LAND AND WATER RESOURCES PLANNING AND MANAGEMENT OF BIJNOR DISTRICT USING REMOTE SENSING AND GIS

Thesis

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C E R T I F I C A T E

This is to certify that the thesis entitled **"LAND AND WATER RESOURCES PLANNING AND MANAGEMENT OF BIJNOR DISTRICT USING REMOTE SENSING AND G.I.S."** submitted in partial fulfilment of the requirements for the degree of **MASTER OF TECHNOLOGY** in **Agricultural Engineering** with major in **Irrigation and Drainage Engineering** of College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bonafide* research carried out by **Moumita Roy,** Id**.** No. 29839, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

(H.C. Sharma)
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C E R T I F I C A T E

We, the undersigned, members of the Advisory Committee of **Moumita Roy,** Id**.** No. 29839**,** a candidate for the degree of **MASTER OF TECHNOLOGY** in **Agricultural Engineering** with major in **Irrigation and Drainage Engineering**, agree that the thesis entitled **"LAND AND WATER RESOURCES PLANNING AND MANAGEMENT OF BIJNOR DISTRICT USING REMOTE SENSING AND G.I.S."** may be submitted in partial fulfilment of the requirements for the degree.

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LIST OF ABBREVIATIONS

ABBREVIATION		DESCRIPTION
bgl	:	Below ground level
3D	:	Three Dimensional
Agril.	:	Agriculture
AISLUSO	:	All India Soil and Land Use Survey Organisation
ARDC	:	Agricultural Refinance development Corporation
ASAE	:	American Society of Agricultural Engineers
ASCE	:	American Society of Civil Engineers
cm	:	Centimetre
cumecs	:	Cubic metre per second
CGWB	:	Central Ground Water Board
Conf.	:	Conference
Dept.	:	Department
ET	:	Evapo-transpiration
FAO	:	Food and Agricultural Organisation
Fig.	:	Figure
GMS	:	Ground Water Modelling System
Govt.	:	Government
GWEC	:	Ground Water Estimation Committe
GWRES	:	Ground Water Resource Estimation Committe
ha-m	:	Hectare metre
i.e.	:	That is
IMSD	:	Integrated mission for sustainable development
ICAR	:	Indian Council of Agriculture Research
IRS	:	Indian Remote Sensing
Jl.	:	Journal
Km.	:	Kilometre
lit.	:	Litre
LDH	:	Lower dissected denudational Siwalik

LISS	:	Linear imaging self scanning
M ha-m	:	Million hectare metre
m	:	Metre
M	:	Million
mm	:	Millimeter
MCM	:	Million cubic meter
m.s.l	:	Mean sea level
Natl.	:	National
NPS	:	Non Point Source
Proc.	:	Proceedings
Sci.	:	Science
Soc.	:	Society
Sq.	:	Square
SCS	:	Soil Conservation Service
Trans.	:	Transactions
USBR	:	United State Bureau of Reclamation
USDA	:	United State Department of Agriculture
U.P.A.U	:	Uttar Pradesh Agriculture University
WHO	:	World Health Organisation

LIST OF SYMBOLS

SYMBOLS		DESCRIPTION
µm	:	Micrometer
D	:	Ground water discharge
E_s	:	Effluent seepage to rivers
E_t	:	Evapotranspiration losses from groundwater reservoir
GW_I	:	Groundwater inflow
GWe	:	Groundwater extraction by pumps
GW_E	:	Evaporation loss of groundwater
GWo	:	Groundwater outflow
GW_n	:	Other items
P	:	Rainfall penetration
R	:	Ground water recharge
R_s	:	Influent seepage from rivers
S	:	Volume change in Storage
W_C	:	Recharge through canal seepage
W_R	:	Recharge from return flow of irrigation water
W_P	:	Natural recharge from precipitation
W_T	:	Recharge from Tanks and Ponds
Y	:	Water table below ground level
%	:	Percentage
ε	:	Error function
°C	:	Degree centigrade

1. INTRODUCTION

Water, the 'Liquid Gold' is a sacred and precious resource for wealth and health of humanity. No function can ever achieve its fulfillment without involving the source of water. No civilization or even the environment can develop to its full potential in absence of water. Thus water has a unique position whether viewed within the context of a developing economy or within that of a developed region. The scarcity of water can severely hamper the economic development. The agriculture, which is the soul of economy in developing countries, hampered badly with the nonavailability of water. Virtually all the development activities seem to show a tendency to center around the prevailing water resources system.

Water, which was once viewed as infinitely renewable and beautiful resource, is no longer available in plenty. The countries that are currently having sufficient fresh water supplies are also facing problems on account of increasing demand due to population pressure, over-exploitation of the resource and rapid growth in agriculture and industry beside urban development. Coupled with potential impact on global warming and climate changes on Earth's water cycle, the future availability of fresh water appears more difficult than before. Optimum use of irrigation sources and irrigation water management would become much relevant in the coming years as about 85% of water is diverted for agriculture now and this will be reduced to 71% in the coming years.

The main sources of water to meet the demand of water for growing crops are rain, surface water and groundwater. About 97% of the world's water resources are confined in the sea and thus of no practical value for human consumption. Of the remaining 3% about 75% is bound in ice-shells, glaciers etc. and only 25% is available as surface water and groundwater. The distribution of this 25% consists of 0.3% in lakes and rivers, and remaining 99.7% is available as groundwater. This clearly shows the importance of groundwater in present scenario and in the coming future also. Groundwater and surface water are mutually linked.

Human population is increasing continuously at the growth rate of about 1.8% per year and hence the water demand for fresh water from different sectors has been growing against a more or less fixed availability resulting in scarcity situation in different parts of our country. Apart from the mismatch in the supply-demand scenario gross mismanagement of water resources, coupled with negligence of the environment have further aggravated the situation in the form of falling water table. Thus to arrest the declining water table in the areas, there is an urgent need for harnessing the available water resources of the country through well planned and balanced water development projects, their implementation and optimal utilization. This requires a detailed study of the geo-hydrological situation and soil-water resources of the area, for which there is necessity to have an efficient and proper planning of available resources.

1.1 HYDRO-GEOLOGICAL SITUATION

India is a vast country having diversified geological, climatological and topographic setup, giving rise to divergent groundwater situations in different parts of the country. The prevalent rock formations, ranging in age from Archaean to Recent, which control occurrence and movement of groundwater, are widely varied in composition and structure. The rainfall pattern, too show similar region wise variations. The topography and rainfall virtually control runoff and groundwater recharge.

The high relief area of the northern and north-eastern regions occupied by the Himalayan ranges, the hilly tracts of Rajasthan and peninsular regions with steep topographic slope and characteristic geological set-up offer high runoff and little scope for rain water infiltration.

The large alluvial tract in the Sindhu-Ganga-Brahmaputra plains, extending over a distance of 2000 km from Punjab in the west to Assam in the east, constitutes one of the largest and most potential groundwater reservoirs in the world. The aquifer systems are extensive, thick, hydraulically interconnected and moderate to high yielding.

Almost the entire peninsular India is occupied by a variety of hard and fissured formations, including crystalline, trappen basalt. The near surface weathered mantle forms the all important groundwater reservoir, and the source for circulation of groundwater through the underlying fracture system. Generally the potential water saturated fracture systems occur down to 100 m depth and in cases yield even upto 30 lit per sec. Though highly productive aquifers occur in coastal and daltaic tracts of the country, tracts' salinity hazards impose quality constraint for groundwater development. In this terrain groundwater withdrawl requires to be regulated so as not to exceed annual recharge and not to disturb hydro-chemical balance leading to seawater ingress.

1.2 PROBLEM OF DEPLETING GROUNDWATER RESOURCES

Water is an abundant natural resource as the three-fourth of the earth surface is covered with it. Only 2.7% of the global water available is in fresh form and of this only 30% is available to meet the water demands of the human and livestock population, both of which are increasing in an alarming manner. The rest of fresh water is locked up in glaciers and snow cover. On 2% of the world land, India supports 16% of the world fresh water resources. Not only the per capita land availability is decreasing day by day but also per capita water availability is decreasing day by day. Per capita water availability was more than 5300 m^3 in 1951 had decreased to 1905 m^3 in 1999 and is likely to be less than 1500 m^3 by 2005. Per capita availability less than 1700 m^3 is considered as 'stress' level beyond which water availability gets classified as 'scarcity level'.

The over-exploitation of groundwater has become an acute problem in the agriculturally important states e.g. Punjab, Haryana, Gujrat, Maharasthra, Rajasthan, Uttar Pradesh and Tamil Nadu. There are 28 dark blocks in Andhra Pradesh, 24 in Haryana, 69 in Punjab, 81 in Rajasthan, 47 in Tamil Nadu and 25 in Uttar Pradesh. In these blocks stage of groundwater development is more than 85% of the net rechargeable water. In addition to 319 dark blocks in the country there are about 420 grey blocks where the stage of groundwater development is between 65% to 85%.

Over-exploitation of groundwater leads to progressive lowering of water table and consequent decline in well yield due to increase in suction lift, intrusion of sea water along the coast, drying of springs and dugwells etc. If necessary attempts are not made to protect the further degradation of water table, the situation will be more critical in near future.

1.3 LAND EVALUATION

The total geographical area of India is about 329 M ha. Of this about 23% is under forest and 47% is under cultivation. Barren and uncultivable land is about 12%. Considering the recent emphasis on conserving degraded forests and land, producing sufficient food, fibers, fuel and fodder, the utilization of land resources should be proper. To achieve this each piece and tract of land should be evaluated on scientific principles.

Land evaluation is the process of assessment of land performance when used for specific purposes. It involves the execution and interpretation of basic surveys and studies of landforms, climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. Another aspect of land evaluation is that of taking a specific area of land as the basis and making comparisons of this land with the land use.

Broader aspect of land evaluation is to assess the current and future potential of land for given purpose, and to plan land use in such a way that the resources of the environment are put to the most beneficial use of mankind. To get optimum returns from available land and water resources it is necessary that the land should be evaluated for its capability, irrigability and suitability for major crops.

1.4 GROUNDWATER SIMULATION

Planning for the best use of water requires an evaluation of the resource, prediction of extent of its future uses and various ways in which the water can be obtained for the predicted uses. The complex problems related to functioning of groundwater system can be solved with the aid of models that simulate the response of groundwater system. Models have enabled hydrologists to develop a better understanding of the functioning of regional aquifers and to test hypothesis regarding the behaviour of particular facts of groundwater systems. Models have become a tool to evaluate the long-term impacts of sustained water withdrawals. Simulation models have been used to predict the impacts upon groundwater system as well as to explore groundwater management alternatives. In such cases a model is executed repeatedly under various design scenarios which attempt to achieve a particular objective. Mathematical formulations, which consist of appropriate multiple regression equations for relationships in different governing parameters of the systems, can also be used as models for evaluating the response of groundwater reservoir.

1.5 REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

Knowledge of land use and hydro-morphology is important for planning and management activities concerned with the surface of the earth. It requires detailed, timely, accurate and reliable data on the extent, location and quality of land water resources and climatic characteristics. The application of satellite remote sensing for land use surveys and mapping is gaining importance largely because of its ability to provide rapid and reliable data within a given time framework. Because of its synoptic coverage and repetitivety, the multistage imagery not only enables to map the spatial distribution of land use, but also to monitor its pattern of change over period of time. Geographic Information System (G.I.S.) provides a digital representation of land characteristics used in hydrologic modeling. G.I.S. link land cover data to topographic data and to other information concerning process and properties related to geographic location. In the present scenario, conjunction of Remote Sensing (RS) and G.I.S. results rational information of sustainable natural resource management.

Remote Sensing and Geographic Information System provide an appropriate base for efficient management of water resources. These offer technologically suitable method for water resource assessment, delineating potential zones for groundwater recharge, flood management, irrigation water management, assessment and monitoring of environmental impact of water resource projects. Satellite data offers the unique capability for extracting information on geology, geo-morphology, drainage, land use and soils which are essential in identifying the possible zones of groundwater occurrence. It is also useful in delineating hydro-morphological units in the area to decide suitable sites for groundwater recharge plans and in selection of water harvesting structures favorable for the problematic sites.

1.6 MANAGEMENT OF GROUNDWATER FOR ITS SUSTAINABILITY

The available water resources need to be optimally and conjunctively utilized. Conjunctive use implies co-ordinated and harmonious development of surface and groundwater to mitigate the demands. Surface water resources are easy to determine but the development of groundwater resources should be planned judiciously to avoid the exploitation of static reserves. Water should be extracted only to the extent that it can be recharged. Remote sensing technology provides a useful and quick means about the occurrence and movement of groundwater, including its recharge potential. Successful exploitation of groundwater is possible by identifying areas with scope for artificial recharge and making use of remote sensing and G.I.S.

The over-exploitation of groundwater can be best replenished by artificial recharging and reducing runoff losses, which occur during monsoon season. For the sustainability of groundwater a hydrological equilibrium must exist between all waters entering and leaving the basin. For identifying the areas where artificial recharging is possible or can be attempted, the use of remote sensing and G.I.S. becomes a powerful tool.

1.7 PROBLEM DEFINITION

The groundwater table is gradually declining in the Bijnor district of northern Uttar Pradesh due to various developmental and economic activities in the region, and as a result of reduction in the protective vegetation cover. The groundwater in the area is also being pumped to meet human and livestock consumption requirements. It is, therefore, important that groundwater potential should be rightly assessed and its exploitation is appropriately planned so as to avoid further depletion. Keeping the above in view the present study was taken up with the following objectives:

1. To study the topography, soil conditions, land use pattern and other hydro-geological conditions prevailing in Bijnor district of Uttar Pradesh.
2. To evaluate the soils of Bijnor district for their land capability, irrigability and suitability for major crops.
3. To study groundwater behaviour and to develop groundwater simulation model using statistical approach.
4. To delineate different land forms, in the study area, using Remote Sensing and G.I.S.
5. To develop strategies for artificial groundwater recharge planning for the problematic areas.

2. REVIEW OF LITERATURE

To prevent the ground water resources from depletion and degradation, it is important to adopt optimized management strategies. The strategies should target at optimum utilization of the resources for maximum production without affecting the regional groundwater balance in quantity as well as quality. This may be worked out considering climate, soil, land use pattern and cropping system of the area. Therefore, in the following sections relevant literature has been cited for the better understanding of present study.

2.1 CHARACTERISTICS AND CLASSIFICATION OF SOILS

Soil is the natural resource for plant growth. To obtain optimum production, it is imperative to have basic information about the general characteristics of soils of a particular place. All soil or land management works, therefore, depend primarily on the soil characteristics, problems of land or soil and their possible solutions. Proper knowledge about soil properties helps to predict its potential to meet the demands. Hence to acquire specific information classification of soil is the easiest way. The classification of soils, as currently being followed includes phases, types and series at lower category units.

The works done by various workers on the characteristics and classification of soils are presented below:

Agarwal (1961) classified the soils of Indo-Gangetic plains in Uttar Pradesh. These soils were reported to be alluvial derived soils and were classified under Aridisol Order. At the sub-order level orthids and argids confirmed their definition. A nitric horizon encountered in the solonetzic complexes was found in the area.

Fehrenbacher *et al.* (1966) recognized six soil series in a detailed soil survey of U.P.A.U. Experimental Farms (now the University farm of G.B.Pant University of

Agriculture and Technology, Pantnagar). The six soil series were tentatively classified in Mollisol Order, Hapludoll and Haplaquoll great groups.

Mehrotra and Mishra (1969) found that the soils present in the northern part of the Pilibhit district, bordering the recently reclaimed submontane areas of Nainital district, to be gray to dark gray in colour, medium in organic matter content, loam to clay loam in texture, neutral to slight acidic in reaction and average in lime content. In addition, these soils had iron mottlings in subsoil, showed slight clay evaluation and were imperfectly drained.

Hurelbrink and Fehrenbacher (1970) studied geo-morphology, stratigraphy and soils of a portion of the western flank of Gola River fan in *Tarai* and *Bhabar* regions of Udham Sing Nagar and Nainital district. The soils of *Bhabar* areas were shallower, coarser in texture, often full of gravels and stones, naturally excessively drained, and had a thinner dark coloured surface horizon compared to those of *Tarai*. *Tarai* soils were reported to be more silty and clayey than the *Bhabar* soils. All the soils had moderate amounts of organic matter in their A horizons varying between 1.47 and 3.60 percent, the lowest being in *Bhabar* soils and the highest in *Tarai* soils.

Gupta and Joshi (1971) reported data from soil survey of the Pilibhit Forest area for clear- felling and ploughing. The soils in this area were deep, sandy loam to loamy sand in texture, neutral to strongly acidic and free of calcareousness. The organic matter content in the surface layer was reported to be medium while in the sub-soil it was low.

Singh (1977) studied the soils of the lower terrace of Sarda river flood plain in Khatima block of Nainital (now Udham Singh Nagar) district. Three soil series, viz. Damgara, Jhankya and Bagulaha, were established. The parent material from which these soils developed was calcareous loamy alluvium. The three soils were classified as follows: Damgara and Bagulaha series – coarse loamy, mixed, hyperthermic, Typic Eutrocherpt; Jhankya series – coarse loamy, mixed, hyperthermic, Typic Hapludoll. Damgara and Bagulaha series had an Ochric epipedon, where Jahnkya series had mollic epipedon. All the three series had a Cambic horizon.

Srivastava (1978) identified four soil series in Shantipuri village of Udham Singh Nagar district. Soils varied in texture from sandy loam to silty clay loam. In general, these soils were high in organic carbon content and base status, neutral to moderately alkaline in reaction. These series were tentatively classified as follows: Shantipuri-I as Typic Ustorthant, Shantipuri-II as Typic Ustochrept, Shantipuri-III as Typic Hapludoll, and Shantipuri-IV as Aquic Haplustoll.

Sharma (2003) conducted a soil study in Chimbal-har micro shed in the western Himalayas, to provide the necessary database for sustainable land use planning in the area. During the study information gathered about morphological characteristics of soil, physical and chemical properties (soil pH, cation exchange capacity, base saturation percentage), classification of soils; actual and potential productivity indices for different land uses; and the results of the evaluation of sol site suitability for growing different crops.

2.1.1 Land Capability Classification

Land capability classification is an interpretative grouping of soils based on three factors – inherent characteristics of soil, external land features, and environmental factors. These factors limit the use of land for various purposes. The capability classification provides three major categories of soil groupings: capability unit, capability sub- classes, and capability classes.

Tejwani and Dhruva Narayana (1961) described techniques of mapping and established some specifications for soil conservation survey and land use capability planning in the ravine land of Gujrat.

Bali and Karale (1978) developed interpretations for land capability units, hydrologic soil groups and irrigation suitability classes for Matatilla catchment area in Madhya Pradesh.

Madsen (1979) elaborated soil survey system for determining soil capabilities. Parameters used were texture, drainage condition, supplemented by content of stones in the profiles, thickness of a horizon and its humus content.

Mathur and Tripathi (1987) studied a mini watershed (11.1 ha), a representative of agroclimatic conditions of Kofra - Bhaura subwatershed in Saili Sundli village of Almora district. Land capability classification of the watershed showed 43, 33, 12 and 12% of the area was under class II, III, IV and VII, respectively.

Singh *et al*. (1989) carried out land capability classification of the soils developed in a periodic moisture regime of Himachal Pradesh using morphological and physico- chemical characteristics of soils.

Ternan *et al.* (1989) provided a valuable framework for land use planning in Grenada, West Indies. The various physical components of watersheds, namely climate, geology, soil and vegetation were used to delimit sub units and each of this evaluated for a number of possible agricultural uses. This survey highlighted the need for careful land capability classification in the source region.

Sharma *et al*. (1995) presented information on soil survey, mapping and land evaluation for agricultural use and planning in 21 districts of Uttaranchal and Uttar Pradesh. In this area there exist three physiographic zones: Himalayan tract, Sub Himalayan tract and Gangetic plain. The areas were divided into four soil regions, namely: Hill soils, *Bhabar* soils, *Tarai* soils and Plain soils. The land capability classes of these soils were as follows:

Table 2.1. Land Capability classes of Western U.P. soils and their limitations.

Soil region	Capability class	Limitation
Hill soils		
Less area	III, IV	Soil erosion and root zone limitation
More area	IV to VIII	---do---
Bhabar soils		
Less area	III	Low moisture holding capacity and root zone limitation
More area	VI to VIII	---do---
Tarai soils	II to IV	Wetness, overflow and erosion
Plain soils		
Less area	VI to VIII	Erosion, alkalinity and wetness
More area	I to IV	---do---

Janakiraman *et al.* (1997) surveyed red sandy soil (Theri soil) of Chidambaranar district of Tamil Nadu and identified four soil series (i.e.Mettutheri, Vandaltheri, Kattotheri and Valarmanntheri). Four typifying pedons representing the above series were evaluated. Potentials and constraints were assessed and interpreted for better land use planning. Different interpretative systems i.e. land capability classification, soil and land irrigability classification, productivity ratings, ratings based on Storie Index and fertility capability classification indicated that those were not suitable for agriculture but could be used if appropriate soil management technologies and conservation were applied.

Dutta and Karmakar (1998) carried out a detailed soil survey of the Horticultural Orchard of Assam Agricultural University, Jorhat. Three tentative soil series were identified on the basis of morphological and physio-chemical soil properties. Soils were mapped at the phase level and seven mapping units were identified along with extent of distribution. A land capability classification was made and land management measures were suggested.

Soil Conservation Service (2002) prepared land capability maps of the eastern and central divisions of the rural lands of North South Wales. The standard eight-class classification was used based on an assessment of the biophysical characteristics of the land, the extent to which there will limit a particular type of land use and the technology available for land management.

2.1.2 Land Irrigability Classification

This is a broad level of generalization. Before an irrigation project is formulated it is necessary that irrigability of a land should be studied and the land should be properly classified. The Indian method of land irrigability classification is based on – the soil irrigability classification and the effect of soil topography and drainge. On the superimposition of the soil irrigability class on soil topography and drainage evolves land irrigability classification.

As per this classification soil is classified as:

Class A: None to slight soil limitation for sustained use under irrigation

Class B: Moderate soil limitation for sustained use

Class C: Severe soil limitation for sustained use

Class D: Very serious soil limitation for sustained use.

Class E: Not suited for irrigation.

Besides the soil irrigability, the suitability of land for irrigation depends on physical and socio- economical factors-

i) *Quality and quantity of water* : this includes equilibrium salinity levels, availability of water to the land in relation to the water requirement of crops.

ii) *Drainage requirements* : Permeability of sub-strata and feasibility of providing drainage and cost of drainage materials.

iii) Other economic considerations such as production cost and yield potentials, land development cost etc.

Sys and Verheye (1974) proposed an index based land evaluation for irrigation of arid region. Soil texture, calcium carbonate and gypsum content, salinity, alkalinity status, soil depth, and average slope were included in the index calculation.

Bali (1977) emphasized the importance of basic soil and land resources data for development planning, particularly, for land and water management and illustrated this by interpreting such data for Indore district in Madhya Pradesh.

Mishra and Nanda (1984) developed a soil and land irrigability classification for humid and sub humid tropics. Three major factors, soil, topography and drainage were taken into account. Depending upon the degree of limitations six soil and land irrigability classes were recognized. The most limiting characteristics decided the class.

Challa *et al*. (1989) carried out land evaluation for irrigation in Kandai village of Dadra and Nagar Haveli in Maharashtra. Land features and soil characteristics were taken into account and soil units were evaluated for irrigation by qualitative and parametric methods.

Mapa (1990) determined suitability of particular soil for an irrigation method. The parameters considered were hydraulic conductivity, available water holding capacity and aeration porosity.

Mayalagu ***et al. (*****1998)** carried out a detailed soil survey of the Tamil Nadu Agricultural University main campus farm. Six soil series were identified. Under different interpretative groupings, land capability classification, index rating, soil and land irrigability, productivity rating and potential productivity rating of the soils of the farm, most productive soils were identified. The coefficient of improvement values showed that there was high scope to enhance the productivity of all soils through extra investment

2.1.3 Land Suitability Classification

In land suitability classification suitability of land is assessed for specified kind of use, such as rain fed agriculture, livestock production, forestry etc. Irrigated agriculture has specialized land requirements that emerges the need for land grading according to its suitability. A land can not simply be graded on a scale from 'best' to 'worst' unless a proper land evaluation is carried out. Land evaluation survey provides information on farming system or kinds of land use possible within the surveyed area. The results show where the land is used best and the possible consequences of that use.

Suitability orders **:** Depending on the use under consideration the land assessed as 'suitable' is separated from that which is not 'suitable'.

- Order S, suitable – land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
- Order N, not suitable – land that has qualities that preclude, sustained use of the kind under consideration.

Suitability classes **:** These indicate degree of suitability within the orders.

Within the order 'suitable' the three classes 'highly', 'moderately' and 'marginally' suitable are identified in relative terms.

- Class S_1, highly suitable – land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
- Class S_2, moderately suitable – Land having limitations, which in aggregate are moderately severe for sustained application of a given use. The overall advantage to be gained from the use, although attractive will be appreciably inferior to that expected on class S_1 land.
- Class S_3, marginally suitable – Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that the expenditure will be only marginally justified.
- Class N_1, Currently not suitable – Land having limitations which may be surmountable in time but which can not be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to produce successful sustained use of the land in the given manner.
- Class N_2, permanently not suitable – Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Suitability subclasses **:** Suitability subclasses indicate kinds of limitations or main kind of improvement measures required within classes. They are indicated by lowercase letters placed after the class symbol, e.g. S_{2m}.There are no subclasses to S_1.

Suitability units : Suitability units reflect the minor differences in required management within subclasses or they are division of subclass that differ from each other in detailed aspects of their production characteristics. They are numbered successively e.g.S_{2d-1}. Land in a single suitability unit has similar productive potential and requires similar management practices. Units are mainly used in surveys at the detailed or farm planning scale.

Table 2.2. Structure of the land suitability classification.

Order	Class	Sub-class	Unit
S, suitable	S_1		
	S_2	S_{2m}	S_{2e-1}
		S_{2e}	S_{2e-2}
		S_{2me}	
	S_3		
	etc.	etc.	etc.
Phase: S_C conditionally suitable S_{c2m}			
N, not suitable	N_1	N_{1m}	
		N_{1e}	
		etc.	
	N_2		

Sinha *et al*. (1977) studied the productivity of Phoolbagh clay loam, Beni Silty clay loam, Haldi loam, Patharchatta sandy loam and Paderi silt loam soils of Pantnagar. The study revealed that for wheat, Haldi loam soil was the most suitable, whereas Phoolbagh clay loam ranked lowest in the series. For maize Haldi loam was found to be the most suitable, whereas Paderi silt loam was the least suitable of all the soils studied. The productivity rating indices (P.R.I.) of these soils for wheat and maize respectively were calculated and are given below; Phoolbagh clay loam – 49.4 and 46.5, Beni silty clay loam – 54.1 and 45.5, Haldi loam – 57.8 and 54.9, Patharchatta sandy loam – 55.7 and 49.1, and Paderi silt loam – 53.7 and 22.7. These PRI data indicate that there is considerable scope for bringing these soils to near their 100% of the maximum production potential.

Valette (1977) proposed a classification system for Northern Nigeria, which follows the FAO guidelines. It can be regarded as a qualitative classification of current suitability for mechanized cultivation of arable crops. It recognizes three suitability order (suitable, conditionally, suitable and unsuitable land) that are sub divided in to suitability classes. This system differs from the system currently used in northern Nigeria (adaptation of USDA system) since it allows much more freedom for determination classes within an order.

Sys (1980) suggested a land rating index (L.R.I.) to be calculated from individual ratings, A, B, C etc. (according to Table 2.3) of characteristics or qualities using the formula,

$$\text{L.R.I.} = A \cdot \frac{B}{100} \cdot \frac{C}{100} \qquad \ldots\ldots \; (2.1)$$

Table 2.3. Limitation level and their rating (Sys, 1978).

Symbol	Intensity of limitation	Rating
0	None	98-100
1	Slight	85-98
2	Moderate	60-85
3	Severe	45-60
4	Very severe	Below 45

The L.R. indices are then matched against limits for suitability classes defined. These are: S_1 (very suitable) when land rating index is 75 or above; S_2 (moderately suitable) when land index is between 50 and 75, and S_3 (marginally) suitable) when L.R. index is between 25 and 50. When land rating index is below 25 the land is considered to be not suitable (N).

Singh *et al*. (1982) reported the productivity and coefficient of improvement in some soils of Sarda river flood plain in Nainital district of Uttar Pradesh. They found that Damgara, Jhankya and Bogulaha soil series productivity was good, excellent and excellent, respectively. Of the three soil series, the highest (4.11) and lowest (1.9) coefficients of improvement were associated with Bagulha and Jhankya series, respectively. Damgara series had intermediate (2.23) coefficient of improvement.

Manrique (1985a) obtained land suitability assessment for forage legume production (genera Stylosanthes, Centrosema and Desmodiun) for 21 Hawaii soils, by using a land suitability classification based on Soil Taxonomy. Land assessment based on four qualities, viz. nutrient availability, water availability, soil acidity and soil thermal regime, indicated that six of the soils were unsuitable for forage legume production without application of agricultural inputs (fertilizer, lime and irrigation). Nutrient availability was the land quality that most frequently failed to meet the requirement of tropical forage legumes. Application of low levels of input reduced the number of unsuitable soils from six to three, whereas high inputs made all soils suitable for forage legume production.

Manrique (1985b) described a systematic computing procedure to use soil survey data based on Soil Taxonomy to assess whether a land is suitable for crop production and to determine the kinds of management input needed to obtain optimum production. Limited field testing of methodology indicated that reliable estimates of land use capability could be obtained. The use of this methodology in developing countries could increase the likelihood of success in assessing which adopted crops can be recommended for a specific location, consequently reducing the risk of crop failure.

Kanyanda (1987) assessed the land suitability in Zimbabwe in eight land capability classes based on the classification developed by United State Department of Agriculture and it was then compared with FAO guidelines for land evaluation.

Chandra Shekhar (1988) evaluated the land and soils of Moradabad and Rampur districts for the suitability of major corps using three models, Sys Model (1980), Limiting Condition Model (FAO, 1976) and Productivity Rating Index (Soil Survey Staff, 1951). Overall matching of suitability cases arrived at by Sys and Limiting Condition Models with the classes determined using PRI model indicated that for maize and wheat Sys model was superior over limiting condition model. Whereas in case of paddy the limiting condition model was superior over Sys model. For sugarcane both the models were equally good. The gross overall matching of these suitability classes indicated that Sys model was superior to Limiting Condition Model.

Tulsa (1990) used four models namely : Sys, Manrique and Uehara, Limiting condition model, and productivity rating index model for four crops viz. paddy, wheat, maize and sugarcane crops on Mollisols of Nainital *Tarai* and she found that no model gave satisfactory relationship from productivity point of view, based on farm data.

Ramasamy *et al.* (2001) carried out a re-assessment of land suitability for sugarcane in Mauritius to determine the impact of changes over the years in inputs mainly of cultivars, irrigation systems and mechanized operations, which constitute some of the criteria used for the land suitability classification. An analysis of cane yield for three years was undertaken and results show that the yield capacity of fields, in different suitability classes (highly suitable, moderately suitable, marginally suitable and not suitable), differs and that the changes (improvements) in inputs are responsible for the shift in obtainable yields i.e. from 90.0 to 101.9 t/ha for the highly suitable class, from 70 to 82.7 t/ha for the moderately suitable class and from 55 to 67.7 t/ha for the marginally suitable class.

2.2 GROUNDWATER SYSTEM

Groundwater, being a dynamic and replenishable resource, is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable ground water structures. For quantification of groundwater resources, proper understanding of the behaviour and characteristics of the water bearing rock formation, known as aquifer, is essential. An aquifer has two main functions – i). to transmit water (conduit function), and ii). to store it (storage function). The groundwater resources in unconfined aquifer can be classified as static and dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of water available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource that is replenished annually or periodically by precipitation, return flow of irrigation water, canal seepage, tank seepage, influent seepage etc.

The water table will be in equilibrium condition if the rainfall is normal. If rainfall is subnormal in a particular year there will be transitory decline in water table, that should, however be restored to the normal level when rainfall is again normal or recharge occurs from some other sources. If rainfall is excessive, excess precipitation drained away. With the introduction of an extraneous cause such as tube well pumping, a new dynamic equilibrium may be set up. If the additional draft, due to pumping, is balanced by the recharge, the water table may be unaffected by pumping. But if overdraft is created due to pumping, the system will be disturbed and the water table will keep on lowering continuously which may cause unavailability of fresh water within the command of tubewell pumping.

Water balance studies are essential to make quantitative estimates of water resources and the impact of various interventions on hydrologic cycle. With water balance approach, it is possible to quantitatively evaluate individual contribution of sources of water in the system over different time periods, and to establish the degree of variation in the water regime due to changes in components of the system.

Estimates of water balance volumes consist of estimation of two basic components of hydrologic cycle:

- Recharge
- Discharge

It can be represented as follows:

Recharge – Discharge = $\pm$ Storage

The general water balance equation, which describes ground water regime in an aquifer, can be expressed as:

$$WL = IWL + SR + UR - UD - P - T \quad \text{.....(2.2)}$$

where WL = the elevation of the water table at the end of the observation period,

IWL = the initial elevation of the water table in terms of the time and space,

SR = the recharge from the surface,

UR = the recharge from underground sources and adjacent sub areas of the aquifer,

UD = the groundwater outflow from the area,

P = the discharge through pumpage and fountains, and

T = the discharge through transpiration.

This equation can be simplified by assuming that the response of the water table is a function of the recharge and discharge to the groundwater system.

Some of the works related to ground water estimation and its proper utilization are given below:

Adyalkar and Kittu (1983) studied the status of groundwater development in Orissa state. This state has a total geographic area of 1,55,842 sq-km, predominantly an agriculture state with 76% of its population engaged in cultivation. The state is endowed with a number of perennial rivers. In spite of these entire positive factors the net cropped area under irrigation in 18% of the net area sown. Suitable suggestions for optimum harvesting of the resources through the structures have been incorporated in the context of the ambitious target of ground water irrigation during the current plan.

Goel (1983) presented the criteria for optimal inter-temporal resource use of depleting non-renewable groundwater resource. He explained that since concept of property right is still not applicable to groundwater resource, the tendency may be to over draw the limited ground water resource without any regard for future use. This causes misallocation of scarce source. The adverse effect of open access management "as applicable to groundwater resource" together for optimal level of extraction in given time and possible regulatory arrangements which can be imposed to avoid over rapid depletion of groundwater resource have been discussed.

Kaushal *et al.* (1989) computed groundwater resources of the area bounded by Bhakra main line canal, Ghaggar Branch, Sirhind canal third Feeder and river Ghaggar for the period 1975-76 to 1985-86. Various components of groundwater recharge and water balance equations were estimated. The total of various components of ground water recharge in the area under study was about 52747 ha-m. Recharge from rainfall, canal seepage and return flow from irrigated areas was found to be 14.23, 18.0 and 67.66% of the total recharge, respectively. Groundwater resource was being over stressed causing decline in the water table.

Pandit and Chaudhary (1990) studied the groundwater potential and its harnessing in Madhya Pradesh. They observed that about 90% area of the state is covered by hard rocks and only 10% by alluvial sediments. As per the estimation of the ground water potential of the state, on 1986 data base, Madhya Pradesh had 4.86 M ha-m annual utilizable recharge, out of which only 0.55 M ha-m was tapped during the year 1986 and 0.67 M ha-m during 1989. The stage of groundwater development in the state was only 13.75% during 1989. Only four districts of the state had 30% to 40% stage of groundwater development, 9 districts 20% to 30%, 16 districts 10% to 20%, and remaining 16 districts below 10% stage of groundwater development.

Sharma (1995) assessed the utilizable groundwater resource of the country on the basis of hydro-meteorological and hydro-geological data, as 45.34 M ha-m. Out of this 6.83 M ha-m was set apart for drinking and the others were committed uses with the utilizable groundwater resource for irrigation at 38.51 M ha-m. The net draft was only 11.58 M ha-m leaving 70% of total groundwater resource available for exploitation. However, the regional development of groundwater was highly variable with 98.2% in Punjab, 80.2% in Haryana in the Northern region, 7.13% in Orissa and 19.23% in Bihar in the eastern region.

Sidhpuria *et al*. (1998) evaluated the groundwater conditions in the sugarcane growing area under Ganga-Ramganga interbasin in the Jyotiba Phule Nagar district of Uttar Pradesh where the groundwater table was continuously depleting. The study revealed that the water table in Amroha, Gajraula, Joya and Hasanpur blocks of Jyotiba Phule Nagar district under Ganga – Ramganga interbasin was rapidly declining at an alarming rate. Situation would further deteriorate due to cultivation of excessive water demanding crops such as sugarcane and paddy, as well as the introduction of new cash crops like mentha, summer vegetables etc., increase in industrial water demand, pressure from growing population for more food, decreasing canal supply, erratic rainfall, poor water management practices, decreasing net recharge area due to construction of building structures and other uses etc., are likely to create severe water scarcity in the region.

Pandey (2000) Conducted studies in Bhadoi district to update the hydrological statistical data concerning with the status of groundwater development. The estimation of block wise replenishable groundwater resource potential was attempted by three different methodologies, viz. hydro-meterlogical, adhoc norms and water table fluctuations. Based on these, the average gross annual resource and the utilizable resource for irrigation were computed to be 325.76 MCM and 276.89 MCM, respectively.

Agarwal *et al.* (2004) developed a field water balance model for rainfed rice in medium land in eastern India with the provision of supplemental irrigation from an on-farm reservoir. The model inputs consist of soil, crop, and daily climate data. By developing a computer programme in visual basic the model simulates various water balance parameters. The model parameters were validated with the observed data of the experimental field. The model hypothesis was found to be accepted at the 5% level of significance for simulating the actual evapotranspiration and ponding depth and at the 1% level of significance for simulating percolation.

2.2.1 Estimation of Recharge Components

The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Thus, a quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for operating groundwater resources in an optimal manner.

Recharge due to Rainfall

Rainfall is the principal means for replenishment of moisture in the soil water system and recharge to groundwater. Moisture movement in the unsaturated zone is controlled by capillary pressure and hydraulic conductivity. The amount of moisture that will eventually reach the water table is defined as natural groundwater recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type. Some of the studies on the estimation of groundwater recharge due to rainfall are being discussed below :

Datta *et al.* (1973) studied the recharge due to rainfall by Tritium Injection Method in Ganga-Sarda interbasin. They found that recharge to groundwater in the area was of the order of 21 cm/year i.e. about 23% of rainfall.

Satish Chandra and Saxena (1975) carried out a detailed water balance study for Ganga-Ramganga *doab*. They analysed the field data for the year 1971-72 and found that 23% of rainfall goes deep down into the ground to recharge the unconfined aquifer.

ARDC (1979) suggested following norms for the estimation of recharge due to rainfall :

i). Alluvial areas

In sandy areas	-	20 to 25% of normal rainfall
In areas with higher clay content	-	10 to 20% of normal rainfall
ii). Hard rock areas	-	10 to 15% of normal rainfall

Stephenson and Zuzel (1981) evaluated natural groundwater recharge characteristics using precipitation data, soil depth, soil water, and groundwater observations for a semiarid rangeland environment of southwest Idaho. He expressed that the recharge in these study areas occurs via three separate mechanisms – by infiltration through low relief rubble basalt outcrops by infiltration through shallow wells; and by transmission through bedrock channels during runoff and channel flow. To initiate recharge, rainfall in excess of 20-30 mm over 24 hrs; or higher intensity cloud burst storms are required. Time to peak, the time from the end of a precipitation event to the peak of the groundwater hygrograph, was found to be independent of season, depending only on soil depth. Regression analysis of time to peak vs soil depth produced a correlation coefficient of 0.941. The rate of groundwater recharge for the study area was computed at 4.6×10^{-4} cm/min.

Bhargava *et al.* (1983) carried out a field study, by radio isotope technique, at U.P.I.R.I., Roorkee to evaluate what part of rainfall penetrates into the ground to recharge the groundwater table. In this study the tritium tagging method was used and an attempt made to estimate the net recharge to groundwater table due to rainfall alone. The downward movement of rainwater into the soil during the period of two years i.e. June 1979 to May, 1981 was traced at seven injection sites well scattered in Ganga-Sarda Interbasin, comprising Budaun, Barielly and Pilibhit districts of Uttar Pradesh. The groundwater recharge as determined by Tritium Injection Method, varied from 21.33% to 26.17% of rainfall. Its average value for the area worked out to 24.1% of rainfall. The statistical analysis of the field data, obtained from their study yielded the following empirical relationship for estimating recharge to ground water as a result of rainfall alone :

$$R_p = 3.24\ (R - 30)^{0.49} \qquad \dots (2.3)$$

where both the annual rainfall (R) and rainfall penetration (R_p) are in cm. They finally expressed that this relationship is applicable only to the area under study.

Anonymous (1986) reported modifications in the norms of Groundwater Resource Estimation Committee (GWREC), by the water Balance Sub-committee of Punjab. This Sub-committee recommended a uniform norm of 25% of the normal rainfall.

Novakowski and Gillham (1988) analysed several water table response tests performed in undulating topography at a field site near Chalk river, Ontario. The objective of the experiment was to gather detailed field information on the nature of the water table rise in response to precipitation in a shallow water table environment. A disproportionate rise in the water table was observed in areas where the zone of tension saturation extended to ground surface. For example, for rainfall of 5 mm over duration of 5.3 min. the water table in the lowest lying areas rose by about 13 cm in the area of higher ground level it was 5 cm only. Further more, as a result of the difference in the response between the low lying and higher ground level area, complex and transient hydraulic gradients were established directed away from the low lying area.

Kaushal *et al.* (1989) used the norms adopted by GWREC. About 70% of their study area in Punjab had coarse textured soils. In view of this, a weighted average value of 18% of total rainfall was taken as recharge to groundwater based on normal value of 20% for alluvial sandy loam and 15% for clayey soils.

Saxena and Ram Singh (1990) studied the recharge to groundwater due to rainfall and surface irrigation through various types of soil covers in parts of Varanasi district of Uttar Pradesh during the year 1984-85. They observed there are several approaches which may be used for the investigation of recharge to groundwater, but the Tritium tagging technique is one of the most advanced and accurate method. Tritium was injected at various sites in pre-monsoon period (June, 1984) and the soil samples were collected from the Tritium injecting point upto the depth of water level. Position of water tables was also recorded at the time of injections. The percentage of recharge estimated for five sites was found to be 6.16% of rainfall at Shivnathpur (block Niymatabad), 6.69% at Khurd Narsingh Pur (block Chandauli), 5.24% at Bhojpur (block-Sakaldiha), 5.39% at Durgapur (block Chania), and Sarai Rasulpur (block-Sakhaldiha). They expressed that the estimated values of percentage recharge were very small due to scanty rain during the period.

Saxena and Saxena (1990) studied recharge to groundwater due to rains and irrigation through various types of soil cover in part of Allahabad district, using Tritium tagging technique. For this purpose a radio-isotope, Tritium was injected at various selected sites in the month of June, 1986 and after rainy season the soil samples were collected from Tritium injecting point up to the depth of water table. Position of water tables was also recorded at the time of injection. The value of percentage of recharge obtained by them varied from 8.30% at Sarai Chachak in Bahadurpur block to 32.9% at Malak Harhar in Chaka Block.

Sharma *et al*. (1991) summarized results from a study undertaken to quantify and predict recharge rates to an unconfined aquifer beneath three land uses (Banksia woodland, Pine plantations, and Pasture land) on the Swan coastal plain, Western Australia. At least two representative sites for each land use were studied. It was estimated that beneath Banksia woodland long term recharge rate was found to be of the order of 15 to 30% of the precipitation, while beneath pasture it was about 50 to 60%.

Beneath mature pine gross recharge was 0 to16% of the precipitation depending on the plant density. The use of a mechanistic model in simulating the dynamics of recharge was demonstrated. Simulation suggested that water uptake by a perennial vegetation can be substantial if the root zone intersects the phreatic surface.

Prihar *et al*. (1993) adopted the GWEC norms modified by the Water Balance Sub-committee of Punjab (**Anonymous 1986**), for assessment of available supply of water in Punjab in which a uniform norm of 25% of the rainfall was recommended as recharge due to normal rainfall.

Kumar and Nachiappan (1995) evaluated recharge of groundwater in Uttar Pradesh, using a Tritium tagging technique at 25 locations. The experimental data were analysed to develop a mathematical formulation with respect to rainfall which can be used to estimate the recharge to groundwater due to monsoon rains in future. The results indicated that the empirical relationships established by other investigators in different regions in India, using parameters which affect rainfall recharge process, are neither valid for this study area nor for the region for which these relationships were developed. Mathematical formulations were suggested which were based on experimental data.

Anonymous (1996) used the norms given by the Groundwater Resource Estimation Committee (GWREC) used for estimation of various components in Bist Doab in Punjab. Twenty five per cent of total rainfall was taken as groundwater recharge for the whole tract. Rainfall recharge was assumed to be nil if rainfall is less than 220 mm/ annum and monthly rainfall was less than 50 mm.

Jin Quan *et al*. (1996) made in-situ lysimeter experiments to study the relationships between rainfall and recharge by infiltration at different groundwater depths. The effect of rainfall pattern and annual rainfall distribution on infiltration recharge was simulated at various groundwater depths using a numerical model based on soil water dynamics and comparisons of the simulated and observed recharges showed very good agreement.

Recharge from Canal Network

Recharge through percolation from canals and streams depend on the infiltration capacity of the canal and stream bed and sides, subsurface lithology, extent of wetted perimeter, length of canal, discharge, sediment load and relative position of bed with respect to the water table. Recharge rates may decline over the years due to water logging, clogging of pores of the bed material or cementation by calcareous precipitates.

According to **Planning Commission Report (1963),** 44 per cent water diverted into a canal system gets lost in transit. Of this, main canal and branches account for 15 per cent, distributaries 7 per cent and watercourses 22 per cent. Percolation losses from the field further add to the groundwater. The loss of water from main canals raises water table in the vicinity of canals. The area of influence widens later as seepage water raises water table in a large part of the irrigation command.

ARDC (1979) suggested the following norms for recharge from canal network:

i). For canals in normal type of soils, which have some clay content along with sand

: 15 to 20 ha m/day/10^6 sq.m of wetted area.

ii). For canals in sandy soils : 25 to 30 ha m/day/10^6 sq.m of wetted area.

Kaushal *et al.* (1989) adopted the values of recharge factor for canals as 2.25 and 0.45 m^3/ sec per million m^2 of wetted perimeter for unlined and lined canal system as recharge from canal network.

Kool and Kushwaha (1989) conducted studies to compute seepage losses from the 10 km long Dhanashri minor canal of Barna Project using empirical formulae and actual field measurements. The design value of seepage losses, considered by the Barna Irrigation Department to prepare irrigation schedule, was 0.05 m^3/m^2/day for minors and sub-minors. The seepage losses determined by empirical methods and field measurements were comparatively high, varying from 0.16 to 0.03 m^3/ m^2/day at Dhanashri minor which showed that there was a need to check the flow of seepage water into the fields.

Anonymous (1996) carried out studies to evaluate seepage losses in different sections of the canals, minor and field channels in the Mula Command using inflow – outflow method. Study revealed that it was observed that the seepage loss in lined canals was 87.5% lesser than the seepage loss in unlined canals. The seepage loss in unlined minor was 37.7% more than the lined minors (Table 2.4). Seepage loss in lined field channels was 54.7% lesser than that of the unlined channels.

Table 2.4. Seepage losses (cumec /M m^2) through water distribution system in Mula Command.

Condition	Main Canal	Minor	Field Channel
Lined	0.82	3.20	1.64
Unlined	6.56	5.14	3.62

The Groundwater Resource Estimation Committee **(Govt. of India, 1996)** suggested the norms for recharge due to seepage from canals, indicating 1.8 to 2.5 cumecs per million sq. m of wetted area for unlined canals in normal soils, 3.0 to 3.5 cumecs per million sq. m of wetted area for lined canals. However, it may be noted that seepage loss from canal depends upon width of canal, depth of flow, hydraulic conductivity of the bed material and depth of water table.

Upadhyaya and Chauhan (2002) obtained analytical solutions of the linearized Boussinesq equation and a fully implicit finite difference numerical solution of the nonlinear Boussinesq equation to study transient and steady state water table rise in a homogeneous, isotropic sloping aquifer. The rise was due to seepage from two canals located at different elevations above the sloping impermeable barrier and constant recharge from the land surface.

Return Flow from Irrigated Areas

In irrigation practice, certain portion of the applied water, over and above the consumptive use, infiltrates into the ground to reach either an aquifer as deep percolation or to a nearby stream as interflow. This contributory replenishment from irrigation is referred to as “Irrigation Return Flow” **(Hurley, 1968; and Jenson, 1983)**. It is one of the most significant components in the water balance of irrigation command areas. It depends upon the geological set up of the irrigation command, soil moisture characteristics, meteorological parameters, crop types, method of irrigation and depth of water table etc.

ARDC (1979) suggested following norms for return seepage from irrigated fields:

i). Irrigation from major irrigation sources (gravity canals)

a). 35% of the water diverted at the outlet for application in the field.

b). 40% of water diverted at the outlet for paddy irrigation only.

ii). Irrigation by all minor irrigation sources (lift canals, tubewells etc.)

30% of water delivered at the outlet.

Kaushal *et al.* (1989) adopted 54 per cent and 34 per cent of water applied at the outlet as the quantity of water reaching the water table through return flow in canal irrigated paddy and non-paddy areas. In case of tube well irrigated areas 41 per cent and 30 per cent of water applied at the outlet for paddy and non-paddy areas were considered as the values of recharge due to return flow of irrigation water.

Agarwal *et al.* (1990) conducted studies for the estimation of groundwater recharge due to return flow of irrigation water, under different crops, in Eastern Yamuna Canal Command, using Tritium as radioactive tracer. The recharge due to return flow of irrigation in study area varied from 25 to 36%, 52 to 62%, and 34% to 40% of the applied irrigation water for wheat, paddy and sugar cane, respectively. These findings were compared with the studies carried out in other States using Drum Culture technique. The technique used, compared fairly well.

Anonymous (1996) reported the use of GWEC norms for the estimation of various components in Bist Doab in Punjab. Recharge from canal-irrigated areas was taken as 35% (for non-rice crops) and 40% (for the rice crop) of the water delivered at the outlet for application in the field. Recharge from tube well irrigated area was taken as 30% (for non-rice crop) and 35% (for rice crop) of water delivered at the outlet.

As per the report of the “Groundwater Resource Estimation Committee **(Govt. of India, 1996)**, the recharge due to return flow of irrigation water may be estimated, based on the source of irrigation (groundwater or surface water), type of crop (paddy or non-paddy), and the depth of water table below ground level, using the norms given in Table 2.5.

Table 2.5. Groundwater recharge due to return flow of irrigation water.

Source of irrigation	Type of crop	Groundwater recharge as % of application when water table below ground level is		
		< 10 m	10 – 25 m	> 25 m
Groundwater	Non-paddy	25	16	5
Surface water	Non-paddy	30	20	10
Groundwater	Paddy	45	35	20
Surface water	Paddy	50	40	25

Groundwater Inflow / Outflow from the Area / to the Neighbouring Areas

Because of non-availability of the data on transmissivity and water table gradients along the boundaries of the area, it is observed that it becomes difficult to quantify this component directly. This is generally estimated indirectly as a residual of the water balance equation **(Kaushal *et al.*, 1989)**. Some other works related to studies on groundwater recharge are reported below:

Sophocleous (1992) analyzed the results of a 6 year recharge study in the Great Bend Prairie of Central Kansas, statistically to regionalize the limited number of site specific, but year round measurements. Emphasis was placed on easily measured parameters and field measured data. The results of the statistical analysis revealed that a typical recharge event in the central Kansas lasts 5-7 days, out of which 3 or 4 days were precipitation days with total precipitation of 83 mm. The yearly recharge in the Great Bend Prairie ranged from 0 to 177 mm with a mean of 56 mm. Most of the recharge events occurred during the months of April, May and June, which coincided with the month of highest precipitation in the region.

Hassan and Bhutta (1996) developed a procedure to evaluate various recharge components of a groundwater reservoir to estimate the long term average seasonal groundwater recharge in the title region. For comparison, recharge was also estimated by a specific yield method from observed groundwater levels. A water balance study was conducted on seasonal basis (6 months) for a period of 31 years. Recharge, estimated by the two methods, was in agreement. The average value of net groundwater recharge during *kharif* season was found to be ~ 60 mm. No recharge occurred during *rabi*, rather there was a depletion of the groundwater reservoir during the winter months. Long term average annual depletion of a groundwater reservoir was greater than the corresponding value of annual recharge. It was concluded that on a regional basis the groundwater reservoir was being depleted resulting in a average groundwater fall of ~ 2.3 m over the 1960-1990 period.

Taylor and Howard (1996) reported that in studies undertaken in the Aroca catchment of the Victoria Nile basin in Central Uganda, the timing and magnitude of recharge determined by a soil moisture balance approach were supported by stable isotope data and groundwater flow modeling. The soil moisture balance study showed that recharge averaged in the order of 200 mm/year and was more dependent on the number of heavy (> 10 mm/day) rainfall events than the total annual volume of rainfall. Stable isotope data suggested independently that recharge occurred during the heaviest rains of the monsoons, and further established that recharge stemmed entirely from the direct infiltration of rainfall, an assumption implicit in the soil moisture balance approach. Aquifer flow modeling supported the recharge estimates but demonstrated that the vast majority (> 99%) of recharge waters were transmitted by the aquifers in the regolith rather than the underlying bedrock fractures which have traditionally been developed for rural water supplies.

2.2.2 Estimation of Groundwater Discharge

Evaporation from Shallow Water Table Areas

Evaporation from soil surface forms one of the major components of groundwater losses in discharge and water logged area. Experimental data on estimation of groundwater losses through evaporation are lacking. For the area with coarse textured soils having water table beyond 2 m below the ground surface, the loss of groundwater as evaporation is considered negligible **(Kaushal *et al.*, 1989).**

ARDC (1979) suggested the value of seepage from tanks as 44 to 60 cm per year over the total water spread. The losses should be taken into account depending on the agro-climatic conditions of the area. Recharge from other sources, like influent seepage from streams, lakes and ponds, should be taken into account but no norms have been given.

Zhao *et al.* (2003) conducted a study to explore the water cycle in mountain region, different evaporation experiments for ground and surface waters carried out in eastern slope of the Gongga Mountain, South Western Chaina. The evapotranspiration modeled for naked land was similar to observed evaporation of surface water. The simulated values of evapotranspiration of forest and shrub-grass were higher in growth period or lower in non-growth period than that of naked land surface.

2.3 GROUNDWATER MODELS

With a phenomenal increase in the use of groundwater in recent years, the need has arisen for a better understanding of the functioning of groundwater reservoirs in response to natural and man-made changes in conditions in the system. The available analytical solutions derived on the basis of certain assumptions are restrictive in use, as the real systems are quite complex, vary widely in space and time. The complex problems related to functioning of groundwater system can be solved with the aid of models that simulate the response of the groundwater system. Based on the principles involved in their designing, models can be classified as follows:

1. Physical models
2. Analog models
3. Mathematical models

Models can not imitate all aspects of groundwater flow problems. In the case of physical models scale factors need to be chosen which result in convenient model characteristics. These are conversion constants that relate the corresponding parameters and variables of the models to those of the aquifers (**Prickett, 1976).**

Analog models can be either viscous flow models or electrical analogue models. The analogy between flow of groundwater and that of viscous flow between two closely spaced parallel plates is used. Electrical Analog models can be divided into two categories : (1). Continuous models, and (2). Discrete models. While in the continuous models, an electric conducting medium like a resistance paper is used, in the latter case an assemblage of discrete electrical components are used.

In developing analytical models, the actual groundwater conditions prevailing in an area are simulated by model aquifers that have straight-line boundaries, effective width, lengths and thickness. Solutions are obtained utilizing ideal aquifers with average hydraulic properties, the image well theory and groundwater flow equations **(Walton, 1970).**

In the case of numerical (digital) models, the continuous aquifer system parameters are first replaced by an equivalent set of discrete volumes. A set of algebraic equations are then developed, utilizing either the finite difference form of the diffusion equation governing groundwater flow or a set of difference equations from energy concepts derived by applying principles of variational calculus. The former procedure is known as finite difference method and the latter as finite element technique.

2.3.1 STATISTICAL APPROACH FOR GROUNDWATER MODELLING

Statistical methods have wider application in groundwater modelling. The areas where detailed groundwater inventorying is not possible due to considerations of cost and requirement of technical personnel, it is possible to study the groundwater regime with the aid of statistical methods.

In groundwater studies, fluctuation of water table is considered to be the dependent variable while the rainfall, the seepage from canals, return flow from irrigation water and pumpage are taken to be independent variables because water table fluctuation is totally dependent on these parameters. While rainfall is totally independent variables but seepage from canals, return flow of irrigation water and pumpage are strictly not independent because they depend upon other factors, e.g. demand for irrigation, pump efficiency, yield of wells which, however, are not pertinent to the analysis considered herein. The groundwater regime consequent upon the initiation of pumping can be tested by seeing whether there is any permanent and significant drop in the water table by analyzing its mean fluctuation. It may be also important to ensure that the rate of pumping is within the safe limits for which a statistical analysis of the factors affecting fluctuation of water table may be called for. Keeping the limitation of the availability of data on groundwater depth and other geohydrological parameters, in view the groundwater modeling of Bijnor district has been done using 'Statistical Methods'.

2.3.2 Multiple Linear Regression

In the groundwater balance equation the effect of water table can be considered as dependent variable. The parameters on the right side of the equation can generally be considered as independent variables. The parameters can also be expressed as multiple linear regression equation of the type:

$$Y_t = b_0 + b_1x_1 + \ldots..+ b_kx_{kt} \qquad \ldots\ldots(2.4)$$

where Y_t is the dependent variable on a set of k independent variables at time t. This equation allows the consideration of changes in several properties simultaneously- a situation which is generally encountered in simulation of water table responses. This equation can be solved by means of least square regression and b_0, b_1, b_2,….b_k can be evaluated.

Equation can be reduced to two independent variables, total discharge and total recharge. This gives rise to the following equation:

$$Y_t = b_0 + b_1x_1 + b_2x_2 \qquad \ldots.(2.4)$$

where x_1, x_2 represent the discharge from, and the recharge to the system respectively. The normal equations which will yield a least- square solution can be found by appropriate labeling of the rows and the columns of the matrix equation and cross multiplying to find the entries of the body of the matrix. For two independent variables the following matrix equation is obtained:

$$
\begin{aligned}
&(\; n \quad x_1 \quad x_2 \;) \,.\, (b_0) = (y) \\
&(\; x_1 \quad x_1^2 \quad x_1x_2 \;) \,.\, (b_1) = (x_1y) \\
&(\; x_2 \quad x_2x_1 \quad x_2^2 \;) \,.\, (b_2) = (x_2y)
\end{aligned}
$$

2.3.3 Field Application of Statistical Methods in Groundwater Studies

Several attempts were made in the past to determine the groundwater behavior in response to various recharge and discharge parameters.

Eriksson (1970) analysed the water level variation using a simple first- order linear Markov process of the form:

$$X_t = a.\, X_{(t-1)} + \mu_t \qquad \text{..... (2.5)}$$

where 'a' is a constant, X_t is water table level on day t and μ_t is a random independent variable. In this connection **Rennols *et al*. (1980)** made a notable work describing the response of the water table level in a borehole to a series of rainfall events using a first order auto-regressive model. The model assumed by them was of the form:

$$Y_t^* = \phi \,.\, Y_{(t-1)} + \alpha \,.\, X_t \qquad \text{. .. (2.6)}$$

and

$$Y_t = Y_t^* + e_t \qquad \text{...(2.7)}$$

where Y_t^* = actual water table level,

ϕ = a constant (drainage factor),

α = a factor depending on drainable pore space,

X_t = rainfall,

Y_t = measured water table level in the borehole,

e_t = the difference between the actual water table level and measured level in the borehole, and the subscript t indicates on day 't'.

The parameters ϕ and α in equation were assumed to be constants and were determined using the maximum likelihood method.

Neuman and Yakawitz (1977) presented a statistically based approach to the problem of estimating spatially varying aquifer transmissivities on the basis of steady state water level data. The method involves solving a family of generalized nonlinear regression problems and then selecting one particular solution from this family by means of a comparative analysis of residuals. A linearized error analysis of the solution is included. This analysis allows one to estimate the covariance of the transmissivity estimates as well as the square error of the estimates of hydraulic heads. In addition to the explicitly statistical orientation of the method, it had an additional feature of permitting the user to incorporate prior information about the transmissivities. This information may be based on actual field data such as pumping tests, or on statistical data accumulated from similar aquifers elsewhere in the world.

Hodgson (1978) described the simulation of water table response. He considered the multiple linear regression as a modeling technique. He calibrated and validated it against the actual field data from the Vryburg aquifer in South Africa. A comparison of the actual and the estimated water table responses indicated that the water table responses can be simulated by merely considering rainfall and discharge as two independent variables in multiple linear regression models.

Saxena and Satish Chandra (1978) studied the effect of groundwater pumpage on flow in the Ganga river. They found that the regeneration in the river Ganga mainly depends upon the canal water input and the rainfall in the basin; however, the canal water has greater effect. They developed following multiple linear regression equation for estimating the regeneration of base flow in the basin:

$$Y = 0.255X_1 - 0.038X_2 + 0.117\ X_3 - 7.058 \qquad \ldots.(2.8)$$

where Y = mean monthly regeneration in cumec,

X_1 = mean monthly canal discharge in cumec,

X_2 = mean monthly groundwater pumpage in cumec, and

X_3 = annual rainfall in centimeters.

They concluded that this regression equation can be applied to estimate the base flows in river basins with similar hydrological and geo-hydrological characteristics, or forecasting future regeneration of base flow in the same basin for estimated values of canal water input and groundwater pumpage.

Ramaswamy *et al.* (1983) presented an optimization technique, based on the least square procedure, for the determination of parameters in semiconfined and confined aquifers. The sum of the square of the difference between the observed and the computed drawdown was used as the objective function. The behaviour of the objective function was studied in detail and the region where the method was effective was identified. The method presented ensures convergence to true values of the parameters, without imposing any constraint on the corrections for the parameters, even if the initial estimates for the parameters differ from the true values by several orders of magnitudes.

Van Tonder and Botha (1985) expressed that parameter identification is always a problem in modeling groundwater systems. Their investigation was concerned with what useful contribution the method of Kriging can make towards solving the problem. After a brief introduction to the method and a particular implementation of it, based on least square spline approximation of the semi-variogram, the method was applied to a study of the transmissivities and storage coefficients of the Cape Flats aquifer. It was shown that Kriging not only yields the best estimates of these parameters required in modeling a system, but that the associated error map can also be used to advantage in pointing out deficiencies in the set of data used.

Nielsen and Widjaya (1989) estimated groundwater recharge to the major aquifers in southern Bali by different techniques: (1). analyses of well hydrographs gave 468 mm per annum for 1984-1985; (2). annual infiltration of 25% of rainfall gave an average recharge of 437 mm per annum; (3). baseflow separation of five years of stream discharge data gave 272 mm per annum discharge, approximately equal to recharge, much of which, however, is removed for upstream irrigation; (4). a flownet analysis gave 492 mm per annum average discharge, approximately equal to annual recharge; and (5) by mathematical modeling. A model for recharge was prepared and calibrated using all relevant available soil; land use, hydrological and meteorological data. Annual recharge was calculated for average, drought and above average rainfall years, and for light, medium and heavy soils.

Murthy and Gokhale (1990) modeled a portion of the 'Nagarjuna Sagar Left Canal Command Area' to estimate the aquifer parameters, and using the proposed model, groundwater resources were computed. These estimated aquifer parameters were applied to the basin to find out feasible solution to control rising water table elevations. The study area was divided into 20 x 19 square grids of the size 2.5 km x 2.5 km. To remove the noise present in the water table data and to find out spatial and temporal variations of the groundwater head, the data were processed by least square polynomial approximation.

Gehrels *et al.* (1994) reported that time series analysis of the fluctuation in shallow groundwater levels in the Netherlands lowlands revealed a large-scale decline in head during recent decades as a result of an increase in land drainage and groundwater withdrawal. The aim of the study was to model groundwater level fluctuation in those areas using a linear stochastic transfer function model, relating groundwater levels to estimate precipitation excess, and to separate artificial components from the natural groundwater regime. In this way, the impact of groundwater withdrawal and the reclamation of a 1000 sq. km polder area on the groundwater levels in the adjoining higher ground could be assessed.

Acharya and Bothara (1995) developed a software package, using FORTRAN 77, for the simulation of water table fluctuations between parallel drains. The software takes rainfall, irrigation data and ET as input and uses the drainage characteristics of the soil to compute water table fluctuation over a time period. Dupuit - Forchheimer idealization was used for computation of water table elevations between parallel drains. Similarly series solutions were also used to compute the quantum of flow to the drains. At any point of time, water table height at given distances from the drain line defined the state of the system. Changes in state variables were computed by taking into account the precipitation, irrigation, ET and flow to drains.

Panda *et al.* (1995) developed a groundwater model, on the basis of mass balance approach, to simulate the groundwater behaviour of a tract in South-West Punjab. A comparison was made between computed rise or fall of water level as per norms laid down by the Groundwater Estimation Committee (GWEC) with the observed average rate of rise/ fall of water level per year (1977-83). A good agreement was achieved between the predicted and the observed water levels. This study provided irrigation-system efficiencies and modified the existing recharge norms of GWEC more accurately and representative of the study area.

Raina and Prabhakara (1995) conducted a study to develop regression model relating cumulative infiltration and rate of infiltration with time under different soil conditions. Mathematical functions were tried, on the infiltration data, infiltration constants were determined to find the best-fit mathematical functions.

Sharma (1998) studied groundwater behaviour of Jamrani Dam command. Groundwater characteristics were predicted using Statistical approach and a suitable model was developed for the Jamrani Dam Command. Appropriate multiple regression equations for relationships in different governing parameters of the system, were used as models for simulating the hydrology and evaluating the response of a groundwater reservoir.

2.4 REMOTE SENSING AND G.I.S.

Remote Sensing (RS) is defined as the acquisition of physical data of an object without touch or contact and compasses technique that obtains reliable information about earth surface from a distance. More specifically this technique is concerned with the detection and recording of radiant energy within the electromagnetic spectrum.

The following points give additional advantages in case of RS over any other method.

1. Synoptic view of large area,
2. Facilitating extrapolation,
3. Interpolation easier,
4. Recollecting coverage,
5. It provides a means of monitoring dynamic features,
6. Save time and manpower by localizing the area for further detail study,

7. Availability of data of inaccessible area,
8. In geology, it helps in sensing lithologic and stratigraphic contacts and correlation of stratigraphic units,
9. Helpful in areas where scanty geographical and geological details are available. Extrapolation and interpolation of data could refill information, and
10. Ocean monitoring.

2.4.1 Principle of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount and kind of energy in different bands of the electromagnetic spectrum incident upon it. This unique property depends on the property of material (structural, chemical and physical), surface roughness, angle of incidence, intensity and wavelength of radiant energy.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. all these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a Remote Sensing System, working as links in a complete, and each of them is important for successful operation.

At temperature above absolute zero, all objects radiate electromagnetic energy by virtue of their atomic and molecular oscillations. The total amount of emitted radiation increases with the body’s absolute temperature and peaks at progressively shorter wavelengths. The sun, being a major source of energy, radiation and illumination, having a sharp power peak around 0.5 µm, allows to capture reflected light with conventional (and some not-so-conventional) cameras and films.

Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation. These spectral characteristics, if ingeniously exploited, can be used to distinguish one thing from another or to obtain information about shape, size and other physical and chemical properties. In so far as we know the spectral characteristics, we can pick an appropriate detector to make the desired measurement, remembering that for a given collector's diameter we get our greatest spatial resolution where wavelengths are shortest and energies greatest, and that these energies decrease at longer wavelengths and distances.

2.4.2 Platforms and Sensors

In the present context, information flows from an object to a receiver (sensor) in the form of radiation transmitted through the atmosphere. The interaction between the radiation and the object of interest conveys information required on the nature of the object. As we know sensor collect and record, energy reflected or emitted from a target or surface, it must reside on a stable platform from which target locations on surface could be observed. Platform is stage to mount the camera or sensor to acquire the information about a target under investigation. Based on its altitude above earth surface, platforms may be classified as:

Ground borne **:** The ground based remote sensing system, for earth resources studies, is mainly used for collecting the ground truth or for laboratory simulation studies.

Air borne **:** Aircrafts are generally used to acquire aerial photographs for photo-interpretation and photo-grammetric purposes. Scanners are tested against their utility and performance from these platforms, before these are flown onboard satellite missions.

Space borne : With the help of remotely placed platforms, users receive the enormous amount of remote sensing data and as such the remote sensing has gained international popularity.

As for image is concerned, the resolution of image plays an important role of data generation for the selected area.

2.4.3 Image Interpretation

Digital image processing is the collection of techniques for manipulation of digital images with the help of some specific software i.e. called image analyst. Remotely sensed digital image is typically composed of picture element (pixel) located at the intersection of each row and column, and in each band of imagery. With each pixel digital number (DN) or brightness Value (BV) depicts the average radiance of relatively small area within a scene. It becomes necessary to process the voluminous data that are in digital form stored in a Magnetic Tape from it a visual image can be produced for further processing.

Aerial photographs as well as imagery obtained by remote sensing using aircraft or spacecraft as platforms have applicability in various fields. By studying the qualitative and quantitative aspects of images recorded by various sensor systems like aerial photographs (black and white, black and white infrared, colour and colour infrared), multiband photographs, satellite data (both pictorial and digital) including thermal and radar imagery, an interpreter well experienced in his field can derive lot of information. Image interpretation is nothing but act of examining image to identify objects and judge their significance.

Elements of Image Interpretations

Image interpretation is essential for the efficient and effective use of the data. While the above properties of aerial photographs/ imagery help an interpreter to detect objects due to their tonal variations, he must also take advantage of other important characteristics of the objects in order to recognize them. The following seven elements of image interpretation are regarded as being of general significance, irrespective of the precise nature of the imagery and the features it portrays.

Shape : Numerous components of the environment can be identified with reasonable certainty merely by their shape. This is true of both natural features and man-made objects.

Size : In many cases, the length, breadth, height, area and/ or volume of an object can be significant, whether these are surface features (e.g. different tree species) or atmospheric phenomena (e.g. cumulus versus cumulonimbus clouds). The approximate size of many objects can be judged by comparisons with familiar features (e.g. roads) in the same scene.

Tone : We have seen how different objects emit or reflect different wavelengths and intensities of radiant energy. Such differences may be recorded as variations of picture tone, colour or density. Which enable discrimination of many spatial variables, for example, on land different crop types or at sea water bodies of contrasting depths or temperatures. The terms ‘light’, ‘medium’ or ‘dark’ are used to describe variations in tone.

Shadow : Hidden profiles may be revealed in silhouette (e.g. the shapes of buildings or the forms of field boundaries). Shadows are especially useful in geomorphological studies where micro relief features may be easier to detect under conditions of low-angle solar illumination than when the sun is high in the sky. Unfortunately, deep shadows in areas of complex detail may obscure significant features, e.g. the volume and distribution of traffic on a city street.

Pattern : Repetitive patterns of both natural and cultural features are quite common, which is fortunate because much image interpretation is aimed at the mapping and analysis of relatively complex features father than the more basic units of which they may be composed. Such features include agricultural complexes (e.g. farms and orchards) and terrain features (e.g. alluvial river valleys and coastal plains).

Texture : Texture is an important image characteristic closely associated with tone to be differentiated on the basis of microtonal patterns. Common image textures include smooth, rippled, mottled, lineated and irregular. Unfortunately, texture analysis tends to be rather subjective, since different interpreters may use the same terms in slightly different ways. Texture is rarely the only criterion of identification or correlation employed in interpretation. More often it is invoked as the basis for a subdivision of categories already established using more fundamental criteria. For example, two rock units may have the same tone but different textures.

Site : At an advanced stage in image interpretation, the location of an object with respect to terrain features of other objects may be helpful in refining the identification and classification of certain picture contents. For example, some tree species are found more commonly in one topographic situation than in others, while in industrial areas the association of several clustered, identifiable structures may help us determine the precise nature of the local enterprise. For example, the combination of one or two tall chimneys, a large central building, conveyors, cooling towers and solid fuel piles point to the correct identification of a thermal power station.

2.4.4 Remote Sensing Application in Water Resources

Remote Sensing has become an indispensable tool for the management of natural resources of which groundwater is a part. Hydro-morphological studies coupled with hydrogeological and structure/lineaments have proved to be very effective tool to discern groundwater potential zones in the watershed (**Sharma and Jugran, 1992, Rao *et al.*, 2001, Bahuguna *et al*., 2003**).

Some of works related to remote sensing application in water resources are being described as below:

Rao *et al.* (1983) conducted soil survey in an area of 70156 ha in Macherla Taluk of Guntur district, Andhra Pradesh, using 1:25000 aerial photographs. The area was divided into 4 landscapes, viz., limestone, shale, slate and sandstone. Each landscape was further divided into different physiographic units and subunits based on slope and erosion. The mapping units of the survey area were grouped into different classes and subclasses on the basis of various land soil characteristics such as slope, drainage, soil depth and rockiness etc. Out of the total area of 70156 ha surveyed, 31943 ha (45.5 per cent) was found suitable and the remaining area of 38213 ha was found unsuitable for irrigation. Out of the total irrigable area 31943 ha, 17499 ha (54.8%) was classified as class II land, 12227 ha (38.3%) was categorized as class III land and 2217 ha (6.9%) was categorized as class IV land. Out of the non-irrigable land 38213 ha, 7234 ha (18.9%) was under class V, 26548 ha (69.5%) was under class VI lands, and the remaining land of 4431 hectares (11.6%) was under miscellaneous land type.

Wodeyar *et al*. (1988) studied Kumadvati River Lower Basin covering south-eastern part of Dharwar disterict, Karanata State, consisting mainly of grewacke and metavolcancies. On account of increased demand for groundwater and due to frequent drought in most part of the area, the groundwater exploration was erratic, and high degree of failure of borewells in greywacke terrain was evident. His investigation mainly aimed at delineation of fresh groundwater potential zones using the newly emerged techniques of remote sensing integrated with electrical resistively method. The study revealed that in most part of the greywacke covered region, groundwater yield was low to moderate and patches of brackish quality water were also observed. The south-western valley part covered with metavolccanics possesses thick weathered zone and deep seated fractures and joints, was characterized by moderately good groundwater potential.

Mishra and Chachadi (1990) developed methodology to ascertain groundwater recharge affected through a rectangular recharge basin. The storage coefficient and transmissivity of the aquifer, dimension of the recharging basin, duration of recharge and a continuous record of water levels in observation well (s) in the vicinity of the recharging basin, are required for the assessment. They also prescribed a methodology to find out the temporal variation of the fraction typical example has been given for knowing the fraction of recharged water available within a circular zone at different times.

Cruise and Miller (1993) expressed that remotely sensed spatial databases can form the basis of appropriate and convenient modelling strategies for hydrologic simulation. Much of data necessary for application of watershed model can be obtained from processed spectral images and digitized topographic and soil information.

Jagadeeswara *et al.* (2004) made an attempt to locate potential groundwater zones and exploit groundwater to cater the needs of the people in the area. IRS-IB-LISS-II and IRS-ID-LISS-III data for the years 1992 to 1999 have been used respectively. The study area is divisible into 9 landforms; these landforms act as groundwater recharge and runoff zones. The groundwater potential of the study area has been assessed on the basis of physiography, drainage, rock types and geo-morphological studies.

2.4.5 Geographic Information System (G.I.S.)

G.I.S. is a Computer system capable of assembling, storing, checking, integrating, manipulating and displaying geographically referenced informations, i.e. data identified according to their locations. An information system that is designed to work with data referenced by spatial or geographic co-ordinate. In other words, G.I.S. is a database system with specific capabilities for spatially referenced data. G.I.S. brings together computer software approaches, spatial database management, statistical analysis and cartographic modeling with in a computer hardware and software configuration. Thus, in essence, G.I.S. can be viewed as an enhanced information system that aids decision-making by referencing data to spatial or geographic coordinates **(Schoolmaster and Marr, 1992, Sasowsky and Gardner, 1991).**

G.I.S. helps in managing geographic information and data that has both size and spatial location. Size means physical dimension-height, width, depth and area and spatial location means that occupy a measurable position in spare relation to the surface of the earth. To manage our environment, we have to understand how it is organized and which process plays a role (Fig. 2.1)

A first step for all these disciplines is to describe spatial situation as it is at a certain time.

Data integration entails bringing together disparate data sets, which are available on different spatial bases, in order that meaningful analysis and constructive decisions may be undertaken on them. The G.I.S. needs the detailed information of location, condition trends, patterns and modelling.

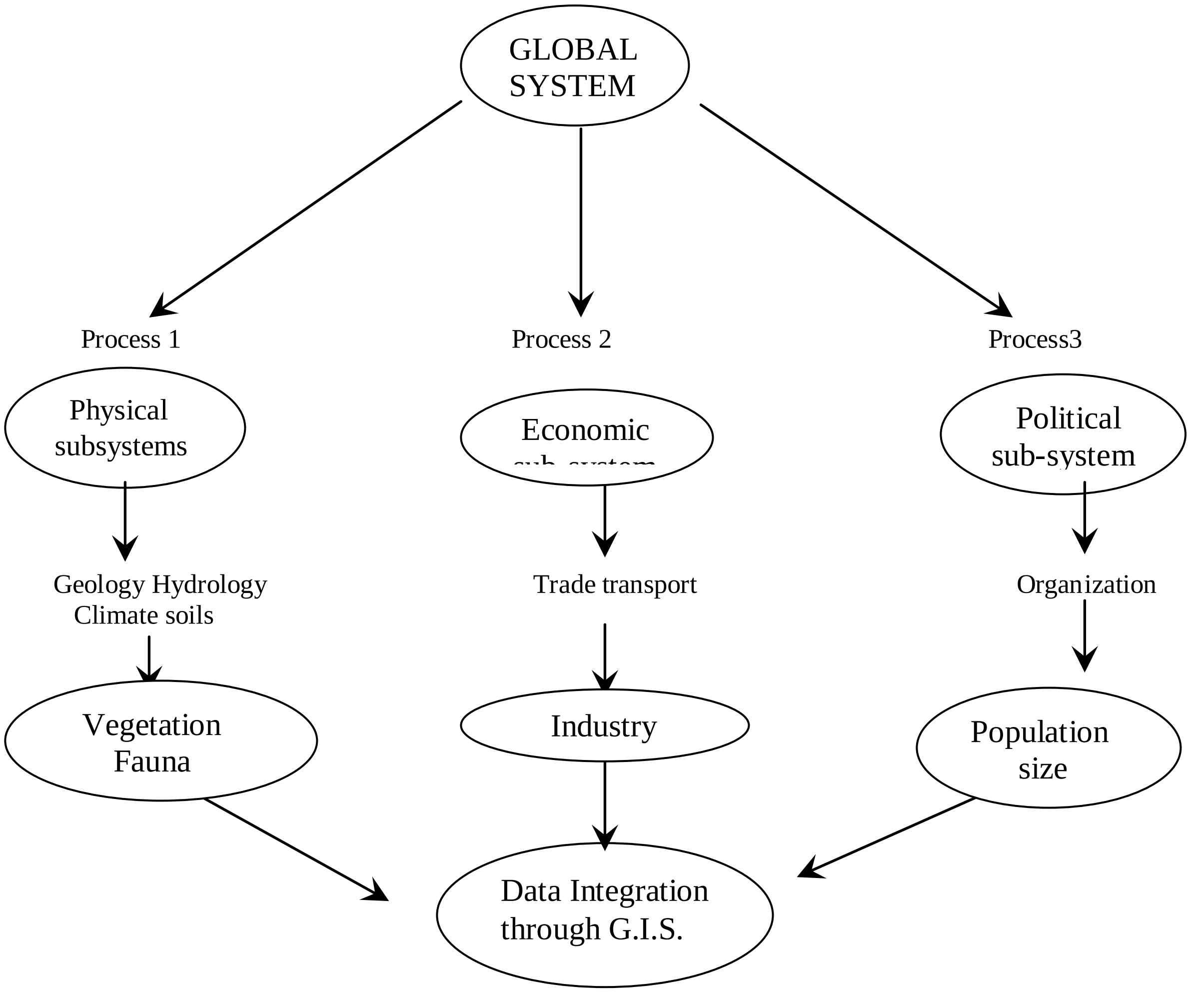


Fig. 2.1. Data flow diagram of G.I.S. system

History of G.I.S.

The G.I.S. history dates back 1960 where computer based G.I.S. was used and its manual procedures were in life 100 years earlier or so. The initial developments originated in North America with the organizations such as US Bureau of the Census, the US Geological Survey, and The Harvard Laboratory for Computer Graphics, Environmental Systems Research Institute (commercial), Canadian Geographic Information Systems (CGIS) in Canada, Natural Experimental Research Center (NREC), Department of Environment (DOE), and notable organizations in U.K. involved in early developments. The laboratory for Computer Graphics and Spatial Analysis of the Harvard Graduate School of Design or the State University of New York at Buffalo achieved worldwide recognition. Commercial agencies started to develop and offer GIS software. Among them was today's market leaders ESRI, Integraph, ERDAS, Laserscan and Autodesk, Mapinfo etc.

A sound and stable data structure to store and analyse map data became dominant in the early 1970's. This has lead to the introduction of topology into G.I.S. Topology and the related graph theory proved to be effective and efficient tools to provide logically consistant two-dimensional data representations. Another significant breakthrough occurred with the introduction and spread of personal computers in 1980's. it was possible to have a computer on the desk that was able to execute programs that previously could only be run of mainframe computers. At the same time minicomputers, and later, workstations became widely available. Relational database technology became the standard. Research on spatial data structures, indexing methods, and spatial databases made tremendous progress. The 1990's can be characterized as a period of the breakthrough of object-orientation in system and database design, recognition of geoinformatics as a professional activity, and spatial information theory as the theoretical basis for G.I.S. Potentiality of G.I.S. is realized in the recent fast and now it has become popular among many users for variety of applications.

In India the major developments have happened for the last one-decade with significant contribution coming form Department of Space emphasizing the G.I.S. applications for Natural Resources Management. Notable among them are Natural Resource Information System (NRIS), Integrated Mission for Sustainable Development (IMSD), and Bio-diversity Characterization at National Level. IIRS is also playing major role in G.I.S. through education and training programs at the National and International level. Recently the commercial organizations in India have realized the importance of G.I.S. for many applications like natural resource management, infrastructure development, facility management, business/market applications etc. and many G.I.S. based projects according to the user organization requirements.

2.4.6 Linkages between RS and G.I.S.

A certain relationship exists between RS and G.I.S. The obvious linkage exists in data collection and its subsequent analysis in response to the ‘Pixel’ = “RASTER FORMAT” inherent relationship between RS and G.I.S. RS provides thematic spatial information (pixel basis) in Raster format. G.I.S. platform with Raster and Vector Formal Data Structure (FDS) provides an integration of spatial and numerical attributes.

In the present scenario, conjunction of RS and G.I.S. results rational information of sustainable natural resource management. The integration of spatial and nonspatial data sets can often be most appropriately displayed in 3D perspective digital terrain modelling (DTM) to reconstruct the topological/landform changes of the area. Spectrally oriented classification procedures for land mapping include supervised and unsupervised GIS. Classification is the process of assigning the pixels of a multispectral image under various categories or classes. When image is classified or unclassified the pixels are compared to the clusters of statistically similar pixels. Each unclassified pixel is assigned to the most similar cluster.

Supervised G.I.S : under this classification, the image analyst supervise the pixel categorization process by specifying to, the computer algorithm, numerical descriptors for the various land cover types present in the scene. To this, representative sample sites of known cover type, called training area, are used to compile a numerical “interpretation key that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key.

Unsupervised G.I.S : The unsupervised procedure is applied in two separate steps. The fundamental difference between these techniques is that supervised classification involves a training step followed by a classification step. In the unsupervised approach the image data are first classified by aggregating them into the natural spectral groupings, or clusters, present in the scene. Then the image analyst determines the land cover identity of these spectral groups by comparing the classified image data to ground reference data.

Classification can be used to specify as much detail as desired within an image. A classified image will appear as a mosaic of uniform parcels, each of which is identified by a value and colour. Then the classified image is brought under processing for developing thematic maps.

2.4.7 Delineation of Groundwater Prospect Zones

The satellite remote sensing technique is most beneficial and advanced scientific tool for mapping of hydrogemorphological features and delineation of groundwater prospect zones. The alluvial terrain in the north and hard rock terrain in the south has vast potential for groundwater exploration. Remote sensing inputs coupled with GIS are a powerful tool for evaluation of suitable sites for groundwater development in any region. Few Geomorphic units having better prospect for groundwater are described as below.

***(l). Flood plain*:** Flat surface adjacent to a stream/river composed of unconsolidated fluvial sediments subjected to periodic flooding is very good for groundwater development. Low-lying areas are temporarily waterlogged during floods.

***(2). Alluvial plain*:** Flat to gently sloping surface formed by river consists of unconsolidated sediments. It has well to excellent prospect and promising zone for shallow unconfined aquifers.

***(3). Valley fills* :** Sediments deposited by stream/river in a narrow valley mostly fracture controlled. The prospect of groundwater varies depending on the thickness of fills.

(4). River sand : Sandy material deposited along stream channels acts as very good recharge zone for groundwater.

***(5). Ravines* :** Small narrow depression usually carved out by running water has poor groundwater yield.

***(6). Meander Scar* :** A crescent shaped scars of meandering stream still discernible no surface has excellent potential for groundwater.

***(7). Old Meander* :** Abandoned meandering loop of river/streams has excellent potential for groundwater.

(8). Palaeochannel **:** A remnant to stream/river appears, as buried or abandoned channels are promising zone for shallow aquifer with excellent groundwater yield**.**

***(9). Back Swamp* :** A low-lying swampy/marshy area adjoining natural levee has good prospect.

(10). Pond/Lake : Groundwater recharge also takes place through tanks/ponds/reservoirs and check dams besides the natural mechanism.

***(11). Pediment*:** A gently slopping smooth surface of erosional bedrock with thin veneer of detritus. Groundwater prospects are moderate to poor at the intersections of lineaments.

***(12). Shallow weathered buried pediplain*:** A flat and smooth surface of buried pediplain with thickness of 0 to 5 m consisting shallow overburden of watershed derivative material. Groundwater prospects are moderate to poor but open wells yield good amount of potable water after monsoon.

***(13). Medium weathered buried pediplain*:** A flat and smooth surface of buried pediplain with moderately thick 5 to 20-m overburden of watershed derivative material. Ground eater prospects are good to moderate.

***(14). Deep weathered buried pediplain*:** A flat and smooth surface of buried pediplain with very thick i.e. more than 20 m overburden of weathered derivative material and has good potential for groundwater and less seasonal variations in water table is observed.

Some of the available literature on the research works related to delineation of groundwater prospect zones by using remote sensing and G.I.S. system are given below:

Roza (1993) described the advantages of G.I.S. They also reported that recently, geographical information system (G.I.S.) had been used to provide susceptible to soil erosion and other forms of NPS pollution. They were all suited to store and analyses immense quantity of spatial data required for large scale, high-resolution erosion modeling. The universal soil loss equation (USLE) was the most widely used predictor of soil erosion for agricultural lands. Potential erosion was calculated by multiplying empirically derived regression factors that relate climate and terrain characteristics to erosion.

Fraser (1995) expressed that the modified universal soil loss equation (MUSLE) extends the USLE to rangeland and forested environment replacing the cropping management (C) factor and erosion control practice factor (P) with more suitable Vegetation Management (VM) factor. This factor accounts for erosion protection provided by canopy cover, vegetation etc. and is defined as soil loss from land managed under specified vegetation conditions to the same site with bare soil. Ho found that Remote Sensing (RS) can provide rapid, cost effective means of deriving land cover for large areas. Remotely sensed data is particularly appropriate for use with USLE's VM factor and modelling for surface water harvesting through GIS.

Raju *et al.* (1995) conducted studies on hydro-gemorphology and lineament for the upper Gunjanaeru river basin, Cuddapah District of Andhra Pradesh during the year 1990. The objective of the investigation was to delineate various geomorphologic units and lineaments for the groundwater development. In land use/ land cover studies, they observed that wasteland covered an area of 6,025 hectares. The area could be brought under irrigation by providing the appropriate technology of water and soil management. Such an effort would be very beneficial because it doubled the area under irrigation in a zone that was under drought prone area programme.

Lauser (1997) expressed that the lansat Thematic Mapper^{TM} imagery may be a viable alternative, which provides image classification in a rapid systematic and defensible means for developing land cover databases for modeling and management over large watershed areas. Manual data acquisition methods cannot practically provide digital elevation model of required resolution

Rao *et al.* (1998) reported that about 311 watersheds had been identified in Andhra Pradesh by Department of Agriculture, Government of Andhra Pradesh and National Remote Sensing Agency of India to develop strategies for taking up watershed management programme to optimize productivity in aerable lands and rejuvenate non arable land with forest and pasture development on friendly eco system.

Biswas and Agarwal (1998) reported that the Soil Conservation Department of Damodar Valley Corporation adopted an integrated watershed development approach in Baramasia watershed in the district of Giridih, Bihar. Micro level analysis was made to pinpoint the appropriate measures along with fast availability of water resources through the construction of water harvesting structures. After almost all the schemes were implemented successfully, it was observed in the year 1997 that a drastic change had occurred with respect to the land use pattern in the watershed and also in the per capita income. They used mainly Ilwis version of GIS to ascertain reduction in annual and per hectare soil loss through Universal Soil Loss Equation (USLE) method. IRS- 1C PAN data along with many basic maps were used for the analysis. The results showed 56% annual soil loss reduction in the watershed, thus amply showing the effect of soil and water conservation programmes.

Mahamood and Rao (2001) attempted to model the groundwater flow to simulate various scenarios of pumping and recharge rates and to study the fluctuations and forecast the depletion rate of watertable.Watertable and aquifer depth information collected from the field were used to create various thematic and spatial data layers in GIS environment and used as input of MODFLOW software to run the groundwater model of the study area. Runoff was calculated using SCS model by integrating land use map prepared from satellite data, soil information, meteorological data and other field data. The simulated groundwater levels through MODFLOW were in close agreement with the observed water levels.

Sankar (2001) carried out geomorphological investigations using IRS-IB LISS-II false color composites in the scale of 1:50,000 scale by visual interpretation techniques. Different geomorphic units such as shallow pediments, buried pediments, bajada zones, structural hills, residual hills and denudational hills were identified. Lineaments were existing in the direction of N-S, E-W and NE-SW. Collateral data such as rainfall, water table contour map, depth of weathered zone map, fractured zone map, water level fluctuations and bore well lithology are integrated and hydro-geomorphology map was prepared. Bajada zone, buried pediments and flood plains were found as most prospective zones for groundwater targeting. Occurrence of lineaments in such zones was also a favourable indicator.

Tomar *et al.* (2002) prepared site specific action plan of Upper Shipra Watershed (USW) in Ri-Bio district of Meghalaya by integrating natural resource information generated from satellite data in conjunction with other conventional and socio-economic data. The forest was the main land use (76.4%) of the watershed followed by agriculture (*bun/shifting* cultivation) and remaining land was under settlement, pasture, barren hills, ponds, quarry etc. The information on soils, land use/land cover, hydro-geomorphology, surface water, climate, and demographic and socio-economic characteristics were integrated to generate the action plan. The study aims at investigating the relative role of landforms and lineaments as an integrated unit for the assessment of groundwater availability with an example of an area occurring in basaltic terrain. The paper describes the use of remote sensing data for hydro-geomorphological mapping, zoning of the area into groundwater prospects and evaluation of zones by using well discharge data of handpumps located in the area. It has been found that the rocks, which are both, fractured and weathered, are more productive in groundwater discharge. The study showed that the lower elevation zones of micro-watersheds had better groundwater prospects.

Hazrat *et al.* (2003) derived an equation to evaluate the performance of water balance components using GIS. The components were modeled without calibration, and compared with measured data. The overall project efficiencies for the main and off-season were also obtained. The mean water balance components results for different months were stored in GIS database, analyzed and displayed as the monthly crop water requirement maps.

Ambrish Kumar (2003) made a study for Ganga-Ramganga inter-basin to study groundwater behaviour, to delineate different landforms by recent satellite imageries and correlate the identified geo-morphological groundwater prospect zones. He suggested a comprehensive groundwater recharge plan to maintain the groundwater at a safe and desired level in the future in the basin utilizing he GIS system.

2.5 Artificial Groundwater Recharge Methods

In Indo-Gangetic plains with alluvial strata have good potential for recharge as compared to hard rocks mostly found in peninsular regions. The recharge is less in the western alluvium zone due to less rainfall then in eastern zone. So, local topographic features, geological and soil conditions, quantity, quality of water and the techno economical viability of the method, govern recharge method.

Most recently used artificial recharge methods include direct surface technique i.e. surface flooding, ditch and furrow system, basin and stream channel modification etc.

Groundwater recharge by sub-surface injection method is practiced in places where groundwater is deep or prevailing land situation is not suitable for surface recharge .The method is advantageous in creating fresh water barriers in coastal aquifers against intrusion of salt water from the sea.

Recharge methods also include storage of runoff water in percolation tanks and allowing water to percolate down naturally or inducing the runoff water to aquifers via recharge shaft or cavity wells using appropriate physical/chemical/biological contamination.

Rooftop harvesting of rainwater in small-unlined tanks constructed below ground level is a practice mostly recommended for urban areas. Rainwater conservation in paddy fields through constructing bunds of optimum height can also add to the recharge process.

Various artificial groundwater recharge techniques generally adopted are given in Appendix A-1. The suitability of sites for most commonly used artificial groundwater recharge techniques is given in Appendix A-2.

Chandrashekharan and Sivanappan (1980) presented the case studies on recharging groundwater in Coimbatore district. They selected 15 percolation ponds in red and black soil areas and one hundred and fifteen wells both on the upstream and downstream of these ponds and recorded weekly groundwater levels. They reported that the water level on the down stream side was rising more by 1 to 15 m and about 15 to 20 wells got benefited by a single percolation pond, the zone of influence being 10 to 20 ha. They concluded that in canal irrigated areas, the water table rose nearer to the ground owing to the lavish use of irrigation and in contour bunded areas the water table was raised by 8.5 m due to intercepted flood by the bunds.

Sophocleous (1981) reported the depleting water resources of the Pawnee Valley Kansas, calculated a preliminary hydrologic budget and applied a mathematical model that adequately simulated the operation of the hydro-geologic system for the purpose of evaluating several schemes for managing the groundwater resources. He found that regional groundwater recharge in the area is approximately 12.7 mm/year, while the amount of appropriated groundwater in the area exceeded the natural recharge by about 11 times. According to him, the life of groundwater resources can be prolonged by concerted efforts to reduce the wastage of water and an increased efficiency of water use; implementation of not more than 40% saturated thickness depletion allowance for the next several years; imposition of a freeze on the number of irrigation wells at individual levels and engagements in an artificial recharge program.

Molden *et al.* (1984) presented an interactive computer program to solve Glover's problem involving recharge from a rectangular basin, capable of graphically displaying the rise and decline of recharge mound for either an infinite homogeneous medium or for a stream aquifer system. As reported the effects of various recharge strategies, changing basin geometry, recharge rates and duration of recharge, different soil characteristics and boundary conditions can be easily studied using this program.

Hiyama *et al.* (1989) conducted experimental study on artificial recharge of groundwater in Yamagata City, Japan using two types of installation, pit and basin method. The rainwater on roof was injected for pit method and the same for basin, and agricultural canal water during non-irrigation period. According to their estimation, about 2/3 of rain water on roof can be used and annual input of rain water of 3.52 M m^3 through pit and 225000 m^3 through basin were obtained in experimented period of 228 days.

Warner *et al.* (1989) presented seven analytical solutions that describe artificial recharge from basins by directly solving the general partial differential equation for groundwater flow. They demonstrated analytical solution application to an example problem and presented comparison to give suggestions on their use, their ease of implementation, and their relative agreement.

Sendil *et al.* (1990) reported that reservoir recharge is one of the artificial recharge methods used extensively to replenish groundwater, especially in arid regions. It requires precursory site evaluations, surveys and careful consideration of the constraints affecting the recharge water and the aquifer. They discussed the steps to be followed in the selection of alternative management plans and presented studies from two recharge dams located in Central Saudi Arabia

Berger (1992) investigated a potential for recharge in an area covered by sand dunes in Desert Valley, north-western Nevada, using a deep percolation model which uses daily measurements of precipitation and temperature to determine energy and moisture balance, from which estimates of long-term mean annual recharge are made. He reported a mean annual recharge rate of as 1.3 inches per year, or 17 percent of the long-term mean precipitation and observed that recharge would be virtually zero if the study area were covered by vegetation rather than dunes.

Lee *et al.* (1992) reported percolation of 1.5 x 10^6 T of imported water through a pond of 128 m x 128 m during a three month recharge experiment related to conjunctive use of water resources in the San Jacinto basin. They described that the water table 80 m downstream from the ponding edge began to rise slowly one month after the start of ponding; levelled off at 8 m above the pre recharge water table depth of 75 m and did not recede two months after termination of ponding water level in wells bottomed in the original vadose zone. They suggested that an inverted water table migrated downward to meet the rising water table and minor local perching occurred at the depth of 14 m as indicated by the presence of moist ground near one monitoring well and by hydraulic responses during a 20 day intermission in percolation.

Beke *et al.* (1993) measured water table depth, piezometric head and precipitation at nine sites in southern Alberta over a period of up to 28 years to determine the effect of irrigation on long-term groundwater levels. They reported direct recharge to the unconfined aquifer due to irrigation and precipitation mainly rainfall and temporary mounding of water immediately following irrigation application causing short term lateral groundwater movement. They described that irrigation method and management also affected average water table depth and emphasised the need for special management schemes for soils with increasing water table levels, before salinization becomes a problem.

Datta *et al.* (1996) studied recharge conditions of the phreatic aquifers in the Delhi area, tracing the flow paths of groundwater mixing. They reported a slow process of natural mixing of groundwater in its lateral extent due to wide range and spatial in-homogeneity of delta18O in the groundwater and infiltration of river water in the groundwater in addition to recharge from rainfall. Groundwater recharge in the area also occurred through stagnant water pools in the low elevation area where water surface runoff collected. They concluded that detailed investigation on identifying the potential recharge zone, flow paths of mixing and recharge conditions are useful to protect the groundwater resource from depletion and salinization.

No systematic study had been conducted in the past on the land and water use planning and management for Bijnor district where the water table is continuously declining. Keeping it in view an attempt has been made to study the groundwater behaviour, soil conditions and prevailing land-forms in the area to develop a suitable groundwater recharge plan with the help of remote sensing and G.I.S. On the basis of rainfall, soil characteristics and application of Remote Sensing and G.I.S. artificial groundwater recharge and water harvesting plans have been suggested for the Bijnor district so that the groundwater table can be arrested at a desired level.

3. MATERIALS AND METHODS

3.1 GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1 Location

Bijnor occupies the north-west corner of the Moradabad division, and it is roughly triangular stretch of country with its apex to the north. The western boundary is formed throughout by the deep stream of the river Ganges, beyond which lie the four districts of Dehradun, Saharanpur, Muzaffarnagar and Meerut. In the east the Phika river for the greater part of its course constitutes the boundary, separating the district from Nainital, Udham Sing Nagar and Moradabad district; and to the south lie the Thakurdwara, Amroha and Hasanpur tehsils of Moradabad district and Jyotiba Phule Nagar district, the boundary being conventional and undetermined by natural features. The district lies between latitudes of 29^0 2' and 29^0 58'N and of east longitude of 78^0 0' and $78^0$57'E. The total area of the district is liable to change slightly from time to time by reason of the erratic action of the rivers Ganges and Ramganga. There are five tehsils (Bijnor, Dhampur, Nagina, Nazibabad and Chandpur) and 11 development blocks in the district namely: Nazibabad, Kiratpur, Mohammodpur Deomol, Haldaur, Kotwali, Afzalgarh, Dhampur, Seohara, Nahataur, Jaleelpur and Noorpur. Index map of the district is shown in Fig. 3.1 and their geographical area has been given in Appendix B-1.

3.1.2 Topography

The land is level or nearly level. The gradient is up to 1 per cent. In general, alluvial belt is flat with very gentle undulations. These regions are made from the flood deposition. There remains the low fringe of *khadir* along the Ganges to the west. This generally resembles the lowlands that skirt the rivers of the interior, the low flats which adjoin the stream itself being purely alluvial in character while above them rises a terrace of higher ground lying immediately under the *bhangar* cliff. Being a part of Gangetic plain, the study area has no sharp topography except some small pockets in the north-west part of district.

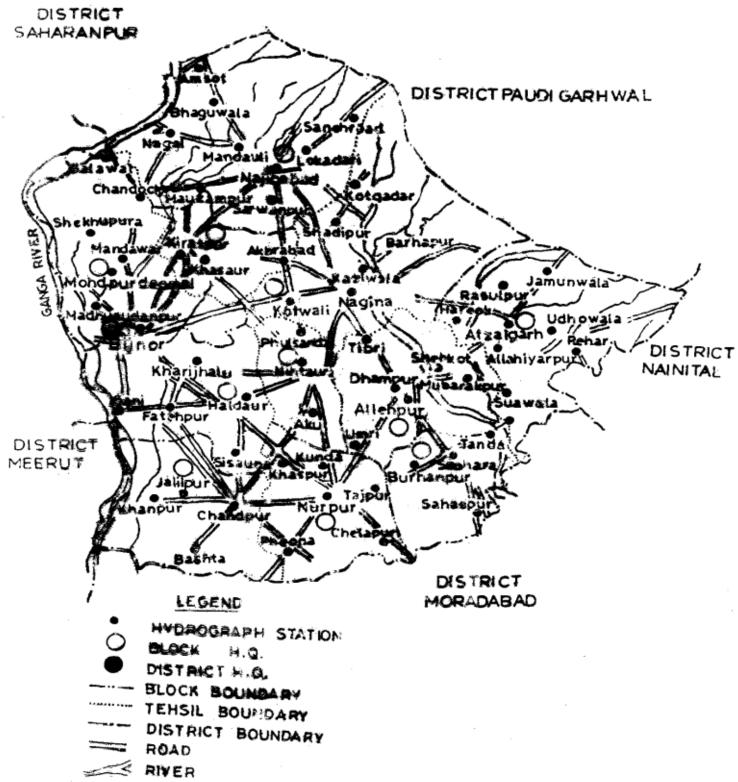


Fig. 3.1. Index map of the Bijnor district.

3.1.3 Geology

The study area is a part of alluvial region of Indo-Gangetic plain. The soil characteristics are affected by sub-humid climate. The geology of the area expresses nothing but the ordinary Gangetic alluvium, which consists mostly of gravel, sand, silt, clay and *kankar* (nodular limestone). Its deposition commenced in the Pleistocene period after the final upheaval of the Himalayas and it is still in progress. In the north-west area of Nazibabad block existence of perched aquifers are expected. In the study area topmost alluvial cover consists of soil having mixed sand and tiny mica flakes. Almost everywhere massive structure is found a few meters below the surface.

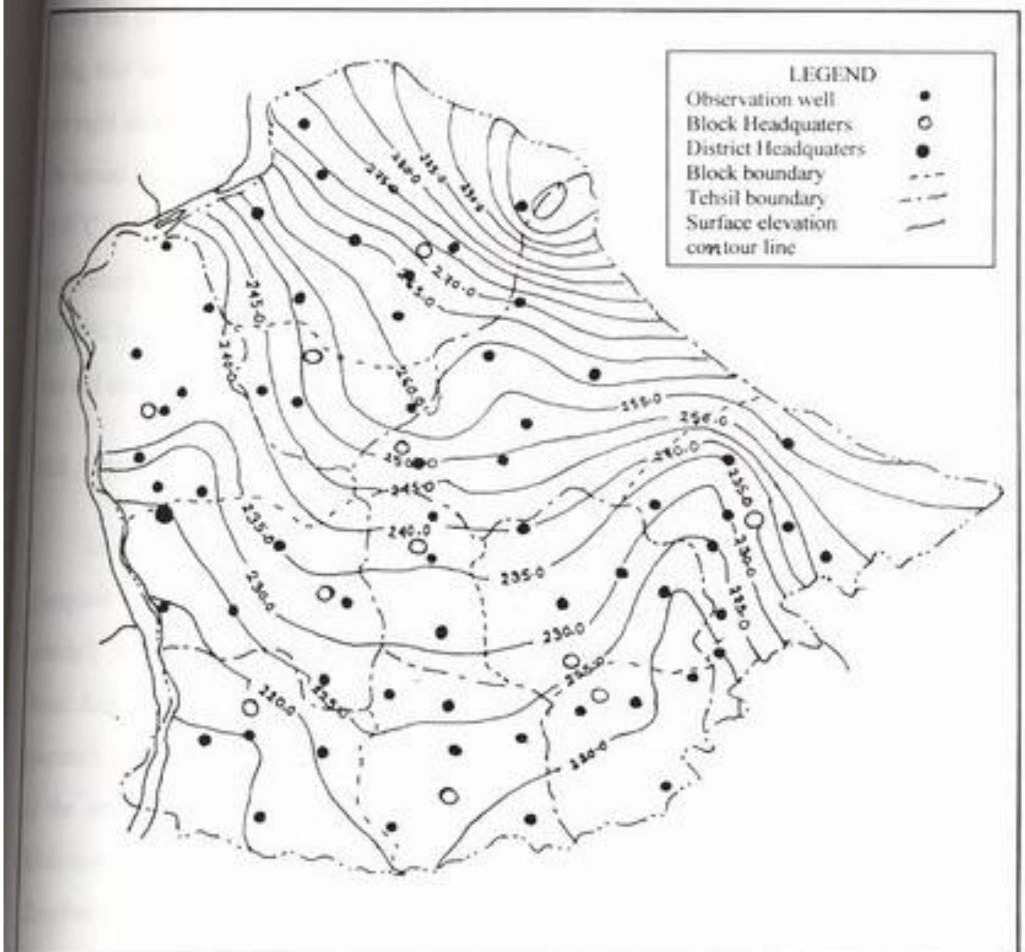


Fig. 3.2. Ground level contour map of Bijnor district.

3.1.4 Climate

The climate of the area can be classified as subtropical with three well-defined seasons i.e. winter (November to March), summer (April to mid June) and rainy season (mid June to September). The average annual rainfall in the area is about 901 mm. Most of the rainfall occurs from southwest monsoon, starting from middle June and extending till the end of September. About 75 to 80% of the annual total precipitation is received during four months (June to September) and the rest of the precipitation is distributed over eight months, of which the largest precipitation is received in December to January. The annual mean daily temperature is about 22.71^0C. The mean summer temperature is 28.05^0C and the mean winter temperature is 14.21^0C. The mean monthly minimum temperature is observed in December (4.08^0C). The mean relative humidity remains more than 90% in July to February. From March onward it decreases to about 55% till the mid June and steadily rises till August.

3.1.5 Natural Vegetation

In the relevant area native vegetation are the Shisham (*Dalvergia sisso*), Jamun (*Syzygium cumini*), Imli (*Tamarindus indica*), Kikar (*Acacia arabica*), Khair (*Acacia catechy*), Sal (*shorea frobusta*), ber (*Zizyphus mauritiana*), Babul (*Acacia nilotica*), Neem *Azadirachta indica*). The orchards of Mango (*Mangifera indica*), Guava (*Psidium quajava*), citrus (*Citrus sp*.) and some other fruit crops are also present. Common weeds of the area are *Cyperus rotundus*, *Phalris minor*, *Melilotus alba*, *Melilotus indica*, *Midicago lenticuleta*, *Chenopodium album*, *Cynodon dactilon*, *Saccharum spontanium*, *Zizyphus rotundifolia*, *Cannabis sativa*, *Tamarix dioica*, and *Saccharum munj*.

3.1.6 Irrigation

Different minor irrigation structures like Govt./private tubewells and pumping sets are present in the area for irrigation purpose. A drastic increase in the number of private tubewells and pumping units in last few years has been noticed. No increase in number of Govt. tubewells was recorded during last five years. A few blocks of the district – Nazibabad, Kiratpur, Mohd.pur Deomol, Haldaur, Kotwali and Nahataur are irrigated by canals. Canal irrigation is merely available for *kharif* crops of Bijnor district. The canal network of the area is meager and canal supply is uncertain. So, farmers generally depend on minor irrigation structures.

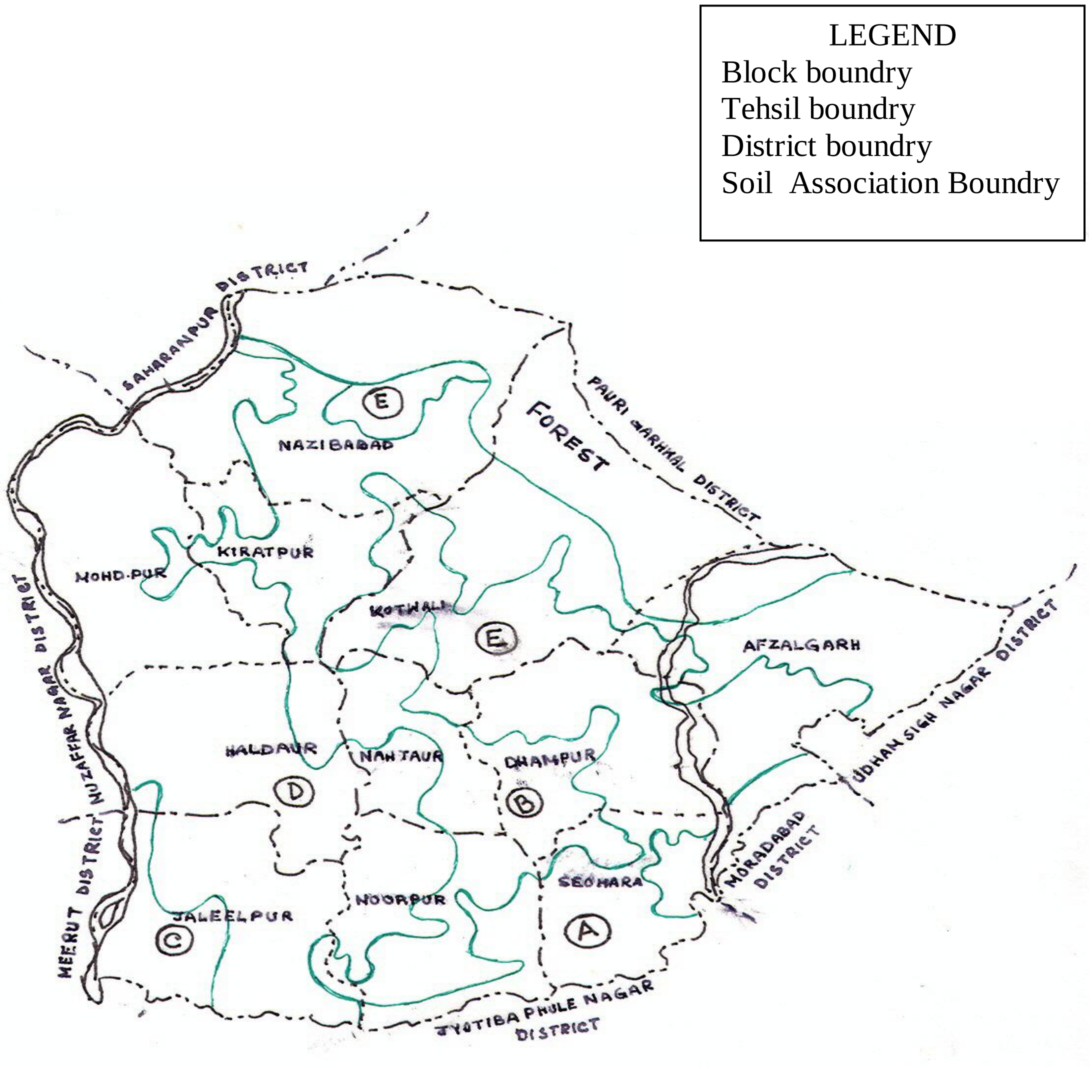
3.2 DESCRIPTION OF SOILS

Based on morphological, physical and chemical characteristics of soil studied, their associated landscape features and field correlation of augerhole data, 6 soil series, tentatively named after the nearest village/town of the soil profiles in the district were identified as Nagina, Daulatpur, Fulsunda, Kheda, Fazalpur and Kharee. The surface texture of all soil series varies from loamy sand to clay loam, whereas in case of subsoil texture it varies from clay to sandy loam. The soil profiles are well drained to moderately well drained. Soil has a mean annual soil temperature of more than 22^{o}C and difference between mean summer and mean winter soil temperature is more than 5^{o}C. Nearly level to gently slope prevails all over the area. All the soils are prone to very slightly eroded and are in “occasional” class of flooding.

These series occur together in a particular pattern in the group of two or more and their separation on the scale of reconnaissance soil map was not practically feasible. Therefore, they have been combined in the soil map into 5 soil associations. These soil associations were designated with the names of constituent soil series listed in order to their area occupied in a particular soil association. The soil association map of Bijnor district (Fig.3.3) shows the different soil association areas marked by A, B, C, D and E.

3.2.1 Land Capability Classification

Land capability classification is a systematic arrangement of different kinds of land according to the properties. Land properties, which decide the ability of the land to produce common cultivated crops and pasture plants virtually on permanent basis, are



A = Daulatpur-Nagina-Kharee, B = Fulsunda-Kheda-Fazalpur,
C = Kheda-Fazalpur, D = Nagina-Daulatpur-Kharee and
E = Nagina-Daulatpur

Fig. 3.3 Soil Associations in the mapof Bijnor district

considered. This classification is made primarily for agricultural purposes. It enables the farmers to use the land according to its capability and to treat it according to its need. Land is arranged in various capability classes by considering several of soil characteristics and associated land features and environmental factors (climate). The morphological and physical properties that were taken into account for the classification is shown in Table 3.1.

Table 3.1. Morphological and Physical properties of soils of Bijnor district.

Sl.No.	Soil series	Surface soil	Sub soil	Root zone depth (cm)	Drainage	Erosion
1.	Nagina	Sl	L	50-75	wd	Slight
2.	Daulatpur	L	L	50-75	wd-md	Slight
3.	Fulsunda	Sil	Cl	75-100	mw-wd	Slight
4.	Kheda	Cl	L	75-100	imp	Slight
5.	Fazalpur	Sicl	L	>100	imp	Slight
6.	Kharee	Ls	L	>100	wd	Slight

Sl – sandy loam, L – loam, Sil – silty loam, Ls – loamy sand, Cl – clay, Sicl – silty clay loam, wd – well drained, mw – moderately drained, imp – imperfectly drained.

The concept of land capability classification was initiated by the U.S.D.A. Soil Conservation Service (1975) as a method of assessing the extent of land limitation, which may interfere with agricultural operations on the land. This idea has been adopted in India also by A.I.S.L.U.S.O. (1970) (Table 3.2) for similar purpose.

Capability Classes

The land is divided into eight capability classes I to VIII. These 8 classes are grouped in two land-use suitability groups, viz. (i).land suited for cultivation and other

Table 3.2. Land capability classification (A.I.S.L.U.S.O., 1970).

Land characteristics	Land capability class							
	I	II	III	IV	V	VI	VII	VIII
Surface texture	loam, sandy loam, silty loam	loamy sand, clay loam, silty clay loam	Sand, clay	-	-	-	gravel	stony
Soil depth (cm)	> 90	45 – 90	22.5 - 45	7.5 – 22.5	< 7.5	< 7.5	-	-
Drainage	Well drained	Moderately drained	Imperfectly drained	Poorly drained	Very poorly drained	-	Excessive	-
Slope (%)	0 - 1	1 – 5	5 – 10	10 - 15	15 – 25	25 - 35	30 - 50	> 50
Erosion	Very slight	Slight	Moderate	Severe	-	Very severe	-	Very very severe
Salinity class	Slight	Moderate	Strong	Very strong	Severe	-	-	-
Rainfall (cm)	100 - 200	-	50 – 100	25 - 50	< 25	-	-	-

uses (class I to IV) and (ii).land not suited for cultivation but suitable for other uses (Class V to VIII). Soil and water conservation farm practices suited for Classes I to VIII are given in Appendix B-2. Each class of land may need one or more of the practices, depending upon the prevailing conditions of farming.

Sub classes

Sub classes are given according to British Columbia Land Inventory (BCLI) classification system. They are indicated by small case letters such as 'c' for adverse climate (temperature or lack of moisture), 'd' for low permeability or undesirable soil structure, 'e'for erosion limitation, 'm' for moisture limitation, 'n' for salinity, 'p' for stoniness, 't' for topography and 'w' for excess water, drainage problems and overflow and 's' for soil limitations within the rooting zone.

These inculcate information regarding the type of conservation problems or limitations involved. Within a capability class in case there are two kinds of limitations, both can be indicated, the dominant one being shown first. If both kinds of limitations are essentially equal, the symbols for sub-classes are used with the priority e, w, s and c.

3.3.2 Land Irrigability Classification

Soils of Bijnor district have been classified for their land irrigability following USBR land irrigability classification method. It is quite recent; the factors encountered are texture, depth, erosion, infiltration, wetness, fertility, and alkali/salt limitation. This is a broad level of generalization. This classification has similar considerations as those of land capability classification. Accordingly, 5 land classes have been identified. Three of them are suitable for general irrigation, one is limited suitable or suited for special crops and only one is unsuitable for irrigation. The classes indicated by I, II, III, IV and V have decreasing order of suitability.

Sub Classes

This is the second degree of generalization. Each class of soil is sub divided into sub classes according to dominant kind of limitations, which is indicated by small case letters e.g. t, e, s, w following the class number. The Table 3.3 gives the summery for determining the irrigability classes and subclasses.

Table 3.3. USBR land classification for irrigation.

Irrigability class limitation criteria	Sub class	Land Irrigability Class				
		I	II	III	IV	V
Texture of top soil	t	Sandy loam, clay loam	Loamy sand, clay	Sand, clay	Sand, clay	Includes land which do not meet the requirements of other land classes
Available moisture holding capacity (mm)	w or t	100	80	60	40	
Drainage	w	Well drained	Moderately well drained	Imperfe-ctly drained	Poorly drained	
Slope (%)	s	0–2	2 -3	3 – 5	5 - 8	
pH	f or a	5.5 – 6.5	6.5 - 7	7 - 7.5	7.5 – 8.5	

3.2.3 Land Suitability Classification

Three models were used for the land suitability studies. These were**:**

1. Sys Model (Sys, 1980),
2. Limiting Condition Model (FAO, 1976), and
3. Productivity Rating Index Model (Soil Survey Staff, 1951).

1. ***Sys Model*** **:** The climate, landscape and soil requirement for the crops under investigation in relation to limitations and suitability classes were taken as per guidelines of Sys (1980). The observed climatic, landscape and soil data in the area under investigation were set against these requirements on the framework of Sys (1980). The Land Rating Indices (L.R.I.) were then calculated, as follows, using the formula proposed by Sys:

$$L.R.I. = A.(B/100).(C/100) \quad \ldots\ldots \quad (3.1)$$

where A, B and C are the ratings on 0 to 100 scale of individual land characteristics and or qualities according to degree of limitation proposed as follows (Table 3.4):

Table 3.4. Limitation levels and their rating.

Symbol	Intensity limitation	Rating
0	None	98 – 100
1	Slight	85 – 98
2	Moderate	60 – 85
3	Severe	45 – 60
4	Very severe	Below 45

This value of L.R.I. was then matched against limits for suitability class defined to arrive at the land suitability class of Sys (1980) model. These are S_1 (highly suitable) when L.R.I. is 75 or above; S_2 (moderately suitable) when L.R.I. is between 50 and 75; and S_3 (marginally suitable) when L.R.I. is between 25 and 50. When L.R.I. is below 25 the land is considered to be not suitable (N).

2. ***Limiting Condition Model* :** In deciding the suitability class on limiting condition model, the individual land characteristics / qualities rated equal to or above 85 were considered as highly suitable (S_1), between 60 and 85 as moderately suitable (S_2), between 45 and 60 as marginally suitable (S_3) and below 45 as unsuitable (N). The overall suitability of the soil group was then decided on the basis of the lowest individual rating as limiting to overall suitability. As for e.g. the land rated as S_1 on rooting conditions, S_1 on erosion hazard but S_3 on moisture availability will be assessed as overall S_3.

3. ***Productivity Rating Index Model*:** In this model evaluation is carried out using data on crop performance, such as yield. The Productivity Rating Index (P.R.I.) was calculated as follows, using the yield data of a particular crop.

$$\text{P.R.I.} = \frac{\text{Expected or actual yield of crop per hectare}}{\text{Standard yield of crop per hectare}} \times 100 \qquad \text{.....(3.2)}$$

In the present investigation the standard yields of four major crops maize, paddy, wheat and sugarcane were taken as 50, 60, 60 and 900 q/ha, respectively. The P.R.I.'s were then matched against the percent of optimum yield values of **Dent and Young (1981)** for developing countries to arrive at the appropriate suitability class.

Table 3.5. Suggested guidelines for comparing crop yield with suitability class for developing countries.

Suitability class	% of optimum yield
S_1	> 80
S_2	40 – 80
S_3	20 – 40
N	<20

3.3 GROUND WATER INVENTORY

The water table represents the groundwater reservoir level and changes in its level represent changes in the groundwater in storage. In areas with well-defined seasonal rainfall the water table rises and falls in annual cycles, the rise corresponding to the rainfall period, and the low stage corresponding to the dry period. The magnitude of the water table fluctuation depends also on climatic factors, drainage, topography and geological conditions. Water table fluctuations are also caused by evaporation and transpiration processes. Withdrawal of groundwater by pumping wells causes decline in water levels. Water levels reflect the cumulative effect of natural recharge-discharge conditions and withdrawal by pumpage.

Therefore, to maintain the groundwater resources indefinitely a hydrologic equilibrium must exist between all water entering and leaving the basin. Keeping this in view, the groundwater inventory of Bijnor district was prepared. The groundwater balance of a basin or an area, for an inventory period, may be expressed as:

$$\text{Recharge} - \text{Discharge} = \pm \text{Storage}$$

In an expanded form, the equation can be written as below:

$$S = W_P + W_R + W_C + W_T + GW_I - GW_e - GW_E - GW_o - GW_n \qquad \ldots\ldots(3.3)$$

where S = volume change in storage,

W_P = recharge from precipitation,

W_R = return flow of irrigation water,

W_C = recharge through canal seepage,

W_T = recharge from tanks and ponds,

GW_I = groundwater inflow,

GW_e = groundwater extraction by pumps,

GW_E = evaporation loss of groundwater,

GW_o = groundwater outflow, and

GW_n = other items, if any.

3.3.1 Estimation of Groundwater Recharge

The methods adopted for estimation of recharge take into account amount of rainfall, evapotranspiration, runoff, water level fluctuations and movement of groundwater. The various recharge components are –

- Natural recharge from rainfall,
- Recharge due to seepage from canals,

- Recharge from return flow of irrigation water,
- Groundwater inflow into the area, and
- Influent seepage from rivers.

The various parameters are estimated by the following methods:

Recharge due to Rainfall

Rainfall is the main source of groundwater recharge in the study area. The monthly rainfall data of five tahsils were collected from the Revenue Department of Uttar Pradesh for the period 1990 to 2002. The recharge due to rainfall has been estimated by using U.P.I.R.I. formula as follows:

$$P = 3.41\,(R - 38)^{0.4} \qquad \text{….(3.4)}$$

where P = Rainfall penetration in cm,

R = Annual rainfall in cm.

Recharge due to Seepage from Canals

Limited supply from canal is available in few blocks of the study area. Seepage losses from canal depend on factors like channel dimensions (wetted perimeter), coefficient of permeability of the soil, distance of natural drainage, difference in the water levels of canal and drainage line etc. Computation of seepage losses for different canals at various locations is a difficult proposition, due to non-availability of sufficient data. The values of seepage loss through the canal have been taken from the Report of Ground Water Department, Uttar Pradesh (Govt., 1999) for the district of Bijnor,

Recharge from Return flow of Irrigation Water

This component of recharge is due to the return flow of irrigation water when carried out through unlined channels and applied to the fields for irrigating the crops. It has been assumed that 30% of the total groundwater used for irrigation goes to groundwater reservoir as return flow of irrigation water (**Singhal *et al.*, 1979**) For the present study, due to absence of surface water sources for irrigation, 35% of the total groundwater draft from different minor irrigation structures has been considered as return flow of irrigation water.

Groundwater Inflow into the area

Due to lack of information regarding transmissivity of the aquifers it has been assumed that ground water inflow into the area equals the ground water outflow from the area under study.

Influent Seepage from the Rivers

Due to lack of adequate information regarding river discharge data it has been assumed that the influent seepage from rivers during monsoon period equals the effluent seepage to rivers during non-monsoon period.

3.3.2 Estimation of Groundwater Discharge

After the estimation of groundwater recharge the groundwater losses have to be accounted for to quantify the available exploitable surplus. The various means of groundwater discharge include:

- Effluent seepage to rivers,
- Groundwater outflow from the area,
- Evapo-transpiration loss from groundwater reservoir, and
- Groundwater pumpage through wells

Effluent Seepage to Rivers

Due to lack of information regarding river discharge data, it has been assumed that the effluent seepage to rivers during non-monsoon period equals influent seepage from rivers during monsoon period.

Groundwater Outflow from the area

Groundwater outflow from the study area was also calculated on the similar lines as inflow into the area.

Evapo-transpiration Losses

The data of water table elevation in the area show that no area was within the depth of 1.5 m from the ground surface during various crop seasons. So for areas having water table depth >1.5 m the contribution from groundwater would be negligible.

Pumpage through Groundwater Structures

It includes following components:

1. groundwater withdrawal through minor irrigation structures,
2. groundwater withdrawal for domestic use,
3. pumpage for livestock consumption, and
4. pumpage for industrial consumption.

The groundwater pumpage for irrigation was estimated on the basis of existing minor irrigation structures in the area and the unit drafts being used by the Irrigation Departments and Tubewell Division, U.P. for various groundwater structures in different blocks as shown in Appendix B-3.

For the estimation of pumpage for domestic use, human population was estimated on the basis of the census reports of the years 1991 and 2001 and the percent growth in the human population in the last decade. The domestic utilization of groundwater was worked out on the basis of Indian Standards of Consumption of water equal to 40 lit/day/capita.

The groundwater pumpage for livestock and poultry consumption has been computed on the basis of the following WHO norms for per capita consumption.

Cattle	55 lit/day
Horse/Donkey	30 lit/day

Pigs	15 lit/day
Goats/Sheep/ Poultry	5 lit/day
Others	15 lit/day

The groundwater requirement for livestock was assumed to be 10% of the total requirement, as major portion of livestock takes water from surface resources. For industrial utilization, water requirement has been taken as 1% of the groundwater pumpage.

3.4 CONSTRUCTION OF NODAL NETWORK

Due to large spatial variations of argoclimatic and hydrological conditions in the study area, it has been sub divided into smaller units, i.e. sub-areas/nodal areas. On the basis of model suitability the nodal areas may be rectangular, square or polygonal.

The area was sub-divided into 47 nodes applying Thiessen Polygon method (Fig.3.4). In order to avoid computational error triangles were formed in such way that the internal angles were less than 90^0. Perpendicular bi-sectors were drawn to all sides of the triangles to obtain polygons. (**Rushton and Redshaw, 1979).**

For the construction of the existing network some arbitrary nodes have been formed, as the setting and spacing of observation wells did not coincide with the nodes of the polygonal cells. The water table data of these arbitrary nodes was found by interpolation of the nearest observation wells data.

3.5 ESTIMATION OF MODEL INPUTS

3.5.1 Statistical Approach for Groundwater Modelling

Statistical methods have widely been used in groundwater modelling. The method is generally applicable in areas where detailed groundwater inventorying is not possible considering the cost and technical personnel requirement. Thus keeping the limitations of the availability of data on groundwater depth and other geo-hydrological parameters in

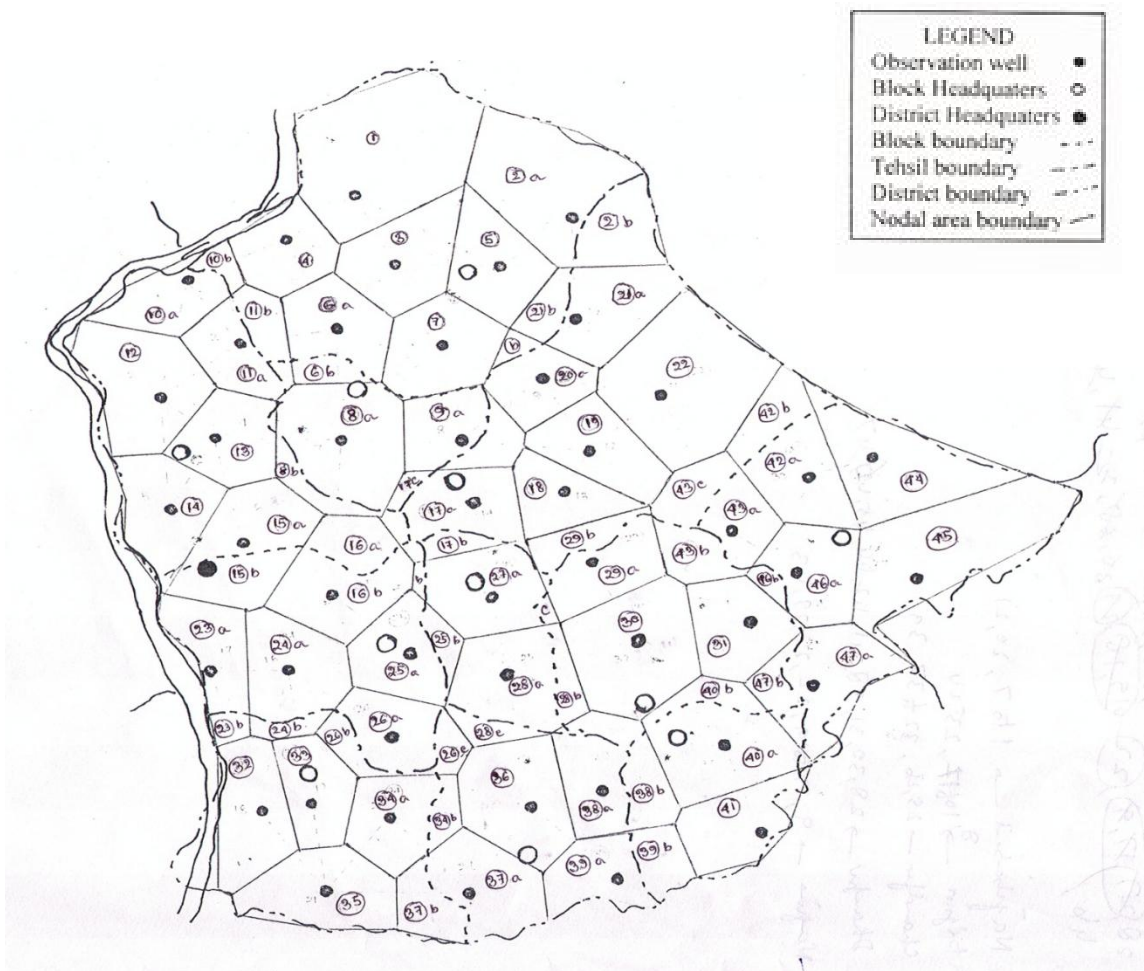


Fig. 3.4 Nodal Network of the Bijnor district

view the 'Statistical Methods' has been adopted for the groundwater modelling of the study area. The method is simple and easy to implement in the problem.

The association of three or more variables can be investigated by multiple linear regression and correlation analysis. The derivation of relationships among hydrologic variables is of importance for the transfer of information from few gauged stations to many gauged stations. The general form of the multiple linear regression is:

$$X_1 = B_1 + B_2X_2 + B_3X_3 + \ldots\ldots + B_nX_n + \varepsilon \qquad \ldots\ldots(3.5)$$

where X_1 is dependent variable and X_1, X_2,….X_n are independent variables and ε is error term.

In designing the multiple linear relationships, the dependent variable is defined by the problem itself. The independent variables are selected on the following basis:

i). The variables have been observed in the past concurrently with the dependent variable so that the regression equation may be established, and they will continue to be observed in the future also. So that dependent variable may be predicted in future also.

ii). The dependent variable should have dependence upon independent variables, from physical point of view.

In the study, fluctuation of water table was considered to be the dependent variable, while rainfall, seepage from canals, return flow of irrigation water and total groundwater draft were taken as the independent variables.

3.5.2 Input Data Generation

The polygon area of the nodal network was estimated using digital planimeter. There are 47 nodes in the study area. The polygon area of each node is given in Appendix B-4. Then recharges due to pre-monsoon and post-monsoon rainfall were calculated for each node using the Rainfall Infiltration Factor (RIF) method (U.P. Govt., 1999). Pumpage, livestock consumption and domestic/industrial consumption have also been calculated for individual node for pre-monsoon and post-monsoon periods.

3.5.3 Simulation Models

Keeping in view the above concept for the groundwater modelling of the Bijnor district following multiple regression models were tried and input and output parameters were fit accordingly for the prediction of depth of water table below ground level, Y and evaluated for their performance:

Model 1:

$$Y = a + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 \quad \text{....(3.6)}$$

Model 2:

$$Y = b + b_1R + b_2D \quad \text{....(3.7)}$$

Model 3:

$$Y = c + c_1R + c_2D + c_3R^2 + c_4D^2 \quad \text{.... (3.8)}$$

Model 4:

$$Y = d + d_1R + d_2D + d_3R^2 + d_4D^2 + d_5R^3 + d_6D^3 \quad \text{....(3.9)}$$

Model 5:

$$Y = e + e_1R + e_2D + e_3R^2 + e_4D^2 + e_5R^3 + e_6D^3 + e_7R^4 + e_8D^4 \quad \text{...(3.10)}$$

Model 6:

$$Y = f + f_1R + f_2D + f_3R^2 + f_4D^2 + f_5R^3 + f_6D^3 + f_7R^4 + f_8D^4 + f_9\ln(R) + f_{10}\ln(D) \quad \text{....(3.11)}$$

where Y = depth to water table below ground level,

x_1, x_2 and x_3 = different recharge components,

$x_4 = D$ = total groundwater discharge value,

$R = x_1 + x_2 + x_3$ = total groundwater recharge, and

$a, a_1, a_2, \ldots f_9, f_{10}$ = regression constants.

3.6 APPLICATION OF REMOTE SENSING AND G.I.S.

3.6.1 Base Map Preparation

Base maps were prepared using Survey of India (SOI) Topo sheets of 1: 250000. Base maps for river boundary, drainage network, district and block boundaries prepared by digitizing Topo sheets and other ancillary maps in GeoMedia software with polygonic projection.

3.6.2 Digital Classification

Geo-morphological map of 5th May, 2003 was prepared for the study area by using digital classification techniques. The supervise classification was carried out to prepare the geo-morphological maps of the study area. In supervise classification there are three stages for classifying the images:

1. Training stage
2. Classification stage, and
3. Output stage.

In the present study, best results were obtained from maximum likelihood classifier in classification stage. Using this method the Bijnor district was classified into following hydro-morphological classes:

1. Young Flood Plain
    - Mixed sand and silt dominated (YFP-1)
    - Sand dominated (YFP-2)
2. Old Flood Plain
    - Sand dominated (OFP-1)
    - Silt dominated (OFP-2)
    - Mixed sand and silt (OFP-3)
3. Palaeochannels and natural drains,
4. Natural levee and back swamp,
5. Piedmont Plain (P)
    - Upper Piedmont (P1),
    - Lower piedmont (P2), and
    - Transitional plain or piedmont flood plain (P3).

3.7 WATER HARVESTING AND RECHARGE STRUCTURES

Technical guidelines for selecting suitable sites have been suggested by Integrated Mission for Sustainable Development (IMSD) of National Remote Sensing Agency (NRSA), Hyderabad and Indian National Committee on Hydrology (INCON), National Institute of Hydrology (1995). The entire study area was reviewed for the construction of suitable water harvesting structures and on the basis of above mentioned recommendations the following water harvesting structures were considered for their suitability.

1). Check Dams: These are the barriers of low height, which are constructed across the *Nala* to reduce runoff velocity and allow the retained water to percolate. Such types of structures are constructed on lower order streams generally up to third order and on medium to gentle slope topography. Where the water table fluctuations are very high and stream is influent or intermittent are also the favorable conditions. While constructing the check dam, following points are considered.

- The catchment area should be about 25 hectares,
- Minimum ecological disturbances, and
- Should be 500 metres away from settlement area.

2). *Nala* Bunds and Percolation Tanks: *Nala* bunds and percolation tanks are constructed across *Nalas* (streams) for checking velocity of runoff, increasing water percolation and increasing soil moisture regime. *Nala* bunds are less expensive, smaller in dimensions and constructed using locally available materials where as percolation tanks are large and more costly. The selected site should have following features:

- The site should be selected in relatively flatter *Nala* reach, the slope of the *Nala* should not be more than 2 percent.
- The bed should have soil with adequate permeability and good fracture development to facilitate good groundwater recharge,
- The catchment area should be about 40 hectare,
- Should not be constructed within 500 meters periphery of settlement areas,

- Minimum ecological disturbances.

3). Farm Ponds: Farm pond is made by either constructing an embankment across a water course or by pit or the combination of both. Normally, such structures are provided within individual farms. The purposes of farm pond construction are to provide water storage for life saving irrigation in a limited area, and drinking water for live stocks and human beings, and to reduce the load on groundwater reservoirs. While constructing such structures, following points should be remembered.

- Area having flat topography,
- Area having low soil permeability,
- The catchment area should be around two hectares, and
- Minimum ecological disturbances.

In addition to above guidelines while selecting the water harvesting and groundwater recharge structures for the study area the norms mentioned in Table 3.6 and Appendices A-1, A-2 and B-5 were also considered.

Table 3.6. Weightage of different parameters defined for suitable sites for artificial recharge.

Sl.No.	Parameter	Weightage	Classes	Class weightage
1.	Slope (in degrees)	10	0-2	10
			2-5	8
			5-10	3
			10-15	1
			>15	0
2.	Geomorphology	9	Palaeo-channel fill	10
			Yong flood plain-2	8
			Yong flood plain-1	6
			Old flood plain-2	1
			Old flood plain-3	1
4.	Geology	7	Unconsolidated	10
			Consolidated	5
5.	Soil depth	7	Slightly deep	10

			Shallow	5
6.	Depth to water level (m)	6	11-14	10
			9-11	8
			7-9	6
			4-7	4
			2-4	2

4. RESULTS AND DISCUSSION

Due to over-exploitation of groundwater, water table is continuously declining in most part of the Bijnor district. Since groundwater is one of the precious thing, it must be conserved properly by all sustainable means. The water table declining area is increasing day by day. Therefore the situation calls for an urgent need for a detailed study of soil conditions, geo-hydrology, and groundwater behaviour to develop suitable strategies for the assessment of groundwater and planning for proper groundwater management so that the declining of water table can be arrested within the safe limits. Keeping it in view, the present study was taken up to study the hydro-geological conditions of the district, to evaluate the soils according to their land capability, irrigability and suitability for major crops, to develop groundwater model on the basis of its behaviour, to delineate different landforms using Remote Sensing and G.I.S., and to develop strategies for artificial groundwater recharge planning for the problematic areas of the Bijnor district. The results obtained are being discussed below:

4.1 SOIL CHARACTERIZATION

The Bijnor district of Uttar Pradesh is a part of alluvial region of Indo-Gangetic plain. The soil characteristics are hereby affixed by sub-humid climate. Soils of this area, in general, are coarse to medium textured and considerably deep. As per USDA Soil Taxonomic Classification System the soils belong to Natrustalfs, Eutrochrepts, Haplaquepts, Dystrochrepts, Ustrochrepts, Ustipsamments great groups. Among the eleven orders of soil taxonomy Nagina, Daulatpur, Fulsunda and Kheda soil series are placed under the order Inceptisol. Nagina, Daulatpur and Kheda are placed under the suborder Ochrept whereas Fulsunda is placed under the suborder Udalf.

4.1.1 Soil Series and Soil Associations

Six soil series have been identified in Bijnor district, tentatively named after the names of different nearest places of profiles in the district as- Nagina, Daulatpur, Fulsunda, Kheda, Fazalpur and Kharee. These soils have been grouped under five soil associations. Around 50% area of the district is covered by the soil associations Fulsunda - Fazalpur – Kheda and Nagina – Daulatpur. Whereas Kheda – Fazalpur soil association covers minimum area of the district. The north – west part of the district is under forest. Therefore, that forest area has been considered as forestland. Table 4.1 shows the blocks under different soil associations. Percentage of area covered by each soil series in a particular soil association is given in Appendix C-3.

Table 4.1. Soil associations of Bijnor district (alphabet in parentheses indicates that particular soil association in the soil association map).

Sl. No.	Soil Association	Blocks covered
1.	Daulatpur – Nagina – Kharee (A)	Seohara, Noorpur, Dhampur
2.	Fulsunda – Fazalpur – Kheda (B)	Noorpur, Nahataur, Dhampur, Kotwali, Nazibabad, Mohd.pur Deomol
3.	Kheda – Fazalpur (C)	Jaleelpur, Haldaur, Kiratpur, Nazibabad
4.	Nagina – Daulatpur – Kharee (D)	Jaleelpur, Noorpur, Nahataur, Haldaur, Mohd.pur Deomol
5.	Nagina – Daulatpur (E)	Nazibabad, Kiratpur, Kotwali, Dhampur, Afzalgarh

4.1.2 Morphological Properties of Soils

The morphological properties of soil indicate the physical constitution of soil as exhibited in a vertical section (soil profile). Various morphological properties of soils of

Bijnor district like – thickness of horizons, texture and structure are given in Appendix C-1. All the six soil series identified developed on upland plain. Locally, Nagina-series occupied the highest position on landscape, Daulatpur and Fulsunda series occupied uppermid position and the lowest position was occupied by Kheda soil series. Soils are well to moderately well drained.

4.1.3 Physical Properties of Soils

Various physical properties of the soils for each horizon of the profile are given in Appendix C-1.The sand content in Nagina soil varied from 44.3% to 87.2%. In Kheda soil series sand content ranged from 21.8% to 86.2% and this profile showed a gradual increase in sand content. Relatively higher content of silt was found in Fulsunda and Fazalpur soil series (47.8% to 54%). Kharee soil series has 70% to 83.4% sand, 19.4% silt and 5.6% clay in the topsoil. Variation in particle density was observed among these soils depending upon land use. The highest particle density (2.46 Mg m^{-3}) was observed in Daulatpur series. Bulk density of these soil series increased with depth due to increase in compactness of the horizons. Porosity decreased with depth due to compaction by cementing agent viz. carbonate and higher sand content.

4.1.4 Chemical Properties of Soils

Various chemical properties of the soil profiles were determined and are presented in Appendix C-2. pH values for all the soil series ranged from 6.85 to 7.83, indicating the neutral to slightly sodic nature of the soil. The maximum amount of organic carbon was found in the surface horizons and it gradually decreased with depth in all the profiles except Fulsunda series. Daulatpur soil series has higher organic carbon content (0.138 to 1.046%).

4.2 LAND EVALUATION

Land productivity varies as the soil properties vary in a place. Therefore, it is necessary to identify the particular soil property which governs the soil productivity of the area. Soil should be judiciously used on the basis of its inherent properties. Thereby, this basic concept of proper land utilization has been utilized for classifying soils according to their capability, suitability and irrigability characteristics.

4.2.1 Land Capability Classification

The soils of Bijnor district have been classified as per land capability classification of A.I.S.L.U.S.O (1970). Nagina and Fulsunda soil series have been put under land capability class II, as these soils need no special attention while growing crops but have slight limitation of soil depth (Table 4.2). Daulatpur soil series has been put in capability subclass II_w due to slight limitation of drainage. Kharee soil series was considered under class II for loamy sand texture. Fazalpur and Kheda soil series have been put under capability class III_w as these soils have moderately severe limitation of drainage and require special farm practices to maintain the property. Therefore, these soils have slight limitations to cultivation.

Limitations of Daulatpur, Kheda and Fazalpur soil series include singly or in combination the effects of gentle slopes, slight to moderate sodicity and slight climatic limitations on soil use and management. Fazalpur and Kheda soil series when cultivated, due to low permeability but nearly levelled soils, require proper drainage and a cropping system that maintains or improves the structure and tilth of soil.

4.2.2 Land Irrigability Classification

Daulatpur, Fulsunda and Kheda – all three soil series were classified under class III of land irrigability classification due to moderately severe limitation of alkalinity (Table 4.2). Nagina, Daulatpur, Fulsunda and Kheda soil series have subclass ‘a’ due to domination of natural soluble salts in the profiles. Among these, Nagina series has well drainage condition so it has low alkalinity in comparison to other three soil series and has been put under class II_a. Daulatpur, Fazalpur and Kheda soil series have subclass ‘w’ due to moderate to imperfect drainage. Kharee soil series has class II and subclass‘t’ due to loamy sand texture.

Table 4.2. Land Capability and Land Irrigability Classification.

Sl. No.	Soil series	Land capability class	Land irrigability class
1.	Nagina	II	II_a
2.	Daulatpur	II_w	III_{aw}
3.	Fulsunda	II	III_a
4.	Kheda	III_w	III_{aw}
5.	Fazalpur	III_w	III_w
6.	Kharee	II	II_t

4.2.3 Land Suitability Classification

The soils of Bijnor district have been evaluated for their suitability to grow four major crops: wheat, paddy, sugarcane and maize.

For paddy production

Table 4.3 gives the Land Rating Indices (L.R.I.) and corresponding suitability classes of different soil series in the district for paddy. The L.R.I. varied from 14 to 68. Kheda and Fazalpur soil series were assigned to moderately suitable (S_2) class for paddy production. Nagina, Daulatpur Fulsunda and Kharee soil series having L.R.I. value less than 25, were not suitable for paddy production. The Limiting Condition model (LCM) results were identical for Nagina, Fulsunda and Kharee series. As per P.R.I. model all soil series were moderately suitable.

Table 4.3. Suitability classes of different soil series for paddy production.

Sl.No.	Soil series	Sys method		L.C.M suitability class	P.R.I. suitability class
		L.R.I.	Suitability class		
1.	Nagina	14.90	N	N	S_2
2.	Daulatpur	15	N	S_3	S_2
3.	Fulsunda	16.43	N	N	S_2
4.	Kheda	68.77	S_2	S_1	S_2
5.	Fazalpur	51.34	S_2	S_3	S_2
6.	Kharee	13.23	N	N	S_2

For wheat production

Table 4.4 gives the Land Rating Indices (L.R.I.) and the corresponding suitability classes for wheat production in the district. On suitability scale Fazalpur and Fulsunda soil series having L.R.I. between 85 and 93, fell in highly suitable class. Daulatpur and Kheda series having L.R.I. between 59 and 72, were assigned to moderately suitable class. Nagina and Kharee soil series fell in marginally suitable class for wheat production. Except Fulsunda and Kharee soil series the Limiting Condition model showed identical results. On the basis of PRI model all the soil series were moderately suitable.

For sugarcane production

The Land Rating Indices in this case varied from 61 to 87 (Table 4.5). Nagina, Daulatpur, Kheda and Fazalpur soil series, having L.R.I. between 61 to 66, were classified as moderately suitable. Fulsunda soil series fell in highly suitable class. Kharee soil series was put under marginally suitable class. According to Limiting Condition model Nagina, Fazalpur and Kharee soil series were classified as moderately suitable. From productivity point of view all series came under moderately suitable class.

Table 4.4. Suitability classes of different soil series for wheat production.

Sl. No.	Soil series	Sys method		L.C.M. suitability class	P.R.I. suitability class
		L.R.I.	Suitability class		
1.	Nagina	45.03	S_3	S_3	S_2
2.	Daulatpur	72.06	S_2	S_2	S_2
3.	Fulsunda	85.90	S_1	S_2	S_2
4.	Kheda	59.30	S_2	S_2	S_2
5.	Fazalpur	93.71	S_1	S_1	S_2
6.	Kharee	28.53	N	S_3	S_2

Table 4.5. Suitability classes of different soil series for sugarcane production.

Sl. No.	Soil series	Sys method		L.C.M. suitability class	P.R.I. suitability class
		L.R.I.	Suitability class		
1.	Nagina	61.06	S_2	S_2	S_2
2.	Daulatpur	65.92	S_2	S_1	S_2
3.	Fulsunda	86.62	S_1	S_1	S_2
4.	Kheda	64.8	S_2	S_1	S_2
5.	Fazalpur	66.40	S_2	S_2	S_2
6.	Kharee	48.84	S_3	S_2	S_2

For maize production

The Land Rating Indices in this case varied from 45 to 92 (Table 4.6). Nagina, Daulatpur, Fulsunda and Fazalpur soil series having L.R.I. between 75 and 92 were assigned to highly suitable (S_1) class and Kheda soil series, having L.R.I. 61, was assigned to moderately suitable class. Limiting Condition model gave similar results for Kheda and Fazalpur soil series. Using P.R.I. model all soils fell in marginally suitable class (S_3) for the maize production.

Table 4.6. Suitability classes of different soil series for maize production.

Sl. No.	Soil series	Sys method		L.C.M. suitability class	P.R.I. suitability class
		L.R.I.	Suitability class		
1.	Nagina	77.42	S_1	S_2	S_3
2.	Daulatpur	80.22	S_1	S_2	S_3
3.	Fulsunda	86.33	S_1	S_2	S_3
4.	Kheda	61.70	S_2	S_2	S_3
5.	Fazalpur	91.90	S_1	S_1	S_3
6.	Kharee	45.73	S_3	S_1	S_3

A matching of suitability classes revealed that in 2 out of 6 cases suitability classes of Sys Model agreed with P.R.I. model for paddy cultivation. Thereby, indicating that Sys model gave good results of land suitability classification in terms of paddy production. Similarly Sys model gave better results in terms of sugarcane production. Both Sys model and the Limiting Condition model gave equally good results of land suitability classification in terms of wheat and paddy production.

4.2.4 Use and Management

Due to variation in soil properties, topographical features and climatic components, crop production also varies. Hence, management of a particular type of soil to produce a particular crop should be done taking into consideration the soil characteristics, climate and socio-economic conditions prevailing in the area. Use and management of different soil series according to their associated problems are discussed below:

Nagina series **:** Problems of this soil series that need attention for better crop production are its lighter texture, excessively well drained condition, slight erodibility and slight sodicity. However proper fertilization and manuring help to grow crops satisfactorily.

Daulatpur series **:** Major problems associated with the majority of soils of this series are their moderate to well drainage, medium texture and presence of free calcium carbonate in the sub-surface and sub-soil horizons. Through the provision of surface and sub-surface drainage some extent of free calcium carbonate can be removed. For better crop production application of zinc will be required in the soils having calcium carbonate in the profile.

Fulsunda series **:** The soils of this series are medium textured with well drainage condition but have limitation of alkalinity. So, proper manuring and surface drainage will help to retain the soil productivity. Application of zinc would be required to overcome the effects of calcareousness.

Kheda series **:** This soil series have the problem of medium texture and imperfect drainage. The problem can be overcome by providing surface/sub-surface drainage. Addition of gypsum would be required for reclaiming the areas affected by alkalinity.

Fazalpur series **:** Soils of this series are heavy textured having imperfect drainage profile. Providing surface/sub-surface drainage, the problem can be overcome.

Kharee series **:** This soil series has sand dominated top soil with better drained condition. Therefore, addition of organic green manure and compost would be helpful to reduce soil loss due to erosion during rainy season and to retain better moisture and nutrients. These soils require frequent irrigation for *rabi* crops. To increase the yield chemical fertilizers can be added as per requirement of crop.

4.3 GEO-HYDROLOGY

On the basis of the pre-monsoon and post-monsoon water table data, collected from the observation wells, water table behaviour of the study area was studied. Fig 4.1 shows the location of the observation wells in the area. The results of the study are being discussed in the following sections.

Fig.4.1. Location of observation wells in Bijnor district.

4.3.1 Water Table Depth

Water table depth of an area is highly co-related with the parameters like-topography, sub-surface lithology, precipitation, methods of irrigation, surface water bodies and groundwater draft of the area by different means. Fluctuation in water table depth is the result of mutual balance between the discharge and the recharge from different sources in the area.

Pre-monsoon and the post-monsoon water table depths below ground level are shown in the Figs 4.2 and 4.3 for the year 2002. The minimum depth of water table in pre-monsoon conditions was found near rivers Ganga and Ramganga, varying from 3 m to 7 m in the blocks of Dhampur, Afzalgarh, Mohd.pur Deomol, south-east part of Noorpur, Seohara and in Mandouli area of Nazibabad block. The maximum depth of water table was found to vary between 9 m to 13 m in Haldaur, Jaleelpur, Kiratpur, Nazibabad, Nahataur and Noorpur blocks. In post-monsoon season minimum water table depth varied from 2 m to 4 m in southern part of Nazibabad, Afzalgarh and near the river Ganga in Mohd.pur Deomol block. The maximum water table depth (9-12 m) was noticed in Haldaur, Mohd.pur Deomol, Nahataur and Jaleelpur blocks, and north-east part of Noorpur block. In the remaining blocks water table depth varied from 5 m to 9 m. Both the pre- and post-monsoon water table contour maps show that water table increased from east to west except south-west parts of the Jaleelpur block. The water table depth in the central part of the district was maximum from north to south. The water table depth in the eastern riparian area of river Ganga was comparatively deeper than western riparian area of river Ramganga.

4.3.2 Water Table Fluctuation

Water table fluctuates in response to: (i). natural recharge from rainfall, (ii). seepage from surface water bodies, (iii). recharge due to return flow of irrigation water, (iv). loss of groundwater due to evapo-transpiration, (v). pumping of groundwater through wells, and (vi). groundwater movement. These factors are responsible to show seasonal pattern of fluctuation.

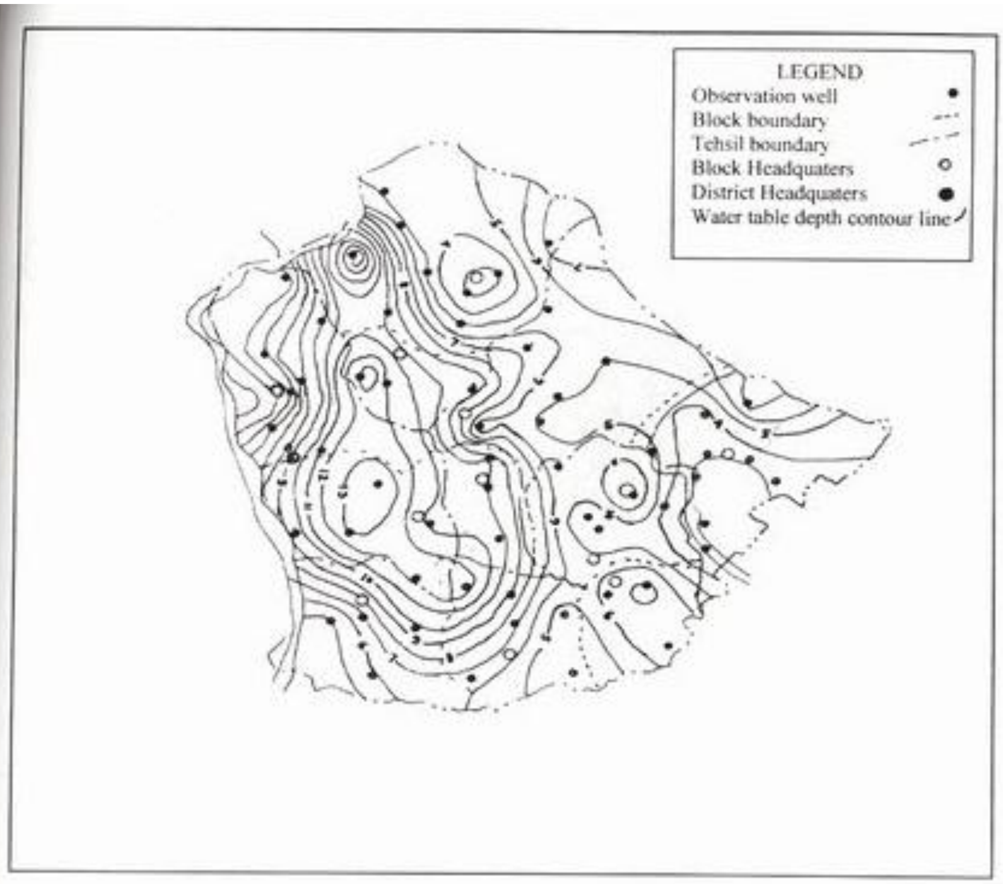


Fig. 4.2. Pre-monsoon water table depth contour map for the year 2002.

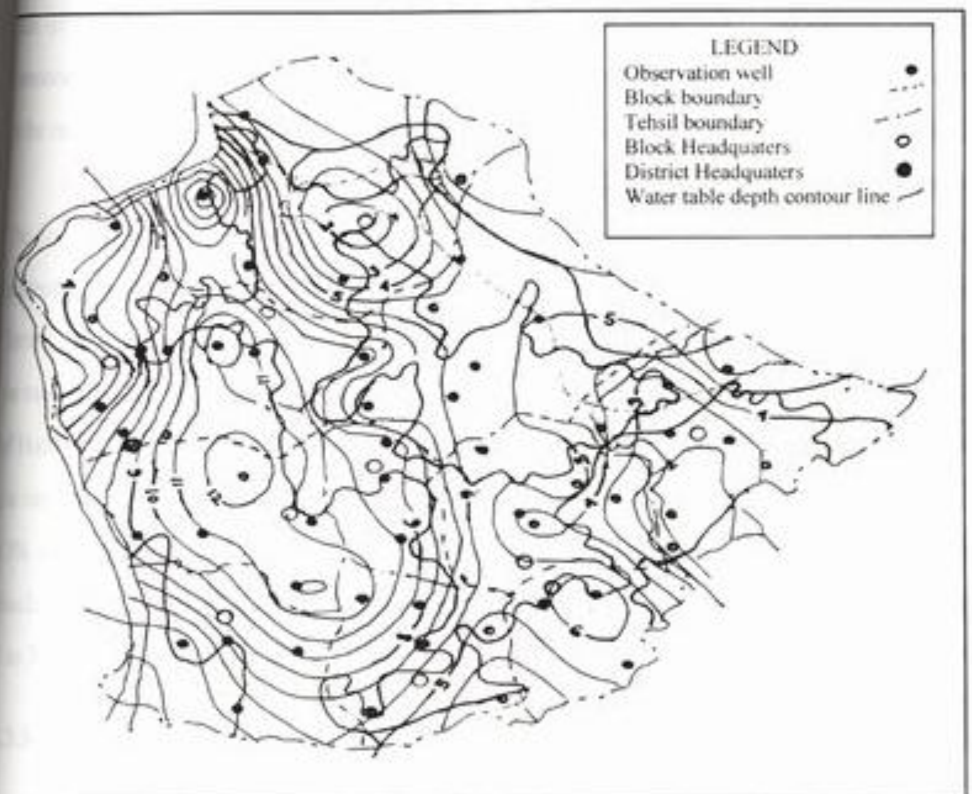


Fig.4.3. Post-monsoon water table depth contour map for the year 2002.

Water table variation (rise or fall in 20 years' period) contour maps were prepared for the study area for the period 1983-2002. Pre-monsoon and post-monsoon water table depth variations during the 20 years are shown in Figs. 4.4 and 4.5**,** respectively. From the pre-monsoon water table variation (Fig. 4.4) it was found that water table declined by 2 to 9 m in Haldaur, Nahataur, Dhampur, Kotwali, Jaleelpur and Noorpur blocks. In some parts of Nazibabad, Seohara and Noorpur blocks water table declined below 1 m. Post-monsoon water table depth variation during 20 years' period (Fig.4.5) was found to vary in the range of 2 to 4 m in Noorpur, Kotwali, Haldaur, Jaleelpur and Kiratpur blocks.

In this way, the areas having different water table decline depths were delineated. The distribution of area under different water table declining depths for the pre-monsoon and post monsoon season, as percentage of total area under different blocks, are shown in Tables 4.7 and 4.8 respectively. About 28% area was affected by water table decline in the range of 3 to 4 m in Kotwali block. Water table has declined by 3 to 9 m in 83% area of Haldaur block. About 5% area of Nazibabad block experienced water table decline in the range of 1-2 m. In case of post-monsoon season, water table declined by 3 to 4 m in 15% area of Noorpur, 20% area of Kotwali and in 10% area of Jaleelpur and Haldaur blocks. In 80% area of Kiratpur, Nahataur and Seohara blocks water table went down by 1 to 2 m.

4.3.3 Causes of Water Table Decline

The study of the statistical data revealed following causes, responsible for water table decline in Bijnor district.

Cropping pattern : A major portion of groundwater draft is utilized for agriculture purpose. Therefore, the existing cropping pattern plays a vital role in determining groundwater potential. The areas occupied by major crops (such as wheat, paddy, and sugarcane) as well as minor crops (such as maize, pulses, and oilseed) have been shown in Figs. 4.6 and 4.7. The sugarcane crop occupied the maximum cultivated area with an increasing trend from 160335 to 213205 ha. Table 4.9 shows that sugarcane production area has increased by 32% within the period 1990 to 2002. Wheat production area has

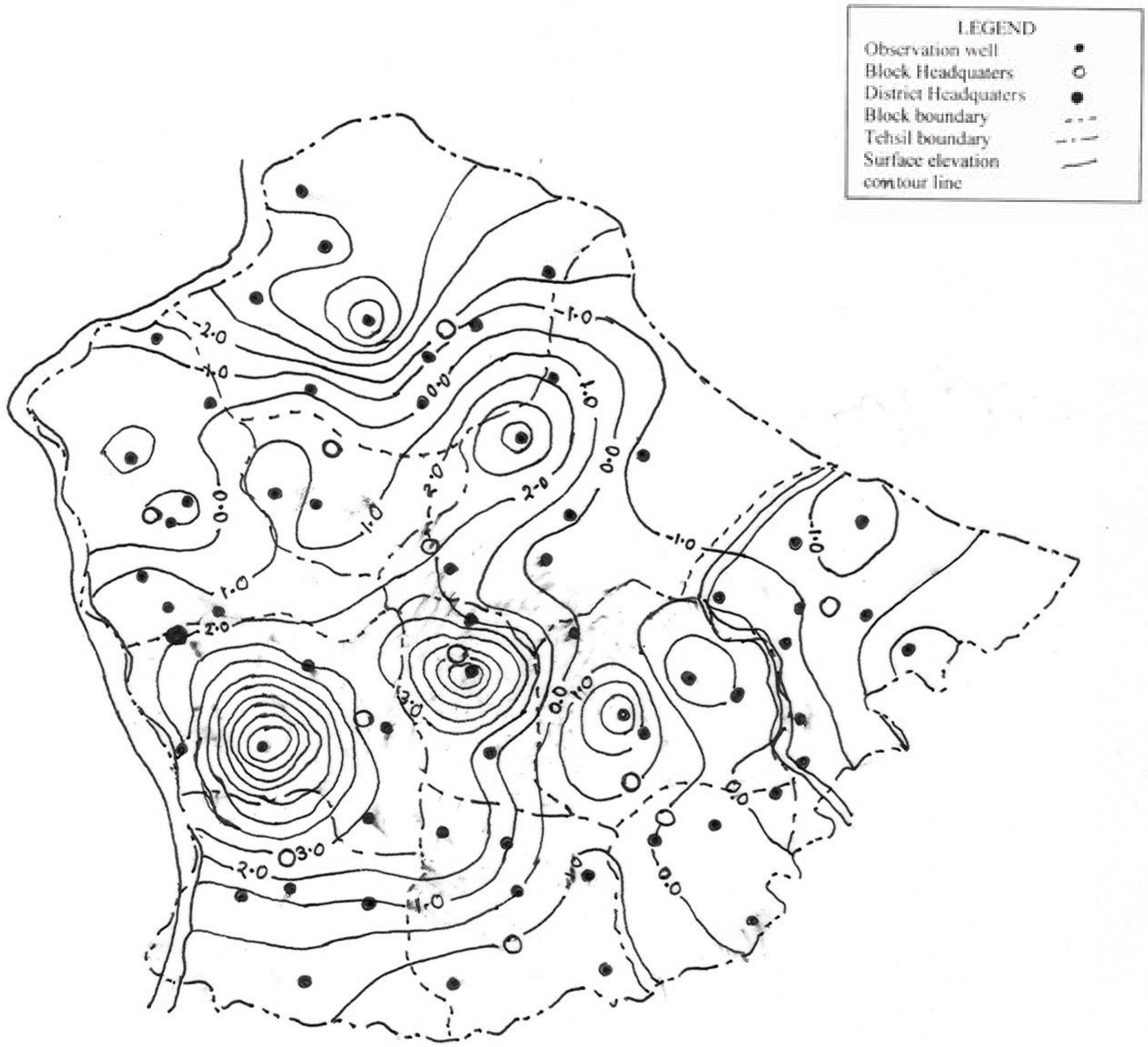


Fig. 4.4 Pre-monsoon rise or fall of water table in 20 years' period (1983-2002).

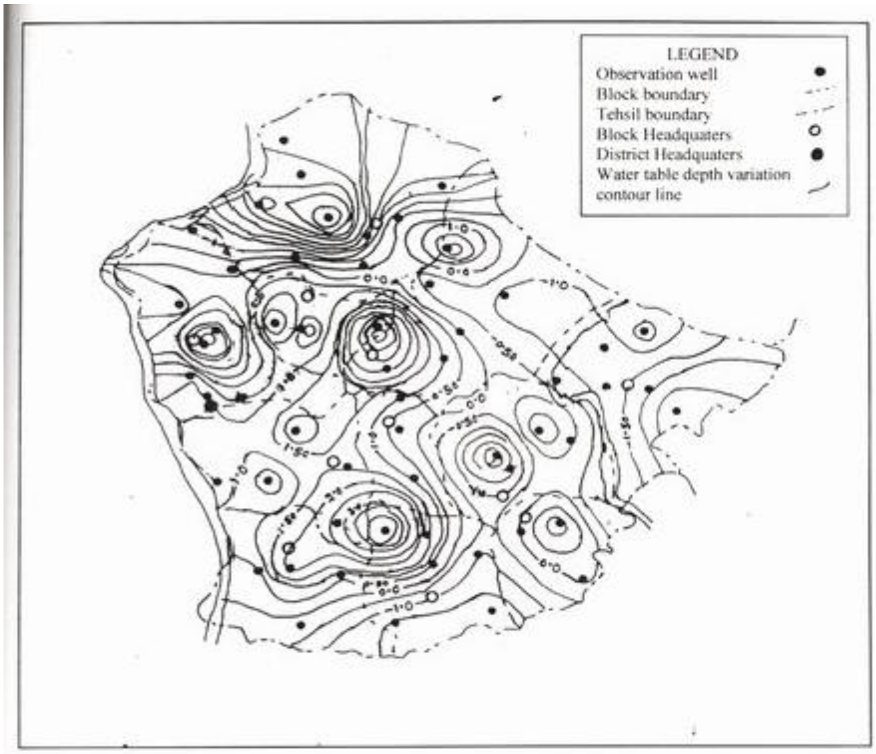


Fig. 4.5. Post-monsoon rise or fall of water table in 20 years' period (1983-2002).

Table 4.7. Block wise distribution of area (%) under different water table decline depths in pre-monsoon season.

Block	Percent of total area of the block facing the depth of water table decline (m) in the range					
	1-2	2-3	3-4	4-5	5-6	>6
Nazibabad	5	-	-	-	-	-
Kiratpur	86	-	-	-	-	-
Mohd.pur Deomol	56	-	-	-	-	-
Haldaur	-	10	45	16	10	12
Kotwali	22	11	28	-	-	-
Afzalgarh	60	-	-	-	-	-
Dhampur	34	20	-	-	-	-
Nahataur	-	-	34	12	-	20
Seohara	21	-	-	-	-	-
Jaleelpur	51	23	10	-	-	-
Noorpur	50	43	-	-	-	-

Table 4.8. Block wise distribution of area (%) under different water table decline depths in post-monsoon season.

Block	Percent of total area of the block facing the depth of water table decline (m) in the range		
	1-2	2-3	3-4
Nazibabad	10	-	-
Kiratpur	80	10	5
Mohd.pur Deomol	45	-	-
Haldaur	70	15	10
Kotwali	50	20	20
Afzalgarh	5	-	-
Dhampur	10	-	-
Nahataur	80	-	-
Seohara	80	-	-
Jaleelpur	60	20	10
Noorpur	65	10	15

Table 4.9. Percent variation in the area under major crops in the district during 1990-2002.

Block	Rice		Change	Wheat		Change	Sugarcane		Change
	1990	2002	(%)	1990	2002	(%)	1990	2002	(%)
Nazibabad	8332	7570	-9.15	13124	10280	-21.67	11636	19316	66.00
Kiratpur	4610	4410	-4.34	7639	8054	5.43	14721	15229	3.45
Mohd.pur	3950	4010	1.52	11934	10956	-8.20	15876	21062	32.67
Haldaur	3434	2342	-31.80	12520	13323	6.41	18522	22031	18.95
Kotwali	10676	11890	11.37	17627	12399	-29.66	16312	29729	82.25
Afzalgarh	9236	15245	65.06	15082	12590	-17.79	10322	15525	50.41
Nahataur	5023	4690	-6.63	6901	7373	6.84	14845	14239	-4.08
Dhampur	3831	4910	28.16	6584	6736	2.31	9321	18459	98.04
Seohara	3431	4355	26.93	7387	6643	-10.07	12812	13006	1.51
Jallelpur	4312	2841	-34.11	12659	15554	22.87	18985	23056	21.43
Noorpur	5389	4296	-20.28	11579	13233	14.28	16983	21556	26.93
Total District	62224	66559	6.97	123036	116950	- 4.95	160335	213205	32.97

Table 4.10. Percentage change in the area under minor crops in the district during 1990-2002.

Block	Pulses		Change	Oilseed		Change	Millet		Increase
	1990	2002	(%)	1990	2002	(%)	1990	2002	(%)
Nazibabad	1581	801	-49.336	3575	1196	-66.545	98	13	-86.73
Kiratpur	891	459	-48.485	406	131	-67.734	155	9	-94.19
Mohd.pur	700	400	-42.857	2735	882	-67.751	184	9	-95.11
Haldaur	643	571	-11.198	1020	168	-83.529	182	7	-96.15
Kotwali	2689	1485	-44.775	1607	621	-61.357	133	33	-75.19
Afzalgarh	1664	567	-65.925	1185	259	-78.143	1051	96	-90.87
Nahataur	556	370	-33.453	90	81	-10	54	11	-79.63
Dhampur	1346	484	-64.042	224	127	-43.304	123	24	-80.49
Seohara	585	262	-55.214	131	52	-60.305	93	12	-87.10
Jallelpur	656	413	-37.043	408	223	-45.343	268	9	-96.64
Noorpur	978	581	-40.593	370	171	-53.784	49	10	-79.59
Total District	12289	6393	-47.978	11751	3911	-66.718	2390	233	-90.25

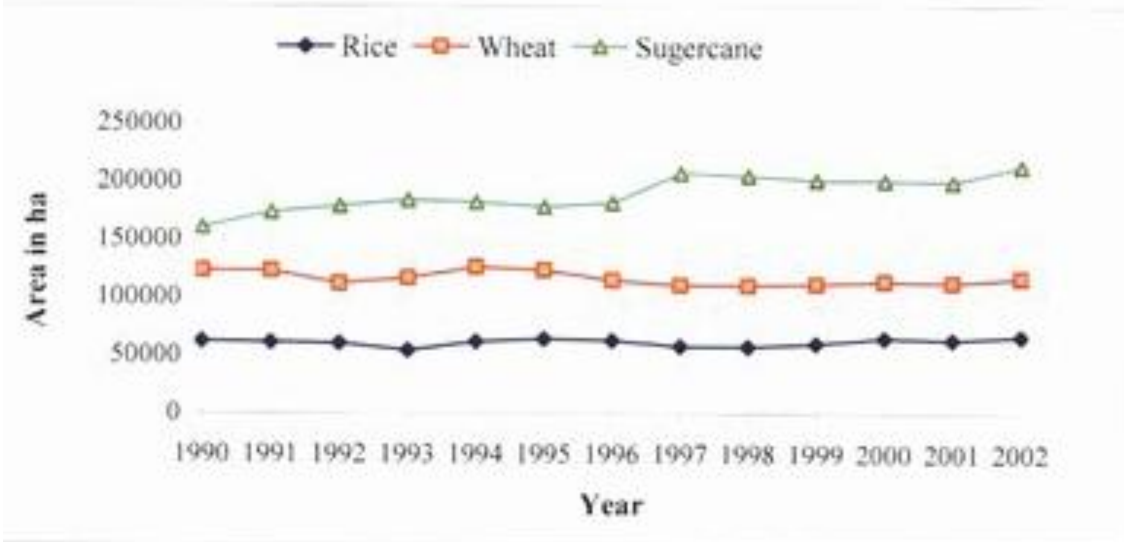


Fig. 4.6. Yearly variation in the area under major crops in Bijnor district.

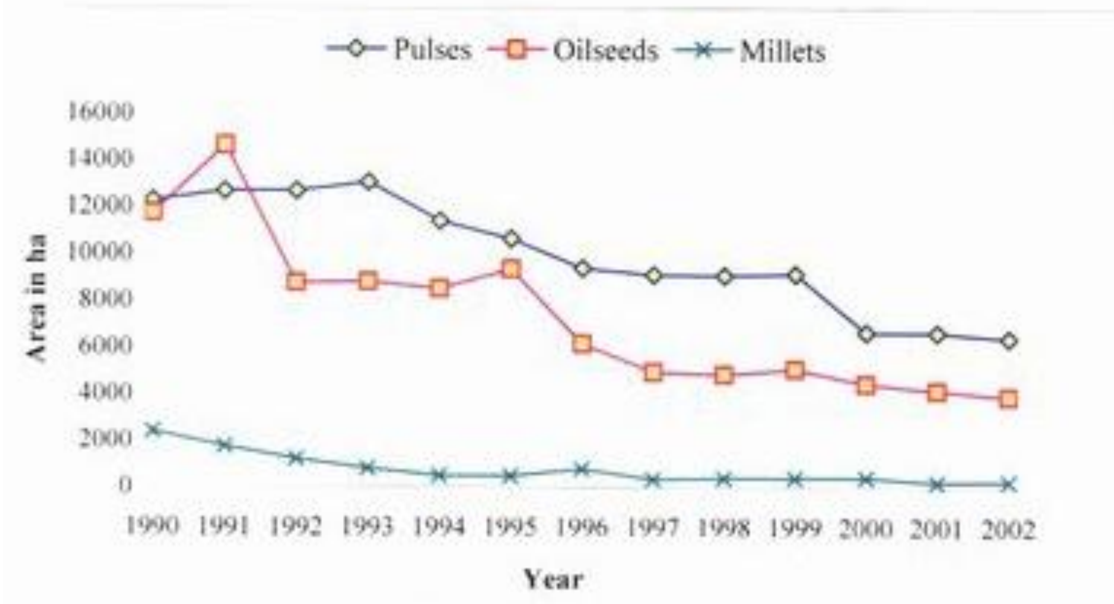


Fig. 4.7. Yearly variation in the area under minor crops in Bijnor district.

decreased slightly but rice growing area has increased. In relation to that millets, oilseeds and pulses producing areas have decreased severely.

From the above study it is clear that the areas under maize, pulses and oilseed are much less as compared to areas covered by sugarcane, wheat and paddy. Sugarcane is the dominating crop in the district. Cultivation of high water demanding crops like sugarcane, rice, summer vegetables etc. results in the decline of water table.

Minor irrigation structures : Variation in the number of minor irrigation structures, in the study area, for the period 1990 to 2002 is shown in Fig 4.8. From the figure it is clear that number of Government tubewells remained more or less constant during the study period. A moderate increase was observed in the number of private tubewells. A continuous and fast increasing trend was observed in the number of pumpsets in the district. This may be due to poor and uncertain electricity supply that creates uncertainty to the farmers, forcing them to install oversized pumps in large numbers. This increment in the number of pumpsets, in the study area, caused rapid declination of water table.

Area irrigated by canals and tubewells : Area irrigated by canals, tubewells and pumping sets is shown in Fig 4.9. Canal irrigated area remained the same whereas area irrigated by tubewells and pumpsets showed an increasing trend. Reduction in canal irrigated area not only minimizes the recharge opportunity in that area but also increases the load on groundwater reservoir.

4.4. GROUNDWATER INVENTORY

Groundwater inventory was prepared, for the district, for the years 1990 and 2002. By estimating net recharge and net discharge, groundwater exploitation level was interpreted during the period 1990-2002. Blockwise net recharge, net discharge and stage of groundwater development for the years 1990 and 2002 are shown in Tables 4.11 and 4.12, respectively. From the Table 4.11, it is quite clear that groundwater status was satisfactory in the year 1990, when most of the blocks in the district were under white category that means

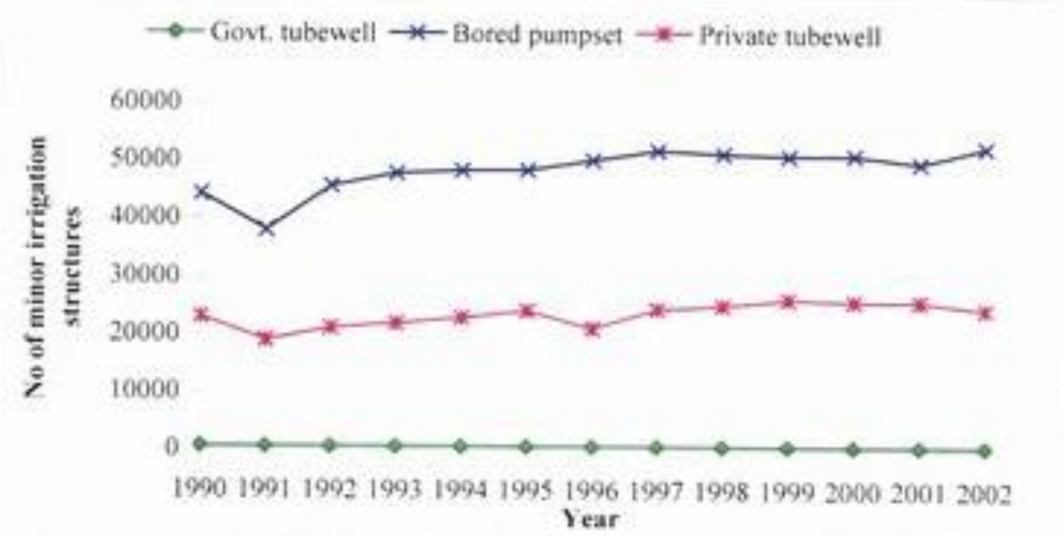


Fig. 4.8. Variation of minor irrigation structures number with time in Bijnor district.

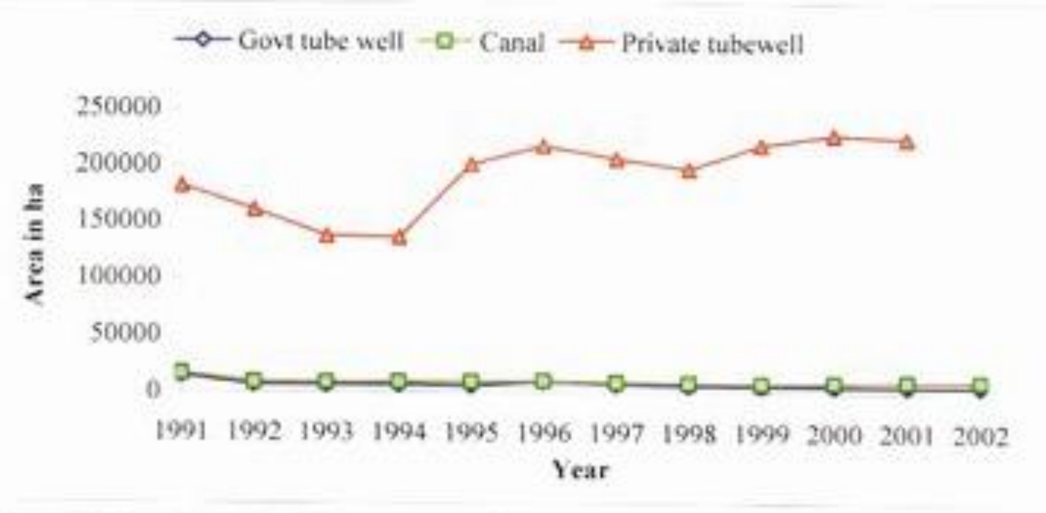


Fig. 4.9. Variation in irrigated area by minor irrigation structures with time in Bijnor district.

groundwater exploitation was below 65%. Only the Noorpur block was in grey category where groundwater exploitation level was within 65% to 85%. The maximum net recharge of 19245.44 ha-m was found in Nazibabad block whereas minimum recharge of 8997.39 ha-m was found in Kiratpur block. Similarly maximum and minimum discharge values were observed to be 9365.25 ha-m and 4705.56 ha-m in Jaleelpur and Nahataur blocks, respectively. The maximum groundwater balance was observed to be 11981.72 ha-m during the year 1990 in Nazibabad block. During this year, except Noorpur block other ten blocks were safe for further groundwater development in the area. But due to indiscriminate use of groundwater reservoir the picture changed during the year 2002. Groundwater inventory for the year 2002 clearly shows the over-exploitation feature of the district. The maximum and minimum net recharge values were found to be 19426.44 ha-m and 9821.81 ha-m in Nazibabad and Nahataur blocks, respectively. In this year the maximum and minimum groundwater discharge values were found to be 12844.90 ha-m and 6453.90 ha-m in Jaleelpur and Nahataur blocks, respectively. In Nazibabad block maximum groundwater balance was observed to be 9463.91 ha-m. In the year 2002, Kiratpur, Dhampur, Seohara and Nahataur blocks were under grey category. Jaleelpur and Noorpur blocks were under dark category where groundwater exploitation was more than 85% of the net recharge.

The study of groundwater inventory reveals that in year 1990 the status of groundwater was satisfactory, as most of the blocks were safe for groundwater exploitation. But in the year 2002 the scenario changed, so far when out of 11 blocks two (Jaleelpur and Noorpur)blocks were under dark category and four blocks (Kiratpur, Nahataur, Dhampur and Seohara) were under grey category. That means regional imbalance has been created in the areas having higher abstraction than recharge. Maximum groundwater draft was found in Jaleelpur block where abstraction structures increased rapidly by 31% with 21% increase in wheat and sugarcane production area. Similar was the case in Noorpur block where bored pumpset and private tube wells had been increased by 46% and 31%, respectively, resulting in a net groundwater draft of 12751.52 ha-m. The study also suggested that to retard the rate of declining water table,

Table 4.11. Groundwater inventory of Bijnor district for the year 1990.

Sl.	Block	Net recharge (ha-m)	Net draft (ha-m)	Groundwater balance (ha-m)	Stage of Groundwater development (%)	Category
1.	Nazibabad	19245.44	7263.71	11981.72	37.74	White
2.	Kiratpur	8997.40	4807.86	4189.53	53.44	White
3.	Mohd.pur	15859.27	6625.84	9233.43	41.78	White
4.	Haldaur	13393.93	5320.83	8073.10	39.73	White
5.	Kotwali	18402.84	8075.09	10327.75	43.88	White
6.	Afzalgarh	14680.38	5808.60	8871.78	39.57	White
7.	Nahataur	9730.30	4705.56	5024.74	48.36	White
8.	Dhampur	14240.18	8416.88	5823.30	59.11	White
9.	Seohara	10323.32	5606.77	4716.55	54.31	White
10.	Jaleelpur	14772.58	9365.26	5407.33	63.40	White
11.	Noorpur	12807.14	9297.18	3509.96	72.59	Grey

Table 4.12. Groundwater inventory of Bijnor district for the year 2002.

Sl.	Block	Net recharge (ha-m)	Net draft (ha-m)	Groundwater balance (ha-m)	Stage of Groundwater development (%)	Category
1.	Nazibabad	19426.44	9962.53	9463.91	51.28	White
2.	Kiratpur	9082.02	6594.21	2487.80	72.61	Grey
3.	Mohd.pur	16008.43	9087.66	6920.77	56.77	White
4.	Haldaur	13519.90	7297.77	6222.13	53.98	White
5.	Kotwali	18575.92	11075.16	7500.54	59.62	White
6.	Afzalgarh	14818.45	7966.78	6851.67	53.76	White
7.	Nahataur	9821.82	6453.90	3367.91	65.71	Grey
8.	Dhampur	14374.11	11544.16	2829.95	80.31	Grey
9.	Seohara	10420.42	7689.96	2730.46	73.80	Grey
10.	Jaleelpur	14911.52	12844.90	2066.62	86.14	Dark
11.	Noorpur	12927.59	12751.52	176.06	98.64	Dark

water table monitoring, artificial recharge, water harvesting and proper water use planning must be implemented in the area.

4.5 GROUNDWATER MODELLING

4.5.1 Scope of Groundwater Modelling in the Present Context

Groundwater modelling helps to determine possible trends in groundwater withdrawal, depending on the overall physical and hydro-geological factors being taken into account, through an integrated empirical approach. In the present context an appropriate representation of trend of water table fluctuation incorporating various inflow, outflow and hydro-geological characteristics would provide a reasonable prediction of future trend of water table based on present increase in withdrawal rate.

4.5.2 Development of Groundwater Simulation Models for Bijnor District

For the groundwater modelling of the Bijnor district following multiple regression models were tried for the prediction of depth to water table below ground level, Y and evaluated for their performance:

Model 1: $Y = a + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$ …. (4.1)

Model 2: $Y = b + b_1R + b_2D$ ….(4.2)

Model 3: $Y = c + c_1R + c_2D + c_3R^2 + c_4D^2$ …. (4.3)

Model 4: $Y = d + d_1R + d_2D + d_3R^2 + d_4D^2 + d_5R^3 + d_6D^3$ ….(4.4)

Model 5: $Y = e + e_1R + e_2D + e_3R^2 + e_4D^2 + e_5R^3 + e_6D^3 + e_7R^4 + e_8D^4$ …(4.5)

Model 6: $Y = f + f_1R + f_2D + f_3R^2 + f_4D^2 + f_5R^3 + f_6D^3 + f_7R^4 + f_8D^4 + f_9\ln(R) + f_{10}\ln(D)$ …(4.6)

where Y = depth to water table below ground level,

x_1, x_2 and x_3 = different recharge components,

$x_4 = D$ = total groundwater discharge,

$R = x_1 + x_2 + x_3$ = total groundwater recharge,

$a, a_1, a_2, \ldots f_9, f_{10}$ = regression constants.

4.5.3 Model Inputs

To determine the water table depth, recharge and discharge as input data to the above mentioned models were estimated as discussed in the previous sections. For Model 1 various recharge components and total discharge for different years were put to equation (4.1) to estimate the water table depth of a particular node. For the rest of the models total recharge and total discharge in the pre-monsoon and post-monsoon season were considered to fit to the models accordingly. The recharge data of various years did not show any definite trend as rainfall is the major source of recharge and it varies from year to year. Whereas node wise discharge data has an increasing trend in every year due to increase in demand for groundwater to meet the requirement of water for irrigation, industries, human and livestock population.

PERFORMANCE OF MODELS

Models 1 and 2 are the simple linear regression models as represented by straight line. Models 3, 4, 5 and 6 are curvilinear regressions, and are represented by polynomials. Among the models, the best-fit regression equation that would be appropriate for any given set of data can be judged from their correlation coefficient values. The correlation coefficient values of each model when plotted in graph for every node season wise (Figs. 4.10 and 4.11) showed that Model 6 has higher correlation coefficient value in both the pre-monsoon and post-monsoon seasons. Model 1 and Model 2 have low correlation coefficient for any node. This may be because that there is no linear relationship between depth to

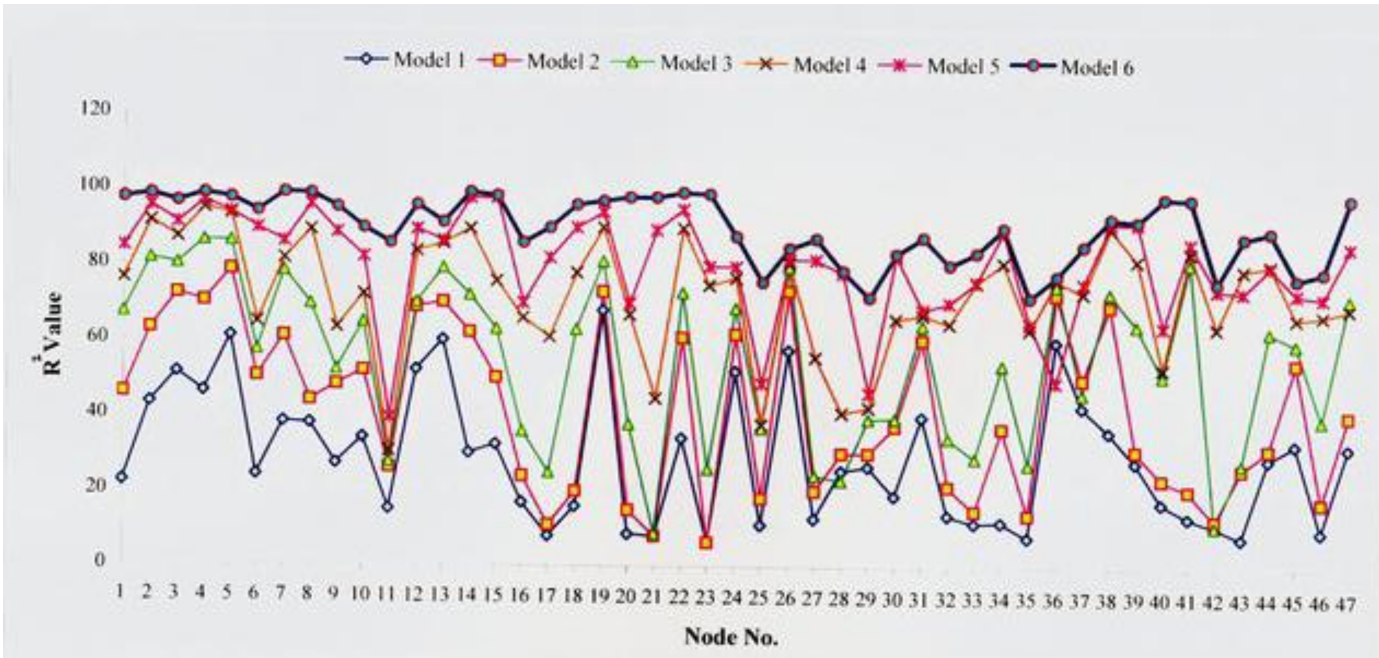


Fig. 4.10 Variation of correlation coefficient for all six prediction models for pre-monsoon season.

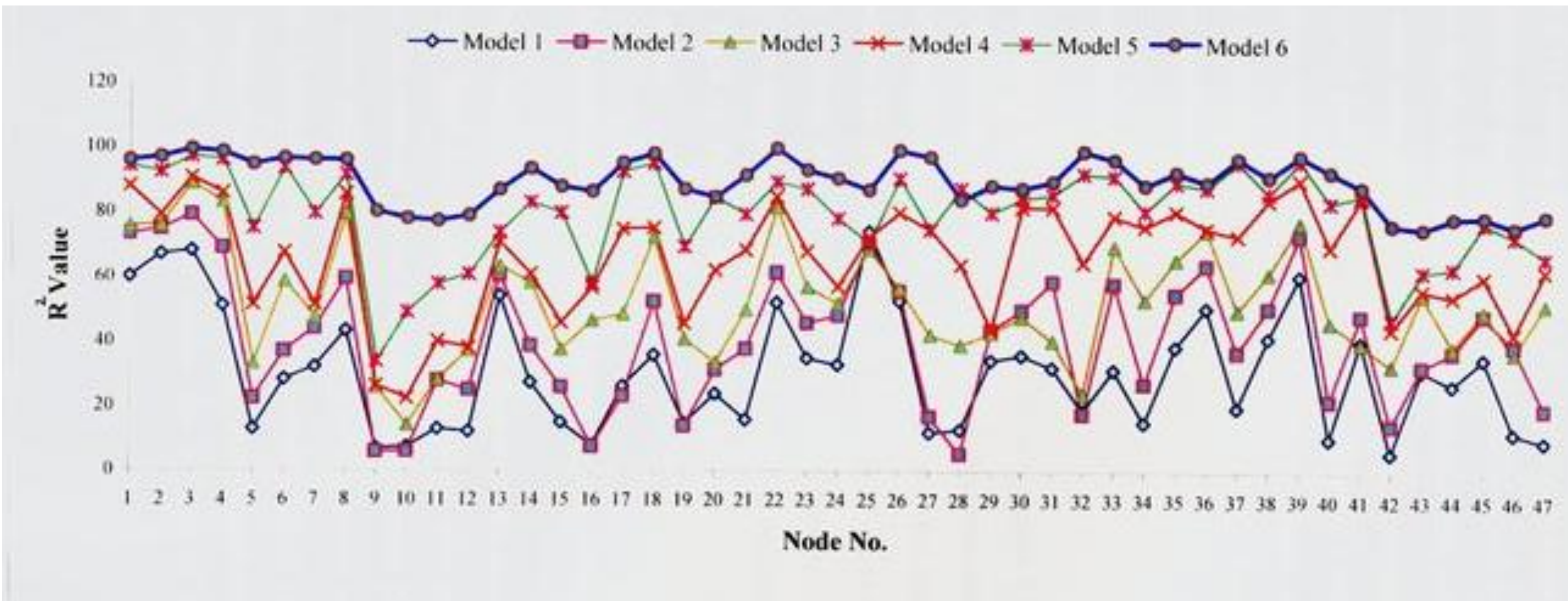


Fig.4.11 Variation of correlation coefficient for all six prediction models for post-monsoon season.

water table, and the recharge and discharge parameters but a curvilinear one. So, Models 3, 4, 5 and 6 gave better results than Models 1 and 2. Model 6 was the best fit model which correlate the independent variable (Water table depth) to the dependent variables (Recharge and Discharge) in a relatively better manner, showing higher correlation coefficient than Models 3, 4 and 5.

4.6.1. Sample Output

The listing of sample input is given in Appendix C-3. As the Model 6 gave the best correlation coefficient value for all the nodes considered, it has been considered as the best fit model to predict the water table depth. For clear the regression coefficient values obtained for different models for node 14 are shown in Fig. 4.12. The model was fit to the observed data of node 14 for the pre-monsoon and post-monsoon seasons separately. For the same node i.e. node 14, observed and predicted water table depths are shown in Fig.4.13. The results show fairly good agreement between the observed and predicted values.

4.7 APPLICATION OF MODEL FOR FUTURE PREDICTION

In the similar way, Model 6 was used to test the goodness of fit for the prediction of water table depth for the remaining nodes. Water table depths predicted by the above model and the observed values are shown in Appendix C-4. The predicted values of depths to water table bgl were in fairly good agreement with the observed values for every node. The model gave good results in nodes 4, 5, 7, 12 with a variation of $\pm$ 1% in predicted values whereas it gave moderately good results in nodes 6, 9, 11, 24, 29 with a variation of 15% in predicted values. For the rest of the nodes the results were satisfactory.

Thus the water table depth, for the study area, can be fairly well predicted by applying the Model 6. The model can be utilised for predicting useful information for other years also with the help of “Data Analysis” programme software of Microsoft

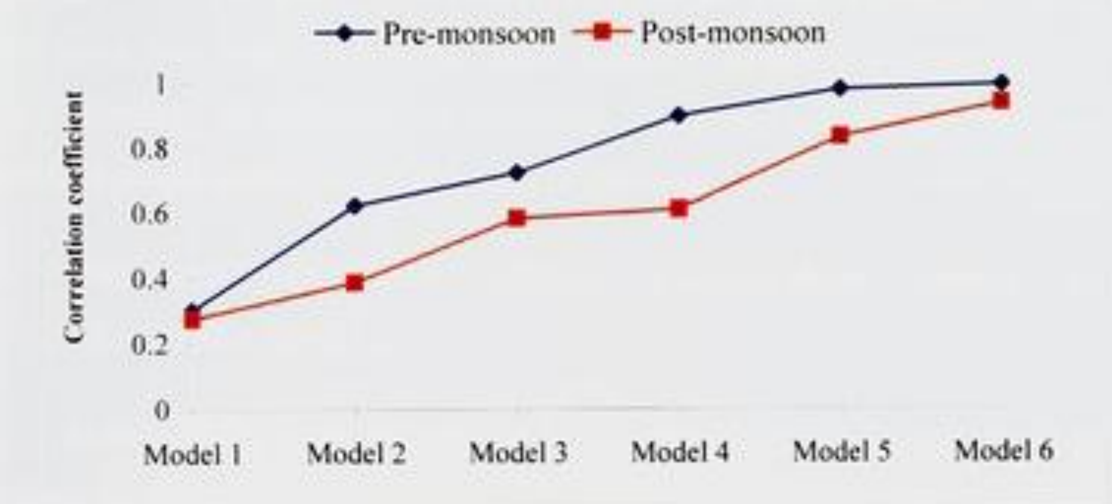


Fig. 4.12. Variation of correlation coefficient value for all the six models in pre-monsoon and post-monsoon season for node 14 .

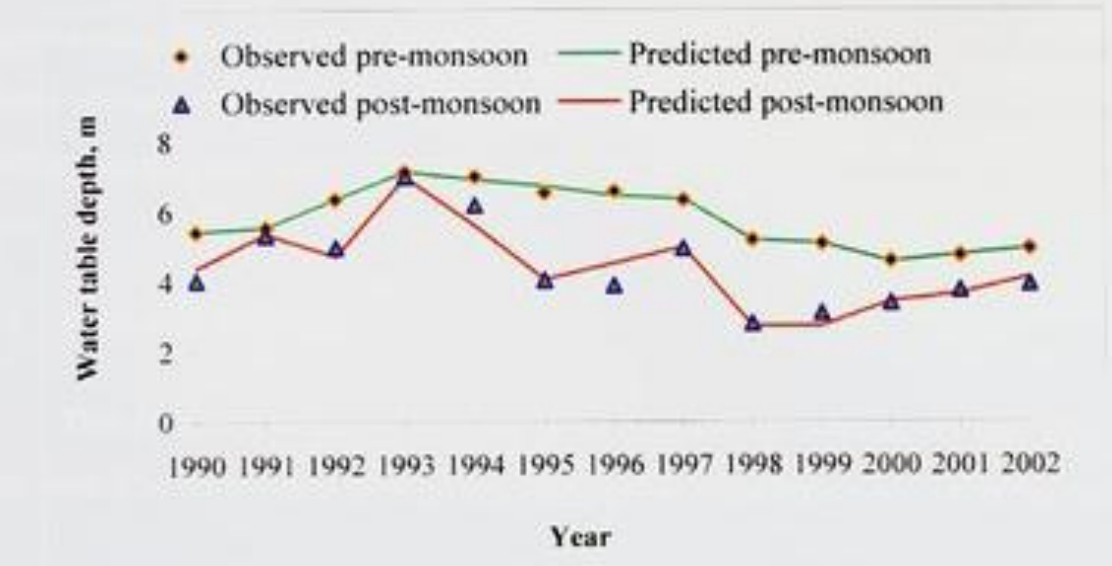


Fig. 4.13. Observed and Predicted values of depth to water table in different years for node 14 using model 6.

Excel, if values of recharge and discharge parameters are known. The accuracy of prediction would depend on the accuracy of the input data.

4.8 DELINEATION OF VARIOUS LANDFORMS USING REMOTE SENSING AND G.I.S.

In the present study, different types of landforms have been delineated for hydro-morphological study of Bijnor district. Fig.4.14 depicts the entire Bijnor district in false colour composite (F.C.C.). The upstream area like upper and lower piedmont areas, lying in the upper part of the district are also shown in the F.C.C. image because the geo-hydrology is directly linked with northern parts of the study area and fluvial action of rivers. The image is well superimposed with block and district boundaries of the study area. The textural and tonal differences can easily be seen by visual interpretation of the image varying from one block to another. Thematic map, for different landforms showing various colour schemes of the study area was prepared (Fig. 4.15). Four landforms were identified in the study area. The geomorphic details of these landforms are described as below.

4.8.1 Piedmont Plain (P)

This is the transition zone lying at the junction of Siwalik hill and plain of the study area. The landform is divided into three geo-morphological units as given below:

Upper Piedmont plain (P1): This geo-morphological unit is located in upper most zone of the study area, extending from north-east to north-west of the district under Nazibabad, Afzalgarh and Kotwali blocks (Fig. 4.15). Unconsolidated sediments with variable runoff and infiltration characterize it. Depth to water table is also varying from shallow to deep. In upper and lower piedmont zones, a number of buried and abandoned channels is found due to regular and frequent changing of flow direction of different riverlets. The groundwater prospect is high along buried and abandoned channels.

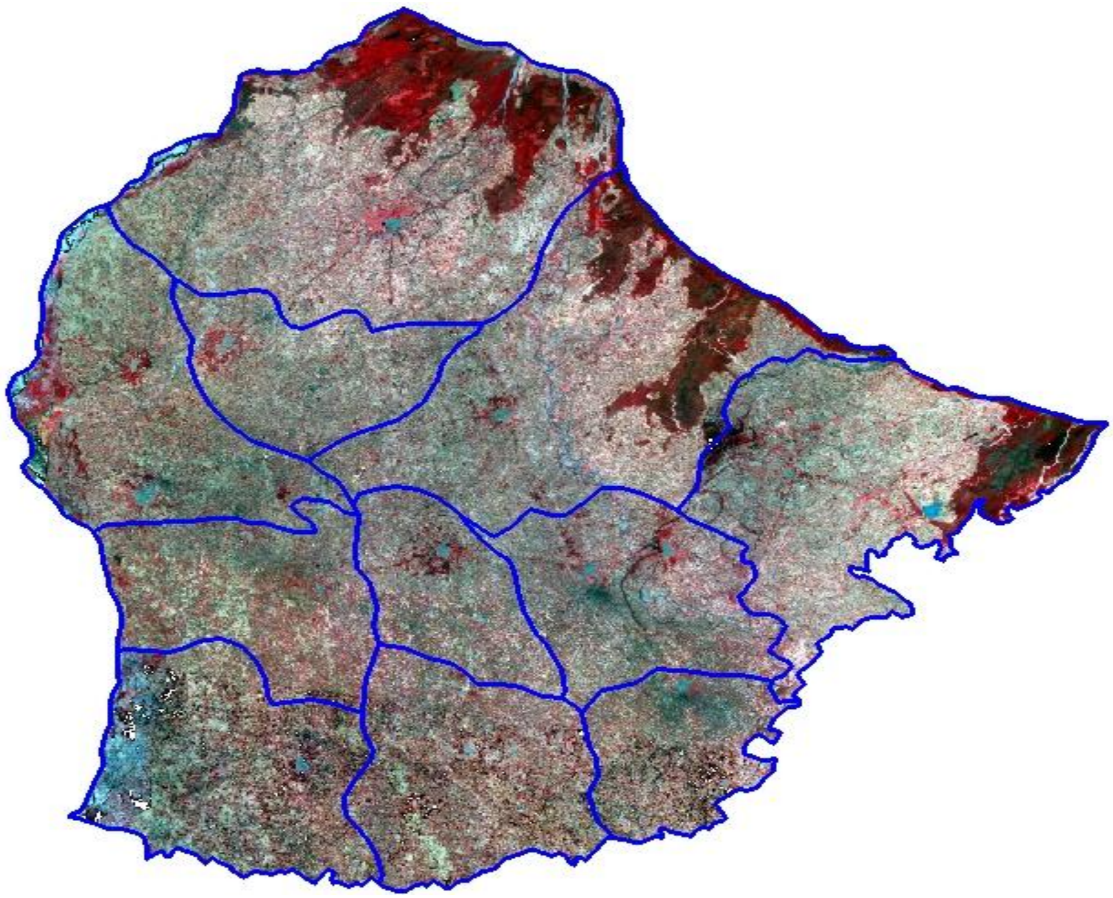


Fig. 4.14 False Colour Composite (FCC) of Bijnor district after superimposing block boundary.

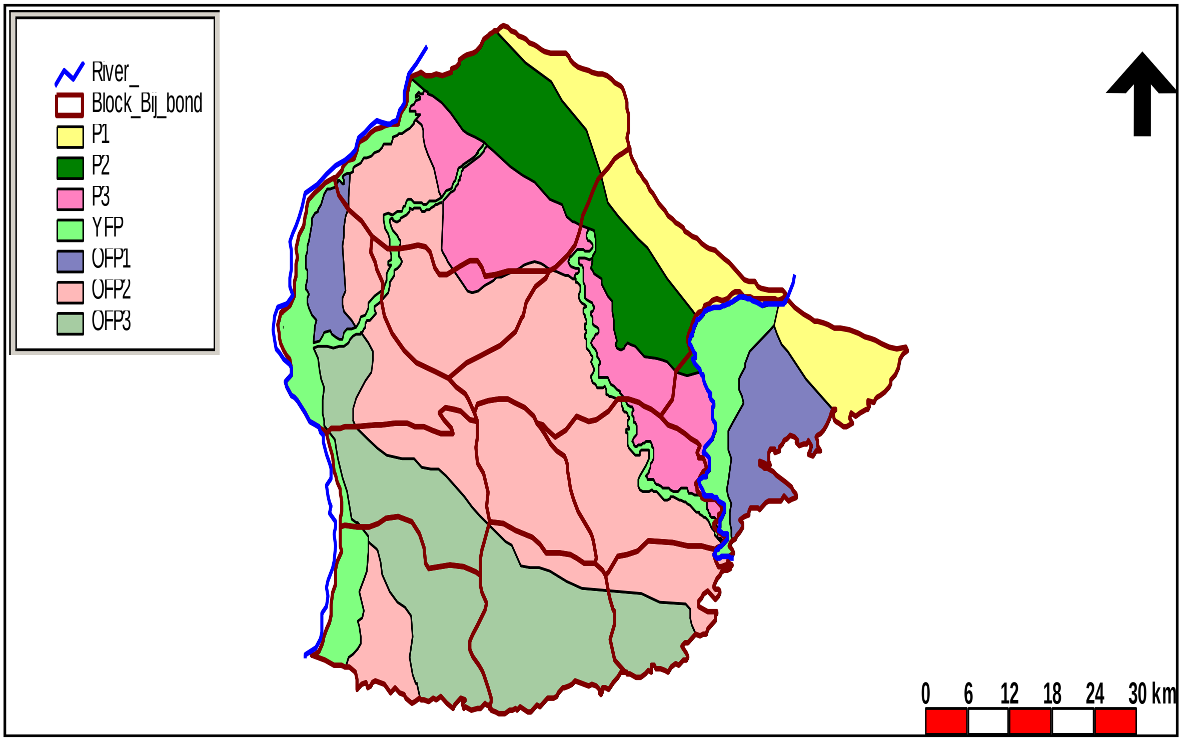


Fig. 4.15. Landforms identified in different blocks of Bijnor district.

Lower Piedmont plain (P2)**:** It is located in Nazibabad and Kotwali blocks of Bijnor district just south of upper piedmont zone lying in north-east region of the district. The geo-morphological characteristics of the unit are by and large similar to upper piedmont landform, except altitude and slope, which is relatively low. The zone has equally groundwater prospects varying from shallow to deep.

Piedmont flood plain (P3): It is also known as transitional plain between piedmont and flood plain lying under Nazibabad, Kotwali, Dhampur and Afzalgarh block of Bijnor district. The unit is frequently visited by flood from upland runoff during monsoon season. The geo-morphological feature is similar to other flood plains. The prospect of groundwater is very high; somewhere the depth to water table in the unit is quite shallow.

4.8.2 Young Flood Plain (YFP)

The young flood plain was identified at either side of river courses. The sand content and depth of sand layer in the area are comparatively medium to high (Fig. 4.15). The study area has been divided into two geomorphic units depending upon the sand content:

Mixed sand and silt dominated young flood plain (YFP-1)**:** Such unit is concentrated in small patches along the riverlets flowing in upper piedmont, lower piedmont and transitional plains in Nazibabad, Afzalgarh, Dhampur, Mohd.pur Deomol, Haldaur, Jaleelpur and Seohara blocks. The percentage of sand and silt contents varied from one patch to another.

Sand dominated young flood plain (YFP-2): This is sand dominated landform. It extends from Nagal in Nazibabad block along the Ganga river. The depth and width of the unit vary from place to place. The width of landform along river Ramganga is broad. The groundwater prospect of this unit is high due to presence of high percentage of sand contents.

4.8.3 Old Flood Plain (OFP)

This type of geomorphic unit is known as older upper alluvial plain because such plains do not come under active flood plain. It means a larger area between the Ganga and Ramganga rivers falls under the category of old flood plain. This landform has been classified into three geomorphic units as below:

Sand dominated old flood plain (OFP-1): This is sand dominated geomorphic unit of old alluvial landform. Fig. 4.15 shows the geomorphic unit having dominating sand content after Young Flood Plain. This unit is concentrated in small patches along the river Ganga of Mohd.pur Deomol block and in Afzalgarh block. The prospect of groundwater is sufficient but the unit is better to convert the underlying hydrological strata.

Silt dominated old flood plain (OFP-2)**:** This is a geomorphic unit of old upper alluvial landform having high silt proportion in surface textural morphology (Fig. 4.15). Such type of landform exits in upland portion of the Bijnor district. It spreads over Nazibabad, Mohd.pur Deomol, Kiratpur, lower part of Kotwali, Haldaur, Nahataur, Dhampur, Seohara and some parts of Jaleelpur block. Such landform needs attention for developing recharge structures to sustain the prospect of groundwater in future.

Old flood plain with mixed sand and silt (OFP-3)**:** The main constituent of the unit is sand and silt, the proportion of the sand and silt varies from one part to another. This landform prevails in the Mohd.pur Deomol, parts of Haldaur block, Jaleelpur, Noorpur and Seohara block.

4.8.4 Fluvial Landforms

Various kinds of geomorphic features, formed either sides of river by fluvial action of river, are known as fluvial landforms e.g. channel bar, channel island, point bar, river terrace, natural levee, back swamp, palaeochannel and buried channel. Palaeochannels are ramnants of stream/river, appear as buried or abandoned channels. They are found in Kiratpur and Dhampur blocks. These features possess a good promising zone for shallow aquifer with excellent groundwater yield.

4.9 STRATEGY FOR ARTIFICIAL GROUNDWATER RECHARGE

Augmentation of water in the underground reservoir by artificial means is nothing but groundwater recharge as defined earlier. Planning for groundwater recharge in any problematic area may include measures to reduce groundwater draft and increasing recharge through various methods. From the fore-going discussion it is evident that in respect of declining groundwater table, the problematic areas were identified in most of the blocks of Bijnor district except few pockets of Nazibabad, Dhampur and Seohara blocks. Thus for proper groundwater recharge planning, it is imperative to study in detail the delineation of various landforms and their hydro-geomorphic characterization, water table behaviour under various soil associations, the trends of adoption of various cropping patterns in the problematic zone, and the need to monitor in terms of changing water requirements.

4.9.1 Groundwater Table Decline under Various Soil Associations

To have a proper groundwater resource planning, demarcation of the problematic areas for artificial groundwater recharge in future is very necessary. As recharge also depends on soil characteristics of that area, soil association of the area is also very important factor to consider. Keeping this in view, the areas having different water table decline depths were delineated under different soil associations by superimposing the soil association map on water table decline contour maps, depicted in Fig. 4.16.

In Table 4.13 all the blocks of the district have been distributed according to water table decline depths under various soil associations. The maximum decline of water table was recorded in Fulsunda-Fazalpur-Kheda (B), Kheda - Fazalpur (C) and Nagina-Daulatpur-Kharee (D) soil associations where it varied upto 9 m.

Table 4.13. Water table decline in pre-monsoon season in different blocks along with the soil associations of Bijnor district.

Soil Association	Blocks	Water table decline (m)
A	Seohara, Noorpur, Dhampur, Afzalgarh	0 to 2
B	Noorpur, Nahataur, Dhampur, Kotwali, Nazibabad, Kiratpur, Afzalgarh	0 to 6
C	Jaleelpur, Haldaur	1 to 6
D	Jaleelpur, Noorpur, Nahtaur, Haldaur, Mohd.pur Deomol	0 to 9
E	Nazibabad, Kiratpur, Kotwali, Dhampur, Afzalgarh	0 to 3

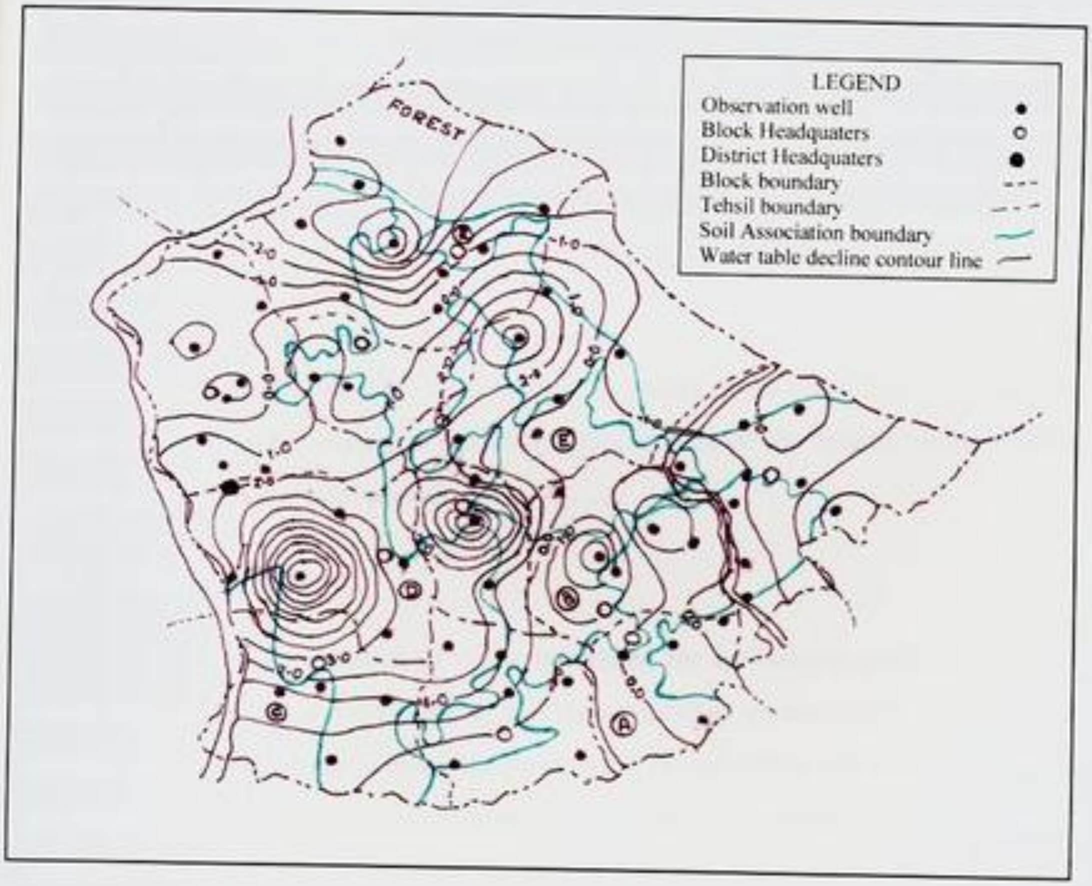


Fig. 4.16. Map of water table rise or fall, in pre-monsoon season, along with soil associations of the Bijnor district.

4.9.2 Water Table under Different Landforms

All identified landforms under the study area have been correlated with present situation of rise or fall of water table within 20 years (1983 – 2002). The area of block lying under the landforms, alongwith decline of depths to water table, is given in Table 4.14. The area lying under back swamp showed water table fluctuation from 0 to 5 m because the area would have been opportunity of flood, time and again. Besides, the situation of palaeochannels was also satisfactory as shown in the water table decline map. The area lying under Old Flood Plain-1 was having a water table decline range of 0 to 2 m and this landform comprises high percentage of sand contents. The maximum decline of water table observed to be about 9 m, was in OFP-2 and OFP-3 landform. Hence these areas need immediate recharge plan. Although some parts of the study area are experiencing no decline of water table, almost all blocks of the study area are facing the danger of groundwater mining or blocks would come under the mining situation if the present agriculture practices prevail.

4.9.3 Cropping Pattern

A major portion of water is utilized for agricultural purposes. In areas where topography is not favourable or monsoon rainfall is uncertain groundwater is the reliable source to meet the ever-increasing demand of agriculture and other purposes. In the Bijnor district a vast portion is occupied by the paddy and wheat crops along with the sugarcane crop. Paddy cultivation is said to be the main factor responsible for groundwater depletion. Sugarcane comes next to paddy. The requirement of high amount of water during their growth period has to be met out through groundwater abstraction. To save the groundwater resources from further depletion, it is necessary to diversify the cropping pattern, keeping in view the recharging pattern. The shifting of paddy and sugarcane cultivation to oilseeds and pulses cultivation would reduce the water table decline substantially. Thus there is an urgent need to change the prevailing cropping pattern.

Table 4.14. Blocks and water table decline under different landforms of the study area.

Landforms	Blocks	Water table decline (m)
P1	Northern part of Nazibabad, Afzalgarh, Kotwali	0 – 2
P2	Central part of Nazibabad, Kotwali	0 – 3
P3	Nazibabad, Kotwali, Dhampur,Afzalgarh	0 – 1
YFP	Nazibabad, Mohd. pur Deomol, Kotwali, Jaleelpur, Afzalgarh	0 – 3
OFP-1	Mohd.pur Deomol, Afzalgarh	0 – 2
OFP-2	Nazibabad, Mohd.pur Deomol, Kotwali, Kiratpur, Nahataur, Haldaur, Dhampur,Jaleelpur, Seohara	0 – 6
OFP-3	Mohd.pur Deomol, Haldaur, Jaleelpur, Noorpur, Seohara	0 – 9

4.9.4 Increasing Canal Irrigated Area

Only Kotwali, Nahataur, Dhampur and Seohara blocks are having canals. Total canal length available in these blocks is 12880 m with canal irrigated area of about 9874.4 ha. Therefore, increasing canal irrigated area is the prime need, which not only reduces the pressure on groundwater but also serves as potential source of recharge to the aquifer through seepage and return flow of irrigation water.

4.10 FEASIBLE RECHARGE MEASURES

Groundwater has several distinct advantages over surface water. It is less susceptible to fluctuations and can give uniform rate of supply that can be readily taken almost to the place where it is required. Considering the problems of the study area and the guidelines defined in Appendices A-1, A-2 and B-5, the following measures may be adopted for recharging the ground water aquifer.

4.10.1 Series of Check Dams on Natural Streams

In this system the artificial groundwater recharge is made to restrict the surface runoff through streams and by making additional water available for percolation. The surface water impounded during monsoon behind the structure spreads over the entire stream bed thereby increasing the wetted area. The impounded water helps in replenishment of groundwater. Therefore, a series of check dams can be constructed on a stream to recharge the depleted groundwater aquifers in the Nazibabad, Kotwali, and Dhampur blocks.

4.10.2 Percolation Tanks

In the present study, the OFP-1 and YFP-2 are highly suitable for percolation tanks because this landform contains high percentage of sand contents in the top soil. As shallow permeable strata are available, this landform is highly suitable for the construction of trenches across the slope. In the YFP and OFP-3, the silt content retards the infiltration rate, therefore, these areas should have the percolation tanks having more width and less depth.

4.10.3 Bunds, Trenches and Stream Modification

Construction of bunds in the field serves as water harvesting structure during scarcity period and recharging structure of groundwater aquifer. As the soils are almost sandy in the study area, the presence of bunds near cropped area would not create any waterlogged conditions. The construction of trenches in upper piedoment zone and in the riverside area of OFP-1 across the slope would enhance the recharge of the area.

Dug well recharge method can be powerful tool for the landform OFP-3 where the silt and clay contents in the upper surface are high. Under sub-surface practice, the existing dug wells may be utilized as recharge structures when filter materials or pebbles would properly back fill these wells. Few blocks in the study area have canals. Dredging flowing canals also increases the infiltration efficiency and wetted area. Most of the monsoon seasonal runoff flow remains useless due to improper recharge techniques. But putting permanent low check dams or constructing ditches/furrows across the slope can increase the recharge capability.

4.11 APPLICABILITY OF THE STUDY

The present study was taken up with a view to provide necessary information regarding the soil, present land use pattern and groundwater status of the Bijnor district. An attempt was made to simulate the groundwater behaviour so that future prediction of water table depth can be done for the water table declining zones. Using Satellite data, hydrogeo-morphological units were delineated to demarcate the ground water prospect zones. Existing problems relating declining water table were identified and possible measures were suggested to arrest further decline of water table in the study area.

Depending on the soil characteristics and existing landforms, different recharge structures have been suggested, which may be adopted for increasing the recharge or decreasing the groundwater draft. The study of present land use pattern can be used as a basis for further advancement in this field. The anticipated estimates for groundwater recharge and draft may be used as input parameters for the further study of the area. Above all, the ground water model discussed above and suggested measures for groundwater recharge may be useful for other problematic areas also.

5. SUMMARY AND CONCLUSIONS

There is no getting away from the fact that a substantial part of human sustenance would be based on land and water resources. Concerns of sustainability will call for regulation of the manner in which land and water resources are exploited. In order to achieve long term stability, it is crucial to focus on the management of resources of those areas where it is over-exploited. To protect groundwater and land resources from degradation, it is important to adopt suitable region specific management strategies. Use of Remote Sensing and G.I.S. will be helpful in such endevour. Keeping it in view, the present study was taken up to evaluate land and water resources of Bijnor district, to identify problematic areas where water table is continuously declining and to suggest suitable measures to overcome this problem.

5.1 STUDY AREA

The study area is roughly a triangular stretch of land occupying the north-west corner of the Moradabad Division. The river Ganga forms its western boundary beyond which lie the districts of Dehradun, Saharanpur, Muzaffarnagar and Meerut. The north and north-east portion is surrounded by the Garhwal district. The east boundary is marked by the Nainital, Udham Sing Nagar and Moradabad district; and the south by Moradabad and Jyotiba Phule Nagar districts. The district lies between east longitude of $78^0 0'$ and $78^0 57'$ and north latitude of $29^0 2'$ and $29^0 58'$. The entire study area comprises of 11 blocks and 5 tehsils.

5.2 SOIL CHARACTERIZATION

Based on morphological, physical and chemical characteristics of soils studied, their associated landscape features and field correlation of auger hole data, 6 soil series, namely Nagina, Daulatpur, Fulsunda, Kheda, Fazalpur and Kharee were identified. These soil series have been combined in the soil map into 5 soil associations.

The surface texture of all the soil series varied from loamy sand to clay loam, whereas in the subsoil texture it varied from clay to sandy loam. The soil profiles are well to moderately well drained. The sand content varied between 13.1 to 87.2%. All the soils are neutral to slightly alkaline. The dominant soil associations in the problematic area were identified as - Fulsunda-Fazalpur-Kheda (B), Kheda-Fazalpur (C) and Nagina-Daulatpur-Kharee (D) associations.

5.2.1 Land Capability Classification

The soils of Bijnor district have been classified as per land capability classification of A.I.S.L.U.S.O. (1970). Nagina, Fulsunda, Daulatpur and Kharee have been put under class II of land capability class. The soil series Kheda and Fazalpur have been put under class III. Daulatpur, Kheda and Fazalpur soil series have subclass ‘w’ due to moderate to poor drainage. Soils in class II have moderate limitations that restrict the range of crops or require moderate conservation practices. Soils in class III have moderately severe limitations and require cultivation with careful management practices. The north - east part of the district is marked as forest land and most of the area is under *Bhabar* class.

5.2.2 Land Irrigability Classification

All the soil series except Nagina and Kharee series, under this classification, fall in class III. Due to surface soil texture Nagina and Kharee soil series were classified in class II. Soils of Kheda and Fazalpur series have severe limitation of imperfect drainage. Due to presence of soluble salts in surface soil Nagina, Daulatpur, Fulsunda and Kheda soil series have moderately severe limitation in agricultural operations.

5.2.3 Land Suitability Classification

The soils of the study area have been evaluated for their suitability to grow four major crops like wheat, paddy, sugarcane and maize. Three models were used to classify the soil properly under various suitability classes. The result has been summarized in Table 5.1, below.

Table 5.1. Land Suitability Classification for different major crops.

Crops	Soil series	Land Suitability class as per		
		P.R.I Model	Sys Model	Limiting Condition Model
Wheat	Nagina	MS	MAS	MAS
	Daulatpur	MS	MS	MS
	Fulsunda	MS	HS	MS
	Kheda	MS	MS	MS
	Fazalpur	MS	HS	HS
	Kharee	MS	NS	MAS
Paddy	Nagina	MS	NS	NS
	Daulatpur	MS	NS	MAS
	Fulsunda	MS	NS	NS
	Kheda	MS	MS	HS
	Fazalpur	MS	MS	MAS
	Kharee	MS	NS	NS
Sugarcane	Nagina	MS	MS	MS
	Daulatpur	MS	MS	HS
	Fulsunda	MS	HS	HS
	Kheda	MS	MS	HS
	Fazalpur	MS	MS	MS
	Kharee	MS	MAS	MS
Maize	Nagina	MAS	HS	MS
	Daulatpur	MAS	HS	MS
	Fulsunda	MAS	HS	MS
	Kheda	MAS	MS	MS
	Fazalpur	MAS	HS	HS
	Kharee	MAS	MAS	HS

HS = Highly suitable, MS = Moderately suitable, MAS = Marginally suitable,

NS = Not suitable.

5.3 GROUNDWATER BEHAVIOUR

The Pre-monsoon and post-monsoon depth to water table data of 47 observation wells were collected from Groundwater Department, U.P. The pre-monsoon and post-monsoon water table depths were observed to vary between 3 to 13 m and 2 to 12 m respectively. During the period of twenty years (1983-2002) groundwater table was found to fluctuate within 3 m to 9 m in pre-monsoon season in Haldaur, Jaleelpur and Nahataur blocks. In other parts, water table has declined by 1 to 3 m. In post-monsoon season water table was found to vary in the range of 2 to 4 m in Noorpur, Kotwali, Haldaur, Jaleelpur and Afzalgarh blocks. The investigation shows that about 22% of the total area is facing the groundwater table decline problem drastically, while in 60% area of the district the problem is moderately severe.

5.4 FACTORS RESPONSIBLE FOR WATER TABLE DECLINE

Excessive draft of groundwater is taking place to mitigate the demands of cultivated crops, expansion of industrial and domestic activities etc. Growing crops irrespective of soil conditions in the area, increasing trend of groundwater structures or reduction of area under canal irrigation made the situation more worser than before.

***Cropping Pattern* :** The area under major crops like paddy, wheat and sugarcane has increased tremendously during the twenty years' period (1990 – 2002). Whereas minor crops occupied area has decreased. Cultivation of high water demanding crops, in blocks where water table condition is already at an alarming stage, made the situation more serious.

***Minor Irrigation Structures* :** In the study area the number of pumping sets has increased manyfolds in almost all the blocks. Though no abrupt increase has been found in number of Govt. tubewells but private tubewells has shown a fluctuating trend in the study period (1990-2002). Indiscriminate rise in number of pumping sets caused havoc on the depletion of groundwater resource. Infact this creates the extra load on groundwater draft resulting in groundwater depletion.

5.5 STAGE OF GROUNDWATER DEVELOPMENT

The groundwater budgets were prepared for Bijnor district for the years 1990 and 2002, on the basis of established norms. Groundwater inventory of the year 1990 indicated that except Noorpur block, all other blocks were under white category. In the year 2002, out of eleven blocks, two blocks (Jaleelpur and Noorpur) were under dark category and four blocks namely Kiratpur, Seohara, Dhampur and Nahataur were under grey category. On the basis of the result, it can be predicted that in future the present trend of groundwater exploitation will go on increasing.

5.6 GROUNDWATER MODELLING

Planning for the best use of water requires prediction of the behaviour of groundwater for various development strategies. Mathematical formulations, which consist of appropriate multiple regression equations for relationships in different governing parameters of the system, can be used as models for simulating the hydrology and evaluating the response of a groundwater reservoir.

For the groundwater modelling of the Bijnor district following multiple curvilinear regression models were tried for the prediction of depth to water table below ground level, Y and evaluated for their performance:

Model 1:

$$Y = a + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

Model 2:

$$Y = b + b_1R + b_2D$$

Model 3:

$$Y = c + c_1R + c_2D + c_3R^2 + c_4D^2$$

Model 4:

$$Y = d + d_1R + d_2D + d_3R^2 + d_4D^2 + d_5R^3 + d_6D^3$$

Model 5:

$$Y = e + e_1R + e_2D + e_3R^2 + e_4D^2 + e_5R^3 + e_6D^3 + e_7R^4 + e_8D^4$$

Model 6:

$$Y = f + f_1R + f_2D + f_3R^2 + f_4D^2 + f_5R^3 + f_6D^3 + f_7R^4 + f_8D^4 + f_9\ln(R) + f_{10}\ln(D)$$

where Y = depth to water table below ground level,

x_1, x_2 and x_3 = different recharge components,

$x_4 = D$ = total groundwater discharge,

$R = x_1 + x_2 + x_3$ = total groundwater recharge,

$a, a_1, a_2, \ldots f_9, f_{10}$ = regression constants.

The correlation coefficients for these models, to predict the pre-monsoon and post-monsoon depths of water table below ground level at different nodes, are shown in Figs. 4.10 and 4.11, respectively. Both figures show that Model 6 gave the highest correlation coefficient values at all the nodes and, therefore, may be treated as the best fit model for the groundwater simulation of the Bijnor district.

5.7 DELINEATION OF GEO-MORPHOLOGICAL UNITS OF THE STUDY AREA USING REMOTE SENSING AND G.I.S.

The IRS-1D Satellite data of the study area were analysed, for their characterization of various landforms and its geomorphology with the help of G.I.S. softwares Geo Media and Image Analyst. The Satellite data and imageries of the scale of 1:250000 were of 5th May, 2003. The alluvial plain of the study area was delineated by visual interpretation of the images on the basis of tone, colour and texture of the ground surface properties as Young Flood Plain (YFP), Old Flood Plain dominated with sand (OFP-1), Old Flood Plain dominated with silt (OFP-2) and Old Flood Plain dominated with sand and silt (OFP-3). The OFP-1 was found with high contents of sand with gentle topography. Therefore, this is the potential area for groundwater recharging.

Fluvial Landforms : Out of various fluvial geomorphic features, palaeochannels, natural levees, channel scare/cutoff were delineated distinctly under the study area. These features possess a good promising zone for shallow aquifer with excellent groundwater yield.

5.8 PROPOSED RECHARGE MEASURES

5.8.1 Construction of Recharge Structures

In the Nazibabad, Kotwali and Dhampur blocks there has plenty of scope for construction of series of check dams along the streams to recharge the depleted groundwater aquifers. In this areas, number of 1^{st} and 2^{nd} order streams flow under piedmont landforms. The Old Flood Plain-1 landform is highly suitable for making percolation tanks due to high percentage of sand. In OFP-3 landform with higher silt content, percolation tanks having larger width and lesser depth are suitable. Fluvial landforms are most promising zones for constructing percolation tanks. In the areas where topography does not permit to construct tanks, contour trenches can easily be made.

Another way to recharge the nearby area of stream is to use the monsoon runoff of the stream by constructing ditches/furrows or putting permanent low check dams in the streams. Bunds can also be made surrounding the fields, which serve as water harvesting structure during the scarcity periods in clay or silt dominated areas. These bunds would help in recharging the sand dominated areas without the problem of water logging.

5.8.2 *Change in Cropping Pattern*

Crops should be cultivated depending upon the land criteria that is determined by classifying the land according to its capability, suitability and irrigability characteristics. More area should be allocated under low water demanding crops like - pulses, oilseeds etc. in water depleting zones. These crops would help not only in lowering the groundwater demand but may improve the financial condition of the farmers also, as these crops are treated as cash crops. The area under high water demanding crops such as- Paddy, Sugarcane, Mentha should be reduced in the cropping sequence.

5.8.3 *Construction of Canal Network*

In the study area there is a great need to increase the existing canal network system. Enhancement of canal irrigated area not only reduces the load on groundwater draft but also helps in recharging the under ground reservoir through seepage and return flow of irrigation water.

5.9 CONCLUSIONS

1. Six soil series namely – Nagina, Daulatpur, Fulsunda, Kheda, Fazalpur and Kharee prevail in Bijnor district. Five soil associations formed by these soils were identified as – Daulatpur-Nagina-Kharee, Fulsunda-Fazalpur-Kheda, Kheda-Fazalpur, Nagina-Daulatpur-Kharee, and Nagina-Daulatpur.

2. According to land capability classification the district was classified under land capability class II and III.

3. As per land irrigability classification the district was put under land irrigability class II and III.

4. Land suitability classification of the district was done using three models – Sys model, Limiting Condition model and P.R.I. model.

5. Groundwater inventory for the year 2002 indicated that out of 11 blocks, 4 blocks (Kiratpur, Nahataur, Dhampur and Seohara) were under grey category and two blocks (Jaleelpur and Noorpur) were under dark category. Jaleelpur and Noorpur blocks were identified as the main problematic area. These two blocks specially need immediate attention and suitable remedial measures to manage the problem.

6. In most of the blocks, in twenty years' period (1983-2002) the groundwater table had declined in the range of 2 to 9 m in pre-monsoon season and 2 to 4 m in post-monsoon season which indicated that over-exploitation of groundwater was taking place in major parts of the district.

7. The groundwater draft was continuously increasing due to increase in number of tube-wells and pumping sets every year. Increase in human and livestock population along with the growth of agriculture and industries made the situation more critical than before.

8. Cultivation of high water demanding crops like – paddy, wheat, sugarcane, menthe etc. in place of low water demanding crops, irrespective of present water situation, again increased the water requirement indiscriminately.

9. The area irrigated by tubewells has increased by 36% during the period (1991-2002) under study. Whereas, the area irrigated through canals has decreased significantly, except in few blocks where canal water was supplied only for *kharif* crops.

10. For the groundwater modelling of the Bijnor district, six multiple regression models were tried for the prediction of depth to water table below ground level and evaluated for their performance. Model 6 gave the best results showing the highest correlation coefficient in all the nodes.

11. On the basis of remote sensing data, the district was classified into four geo-morphological units – the piedmont zones (Upper Piedmont P1, Lower Piedmont P2, Piedmont Flood plain P3), Young Flood plain (YFP) and Old Flood plain (OFP-1, OFP-2 and OFP-3).

12. A number of geomorphic fluvial features such as palaeochannel, natural levee, back swamp and channel scars were delineated which are potential sites for groundwater recharge.

13. Dug well recharge method can be a powerful tool for the landform OFP-3. Fluvial landforms delineated in the area were the promising zones for the construction of percolation tanks and contour trenches. Under subsurface practice, the existing dug wells may be utilized as recharge structures when filter materials or pebbles can be used for properly back filling these wells.

14. Old Flood Plain-1 landform is highly suitable sites for percolation tanks because this landform is composed of high percentage of sand content and has favourable stream orders.

15. Canal network of the area should be extended to the problematic areas. So that it can serve as potential source of groundwater recharge or can reduce the groundwater draft. Conjunctive use of canal water and groundwater will help in controlling the declining water table.

16. Recharge capacity can be increased in riparian area by modifying the flowing channels like putting permanent low check dams or constructing ditches/furrows across the slope.

17. A more detailed land use survey is required considering the groundwater status.

18. Besides this some relevant factors should also be considered like, the unproductive water losses e.g. surface runoff, deep percolation and lateral seepage must be reduced by adopting appropriate irrigation strategy in its scheduling, water conveyance, water application and other agronomic practices. Pumping should be done at a discharge permissible under the conditions of aquifer, water table and well design to avoid over-draft condition.

Lastly, social mobilization is needed to restructure research strategies so that they can be turned into farmer-friendly farming methods. The rural knowledge centres should provide computer-aided and internet connected information services, so that farm-families have timely and relevant meteorological, management information.

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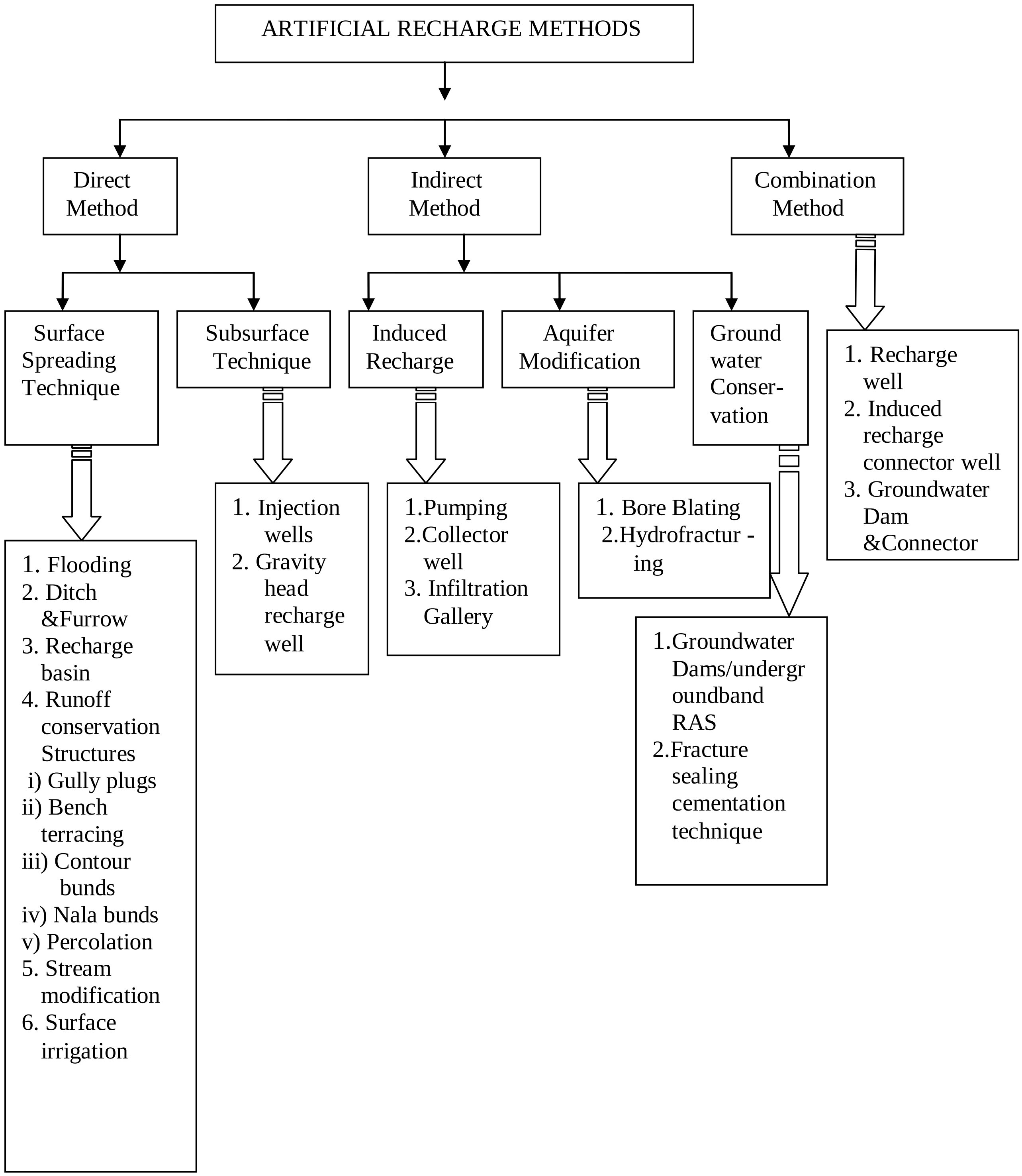
Appendix A-1.


ARTIFICIAL RECHARGE METHODS
Direct Method
Indirect Method
Combination Method
Surface Spreading Technique
Subsurface Technique
Induced Recharge
Aquifer Modification
Ground water Conser-vation
1. Recharge well
2. Induced recharge connector well
3. Groundwater Dam &Connector
1. Flooding
2. Ditch &Furrow
3. Recharge basin
4. Runoff conservation Structures
i) Gully plugs
ii) Bench terracing
iii) Contour bunds
iv) Nala bunds
v) Percolation
5. Stream modification
6. Surface irrigation
1. Injection wells
2. Gravity head recharge well
1.Pumping
2.Collector well
3. Infiltration Gallery
1. Bore Blating
2.Hydrofractur - ing
1.Groundwater Dams/undergr oundband RAS
2.Fracture sealing cementation technique

Appendix A-2. Suitability of various artificial ground water recharge methods.

	Method		Requirements/Site characteristics
1.	Surface spreading technique -Most widely practiced	a. b. c. d. e.	Unconfined permeable and sufficiently thick aquifer. Sufficiently permeable surface soil to maintain high infiltration rate. Gently sloping land Sufficiently deep ground water level to accommodate water table rise. Moderate hydraulic conductivity of aquifer material.
1.1	Flooding -Spreading of surplus surface water from canals/streams over large area for sufficiently long period of time.		Availability of sufficiently large land area adjacent of the canal/stream.
1.2	Ditches and furrow method		Areas with irregular topography
1.3	Recharge basins -Either excavated or enclosed by dykes or leaves. - Commonly built parallel to streams/ canals.		Periodic maintenance such as scraping etc. Water released to basin should minimum sediment.
1.4	Percolation tanks -Small tanks created by making low elevation stop dams across streams or located adjacent to a stream by excavation and connected to the stream by delivery canal.	a. b.	High permeability of rocks coming under submergence areas. Uniform degree and extent of weathering of rock
1.5	Streams channels modification.		Influent streams having bed above water table.
2.	Sub-surface techniques		Deeper aquifers overlain by impervious layers, the infiltration from surface cannot recharge the sub-surface aquifer under natural conditions.
2.1	Injection wells -Treated surface water is pumped in		Adequately filtered and disinfected water for recharge.
2.2	Gravity head recharge wells -Ordinary borewells, tubewells and dug wells used for pumping		Adequately filtered and disinfected water for recharge.
2.3	Connector wells -Special type of wells by which water is made to flow from one aquifer to other without any pumping due to difference in piezometric head		Multiple aquifer system, deeper aquifer having lower piezometric head than lower lying aquifers separated by impermeable confining layer.

Appendix B -1. Block wise geographical area of the district.

Sl. No.	Tehsil	Block	Geographical area, ha
1	Nazibabad	Nazibabad	50980
2		Kiratpur	20090
3	Bijnor	Mohd.pur Deomol	47930
4		Haldaur	40840
5	Nagina	Afzalgarh	55180
6		Kotwali	70960
7	Dhampur	Nahataur	21520
8		Dhampur	34260
9	Chandpur	Seohara	26100
11		Noorpur	33480
10		Jaleelpur	40640
Total Bijnor district area		441980 ha	

Appendix B-2. Soil and water conservation farm practices (Dhurva Narayana, 1993).

Class	Characteristics and recommended land use
I	These are deep productive soils, easily worked on nearly level land, not subject to overland flow, use of fertilizers and lime, cover crops, crop rotations required to maintain soil fertility and soil structure.
II	These are productive soils on gentle slopes, moderate depth, may require drainage, moderate risk of damage when cultivated, use crop rotations, water control systems or special tillage practices to control erosion.
III	Soils are of moderate fertility on moderately steep slopes, subject to more severe erosion, can be used for crops provided adequate plant cover is maintained, hay or other sod crops should be grown instead of row crops.
IV	These are good soils on steep slopes, subject to severe erosion, can be cultivated occasionally if handled with great care, keep in hay or pasture but a grain crop may be grown once in 5 or 6 years.
V	Land is too wet or stony for cultivation but of nearly level slope, subject to only slight erosion if properly managed, should be used for pasture or forestry but grazing should be regulated to prevent plant cover from being destroyed.
VI	These are shallow soils on steep slopes, used for grazing and forestry, grazing should be regulated to preserve plant cover, if the plant cover is destroyed; use should be restricted until cover is re-established.
VII	These are steep, rough, eroded lands with shallow soils, also include droughty and swampy land, severe risk of damage even when used for pasture or forestry, strict grazing or forest management must be applied.
VIII	Very rough land, not suitable even for woodland or grazing, reserve for wildlife, recreation or watershed consideration.

Appendix B-3. Block wise unit drafts of different minor irrigation structures.

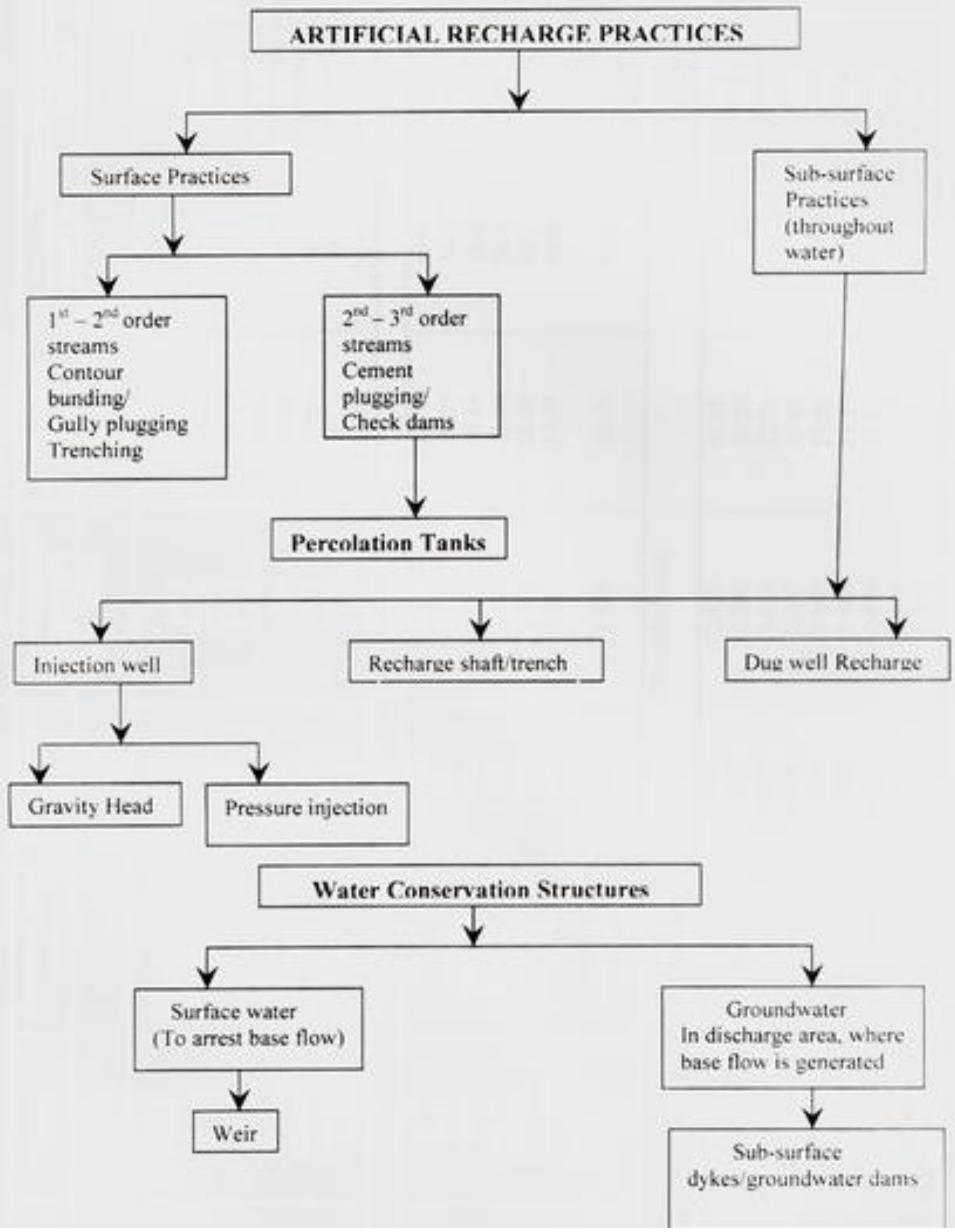
Block		Private tubewells (ha-m)	Govt.tubewells (ha-m)	Pumping sets (ha-m)	Rahats (ha-m)
1.	Nazibabad	2.2	18	1.4	0.6
2.	Kiratpur	1.64	10.01	1.03	0.6
3.	Mohd.pur	1.6	12.93	1.06	0.6
4.	Haldaur	1.09	10.76	0.92	0.6
5.	Kotwali	2.2	18	1.28	0.6
6.	Afzalgarh	2.2	0	1.4	0.6
7.	Nahataur	1.52	11.09	1.29	0.6
8.	Dhampur	2.2	18	1.4	0.6
9.	Seohara	1.29	18	1.4	0.6
10.	Jaleelpur	1.53	10	1.15	0.6
11.	Noorpur	1.43	18	1.28	0.6

Appendix B-4. Polygonal area of different nodes.

Node No.	No. of Sides	Hydrograph Station	Polygonal area, ha
1	6	Bhaguwala	13140.194
2	6	Sanehroad	14315.893
3	5	Mandouli	5829.108
4	6	Nagal	4050.736
5	4	Lokhadari	5236.318
6	5	Mauzampur	5756.735
7	6	Srawanpur	5631.511
8	8	Khasaur	14298.56
9	6	Akbarabad	7653.415
10	5	Balawali	5721.281
11	6	Chandoki	5969.604
12	7	Shekhupura	10946.975
13	5	Mandawar	7988.334
14	6	Mohammodpur	8284.197
15	6	Madhusudanpur	11030.078
16	6	Kharijalu	10633.945
17	5	Kotwali	9695.387
18	4	Nagina	6192.264
19	5	Kaziwala	7865.849
20	5	Shadipur	6085.382
21	5	Kotqudar	9583.743

22	6	Barhapur	18409.435
23	6	Ganj	7279.338
24	7	Fatehpur	10358.459
25	5	Haldaur	8141.063
26	6	Sisauna	9249.752
27	5	Nahataur	9727.315
28	6	Aku	12192.929
29	4	Tibri	8021.768
30	6	Dhampur	11618.610
31	5	Mubarakpur	6852.00
32	5	Khanpur	9126.780
33	5	Jaleelpur	6027.119
34	5	Chandpur	8341.871
35	7	Basta	10504.407
36	6	Nurpur	10092.058
37	6	Pheona	11786.031
38	6	Tajpur	10203.803
39	7	Chelapur	9052.428
40	5	Seohara	12433.527
41	6	Sahaspur	8242.108
42	5	Rasulpur	10638.221
43	7	Hareoli	11468.133
44	4	Jamunwala	6229.089
45	7	Reharh	16239.159
46	5	Allyharpur	8140.472
47	7	Seuwala	9321.304

Appendix B-5. **Artificial Recharge Plan for different landforms.**



Appendix C-1. Morphological and Physical properties of Bijnor District soil.

Horizons	Depth	Texture of fine earth	Bulk density (Mgm^{-3}) Db	Particle density (Mgm^{-3}) Dp	Pore space (%)	Particle size distribution		
						Sand (%)	Silt (%)	Clay (%)
				Nagina Series				
Ap	0-18	Sandy loam	1.302	2.419	46.18	46.2	48.6	5.2
A	18-44	Sandy loam	1.454	2.380	38.91	52.9	36.9	10.2
BA	44-54	Loam	1.487	2.372	37.32	51.5	41.3	7.2
Bw1	54-94	Sandy loam	1.510	2.369	36.27	47.5	47.4	5.1
Bw2	94-124	Loam	1.570	2.339	32.88	44.3	48.1	7.6
Bw3	124-146	Sandy loam	1.573	2.398	34.41	56.2	35.6	8.2
Cl	146-174	Loamy sand	1.593	2.280	30.14	76.3	22.3	1.4
Cg	174+	Sand	1.612	2.272	39.05	87.2	12.2	0.6
				Daulatpur Series				
Ap	0-18	Loam	1.320	2.429	45.66	41.0	47.8	11.2
A	18-17	Loam	1.337	2.272	39.57	36.0	48.2	15.8
BA	47-64	Silt loam	1.352	2.222	39.16	28.0	59.0	13.0
Bw1	64-97	Silt loam	1.390	2.372	42.40	30.4	61.6	8.0
Bw2	97-115	Loam	1.449	2.352	38.40	42.3	46.4	11.3
BC	115-146	Sandy loam	1.459	2.247	35.07	66.9	32.0	1.1
Cg	146+	Loamy sand	1.464	2.176	32.73	82.3	16.7	1.0
								Clay (%)
				Fulsunda Series				
Ap	0-16	Silt loam	1.399	2.432	42.48	24.9	54.1	21.0
A1	16-33	Clay loam	1.503	2.380	36.85	22.8	48.1	29.1
A2	33-68	Loam	1.574	2.325	32.31	38.5	43.7	17.8
C1	68-99	Sandy loam	1.624	2.302	29.46	61.5	23.0	15.5
2Ab	99-125	Loam	1.624	2.460	33.99	35.4	49.0	15.6
2Bbt1	125-145	Silt loam	1.628	2.447	33.47	22.1	54.3	23.6
2Bbt2	145-178	Clay loam	1.628	2.439	32.85	20.6	40.3	39.1
2Bbt4	178-207	Clay	-	2.429	-	20.8	34.5	44.7
2Bbt4	207-235	Clay	-	2.382	-	13.1	38.3	48.6

Horizons	Depth	Texture of fine earth	Bulk density (Mgm^{-3}) Db	Particle density (Mgm^{-3}) Dp	Pore space (%)	Particle size distribution

Horizon	Depth (cm)	Colour		Texture	Structure	Mottles	Mottles Colour (moist)	Consistency		Boundry	Roots	Reaction to 10% HCL
		Moist	Dry					Moist	Dry			
Bw1	64--97	10YR 5/4	10YR 6/4	sil	3c sbk	c 2 p	10YR 5/3	mvfi	dh	gs	roc	eo
Bw2	97-115	10YR 5/4	10YR 6/4	l	2m sbk	c 2 d	7.5YR 6/8	mfi	dh	di	roc	eo
BC	115-146	10YR 5/4	10YR 7/4	sl	1m sbk	c 2 p	7.5YR 6/8	mvfr	dsh	db	ro	eo
Cg	146+	2.5Y 5/6	10YR 7/3	ls	1m sbk	c 2 p	7.5YR6/8	mvfr	dl	-	ro	eo
Fulsunda Series : At upland flat of 1 per cent north east to south west slope developed on coarse clayey alluviam												
Ap	0-16	2.5 Y 5/3	2.5 Y 7/2	sil	2m sbk	-	-	mfi	dh	as	ra	eo
A1	16-33	2.5 Y 5/2	5 Y 7/3	cl	3 c cpr	-	-	mvfi	dvh	cs	rc	eo
A2	33-68	2.5 Y 5/4	10YR 8/4	l	2m sbk	-	-	mfi	dvh	gs	roc	eo
C1	68-99	2.5 Y 4/4	10YR 6/4	sl	1 c gr	f 1 p	10YR 5/6	mfr	dsh	gs	roc	eo
2Ab	99-125	2.5 Y 6/4	10YR 7/3	l	2m sbk	f 1 p	10YR 6/ 8	mfi	dh	cs	ro	eo
2Bbt1	125-145	2.5 Y 6/2	10YR 8/2	sil	2m abk	c 2 d	10YR 6/ 8	mfi	dvh	gs	ro	eo
2Bbt2	145-178	2.5 Y 6/2	10YR 8/3	cl	3 c abk	m 3 d	7.5YR 5/8	mvfi	dve-eh	-	ro	eo
2Bbt3	178-207	2.5 Y 4/4	10YR 8/4	c	-	m 3 d	7.5YR 6/8	Mvfi-efi	dvh-eh	-	ro	eo
2Bbt4	207-235	2.5 Y 4/4	10YR 8/3	c	-	m 3 d	7.5YR 6/8	mefi	deh	-	ro	eo
Shows lithological discontinuity and presence of clay skins * By augar												
Kheda Series : At upland flat of 1 per cent north east to south west slope developed on coarse loamy alluviam												
Ap	0-14	2.5Y 4/2	5Y 7/2	cl	2 c abk	c 1 p	7.5YR 4/4	mefi	dvh	cs	ra	eo
A	14-32	2.5Y 4/2	5Y 6/3	cl	3 c abk	f 1 p	10YR 5/6	mvfi	dvh	cs	rc	eo
BA	32-62	2.5Y 5/6	5Y 7/3	sil	3 c cpr	c 1 d	10YR 6/8	mvfi	dvh	gs	rc	eo
Bw1	62-98	2.5Y 4/4	10YR 7/4	l	3 vc sbk	c 1 d	10YR 6/6	mvfi	dvh	gs	roc	eo
Bw2	98-117	2.5Y 4/2	5Y 7/3	l	3 vc sbk	c 2 d	10YR 5/6	mfi	dh	gs	ro	eo
BC	117-129	2.5Y 5/2	10YR 6/3	sl	2 m sbk	m 2 f	10YR 6/6	mfr	dsh	gs	ro	eo
CB	129-139	2.5Y 5/2	10YR 6/4	ls	1 m sbk	m 2 f	10YR 5/6	mvfr	ds	gs	ro	eo
C	139+	2.5Y 5/3	10YR 6/4	s	1 M	m 1 d	10YR 5/4	ml	ds	db	ro	eo

Appendix C-3. Percentage of Soil Series in a particular Soil Association.

Soil Association indicating letters.	Soil Association (values in the parentheses indicates the percentage area covered by that particular soil series in that association),
A	Daulatpur (44.68%) – Nagina (40.43%) – Kharee (14.89%)
B.	Fulsunda (65.51%) – Kheda (18.97%) – Fazalpur (15.52%)
C.	Kheda (71.43%) – Fazalpur (28.57%)
D.	Nagina (38.92%) – Daulatpur (32.93%) – Kharee (28.15%)
E.	Nagina (50%) – Daulatpur (80%)

Appendix C-4. Sample input file of node 14 (for pre-monsoon season).

Node No.	Area (ha)	Year	Water table	Rainfall recharge	RIF*	Irrigation draft	Domestic use	Livestock use
14	8284.197	1990	5.440	130.310	345.299	986.568	14.799	1.489
		1991	5.560	178.006	308.883	882.524	13.238	1.585
		1992	6.380	221.619	325.477	929.935	13.949	1.599
		1993	7.160	222.348	341.130	974.657	14.620	1.613
		1994	7.030	160.747	375.733	1073.522	16.103	1.612
		1995	6.550	182.981	383.841	1096.687	16.450	1.629
		1996	6.600	209.772	390.086	1114.531	16.718	1.679
		1997	6.350	256.976	395.379	1129.653	16.945	1.770
		1998	5.200	554.412	404.168	1154.765	17.321	1.657
		1999	5.100	481.146	412.119	1177.483	17.662	1.673
		2000	4.600	327.872	412.119	1177.483	17.662	1.690
		2001	4.760	357.998	413.830	1182.371	17.736	1.704
		2002	4.950	207.020	419.976	1199.931	17.999	1.720

Sample input file for node 14(for post-monsoon season).

Node No.	Area (ha)	Year	Water table	Rainfall recharge	RIF*	Irrigation draft	Domestic use	Livestock use
14	8284.197	1990	4.050	1087.244	169.106	483.159	7.247	0.745
		1991	5.340	1148.335	154.385	441.101	6.617	0.793
		1992	5.000	1659.225	162.679	464.798	6.972	0.800
		1993	7.030	1470.776	170.503	487.150	7.307	0.806
		1994	6.200	1830.542	187.796	536.561	8.048	0.806
		1995	4.050	2167.345	191.849	548.140	8.222	0.814
		1996	3.900	1799.742	194.970	557.058	8.356	0.834
		1997	4.950	847.692	197.616	564.617	8.469	0.844
		1998	2.800	2034.118	202.009	577.169	8.658	0.829
		1999	3.110	990.541	206.032	588.664	8.830	0.835
		2000	3.400	1884.307	205.984	588.525	8.828	0.845
		2001	3.770	1310.139	206.839	590.968	8.865	0.842
		2002	3.940	1613.954	209.922	599.776	8.997	0.853

RIF * = Return flow of irrigation water

Appendix C-5. Observed and Predicted values of depth to water table below ground level (m) for Model 6.

	Pre-monsoon			Post-monsoon		
Node 1	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	9.000	8.963	-0.037	9.000	8.847	-0.153
1991	6.130	6.135	0.005	6.130	6.157	0.027
1992	8.500	8.575	0.075	8.500	8.753	0.253
1993	8.410	8.337	-0.073	8.410	8.443	0.033
1994	8.110	8.212	0.102	8.110	8.043	-0.067
1995	8.500	8.044	-0.456	7.660	6.872	-0.788
1996	3.950	4.882	0.932	3.470	4.406	0.936
1997	3.600	3.026	-0.574	1.900	1.900	0.000
1998	3.250	3.250	0.000	3.250	2.605	-0.645
1999	4.500	4.498	-0.002	4.500	4.502	0.002
2000	4.890	4.920	0.030	4.890	4.974	0.084
2001	4.820	4.825	0.005	4.820	5.120	0.300
2002	4.910	4.904	-0.006	4.910	4.737	-0.173

	Pre-monsoon			Post-monsoon		
Node 2	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	10.670	10.976	0.306	9.600	9.477	-0.123
1991	10.560	10.567	0.007	9.850	9.840	-0.010
1992	10.800	10.678	-0.122	9.800	9.877	0.077
1993	10.050	9.771	-0.279	9.590	9.642	0.052
1994	10.480	10.504	0.024	9.870	9.538	-0.332
1995	9.220	9.269	0.049	8.900	9.346	0.446
1996	9.500	9.692	0.192	8.700	8.662	-0.038
1997	10.380	10.185	-0.195	9.200	9.200	0.000
1998	10.150	10.151	0.001	6.900	6.656	-0.244
1999	7.350	7.231	-0.119	6.950	7.027	0.077
2000	6.350	6.677	0.327	5.150	5.733	0.583
2001	7.350	7.140	-0.210	6.000	5.585	-0.415
2002	7.950	7.969	0.019	8.150	8.077	-0.073

	Pre-monsoon			Post-monsoon		
Node 3	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	11.760	11.846	0.086	9.250	9.224	-0.026
1991	11.640	11.651	0.011	10.150	10.154	0.004
1992	11.750	11.382	-0.368	11.600	11.645	0.045
1993	12.110	11.830	-0.280	11.780	11.816	0.036
1994	12.700	13.537	0.837	11.600	11.458	-0.142
1995	12.100	11.609	-0.491	8.900	8.855	-0.045
1996	10.670	10.496	-0.174	5.000	5.262	0.262
1997	8.500	9.670	1.170	3.690	3.690	0.000
1998	6.500	7.556	1.056	2.300	2.063	-0.237
1999	6.700	6.927	0.227	3.850	3.877	0.027
2000	8.700	7.980	-0.720	2.900	3.080	0.180
2001	8.700	8.210	-0.490	3.300	3.265	-0.035
2002	8.300	9.112	0.812	2.380	2.312	-0.068

Node 4	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	20.670	20.687	0.017	19.750	19.789	0.039
1991	20.700	20.698	-0.002	19.430	19.422	-0.008
1992	22.450	22.407	-0.043	21.350	21.281	-0.069
1993	22.060	22.020	-0.040	21.590	21.676	0.086
1994	21.050	21.272	0.222	20.500	20.071	-0.429
1995	20.450	20.261	-0.189	18.520	19.162	0.642
1996	20.000	19.949	-0.051	18.200	17.940	-0.260
1997	19.800	19.897	0.097	18.400	18.400	0.000
1998	19.750	19.750	0.000	15.970	15.848	-0.122
1999	18.100	17.659	-0.441	15.450	15.523	0.073
2000	15.900	16.564	0.664	13.700	14.267	0.567
2001	15.510	15.152	-0.358	14.550	14.063	-0.487
2002	15.580	15.705	0.125	14.900	14.869	-0.031

Node 5	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	4.300	4.294	-0.006	1.560	1.579	0.019
1991	4.010	4.010	0.000	4.150	4.144	-0.006
1992	4.750	4.774	0.024	3.750	3.729	-0.021
1993	4.700	4.747	0.047	3.800	3.874	0.074
1994	4.950	4.780	-0.170	3.980	3.650	-0.330
1995	4.100	4.279	0.179	2.500	2.779	0.279
1996	4.500	4.327	-0.173	2.900	3.008	0.108
1997	4.200	4.323	0.123	3.450	3.450	0.000
1998	4.200	4.200	0.000	3.800	3.532	-0.268
1999	2.500	2.627	0.127	1.950	2.010	0.060
2000	2.800	2.516	-0.284	2.500	2.912	0.412
2001	2.600	2.746	0.146	2.000	1.736	-0.264
2002	2.850	2.837	-0.013	1.900	1.837	-0.063

Node 6	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	11.560	11.558	-0.002	11.300	11.306	0.006
1991	11.600	11.605	0.005	11.780	11.787	0.007
1992	13.550	13.512	-0.038	13.430	13.328	-0.102
1993	14.190	14.290	0.100	14.000	14.170	0.170
1994	14.100	13.873	-0.227	12.430	11.863	-0.567
1995	13.030	13.174	0.144	11.630	11.987	0.357
1996	12.630	12.668	0.038	11.900	12.543	0.643
1997	12.430	12.385	-0.045	11.380	11.380	0.000
1998	12.800	12.799	-0.001	12.380	11.542	-0.838
1999	5.230	5.946	0.716	5.100	5.238	0.138
2000	10.030	8.291	-1.739	8.930	9.573	0.643
2001	9.380	10.266	0.886	9.260	8.745	-0.515
2002	9.530	9.695	0.165	8.430	8.487	0.057

Node 7	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.850	5.849	-0.001	2.650	2.601	-0.049
1991	5.260	5.259	-0.001	4.730	4.737	0.007
1992	6.300	6.311	0.011	5.290	5.383	0.093
1993	5.350	5.345	-0.005	5.120	5.106	-0.014
1994	5.870	5.923	0.053	4.800	4.920	0.120
1995	5.370	5.168	-0.202	4.990	4.480	-0.510
1996	3.150	3.452	0.302	2.180	2.709	0.529
1997	3.000	2.846	-0.154	1.950	1.950	0.000
1998	2.950	2.950	0.000	2.100	1.879	-0.221
1999	4.950	4.906	-0.044	3.250	3.233	-0.017
2000	4.650	4.688	0.038	2.800	2.621	-0.179
2001	4.500	4.477	-0.023	2.970	3.268	0.298
2002	4.900	4.926	0.026	2.900	2.843	-0.057

Node 8	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	18.090	18.130	0.040	16.790	17.057	0.267
1991	17.450	17.436	-0.014	16.740	16.705	-0.035
1992	17.990	18.053	0.063	17.090	17.288	0.198
1993	17.790	17.722	-0.068	17.110	16.859	-0.251
1994	17.790	17.734	-0.056	17.290	16.755	-0.535
1995	17.890	17.758	-0.132	13.880	13.573	-0.307
1996	16.500	16.666	0.166	13.590	13.654	0.064
1997	15.290	15.181	-0.109	13.940	13.913	-0.027
1998	15.440	15.428	-0.012	12.300	13.006	0.706
1999	14.390	14.437	0.047	10.890	10.831	-0.059
2000	12.700	12.869	0.169	11.670	10.791	-0.879
2001	12.150	11.970	-0.180	11.760	11.453	-0.307
2002	11.510	11.596	0.086	10.690	11.515	0.825

Node 9	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	10.080	10.081	0.001	8.680	8.675	-0.005
1991	11.150	11.148	-0.002	11.000	11.005	0.005
1992	12.100	12.107	0.007	8.880	8.861	-0.019
1993	9.430	9.422	-0.008	9.150	9.167	0.017
1994	12.150	12.223	0.073	11.950	12.023	0.073
1995	12.400	12.082	-0.318	9.880	9.296	-0.584
1996	11.600	12.000	0.400	9.500	10.591	1.091
1997	12.040	11.505	-0.535	11.870	10.637	-1.233
1998	12.200	12.265	0.065	8.090	8.552	0.462
1999	10.900	11.233	0.333	10.110	10.284	0.174
2000	10.170	10.076	-0.094	10.050	10.048	-0.002
2001	9.420	9.538	0.118	9.040	9.018	-0.022
2002	10.310	10.269	-0.041	10.150	10.192	0.042

Node 10	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	4.000	4.120	0.120	3.450	3.767	0.317
1991	4.786	4.321	-0.465	3.530	3.560	0.030
1992	4.100	4.390	0.290	3.880	3.630	-0.250
1993	3.710	3.921	0.211	3.220	3.214	-0.006
1994	4.620	4.604	-0.016	4.160	3.709	-0.451
1995	4.600	4.628	0.028	3.230	3.356	0.126
1996	4.540	4.533	-0.007	3.000	3.457	0.457
1997	4.350	3.997	-0.353	3.960	4.008	0.048
1998	4.450	4.103	-0.347	3.850	3.456	-0.394
1999	5.100	4.965	-0.135	3.360	3.010	-0.350
2000	3.750	3.870	0.120	2.700	3.147	0.447
2001	4.000	4.217	0.217	3.380	3.388	0.008
2002	4.300	4.521	0.221	3.380	3.397	0.017

Node 11	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	8.345	8.178	-0.167	6.875	7.522	0.647
1991	7.945	7.863	-0.082	7.540	7.602	0.062
1992	7.985	8.471	0.486	7.710	7.101	-0.609
1993	8.130	7.476	-0.654	7.685	7.863	0.178
1994	8.710	9.062	0.352	7.500	6.464	-1.036
1995	7.960	8.048	0.088	7.000	6.946	-0.054
1996	8.470	8.702	0.232	4.365	5.481	1.116
1997	8.870	9.360	0.490	7.050	7.105	0.055
1998	9.110	9.379	0.269	5.600	5.817	0.217
1999	7.795	8.056	0.261	6.970	6.381	-0.589
2000	7.260	6.788	-0.472	6.495	6.267	-0.228
2001	7.410	7.393	-0.017	6.895	6.520	-0.375
2002	7.495	7.847	0.352	6.720	7.337	0.617

Node 12	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.790	5.796	0.006	4.500	4.399	-0.101
1991	5.280	5.281	0.001	4.650	4.665	0.015
1992	5.210	5.204	-0.006	5.070	4.999	-0.071
1993	5.810	5.817	0.007	5.340	5.562	0.222
1994	5.721	5.611	-0.110	5.170	5.051	-0.119
1995	5.550	5.807	0.257	5.420	5.204	-0.216
1996	6.300	6.093	-0.207	5.230	5.408	0.178
1997	6.400	6.446	0.046	5.500	5.460	-0.040
1998	6.350	6.349	-0.001	3.400	4.102	0.702
1999	6.340	6.345	0.005	5.890	6.071	0.181
2000	6.450	6.484	0.034	5.990	5.222	-0.768
2001	6.480	6.446	-0.034	5.900	5.587	-0.313
2002	6.780	6.782	0.002	6.340	6.669	0.329

Node 13	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	10.90	10.951	0.051	9.250	10.089	0.839
1991	10.61	10.640	0.030	10.430	10.541	0.111
1992	10.76	10.632	-0.128	10.350	9.727	-0.623
1993	10.45	10.572	0.122	10.030	10.016	-0.014
1994	10.03	10.177	0.147	7.740	7.416	-0.324
1995	9.68	8.628	-1.052	8.580	8.651	0.071
1996	8.80	7.596	-1.204	5.600	6.437	0.837
1997	9.56	8.417	-1.143	8.600	8.702	0.102
1998	9.55	9.641	0.091	7.800	7.640	-0.160
1999	9.25	8.950	-0.300	7.450	7.199	-0.251
2000	9.10	8.104	-0.996	7.000	7.162	0.162
2001	8.34	9.603	1.263	7.890	7.650	-0.240
2002	8.21	8.110	-0.100	7.100	7.592	0.492

Node 14	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.440	5.448	0.008	4.050	4.411	0.361
1991	5.560	5.560	0.000	5.340	5.385	0.045
1992	6.380	6.376	-0.004	5.000	4.740	-0.260
1993	7.160	7.164	0.004	7.030	7.014	-0.016
1994	7.030	6.930	-0.100	6.200	5.615	-0.585
1995	6.550	6.749	0.199	4.050	4.078	0.028
1996	6.600	6.469	-0.131	3.900	4.536	0.636
1997	6.350	6.375	0.025	4.950	4.993	0.043
1998	5.200	5.202	0.002	2.800	2.740	-0.060
1999	5.100	5.095	-0.005	3.110	2.746	-0.364
2000	4.600	4.583	-0.017	3.400	3.457	0.057
2001	4.760	4.779	0.019	3.770	3.672	-0.098
2002	4.950	4.951	0.001	3.940	4.153	0.213

Node 15	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.800	5.805	0.005	3.230	3.690	0.460
1991	4.790	4.790	0.000	4.180	4.284	0.104
1992	5.560	5.555	-0.005	10.250	9.706	-0.544
1993	6.300	6.308	0.008	6.120	6.390	0.270
1994	7.890	7.794	-0.096	6.200	5.105	-1.095
1995	7.300	7.540	0.240	5.880	5.766	-0.114
1996	7.350	7.215	-0.135	5.500	6.681	1.181
1997	6.900	6.901	0.001	4.750	4.788	0.038
1998	6.050	6.047	-0.003	4.330	4.745	0.415
1999	5.700	5.714	0.014	3.600	3.229	-0.371
2000	5.700	5.888	0.188	5.210	4.819	-0.391
2001	6.220	6.064	-0.156	5.780	5.241	-0.539
2002	6.040	5.980	-0.060	5.280	5.866	0.586

Node 16	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	16.050	16.047	0.003	14.950	15.203	0.253
1991	15.360	15.379	-0.019	15.630	15.690	0.060
1992	16.330	16.256	0.074	16.000	15.494	-0.506
1993	16.280	16.341	-0.061	15.980	16.217	0.237
1994	15.800	15.954	-0.154	16.650	17.001	0.351
1995	17.100	16.530	0.570	16.200	16.217	0.017
1996	17.000	16.896	0.104	16.000	14.746	-1.254
1997	17.100	17.097	0.003	15.900	15.917	0.017
1998	17.660	17.673	-0.013	16.890	16.744	-0.146
1999	14.750	14.680	0.070	13.950	13.751	-0.199
2000	14.600	13.539	1.061	12.700	13.423	0.723
2001	13.600	14.510	-0.910	12.860	12.466	-0.394
2002	13.700	14.431	-0.731	13.100	13.939	0.839

Node 17	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	3.810	3.979	0.169	1.940	1.832	-0.108
1991	3.400	3.588	0.188	3.150	3.332	0.182
1992	4.010	3.774	-0.236	3.090	2.892	-0.198
1993	4.250	4.414	0.164	3.660	3.699	0.039
1994	5.070	4.081	-0.989	4.220	4.043	-0.177
1995	4.800	5.850	1.050	2.180	2.311	0.131
1996	3.400	3.050	-0.350	1.700	1.976	0.276
1997	3.350	3.469	0.119	1.900	1.925	0.025
1998	3.350	3.433	0.083	2.760	2.363	-0.397
1999	3.340	3.065	-0.275	2.690	2.593	-0.097
2000	3.580	2.162	-1.418	3.200	3.573	0.373
2001	4.510	5.913	1.403	3.770	3.831	0.061
2002	5.210	5.302	0.092	4.930	4.821	-0.109

Node 18	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.580	5.568	-0.012	3.430	3.433	0.003
1991	5.000	5.047	0.047	5.960	5.961	0.001
1992	5.970	5.901	-0.069	5.960	5.959	-0.001
1993	5.490	5.517	0.027	6.000	5.998	-0.002
1994	6.780	6.762	-0.018	6.220	6.211	-0.009
1995	6.950	6.983	0.033	5.950	5.971	0.021
1996	7.200	6.638	-0.562	6.130	5.649	-0.481
1997	6.300	6.859	0.559	5.150	5.628	0.478
1998	5.750	5.779	0.029	3.300	3.300	0.000
1999	4.630	4.509	-0.121	4.300	4.290	-0.010
2000	2.740	2.830	0.090	2.040	2.041	0.001
2001	3.490	3.478	-0.012	3.090	3.085	-0.005
2002	4.490	4.499	0.009	3.790	3.795	0.005

Node 19	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	2.970	2.939	-0.031	2.400	2.264	-0.136
1991	3.280	3.379	0.099	3.090	3.039	-0.051
1992	4.330	4.183	-0.147	3.900	3.969	0.069
1993	3.820	3.877	0.057	2.450	2.441	-0.009
1994	3.840	3.914	0.074	2.800	2.455	-0.345
1995	3.550	3.461	-0.089	1.640	2.122	0.482
1996	3.020	3.207	0.187	1.750	2.289	0.539
1997	3.400	3.257	-0.143	2.850	2.286	-0.564
1998	3.300	3.303	0.003	2.600	2.596	-0.004
1999	2.450	2.535	0.085	2.050	1.894	-0.156
2000	2.380	2.382	0.002	3.200	3.224	0.024
2001	2.150	2.035	-0.115	2.050	2.234	0.184
2002	2.160	2.178	0.018	2.780	2.748	-0.032

Node 20	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	2.650	2.691	0.041	2.600	3.107	0.507
1991	3.240	3.171	-0.069	2.100	2.329	0.229
1992	3.700	3.832	0.132	2.000	1.490	-0.510
1993	5.480	5.390	-0.090	1.650	2.056	0.406
1994	4.200	4.239	0.039	3.730	3.148	-0.582
1995	4.720	4.695	-0.025	3.150	3.227	0.077
1996	4.720	4.800	0.080	3.350	3.106	-0.244
1997	4.700	4.570	-0.130	3.850	3.850	0.000
1998	3.600	3.600	0.000	2.700	2.786	0.086
1999	3.300	3.203	-0.097	3.020	2.948	-0.072
2000	3.290	3.575	0.285	2.970	2.847	-0.123
2001	2.750	2.601	-0.149	2.100	2.302	0.202
2002	6.210	6.193	-0.017	5.850	5.834	-0.016

Node 21	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	3.320	3.365	0.045	3.110	3.638	0.528
1991	5.050	5.037	-0.013	4.390	4.483	0.093
1992	6.250	6.284	0.034	4.790	4.530	-0.260
1993	5.060	5.022	-0.038	4.550	4.781	0.231
1994	5.550	5.625	0.075	4.680	4.169	-0.511
1995	5.800	5.694	-0.106	3.630	3.529	-0.101
1996	5.300	5.280	-0.020	3.660	3.697	0.037
1997	5.250	5.274	0.024	4.200	4.200	0.000
1998	5.200	5.200	0.000	2.250	2.259	0.009
1999	3.890	3.747	-0.143	2.760	2.715	-0.045
2000	4.180	4.476	0.296	3.690	3.564	-0.126
2001	4.930	4.777	-0.153	4.170	4.304	0.134
2002	5.840	5.839	-0.001	5.120	5.131	0.011

Node 22	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	6.500	6.545	0.045	4.560	4.587	0.027
1991	7.600	7.452	-0.148	6.350	6.360	0.010
1992	7.510	7.729	0.219	6.350	6.336	-0.014
1993	7.960	7.877	-0.083	6.270	6.272	0.002
1994	7.000	6.902	-0.098	6.250	6.328	0.078
1995	6.800	6.911	0.111	5.900	5.789	-0.111
1996	7.450	7.345	-0.105	6.150	6.289	0.139
1997	7.120	7.169	0.049	6.390	6.258	-0.132
1998	6.950	6.939	-0.011	2.550	2.551	0.001
1999	3.950	3.866	-0.084	3.400	3.438	0.038
2000	3.850	3.824	-0.026	2.550	2.545	-0.005
2001	4.500	4.656	0.156	4.100	4.065	-0.035
2002	4.950	4.924	-0.026	4.900	4.904	0.004

Node 23	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	7.700	7.696	-0.004	7.280	7.254	-0.026
1991	7.780	7.788	0.008	7.660	7.664	0.004
1992	9.160	9.114	-0.046	8.060	7.991	-0.069
1993	9.120	9.178	0.058	8.690	8.838	0.148
1994	8.360	8.376	0.016	8.240	8.296	0.056
1995	8.760	8.772	0.012	8.070	8.083	0.013
1996	9.060	9.159	0.099	7.810	8.141	0.331
1997	9.010	9.010	0.000	8.180	8.181	0.001
1998	8.910	8.910	0.000	7.890	7.883	-0.007
1999	8.120	8.119	-0.001	8.040	8.052	0.012
2000	8.340	8.269	-0.071	8.110	7.882	-0.228
2001	9.370	9.431	0.061	9.040	9.024	-0.016
2002	9.890	9.757	-0.133	9.240	9.022	-0.218

Node 24	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	12.400	12.361	-0.039	11.100	11.420	0.320
1991	11.880	12.053	0.173	11.250	11.262	0.012
1992	12.900	11.896	-1.004	12.000	11.583	-0.417
1993	10.080	11.268	1.188	10.010	10.204	0.194
1994	14.600	14.304	-0.296	14.000	13.453	-0.547
1995	15.210	15.480	0.270	14.890	14.853	-0.037
1996	16.370	15.409	-0.961	14.700	14.016	-0.684
1997	16.350	16.347	-0.003	14.900	14.902	0.002
1998	15.250	15.248	-0.002	13.230	13.214	-0.016
1999	15.100	15.113	0.013	12.000	11.825	-0.175
2000	13.200	13.950	0.750	11.400	12.312	0.912
2001	12.950	12.292	-0.658	11.700	11.241	-0.459
2002	13.580	14.150	0.570	13.340	14.236	0.896

ode 25	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	12.780	13.223	0.443	12.340	12.410	0.070
1991	13.090	13.156	0.066	12.850	12.884	0.034
1992	12.410	12.274	-0.136	13.110	13.062	-0.048
1993	12.870	12.995	0.125	12.280	12.250	-0.030
1994	12.200	11.611	-0.589	13.400	13.681	0.281
1995	13.860	13.856	-0.004	13.100	12.229	-0.871
1996	14.630	12.513	-2.117	13.010	13.100	0.090
1997	14.300	14.315	0.015	13.200	13.196	-0.004
1998	14.200	14.073	-0.127	10.840	10.860	0.020
1999	10.850	11.017	0.167	10.700	10.190	-0.510
2000	11.210	10.384	-0.826	9.560	9.559	-0.001
2001	10.010	11.569	1.559	9.600	9.585	-0.015
2002	10.200	11.624	1.424	10.800	11.385	0.585

Node 26	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	11.760	12.031	0.271	11.170	11.248	0.078
1991	11.320	11.295	-0.025	11.760	11.759	-0.001
1992	12.010	12.214	0.204	12.410	12.409	-0.001
1993	12.440	12.039	-0.401	12.230	12.144	-0.086
1994	13.260	13.078	-0.182	12.530	12.510	-0.020
1995	13.400	13.403	0.003	13.230	13.384	0.154
1996	13.890	13.407	-0.483	12.690	12.694	0.004
1997	13.720	13.738	0.018	12.900	12.898	-0.002
1998	13.360	13.224	-0.136	14.670	14.687	0.017
1999	14.090	14.120	0.030	13.560	13.439	-0.121
2000	13.240	13.710	0.470	13.110	13.110	0.000
2001	13.770	13.347	-0.423	12.190	12.172	-0.018
2002	12.470	13.125	0.655	12.120	12.115	-0.005

Node 27	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	10.900	10.902	0.002	9.430	9.430	0.000
1991	9.430	9.475	0.045	9.240	9.233	-0.007
1992	11.180	11.159	-0.021	10.930	10.933	0.003
1993	11.820	11.632	-0.188	11.000	11.017	0.017
1994	11.650	12.376	0.726	11.120	11.382	0.262
1995	11.890	12.465	0.575	11.350	10.946	-0.404
1996	14.100	13.711	-0.389	13.800	13.374	-0.426
1997	13.500	12.790	-0.710	12.800	13.255	0.455
1998	12.950	12.863	-0.087	11.200	11.200	0.000
1999	11.250	10.509	-0.741	10.400	10.507	0.107
2000	10.789	11.132	0.343	10.211	10.207	-0.004
2001	9.400	10.273	0.873	8.650	8.672	0.022
2002	10.000	9.573	-0.427	9.350	9.326	-0.024

Node 28	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	10.490	10.506	0.016	9.670	9.686	0.016
1991	10.330	10.345	0.015	10.210	10.100	-0.110
1992	10.810	10.796	-0.014	10.110	10.183	0.073
1993	10.910	10.879	-0.031	9.930	10.343	0.413
1994	11.450	12.522	1.072	11.020	10.260	-0.760
1995	11.830	12.239	0.409	11.060	11.112	0.052
1996	12.340	11.183	-1.157	11.780	11.805	0.025
1997	13.650	13.299	-0.351	13.050	12.988	-0.062
1998	12.250	11.694	-0.556	11.670	11.641	-0.029
1999	9.900	10.232	0.332	9.300	9.504	0.204
2000	9.450	9.769	0.319	9.280	9.297	0.017
2001	8.700	9.450	0.750	8.600	9.264	0.664
2002	10.400	9.597	-0.803	9.200	8.847	-0.353

Node 29	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	9.350	9.427	0.077	8.050	7.983	-0.067
1991	11.500	11.178	-0.322	10.870	10.900	0.030
1992	9.550	10.049	0.499	8.250	8.375	0.125
1993	11.600	9.219	-2.381	10.550	9.538	-1.012
1994	11.600	11.375	-0.225	9.000	9.076	0.076
1995	10.900	10.137	-0.763	8.400	8.096	-0.304
1996	10.000	9.371	-0.629	8.550	8.351	-0.199
1997	9.600	10.607	1.007	8.750	8.951	0.201
1998	9.400	9.741	0.341	7.200	7.213	0.013
1999	8.500	8.527	0.027	8.130	9.078	0.948
2000	8.650	9.237	0.587	4.120	4.034	-0.086
2001	7.500	9.232	1.732	4.310	4.277	-0.033
2002	7.980	8.031	0.051	5.110	5.169	0.059

Node 30	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	6.770	6.909	0.139	4.640	4.566	-0.074
1991	6.510	6.553	0.043	6.310	6.259	-0.051
1992	5.750	4.969	-0.781	5.200	4.275	-0.925
1993	5.930	6.082	0.152	5.340	5.357	0.017
1994	7.500	8.640	1.140	6.850	6.856	0.006
1995	7.340	7.218	-0.122	5.620	5.456	-0.164
1996	7.240	5.940	-1.300	6.150	6.073	-0.077
1997	7.650	7.020	-0.630	6.250	6.441	0.191
1998	6.850	6.288	-0.562	3.350	3.401	0.051
1999	4.850	5.114	0.264	4.350	3.591	-0.759
2000	2.000	2.323	0.323	1.980	1.951	-0.029
2001	3.400	4.745	1.345	2.450	3.681	1.231
2002	3.680	3.669	-0.011	4.000	4.583	0.583

Node 31	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	3.330	3.313	-0.017	2.250	2.197	-0.053
1991	3.260	3.237	-0.023	2.800	2.569	-0.231
1992	3.550	3.687	0.137	2.430	2.229	-0.201
1993	3.760	3.750	-0.010	3.120	3.136	0.016
1994	3.800	3.329	-0.471	2.600	2.776	0.176
1995	2.620	2.991	0.371	1.650	1.388	-0.262
1996	2.850	2.683	-0.167	1.650	1.593	-0.057
1997	2.500	2.627	0.127	1.850	1.996	0.146
1998	2.500	2.685	0.185	1.780	1.814	0.034
1999	1.650	1.573	-0.077	1.670	1.788	0.118
2000	2.700	2.480	-0.220	2.400	2.381	-0.019
2001	2.550	2.796	0.246	1.900	1.829	-0.071
2002	3.620	3.538	-0.082	2.250	2.405	0.155

Node 32	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.250	4.800	-0.450	3.980	4.007	0.027
1991	5.210	4.763	-0.447	5.080	5.079	-0.001
1992	5.670	5.438	-0.232	4.950	4.900	-0.050
1993	5.860	6.058	0.198	5.230	5.373	0.143
1994	6.000	6.782	0.782	5.530	5.431	-0.099
1995	5.980	5.978	-0.002	4.700	4.640	-0.060
1996	5.820	4.919	-0.901	4.500	4.500	0.000
1997	2.730	3.445	0.715	4.620	4.662	0.042
1998	5.700	5.476	-0.224	4.550	4.551	0.001
1999	3.400	3.525	0.125	2.200	2.196	-0.004
2000	3.900	4.035	0.135	3.700	3.700	0.000
2001	4.450	4.784	0.334	3.850	3.847	-0.003
2002	4.900	4.871	-0.029	4.210	4.214	0.004

Node 33	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.850	6.132	0.282	4.900	4.823	-0.077
1991	5.950	5.608	0.342	5.800	5.804	0.004
1992	6.450	6.471	0.021	5.770	5.990	0.220
1993	6.810	6.801	-0.009	7.200	6.687	-0.513
1994	7.340	7.462	0.122	6.250	6.527	0.277
1995	6.860	6.853	-0.007	5.430	5.725	0.295
1996	6.670	6.845	0.175	5.200	5.183	-0.017
1997	6.600	6.080	-0.520	5.330	5.157	-0.173
1998	6.550	6.059	-0.491	4.100	4.104	0.004
1999	5.800	6.090	0.290	3.750	3.744	-0.006
2000	5.100	5.332	0.232	3.500	3.499	-0.001
2001	5.200	5.360	0.160	4.600	4.600	0.000
2002	6.600	6.586	-0.014	7.230	7.218	-0.012

Node 34	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	11.32	11.501	0.181	10.78	10.560	-0.220
1991	12.41	12.379	-0.031	11.9	11.045	-0.855
1992	14.19	13.947	-0.243	11.24	11.232	-0.008
1993	12.25	12.341	0.091	13.76	12.975	-0.785
1994	12.51	12.332	-0.178	11.57	10.620	-0.950
1995	11.94	11.952	0.012	11.84	11.206	-0.634
1996	13.64	12.743	-0.897	11.59	11.395	-0.195
1997	12.72	13.482	0.762	11.19	10.895	-0.295
1998	12.74	13.073	0.333	10.64	10.035	-0.605
1999	11.78	11.515	-0.265	11.07	10.768	-0.302
2000	10.33	10.331	0.001	8.03	8.834	0.804
2001	9.98	10.124	0.144	9.1	9.230	0.130
2002	10.67	10.759	0.089	9.18	9.278	0.098

Node 35	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	8.585	9.083	0.498	7.840	7.709	-0.131
1991	9.130	8.706	-0.424	8.850	8.846	-0.004
1992	10.320	9.820	-0.500	8.505	8.830	0.325
1993	9.530	10.332	0.802	10.480	9.760	-0.720
1994	10.155	10.203	0.048	8.910	9.467	0.557
1995	9.400	9.426	0.026	8.635	8.825	0.190
1996	10.155	9.624	-0.531	8.395	8.369	-0.026
1997	9.660	9.028	-0.632	8.260	8.004	-0.256
1998	9.645	9.440	-0.205	7.370	7.448	0.078
1999	8.790	8.626	-0.164	7.410	7.450	0.040
2000	7.715	8.464	0.749	5.765	5.763	-0.002
2001	7.590	7.957	0.367	6.850	6.777	-0.073
2002	8.375	8.341	-0.034	8.205	8.228	0.023

Node 36	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	9.060	8.992	-0.068	8.75	8.698	-0.052
1991	9.540	9.546	0.006	8.65	8.663	0.013
1992	10.360	10.313	-0.047	10.18	10.106	-0.074
1993	10.680	10.738	0.058	10.12	10.197	0.077
1994	9.590	11.228	1.638	10.03	10.864	0.834
1995	12.730	11.828	-0.902	12.71	11.860	-0.850
1996	12.960	12.054	-0.906	11.48	11.295	-0.185
1997	12.930	13.287	0.357	11.68	11.928	0.248
1998	12.880	12.165	-0.715	11.76	11.393	-0.367
1999	12.340	12.361	0.021	11.98	12.380	0.400
2000	12.210	12.643	0.433	12.03	12.009	-0.021
2001	12.000	12.672	0.672	11.79	12.136	0.346
2002	12.560	12.013	-0.547	11.92	11.551	-0.369

Node 37	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	8.830	8.827	-0.003	7.160	7.195	0.035
1991	8.190	8.174	-0.016	7.860	7.861	0.001
1992	8.830	8.899	0.069	7.930	7.938	0.008
1993	9.030	8.974	-0.056	8.570	8.552	-0.018
1994	8.710	8.797	0.087	8.260	8.001	-0.259
1995	9.080	9.062	-0.018	8.200	8.107	-0.093
1996	10.090	8.413	-0.237	9.080	9.179	0.099
1997	10.180	8.700	-0.150	9.180	9.107	-0.073
1998	9.110	8.256	-0.214	7.200	7.026	-0.174
1999	7.680	8.197	0.267	5.930	5.917	-0.013
2000	8.800	8.334	0.104	7.000	6.994	-0.006
2001	6.480	8.330	0.180	7.300	7.467	0.167
2002	6.580	8.627	0.127	7.500	7.826	0.326

Node 38	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	6.200	6.241	0.041	4.430	4.687	0.257
1991	5.330	5.326	-0.004	4.850	5.115	0.265
1992	5.340	5.401	0.061	5.110	4.650	-0.460
1993	6.190	5.855	-0.335	5.480	5.278	-0.202
1994	5.710	5.942	0.232	4.900	5.093	0.193
1995	5.890	5.965	0.075	4.990	5.103	0.113
1996	6.460	6.426	-0.034	4.640	4.696	0.056
1997	6.200	6.155	-0.045	5.490	5.294	-0.196
1998	6.430	6.478	0.048	4.020	3.987	-0.033
1999	6.530	6.503	-0.027	3.690	3.515	-0.175
2000	6.740	6.719	-0.021	3.390	3.409	0.019
2001	6.670	6.664	-0.006	3.250	3.440	0.190
2002	6.560	6.575	0.015	4.150	4.122	-0.028

Node 39	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	4.820	4.901	0.081	3.250	3.287	0.037
1991	4.360	4.360	0.000	3.580	3.534	-0.046
1992	4.600	4.527	-0.073	4.170	4.108	-0.062
1993	4.860	4.946	0.086	4.110	4.331	0.221
1994	5.340	5.127	-0.213	4.450	4.166	-0.284
1995	4.800	4.790	-0.010	3.900	3.972	0.072
1996	4.650	4.893	0.243	4.000	3.945	-0.055
1997	4.400	4.415	0.015	3.590	3.680	0.090
1998	4.300	4.038	-0.262	2.800	2.880	0.080
1999	2.400	2.549	0.149	1.950	1.948	-0.002
2000	2.500	2.984	0.484	1.850	1.855	0.005
2001	3.400	2.851	-0.549	2.350	2.273	-0.077
2002	3.850	3.899	0.049	2.700	2.722	0.022

Node 40	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	8.340	8.140	-0.200	7.140	6.755	-0.385
1991	8.410	8.471	0.061	7.550	7.545	-0.005
1992	8.490	8.463	-0.027	7.390	7.360	-0.030
1993	8.560	8.575	0.015	7.880	7.911	0.031
1994	8.410	8.569	0.159	8.660	8.780	0.120
1995	8.980	8.649	-0.331	8.280	8.086	-0.194
1996	8.910	8.965	0.055	8.060	7.984	-0.076
1997	8.760	9.000	0.240	7.860	8.097	0.237
1998	8.710	8.760	0.050	5.810	5.871	0.061
1999	6.110	6.077	-0.033	5.760	5.152	-0.608
2000	6.080	6.050	-0.030	4.960	4.924	-0.036
2001	5.560	5.551	-0.009	4.560	5.429	0.869
2002	7.430	7.479	0.049	7.360	7.377	0.017

Node 41	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	8.250	8.251	0.001	7.120	6.471	-0.649
1991	7.800	7.796	-0.004	6.700	6.697	-0.003
1992	8.440	8.436	-0.004	8.100	8.051	-0.049
1993	8.620	8.622	0.002	7.900	7.940	0.040
1994	8.490	8.551	0.061	7.500	7.681	0.181
1995	8.980	8.858	-0.122	7.400	7.138	-0.262
1996	8.500	8.587	0.087	7.780	7.683	-0.097
1997	8.090	8.113	0.023	7.120	7.435	0.315
1998	7.980	7.904	-0.076	5.580	5.662	0.082
1999	7.330	7.380	0.050	6.380	6.275	-0.105
2000	7.050	7.132	0.082	6.570	6.522	-0.048
2001	6.830	6.686	-0.144	6.080	6.141	0.061
2002	6.860	6.903	0.043	5.670	6.206	0.536

Node 42	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	3.830	3.717	-0.113	2.380	2.748	0.368
1991	3.750	3.820	0.070	2.460	2.919	0.459
1992	3.900	4.455	0.555	3.540	3.670	0.130
1993	4.190	4.137	-0.053	4.020	3.983	-0.037
1994	4.670	4.611	-0.059	4.210	3.043	-1.167
1995	4.500	4.426	-0.074	2.350	2.850	0.500
1996	3.780	3.773	-0.007	2.750	2.902	0.152
1997	4.450	4.446	-0.004	3.550	3.061	-0.489
1998	5.480	4.962	-0.518	3.400	3.249	-0.151
1999	3.850	4.418	0.568	3.450	2.957	-0.493
2000	2.000	2.738	0.738	1.950	2.038	0.088
2001	2.850	2.221	-0.629	2.000	2.817	0.817
2002	3.950	3.848	-0.102	2.100	1.923	-0.177

Node 43	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.050	5.870	0.470	4.000	4.168	0.168
1991	5.140	5.870	0.110	4.440	4.506	0.066
1992	4.850	5.608	0.358	4.350	4.226	-0.124
1993	4.830	5.671	0.271	4.550	4.359	-0.191
1994	5.450	5.911	0.461	4.900	4.453	-0.447
1995	5.400	5.030	-0.370	4.200	4.440	0.240
1996	4.840	4.813	-0.027	4.500	4.208	-0.292
1997	5.200	5.111	-0.089	3.900	4.370	0.470
1998	5.400	5.723	0.323	3.350	3.358	0.008
1999	4.500	4.178	-0.322	4.050	4.422	0.372
2000	2.200	2.743	0.373	3.850	3.804	-0.046
2001	5.100	4.702	-0.398	4.600	4.393	-0.207
2002	5.450	5.516	0.066	4.400	4.383	-0.017

Node 44	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	9.380	9.039	-0.341	5.890	7.292	1.402
1991	8.510	8.789	0.279	8.340	7.085	-1.255
1992	8.370	8.152	-0.218	8.400	7.603	-0.797
1993	9.280	9.302	0.022	9.120	9.231	0.111
1994	9.450	9.450	0.000	8.650	8.591	-0.059
1995	9.150	9.186	0.036	7.630	7.524	-0.106
1996	8.620	8.761	0.141	7.900	7.919	0.019
1997	8.550	8.558	0.008	7.700	7.591	-0.109
1998	8.700	8.249	-0.451	7.200	7.213	0.013
1999	7.900	8.165	0.265	7.550	7.139	-0.411
2000	6.850	7.261	0.411	5.550	5.543	-0.007
2001	7.250	6.907	-0.343	6.600	7.089	0.489
2002	7.500	7.690	0.190	6.600	7.310	0.710

Node 45	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	7.430	5.866	-0.744	4.600	5.578	0.978
1991	7.500	8.769	0.539	5.400	4.619	-0.781
1992	7.450	8.520	-0.510	6.800	5.899	-0.901
1993	7.620	8.270	0.650	5.450	5.585	0.135
1994	8.250	6.836	-0.584	7.350	7.350	0.000
1995	5.800	5.770	-0.030	4.100	3.918	-0.182
1996	6.220	4.705	0.105	4.150	4.143	-0.007
1997	5.250	4.557	-0.443	5.300	5.283	-0.017
1998	5.400	4.727	-0.353	3.700	3.739	0.039
1999	4.550	5.069	0.519	3.800	3.372	-0.428
2000	2.050	5.385	0.585	1.900	1.877	-0.023
2001	3.150	5.702	0.502	3.110	3.128	0.018
2002	3.140	5.302	-0.348	3.740	4.668	0.928

Node 43	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	5.050	5.870	0.470	4.000	4.168	0.168
1991	5.140	5.870	0.110	4.440	4.506	0.066
1992	4.850	5.608	0.358	4.350	4.226	-0.124
1993	4.830	5.671	0.271	4.550	4.359	-0.191
1994	5.450	5.911	0.461	4.900	4.453	-0.447
1995	5.400	5.030	-0.370	4.200	4.440	0.240
1996	4.840	4.813	-0.027	4.500	4.208	-0.292
1997	5.200	5.111	-0.089	3.900	4.370	0.470
1998	5.400	5.723	0.323	3.350	3.358	0.008
1999	4.500	4.178	-0.322	4.050	4.422	0.372
2000	2.200	2.743	0.373	3.850	3.804	-0.046
2001	5.100	4.702	-0.398	4.600	4.393	-0.207
2002	5.450	5.516	0.066	4.400	4.383	-0.017

Node 44	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	9.380	9.039	-0.341	5.890	7.292	1.402
1991	8.510	8.789	0.279	8.340	7.085	-1.255
1992	8.370	8.152	-0.218	8.400	7.603	-0.797
1993	9.280	9.302	0.022	9.120	9.231	0.111
1994	9.450	9.450	0.000	8.650	8.591	-0.059
1995	9.150	9.186	0.036	7.630	7.524	-0.106
1996	8.620	8.761	0.141	7.900	7.919	0.019
1997	8.550	8.558	0.008	7.700	7.591	-0.109
1998	8.700	8.249	-0.451	7.200	7.213	0.013
1999	7.900	8.165	0.265	7.550	7.139	-0.411
2000	6.850	7.261	0.411	5.550	5.543	-0.007
2001	7.250	6.907	-0.343	6.600	7.089	0.489
2002	7.500	7.690	0.190	6.600	7.310	0.710

Node 45	Pre-monsoon			Post-monsoon		
	Observed	Predicted	Variation	Observed	Predicted	Variation
1990	7.430	5.866	-0.744	4.600	5.578	0.978
1991	7.500	8.769	0.539	5.400	4.619	-0.781
1992	7.450	8.520	-0.510	6.800	5.899	-0.901
1993	7.620	8.270	0.650	5.450	5.585	0.135
1994	8.250	6.836	-0.584	7.350	7.350	0.000
1995	5.800	5.770	-0.030	4.100	3.918	-0.182
1996	6.220	4.705	0.105	4.150	4.143	-0.007
1997	5.250	4.557	-0.443	5.300	5.283	-0.017
1998	5.400	4.727	-0.353	3.700	3.739	0.039
1999	4.550	5.069	0.519	3.800	3.372	-0.428
2000	2.050	5.385	0.585	1.900	1.877	-0.023
2001	3.150	5.702	0.502	3.110	3.128	0.018
2002	3.140	5.302	-0.348	3.740	4.668	0.928

VITA

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ABSTRACT

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Thesis title : Land and water resources planning and management of Bijnor district using Remote Sensing and G.I.S.

Advisor : Dr. H.C. Sharma

The rapid expansion of population, agriculture and industry in recent years, throughout the country, has brought about a steep increase in water demand. All these requirements have to be met mostly from available surface and groundwater resources. The water resources which looked plentiful at one time have become scare with the increasing demand on the available supplies. Situation turned grim in Bijnor district of Uttar Pradesh where in some blocks withdrawal rate of groundwater is beyond the limits of recharge capacities. The area has no sharp topography and consists of alluvial soil. Groundwater abstraction structures were made abruptly along with the prevailing cropping pattern. The present investigation was, therefore, undertaken to study the prevailing land use pattern, ground water behaviour and to suggest appropriate recharge techniques suited to this condition with the help of Remote Sensing and G.I.S.

Keeping this in view, soils of Bijnor district were classified according to land capability, land irrigability and land suitability to suggest alternative cropping pattern for the district to commensurate with the present situation. Groundwater inventory for the years 1990 and 2002 revealed that in 1990, out of eleven blocks only in Noorpur block groundwater exploitation level was between 65% to 85%. But in 2002, in two blocks groundwater exploitation level was above 85% and in four blocks it was between 65% to 85%. To predict the future groundwater table depth, six simulation models were developed for the area. Model 6 gave significantly better results correlating the discharge

and recharge parameters in a better way. Remote Sensing and G.I.S. were applied to delineate different landforms from the Satellite imageries (IRS-1D LISS-III). The landforms were correlated with identified soil associations and water table decline contours of pre-monsoon season**.** Suitable groundwater recharge plans have been suggested, considering the geomorphic features, to keep the groundwater level within safe and desired limit in future.

Dr. H.C. Sharma | **Moumita Roy**
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