropping Pattern, I.C.A.R., New Delhi.
- **Kar Gouranga**; and Chakravarthy, N.V.K.;2002, Computation of PET by different methods and its Comparision With Pan Evaporation Rates Under Semi Arid Environments of Delhi Region. Indian Jnl. Soil Cons. 30(2):127-131
- **Kassam, A. H.**, 1980, Agro climatic Suitability for Rain fed Crops in Africa: In FAO, Rome.
- **Khanna, S. S.**; and Pavate, M. V.; 1998, Agriculture Challenges Aead. Yojana 33 (7), 13-18.
- **Kite, M.**; and Pietroniro, A.; 1995, Remote Sensing Applications in Hydrological Modeling. Hydrol Sci, Jnl. 5: 1-48.

- **Krishnan, M. S.**; 1960, Geology of India and Burma Higginbothams (Private) Ltd., Madras-2.
- **Krishnan, R.**; 2002, Classification Method. .IAPRS And SIS. 134 (7). Resource And Environmental Monitoring.Hyderabad. pp 48-54.
- **Leopold, L. B.**; and Miller, J. P.; 1956, Ephemeral Steams, Hydraulic Factors and their Relations to the Drainage net. US Geological Survey Professional Paper 282A.
- **Leopold, L. B.**; Wolman, M.G.; and Miller, J. P.; 1964, Fluvial Processes in Geomorphology. Freeman, San Francisco
- **Lillesand, T.M.**; Kiefer, R.W.; 1999, Remote Sensing and Image Interpretation. John Wiley & Sons. N.Y.
- **Mandal, R.B.**,1982, Land Utilization, Concept Publishing Co. New Delhi.pp:203:210
- **Mather, P. M.**;1999, Land Cover Classification Revisited. In: P.M. Atkinson And N. J. Tate(eds).Advances In Remote Sensing And GIS Analysis. Wiley. Chichester. pp7-16
- **Mc Cormack,** D.E.;1974, Soil Potentials a Positive Approach to Urban Planning. Jnl. Of Soil Water Conservation29:258-262
- **Meijerink A. M. J.**; 1974, Photo Hydrological Reconnaissance Survey. , Int. Instt. For Arial Survey And Earth Science, (ITC) Enschede, The Netherlands.
- **Meijerink, A. M. J.**; 1989, Modeling in the Land and Water Domain with a Versatile GIS (ILWIS): Experiences from large Tropical catchments. In: Land Qualities in Space and Time. Proc of ISSS Symp, Wageningen 1988, Wageningen. pp 73-78.
- **Mithal R.S.,** and Srivastava, L. S.; 1959. Geotectonic Position of Ganga-Brahmaputra Region. Proc Intl, Symposium on Earthquake Engineering, Roorkee.Pp192-205.

- **Mithal R.S.**,Singhal B.B.S.And Bajpai I.P.,1973, Groundwater Conditions In Gangetic Alluvium Of Western Uttar Pradesh. Proc. Int. Symp. On Development of Groundwater Resources, Madras, India. pp53-61
- **Moffitt, F. H.**; and Mikhail, E. M.; Photogrammetry. Harper & Row, New York, 1980.
- **Moore, E.H.**;1920, On Reciprocal Of the General Algebraic Matrix. Bull. Amer. Math Soc. 26:394-395.
- **Musampa D.T.**, 1994, An Integrated Hydrological study Of Roorkee Town. M. E. Dissertation. Dept. Of Hydrology, University Of Roorkee, Roorkee, India.
- **Nag, S. K.**; 1998, Morphometric Analysis Using Remote Sensing Techniques in the Chaka sub-basin, Purulia district West Bengal. Photonirvachak, Journal of the Indian Society of Remote Sensing, 26(14): 69-76.
- **Nagraja; R.**, 2002, Land Use, Land Cover Studies Using Remote Sensing Data: Indian Experience; pp: 546. ISPRS & SIS; WL 34, part 7, Resource and environmental monitoring, Hyderabad, pp _ 529 _ 530
- **Naidu,L.G.K.**;and Hunsigi, G. 2001, Application and Validation of FAO frame Work and Soil Potential Rating for Land Suitability Evaluation of Sugarcane Soils of Karanataka. Agropedology 11(2):91-100.
- **Narain, P.**; Khypri, M. L, Tomar, H. R. S.; and Sidhwal, N. S.; 1994, Estimation of Runoff, Soil Loss and USLE Parameters for Doon Valley. Indian Journal Soil Conservation 22(3):1-9.
- **Narayanan L.R.A.**; Gautam N.C.; 1986, Land Use Land Cover Change Monitoring Using Remotely Sensed Data. International Seminar on Photogrammetry and Remote Sensing For Developing Countries. 2 : TP-7.1 – 7.9
- **Narayanan L.R.A**; 1996, Using Land Through Remote Sensing. The Hindu. Sunday, July 21.

- **Nautiyal, M. D.**, 1994, Morphometric Analysis of a Drainage Basin Using Aerial Photographs: A case study of Khairkuli basin, District Dehradun, U.P., Photonirvachak, Journal of the Indian Society of Remote Sensing, 22(4): 251-261.
- **Nautiyal, S.P.**; 1945, Artesian Water Supply of the Tarai and Bhabhar, Nainital District, Uttar Pradesh.Proc. Symposium Groundwater, Central Board Of Geophysics. Govtt. of India.
- **NIH**, 1999, Water Quality of District Hardwar (U.P.).Tech. Rep. CS(AR)-10/98-99, National Institute Of Hydrology, Roorkee, India.
- **NRSA,** 1989, Manual of Nation Wide Land use / Land Cover Mapping Using Visual Interpretation Techniques, Part - 1, Hyderabad. pp 1 - 58
- **NRSA,** 1992, A Report on Reconciliation of Land Use / Land Cover Statistics Generated by Remote Sensing and Ground Based Techniques, Hyderabad, pp: 1-80
- **Pandey, M.P.**; Raghava Rao, K.V; and Raju, T.S.;1962, Groundwater resources of Tarai-Bhabhar belt and Intermontane valley of Western Valley, U.P. ETO, Tech. Bulletin, Series A (1).
- **Planning Commission,** 1989, Agro-Climatic Regional Planning: An Overview, Publ. Govt. India. New Delhi. 144p.
- **Rao Raghava**, K.V.; 1962, Recent Observations on the Near Surface Groundwater along the Upper Ganga Canal in Roorkee. Proc. National Institute Of sciences Of India. 28 (4):125-130
- **Rao Raghava**, K.V.; 1965, Hydrological Studies of Alluvial Areas in Parts of Saharanpur District.Ph.D. Thesis University of roorkee, Roorkee, India.
- **Rao, M .B. R.**; 1973, The Sub-surface Geology of Indo-Gangetic Plains. Jnl. Geol.Soc. India 14:217-242.
- **Rao, D.P.**;1995, Remote sensing of Earth Resources. Publication of Association of Exploration Geophysicists, Hyderabad.

- **Rao, S. M.**; Kumar Bhishm; Singh,U.K.; Nachiappan,R.P.; 2002, Exploring Recharge Source And Zones Of Deeper Aquifers Using Environmental Isotope.NIH,Roorkee.
- **Reddy G. P.**; 2003, Conservation Farming for Sustainable development. Kurukshetra 50 (7):38 - 40)
- **Revees,** 1999, Remote Sensing for the earth sciences, Manual of Remote Sensing, American Society for Photogrammetry and remote Sensing. Wiley, N.Y.
- **Reeves, M. J.**; Parry, E. L.; and Richardson, G.; 1978, Preliminary Evaluation of Ground Water Resources of the Western Part of the Vale of Pickering. Q.J. Engg. Geol., 11, pp 253-262.
- **Rogers, W. F.**; 1971, Hydrograph Analysis and Some Selected Geomorphic Variables. In Morisawa, M.; Quantitative Geomorphology: Some Aspects and Applications, pp:245-257.
- **Samant, H. P.**; Subramaniyam, V.; 1996, Land Use / Land Cover Change in Mumbai-Navi Mumbai Cities and its effects on Drainage Basins and Channels – A study using GIS- Jnl. Of the Indian Society of Remote Sensing vol. 26(2):192-202.
- **Schiedegger, A. E.**; 1973, Hydro geomorphology. J Hydrology 20(2):193-215.
- **Sehgal J. L.**; Mandal D.K.; Mandal C.; and Vadiveli, S.;1990, Agro- ecological Regions of India, Pub. 24,NBSS&LUP, Nagpur
- **Sehgal J**; and Gajbhiye, K.S.; 1996, Land Resources for Sustainable Agriculture: The challenges and views. 6(1): 1-12.
- **Siegal,B.S.**; And Gillespie, A.R.; 1980, Remote Sensing In Geology. Wiley, New York.
- **Singh, V.P.**;1989, Hydrologic Systems, Vol, II, Watershed Modelling. Prentice Hall, Englewood Cliffs, N.J.
- **Singh, A. S.**, 2001, Study of Drainage Morphometric Charateristics over the Upper Cauvery Basin Karnataka Using IRS Data ICORG- 01, PP 119-121.

- **Singh C. B.**; and Sharma S. P.; 2001, Farming System Approach for Sustainable Animal Production. Indian Dairy Man , (1):15 - 22.
- **Singh, R.P.**; Felix Kogan; 2002, Monitoring Vegetation Condition from NOAA Operational Polar Orbiting Satellites over Indian Region. Jnl. Of the Indian Society of Remote Sensing.30 (3):117-118
- **Seth,A.K.**; And Singhal, D. C.; 1994, Status Of Groundwater Quality In Upper Hindon Basin, Saharanpur Area (Uttar Pradesh). Proc. Regional Workshop on Environmental Aspects of Groundwater Development, Indian Association of Hydrologists, Roorkee, India.
- **Seth, S. M.;** 1999, Physically Based Hydrological Modeling GIS @ Development 3(6) 29-30
- **Shah, D. L.**; 1961, The Detailed Geohydrolocial Investigations in the Areas Covered by the Exploratory Drilling in District Nainital, U.P. including the Terai colonization area" G.S.I. Progress Report for the Field Season 1959-60.
- **Sokolov, A.A.**; and Chapman, T.G.;1974, Methods For Water Balance Computations. The UNESCO, Press, Paris.
- **Sombroek, W.**; and Eger, H.; 1996, What do We Understand by Land Use Planning: a state-of-the-Art Report. Entwicklung and Landlicher Raum, (2): 3-7.
- **Srivastav,S.K.**; Srivastav, J.B.; Chandra, P. C. And Chaturvedi, P. C.2002, Mapping of Recharge Zones and Delineation of Favorable Areas for Groundwater Devlopment. pp 529-537.
- **Stampe, William**; 1936, The Ganges Valley State Tube well Irrigation Scheme U.P. State Government Publication
- **Suresh Babu D.S.**; JayaPrasad, Rajeev , B.K. V.S.; 1999, A Terrain Evaluation Using Remote Sensing And GIS-A Case Study Of Neyyar Wild Life Sanctuary, Kerla. Photonirvachak, Jnl. of Indian Society Of Remote Sensing 27(4):253-257.
- **Sys., C.; Van Rast**; Debaveye, J.; and Beeronet, F.;1993, Land Evaluation, Part 3. Crop Requirements. Agric. Pub-N-7, Belgium.

- **TAC**; 1988, Sustainable Agricultural Production. Implication for International Agricultural Research, Advisory Committee, Consultative group of International Agricultural Research (CGIAR), Washington, D.C.
- **Taylor, G. C.**; and Mackenzie, E.; 1936, Report on the Possible Lowering Of Water Table in U. P. as a Result Of Tube well Pumping. Published by U.P. Govt., Roorkee, India.
- **Thomas, D. M.**; and Benson, M. A.; 1970, Generalization of stream Flow Characteristics from Drainage Basin Characteristics. US Geological Survey Water Supply Paper 1975.
- **Todini, E.**; 1988, Rainfall Runoff Modeling-Past, Present and Future. J. Hydrology. 100, 341-352.
- **Townshend, J.R.G.**; 1981, Terrain Analysis and Remote Sensing . George Allen & Unwin, Boston, London.
- **Trainer, F. W**; 1969, Drainage Density as an Indicator of Base flow in part of the Potomac River Basin. US Geological Survey Professional Paper 650C, C117-183.
- **Twidale, C. R**.; 1976, Analysis of Land Forms. Wiley, New York.
- **USDA**; 1960, National Engineering Hand Book. Section 1J, Chapter 1. Soil Plant Water Relationship, United States Department Of Agriculture, SCS, Washington, D.C.
- **Van Diepen**; C. A. H., Van Keulen, Wolf, J., and Berkhout, J. A.; 1991, Land Evaluation: from Intuition to Quantification. In: Advances in Soil Science, Springer-Verlag, New York, 15:139-204.
- **Verheye, W. H.**, 1992, Application of the FAO approach for land evaluation to European conditions. Paper presented at the land Evaluation Seminar, Univ. International Menedez Pelayo, Valencia, Spain, July 1992.8
- **Verma, N. K.**; Priyakant, S. N.; Das, Sinha, A. K.; and Krishna Murthy, Y. V. N.; 2001, Changes in Land Use and Land Cover and its Influence on Hydrological Parameters- in Sarda river basin. A.P., ICORS 01, PP 367-375.

- **Verstappen, H. T.**, 1977, Remote Sensing in Geomorphology, (Elsevier Scientific Publishing Company).
- **Victor Mockous**; 1969, National Engineering Hand BookSEction 4, U.S. Government Printing Office, Washington, D.C.
- **Vincent, R. K.**, 1997, Fundamentals of Geological and Environmental Remote Sensing Prentice- Hall, Upper Saddle river, N.J.
- **Williams, G. P.**, 1978, "Hydraulic Geometry of River Cross Sections-Theory of Minimum Variance, "Professional Paper 1029, U.S. Geological Survey, Washington, D.C.
- **Wischmeier, W.H.**, and Smith, D. D.;1978, Predicting Rainfall erosion Losses- A guide to Conservation Planning.Agricultural hand Book. No. 537. Science and Education Administration, U.S.Department Of Agriculture, Washington, D.C.
- **Wolf, P. R.**, 1983, Elements of Photogrammetry with Air photo Interpretation, McGraw Book Co., New York, 1983.
- **Yang, X**; and LO, C. P.; 2002, Using a Time Series of Satellite Imagery to detect Land Use and Land Cover Changes in the Atlanta , Georgia , Metropolitan area. International Journal of Remote Sensing, 23 (9):1775 - 1798.
- **Zachar, D.**;1982, Soil Erosion. Developments in Soil Science 10, Elsevier Scientific Publishing CO., N.Y.