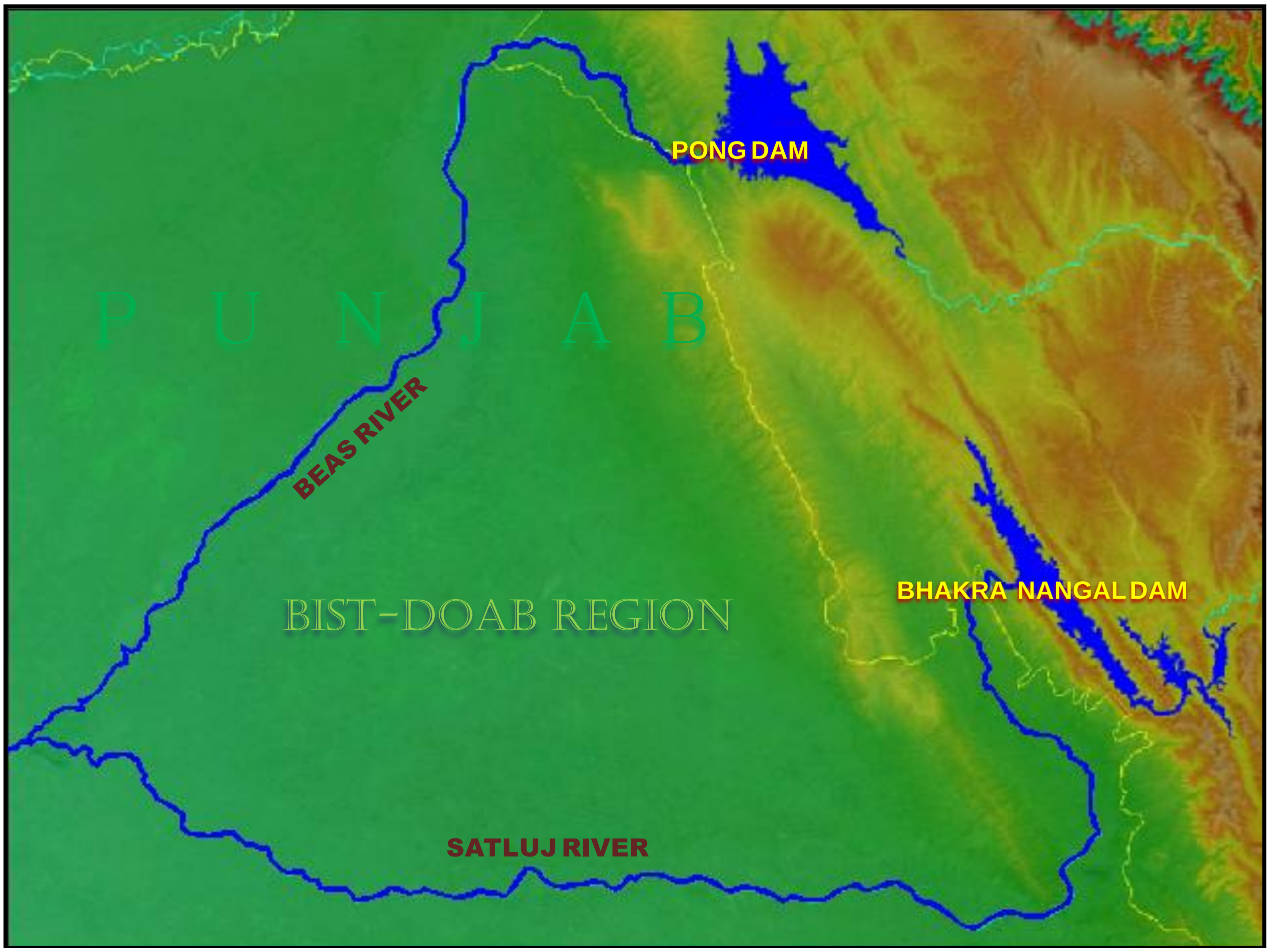
GROUNDWATER DYNAMICS OF BIST-DOAB REGION USING ISOTOPES



National Institute of hydrology

Roorkee-247667

(July 2009 - March 2014)

PREFACE

Hydrology Project Phase II (HP-II) is the follow-up of the Hydrology Project (HP-I). HP-I was an 8 year project (during 1995-2003) and was taken up to develop Hydrological Information System (HIS) by creating facilities and standardized procedures for data collection, data compilation, processing and data storage for data use. It was proposed by the Ministry of Water Resources, Government of India. After successful completion of HP-I, HP-II started. The objectives of HP-II are i) To extend and promote the sustained and effective use of Hydrological Information System (HIS) by all potential users concerned with water resources planning and management, both in public and private, thereby contributing to improve productivity and cost effectiveness of water related investments in 13 participating States and 8 Central agencies. ii) To extend HIS to the four new state agencies of Goa, Himachal Pradesh (H.P.), Pondicherry and Punjab and two central agencies Bhakra Beas Management Board (BBMB) and Central Pollution Control Board (CPCB). iii) Strengthening the capabilities of implementing agencies at state/central level in using HIS for efficient water resource planning and management; Awareness building and outreach services about HIS use.

The Purpose Driven Study (PDS) is a new component that is included in HP-II which was not there earlier in HP-I. Under PDS, National Institute of Hydrology has taken up various hydrological studies including the present one that is conducted in Beas-Satluj Doab region (popularly known as Bist Doab) of Punjab by Hydrological Investigations Division of the Institute. The water table in the Bist Doab region is falling at alarming rate especially in the central part of the Bist Doab where stage of groundwater development is one of the highest in the country. The spatial variability of groundwater condition, its depletion rate, specific reasons for this it and remedial measures to abate or rejuvenate it have been investigated in detail by the research team of this study. The PI of the study team Dr. M. Someshwar Rao and his team members have spent enormous efforts in collecting and analyzing large number of water samples and corroborated their results with field based data. During the course of study the team has also disseminated the knowledge through public interactions, mass awareness programmes, organizing conferences, brain storming session and also through publications in journals and conferences. The report prepared by the team will be of immense use to scientists and engineers of field organizations and also to academic institutions particularly for those from Punjab.

(R.D. Singh)
Director

ACKNOWLEDGEMENT

The present work is part of the research project funded by the World Bank under Purpose Driven Study of PDS (Groundwater Dynamics of Bist-Doab), Ministry of Water Resources, Government of India, initiated by the Hydrological Investigations Division of NIH, Roorkee, India. Hence, the financial support from the World Bank is acknowledged.

The National Institute of Hydrology has made remarkable contributions in the field of hydrological research with all the aspects. The learned guidance and thoughtful directions from the director & Head of the department has played a great role in completion of the project work. At the time of preparation final project report of "Groundwater Dynamics of Bist - Doab area of Punjab using Isotopes" the authors also express the gratitude to the NIH authorities for their help and valuable cooperation. The Institute records its appreciation to the officers of the Ministry of Water Resources for their cooperation and help. Central Water Commission, Central Ground Water Board, India Meteorological Department, Central Pollution Control Board and several other Central and State government organizations provided help, guidance and cooperation. Various significant achievements during the period of project would not have been possible without their help.

The authors also gratefully acknowledge the advice and cooperation received from members of the Working Group, Regional Coordination Committees, and the eminent scientists and engineers from various academic and research organizations. Hydrology being a field-oriented, multidisciplinary science, in study the role of states is very important. The authors are thankful to Chandigarh regional Directorate of Central Ground Water Board for providing the help to collect the data for Hoshiarpur, SBS Nagar (previously known as Nawanshahr), Jalandhar and Kapurthala districts of Punjab, India. The authors are also thankful to Punjab State Government and their organisations for providing help in collecting the hydrological data for carrying out collaborative studies and for inviting the Institute for organizing short duration workshops in the States for the benefit of their in-service engineers and technical personnel level also. At last but not least authors express thanks to all team members, Lab staff and office staff that actively supported to make this project successful.

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Abbreviations

CGWB: Central Ground Water Board
DWSS: Department of Water Supply and Sanitation
IAEA-: International Atomic Energy Agency
WMO: World Meteorological Organization
MWL: Meteoric Water Line
WHO: World Health Organisation
GMWL: Global Meteoric Water Line
BIS: Bureau of Indian Standards
RSC: Residual Sodium Carbonate
SAR: Sodium Adsorption Ratio
PCA: Principal Components Analyasis
SMOW: Standard Mean Oceanic Water
VSMOW: Vienna Standard Mean Ocean Water
SLAP: Standard light Antarctic precipitation
NBS: National Bureau of Standard
GISP: Greenland ice sheet precipitation
BGL: Below Ground Level
SAR: Sodium Adsorption Ratio
RSC: Residual Sodium Carbonate
Ca: Calcium
Mg: Magnesium
Na: Sodium
K: Potassium
CO_3: Carbonates
HCO_3: Bi Carbonate
Cl^-: Chloride
SO_4: Sulphate
Al: Aluminium
OH: Hydroxide
USSD: Unstructured Supplementry Service Data
TGA: Total Geographical Area
GCA: Gross Cropped Area
NRCD: National River Conservation Directorate
CRU: Climate Research Unit
GHCN: Global Historical Climatology Network
GRASS: Geographic Resourses Analytical support system
DI-IRMS: Dual Inlet Isotope Ratio Mass Spectrometer
CF-IRMS: Continous Flow Isotope Ratio Mass Spectrometer
EC: Electric Conductivity
TDS: Total Dissolved Solids
CAI: Chloro Alkaline Indices
IMWL: Indian Meteoric Water Line
TU: Tritium Units
AWLR: Auto-graphic Water Level Recorder
SBS: Sardar Bhagat Singh
DEM: Digital Elevation Model
NWR: North Western Region

1

INTRODUCTION

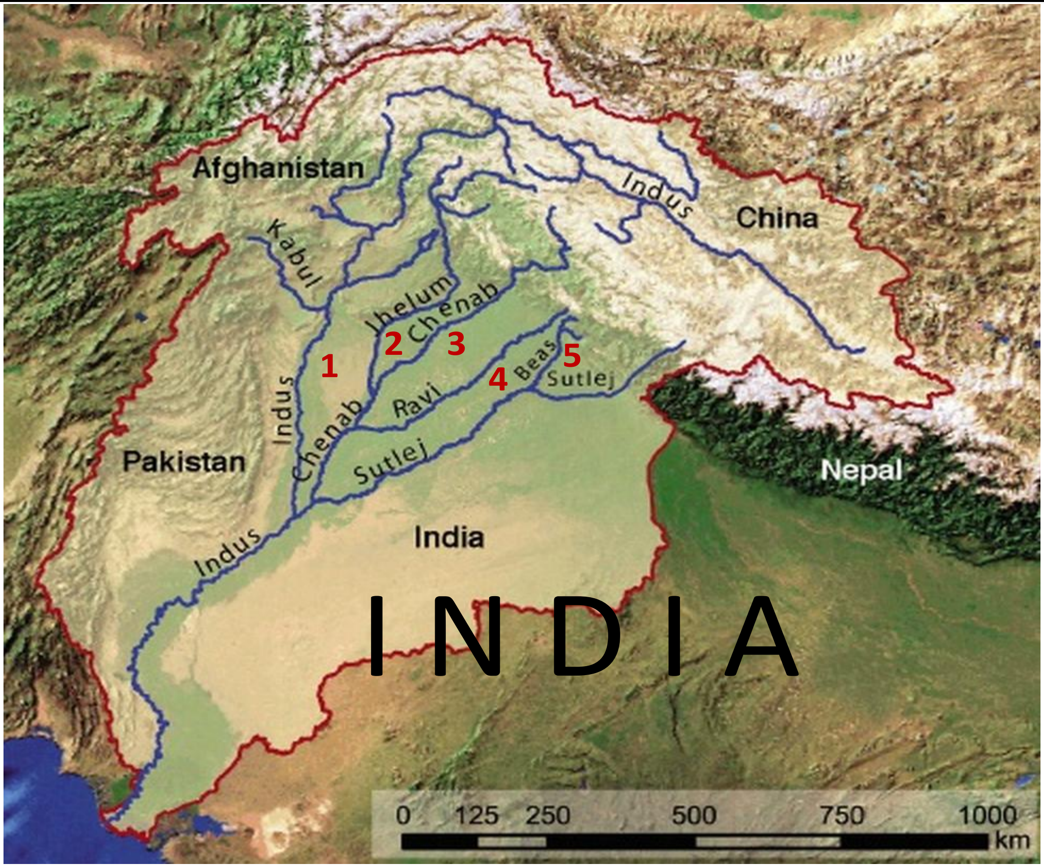
Chapter 1

INTRODUCTION

The Purpose Driven Studies (PDS) is a vertical component wherein the Institute has actively participated with State and Central Agencies in carrying out eleven PDS. The present PDS entitled "GROUNDWATER DYNAMICS OF BIST-DOAB REGION USING ISOTOPES" is conducted in the Beas-Satluj (abbreviated as Bist) Doab (Doab means an interfluves region i.e., the region enclosed between the two rivers) region of Punjab and is conducted in technical consultation with CGWB, North West Region, Chandigarh and the Punjab Water Resources & Environment Directorate (PWR&ED), Chandigarh.

Punjab literally meaning the Land of Five Rivers ('punj' means five and 'ab' means rivers) that refers to the rivers: Jhelum, Chenab, Ravi, Satluj and Beas. All are tributaries of the Indus River. Each of the tracts of land lying between the confluent rivers or interfluvial region have the names (said to have been coined by Raja Todar Mal, a minister of the Mughal emperor Akbar) from west to east: Sindhu Sagar Doab (between Sindhu (i.e., Indus) and Jhelum), Jech Doab (between **J**h**e**lum-**Ch**enab), Rechna Doab (between **R**avi-**Chena**b), Bari Daob (between **Bea**s-**R**av**i**). After the independence, India and Pakistan signed the Indus Water Treaty in 1960 on the matter of sharing of water of these rivers (Fig 1.1). As according to this, since March 31, 1970, India got full rights for use of the waters of the three rivers: Ravi, Beas and Sutlej; before they enter Pakistan while, Pakistan has got exclusive right to waters of the rivers: Jhelum, Chenab and Indus but with some stipulations for development of projects on these rivers in India.

The Indian part of Punjab is divided into four natural regions: Malwa (region south of river Satluj), Bist Doab or simply Doaba (region between the rivers Satluj and Beas), Majha (region west of river Beas) and Powadh (region in Rupnagar and Ambala district) that falls between the rivers Satluj and Ghaggar (Fig 1.2). The people living in Malwa, Doaba, Majha and Powadh are known as Malwai, Doabi, Majhai and Pawadhi. Of these, the Doaba region is the largest producer of wheat in India. Majhi is the main dialect of Punjab.



Interfluvial (Doab) regions 1. Sind Sagar Doab, 2. Jech Doab, 3. Rechna Doab, 4. Bari Doab and 5. Bist Doab.

Fig 1.1: **Rivers of Indus basin and the inter-fluvial (Doab) regions 1-5.**

The Bengal famine of 1943 of pre-partition India estimated 3-4 million deaths due to starvation, malnutrition and diseases. After the independence, India tried to increase its food production but could not stand much in front of the growing population. This called for drastic action- Green Revolution (GR) in 1967. The GR's main elements were to expand the farming areas, increase in cropping intensity (more than one cropping in the farmland), use of high yielding varieties of wheat and rice crops, use of mechanized farming, use of chemical fertilizers and expansion in canal and well irrigated areas. The GR over a period from 1967 to 1985 transformed India from starving nation to an exporter of food. Compared to all other states of India the GR was most successful in Punjab and this earned the name to the state as *Bread Basket of India or Food Bowl of India*. The agricultural development made the Punjab the most prosperous state in the country. The state occupies only 1.6% of India's land but, produces about 21% of India's wheat, 8.5% of its rice, and 7.5% of its cotton. Although the Green Revolution in India particularly in

Punjab has been able to improve agricultural output, its blind use has also led to some serious consequences like depletion in ground water level, deterioration of soil & water quality, soil salinity, water-logging and other environmental issues.

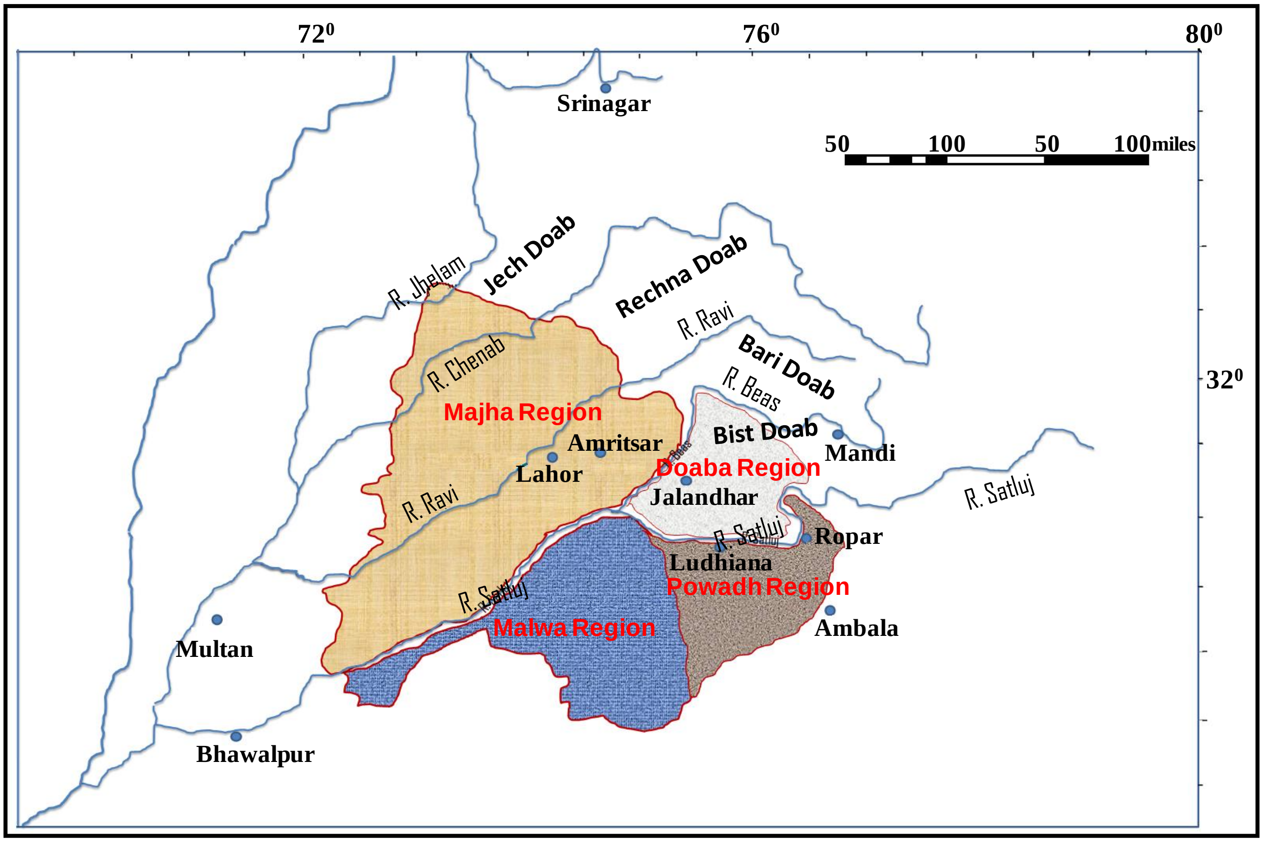


Fig 1.2: Rivers, Doabs and the dialects in the Doabs (Majha, Doaba, Malwa and Powadh) of Punjab.

With the continuous rotation of wheat & paddy cropping pattern, the soil and water of Punjab have been degraded and depleted. Excessive use of chemical fertilizers & insecticides have destroyed the physical structure of the soil leading to decreased water holding capacity and friable & loose structure. Fertility and production capacity of soil has reduced. The water and soil problems is causing increasing costs of food production and declining the productivity & profitability levels. The soils of Punjab are now sic and need relief & proper treatment. Intensive use of groundwater has resulted 93 out of 138 blocks to dark category. In Nihal Singh Wala block of Moga district the groundwater development is at 513% (highest in the country). To arrest the groundwater quality and quantity problems, government is promoting for groundwater recharge measures and development of surface water bodies. These measures have marginally improved the conditions.

Isotope hydrology tools have proven to be very useful in assessing groundwater hydrology, addressing aspects related to recharge processes, delineation of flow patterns, water quality issues and interactions with surface water bodies.

The present study is undertaken in the Bist Doab region of Punjab keeping in mind a sharp decline in water level due to high rate of population growth and increasing pressure for agriculture and drinking water demand. Under the PDS, extensive field visits to the study areas was conducted to collect water samples, field related data, installed field based systems to collect time series data etc. Collected samples were analysis for isotope and chemical parameters and the data collected was examined for trend analysis. Based on the field data, laboratory data and trend analysis recommendations to improve the groundwater conditions for its sustainability are given. The present report is undertaken with the following specific objectives:

- Identification of recharge zones in deep aquifers
- Identification of recharge sources in deep and shallow aquifers
- Identification of flow pattern and flow velocity in groundwater
- Integrating the results for application in Groundwater Management

The report has been structured into 7 chapters which included:

Chapter1. Introduction: The first chapter provides a brief note on the water resource of the state Punjab & the study area. Depending upon geology, Punjab is facing both water quality and quantity/availability problems. Of these, Bist Doab is mainly facing the problem of groundwater availability due to its rapid falling trend of groundwater level in almost the entire region. Keeping this in mind, the present study is taken up to investigate the availability of groundwater resource, mapping of its recharge sources and recharge zones and management measures for abatement and augmentation of this precious natural resource. Various techniques have been used to attain these objectives. This is also summarized in the chapter.

Chapter2. Punjab state and study area: In the chapter 2, hydrogeology of the study, surface water bodies (rivers, canals, reservoir etc) and land use details are described briefly. Over the years, groundwater withdrawal has increased tremendously through lowering of government and private tubewells. These details of surface water and groundwater and their utilization is discussed in the Chapter.

Chapter3. Data collection and Trend Analysis: In the present project various physico-chemical and isotopic techniques have been used to analyze the samples. These techniques are discussed briefly in the chapter. The trend analysis of rainfall and ground water depth of the study area are discussed as well as seasonal variation in rainfall and water table depth also are analysed in this chapter.

Chapter4. Result and discussions: As the much analytical work are done for the water quality during the study the results of these analysis are discussed in chapter 4. Information of different types of water sample collection (rain water, surface water, ground water) and its analysis (stable and unstable isotopic) with the are given in this chapter. Besides this the peizometer installation and sampling with their location in the study also shown in this chapter.

Chapter5. Management Measures and Artificial Recharge- In this chapter the management measures for the problems in study area have suggested. Moreover this will give enough information to consider possible future risks in all phases of water resource. The possible link canal in the study area for the irrigation and ground water recharge purpose discussed in this chapter.

Chapter6. Conclusions: In sixth chapter all the study has conclude. The chapter gives the information of the qualitative and quantitative problem of water in the study area with agriculture and domestic point of view. This gives an opportunity to define the degree of vulnerability of local water resources and plan appropriate adaptation measures that must be taken ahead of time.

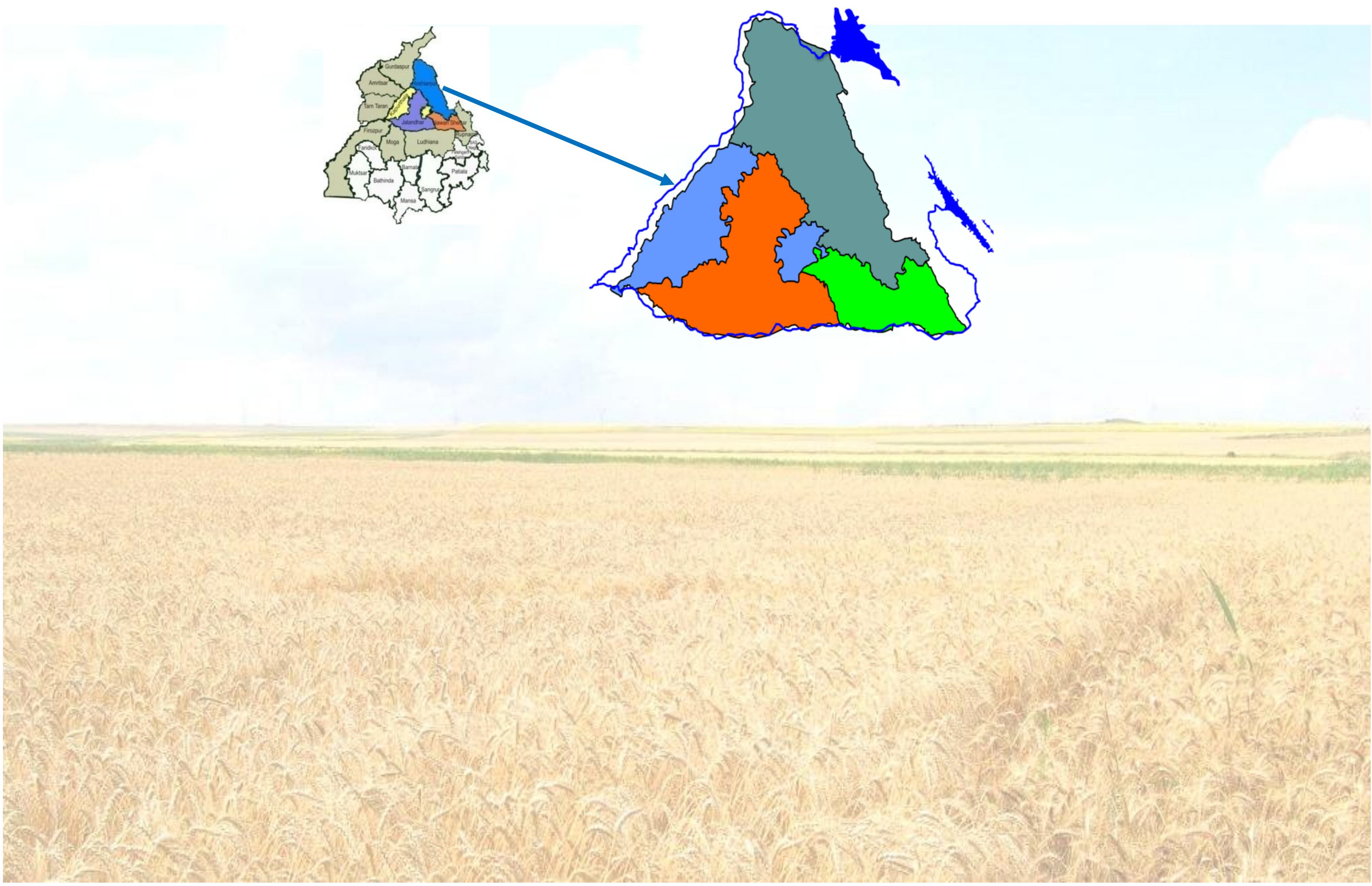
Chapter7. Executive Summary: This chapter reflect the brief knowledge of whole study of the area including the isotopic analysis, ground water analysis, surface water analysis, and rainfall analysis. The result of the all over study in brief also has been discussed in this chapter. There is a growing need for an integrated analysis that can quantify the impacts of rainfall and ground water change on various aspects of water (quality and availability).

Indus Water Treaty

The Indus Water Treaty came into existence on September 19, 1960. The treaty was signed in Karachi by the then Indian Prime Minister Jawaharlal Nehru and the then President of Pakistan Ayub Khan. According to this treaty, Ravi, Beas and Sutlej, which constitute the eastern rivers, are allocated for exclusive use by India before they enter Pakistan. However, a transition period of 10 years was permitted in which India was bound to supply water to Pakistan from these rivers until Pakistan was able to build the canal system for utilization of waters of Jhelum, Chenab and the Indus itself, allocated to it under the treaty. Similarly, Pakistan has exclusive use of the western rivers Jhelum, Chenab and Indus but with some stipulations for development of projects on these rivers in India. Pakistan also received one-time financial compensation for the loss of water from the eastern rivers. Since March 31, 1970, after the 10-year moratorium, India has secured full rights for use of the waters of the three rivers allocated to it. The treaty resulted in partitioning of the rivers rather than sharing of their waters. Under the treaty both the The countries agree to exchange data and co-operate in matters related to the treaty. For this purpose, treaty creates the Permanent Indus Commission, with a commissioner appointed by each country. With the emerging knowledge of environmental flow requirement, land use change, growing energy demand, population growth, the knowledge of geohydrology and changing climate the analyst acknowledge for revision of the treaty.

2

STUDY REGION - BIST DOAB IN PUNJAB



Chapter 2

STUDY REGION-BIST DOAB IN PUNJAB

Punjab state is one of the most productive agricultural regions in the country and is supported by its dense network of canals spanning over 14500 kms of length that distributes its source water from the rivers Satluj, Ravi and Beas and also through extensive groundwater extraction (by over 33 BCM) through millions of its state and private owned pumps. The era of sharp agricultural growth with intensive irrigation support begun with Green Revolution and this ultimately earned the name- 'Bread Basket of India' to the state. Regarding the prosperity, Punjab is the second largest producer of cotton and blended yarn in India, it is the second highest rural tele-density in the country, it is the highest per capita electricity consuming state in the country, the survey done by India Today Group accorded Punjab as the best overall state in India from 2003 to 2010. The agriculture prosperity can be seen from the fact that the state produces 19.5 % of India's wheat, 11% of India's rice and 10.26 % of India's cotton. The state's fertilizer consumption is 223.46kg per hectare compared to 90 kg nationally. The state has been awarded the National Productivity award for agricultural extension services for ten years from 1991-92 to 1998-99 and from 2001 to 2003-04. The Doaba region of Punjab is one of the most fertile region of the world and it is one of the largest per capita producer of wheat in the world. In the recent years, a drop in the productivity due to falling fertility of soil and falling groundwater levels is a major concern of the state. The extensive water use in Punjab is resulting in falling groundwater levels in most of the regions most specifically in Bist Doab region, water logging in some locations and soil & water quality deterioration in various parts. and also water logging in some parts (mostly in south-western region). The present chapter provides an overview of Punjab and details of the study region.

The state Punjab is bounded by Jammu & Kashmir in the north-east, by Himachal Pradesh in east and south-east, by Haryana in south, by Rajasthan in south and west and shares the international boundary with Pakistan on western side (fig 2.1). Punjab shares the capital (Chandigarh) with the neighboring state Haryana. Punjab state is divided into 22 districts which are further divided into 77 tehsils and 141 development blocks.

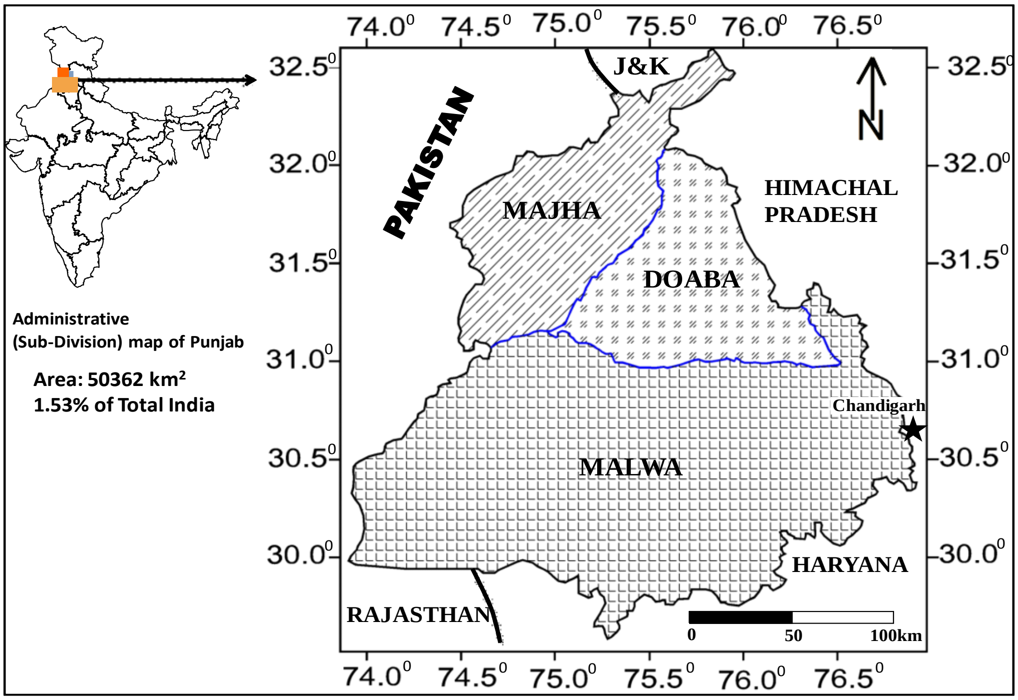


Figure 2.1: Socio-Cultural region of Punjab State

With total geographical area of Punjab at 50,362 sq. km the population density of Punjab is 550 per sq km. This is higher than national average of 382 per sq. km. With the economic growth of Punjab the population of Punjab is also growing at a rapid rate (fig 2.2).

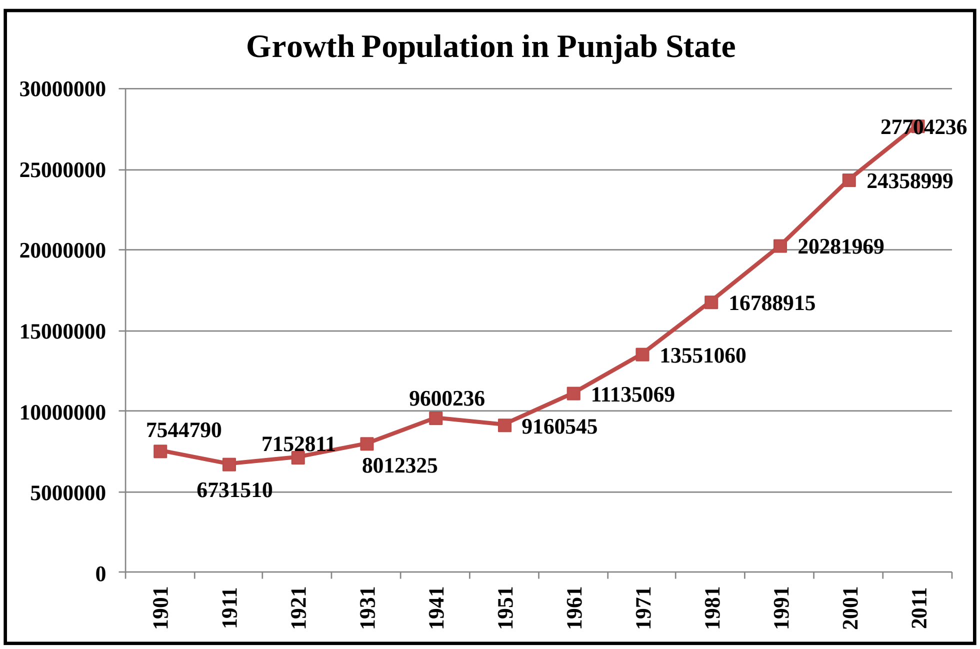


Figure 2.2: Decadal Growth of population in Punjab State

Source: 1.Statistical Abstract, Punjab, 2. State Agricultural Profile – Punjab

The tributaries of the Indus rivers: Satluj, Beas, Ravi form the main drainage system in the state of Punjab. Two major rivers, the Satluj and Beas, traverse in the state whereas, Ravi and Ghaggar touch the northern and southern borders of the state respectively. At Harike headworks, the two rivers Beas and Satluj join and continue thereafter as the river Satluj. Besides these major rivers, the state is also drained by several small rivers like White Bein, Black Bein, Ghaggar river and seasonal revaluates in the state (fig 2.3).

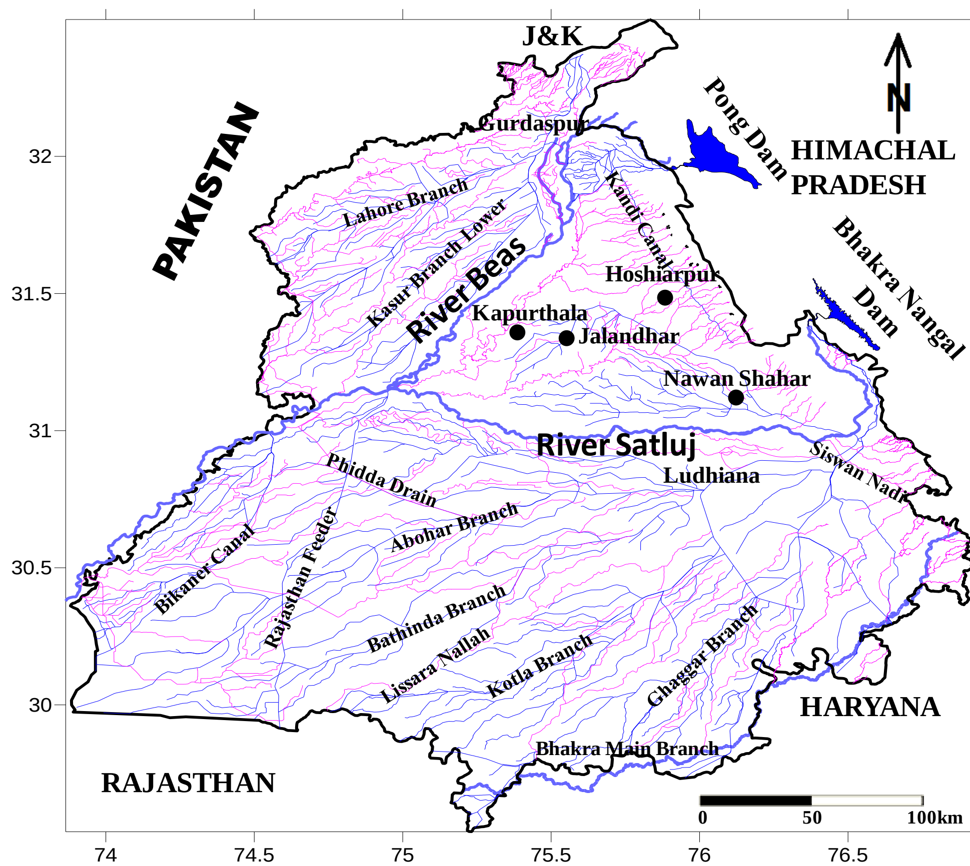


Figure 2.3: Drainage map of Punjab

The rainfall deficiency in the state is made up by canals taken out from the perennial rivers Beas, Satluj and Ravi. It is this efficient canal system which has enabled this area to be called as the granary of the country and nucleus of the Green Revolution. Although there has been some decline in the importance of canal irrigation due to popularity of tube-wells and pumping sets but canals still irrigate over 39% in Punjab. The canal network in the state is shown in the figure

(2.2), some details are given in the table (2.1 & 2.2) and highlights of some of the important canals of Punjab are described below (Fig 2.4):

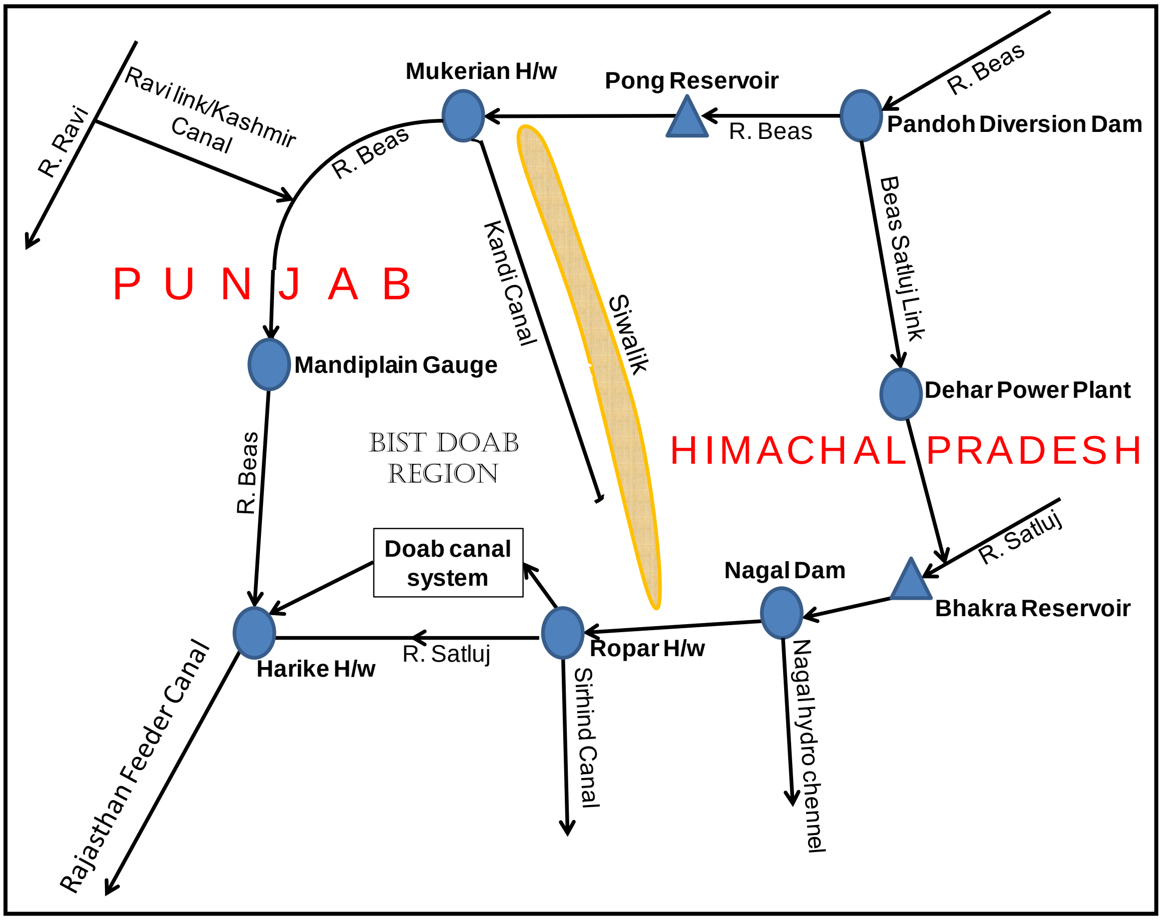


Figure 2.4: Schematic of Canal and river systems in Doab region of Punjab

2.1 Canals & Dams of Punjab

The main storage on Satluj is at Bhakra while that on Beas is at Pong. Another dam on Ravi namely, Ranjit Sagar dam provide additional water to Beas.

Canal irrigation systems in Punjab comprise of Sirhind Canal system, Bist Doab Canal system, Bhakra Main Line (BML) Canal System, Upper Bari Doab Canal system, Kashmir Canal , Ferozepur Feeder/Sirhind Feeder system, Eastern Canal system, Makhu Canal System, Shahnehar Canal system and the Kandi Canal system. The Rajasthan Feeder and Bikaner Canal which carry Ravi-Beas & Sutlej water exclusively for Rajasthan also run in a considerable length over Punjab Territory.

Sirhind Canal System

The Sirhind Canal system is about 150 years old. The Sirhind Canal which offtakes from Ropar headwork has an authorized capacity of 12620 Cs with a culturable command area of 13.59 lac hect. The Sirhind Canal and its distribution network are spread over a length of 3215Km .

Bhakra Main Line System.

The Bhakra Main Line Canal is an extension of Nangal Hydel Channel. The authorized capacity of Nangal Hydel Channel which offtakes from Nangal Barrage downstream of Bhakra Dam is 12500 Cs. The authorized capacity of BML canal is 12455 Cs at head after taking into account 45 Cs. of losses in Nangal Hydel Channel . The Nangal canals originating from the Nangal dam is about 64 km long. It acts as a feeder canal to the Bhakra canal. The Bhakra Main Line has a length of about 164Km, out of which 159 Km falls in Punjab Territory and the balance is in Haryana. The BML canal was built during 1950-54. It is an inter-state channel which supplies water for irrigation and drinking purposes to Punjab, Haryana and Rajasthan. The drinking water supplies are also made to Chandigarh (160 Cs) and Delhi (370 Cs) through the B.M.L Canal. The carrying capacity of BML canal was restored to its authorized discharge of 12455 Cs in the year 2004.

Narwana Branch Canal with an authorized capacity of 4500Cs, off takes at RD 158230/L of BML Canal, out of which 4022 Cs water is supplied to Haryana . The length of Narwana Branch is about 98 Km, out of which 49 Km falls in Punjab. The total length of channel off takes from BML Canal and Narwana Branch in Punjab portion is of the order of 1256 Km, with an irrigation potential of 7,35,463 acres.

Shahnehar Canal System

Shahnehar Headwork was constructed downstream of Pong Dam in the year 1983 on river Beas. Mukerian Hydel Channel off takes from this headworks. It’s total installed capacity is 207 MW. The old Shahnehar canal was replaced by constructing feeder No.1 and feeder No. II canals (designed capacity 306+252=558 Cs) off-taking from Mukerian Hydel channel and extending irrigation in Kandi areas for ensuring 0.32 MAF of pre-partition usage of Beas water.

Bist Doab Canal system.

The Bist Doab Canal off takes from the right bank of river Sutlej upstream of Ropar headwork. The Bist Doab Canal system, constructed in 1954-55, is spread over a length of 805 Km. The canal has an authorized capacity of 1452 Cs. with a culturable command area of 1.99 lac hect. Over the years, the carrying capacity of the canal has got reduced to 1000 Cs. The system needs comprehensive rehabilitation/ renovation.

Upper Bari Doab Canal (UBDC) system

A barrage was constructed at Madhopur after the weir type structure got damaged in the flood of 1955 and the UBDC system which off-takes from Madhopur Headworks was further developed by including additional areas. The UBDC system was remodeled during 2001-2005, to ensure full utilization of stored waters of river Ravi, as a result of commissioning of Ranjit Sagar Dam in the year 2000. The UBDC presently, has an authorized discharge of 9000 Cs. Seven main / branch canals off take from UBDC with 247 distributaries and minors, off taking from these main branch canals. The UBDC system is spread over a length of 3119 Km, having a culturable command area of 5.73 lac hect.

Rajasthan Feeder, Ferozepur Feeder & Sirhind Feeder

The Rajasthan Feeder (Indira Gandhi Nahar) which carries Ravi-Beas waters exclusively for Rajasthan off- takes from Harike Headworks. It has a capacity of 18500 Cs. However, the head regulator of the canal has a capacity of 15000 Cs which is sufficient for supplying allocated Quantum of Ravi Beas waters to Rajasthan. The canal was constructed in the year 1958-1961. The canal takes off from Harike H/w to transfers 9.36 BCM of surplus waters of Ravi, Beas and Satluj to Rajasthan right up to Jaisalmer and Barmer for irrigating the areas of Thar Desert. The canal network is spread in an area of about 60 km wide and 1,000 km long belt. It consists of 204 km of feeder, 450 km main canal, 8000 km of distribution networks and several thousand km of lined water courses, to spread over a gross command area of 2.5 Mha and provide irrigation to a culturable command of 1.55 Mha.

Ferozepur Feeder off takes from Harike Headworks. It has capacity of 11192 Cs was constructed in 1952-53 and runs in a length of about 51.30 Kms, for supply of Ravi Beas waters to two distributary systems (Mayawah, Sodhinagar) having a combined discharge of 309 Cs.

The Sirhind Feeder off taking from Ferozepur Feeder at RD 55413 ft. was constructed during 1954-55 and runs in a length of about 136.50 Km . It has an authorized capacity of 5264Cs, having a culturable command area of 3.6 lac hect.

The Rajasthan Feeder is a lined channel, with single tile lining in bed and double tile lining on side slopes. This type of lining was adopted, probably for the reason, that ground water table was 33 meters deep at the time of construction of Rajasthan Feeder. The full supply depth from 0-179000 was kept as 14.40 ft and in the downstream reach RD 179000 to tail, the same was kept as 21.0ft .

The seepage from Rajasthan Feeder and Sirhind Feeder in Punjab Territory has assumed alarming proportions in as much as, the seepage from these canal systems has been found to be 191.05 MCM i.e. 21% of the total annual ground water recharge. There has been an enormous rise in sub soil water level(SSWL) in reach RD 179000 to 496000 of the Rajasthan Feeder and RD 124000 to 434000 of Sirhind Feeder. Out of 84800 hectare of fertile land critically affected by water logging in Faridkot, Mukatsar, Malout, Lambi, Abohar and Gidderbaha tracts of Punjab, 25% area is adjoining Rajasthan and Sirhind Feeders.

The continous seepage from these canals is aggravating the situation and further making the land saline and unfit for cultivation. Relining of these canals is the only option for which two projects have been prepared at an estimated cost of Rs. 889.95 crore and 363.50 crore respectively for Rajasthan and Sirhind Feeder Canals.

Eastern Canal system.

Eastern Canal system is a non-perennial system. Its construction was completed in 1927 and it used to off take from Hussainiwala Headworks. However, after the construction of Harike Headworks, the supply of water to Eastern canal system and Bikaner Canal has been switched over to Harike Headworks, except for a portion of Eastern canal running in a length of about 8.02 Kms which receives water supply from Hussainiwala Headworks for feeding 7 distribution and 8 minors. The authorised discharge of Eastern Canal system is 3197 cs, which has culturable command area of 2.16 lac hect and runs in a length of 856 Kms.

Makhu Canal System

The Makhu Canal, with a designed capacity of 292 cs offtakes at Harike headwork. The Makhu Canal system spreads over a length of 92.8 Km and has a culturable command area of 20600 hectares.

Kashmir Canal

Kashmir Canal off-takes from River Ravi upstream of Madhopur Headworks and provide irrigation water to the State of J&K and some areas of Punjab as per old agreements. The length of canal is 5.26 Km with an authorized capacity of 1050 Cs at head. Lift schemes installed on the canal draw 250 Cs of water. The Canal bifurcates into two branches, namely chakandar feeder and Kathua Canal with a discharge of 400 Cs. each.

Table 2.1: The details of main canals

Sr. No.	Name of Canal system	Length in KM of Main Canal	Discharge at Head in Cs	CCA lac Hectare
1	Sirhind Canal	59.44	12620	13.59
2	Bist Doab Canal	43.00	1408	1.99
3	Upper Bari Doab Canal	42.35	9000	5.40
4	Sirhind Feeder	136.53	5264	3.60
5	Eastern Canal	8.02	3197	2.16
6	Bhakra Main line	161.36	12455	3.81
7	Shahnehar Canal	24.23	875	0.33

Table 2.2: The water allowance of canal systems of Punjab

S. No.	Name of System	Water Allowance in cusecs/acres
1	Sirhind Canal System	3.05
2	Bist Doab Canal System	1.95
3	UBDC system	4.15 (5.5 Cs Khara Majah area)
4	Sirhind Feeder System	3.05
5	Eastern Canal System	5.5
6	Bhakra Main Line System	2.04
7	Shahnehar Canal system	7.00

Bhakra Dam

The construction of Bhakra dam is completed in 1963. It creates a lake called Gobind Sagar with total storage capacity of 0.9621 M ha-m at an elevation 515.11 m and having a surface spread of 16, 868 hectare (41,680 acre). The flow of Satluj River at Bhakra is supplemented by diversion of Beas water through Beas-Satluj link, which takes off from Pondoh dam across Beas River.

Hydropower plants in Bhakra system

There are several hydropower plants under Bhakra System in Indus basin.

Table 2.3: The installed capacity of hydropower plants under Bhakra system

Name of the hydropower plant	**Installed Capacity**	**(MW)**
Bhakra (Right Bank)	3x132 + 2x157	710
Bhakra (Left Bank)	5x108	540
Ganguwal	2x24.2 + 1x29.25	77.65
Kotla	2x24.2 + 1x29.25	77.65
Dehar	6x165	990
Pong	6x60	360
	Total	**2,755.30**

Beas-Satluj Link

Beas river water is diverted from Pandoh dam into the Satluj River near village Dehar, upstream of Bhakra reservoir through a 38 km long water conductor system. The head due to an elevation difference of more than 335 m is utilized to generate 990 MW power. Water of Beas river at Pandoh dam is carried through a tunnel up to Baggi, through an open hydel channel up to Sundarnagar, and through a tunnel from Sundarnagar to Slapper.

Distribution of water

- Sutlej water: As per the Bhakra Nangal Agreement of 1959, the share of Punjab, Haryana and Rajasthan is 57.88%, 32.31% and 9.81% respectively.

- Ravi Beas water: According to the agreement of 1981 and the distribution approved by BBMB in 1982, the surplus Ravi Beas water (after taking out pre-partition utilization) is distributed among Punjab, Haryana and Rajasthan in the ratio of 30%, 21% and 49%, respectively. Delhi and Jammu & Kashmir have been given fixed shares of 0.2 MAF and 0.65 MAF as per 1981 agreement.

The network of canals, which is more than 150 years old, is unable to take its full discharge due to reduction in their carrying capacity of the system and decreased availability of surface water. The net-area irrigated by canals has gone down from 55% in 1960-61 to 29% in 2006-07. The canal irrigation system irrigated about 1.3 million hectare of land in 1970-71, while only one million hectare was irrigated during 1999-2000. On the other hand, tube well irrigation, particularly in the central and northern region of Punjab has increased from 55% in 1970 to 75% in 2001-02 (Fig. 2.5).

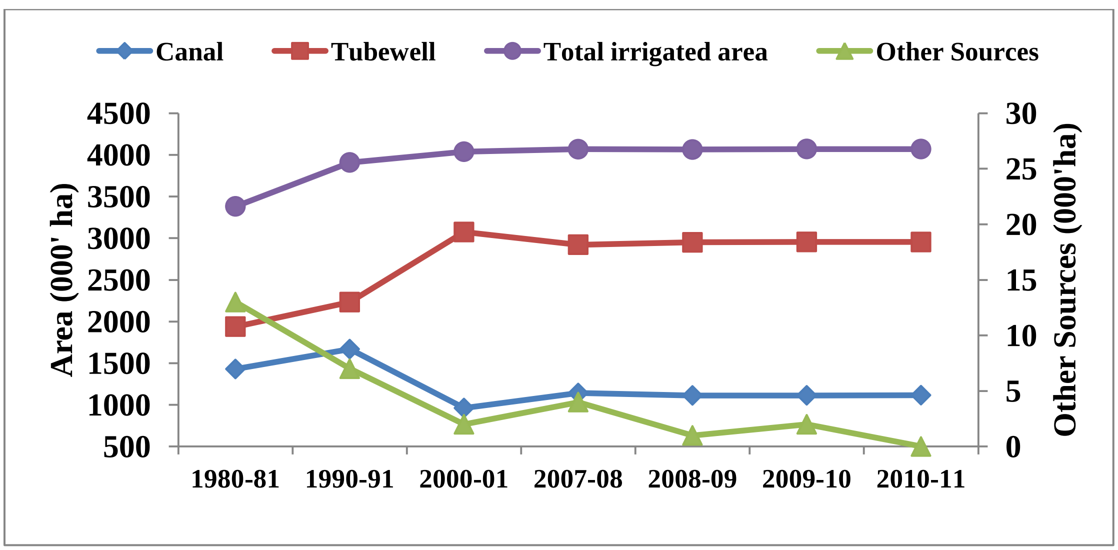


Figure 2.5: Comparison of net irrigated area ('000 ha) by different sources in Punjab

(Source: Statistical Abstract of Punjab, 2003, 2012)

There are 1.15 million tube wells in the state to lift underground water for agricultural irrigation and another 150,000 in urban and semi urban areas to provide water for domestic and industrial purposes.

Agriculture is the largest industry in Punjab; it is the largest provider of wheat to India. Indian Punjab led the country's Green Revolution of the 1960s and earned for itself the distinction of becoming 'Granary of India' or 'India's bread- basket'. The cropping pattern also got changed with the increasing facilities in agriculture field including irrigation (Table-2.4).

Table 2.4: Shift in cropping pattern in Punjab (Area in '000ha.)

Crop	**1970-71**	**1980-81**	**1990-91**	**1999-2000**	**2000-01**	**2011-2012**
Rice	390 (6.87)	1183 (17.49)	2015 (26.86)	2604 (33.18)	2612 (32.92)	2826(35.85)
Maize	555 (9.77)	304 (4.50)	183 (2.44)	163 (2.08)	164 (2.07)	133 (1.69)
Bajra & Jowar	212 (3.73)	70 (1.03)	12 (0.16)	5 (0.06)	6 (0.08)	2.5 (0.03)
Groundnut	174 (3.06)	83 (7.23)	11 (0.15)	5 (0.06)	4 (0.05)	2.0
Cotton (American)	212 (3.73)	502 (7.42)	637 (8.49)	381 (4.86)	358 (4.51)	482.8 (6.25)
Sesame	15 (0.26)	17 (0.25)	18 (0.24)	145 (1.85)	19 (0.24)	5
Sugarcane	128 (2.25)	71 (1.05)	101 (1.35)	108 (1.38)	121 (1.52)	70 (0.89)
Kharif Pulses	33 (0.58)	58 (<0.86)	73 (0.97)	51 (0.65)	42 (0.53)	-
Wheat	2299 (40.49)	2812 941.58)	3273 943.63)	3388 (43.18)	3408 (42.95)	3510 (44.5)
Barley	57 (1)	65 (0.96)	37 (0.49)	51 (0.65)	32 (0.40)	11.7 (0.15)
Gram	358 (6.3)	258 (3.81)	60 (0.8)	6 (0.08)	8 (0.1)	2.2 (0.03)
Rapeseed & Mustard	103 (1.81)	136 (2.01)	69 (0.92)	56 (0.71)	55 (0.69)	-
Potato	17 (0.30)	40 (0.59)	23 (0.31)	76.0 –(1)	64 (0.81)	64 (0.81)
Other Vegetable	23 (0.41)	24 (0.36)	31 (0.41)	47 (0.6)	46 (0.58)	-
Fruits	50 90.88)	29 (0.43)	69 (0.92)	30 (0.38)	34 (0.43)	71.5
Net Sown Area	4053	4191	4218	4243	4264	4158
Total Cropped Area	5678	6763	7502	7847	7935	7882
Cropping Intensity	140	161	178	185	186	190

Source: Statistical Abstract of Punjab, 1971, 1981, 2000, 2001, 2010; Figures in parentheses indicate area under crops as percentage share to total cropped area.

Also Punjab state has been awarded National Productivity Award for agriculture extension services for consecutively ten years from 1991-92 to 1998-99 and 2001 to 2003-04. Intensity of cropping has jumped from 1.4 in 1970-71 to 1.86 by 2000-01. This shows that agriculture in the state have shown remarkable progress since the adoption of modern techniques in the late 1960s (Sidhu, 2005). Other crops in the state include rice, sugarcane, fruits and vegetables, Industries in the state include the manufacture of scientific instruments, electrical goods, financial services, machine tools, textiles, sewing machines, sports goods, starch, tourism, fertilizers, bicycle, garments and the processing of pine oil and sugar. Most of the Punjab is an alluvial plain, bounded by mountains to the north. Despite its dry conditions, it is a rich agricultural area due to the extensive irrigation made possible by the great river system traversing it.

In the central plains, the ground water table declined in the range of 0.7 m to 1.7 m during 1974-84 but it declined between 1.5 m to 5.1 m during 1984-94 (Sidhu and Johl, 2002). Most of the area in the central plains is labeled as 'dark area' from the point of view of ground water.

2.2 Irrigation

Water requirement for agriculture in Punjab is supported both using canal and groundwater. Overtime, canal irrigation has been declining whereas tube well irrigation has been on an increase. This is mainly due to existing cropping pattern availability of cheap credit and free supply of electricity in the state. Ground water draft has increased by 11% between 2004 to 2009 (CGWB, 2012). Rice and wheat, being the major crops of the state, account for the 81.33 per cent of the gross cropped irrigated area in state (Table 4.11)., The water table in the central districts of Punjab has been going down whereas in south western parts it is going up resulting into the problem of water logging. Most of the centrifugal pumps have been replaced by the submersible pumps leading to additional expenditure along with tremendous increase in energy consumption. The cultivation of high water demanding crops particularly paddy is an important factor contributing towards decline of underground water levels in Punjab.

Table 2.5: Gross cropped and irrigated area in Punjab (000, ha.)

Year	Gross cropped area	Irrigated area	% of gross irrigated area to gross cropped area
2007-08	7870	7689.3	97.7
2008-09	7912	7723.6	97.6
2009-10	7876	7714.2	97.9
2010-11	7882	7723.8	98.0

Source: Statistical Abstract, Punjab

Table 2.6: Status of water resources on Punjab

Annual canal water available at H/w	1.79 M ha-m
Annual canal water available at outlets	1.45 M ha-m
Annual canal water available	2.03 ha-m
Total annual available water resource	3.48 M ha-m
Annual water demand	4.76 M ha-m
Annual water deficit	1.28 M ha-m

Source: Jain A K, Department of Soil & water Engineering, PAU, Ludhiana

Table 2.7: Land use pattern in Punjab (000 hectares)

Area/Period	**2007-08**	**2008-09**	**2009-10**	**2010-11**
Geographical area	5036	5036	5036	5036
Forests	287	296	295	294
Barren and un cultivable land	24	23	25	24
Land put to non –agriculture use	483	494	503	508
Cultivable waste	3	2	2	4
Permanent pastures & other grazing land	3	4	4	4
Land under misc.& groves not included in net area sown	4	4	5	4
Current fallow	41	38	37	33
Fallow land other than current fallow	1	1	4	4
Net area sown	4187	4171	4158	4158
Net area sown as percentage to total area	83	83	83	83
Area sown more than once	3683	3741	3718	3724
Gross cropped area	7870	7912	7876	7882

Source: Statistical Abstract, Punjab

Table 2.8: Consumption of insecticide/Pesticide in Punjab

Year	**Consumption in technical grade (M.T)**
2007-08	5900
2008-09	5760
2009-10	5745
2010-11	5600
2011-12(P)	6150

Source: Agriculture at a Glance, Department of Agriculture, Govt. of Punjab, Chandigarh

Table 2.9: Consumption Fertilizer in Punjab (000, nutrient tones)

Year	**Nitrogenous (N)**	**Phosphatic (P)**	**Potassic (K)**	**Total (NPK)**	**Consumption per hectare (kg)**
2007-08	1317	341	37	1695	213
2008-09	1332	379	55	1766	223
2009-10	1348	383	56	1787	226
2010-11	1403	435	73	1911	243
2011-12	1416	449	53	1918	244
2012-13	1486	462	24	1972	250

Source: Agriculture at a Glance, Department of Agriculture, Government of Punjab, Chandigarh

Table 2.10: Source-wise net area irrigated in Punjab (000, hectre)

Year	**Govt. canals**	**Private canals**	**Tube wall & wells**	**Other sources**	**Total**	**% of net irrigated area to net area sown**
2007-08	1142	-	2922	4	4068	97.2
2008-09	1110	3	2950	1	4064	97.4
2009-10	1111	3	2955	2	4071	97.9
2010-11	1113	3	2954	-	4070	97.9

Source: Statistical Abstract, Punjab

The existence of deep aquifers in Punjab is well established, starting from the depths of 100-150m down to depths of 300m in most parts and up to 600m or more in Kandi region. The deeper aquifers are confined in nature, and the tube wells tapping these zones have discharge approximately in the range of 150-200 m^3/hr, with drawdown ranges from 1.97 to 11.72m (DWSS, 2006).

Table 2.11: Distribution of blocks in different categories on basis of underground water resources in Punjab (total blocks = 138)

Category (Groundwater draft in % of annual net recharge)	**2000**	**2005**	**2010**
Over-exploited (Dark) (above 100%)	73 (52.90)	103 (75.18)	110 (79.71)
Critical (85-100 %)	11 (7.97)	5 (3.65)	3 (2.17)
Semi critical (65-85 %)	16 (11.59)	4 (2.92)	2 (1.45)
Safe (less than 65%)	38 (27.54)	25 (18.25)	23 (16.67)

Source: Jain A K, Department of Soil & water Engineering, PAU, Ludhiana

Table 2.12: Ground Water Potential

Total Replenishable Ground Water Resource (mham/yr)	1.821577
Provision For Domestic, Industrial and Other Uses (mham/yr)	0.182158
Available Ground Water Resources for Irrigation (mham/yr)	1.639419
Utilizable Ground Water Resources for Irrigation (mham/yr)	1.475477
Gross Draft (mham/yr) Pro-rata Basis	2.030674
Net Draft (mham/yr)	1.421472
Balance Ground Water Resource For Future Use (mham/yr)	0.217947
Level of Ground Water Development (%)	86.71

Source: DWSS, Punjab, 2006

Punjab At a Glance

GENERAL FEATURES

Area: 50,362 km^2

Lat long: $29^0 33'$ & $32^0 32'$ N latitudes and $73^0 53'$ & $76^0 55'$ E

Population: 2011 Census: 27,704,236;

Population Growth rate: Between 2001 to 2011: 13.73 %; 1991 to 2001: 20.10%

Number of Districts: Number of Tehsils: Number of Blocks

Socio-cultural region: Malwa, Majha, Bist Doab and Powadh

Rivers: Ravi, Beas, Satluj, Ghaggar

CANALS & DAMS

Major Canals:

Canals of River Beas: Shah Nahar Canal and Kandi canal (Kandi canal from Talwara to Balachaur total length 130 km; discharge capacity: 500 cusec; CCA: 22594 Ha.)

Canals of River Ravi: Madhopur H/w: Upper Bari Doab Canal

Canals of River Satluj:

Bhakra Main Canal

Ropar H/W: Bist Doab Canal, Sirhind Canal

Firozpur H/w: Bikaner Canal & Eastern canal

Harke H/w: Rajasthan feeder canal

Ferozepur Canal, Satluj Yamuna Link canal

Beas-Satluj Link canal (link from Pandoh dam to Baggi control works (Dehar power plant))

State Water share from river Satluj : Punjab:84.78% Rajasthan:15.22%

Total canal length: 1,45,000-km (branch canal + minor distributaries)

Water course length: About 1 lakh km

Dams:

On the river Satluj: Bhakra & Nangal Dam:

Bhakra Dam: Storage capacity: 9340 million cum; Purpose: 1200 MW power generation

Nangal Dam: Power generation: 77 MW

On river Beas: Pong dam

Purpose: for irrigation water to Rajasthan, Punjab and Haryana; for power generation; Gross storage cap: 8570 million Cum.; Power generation: 396MW

On the river Ravi: Ranjit Sagar Dam (Thein Dam)

Purpose: 600 M.W of Power generation; Irrigation potential of 3.48 lakh hectares

Table 2.13: Kandi Dams of Bist Doab region*

Dam	Irrigation area (Ha)	Dam	Irrigation area (Ha)
Dholbaha dam	3745 Ha	Perch	340
Janauri dam	492	Chohal	1170
Maili	914	Mirzapur	902
Damsal	340	Saleran	474
Siswan	931	Patiari	730
Jainti	676	Thana	1160

: *Out of the 29 proposed dams in Kandi region, 12 are in operational and 9 are under construction. These are for flood control and irrigation purpose

WATER DEMAND & USE

Agriculture area of Punjab: (84% of the state area)

Total irrigated area of the state: 4070 thousand hectares (97% of the agricultural area)

Cropping intensity: 185%

Number of tubewells in the state: ~1.4 million

Source wise Irrigation (2010-11): Using tube-wells 73% of irrigated area; using Canal 27% of irrigated area

Block wise category of groundwater utilization (2010):

Over exploited (Dark): 110 (79.71%); Critical: 3 (2.17%); Semi-critical: 2 (1.42%),

Safe: 23 (16.67%)

Irrigation water demand: 4.38 to 4.76 M ha-m

The total surface and ground water resources in the state = 3.13 to 3.48 Mha-m

Annual deficit=1.25 M ha-m (Sondhi and Khepar, 1995)

Annual water demand: 4.76 M ha-m

Annual water deficit: 1.28 M ha-m

Total Replenishable groundwater (data of year 2006): 1.82M ha-m/yr

Domestic and industrial uses of groundwater= 0.18mham/yr

Net draft for irrigation in the state is 1.42 mham/yr (Mittal & Vashisht, 2004).

Net draft for all the purposes: 1.61 M ha-m/yr

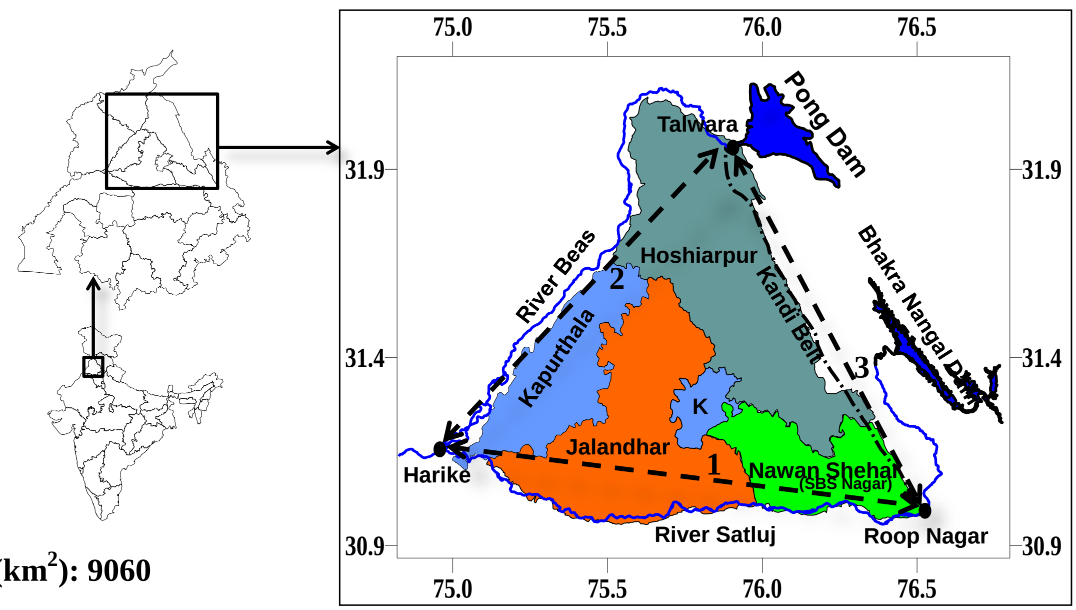
Level of groundwater development: 86.71%

2.3 General Features of Bist Doab Region

The Punjab state is facing dual problem of rising water table (mostly in south-western parts, where water extraction is limited due to brackish/saline quality) and falling water table in north western, central, southern and south-eastern parts of the state where groundwater is generally fresh and fit for irrigation. One such region in the state where such a severe groundwater stress is been experienced over the past few years is Bist- Doab region. This region falls between the two rivers Beas and Satluj (Popularly known as Bist-Doab). The study area contains four districts namely Hoshiarpur, Kapurthala, Jalandhar and SBS Nagar districts. The Bist- Doab area is hydrologically non-uniform. The water table varies from shallow to deep depending upon geographical location. The area falls in the multi aquifer system of Indo-Gangetic plain.

2.4 BIST- DOAB REGION

The Bist- Doab is a triangular region and covers an area of 9060km^2, 17.6% of total area of Punjab. The area lies between 30°51′ and 30°04′ N latitude and between 74°57′ and 76°40′ E longitude (Fig. 2.6). It comprises the Hoshiarpur, Kapurthala, Jalandhar and SBS Nagar districts



Area (km^2): 9060

(Kandi: 1060+; Plains: 8000)

1.Ropar to Harike: 155 km; 2. Talwara to Harike: 125 km; 3. Ropar to Talwara: 118 km

Figure 2.6: Bist-Doab region

of Punjab State, India. It is bounded by Shivaliks in the north-east, the river Beas in the north east-south west and the river Satluj in south east-south west. There is a choe ridden (ravine-ridden) belt in the area bordered by the Shivaliks called the Kandi area. This area is a bhabhar, or a piedmont plain, lying at the foothills of the Shivaliks and formed by the coalescence of various alluvial fans resulting from the deposition of sediments by various choe at the foothills. Doaba has the highest road density of all the regions in Punjab.

A Brief History of the cities: Jalandhar, Kapurthala, Shahid Bhagat Singh Nagar, Hoshiarpur and Rupnagar

Jalandhar was the capital of Punjab from India's independence (1947) until Chandigarh was built in 1953. The city was known as Prasthala in the time of the Mahabharta and as Jullundur in British India. Jalandhar is the oldest surviving city of the Punjab region, with historical references as far back as A.D. 100.

Kapurthala- The history of the Town of Kapurthala goes back as early as the 11th Century when it is said to have been founded by Rana Kapur, a Bhatti Rajput who was scion of the ruling house of Jaisalmer (Rajasthan). It is said that Kapurthala was founded in the 11th Century during the period of Mahmood Gaznvi. This town was established by Rana Kapoor of Rajput Gharana, of Jaselmer. On his name, the place has got its name- Kapurthala.

Shaheed Bhagat Singh Nagar (SBS Nagar) district was carved out of Hoshiarpur and Jalandhar districts of Punjab on November 7, 1995, as the sixteenth district of Punjab State named from the headquarters town of Nawanshahr. Nawanshahr town is said to have been built by an Afghan Military Chief, Nausher Khan. Previously it was called "Nausar" but with the passage of time, the town came to be known "The Nawanshahr".

Hoshiarpur is a city and a municipal corporation in Hoshiarpur district in the Indian state of Punjab. It was founded, according to tradition, during the early part of the fourth century. In 1809 it was occupied by the forces of Maharaja Karanvir Singh and was united into the greater state of Punjab

Rupnagar also spelled **Ropar** or **Rupar**, is a newly created fifth "Divisional Headquarters" of Punjab comprising Ropar, Mohali, and its adjoining districts. The ancient town of Rupnagar is said to have been named by a Raja called Rokeshar, who ruled during the 11th century and named it after his son Rup Sen. It is also one of the bigger sites belonging to the Indus Valley Civilization

The area is drained by the perennial rivers Satluj and Beas and their tributaries. The Satluj and Beas rise in the high Himalayas and after traversing through long courses of several hundred kilometers enter the state of Punjab. The Satluj enters Punjab near Nangal, moves on to plains at Ropar, passes through district Ludhiana (where the highly polluted Budha Nallah merges with it) and joins Beas at Harike before crossing over to Pakistan. Its total length is 440 km in the state. The Beas enters Punjab near Talwara and enters the plains and discharges into the river Satluj at Harike. Its total length is 470 km and catchment area is 20,303 km^2.

2.4.1 Climate

Doaba has a continental climate. Temperature in summers ranges from 30 to 32 degrees Celsius while the maximum can go upto 45 degrees Celsius. Winters are moderately cold with normal temperatures falling between 10 and 15 degrees Celsius. Loo in the summers and frost in the winters are common features. The area nearest the Shivaliks receives more rainfall (1200mm at Dhar Kalan) than plains that are far away from it. High rainfall and poor vegetation cover are responsible for soil erosion in the Shivalik foot hill zone (Sehgal et al., 1988).

The major canal network Bist-Doab canal arises from River Satluj. Besides these, the Kandi region is full of seasonal streams. The drainage density is high in the north east strip bordering the Shivaliks, but it is moderate to low in the rest of the area with sub-parallel and sub-dendritic patterns. The region is rich in water power. The Pong dam on the river Beas and various power houses on the Mukerian Hydel Canal provide power to the region. The stretch of the river Satluj from Ludhiana to Harike has been identified as the most polluted and has been covered by the National River Conservation Directorate (NRCD), Ministry of Environment & Forests for monitoring of water quality.

2.4.2 Geomorphology

The Quaternary alluvium of considerable thickness is deposited on semi consolidated Tertiary rocks or on the basement of metamorphic/ igneous rocks of Pre-Cambrian age. The basement of basin becomes deeper near to the foot hills comprising of Upper Shivalik formations. The alluvial plain towards the hills is bordered by the piedmont deposits comprise of Kandi region. The Kandi deposits are made up of boulders, pebbles, gravels, sand and minor layer of clays. It forms the recharge belt of the alluvium. The Quaternary alluvial deposits comprise of fine to medium sands, sandy clays and silty clays and occasional occurrence of gravels. Kankers are calcium carbonate deposit of secondary origin is also associated with finer material at many places. The older alluvial consisting of pale to reddish brown coloured layers of massive clays are found generally in the central part of Doab.

Geomorphologically, the Bist- Doab is divisible into three zones, i.e.

- The Shivaliks and the Kandi Watershed
- The interfluvial plain between the Beas and Satluj
- The flood-plain area

The existing and earlier Beas, Satluj and other rivers deposited a great thickness of Pleistocene to Recent sediments derived from erosion in the mountains. The relevant lithologies and sequences are as follows:

- Surface deposits (Recent).
- Sirowal sediments and occasional gravels to the northeast with Kandi coarse clastics including red clay beds to the southwest (Holocene).
- Boulder beds with inter-bedded clays (Pleistocene).

The alluvium at the surface reflects the latest stages of sedimentation in a process which commenced in the Tertiary. Cenozoic sedimentation involved sediments in the Shivaliks which, according to Chaudhri and Dhanda (1980), can be divided into late, middle and early portions. The upper part ranges in age from middle Pleistocene downwards and comprises three members which are as follows:

- Boulder conglomerate (middle Pleistocene)
- Pinjore lithic arenites (late Pliocene)
- Tatrot sediments (Neogene)

Geomorphologically the area is divisible into eight main Zones (Fig. 2.7) which are described as below (Singh, 1987):

2.4.2a Structural hills

The north-eastern portion of the Bist- Doab tract forming the boundary with the sub-mountainous zone where upper Shivaliks rocks are exposed and cover about 1200 km^2, out of which about 900 km^2 lie in the Punjab portion of this tract. The altitude of these low hills varies from 300-600 m. These hills are made up of predominating bands of clays alternated with sands of varying grade. The hills are covered with sparse vegetation, mainly bushy in nature with tree cover varying from 10 to 30% at places. There are few seasonal streams which cause extensive erosion of the soft sediments present in this region.

2.4.2b Table land

An extensive patch of gently undulating flat topped table land is located in the eastern corner of the tract.

2.4.2c Upper Piedmont

The upper piedmont occurs parallel to the foothills of hilly terrain and slopes towards south-west. It is made up of loose to semi consolidated very coarse materials including boulders, etc. which seems to be derived from the hilly terrain and deposited on the lower slopes in the shape of fans which at a later stage merged to form a continuous zone parallel to the hills. This zone is characterized by the presence of extremely dissected large number of sub-parallel streams. The area is marked by poor vegetation and is under rainfed cultivation.

2.4.2d Lower Piedmont

This zone occurs as a large fan shaped body and extends nearly upto one third of the area of the Bist- Doab Tract. It is made up of less coarser sediments than the upper piedmont zone and soil texture is finer, though cobbles & pebbles are still noticed scattered on the soil surface at some places. The drainage pattern becomes parallel and slope varies from flat to undulating. The soil moisture is not a limiting factor in this zone and it is under cultivation mostly through tube well irrigation. The tree population is higher in this zone and at places natural forests and orchards are dense specially, in the south eastern corner.

2.4.2e Alluvial Plain

The central triangular portion of the Bist- Doab tract is made up of clay and sand mixed soils of alluvial origin. The soils are fine loamy in the lower reaches and coarse loamy in the upper reaches. This zone is gradually sloping towards SW which can be inferred from the flow direction of streams and rivers as the two major rivers Beas & Satluj meet in the SW corner of the tract. The area is under intensive cultivation and irrigated by both canals as well as tube well irrigation.

2.4.2f Sandy & Saline Zone

Slight saline and slight to moderately alkaline and sandy zone is found to be sloping and gradually increasing towards the south western part of the Bist-Doab Tract. It covers NE to SE part of Kapurthala & Jalandhar districts. The sandy patches are representative of earlier level deposits/wide flood plain in the past.

2.4.2g Flood Plain- Older

It is a land form composed primarily of unconsolidated material deposited along the banks of the rivers while subjected to periodic or occasional flooding. The older flood plains of river Beas and Satluj are fairly wide with flat surfaces. The area has been brought under intensive cultivation as the fear of flooding in the area has been minimized by providing flood protection measures through earthen bunding along the banks of the two rivers. Most of the palaeochannels of river Beas and Satluj lie within this zone.

2.4.2h Flood Plain- Active

It is a land form subjected to periodic flooding and consists of silt and fine sand deposited by the rivers during high flood times and generally confined to the neighbor hood of the channel. The sediments geologically belong to the newer alluvium and poor in calcareous matter. This zone forms narrows strips along the banks of the two rivers.

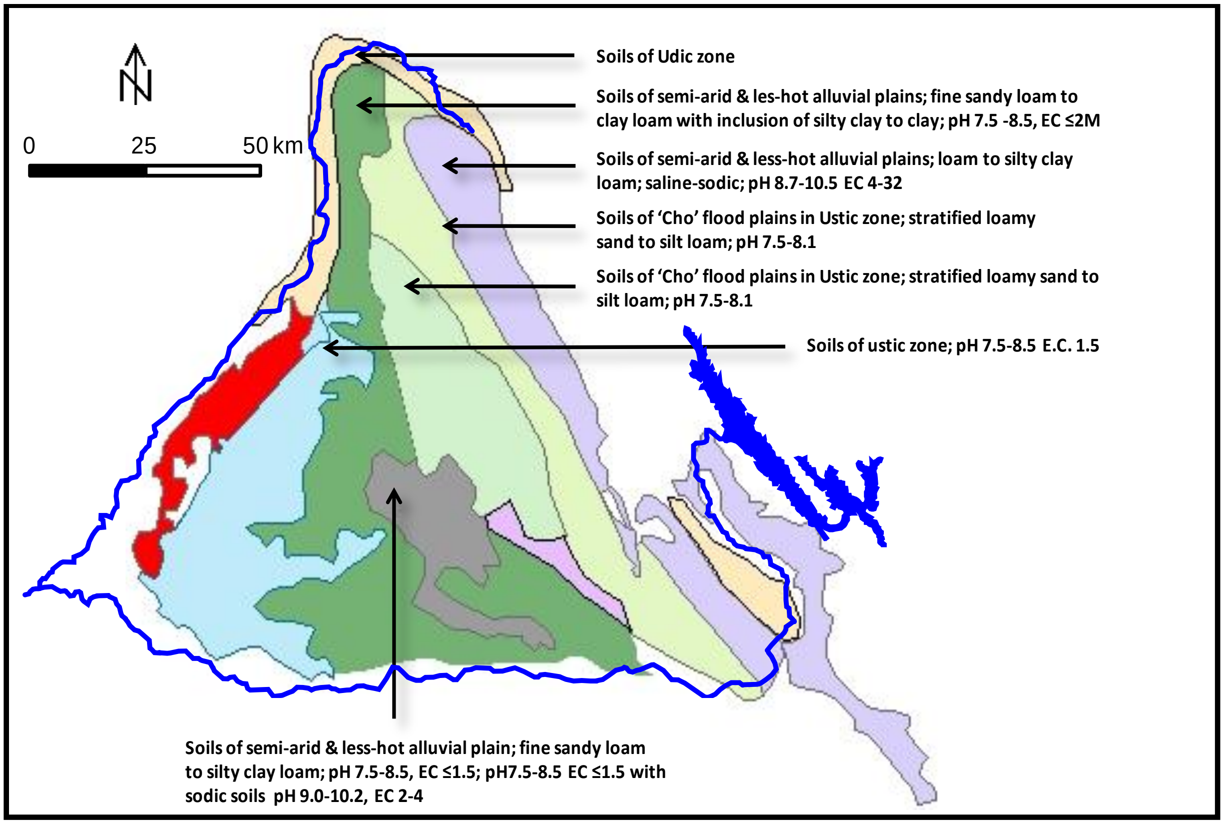


Figure 2.7: Geomorphological map of Bist-Doab tract, Punjab (after Singh, 1987)

2.4.3 Demography & economy

Doaba is a densely populated region, accounting for 19.64 percent of the population of Punjab (2001). Average density of population was 465 persons per square kilometre in 1991, which increased to 539 persons (Census 2001). Jalandhar has the second highest population density in the state, coming second to Ludhiana in Malwa. The eastern parts of Hoshiarpur and SBS Nagar have a low population density because these regions have choe–ridden hilly tracts. Sikhs do not predominate in the Doaba region. In 1991, there were 44% Sikhs in Jalandhar and 42% in Hoshiarpur district.

Major industries include cotton textiles, sugar, leather and paper are in Bist-Doab area. The economy of Hoshiarpur district has remained predominantly agrarian. Over time there has been a decline in share of agricultural and allied activities. The economy of the district has experienced a rate of growth which is much below the standard norm of economic development. Similarly the per capita income of the district is one of the lowest in Punjab. Jalandhar is famous for sports goods production and one of the largest producers of vehicles of the country. Jalandhar being the center city of Punjab provides goods like glass and furniture to the neighboring cities. The economy of the Kapurthala and SBS Nagar district is still predominantly agricultural. The major crops are wheat, rice, sugarcane, potato and maize.

2.4.4 Hydrogeology

Aquifer group I

The top layer of this aquifer group comprises of coarse sand beds, places gravelly in nature. The sand beds are generally thick separated by small, thin clay beds that are not regionally extensive. In the thickness of clay beds and their occurrence increase substantially. This layer varying thickness that ranges from 72 m to 94 m. The average top layer is 72 m in Hoshiarpur district, 76 m in SBS Nagar district, 81 m in Jalandhar district and 94 m in Kapurthala district. A regionally extensive clay layer with varying thickness from 16 to 32 m separates this aquifer from underlying aquifer group II. This confining clay layer is only 16m thick in Kapurthala district, 21 m in SBS Nagar and around 24 m in Jalandhar district. The thickness of this layer is maximum towards north of Hoshiarpur district where it is 32 m thick. This layer generally acts as a confining layer though confining properties is not very much clear.

Aquifer Group II

This group comprises of alternating sequences of thin layers of sand and clay beds. Sediments of this aquifer group are chiefly sand, clay, gravel and occasional kankar. The sand beds are generally thick and are separated by thin clay beds. Clay beds are not regionally extensive and they normally pinch out.

The aquifer thickness of this group below the confining layer up to 250 m has also been worked out. It has been estimated that a thick aquifer having a thickness ranging between 81 m to 105 m occur in the area. The thickness of aquifer material bearing fresh water sediments is 81 m in Hoshiarpur district, 85 m in Kapurthala district, 87 m in Jalandhar district and 105 m in SBS Nagar district.

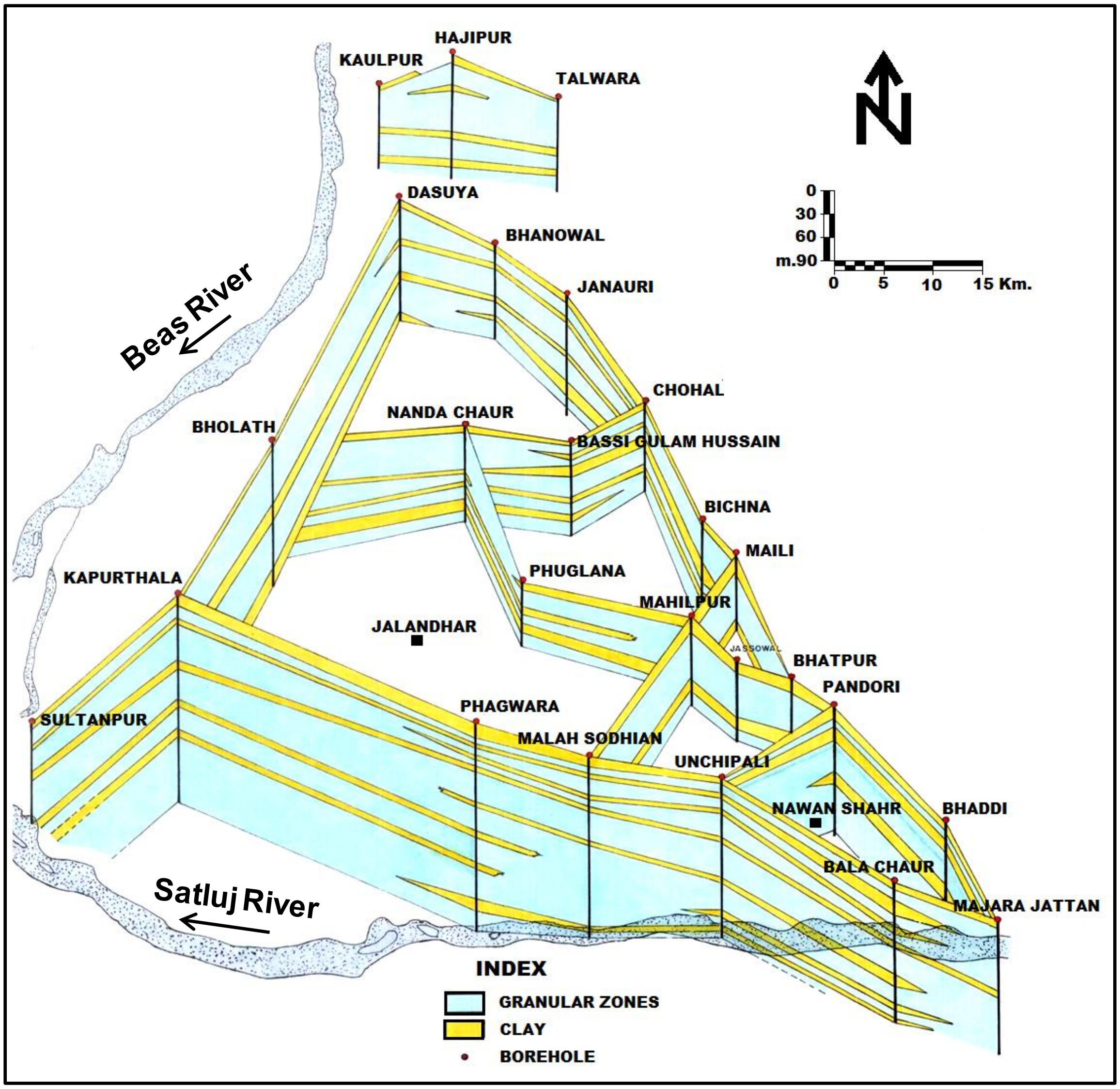


Figure 2.8: Fence Diagram of the Study area showing Aquifer Groups (Source: CGWB)

Though no pumping test data is available for exclusively determining the aquifer parameters of this group, it is estimated that S values of this aquifer group in the Bist-Doab area ranges from 2.5 X 10^{-3} to 7.1 X 10^{-3} with an average value of 3.85 X 10^{-3}. These values have been determined on the basis of pumping tests data of wells tapping multiple aquifer groups.

2.4.5 Agriculture Activity

The area occupied for different agricultural activities is given in Table 2.14. The agricultural area in the Bist-Doab region has increased till 1990-91 and thereafter marginally decreased in the following years (Fig. 2.9) and became almost by 2006- 07.

Table 2.14: Classification of Area ('000 hectares)

Sl. No.	District	Area according to village papers		Area under forest		Net area sown		Area sown more than once		Total cropped area		Cropping Intensity	
		1990-91	2010-11 (P)	1990-91	2010-11 (P)	1990-91	2010-11 (P)	1990-91	2010-11 (P)	1990-91	2010-11 (P)	1990-91	2010-11 (P)
1	***Kapur-thala***	167	167	2	2	141	134	109	136	250	270	177	201
2	***Jalan-dhar***	341	266	3	6	293	236	227	171	520	407	177	172
3	***SBS Nagar***	..	127	..	16	..	97	..	86	..	183	..	189
4	***Hoshiar-pur***	391	339	94	108	247	200	149	157	396	357	160	179
5	***Rup-nagar***	213	139	39	37	112	79	88	67	200	146	179	185

(.. - Not available; P - Provisional ;) Source: (i) Punjab at a Glance, 2011), (ii) Director, Land Records, Punjab

Overall, the net and gross irrigated area in the region have decreased from 1990-91 to 2008-09. There has been a striking increase in the usage of electrically operated tube wells for irrigation purposes during this period (Table 2.15).

Table 2.15: Irrigated area and Number of Tube wells

Sl. No.	District	Net Irrigated Area (000 Hectares)		Gross Irrigated Area (000 Hectares)		Number of Tubewells	
		1990- 91	2010-11(P)	1990- 91	2010-11(P)	1990- 91	2010-11 (p)
1	Kapurthala	140.8	134	250.0	270	50658	63585
2	Jalandhar	288.7	236	515.6	407	103375	93160
3	SBS.Nagar	..	88	..	174	--	35167
4	Hoshiarpur	148.8	185	253.8	318	39383	37308
5	Rupnagar	70.4	70	131.2	125	31089	26884

(P-Provisional), Source (i) Director, Land Records Punjab; (ii) District Statistical Office; (iii) Punjab at a Glance,2011.

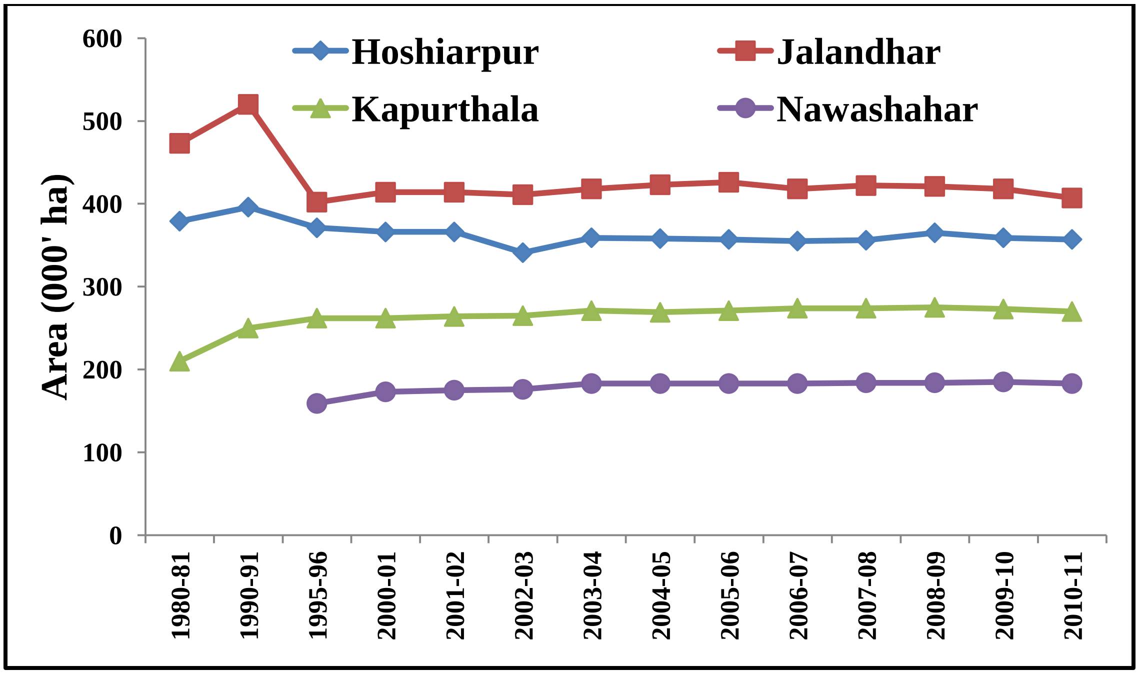


Figure 2.9: Variation of agricultural Area in Bist-Doab Region (Source: Punjab at a Glance 2010)

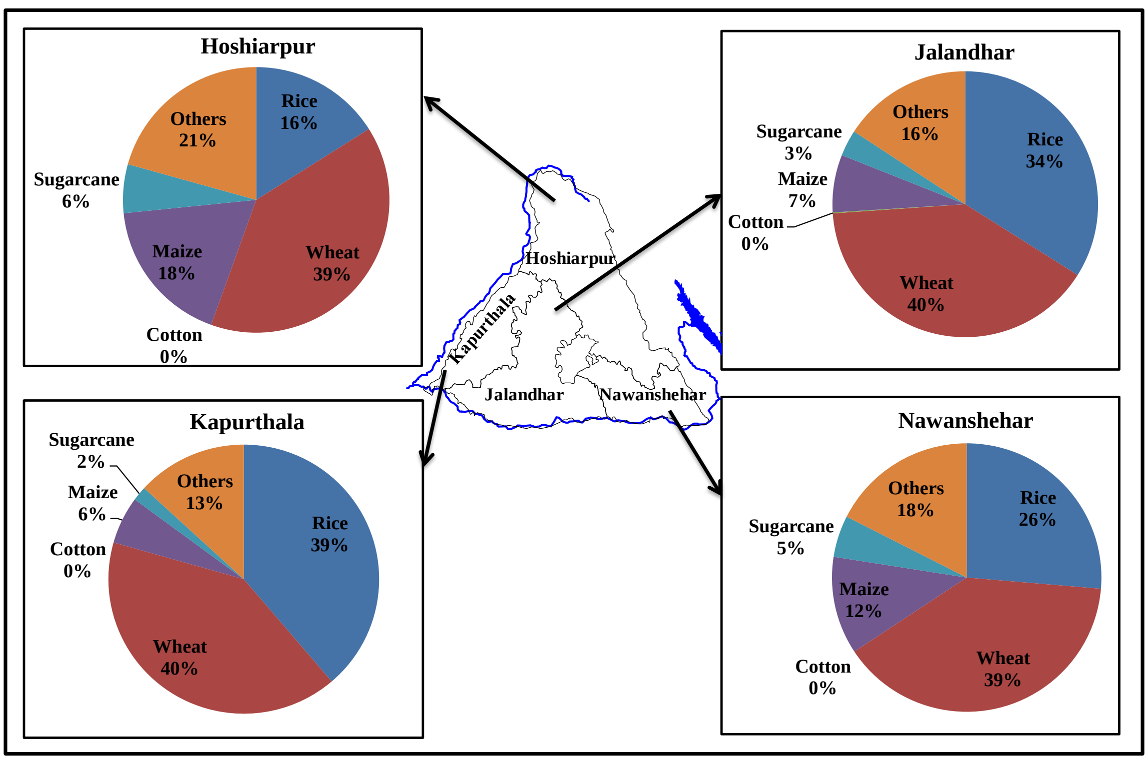


Figure 2.10: District wise crop distribution in study area

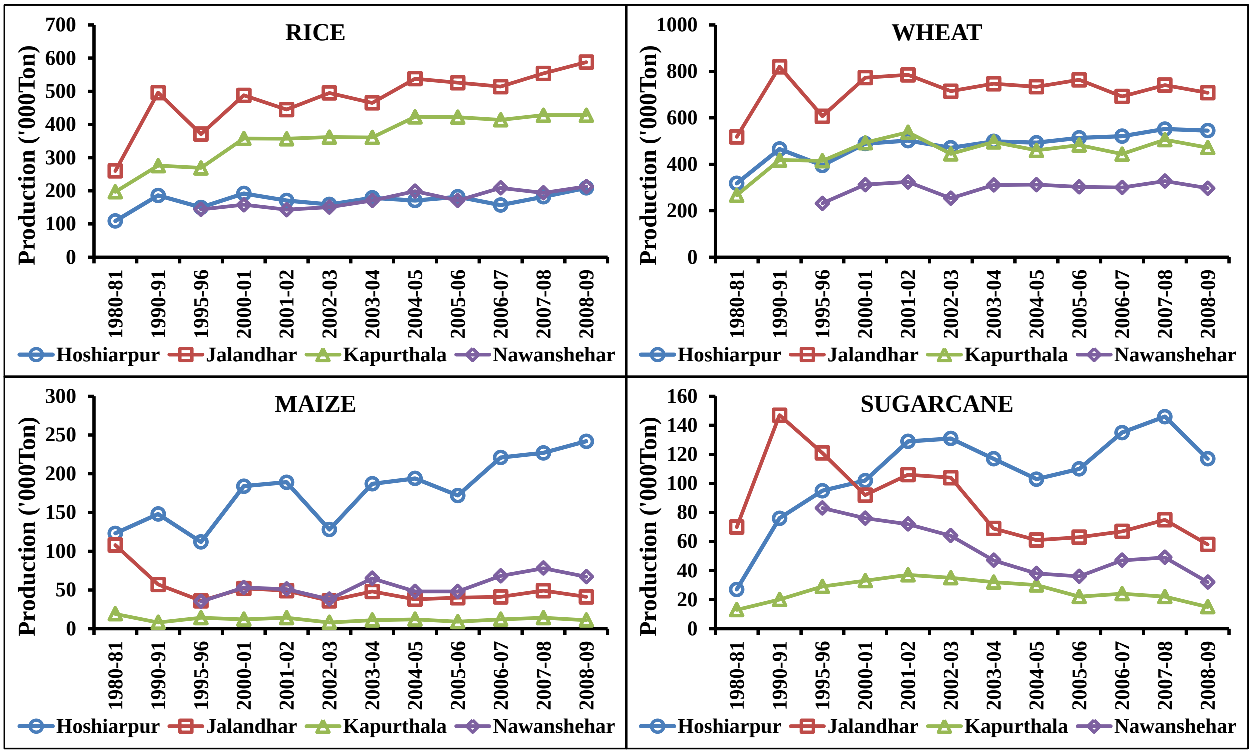


Figure 2.11: Decadal and Annual Production of various crops in Bist- Doab Region

Table 2.16: Water Requirement for Various Crops (Kumar & Jain, 2007)

S. No	Product	Virtual Water (m^3/tonne)	Bist- Doab Region		
			Total Area		VWR
			(km^2)	(%)	(m^3)
1	Cotton Seed	8264	*5*	*0.04*	*16528*
2	Rice	2850	*3564*	*28.63*	*3602717*
3	Maize	1937	*1321*	*10.61*	*593368*
4	Wheat	1654	*4964*	*39.88*	*3367360*
5	Sugar Cane	159	*491*	*3.94*	*44096*
6	others		*2104*	*16.90*	

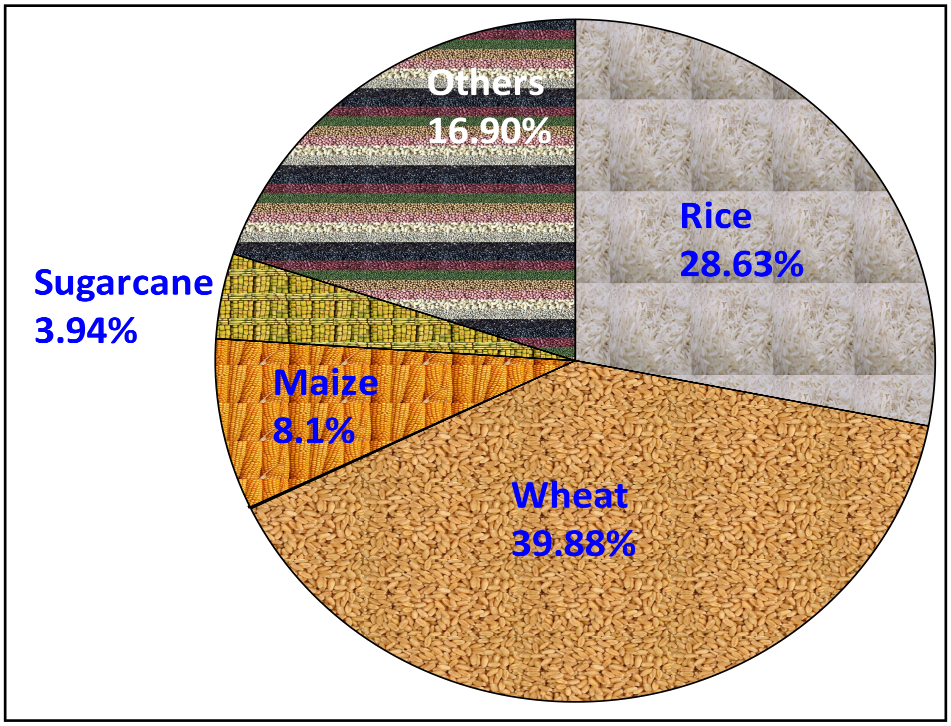


Figure 2.12: Area used by Various Crops in Bist- Doab Region

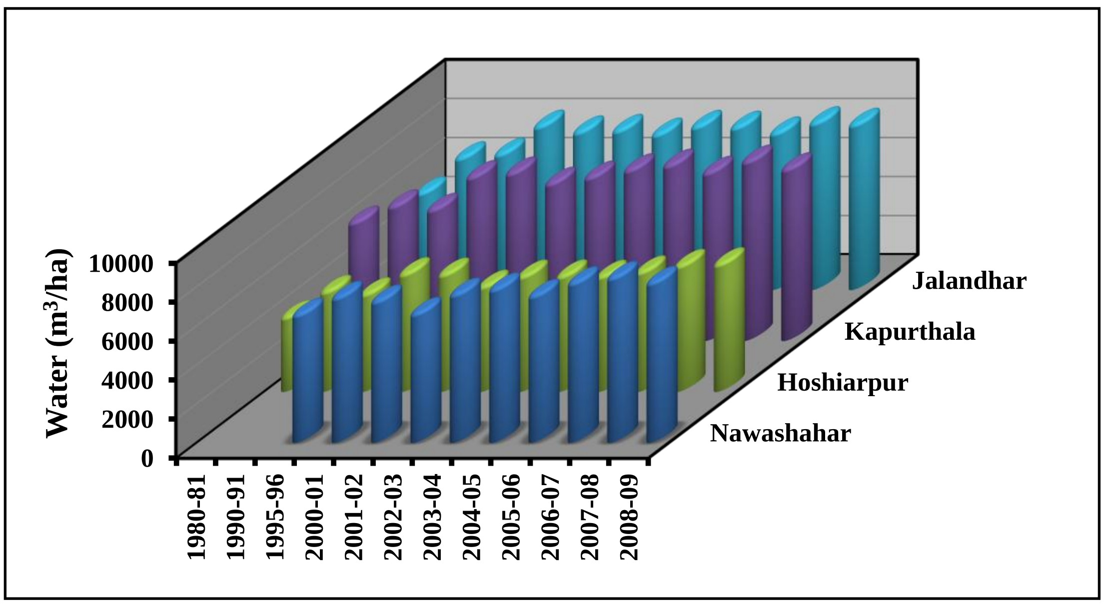


Figure 2.13: Water Utilized/ Unit Area for Irrigation in Bist- Doab Region

Rice and wheat are the major crops grown in the region. The yield of rice shown increase till 1980 and thereafter gradually became constant whereas, wheat shows increase even after 1980 in all the districts in the Bist- Doab region. Jalandhar district shows high production of rice and wheat followed by Kapurthala District in the Bist- Doab region (Fig. 2.11). Hoshiarpur and SBS Nagar have lesser production in rice (Fig. 2.11). Hoshiarpur shows high production in Maize and Sugarcane and Kapurthala shows low production of these crops (Fig. 2.11).

The groundwater over exploitation in the region is mainly due to the agricultural activities. To find out the water utilized by various crops for cultivation in the study area we used virtual water required for various crops (Table 2.16) (Kumar & Jain, 2007). The virtual water required for various crops in the study area have been calculated by multiplying the virtual water amount with the area of irrigated land for the crop of interest. The total irrigated area is given in Table 2.15. The study shows that although area used for irrigation of wheat is more than rice the water consumed by the latter is more than the former. The groundwater utilized per unit area (m/ha) is highest in Jalandhar district followed by Kapurthala district and least in Hoshiarpur district (Fig. 2.13). This is mainly because of the cropping pattern in these districts. It is evident from Fig. 2.10 & 2.11 that the rice is the major crop in Jalandhar and Kapurthala districts which requires more water than other crops. The amount of wheat grown in all the districts in Bist-Daob is similar (Fig. 2.10 & 2.11), hence the major water utilizing crops in this region are Rice and maize.

2.4.6 Available Water Resources for Irrigation

The available water resource for irrigation in the Jalandhar, Kapurthala and SBS Nagar districts were 167655 ham, 116501ham, and 72160ham respectively (Table 2.18). A total of 654 mm water is available in Jalandhar district, out of which groundwater, rainfall and canal water contributes 74%, 21% and 5%, respectively. A total of 573 mm water is available in Kapurthala district, out of which groundwater, rainfall and canal water contributes 86.9%, 12.5% and 0.6%, respectively. In terms of depth, 569 mm of total water is available in SBS Nagar district, out of which groundwater, rainfall and canal water contributes 67.7%, 25.7% and 6.6%, respectively (Aggarwal et al., 2009- 2011).

Table 2.17: Groundwater level (m) in various districts

District	Water table depth (m)			
	Pre-monsoon (June 2009)		Post-monsoon (Oct 2009)	
	Minimum	Maximum	Minimum	Maximum
SBS Nagar	9.25	42.90	7.70	31.47
Kapurthala	3.82	22.26	3.59	22.27
Hoshiarpur	3.59	22.27	2.30	21.06
Jalandhar	5.40	29.05	5.25	30.45

(Source: Statistical Abstracts, 2009)

Table 2.18: Total available water resources (ha-m) for irrigation in various districts

District	Canal Water	Rainfall	Ground-water	Annual water available	Depth (mm)
SBS Nagar	4724	18556	48880	72160	569
Jalandhar	8597	123635	35423	167655	654
Kapurthala	717	14526	101258	116501	573

(Aggarwal et al., 2009- 2011)

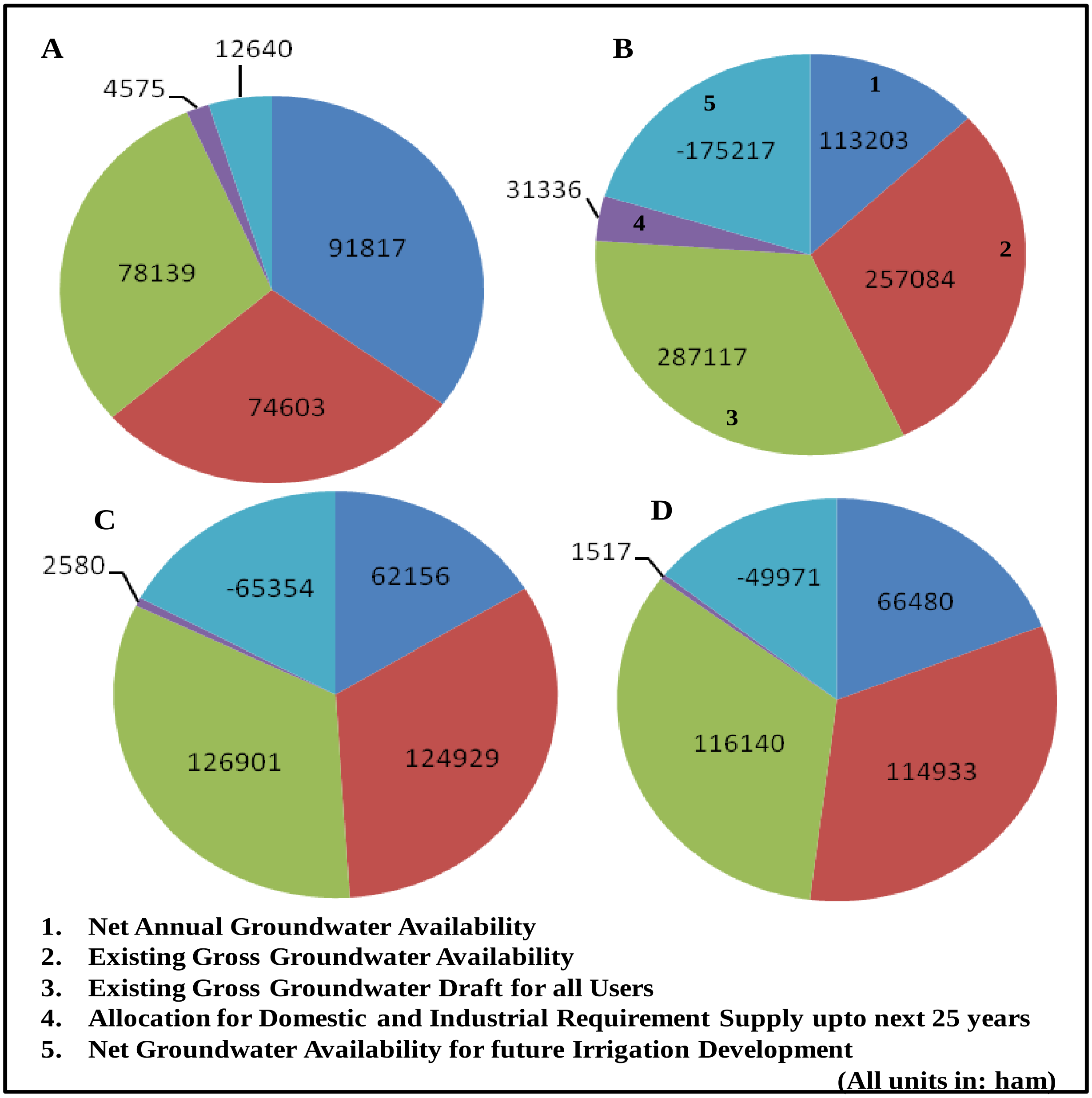


Fig. 2.14: Ground water resources in Various Districts of Bist- Doab region; A: Hoshiarpur; B: Jalandhar; C: Kapurthala; D: SBS Nagar

2.4.7 Climate, landuse and hydrology of districts of Bist-Doab region

Bist-Daob region comprises of four districts namely: SBS Nagar, Kapurthala, Jalandhar and Hoshiarpur.

2.4.7a SBS Nagar District

SBS Nagar district (presently known as SBS Nagar), located in the eastern part of the Punjab State, forms a part of the Bist-Doab region. SBS Nagar district was carved out of Hoshiarpur and Jalandhar districts of Punjab in November 7, 1995 and have been renamed as Shahid Bhagat Singh Nagar on September 27, 2008. Geographically, it lies between latitudes 30°48' 45" - 31°16'15" N and of 75°46' 00" - 76°26'30" E longitudes covering a geographical ambience of 1190 sq.km. with 473 inhabited villages and four towns. The area is bounded by Hoshiarpur district in the north, Siwalik Hills in the northeast, Satluj River in the south, Kapurthala district in the northwest and Jalandhar in the west (Fig. 2.6).

I. Climate & Demography

The most significant climatic elements involved in shaping the region in the present form are temperature and rainfall, their amount, periodicity and fluctuation. A large amount of rainwater goes waste as runoff causing floods and large scale soil erosion. The month of June is the hottest with temperature reaching 33.4 ºC and January is coolest with lowest temperature at 12.3 ºC. The average rainfall of the district is 600.3 mm. According to 2011 Census of India, SBS Nagar district has a population of 1190 sq.km.which is 2.21% of the total population of Punjab State. The density of population is 479 per km^2 with a growth rate of 4.58 % over the decade 2001-2011. Agriculture is the main occupation of the people of SBS Nagar district.

II. Landuse

Land use/Land cover of the district is divided into following major land use classes – built-up land, agricultural land, forest, wasteland and water bodies (Fig. 2.15a). Total area occupied by built up land, which includes urban and rural area, in SBS Nagar district is 8617.77 ha 6.84% of total geographic area (TGA) of the district. The agricultural land constitutes crop land, agricultural plantations and orchards and covers 98384.66 ha (78.08% TGA) out of this crop land covers 97037.18 ha (77.01% TGA). The Siwalik Hills in north-eastern part of the district have reasonably good forest cover. The area occupied by the dense forest (>40% canopy cover) is 10404.70 ha (8.26% TGA), open forest is 1130.27 ha (0.90% TGA) and degraded forest is 618.79 ha (0.49% TGA). In all, 12153.76 ha are under forest cover (9.65% TGA). Most of the wasteland patches have got scrub vegetation. Wasteland, with or without scrub occupies 2406.16

ha area (1.91% of TGA). Water channel of Satluj river, major canals, *choes* and village pond covers 4257.29 ha (3.38% TGA). Out of the total area of water bodies in the district canal of river Satluj (Bist Doab canal) and *choes* covers 3569.44 ha (2.83% TGA). Bist- Doab canal cover 624.86 ha (0.50% TGA) and village ponds collectively cover 62.99 ha (0.05% TGA).

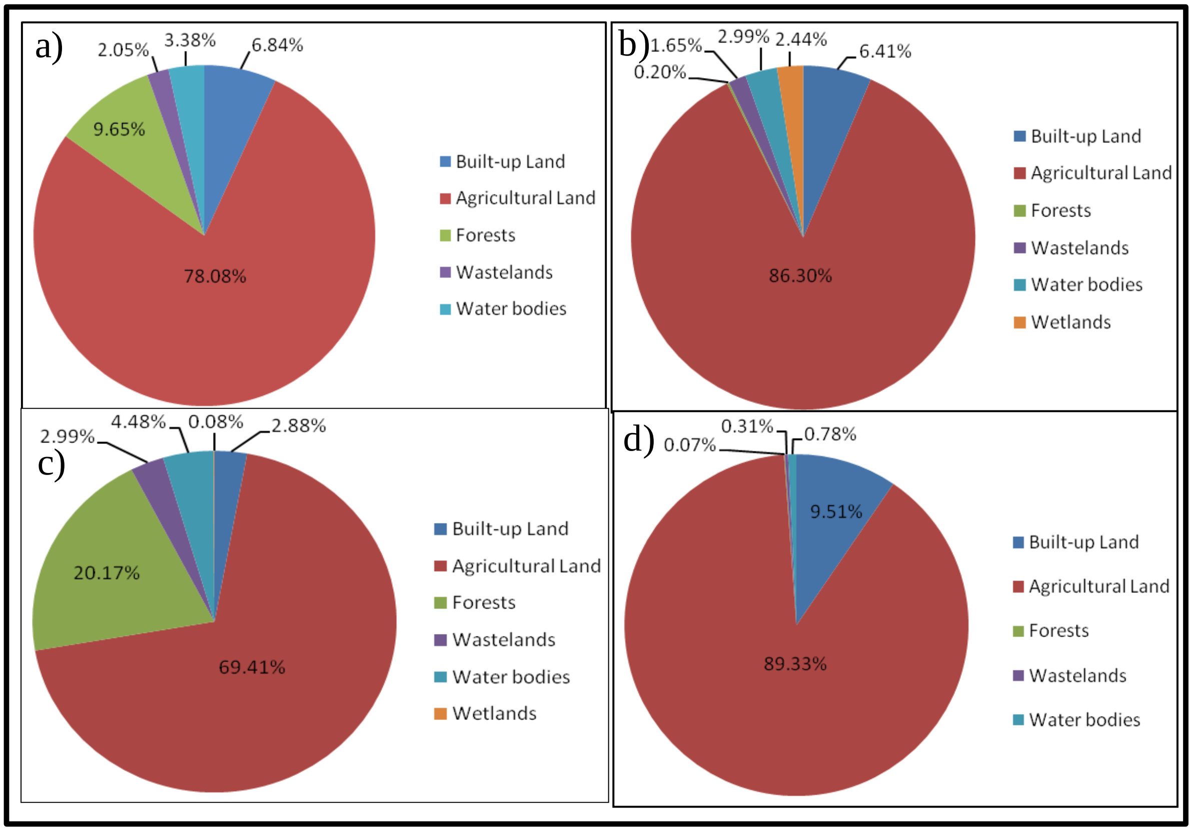


Figure 2.15: Land use in Bist- Doab Region a) SBS Nagar b) Kapurthala c) Hoshiarpur d) Jalandhar (Source: Punjab Remote Sensing Centre, Ludhiana, 2008)

III. Groundwater Development

The gross groundwater draft of the SBS Nagar district is 1161.40 MCM (CGWB, 2007) whereas net groundwater resource is 664.8 mcm resulting in an over draft of 49971 ham (Fig. 2.14 D). The stage of groundwater development in three blocks viz., Aur, Banga and SBS Nagar exceeded 100%, thus categorized as over-exploited while in the remaining two blocks viz. Saroya and Balachaur the stage of ground water development is less than 70% thus categorized under safe category. The stage of ground water development in the district as a whole is 175%. The ground water development is low (<70%) in north eastern part of the district because of bouldry formations. Hence further ground water development can be taken up safely and more tube wells can be constructed. The southern part requires further groundwater development to control over-exploitation of groundwater. The total static groundwater resource of the district is 2569528 ham, which can be exploited for drinking purposes in times of drought.

SBS Nagar district shows rise in the water level in some pockets. However, the long term trend of water level of 10 years in general shows a decline in water level in major part of the area ranging from 0.25 to 0.86 m /year except a few isolated patches where the rise is at the rate of 0.06 m/year which is insignificant. The water table elevation is highest in the north-eastern part (Kandi area) and lowest in the south-western part, which in turn reflects the topographic gradient. In the eastern part of the district, the Satluj River is effluent in nature while moving to the plains it becomes influent in nature. This indicates that Satluj River also has some roles on the occurrence of groundwater in the district. The groundwater flow direction is towards south and southwest along the hilly tract but the flow direction changes to west on the central and western part of the district.

2.4.7b Kapurthala District

Kapurthala District is situated in the Bist- Doab and comprises two noncontiguous parts, separated by some 32 kilometers. Kapurthala, Sultanpur Lodhi and Bholath Tehsils form one part and Phagwara Tehsil, the second separated portion. The area lies between 31° 07′ - 31° 39′ N and 74° 55’ - 75° 36’ Total geographical area of the district is 1633 km^2. There are 684 villages, seven towns and five blocks. Kapurthala District is bounded partly in the North and wholly in the West by the Beas River, famed as the Hydaspes River.

I. Drainage System

The main drainage system of the district forms a part of Beas river system (Fig. 2.16). The flow direction is towards Southwest. West or Black bein drains the central part and flows NE to SW (Fig. 2.16). In Phagwara tehsil, East or White Bein flow west wards and then takes SW turn near western border of the tehsil. It is the main drainage system in the tehsil and joins the Satluj River. The Beas River has tendency to shift westward, there are many small tributaries of Beas and Satluj rivers like Kalna bein, Rau Nala and Kail nala. The active flood plains and old channels have high water table due to their lower topographic position and flooding during the monsoon season. Canals irrigate only the Phagwara and part of Dona area in Kapurthala block.

Bist- Doab canal, Banga distributary and Hardibad and Uchapind minors irrigate Phagwara area whereas Ibban and Kalupur minors irrigate Dona area.

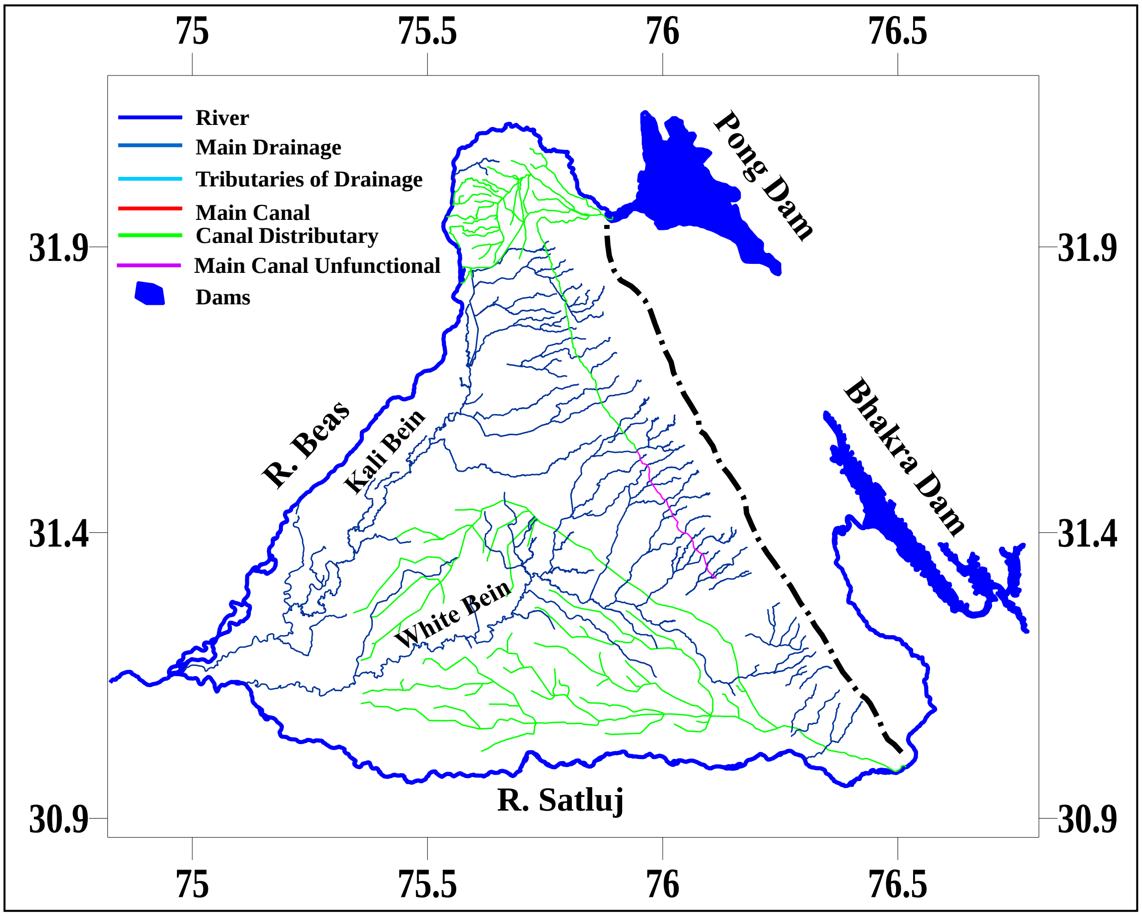


Figure 2.16: Drainage and catchment map of Bist-Doab area

II. *Climate & Demography*

The average annual rainfall in the district is 386.1 mm. The Kapurthala sector receives relatively less rainfall as compared to Phagwara sector. The highest normal monthly rainfall is obtained in August and the lowest in October. There are two pronounced dry periods (March-June and October-November) when the water need exceeds water supply. There is considerable variation between the normal mean maximum (June) and the mean minimum (January) temperatures. Seven to eight months in a year generally have the mean monthly temperature of 20ºC or more.

According to 2011 Census of India, Kapurthala district has a population of 815,168 which is 8.37% of the total population of Punjab State. The density of population is 501 per square kilometer. The major occupation of the inhabitants of the district is farming. The holdings are small and generally fragmented.

III. Land use

Land use/Land cover of the district is divided into six major land use classes – built-up land, agricultural land, forest, wasteland, water bodies and wetlands (Fig. 2.15b). The crop land, fallow land, agricultural plantations and orchards together are categorized as agricultural land and covers 86.30% of TGA of the district. Out of this, the total crop land in the district is 140297.42 ha that comes out to be 86.07% of TGA. Built-up land is the second largest land use category after agricultural land in district Kapurthala. The total area under built-up is categorized as urban, industrial and rural and covers 10453.54 ha (4.41% TGA). The forest land in Kapurthala district is spread over 328.50 ha, which is 0.2% of the TGA of the district. Based upon the crown density of forest cover more than 40%, 315.46 ha of forest cover is categorized as dense forest (0.19% TGA) while 13.03 ha is categorized as degraded forest. Almost 1.65% area (2682.28 ha) of the district is under different categories of wastelands. They include land with/without scrub, salt affected, sand dunes and mining areas for brick kilns. Area covered by water bodies, which includes river channels, canals and village ponds, is 4877.26 ha (2.99% TGA), out of which village ponds cover 71.26 ha (0.04% TGA). Marshy/Swampy and waterlogged areas have been included in Wetlands category. The water logged land covers an area of 1476.73 ha (0.91% TGA). Marshy/ swampy land is spread over 2507.55 ha of land (1.54% TGA). The wetlands in the district cover an area of 3984.3 ha (2.44% TGA). Kanjli wetland is very famous recreational spot present in Kapurthala district and was formed by constructing barrage on West Bein at Kanjli.

IV. Groundwater Development

The stage of ground water development in Kapurthala district ranges between 178% (block-Bholath) to 260% (block-Phagwara) (CGWB, 2007). The total replenishable ground water resource in the district is 62156 ha m. The net ground water draft is 126901 ha m, thus over exploiting 65354 ham (Fig. 2.14 C).The stage of ground water development in the district is 204%.

In Kapurthala district, the depth to water level ranges from 3.82 to 22.26 m BGL. It is shallow and between 5 to 10 m in the Northern (Nadala and Dilwan blocks) and 10 to 15 m BGL in the Southern parts of the district (Sulthanpur Lodhi). Groundwater levels are deeper in the central part ranging from 10 to 15 m and it still becomes deeper in the western parts of the district falling in Kapurthala and Sultanpur Lodhi blocks. In Phagwara block Ground water levels are between 12 and 21 m BGL with deeper water levels in the southern part of the block. During the pre-monsoon period depth to water in the district varies from 3.82 (western part) to 22 m BGL (eastern part). In the post-monsoon period, depth to water table ranged between 4 m to 25 m BGL (Table 2.17). Seasonal fluctuation shows an overall rise in water level due to the monsoon rains. A fall of 0.5 m is seen at Kapurthala and a rise of 3.5 m is seen at Phagwara.

The long-term (10 years) water level trend indicates that the water level decline ranges from 0.2 m/yr to 1.0 m/yr during pre-monsoon and 0.3 m/yr to 0.9 m/yr during post-monsoon. Maximum decline has been noticed in western part of Kapurthala block and the minimum decline in Bholath block.

2.4.7c Hoshiarpur District

Hoshiarpur district falls in the eastern part of the Punjab State and is bounded by latitudes 30°58’30’’ - 32°08’00’’N and longitudes 75°28’00’’ - 76°30’00’’E. It covers an area of 3365 sq.km. It is bound by Himachal Pradesh in the east and north-eastern side, Gurdaspur district in the north-west, Kapurthala and Jalandhar districts in the south-west and SBS Nagar district in the south. Hoshiarpur district has been divided in four tehsils/ sub-divisions namely: Hoshiarpur, Dasuya, Garhshankar and Mukerian which are further divided into ten blocks. There are 12 towns/ cities and 1,449 villages in the district.

i) Drainage System

The district is drained by the number of hill torrents locally called *choes* and by the Beas River on the north-western side (Fig. 2.16). The Hoshiarpur district comprises of two nearly equal portions of hills and plain area. The *Kandi* area comprising of hills and piedmont is rainfed. The district is drained by the river Beas in the north and northwest and Kali Bein. There are three canals (Shah Nehar, Shahpur and *Kandi* canals) providing water for irrigation. On the whole, the water supply (both from precipitation and storage) is not enough to meet the water requirement of crops.

ii) Climate & Demography

The climate of the area is semi-arid and hot with mean annual temperature of 39°C (May& June). May and June are the hottest months and the winter is severe in the months of December, January and February. The south-western monsoon brings the much needed rain during rainy season (July to September). The mean annual rainfall is 938 mm.

According to 2011 Census of India, Hoshiarpur district has a population of 15,86,625, which is 7.10% of the total population of Punjab State. The density of population is 466 per km^2. Agriculture is the main occupation of the inhabitants of the district.

iii) Landuse

Landuse/ Land cover of the district is divided into six major land use classes: built-up land, agricultural land, forest, wasteland, water bodies and wetlands (Fig. 2.15c). The total built-up land (rural and urban area) is 9692.4 ha (2.88% TGA). In agricultural category, there are three sub classes viz. crop land, plantation and fallow land and they cover 69.41% of TGA. The piedmont and alluvial plain area is intensively cultivated. The forest area in the district is classified in two categories- open forest (< 40% canopy cover) and dense forest (> 40% canopy cover). The hilly portion of the district is covered with dense forest, occupying an area of 63477.48 ha (18.84%) and open forest constitutes 1.33% of TGA. There are two reserved/protected dense forests namely Ban Bindraban and Ban Karanpur. Wastelands are classified into two categorized- land with or without scrub and brick kiln areas. Sizable area (9963.04 ha) of the district, along the choe beds, falls in the category of land with or without scrub. The brick kilns and their mining areas cover 107.14 ha (0.03% TGA).The total area under water bodies in the district is 4.48% of TGA of the district. The river Beas passing through the district and *choes* present in the district covers the largest area of 13641.69 ha (4.05% TGA). There are some reservoirs in the district constructed under "Integrated Watershed Development

Programme" which covers an area of 605.88 ha. A total of 273.92 ha (0.08% TGA) has been classified as wetlands, out of which 259.29ha area is waterlogged.

IV. Groundwater Development

The stage of ground water development in the Hoshiarpur district is of the order of 84% (CGWB, 2007). The ground water development in two blocks viz., Tanda (189%) and Hoshiarpur-I (109%) of the district has exceeded the available recharge and thus the blocks have been categorized as over exploited. Talwara block has least development of ground water among all blocks i.e. 45%. Net annual ground water availability of the district is 91817 ham and existing gross ground water draft for all users is 78139 ham (Fig. 2.14A).

In Hoshiarpur district, depth to water level in the area during pre monsoon ranges between 3.96 m BGL to 16.98 m BGL (Table 2.17). The depth to water level is deeper in the south-eastern and shallow in north eastern parts and central and south-western parts. The depth to water level during post monsoon period ranges between 4.41m BGL to 19.84m BGL (Table 2.17). The water level fluctuation varies in between -0.29 to 1.4 m. During the last 10 years, the rate of decline of ground water is in the range of 0.68 to 0.07 m/yr.

2.4.7d Jalandhar District

Jalandhar, the central most district of Punjab State is located between 30°58′& 31°37′ N latitudes and 75°04′ & 75°58′ E longitudes. Total geographical area of the district is 2662 km^2. It is bound by Hoshiarpur district in the north, Ludhiana and Moga districts in the south, Kapurthala district in the west and by SBS Nagar district and Phagwara tehsil of Kapurthala district in the east. The general gradient of the area is towards south-west. There are 14 towns and cities in the district and 1006 villages which are distributed in 10 development blocks. The district forms a part of Beas sub basin of Indus basin. The district is a part of Bist- Doab tract, which is inter alluvial plain between Beas and Satluj River.

i) Drainage System

The Satluj River is the major natural drainage channel observed in the area (Fig. 2.16). It flows westwards and registers the south boundary of Jalandhar district. The river Satluj has been changing its course which can be deciphered from the old courses/ paleochannels. High embankments along the river course prevent the area from inundation. East/ White Bein flowing in the north-east to south-west direction are the other natural drainage channel present in the area. Bist- Doab canal traverse the Jalandhar district and cater to the irrigation water requirement of farmers.

ii) Climate & Demography

The district has semi-arid climate. The average rainfall of Jalandhar district is 534.4 mm. The south-western monsoon begins in the first week of July and extends up to mid September. The summer season starts by mind April and continue till the end of June. The temperatures as high as 43.1 ºC has been observed in the month of June while January is the coolest month with mean monthly temperature of 1.4 ºC.

According to 2011 Census of India, Jalandhar district has a population of 2,193,590 which is 7.87% of the total population of Punjab State. The density of population is 831 per km^2. Agriculture is the main occupation of the inhabitants of the district.

iii) Landuse

Agricultural and built-up land area the main land use classes in the district (Fig. 2.15d). The built-up land is the second largest category after agricultural land in Jalandhar district and covered 25028.64 ha (9.51% TGA). The built-up land has been further classified as urban, industrial and rural built-up which cover 12891.85 ha (4.90% TGA), 19.73 ha (0.01% TGA) and 12117.06 ha (4.60% TGA) area respectively. Agricultural land is the major land use category present in the Jalandhar district (235109.95 ha, 89.33% TGA). It includes crop land, fallow, agricultural and horticultural plantations. District Jalandhar is intensively cultivated where 89.06% (234401.68 ha) TGA of the district is under cultivation. District Jalandhar has comparatively very small forest cover (190.29 ha) because the land is very fertile and primarily used for agricultural rather than forestry. Only 0.07% of TGA of the district is under forest cover, which is dense. Nearly 0.31% of TGA (806.23 ha) of the district is under wastelands, which includes mining areas, land with or without scrub, salt affected and sand dunes. The mining activity for brick making and brick kiln cover an area of 435.58 ha (0.17% TGA). Area under the water bodies is 2056.24 ha (0.78% TGA). This includes area covered by water channel of river Satluj, the area under major canals and village ponds.

V. Groundwater Development

The ground water development in the Jalandhar district has exceeded the available recharge with the stage ranging from 125% (block- Jalandhar West) to 418% (Lohian Block), thus the district has been categorized as over exploited. Net replenishable ground water availability in the district has been assessed as 113203 ham (Fig. 2.14B). Gross ground water draft for all uses in the district is 287117 ham, thus leaving shot-fall (over draft) of 175217 ham. Stage of ground water development in the Jalandhar district has been assessed to be 254%.

In district Jalandhar, depth to water level in the area ranges from 6.0 to 29.0 m BGL during pre monsoon period and is shallow in northern part and deeper in southern part. Deepest water levels are normally reported from parts of Shahkot block. In major part of the district, water level varies between 10 and 15 m. Long-term net change of water levels indicates a general decline (negative change) in the large part of the district and it is up to 8.18 m. The maximum fall is observed in parts of Nakodar and Shahkot blocks (CGWB, 2007).

The general information of districts of Bist-Doab region, Punjab area (India) is summarized below in tabular form-

District Details at a Glance

S.N.	Parameters	Hoshiarpur	Janandhar	Nawanshahar (SBS Nagar)	Kapurthala
1	**Lat**	30°58'30'' - 32°08'00''N	30°59' - 31° 37' N	30°48' 45" - 31°16'15" N	31° 07'- 31° 39'
2	**Long**	75°28'00'' - 76°30'00''E	75° 04' - 75° 57' E	75°46' 00" - 76°26'30" E	74° 55' - 75° 36'
3	**Elevation from MSL (m)**	296	262	283	225
4	**Area**	3365 sq.km.	2662 sq.km.	1190 sq.km.	1633 sq.km.
5	**Population(as per 2011census)**	15,86,625	2,193,590	612,310	815,168
6	**Population growth from 2001 to 2011**	7.10%	11.16%	4.58%	8.37%
7	**Normal Annual Rainfall**	938 mm	701 mm	924mm	779 mm
8	**Normal Monsoon Rainfall**	720mm	490mm		584 mm
9	**Normal Rainydays**	38 days	35 days	41 days	33 days
10	**Temperature (Mean Minimum)**	5 °C(January)	6°C	0°C (minimum)	4 °C(January)
11	**Temperature (Mean Maximum)**	39°C(May&June)	42°C	48°C (maximum)	40°C(May&June)
12	**soil type**	Yellowish brown to dark brown in colour, calcerous sand to fine sandy loam to silts.	1) Tropical arid brown and 2) arid brown soils (solonized).	1) Reddish Chestnut Soils and 2) Tropical Arid Brown Soils (Weakly Solonized).	1) Arid brown calcareous soils and 2) Tropical Arid brown soils deficient in N, P & K.
13	**Depth water level (pre monsoon)**	3.96 mbgl to 16.98 m bgl	6.0 to 29.0 m bgl, shallow in northern part and deeper in southern part, Deepest in Shahkot block	Mainly in 10 to 20 m. In western and southern part it is between 5 to 10 m bgl.	5 m bgl in western part, 22 m.bgl in Eastern part.
14	**Depth water level (post monsoon)**	4.41m bgl to 19.84m bgl		8.3 to 23.7m (In unconfined aquifer)	between 4 m to 25 m bgl.

15	**Rate of decline Ground water (m/yr)**	0.68 to 0.07	Water table gradient : 1.08 m/km	0.25 to 0.86 m/yr. At isolated patches water level rise @ 0.06m/yr	During pre-monsoon: 0.2m/yr to 1.0 m/yr. During post-monsoon: and 0.3 m/yr to 0.9 m/yr.
16	**Net area sown**	2,01000 ha.	2,27,994 ha (86% of the total area)	94,0Sq.km	
17	**Agr. Area & total cropped area (Gross sown area)**	2,33,906 ha (69.41%), 3,59,000 ha.	Agriculture area: 89.33% TGA 4,13,279 ha.	Agriculture area: 78.08% TGA	Agriculture:86.3 % TGA
18	**irrigated by**	tubewells (91.36 % of net irrigated area) and canals (8.64% of net irrigated area)	Of the total geographical area, 10% area by canal and 76% area by ground water	By canals 10 Sq.km area (1.2% of total irrigated area) and by groundwater about 98%.	Mainly by Groundwater
19	**gross irrigated area**	301200 ha			
20	**net irrigated area**	162000 ha	2,27,423 ha		
21	**Net Annual Groundwater availability**	91817 ham	1132.03 ham	664.8 mcm	62156 ha-m
22	**Existing gross ground water draft**	78139 ham	287117 ham	1161.40 MCM	1269.01 mcm
23	**Stage of Ground Water Development**	84 %. (Range 45% to 189%)	254 %. (Range 133% to 350%)	175%.	204% (Range: 178% (block-Bholath) to 260% (block- Phagwara)).
24	**GW Quality**	By and large suitable for drinking purposes			
25	**(i) Water Type (Shallow Groundwater)**	pH range: 7.45 to 8.20, Type: C2S1		Ca-Mg-HCO3	Ca +Mg HCO3
26	**(ii) EC (mS/cm)**	280 to 1050	The quality of ground water is suitable for domestic /irrigation purposes		245-2490
27	**Land Use**	Agriculture: 69.41% TGA Water Bodies 4.48% TGA Built up: 2.88% TGA	Agriculture: 89.33% TGA Water Bodies 0.78% TGA Built up: 9.51% TGA	Agriculture: 78.08% TGA Water Bodies 3.38 %	Agriculture:86.3 % TGA Water Bodies 2.99% TGA

		Forest: 20.17% TGA Wasteland: 3% TGA Wetland: 0.8% TGA	Forest: 0.07% TGA Wasteland: 0.31% TGA Wetland: 0.00% TGA	TGA Built up: 6.84 % TGA Forest: 9.65% TGA Wasteland: 2.05% TGA Wetland: --- TGA	Built up: 4.41% TGA Forest: 0.2% TGA Wasteland 1.65% TGA Wetland: 2.44% TGA
28	**Water course**	R. Beas, Shahpur Canals, Kandi canal & Shah Nahar Canal	R. Satluj, Bist Doab canal, White Bein	R. Satluj, Bist Doab canal	R. Satluj, R. Beas
29	**Major crops**	Rice, Wheat, Vegetables. Sugarcane, oilseeds, potato, groundnut and pulses	Wheat, rice, potato, maize and sugarcane	Wheat, rice and sugarcane	Rice, Wheat, Maize, sugarcane & rapeseed

Wastelands: (Land with/without scrub+ Sand dune/Sandy area+ Mining/Brick kilns).

3

DATA COLLECTION AND TREND ANALYSIS

CHAPTER 3

DATA COLLECTION AND TREND ANALYSIS

The study of rainfall trend is most important for the state like Punjab whose food security and economy is significantly depends on timely availability of rainfall. About 80 % of rainfall in Punjab occurs in the monsoon season months (June to Oct). The agriculture output is primarily govern by the timely availability of the water Therefore, for Punjab where agriculture influence on economy availability of adequate water for irrigation under changed climatic scenarios is very important. In future population growth along with higher demand of water for irrigation and industries will put more pressure on water.

Changes in rainfall pattern and increased temperature could have a direct impact on water resources. The pattern of floods, droughts, storms and cyclonic activity could change, leading to major implication with regard to the drinking water supplies, hydropower generation, irrigation activities, and threats to life and property. It is understood that changes in precipitation levels will be accompanied by increase evaporation rates as temperature rise. The combination of these changed will have profound effects on soil moisture level in river catchment, which will effect agriculture production.

Increased frequency and severity of extreme weather conditions will increase the vulnerability of the farming sector. Water stress situation or drought as a result of hotter, drier summers will have a serious impact on soil, and the impact on both crop quality and variability will lead to a higher need for water in agriculture. Equally, waterlogged soil on which excess water needs to be frequently drained may not only lead to crop losses, but can impact severely upon crop quality and variability (Vijay Kumar et al. 2010).

3.1 Rainfall

The long term rainfall data was retrieved from publicly available Climate Research Unit (CRU) TS 2.1 dataset, out of Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich, UK. This published dataset consists of interpolated (on a 0.5 degree latitude- longitude grid) global monthly rainfall data from 1901 to 2002 (Mitchell and Jones, 2005; Vijay Kumar et al. 2010). The raw station data are derived from seven different sources and are corrected for in homogeneities using a modified version of the Global Historical Climatology network (GHCN) method. For the purpose of converting the CRU dataset from its original format, the open source GIS software Geographic Resources Analytical Support System (GRASS) was used (Vijay Kumar et al. 2010). The rainfall data retrieved has been divided into four seasons namely, winter (January to February), pre-monsoon (March- May), monsoon (June- September) and Post- monsoon (October- December).

The average rainfall in Bist-Doab region for the past century (1901- 2011) shows that the region receives maximum rainfall during monsoon period i.e. June to October with almost 80% of total rainfall in a year (Fig. 3.1). The minimum rainfall is during November with the amount less than 10 mm. The rainfall in the Bist- Doab region shows high amount of fluctuation during 1901- 2011 in different seasons. The Hoshiarpur district (Fig. 3.2a) shows high rainfall during the entire period in all the seasons followed by the SBS Nagar district (Fig. 3.2b). Kapurthala district (Fig. 3.2c) shows comparatively less amount of rainfall in the whole study area. All the districts show maximum rainfall during the monsoon season in the year 1980 and almost no rainfall in the winter of 1943 (Fig. 3.2 a- d).

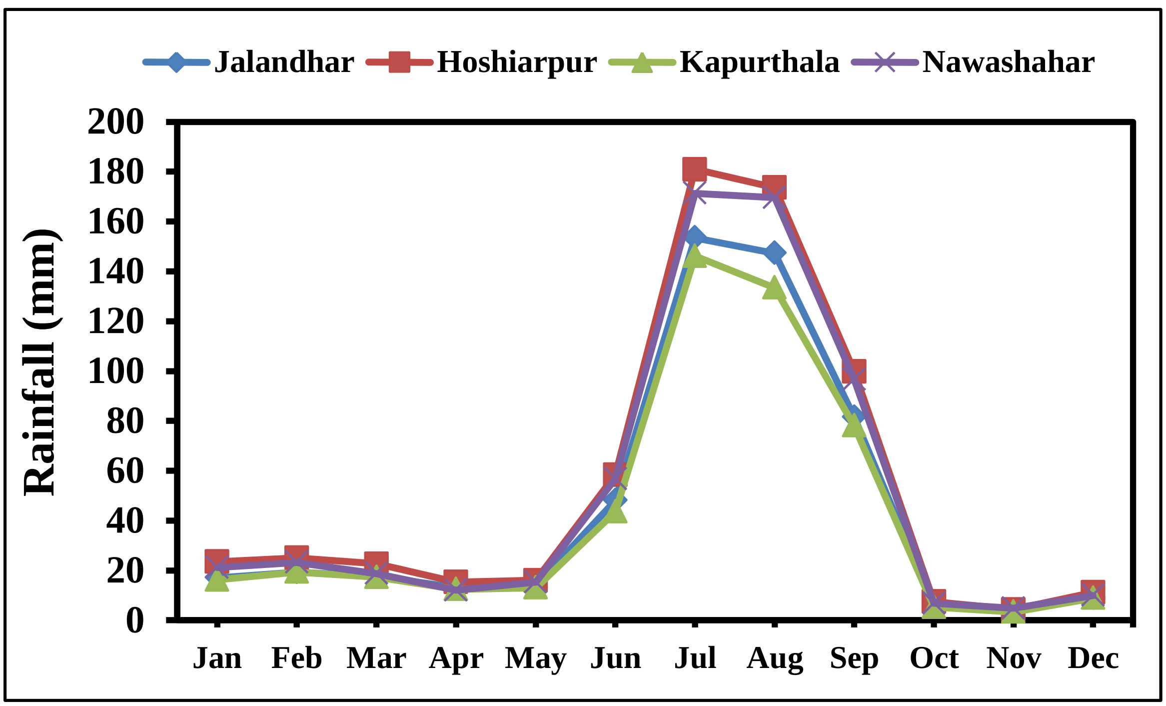


Figure 3.1: Average monthly rainfall (mm) from 1901- 20011 in Bist- Doab region

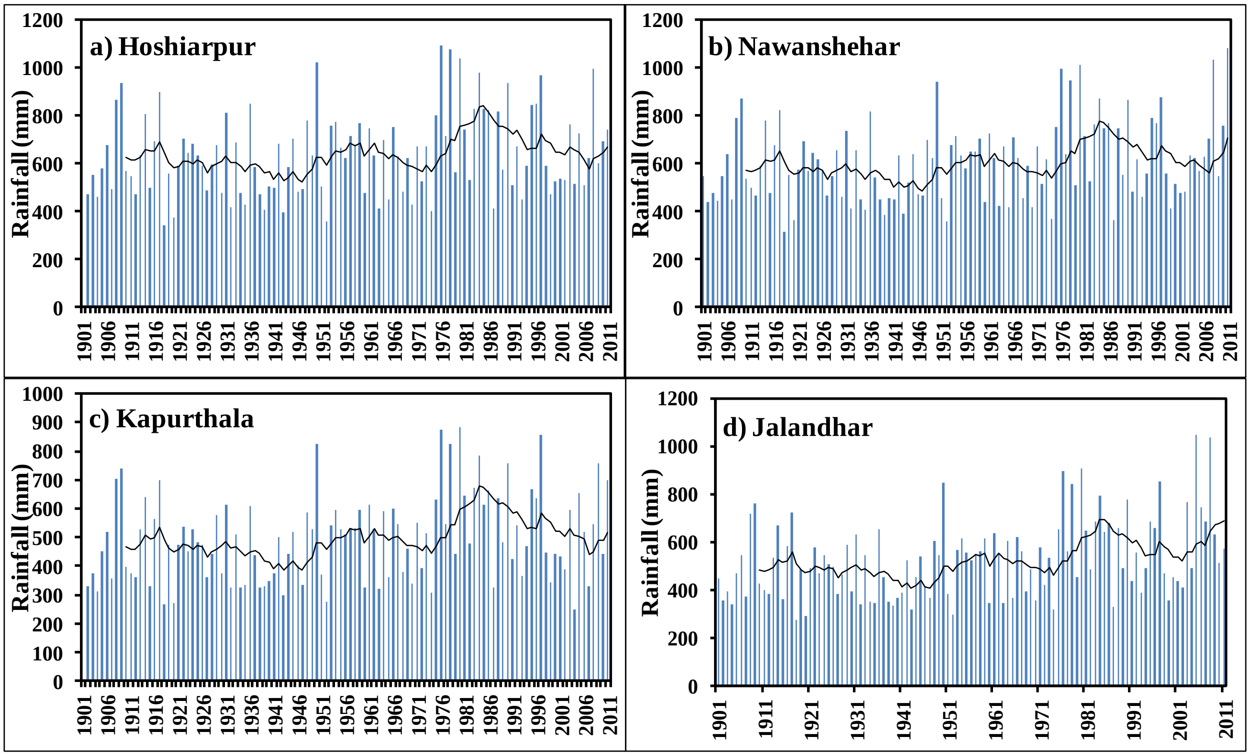


Figure 3.2: Rainfall amount (annual) during 1901- 2011 in Bist-Doab region

3.1.1 Change in Rainfall Pattern

The rainfall pattern in the Bist-Doab region occurs during monsoon period with almost 80% of total rainfall occurring during this period. The long term rainfall data in the region shows that rainfall was high in 1970's with more than 1000mm annually. There is a gradual decrease in annual rainfall amount thereafter i.e. since 1980 till 2008 in the region. On seasonal scale the rainfall in the Bist-Doab region shows similar characters in the hilly regions i.e. in Hoshiarpur and SBS Nagar districts and similar in plains of Kapurthala and Jalandhar districts. The monsoon, pre monsoon and post monsoon rainfall shows that rainfall in hilly region is higher than that of plains. The plains region shows steady increase in the annual monsoon rainfall when compared with hilly regions (Fig. 3.3a-d). The rainfall in hilly regions during monsoon period goes more than 850mm/year but in case of plains it lies less than 750mm (Fig. 3.3a-d). The rainfall amount in the winter period is almost constant or similar since 1901 to 2011 with high amount of rainfall in the last decade (Fig. 3.3a-d).

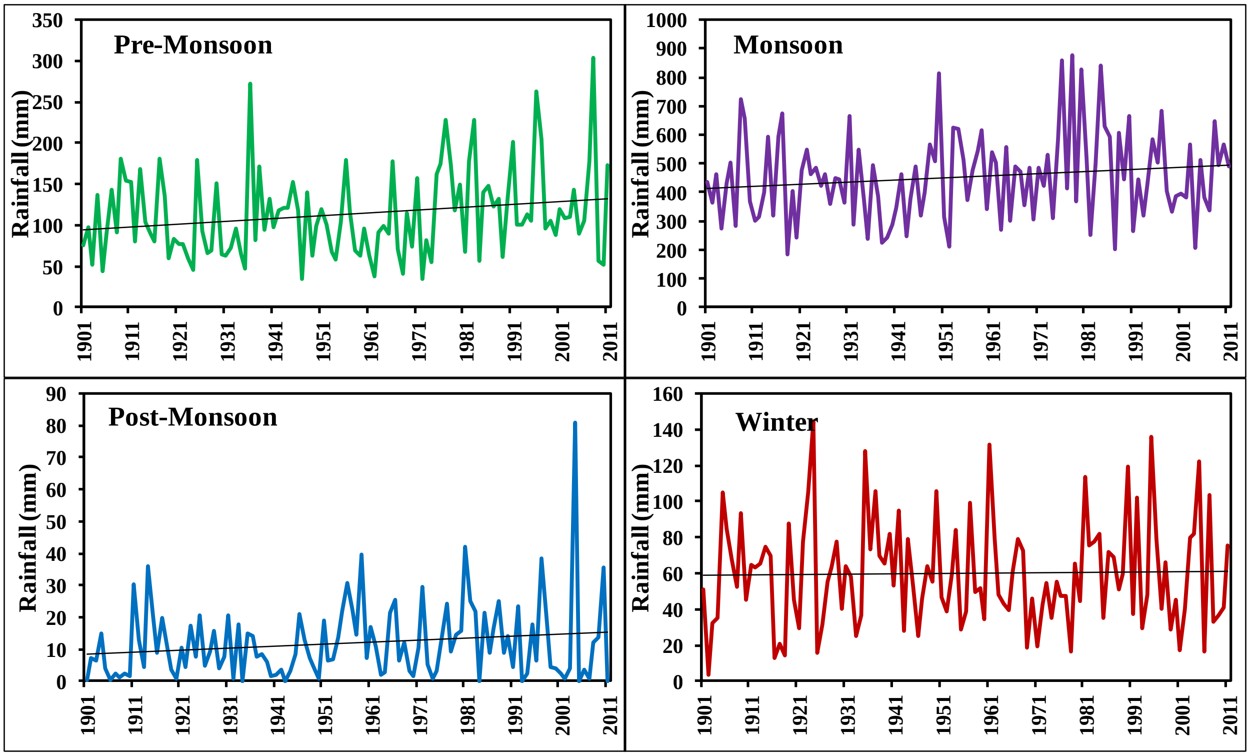


Figure 3.3a: Seasonal Variation in Rainfall in Hoshiarpur district

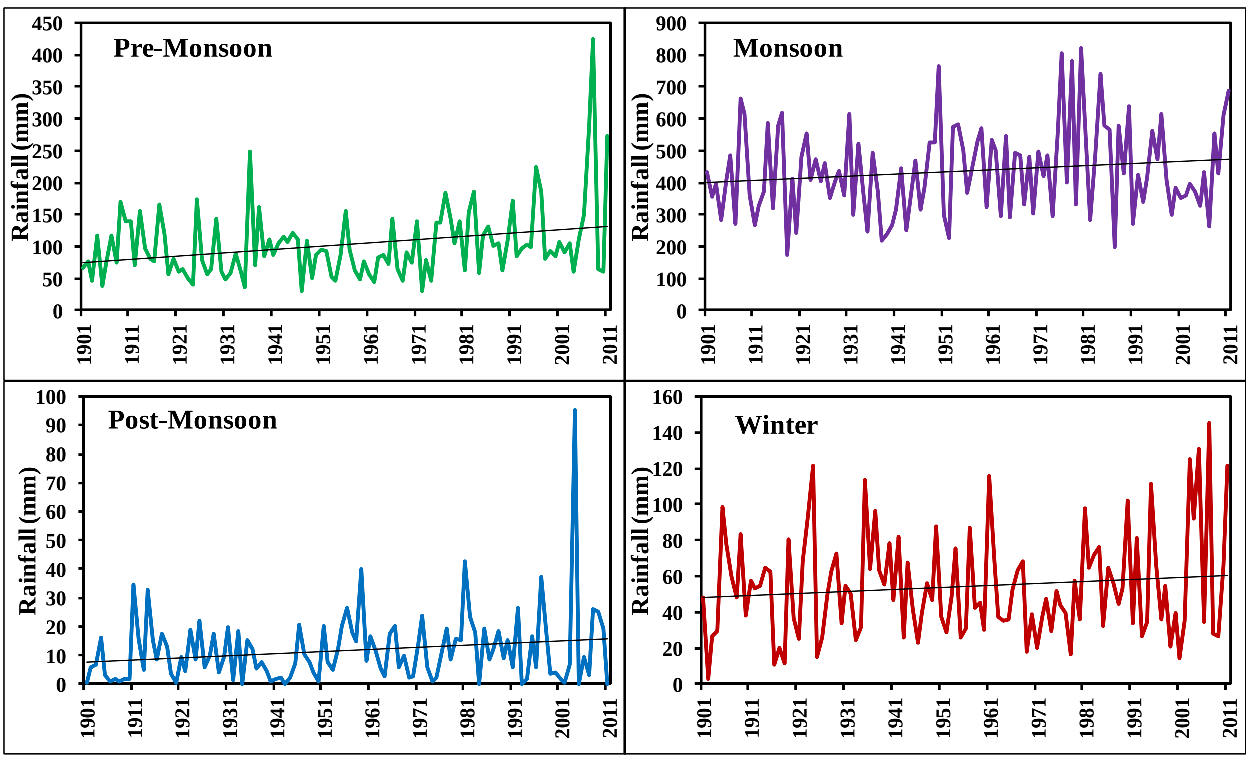


Figure 3.3b: Seasonal Variation in Rainfall in S B S Nagar district

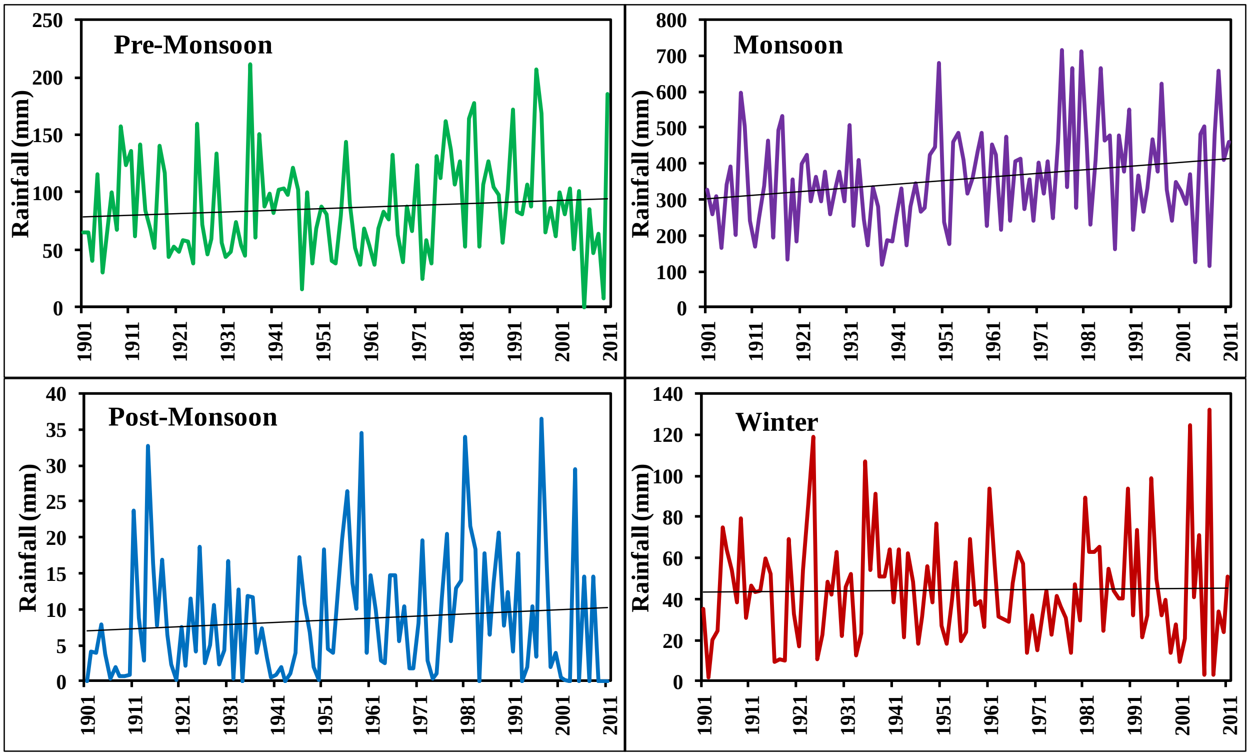


Figure 3.3c: Seasonal Variation in Rainfall in Kapurthala district

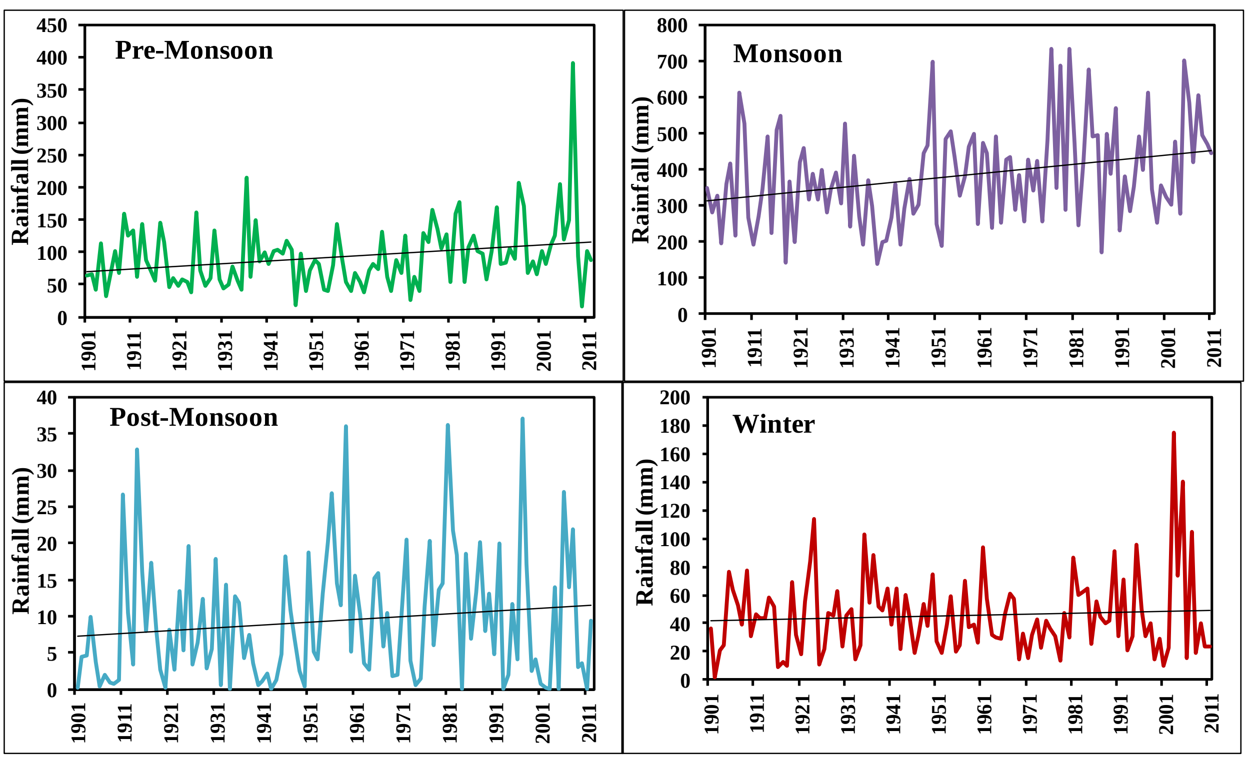


Figure 3.3d: Seasonal Variation in Rainfall in Jalandhar district

The detail statistical rainfall trend analysis done using the data set of Climate Research Unit (CRU) may deviate drastically from the actual trend if ground based data do not match with the CRU based data (Fig 3.4). In order to check this, IMD data for rainfall for the period 1998-2002 taken for the four sites in the Bist Doab region was compared with the CRU data. The comparison of this data is shown in the figure below.

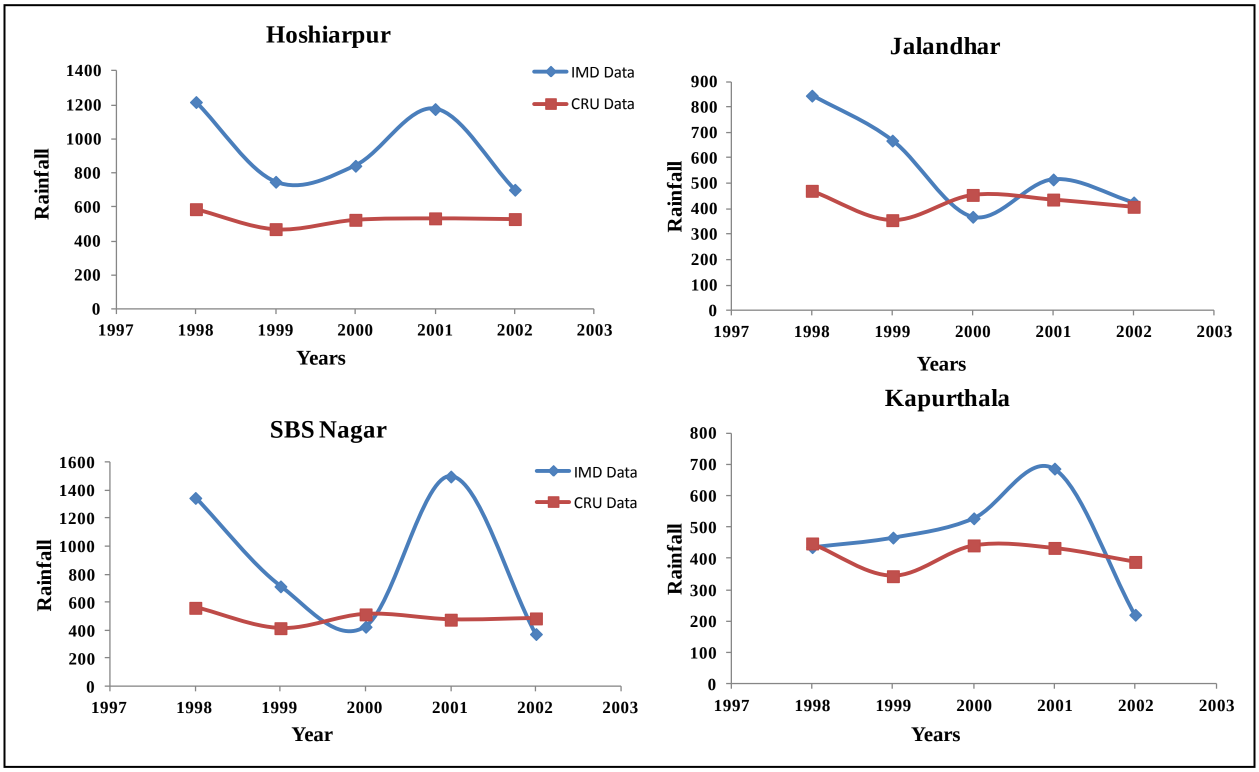


Figure 3.4: Comparison of IMD and CRU rainfall data for the period 1998-2002.

The comparison clearly shows a major mismatch between the CRU and IMD data. Many of the previous works on climate changed used CRU data to interpret the climate trend and future prediction without verifying with the ground based data. It is clearly seen from the above comparison that howsoever long data available from CRU or other sources, without ground based comparison and validation; the drawn interpretation can mislead the interpretation especially where regional data paucity exist. Therefore, all the previous results & interpretations for climate trends based on CRU or similar source may not be of any practical relevance. In the present study, we have compiled as much ground based data as possible for its use in the present and future studies. The average annual rainfall data of IMD for the Bist Doab region gives a different scenario than the CRU data. The rainfall variation shows alternate changing in rainfall intensity. The low rainfall in the region occurred during 2002 and 2007; high rainfall years were 1990, 2005 and 2008. Since 2008, over the last 5 five years, rainfall is continuously decreasing (see also fig 3.13). The effect of decreasing rainfall trend is being seen in terms of continuous depleting reservoir levels and in groundwater table.

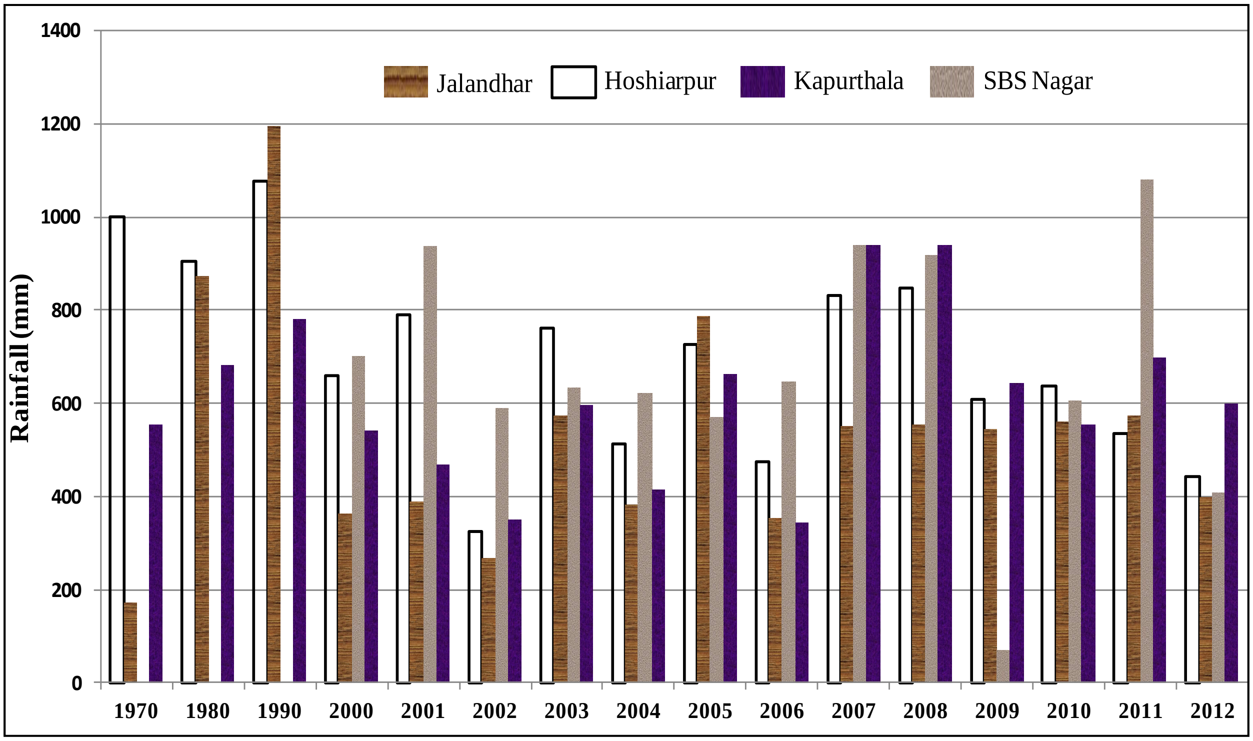


Figure 3.5:Average annual rainfall in the Bist Doab region from 1970 to 2012(Source: IMD)

3.2 Temporal and Spatial trend of Ground water Levels

Depth to water table for the period 1998-2008 and long term data at few locations has been collected from CGWB, NWR Chandigarh. For deriving DEM, elevation data at 30 m x30 m resolution was taken from open source-ASTER. Land use and soil details were procured from Punjab Remote Sensing Agency. For stratigraphic details, strata chart for 26 locations distributed uniformly in space was collected from CGWB and State Groundwater Department. Hydro meteorological data such as, rainfall is collected from Department of Agriculture, Punjab Government.

The piezometric head of groundwater in the study region has been studied for both shallow and deep aquifers. For easy understanding of the groundwater depth in the region the study area have been divided into four parts: 1) North region; 2) Kali Bein region; 3) Central region and 4) Southern region.

The northern region comprises of Mukerian, Talwara and Hazipur shows that the piezometric depth in this region is very shallow i.e. less than 10 m. below ground level (BGL) (Fig. 3.6). The higher depth to water table in the locations Talwara and Hazipur are mainly due to the presence of hilly terrain (kandi belt). The depth to water table in pre monsoon period is almost constant from 1999 to 2009 but in post monsoon period the location Mukerian shows high fluctuation in groundwater depth indicating recharge of groundwater during monsoon periods in this location.

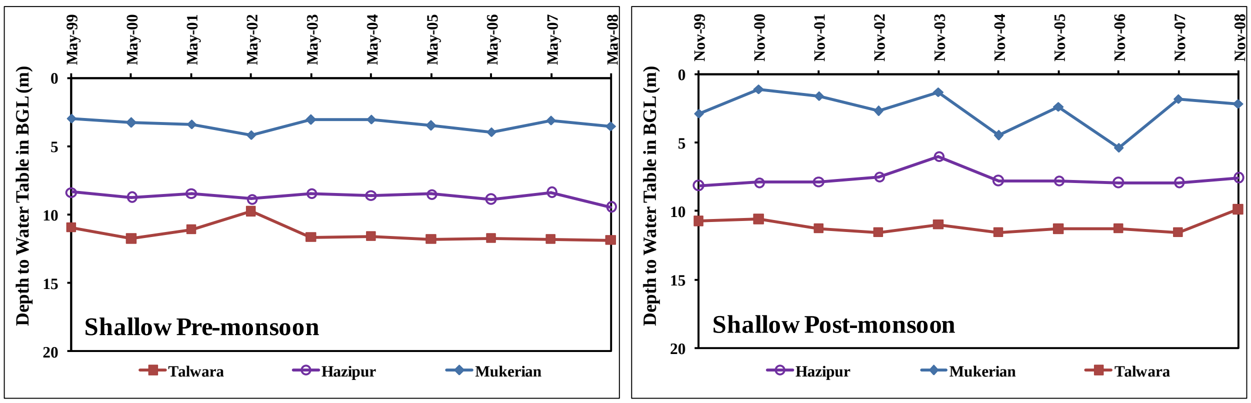


Fig 3.6: Piezometric Head of Water Table (BGL) in Northern Region of the Study Region during Pre and Post Monsoon Period.

In Kali Bein region shallow groundwater shows continues decline in groundwater table from 1999- 2009 in all the locations in this region except Durmiwal which is in the northern most part of the kali Bein catchment. The location Dasuya shows more than 5m decline in water table. The locations, like Kapurthala, Kartapur and Dalla, in the downstream of the region show high fluctuation in piezometric up to 8m decline in the water table. The fluctuation in water table is high since year 2000 with high amount of decline in the piezometric head of groundwater. The water table in this region except that of Dasuya and Bholath shows increase in water table during post monsoon period indicating recharge from monsoon precipitation. The piezometric head of groundwater in the deep aquifer shows negligible amount of seasonal fluctuation with decreasing water table in the downstream of the Kali Bein region (Fig. 3.7).

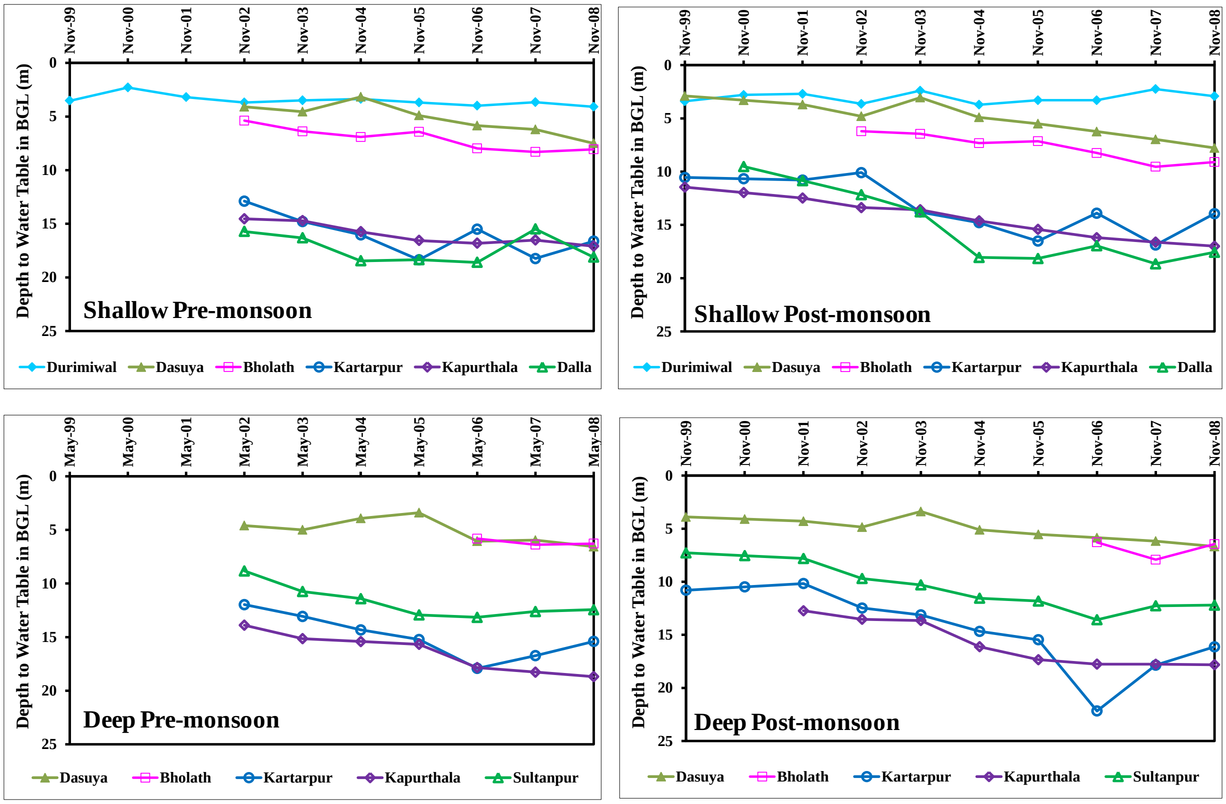


Figure 3.7: Piezometric Head of Water Table (BGL) in Kali Bein Region of the Study Region during Pre and Post Monsoon Period.

The piezometric head of shallow and deep aquifer in the central region is very deep when compared with other regions of the study area with water table below 20 m in locations like Jalandhar, Nakodar and Phagwara (Fig. 3.8). The water table at deep aquifer in Kandi region is deeper which is evident from high depth of water table at Hoshiarpur (Fig. 3.8).

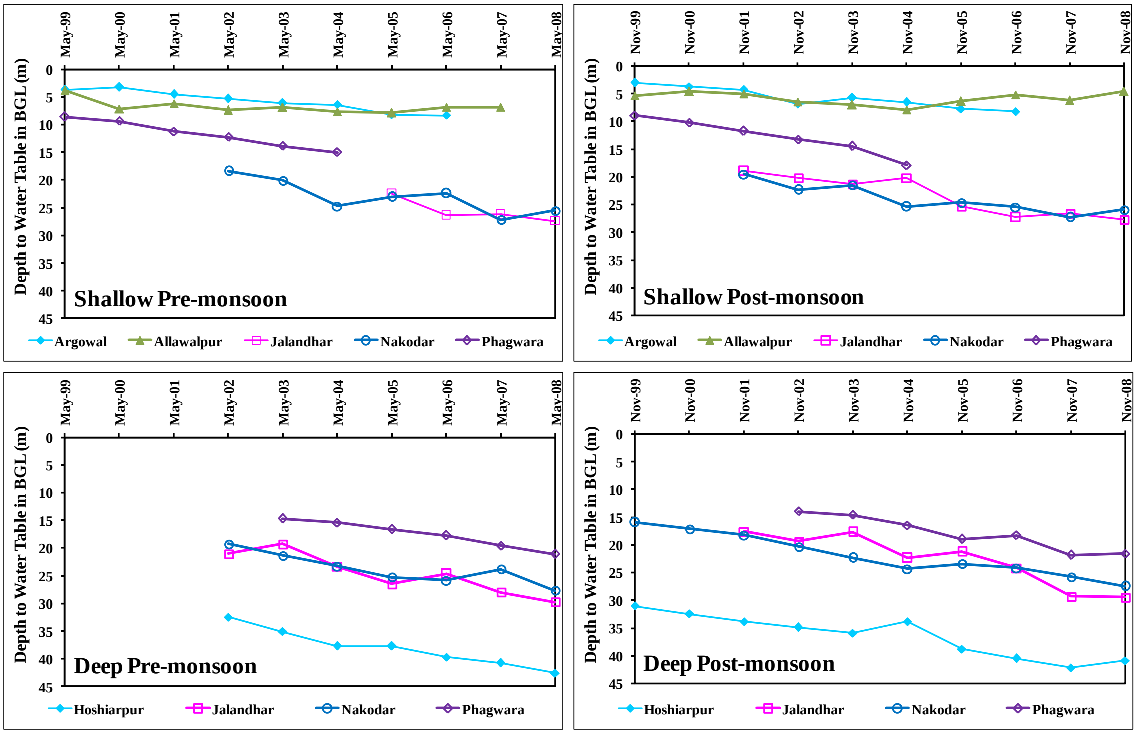


Figure 3.8: Piezometric Head of Water Table (BGL) in Central Region of the Study Region during Pre and Post Monsoon Period.

The southern region of the study area also shows similar characteristics to that of central region with negligible seasonal change in piezometric head both in shallow and deep

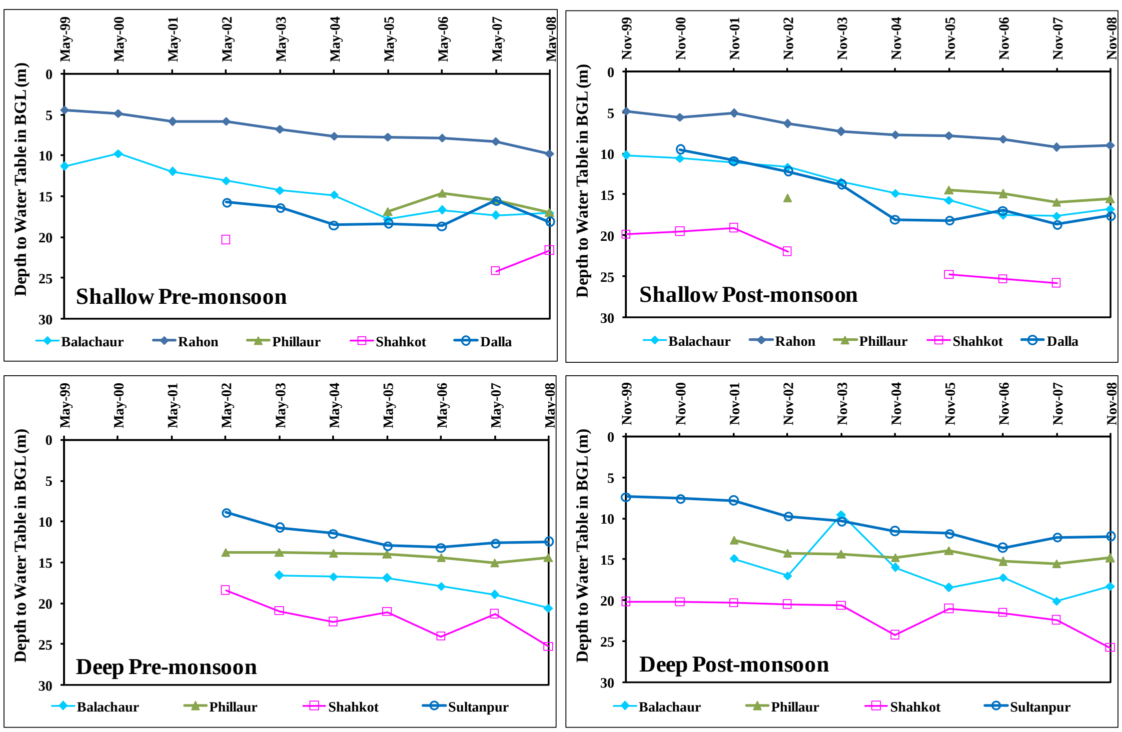
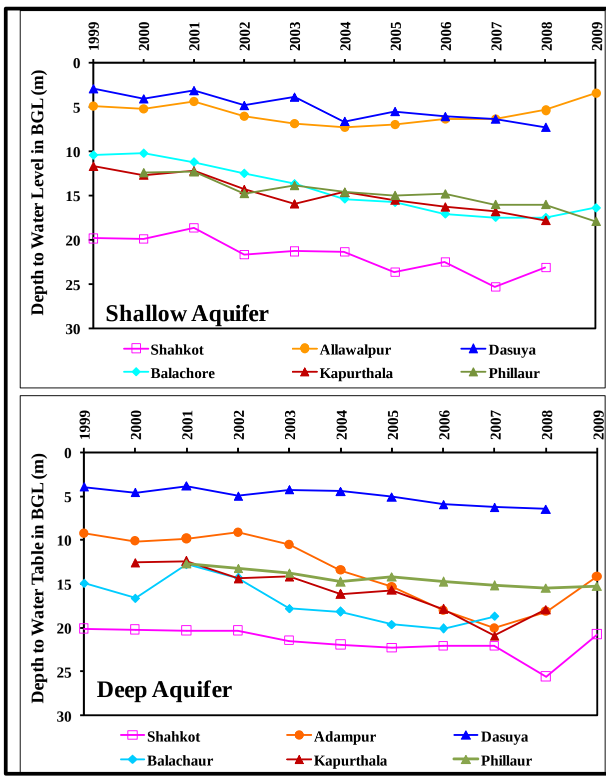
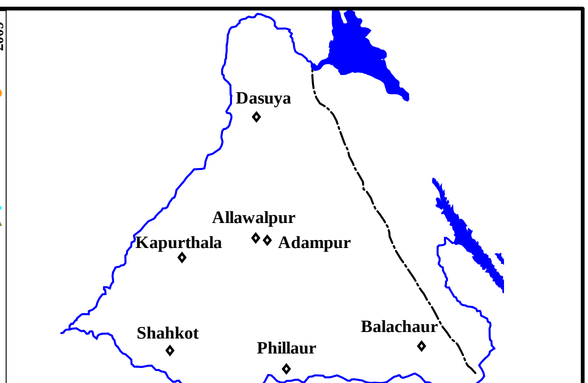


Figure 3.9: Piezometric Head of Water Table (BGL) in Southern Region of the Study Region during Pre and Post Monsoon Period.

groundwater. Shahkot which is situated in the downstream, towards Harike, in this region shows higher depth to water table (Fig. 3.9).

It is interesting to see that out of the five sites analysed in this study where both shallow and deep wells are located, the sites “Nawapind Tapria” (south-eastern part of the study area) and “Shahkot” which are located close to be river Satluj the depth to groundwater in shallow aquifer is maximum. The depth of groundwater table is minimum at “Dasuya” which is located in the north part of the study area near the river Beas (Fig. 3.10). The rate of decline in water table is maximum at “Nawapind Tapria” whereas it is minimum at “Shahkot”. The piezometric-head in deep aquifer is maximum at “Shahkot” and minimum at “Dasuya” similar to that in the case of shallow aquifers. The rate of decline in water table is maximum at “Kapurthala” whereas it is minimum at “Shahkot”.





Location	Water Level Fall/ Rise (m/yr)	
	Shallow	Deep
Dasuya	0.35	0.21
Allwalpur Adampur	-0.10 -	- 1.9
Kapurthala	0.50	0.51
Shahkot	0.21	0.75
Phillaur	0.18	0.32
Balachaur	0.72	0.73

Figure 3.10: Variation in Depth to Water Table in Selected Deep and Shallow Aquifer

The groundwater fluctuation in the shallow aquifer and deep aquifer show different trends. The rate of groundwater drop in Kandi region in shallow aquifer is very high whereas large drop in groundwater levels in deep aquifer is observed in the central region of Bist Doab. In both shallow and deep aquifers the northern region shows negligible changes in groundwater levels (Fig. 3.11). The large drop in groundwater levels can be due to several reasons like high withdrawals, low recharge, low transmissivity, poor conditions of surface water recharge source conditions etc. (Fig. 3.11). Some of these reasons are examined in the preceding chapter using isotopic techniques.

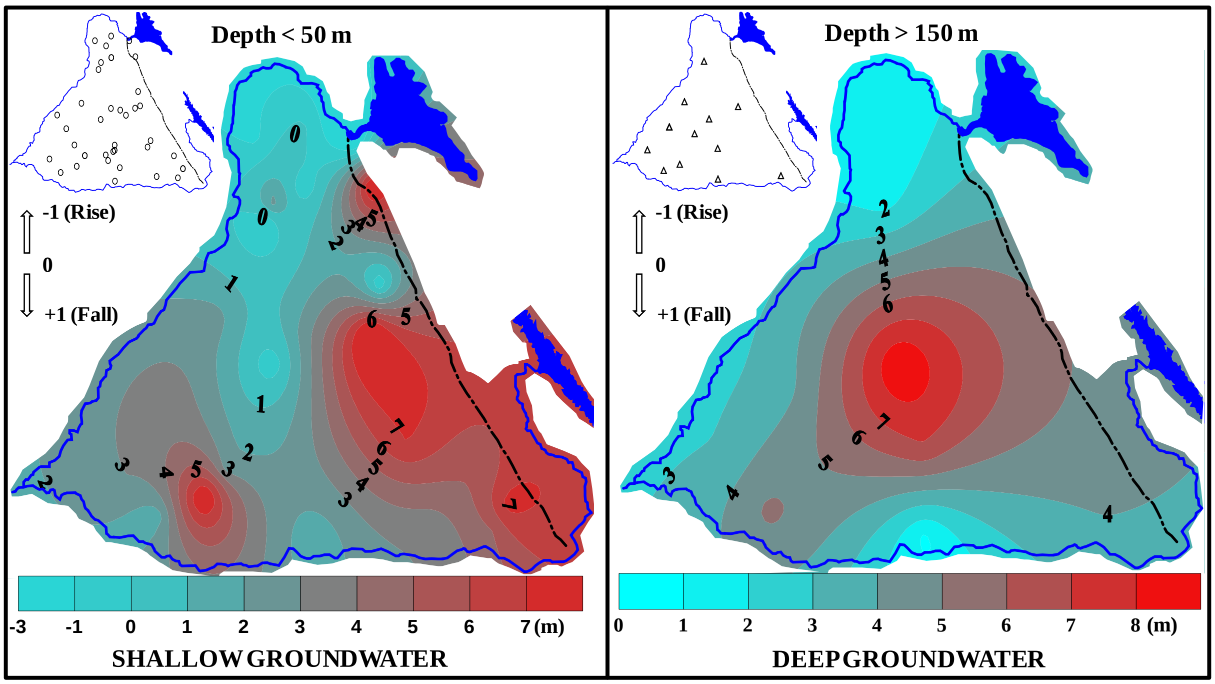


Figure 3.11: Groundwater Fluctuation of Shallow and Deep Aquifer in Bist-Doab Region.

The groundwater flow in shallow and deep aquifers is mainly in the direction diagonally along NE-SW direction from Shivalik-Kandi to confluence of rivers near Harike and along east-west direction in the southern part of the study area parallel to the River Satluj. Since, both surface and groundwater are flowing and accumulating towards confluence zone as a result, groundwater at Harike is at shallow depth (closed to near surface) and is also resulted into water logging. The groundwater fluctuation in the shallow aquifer is high up to 7m in Hoshiarpur district and 5m in Jalandhar district in six years (Fig. 3.12). The groundwater in deep aquifer show high fluctuation mainly at the central part with maximum of 7m fall in six years.

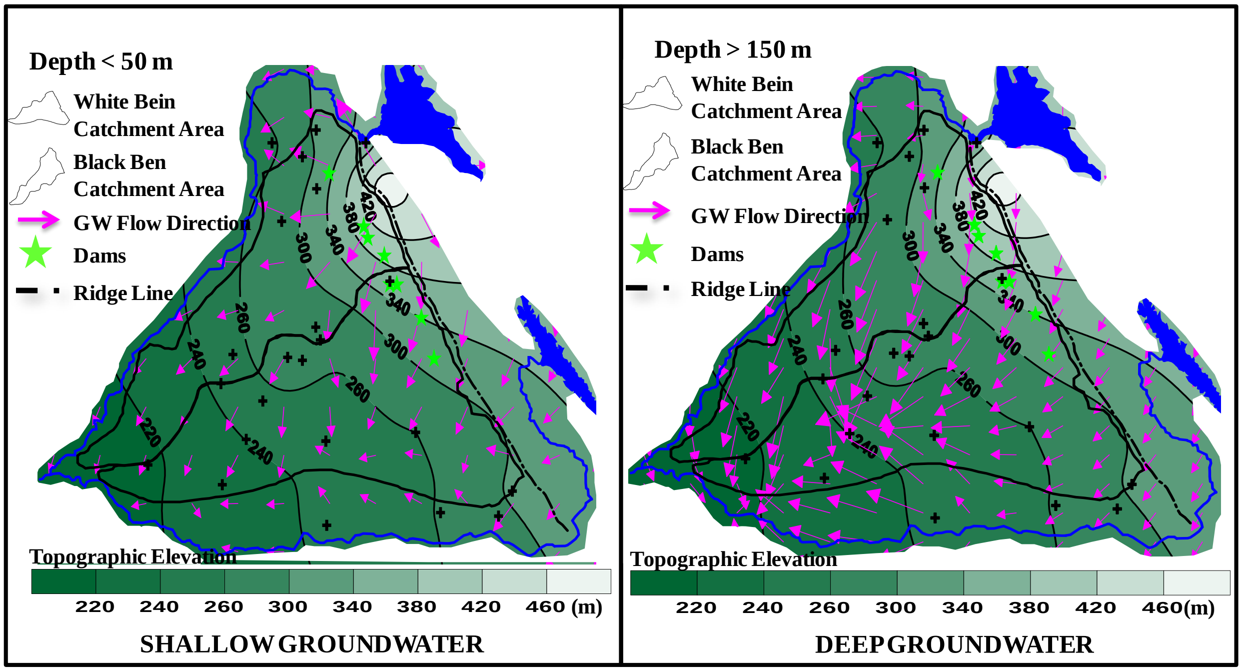


Figure 3.12: Groundwater flow pattern of shallow and deep aquifer in Bist-Doab region.

The groundwater draft has been continuously increasing in the Bist-Doab region. The groundwater availability shows maximum availability (>15000MCM) up to 5-20 km near the river Satluj and in Mukerian block near river Beas in this region (Fig. 3.13). The groundwater

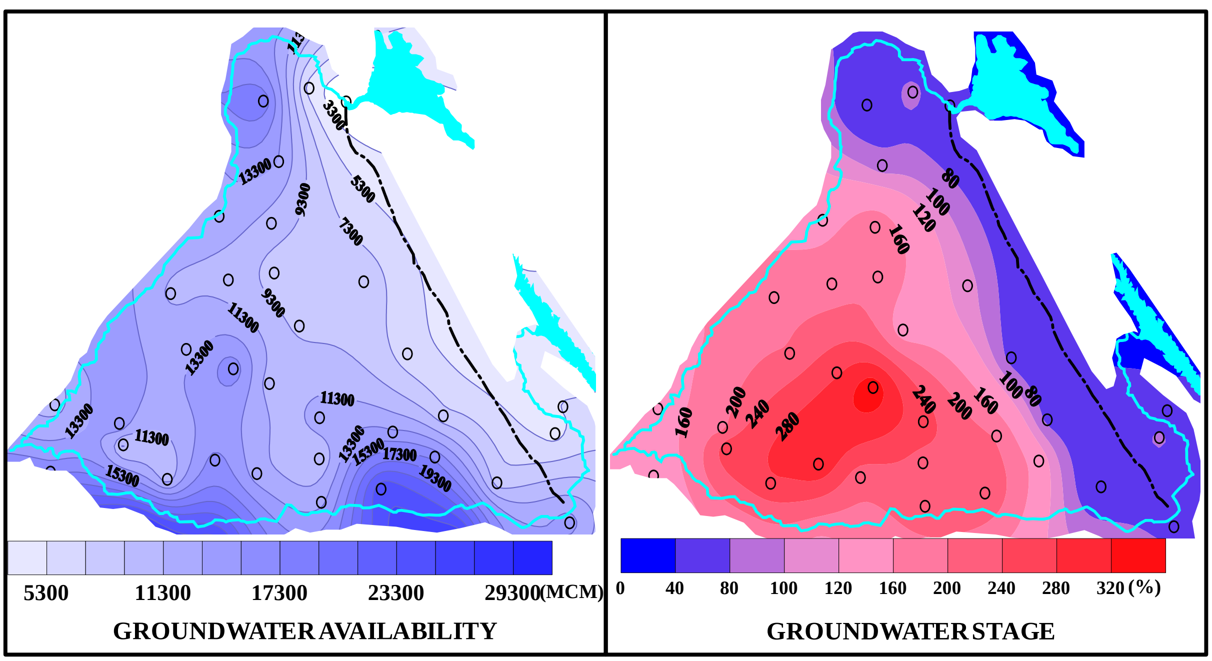


Figure 3.13: Groundwater Availability and Stage (2004) in Bist-Doab Region

availability decreases from central zone to central region of Kandi. The Jalandhar district shows maximum amount of groundwater draft with maximum of 30,000MCM/yr.

Table 3.1: Categorization of Blocks in Bist-Doab Region

S.No.	District	Over-Exploited	Critical	Semi-Critical	Safe
1.	Hoshiarpur (Total 10 blocks)	1 Hoshiarpur-I 2 Tanda	--	1 Garh Shankar 2 Hazipur	1Bajwara 2 Bhunga 3Dasuya 4Mahilpur 5Mukerian 6Talwara
2.	Jalandhar (Total 10 blocks)	1 Adampur; 2 Bhogpur 3 Goraya; 4 Jal-east 5 Jal-west; 6 Lohian 7 Nakodar; 8 Nurmahal 9 Phillaur; 10 Shahkot	--	--	--
3.	Kapurthala (Total 5 blocks)	1 Bholath; 2 Dhilwan 3 Kapurthala; 4 Phagwara 5 Sultanpur	--	--	--
4	SBS Nagar (Total 5 blocks)	1 Aur; 2 Banga 3 Nawanshehar	--	--	1Saroya 2Balachaur

The groundwater stage in the region shows that only 8 blocks (Hoshiarpur and SBS Nager districts) are under safe category and two blocks (Hoshiarpur district) are under semi critical category while most of the blocks (20 out of 30) are over exploited with groundwater stage more than 100% (Table 3.1).

3.3 Trend of Reservoir Level

Long term reservoir level data provides an integrated effect mainly resulting from changing rainfall pattern, increasing groundwater withdrawal and change in base level due to sedimentation. Trend of reservoir level change along with rainfall for the period from May 2010 to June 2013 has been examined for the case of Dholbaha dam (Fig 3.14). The plot shows water levels peaking from July end and reaches maximum in November and thereafter starts declining and reaches minimum during April-June and the cycle continues. There is a delay of about 1.5 month from end of monsoon to peak of water level indicating increase in water level due to addition of inflow as a base-flow. In the plot, the sudden drop in the reservoir levels during

December probably relates to irrigation releases. The gross water level trend of the reservoir shows a decreasing trend. The rainfall pattern in the same plot also shows a

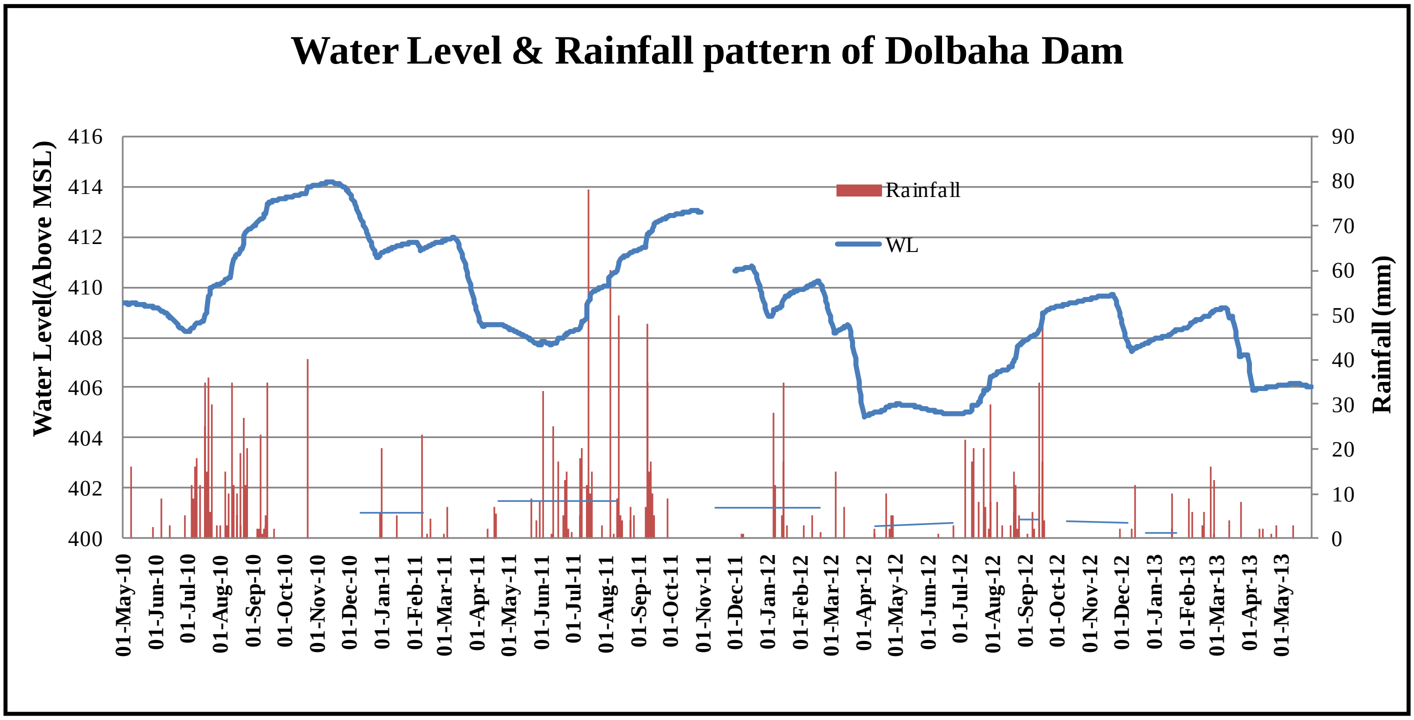


Figure 3.14: Water Level and Rainfall pattern of Dolbaha Dam based on monthly data.

decreasing trend indicating the decreasing rainfall in the region as one of the major cause for the decreasing water level of the reservoir and also the diminishing water resource of the region. Details plots on groundwater levels in various sub-regions of Bist Doab is shown in the figures 3.15 a-f. All the groundwater plots of Bist Doab region excepting the sites Talwara, Hazipur, Mukeria and Durmiwal (all these sites fall in northern region) show fall in water levels in the range 5-17 meters during 1999-2008 period. The groundwater level of northern region sites during this period have not shown any fall indicating either the constant recharge of these aquifers over all the years or that the withdrawal has not changed during this period. Considering the economic progress and growing water demand the latter argument cannot be accepted. Therefore, it can be firmly said that the northern Bist Doab region is continuously getting recharged and for this the main source of recharge could be the perennial river Beas. The only site other than northern region where groundwater fall is not seen is at Alwalpur. This site is located at close proximity to Khurdpur. In the next chapter it has been shown using isotopic data that Khurdpur receives a very good recharge from canal seepage and also that the shallow and deeper aquifers are well connected in this region. It is probably due to this reason of high groundwater recharge in this region that the water level at Allwalpur shows a constant water level during 1999 to 2008. Extending this argument to rest of the region it can be said in general that most of the Bist Doab region has poor recharge conditions and therefore shows falling groundwater level trend from (1999-2008) and the regions supported by good recharge sources and falling in high recharge zones (like northern part, Alwalpur, Khurdpur etc) show almost no fall in groundwater heads over this period. Since such area occupies a few percent of the total area, in general it can be said that the groundwater recharge conditions are poor in the Bist Doab region and groundwater is un-sustainable for the increasing withdrawals.

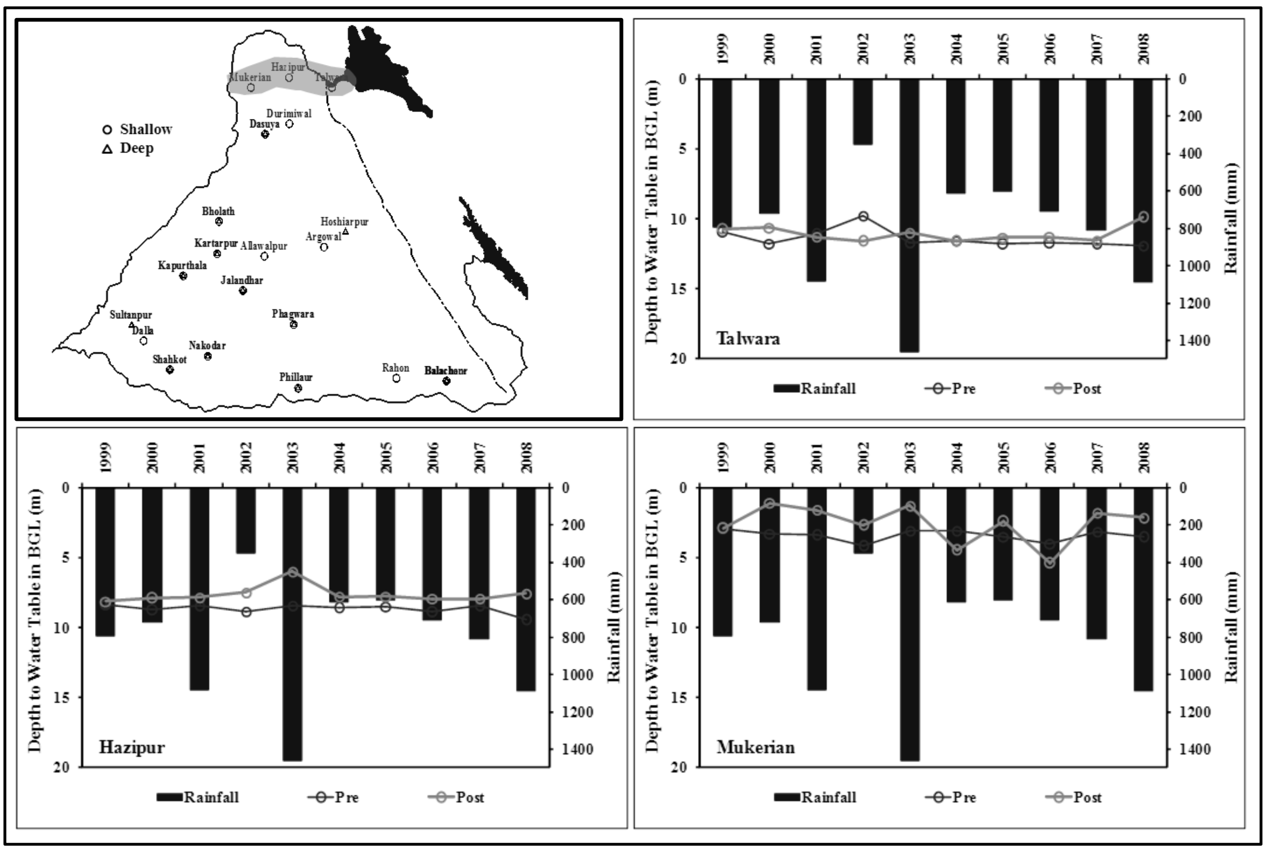


Figure 3.15a: Change rainfall and groundwater depth in shallow aquifer in northern region (shown in shadowed mark in the inset) of Bist Doab for the period 1999 to 2008.

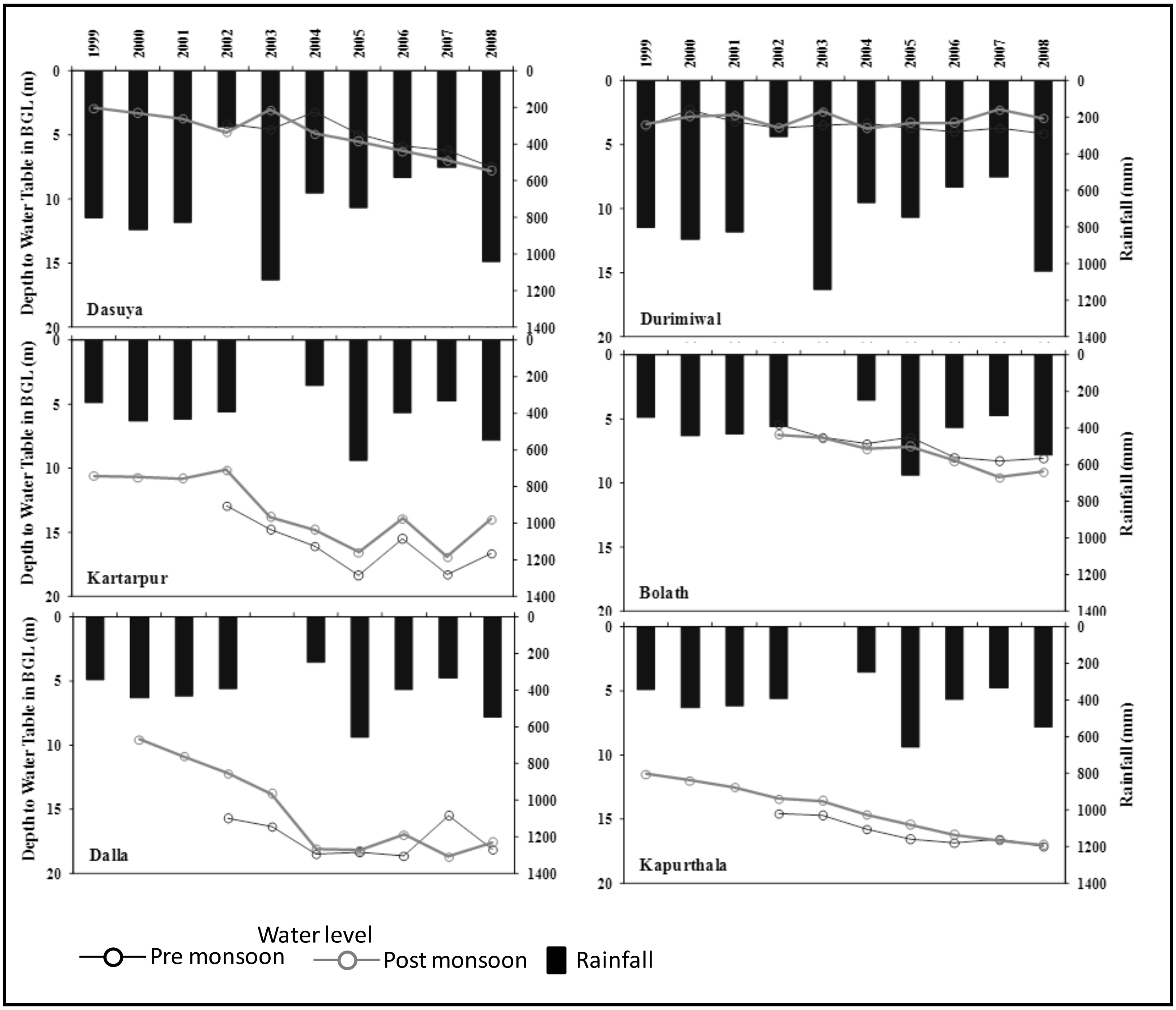


Figure 3.15b: Change rainfall and groundwater level in shallow aquifer Kali Bein watershed region of Bist Doab for the period 1999 to 2008.

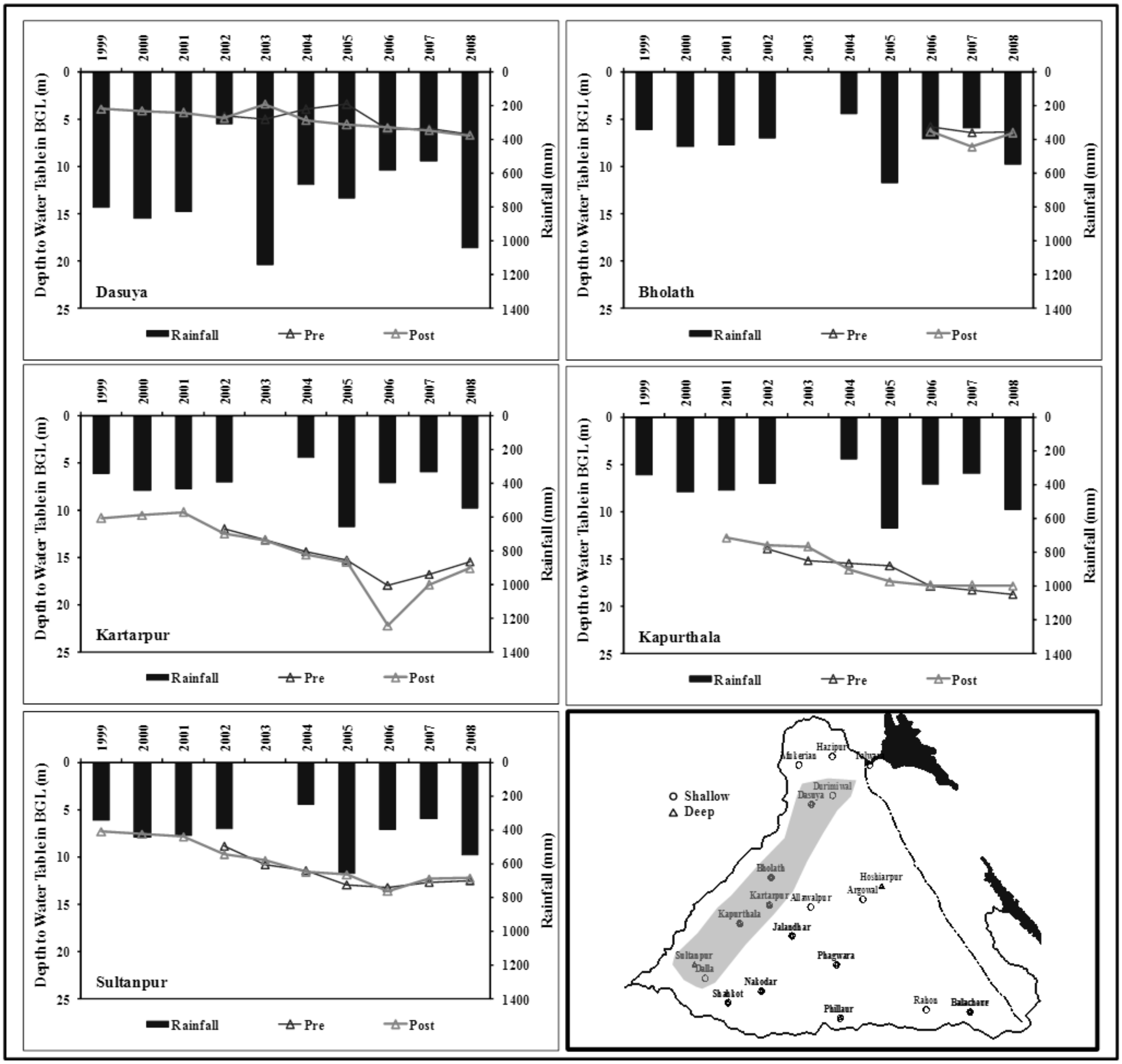


Figure 3.15c: Change rainfall and depth to water level in deep aquifer in Kali Bein watershed of Bist Doab for the period 1999 to 2008

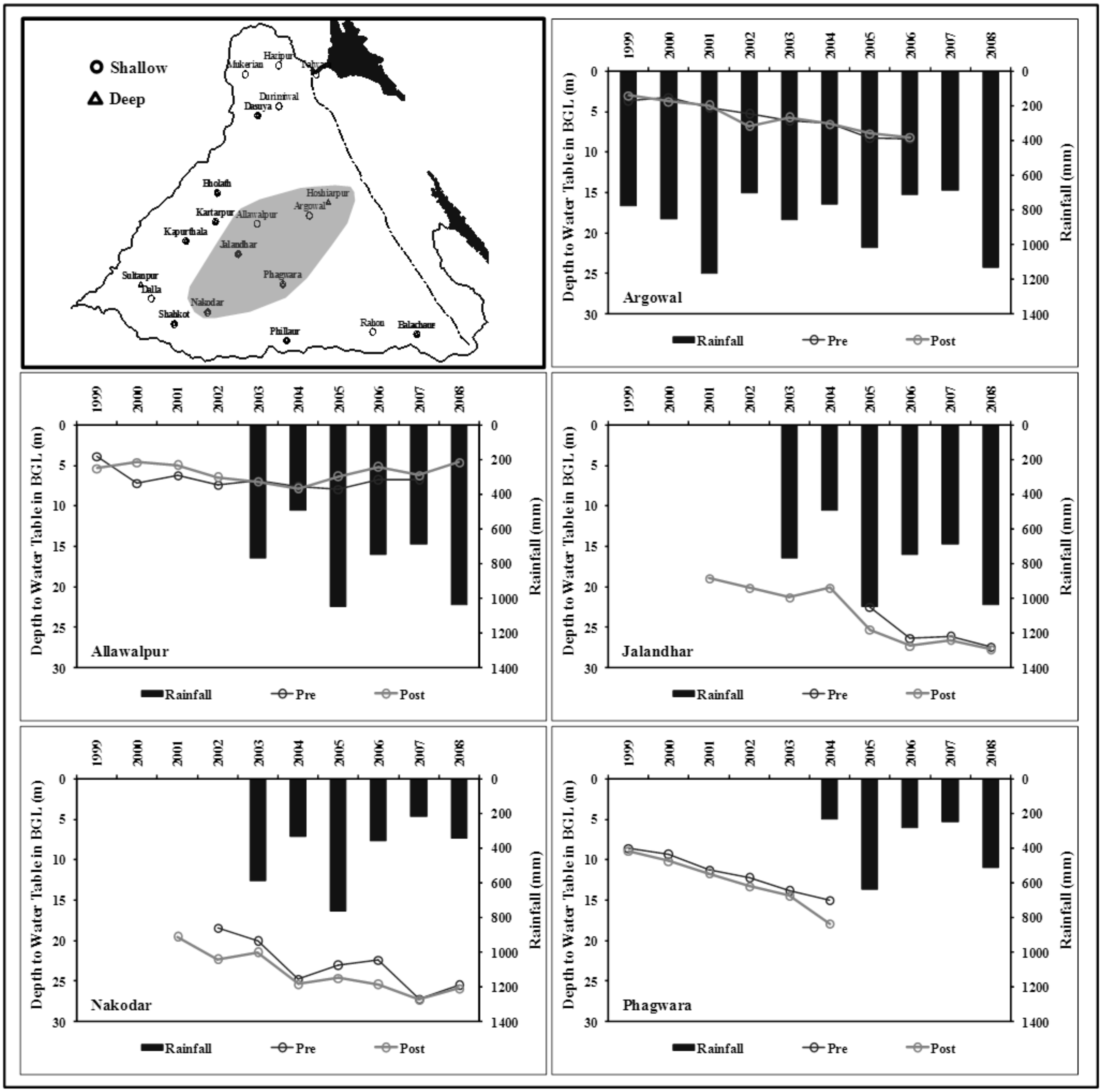


Figure 3.15d: Change rainfall and depth to water level in shallow aquifer in Central Bist Doab (shown by shadow portion in the inset figure) for the period 1999 to 2008.

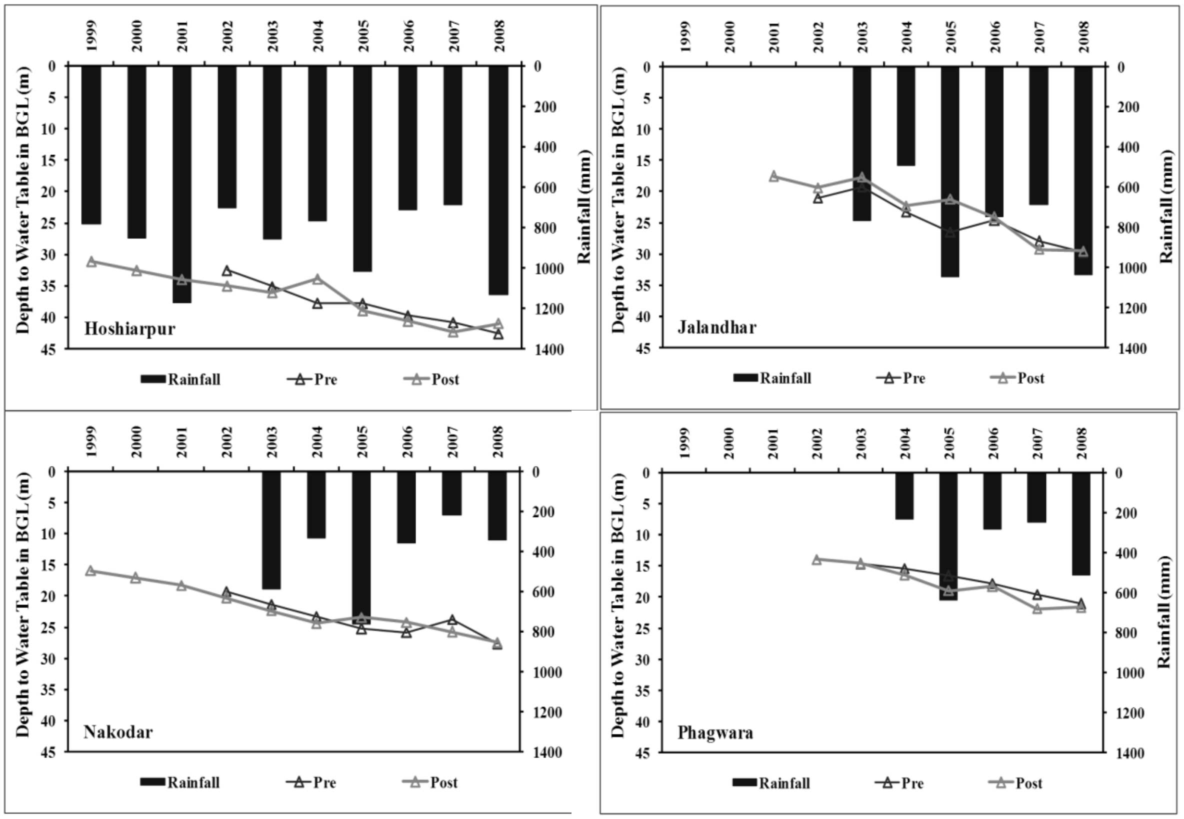


Figure 3.15e: Change rainfall and depth to water level in deep aquifer in central Bist Doab region for the period 1999 to 2008.

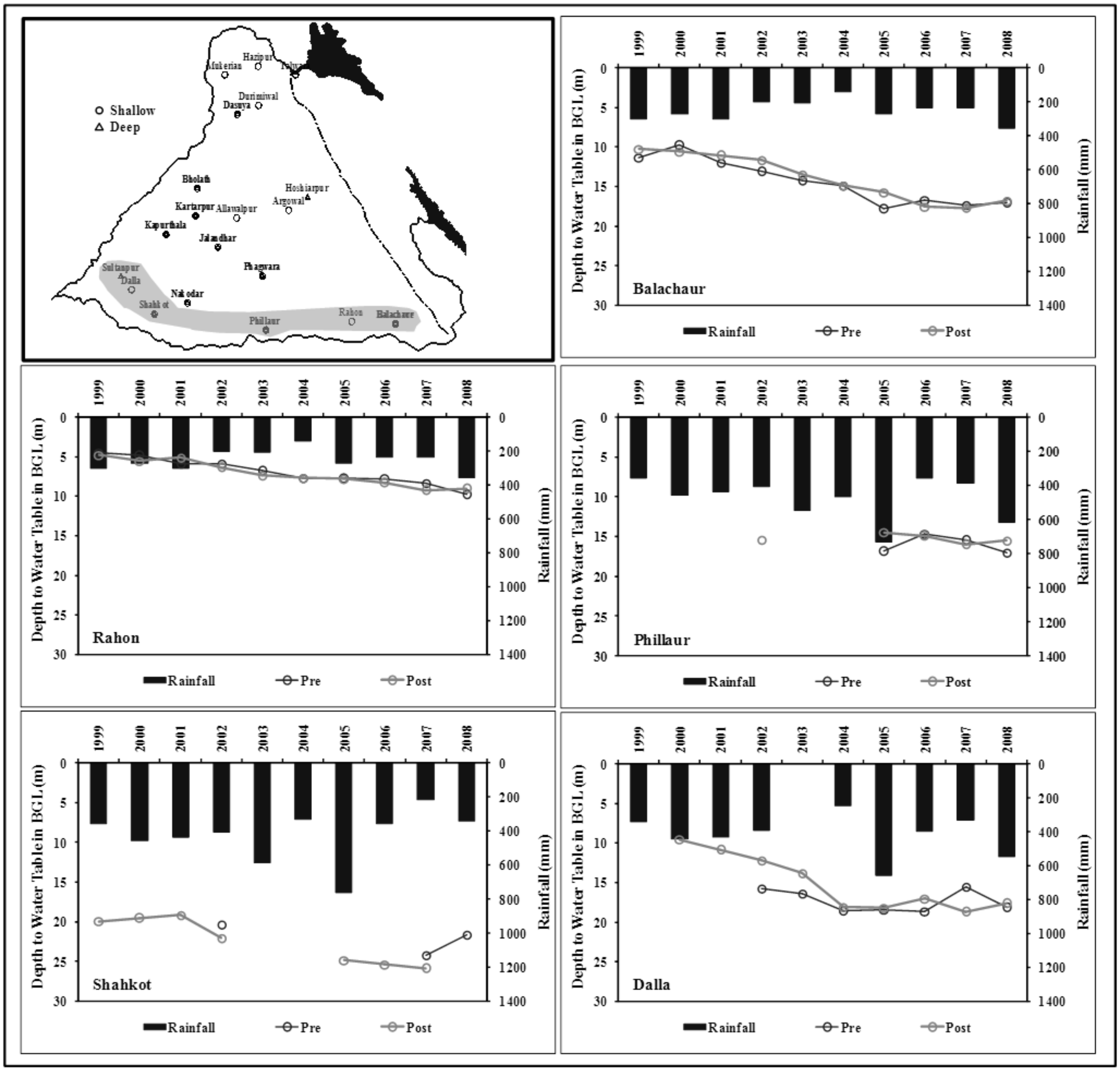


Figure 3.15f: Change rainfall and groundwater level (shallow aquifer) in southern Bist Doab region for the period 1999 to 2008.

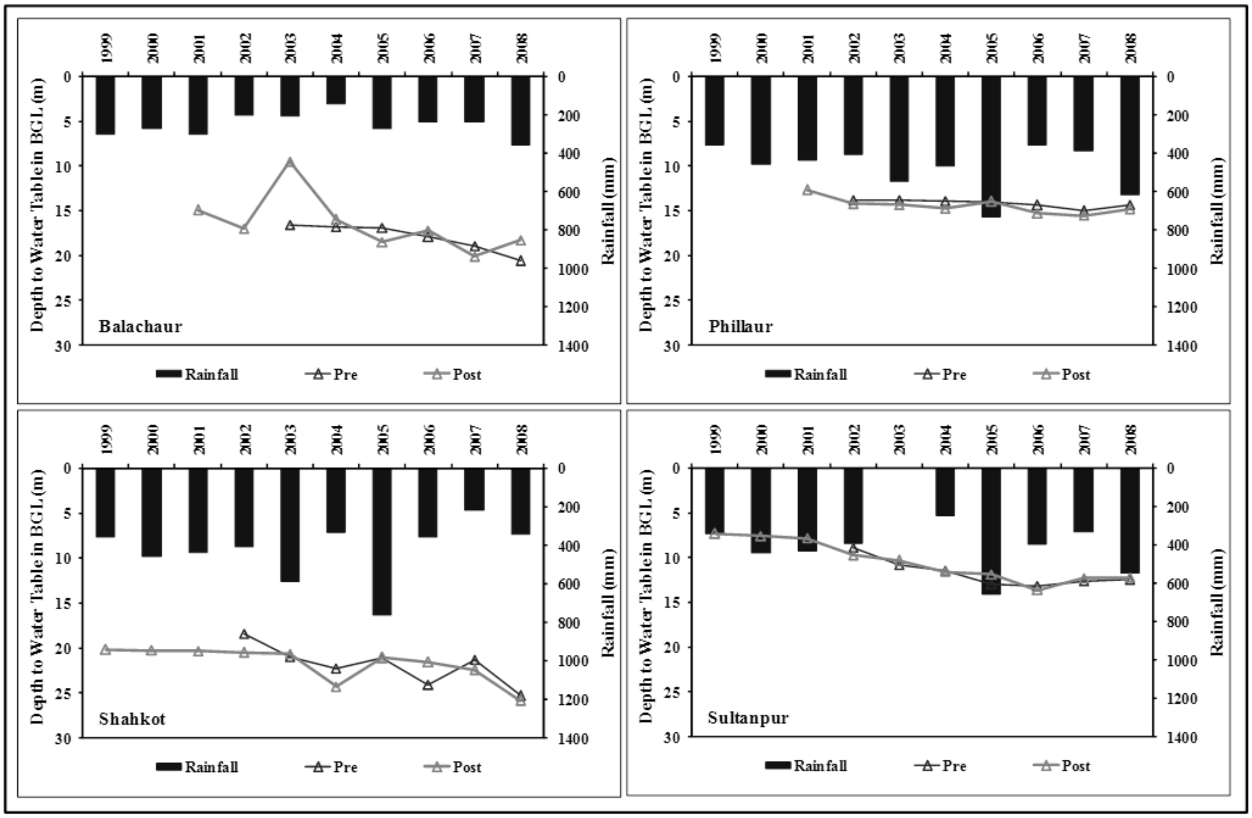


Figure 15g: Change rainfall and depth to water level (in deep aquifer) in southern Bist Doab for the period 1999 to 2008.

4

RESULTS AND DISCUSSION


ION CHROMATOGRAPH

CHAPTER 4

RESULTS AND DISCUSSION

For the purpose of groundwater recharge zone and flow regime analysis using conventional and isotopic data, samples are collected from field at various frequency intervals and analyzed in the laboratory. The details of this are given in the present chapter.

4.1 Samples Collection

Groundwater samples were collected from aquifers at different depths (shallow < 30m, intermediate ~ 60 m and deep wells >120 m) using existing hand pumps and tube wells and piezometers at both pre & post monsoon periods (Table 4.1). Regular sampling of rainfall is collected from 13 locations from different part of Bist- Doab region. Surface water sampling (river/ Dam) is done from 13 locations on ten daily intervals (Fig.4.1). Groundwater (both shallow and deep) from 5 locations (Harike, Ropar, Maili, Dolbaha and Garhshankar) is collected on ten daily basis, 16 shallow groundwater samples are collected on ten daily bases to understand surface water- groundwater interaction. Apart from these sample seasonal groundwater (from deep and shallow) sampling were made from 26 locations (Fig. 4.2).

Table 4.1: Locations and frequency of sampling from different water bodies at Bist-Doab Region

Sample type	No of stations	Starting date	Frequency of sampling
Rain (13 nos.)	5 8	June, 2009 July, 2010	Daily (event basis)
River	11	Aug, 2010	1 per 10 days
Dam	2	June, 2009	1 per 10 days
GW-SW interaction	16	Aug, 2010	1 per 10 days
Shallow & Deep	5 26	June, 2009 June 2010	1 per 10 days Quaterly (4/yr)

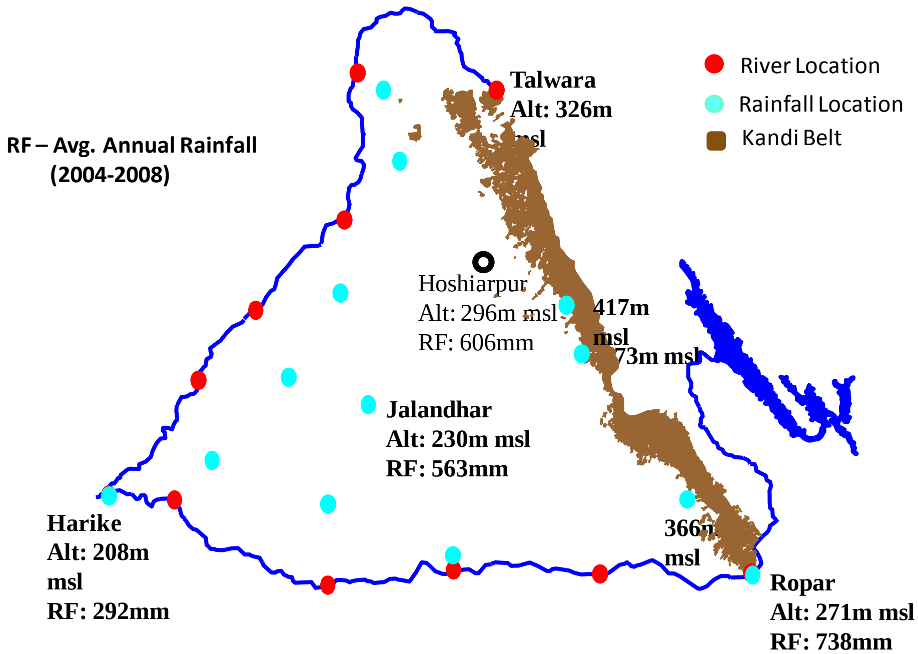


Fig 4.1: Sampling location of River and Rainfall samples

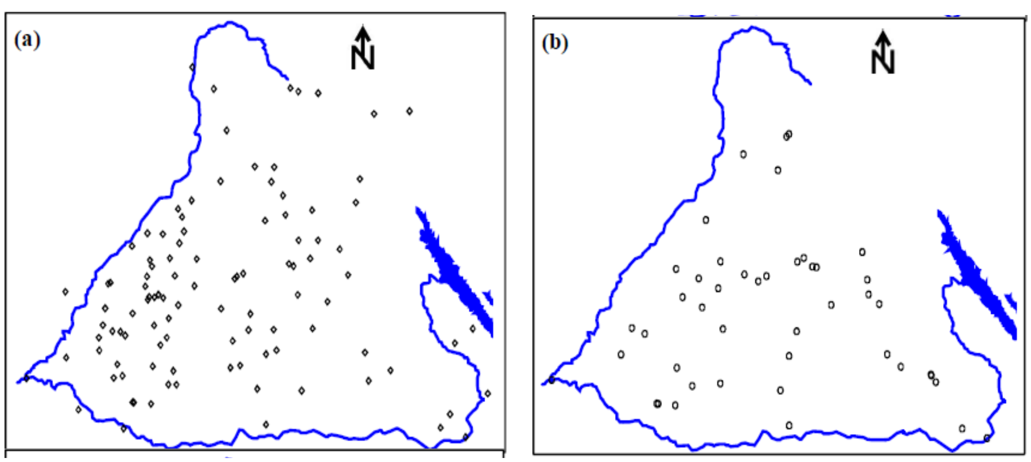


Fig 4.2: Sampling sites in Bist-Doab region a) Shallow groundwater b) Deep groundwater

Photo 4.1: Ground water sample collection from tubewell

Photo 4.2: Ground water sample collection from handpump

4.1.1 Isotopes Analysis

Stable isotopes ($\delta^{18}O$, δD) were analysed on DI-IRMS and CF-IRMS and Tritium using electrolytic enrichment and Ultra Low Level Liquid Scintillation Counting facility of National Institute of Hydrology, Roorkee. The error limit for isotopic analysis is within 0.1‰ for $\delta^{18}O$ and 1‰ for δD. The water samples were collected randomly from the entire study area to avoid any biasness in the analysis. The groundwater from the hand pump and piezometers (shallow aquifer (<30m) and tube well and piezometers (deep aquifer (>80m) were collected during year 2009 and 2013. The isotopic analyses ($\delta^{18}O$ and δD) of collected water samples were done by standard equilibration method in which water samples are equilibrated with CO_2 and H_2 (Epstein and Mayeda 1953, Brenninkmeijer and Morrison 1987). The samples were analysed using a Continuous Flow Isotope Ratio Mass Spectrometer (CF-IRMS) to measure oxygen ($^{18}O/^{16}O$) and Dual Inlet Isotope Ratio Mass Spectrometer (DI-IRMS) to measure D/H ratio and computed the $\delta^{18}O$ and δD using a triple point calibration equation with Vienna standard mean ocean water (V-SMOW), Greenland ice sheet precipitation (GISP) and Standard light Antarctic precipitation (SLAP) standards. The results were expressed by convention as parts per thousand deviations from the VSMOW the calculation is as follows:

$$\delta_{sample}= (R_{sample}-R_{V\text{-}SMOW}/R_{V\text{-}SMOW})x1000‰$$

Where, R is the ratio of D/H or $^{18}O/^{16}O$ in sampled water (R_{sample}) or in VSAMOW (R_{SMOW}). The reproducibility of measurements was better than ±0.1‰ for $\delta^{18}O$ and better than ±1‰ for δD. Isotopic Analyses of samples were done at the National Institute of Hydrology, Roorkee, India.

4.1.2 Tritium Analysis

To clearly understand the residence time of the groundwater in different aquifers the environmental tritium was analysed in rain, river and groundwater samples (Fig 4.3.). The water samples were collected randomly from the entire study area to avoid any biasness in the analysis. Water samples from precipitation, river water and groundwater from shallow aquifer (<30m; both hand pump and piezometers) and deep aquifer (>80m; both tube well and piezometers) were collected during year 2009 and 2011 for environmental tritium analysis. To ensure sampling from the concerned aquifer is done the groundwater has been flushed adequately or till constant pH and EC is achieved. Then the water samples (600ml) were collected in air/ water tight polypropylene (plastic) bottles after rinsing the bottles by the groundwater that is to be sampled.

Figure 4.3: Tritium Enrichment Unit

Tritium activity was measured in an ultra low level liquid scintillation counter (Quantulus, Perkin Elmer) following electrolytic enrichment at Nuclear Hydrology lab, National Institute of Hydrology, Roorkee.

4.1.3 Hydro chemical Analysis

The water samples from Shallow (<40m) and Deep (>100m) groundwater canal, stream and reservoir (Dolbaha) are collected during Nov. 2011. In situ measurements, like pH and EC, are taken in the field immediately after tapping water samples and then bottled in 250ml polyethylene bottles. The samples were analyzed for major ions (Na, K, Ca, Mg, Cl, So_4, No_3, F) in Ion Chromatograph (Dionex® ICS- 5000) at Nuclear Hydrology Laboratory, National Institute of Hydrology, Roorkee, India. The instrument has been calibrated for analysis of major ions using M/s Dionex® elemental standards. The bicarbonate ion is analyzed by titration. The analytical results checked using cation- anion balance is less than 15% error.

4.2 Piezometers Development

To record daily and seasonal withdrawal effect on groundwater 6 piezometers (at depth up-to 150m) at Bhogpur, Kapurthala, Nakodar, Saroya, Sultanpur Lodhi and Tanda have installed and automatic water level recorders have also installed in these piezometers (Fig. 4.4). Water levels in shallow piezometers are also monitoring to investigate interactions between shallow and deep aquifers. The water level recorder is set to record the fluctuations at 6 hr resolution.

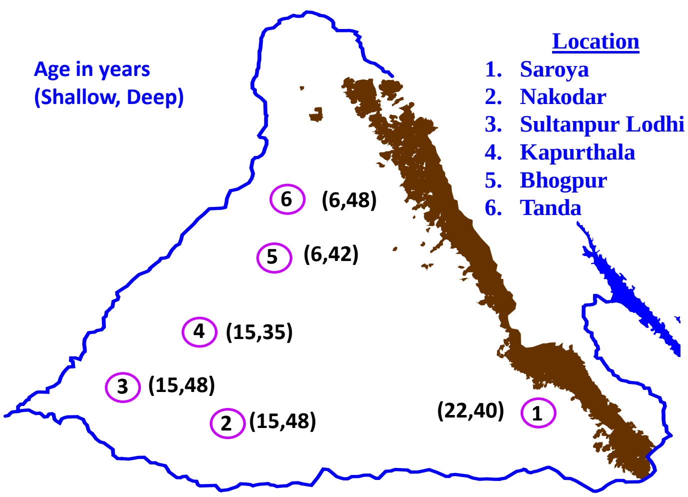


Fig 4.4: Locations for piezometers development

The installation of the piezometers on the different sites in the study area can be seen in the following photographs –

Photo 4.3a: Installation of piezometer on the selected site

Photo 4.3b: Installation of piezometer on the selected site

Photo 4.3c: Installation of piezometer on the selected site

Photo 4.3d: Installation of piezometer on the selected site

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Photo 4.4: Piezometer development at Saroya & Bhogpur

Photo 4.4: Piezometer development at Nakodar, Tanda, Kapurthala and Sultanpur Lodhi

4.3 Isotopic Characteristics of Source waters and groundwater

The isotopic composition of weighted average of precipitation in the Kandi region varies between -13.33‰ to 4.24‰ ($\delta^{18}O$) and -105.23‰ to 38.75‰ (δD) and that at plain is about -9.96‰ to -0.39‰ ($\delta^{18}O$) and -74.03‰ to -12.59‰ (δD). The isotopic composition of Rivers Beas and Satluj varies between -7.3‰ to -6.6‰ & -11‰ to -10‰ and -44‰ to -41‰ & -74‰ to -69‰ for $\delta^{18}O$ and δD respectively. The $\delta^{18}O$- δD bi plot of precipitation in the study area shows similar with that the Indian Meteoric Water Line for the north region (IMWL- North) (Kumar *et al.* 2010) and GMWL (Rozanski *et al.* 1993) and change in intercept indicates change of source. The slope of regression equation (eq. 1) derived for the precipitation in the study area (Fig 4.5) is above IMWL- North (eq. 2) and less than GMWL (eq. 3) and change in intercept indicates change of source or the rain out process.

LMWL: $\delta D = 8.13 \times \delta^{18}O + 7.63$; $R^2 = 0.96$, n = 69 (eq. 1)

IMWL- North: $\delta D = 8.15 \times \delta^{18}O + 9.55$; $R^2 = 0.99$ (eq. 2)

GMWL: $\delta D = 8.17 \times \delta^{18}O + 11.27$; $R^2 = 0.99$ (eq. 3)

The isotopic composition of R. Beas is enriched than that of R. Satluj and is similar to that of precipitation (Fig. 4.6). This might be due to the origin of R. Beas relatively from lesser altitude. The depleted isotopic composition of R. Satluj indicates that it is derived from much higher altitude (Rao et al. 2010). The regression lines derived for the river water shows that both the rivers show evaporation effect with R. Satluj showing higher evaporation effect than R. Beas (eq. 4 and eq.5 respectively).

$\delta D = 6.93 \times \delta^{18}O - 1.16$; $R^2 = 0.92$, n = 44 (eq. 4)

$\delta D = 7.41 \times \delta^{18}O + 7.58$; $R^2 = 0.93$, n = 22 (eq. 5)

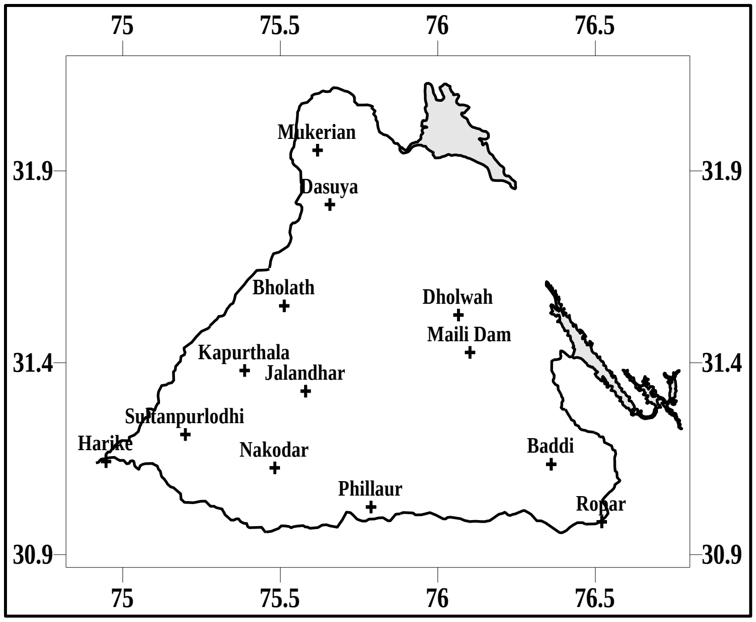

Figure 4.5: Rainfall location in Bist-Doab region

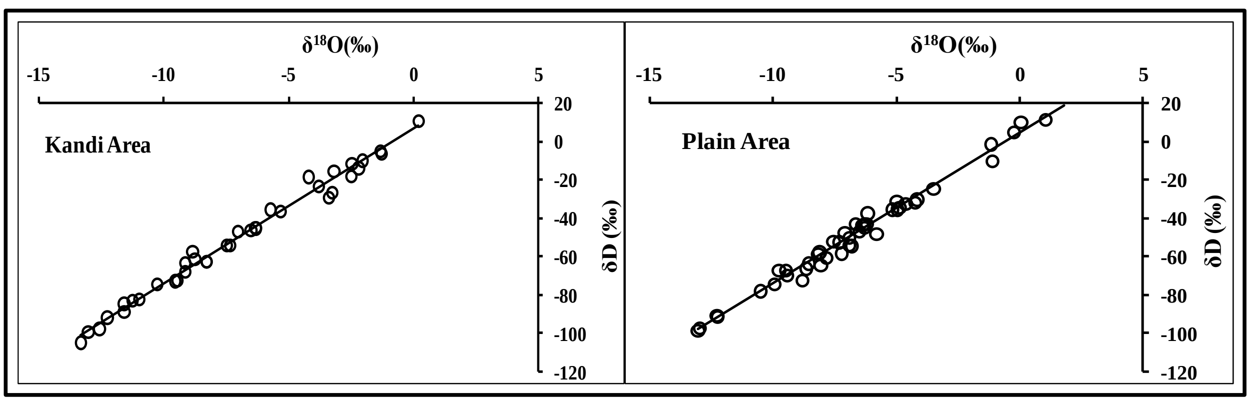

Figure 4.6: Isotopic characterization of Precipitation in region

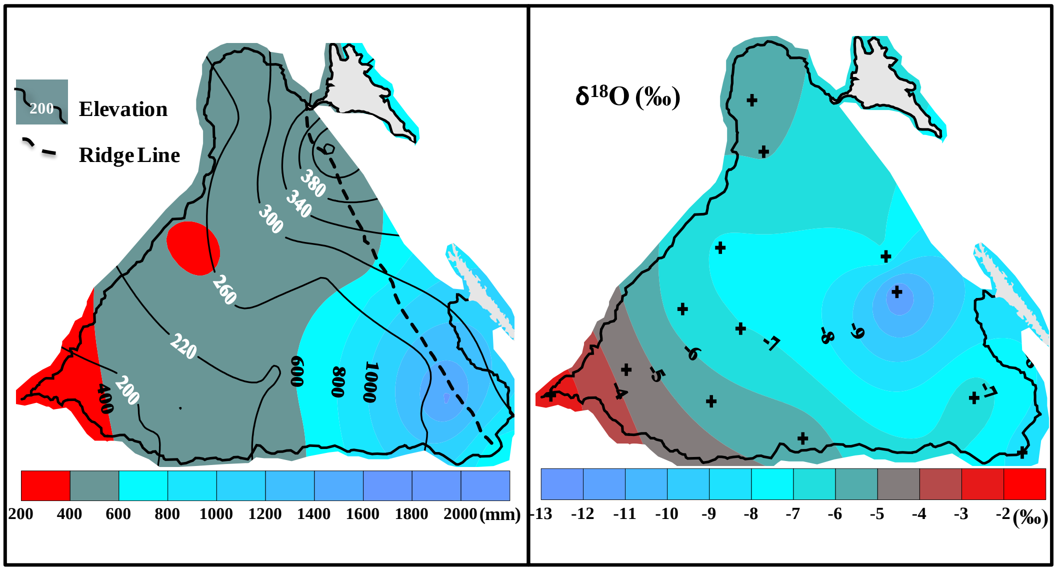

Figure 4.7: Variataion in rainfall amount & its $\delta^{18}O$ in monsoon-2011

The spatial distribution of isotopic composition of shallow and deep groundwater is given in Fig. 4.8. The shallow groundwater show enriched characteristics in the Kapurthala and Jalandhar districts. The deep aquifer shows almost constant isotopic composition throughout the study area resembling the isotopic composition of precipitation. The $\delta^{18}O$- δD bi plot (Fig. 4.9) of the shallow groundwater shows that the isotopic composition of groundwater falls in LMWL, R. Beas and R. Satluj lines indicating possible recharge from precipitation and rivers. Whereas, the deep groundwater falls parallel to the LMWL indicating possible recharge form precipitation.

Table 4.2: Isotopic Composition of precipitation, River Beas and River Satluj

Source	**Equation (calculated from monthly weighted average)**	**Range ($\delta^{18}O$)**
Precipitation	$\delta D = 7.86 \times \delta^{18}O + 5.44; R^2 = 0.98$	**1.8 to -13.3**
R. Beas	$\delta D = 7.57 \times \delta^{18}O + 8.56; R^2 = 0.90; n= 56$	**-7.1 to -9.97**
R. Satluj	$\delta D = 6.75 \times \delta^{18}O – 2.61; R^2 = 0.94; n= 76$	**-9.97 to -13.0**

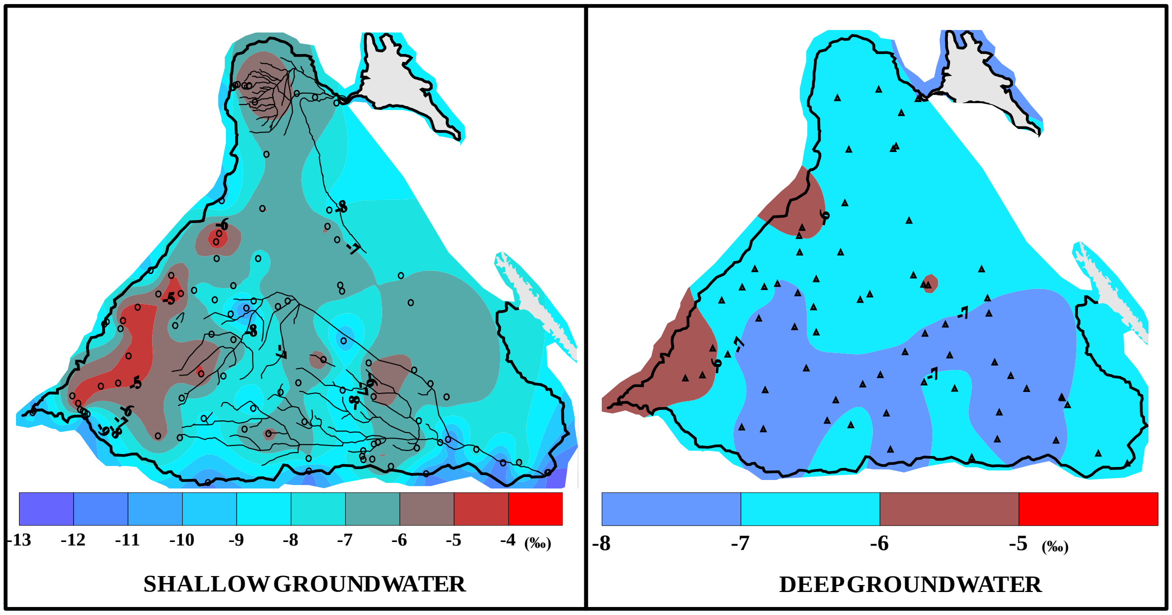

Figure 4.8: Isotopic variation ($\delta^{18}O$) of groundwater in shallow and deep aquifer

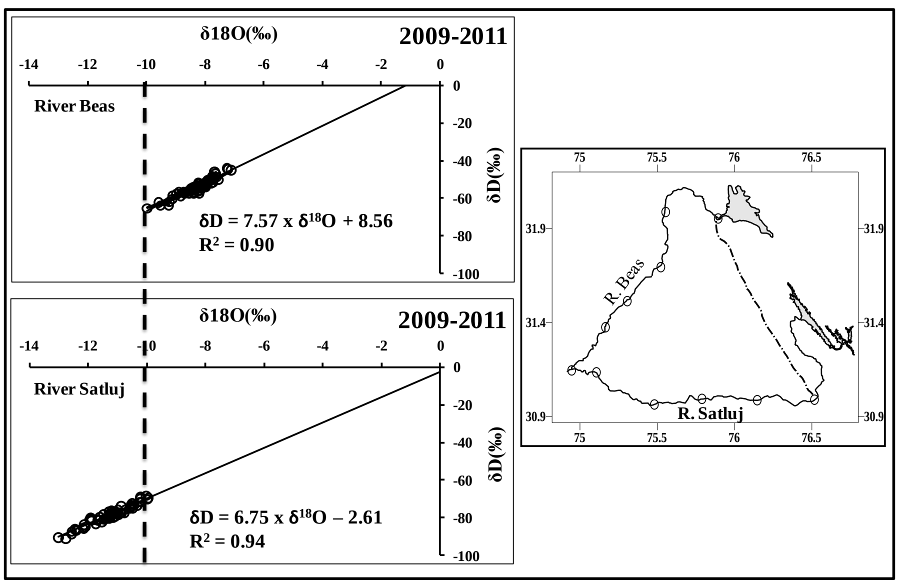

Figure 4.9: Location map and isotopic characterization of River water in region

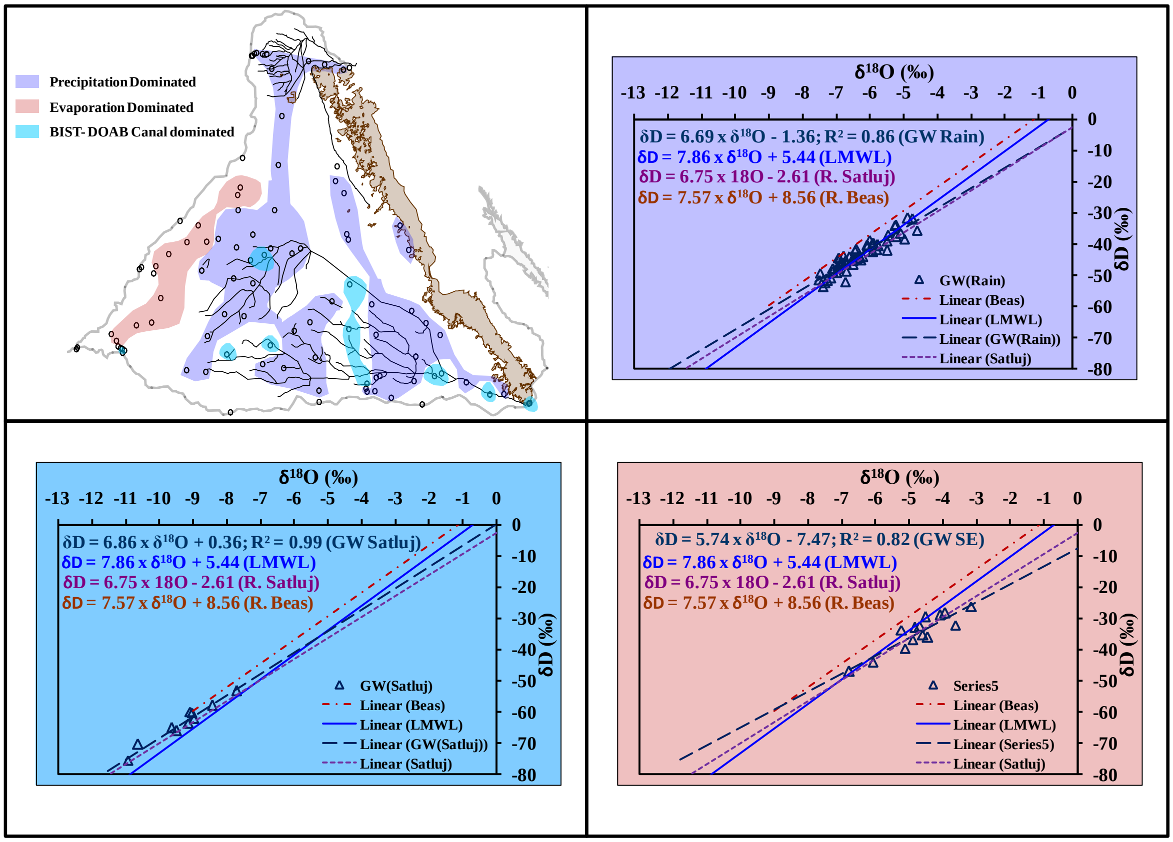

Figure 4.10: Recharge sources in deep and shallow aquifers

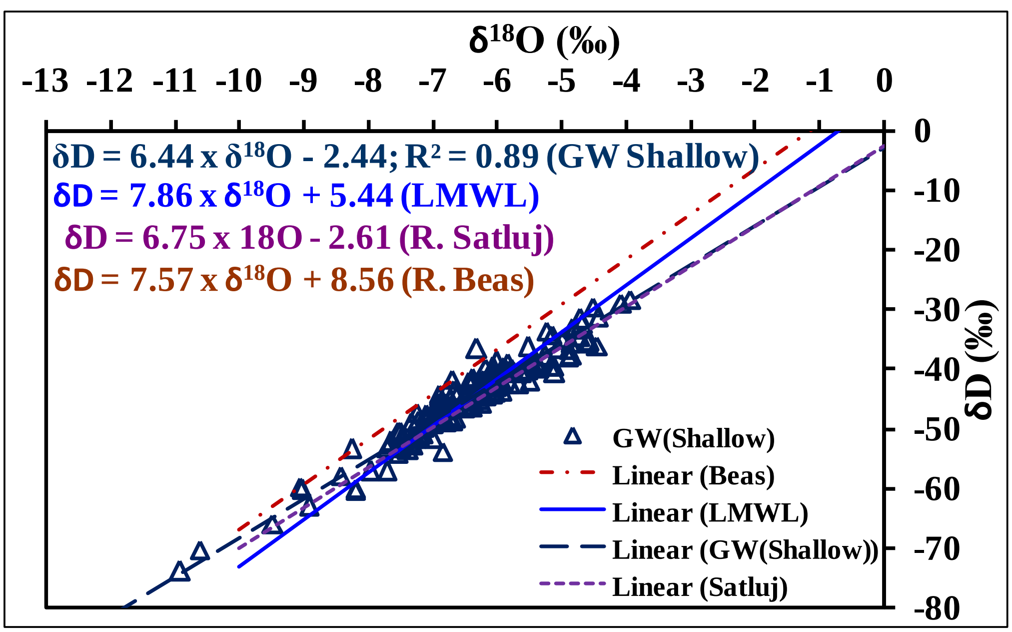

Figure 4.11: Isotopic characterization of groundwater in shallow aquifer

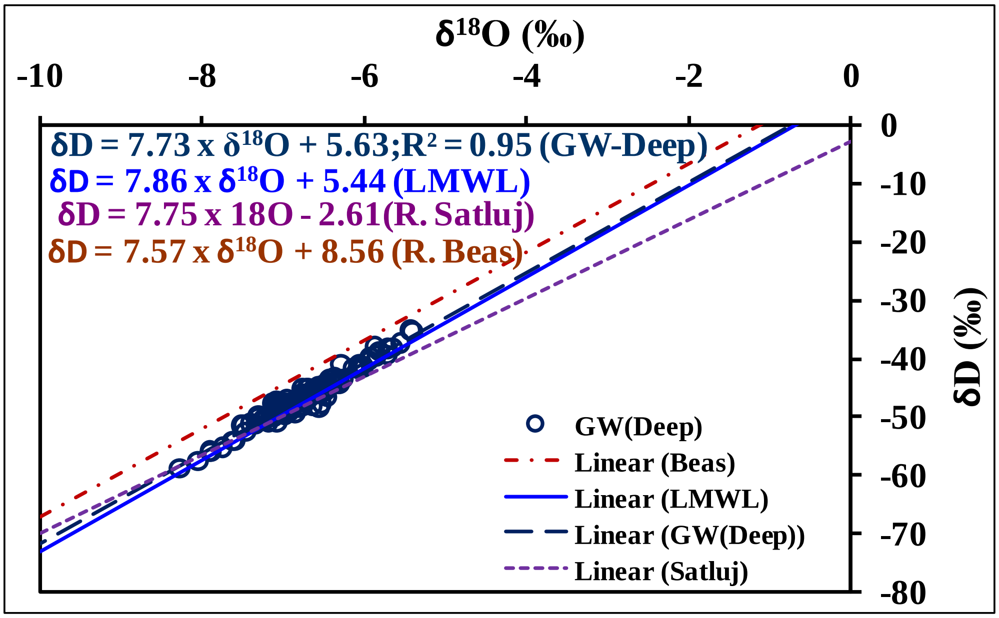

Figure 4.12: Isotopic characterization of groundwater in deep aquifer

Table 4.3: Identification of Recharge sources using stable isotopes

	Equation (calculated from monthly weighted average)	**Range ($\delta^{18}O$)**
Precipitation (At Kandi)	$\delta D = 7.85 \times \delta^{18}O + 5.82$; $R^2 = 0.98$; n= 73	**0.21 to -13.33**
Precipitation (At Plain)	$\delta D = 7.87 \times \delta^{18}O + 5.07$; $R^2 = 0.98$; n= 75	**1.8 to -13.01**
R. Beas	$\delta D = 7.57 \times \delta^{18}O + 8.56$; $R^2 = 0.90$; n= 56	**-7.1 to -9.97**
R. Satluj	$\delta D = 6.75 \times \delta^{18}O – 2.61$; $R^2 = 0.94$; n= 76	**-9.97 to -13.0**
Deep Groundwater	$\delta D = 7.73 \times \delta^{18}O + 5.63$; $R^2 = 0.95$; n= 159	**-5.4 to -8.26**

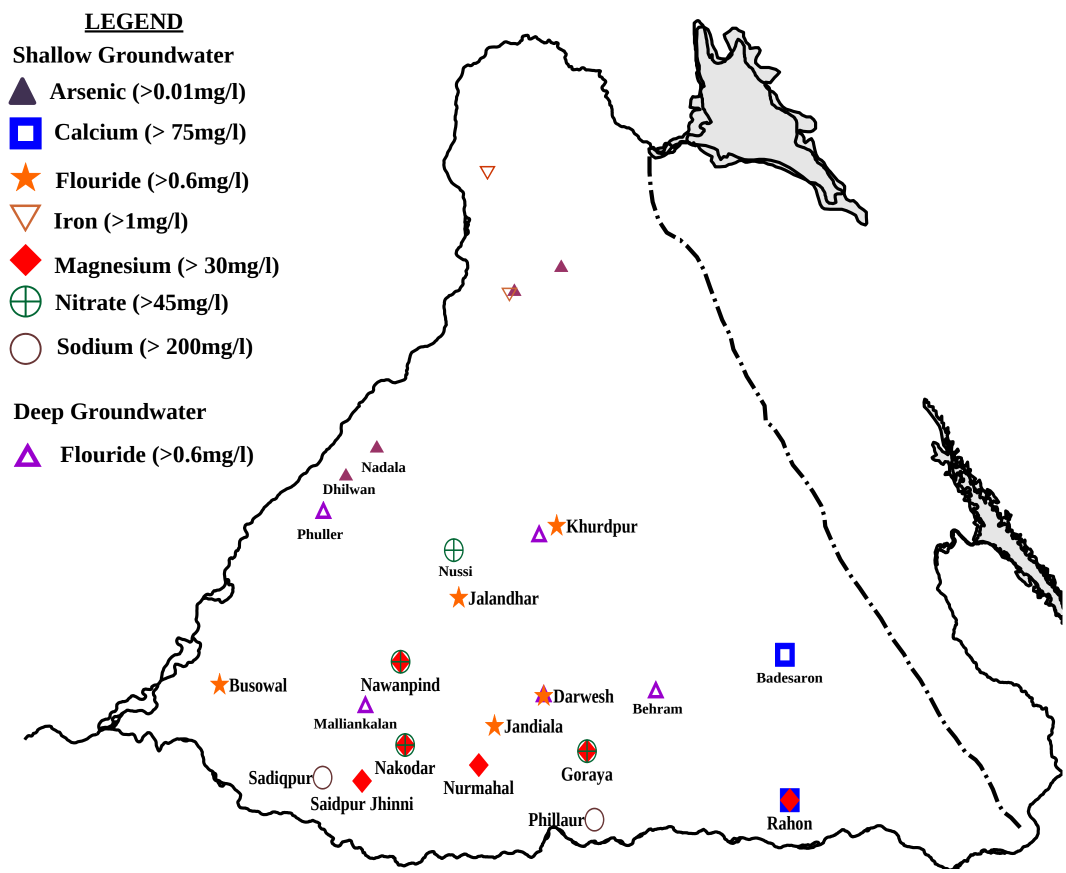

Fig 4.13: The central region of Bist- Doab region shows Poor water quality

4.3.1 Groundwater Surface water interaction

To understand the river water and groundwater interaction, river water samples and groundwater samples have been collected along four traverses, two from river Satluj and two from river Beas. At river Satluj: 1) in upstream from River Satluj to Aur, 2) in downstream from River Satluj to River Beas including Yusufpur and Barwana, the distance between of each traverse was about 6-6.5km across the river Satluj. At River Beas: 1) in upstream from River Beas to Mushaibpur, 2) River Beas to Fattudinga and the distance from river Beas to last location of the traverse is 4.5 and 5km respectively. To find out the distance of river water seepage/mixing with groundwater the isotopic composition of river and groundwater at farther stretch was considered as end member and two component model was applied. The equation used for calculating river water seepage is:

Percentage of river water interaction= {[δ$D_{(mix)}$ - δ$D_{(groundwater)}$]/ [δ$D_{(riverwater)}$ - δ$D_{(groundwater)}$]}*100

Where, δ$D_{(mix)}$ is isotopic composition of groundwater between two end members i.e. two extreme locations, δ$D_{(riverwater)}$ isotopic composition of river water (-58‰ for Beas and -74‰ for Satluj) and δ$D_{(groundwater)}$ groundwater composition at farthest location (which varies between -30 to -40‰).

The study shows that river water and groundwater interaction at R. Beas is prominent at upstream with the river seeping into adjoining areas upto around 3km. The location Naushera Pattan which is approximately 1-1.5km from the River Beas shows river water interaction upto 70% and the locations Leachpur and Harsha shows upto 40% river water (Fig. 4.14a). The River Beas at downstream shows relatively lesser seepage in comparison with River Beas at upstream. The location Amritpur which is around 2km from River Beas shows around 40% river water (Fig. 4.14b).

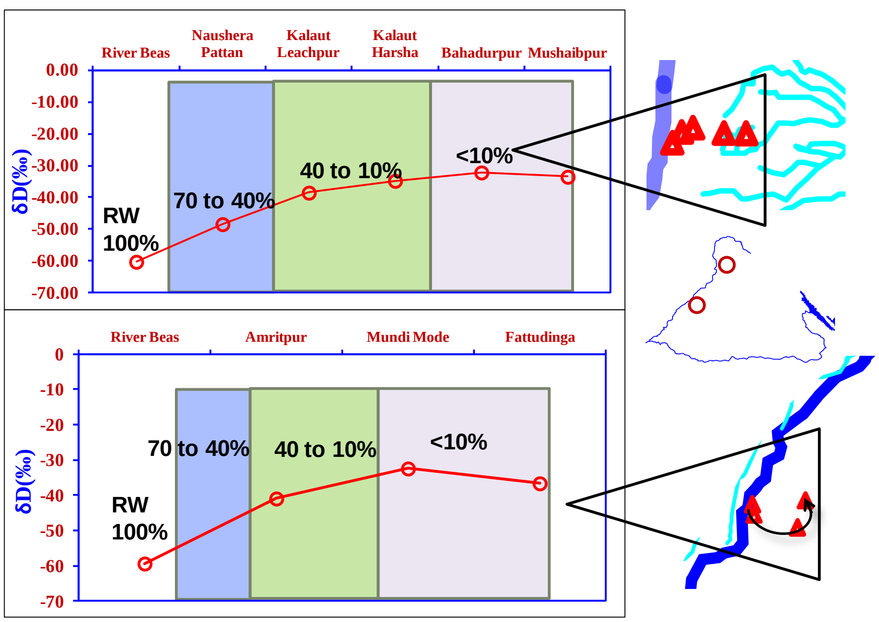

Fig. 4.14: River water- groundwater interaction at R. Beas Stretch (a) Upstream, (b) Downstream

River Satluj shows almost no interaction with groundwater in the upstream of the study area with less than 10% at location Bhurj Thaldas which is around 1km from the river bank (Fig. 4.15a). But the presence of Bist- Doab canal, which is at a distance of around 5km from river, at location chakdana shows canal water seepage (70% canal water). In case of downstream of the River Satluj, the river shows relatively high amount of interaction (upto 60%) with groundwater with river water seeping into groundwater upto around 3km (Fig 4.15c). The presence of R. Beas at the other stretch does not show any influence on the groundwater at this part of the study area.

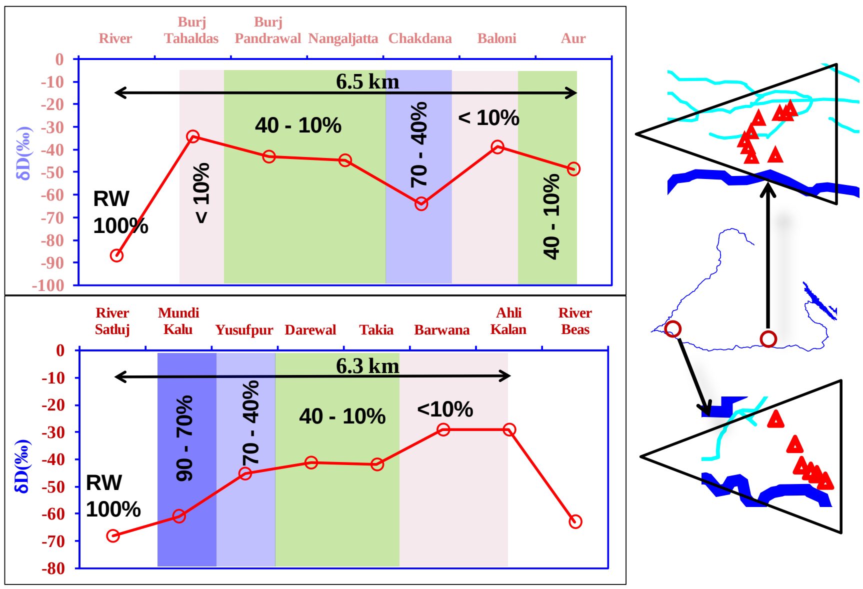

Fig. 4.15: River water- groundwater interaction at R. Satluj Stretch (a) Upstream, (b) Downstream

4.3.2 Environmental Tritium

To clearly understand the residence time of the groundwater in different aquifers the environmental tritium was analysed in rain, river and groundwater samples. The study shows that average environmental tritium activity in the rain water was 9.2TU and the River water (both R. Satluj and R. Beas) was 8TU. The environmental tritium in shallow groundwater ranges between 8TU to 2TU with average of 5TU and in deep groundwater ranges between 7.6TU to 0TU with average of 1TU (Purushothaman et al. 2012). The study shows that the groundwater in shallow aquifer younger in northern part, in eastern part (at Ropar region) and also at Harike where the rivers the confluence. The shallow aquifer is being recharged by the Kandi canal at north and R. Satluj at Ropar and Bist Doab canal at Nakodar and SBS Nagar and Balachaur region. Older nature of shallow groundwater at central part of southern region is due to presence of clayey layer. Both Shallow and deeper aquifers are younger at Kandi region. The presence of dams in this region act as recharge sources for deep aquifer. The central region of study area is connected with the Kandi region. The groundwater age is modern in the northern part due to the presence of

Kandi canal and in Ropar region where canals of the River Satluj debouches to its northern and southern sides of the river. The groundwater is sub-modern in the central region. The groundwater in the West kali Bein region shows that the groundwater is flushed out fast from the recharge area, i.e. northern part, to the downstream. The lower groundwater age at Nakodar and at SBS Nagar and Balachaur region indicates probable recharge from Bist Doab canal (Fig. 4.16). The shallow aquifer at the central part of southern region is older despite the presence of the River Satluj and Bist Doab canal shows that there is no recharge being done from the surface waters. The deeper aquifer is much older with all the locations showing very lower TU values except at the confluence of rivers and at Ropar where the groundwater is modern. The groundwater adjacent to the Kandi region shows age less than <30yrs, indicating contribution/ recharge of deep aquifer from the Kandi region. The deep groundwater shows presence of a narrow connectivity between Kandi region and at the central part of study region.

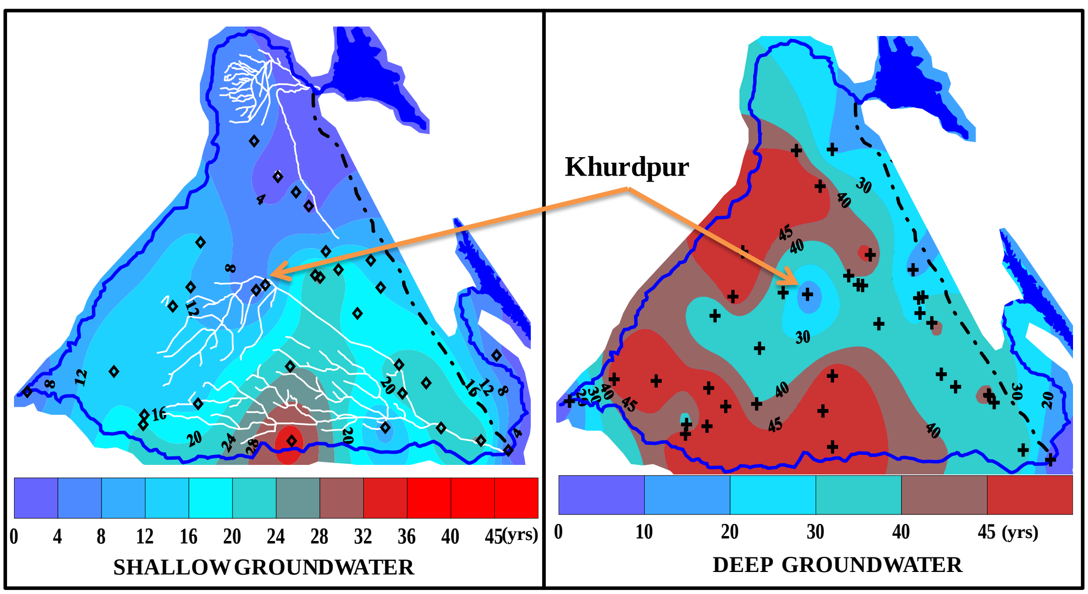

Figure 4.16: Spatial Distribution of Groundwater age in shallow and deep groundwater in Bist- Doab region

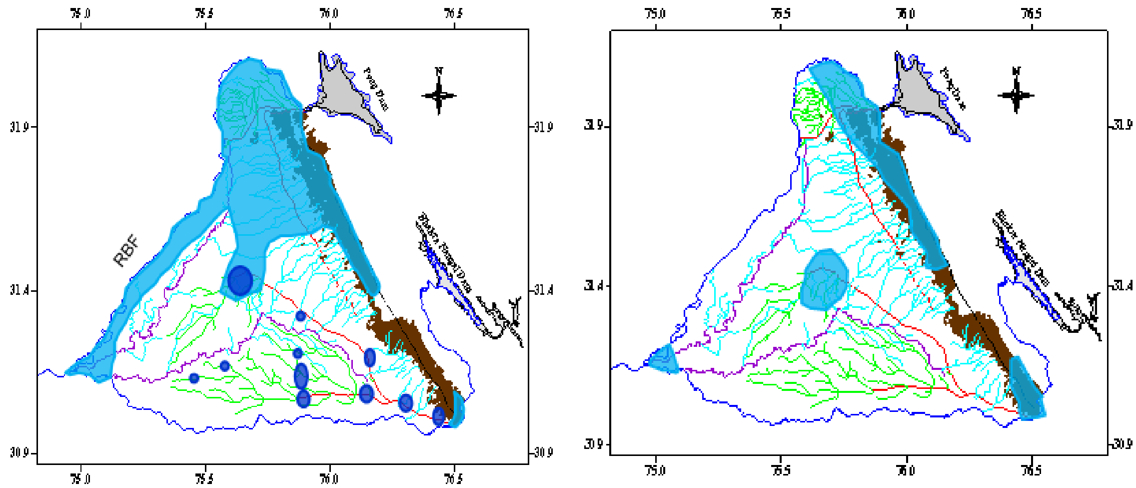

Figure 4.17: Recharge zones in deep and shallow aquifers

The effect of groundwater age is also seen in the rise/fall in the groundwater levels in Bist Doab region (Fig 2.18). Continuous available of water round the year in the Kandi dams and the available water head is resulting into fresh groundwater recharge at this region which is moving down to the central plains. This process is seen in the groundwater age pattern as modern groundwater in the Kandi region and increase in groundwater with the increasing distance from the Kandi region. High recharge conditions in the Kandi region is also seen in the AWLR records installed in the recently developed peizometers (Fig 4.4).

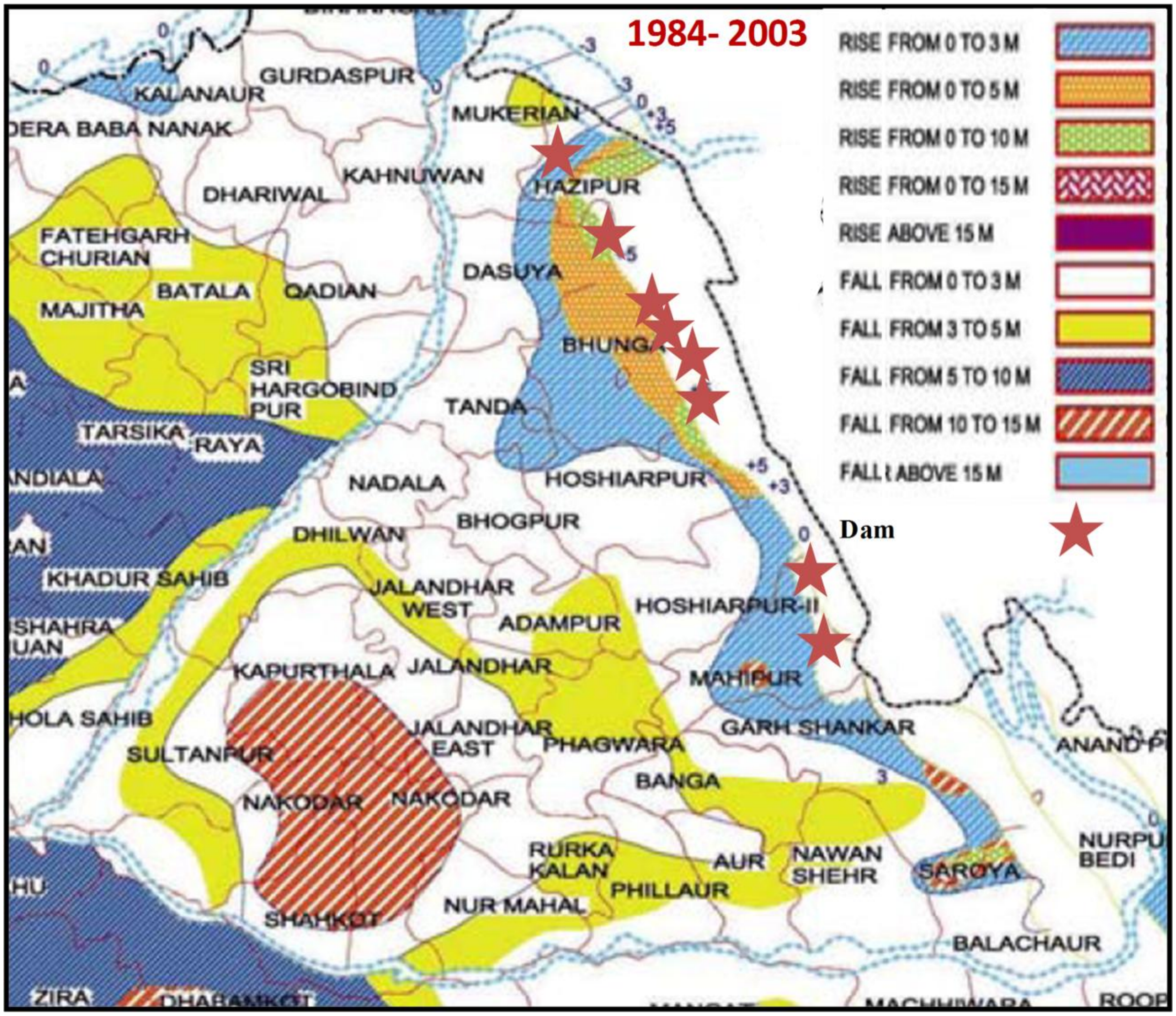

Fig 2.18: Groundwater rise/fall in Bist Doab region

Using the AWLR, water levels were recorded in 6 piezometers of the state department (~ 60 meter depth). Under the present project 6 new peizometers were also constructed at deeper depth (depth 130-160 m) with 3 in the Kandi region and 3 in plains. In the figure 4.3 water level fluctuations in 4 wells of the State Department (2 from Kandi region : Tanda and Bhogpur and 2 from the plains : Sultanpur Lodhi and Kapurthala) are shown. It can be seen from the figure that the Kandi region wells show much faster response to monsoon recharge and irrigation withdrawals compared to the piezometers installed in the plains. Thus the interpretations based on isotopic results are in consistent with the long term water level record of the region. The water level fluctuation in deeper wells (depth 120-160 m) are shown in the figure 4.4.

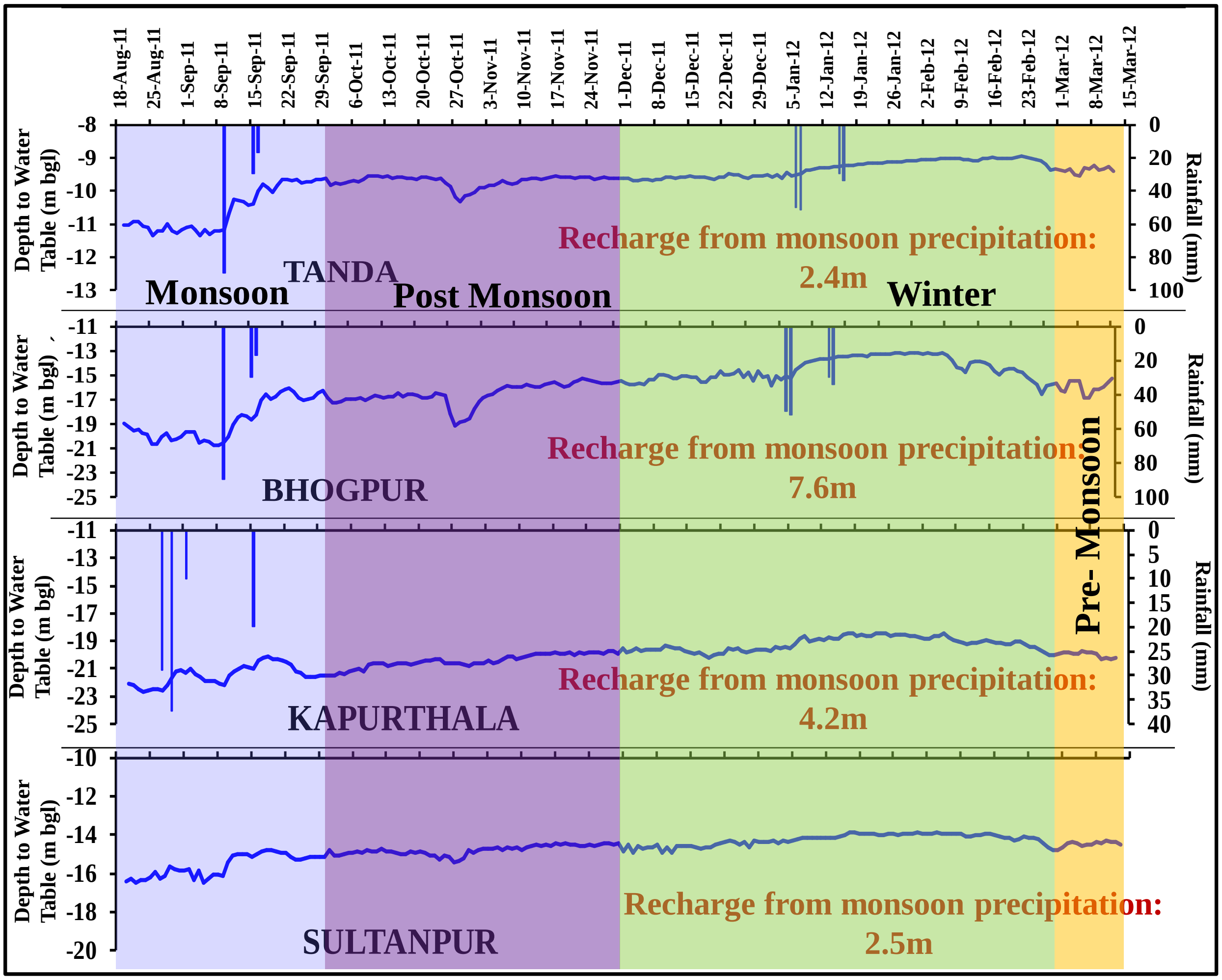

Figure 4.19: Pattern of Depth to water table with Rainfall in Tanda, Bhogpur, Kapurthala and Sultanpur

It is seen that piezometric head of deeper depth wells is sometimes different than that of shallow wells at the same place. This may be due to poor connectivity between shallow and deep aquifers. For example, shallow water table was at about 15 m depth at Bhogpur and Sultanpur lodhi whereas at the same place deeper well peizometric was around 26 m. Similarly, shallow well at Tanda exhebitted sudden rise in water table but in the deeper aquifer the piezoemtric head was constant throughout the year.

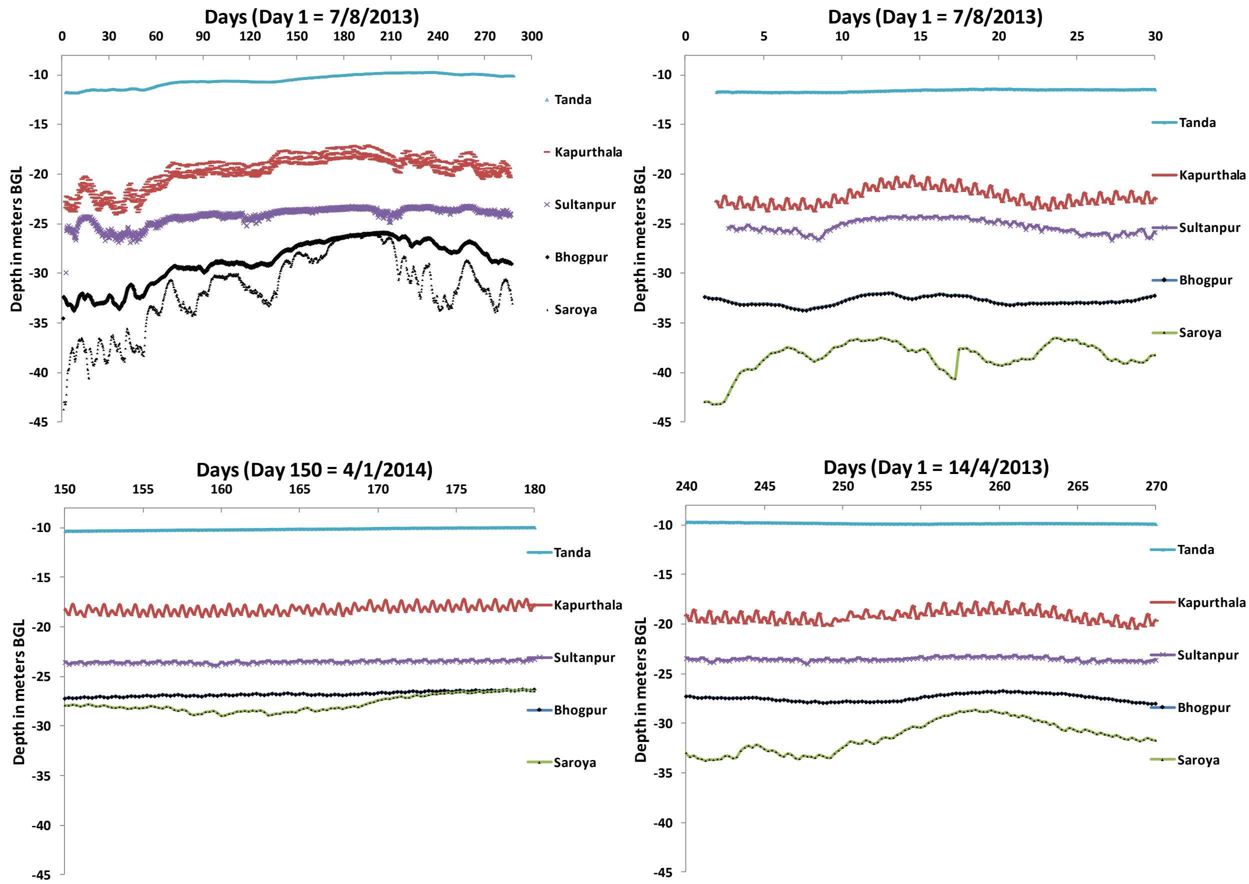

Fig: Water level record at 6 hr. intervals from the deep peizometers (depth 120-160 m) installed under the present study in the Bist Doab region. Fluctuation in piezometer head during August, January and April is also shown separately.

4.4 Hydrochemistry

The water samples in the study area (Both groundwater and surface water) is of alkaline nature with pH values ranging from 6.5 to 8 (Table 4.3). Electrical conductivity (EC) and total dissolved solids (TDS) in canal and reservoirs are less than 450 µS cm^{-1} and 320 mg l^{-1}

respectively (Table 4.3). Deep groundwater shows EC & TDS ranging from 350 to 1070 µS cm^{-1} and 245 to 750 mg l^{-1} respectively. Shallow groundwater exhibits high variation in EC & TDS values with values reaching up to 2000 µS cm^{-1} and 1400 mg l^{-1}.

The order of dominance of major cations in surface water (Canal, Stream and reservoir) samples are: $Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$. Whereas, dominance of major cations in shallow and deep groundwater of the study area is: $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$. High amount of sodium in the study region might be attributed to dissolution of plagioclase minerals. Dominance of Ca^{2+} and Mg^{2+} is mainly due to the presence of Kankar (Calcareous encrustations) present in soil matrix. The anion concentration in both surface and groundwater is dominated by bicarbonate ion followed by chloride ion. Difference in surface and groundwater chemistry indicates influence of rock-water interaction in the study area.

Groundwater chemistry is an important factor as it is used in determining water quality for domestic, agricultural and industrial purposes (Subramani et al. 2005). To understand the similarities between groundwater in the study area, they have been classified hydrochemically using major cations and anions with conventional Piper trilinear diagram (Piper 1944) and Chadha's diagram (Chadha 1999). Chadha (1999) classification of groundwater type helps to understand water type simpler than piper plot. Chada's (1999) classification of waters of Bist-Doab region shows $Mg^{2+}Ca^{2+}HCO_3^{-}$ water type in surface water, with Shallow and deep ground waters showing $Ca^{2+}Mg^{2+}HCO_3^{-}$ and $Na^{+}HCO_3^{-}$ water type. Two locations, namely Khurdpur and Nawanpind, shows $Na^{+}HCO_3^{-}Cl^{-}$ water type in shallow groundwater (Fig. 4.20).

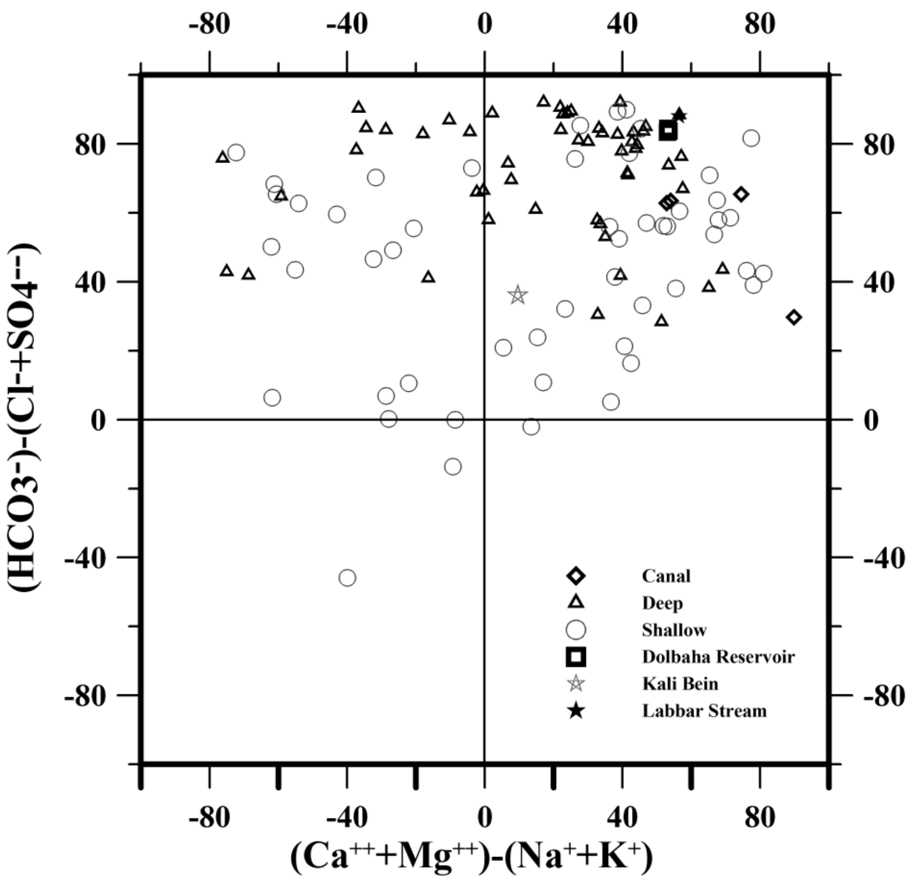

Figure 4.20: Chadha's classification of Groundwater type in Bist- Doab region

Detailed classification of water types using Piper plot shows similar water types ($Mg^{2+}HCO_3^-$) in canal waters in both Kandi and Bist- Doab. While, Dholbaha reservoir in Kandi area showing Mg^{2+} type (Mg^{2+} Ca^{2+} $Na^+HCO_3^-$) (Fig. 4.21a). The water types of shallow and deep groundwater in the region is complex in nature with Kandi region showing $Mg^{2+}Ca^{2+}$-bicarbonate type and southwestern part showing Na^+-bicarbonate type invariably in both aquifers (Fig.4.21a,b). The water type in both shallow and deep groundwater is influenced by Mg^{2+} bicarbonate type indicating recharge from Kandi region. The area between R. Satluj and R. White Bein shows dominance of Na^+ in shallow and deep groundwater which might be due to the dissolution sodium rich minerals (Plagioclase feldspars). The central and northeastern part of the study region shows higher amount of calcium in both shallow and deep groundwater which is due to presence of Ca^{2+} in the form of Kankar. The water type of shallow groundwater adjacent to canal (Kandi and Bist- Doab) network indicates recharge from the canals with Mg^{2+} being second dominant cation in these locations. Dominance of sodium/ calcium in these locations again indicates influence of rock- water interaction processes. In general, deep groundwater exhibits dominance of calcium compared to that of shallow groundwater which shows high amount of sodium. Presence of high concentration of $Na^{+}HCO_3^{-}$ type water in shallow and deep groundwater in the region is due to dominance of sodic rich lithology, i.e. weathering of minerals like plagioclase/ clinopyroxene. The dissolution of feldspar/ clinopyroxene with carbonic acid releases Cation and HCO_3, e.g.:

$$\underset{\text{Albite}}{2NaAlSi_3O_8} + 2H_2CO_3 + 9H_2O \rightarrow \underset{\text{Kaolinite}}{Al_2Si_2O_5(OH)_4} + 2Na + 4H_4SiO_4 + 2HCO_3$$

The above equation shows that dissolution of plagioclase feldspar and clinopyroxene results in the release of cations (Na^{+}, Ca^{2+} and Mg^{2+}) and H_4SiO_4 & HCO_3^{-} (Guo and Wang, 2004).

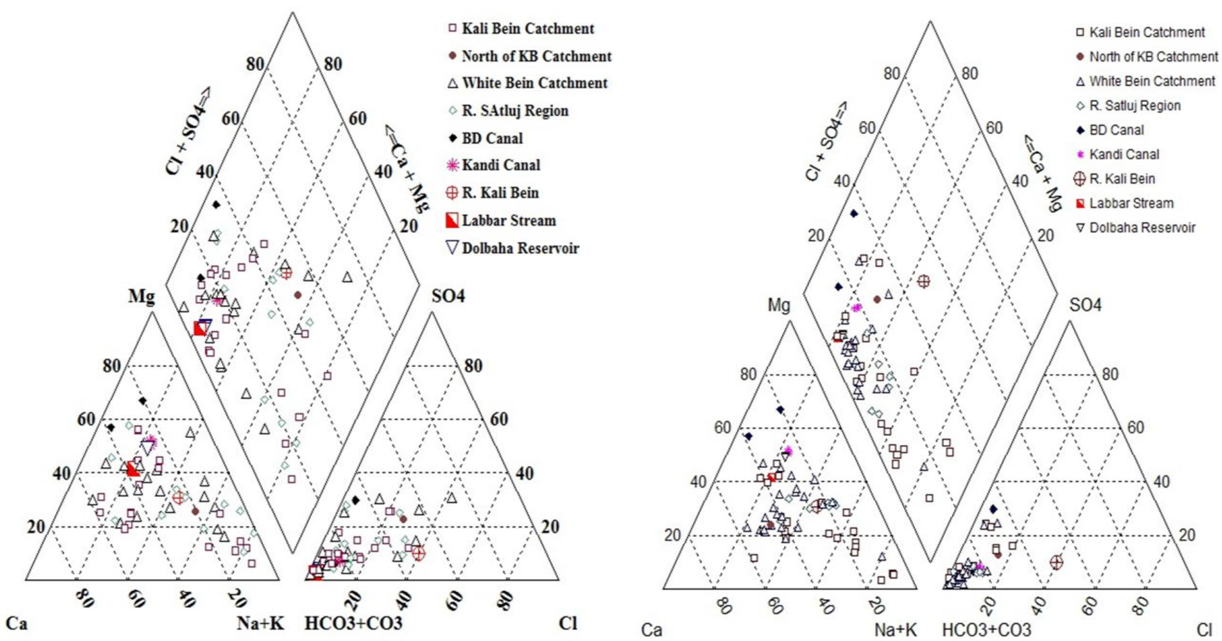

Figure 4.21: Piper plot showing the Groundwater type in Bist- Doab region a) Shallow b) Deep groundwater

4.4.1 Hydrogeochemical Processes Dominating Water Chemistry

Water chemistry is mainly influenced by water- rock interaction taking place from the recharge area to the location of sampling. Hence, it is very important to understand the geochemical processes undergoing in the study area. Gibbs (1970, 1971) differentiated water quality based on evaporation, water- rock interaction and precipitation using ratio plots of $Cl^-/(Cl^-+HCO_3^-)$ and $Na^+/(Na^++Ca^{2+})$ vs TDS, also known as Boomerang plot, is widely employed to assess functional sources of dissolved chemical constituents. Gibbs plot (Fig. 4.22a&b) shows that all samples plot at centre of Boomerang, indicating dominance of weathering of rocks in groundwater chemistry. Gibbs plot for cations (Fig. 4.22b) also supports dominance of rock-water interaction, but higher concentration of sodium shows influence of sodic rich minerals (like plagioclase feldspars) and influence of evaporation of percolating rain water.

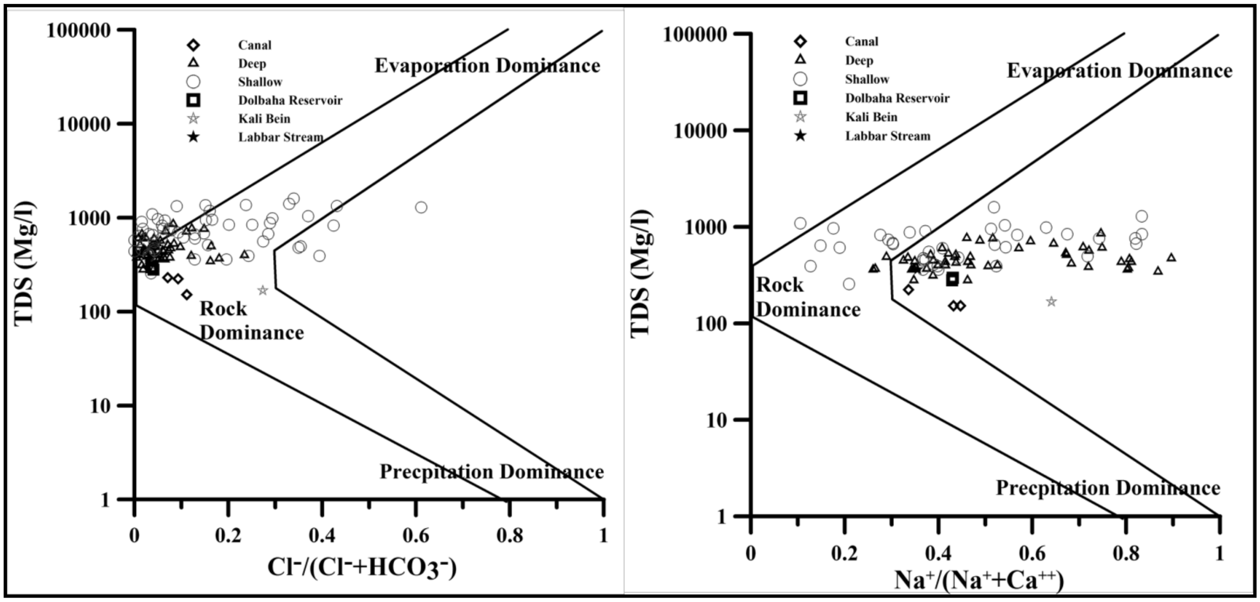

Figure 4.22: a) log TDS vs Cl/ (Cl+HCO$_3$); b) log TDS vs Na/ (Na+Ca) plot showing dominant source of groundwater chemistry.

Na^+/Cl^- vs EC plot is used to decipher influence of evaporation on water chemistry. With increase in evaporation, total dissolved solids and EC in groundwater increases, whereas Na/Cl value remains constant (Jankowski and Acworth 1997). The Na^+/Cl^- vs EC plot for shallow groundwater shows almost constant Na^+/Cl^- with increasing EC indicating evaporation of percolating rain water and water used for irrigation purposes (Fig. 4.23). In case of deep groundwater the inverse trend line indicates contribution of rock-water interaction processes than evaporation of percolating water.

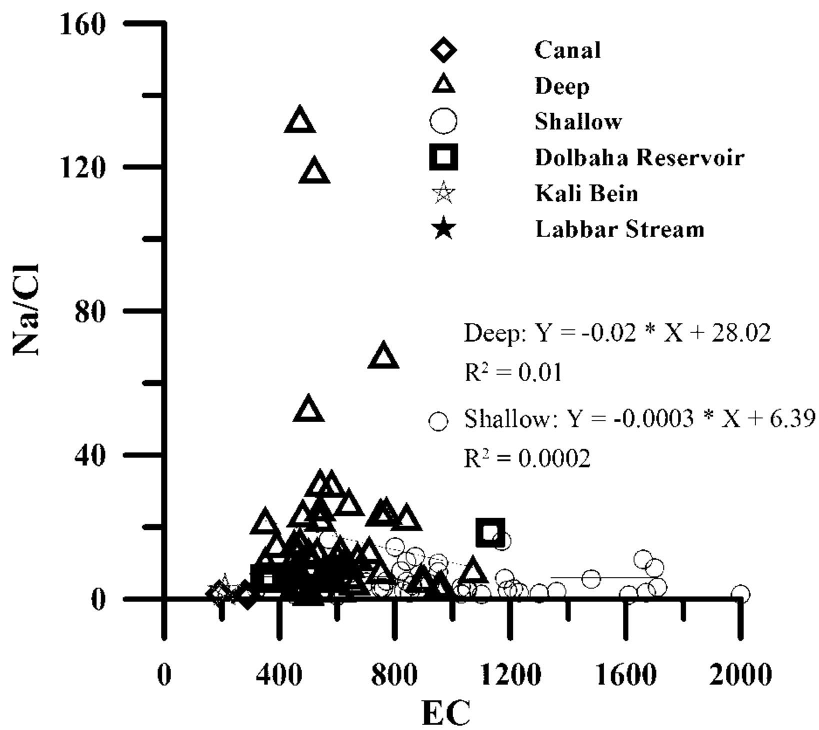

Figure 4.23: Na^+/Cl^- vs EC plot showing dominance of evaporation and evapo-transpiration in groundwater

4.4.2 Weathering and Dissolution

The weather ability of rock and release of ions depends on mineralogy of host rock. Hence, knowledge about host rock characteristics will help in understanding water quality of a region. High concentration of Na^+ followed by Ca^{2+} and Mg^{2+} in shallow and deep groundwater might have resulted from dissolution of silicate and carbonate minerals. The study area consists of kankars (calcium rich encrustations) and alluvium which are rich in feldspars that contribute to these ions in water. The calcium in the water might have been derived from dissolution of these minerals during percolation of rain water or water used for irrigation. Na^+ ion can be introduced into groundwater through percolating rain water or through dissolution of sodic rich minerals such as plagioclase feldspars and NaCl addition. The Na^+/Cl^- vs Cl^- plot (Fig. 4.24a) shows increasing Na concentration when compared to Cl^- indicating little or negligible contribution from rainwater or NaCl. High concentration of Na^+ is due to dissolution of sodic rich minerals like plagioclase/ clinopyroxene.

Ca^{2+}+Mg^{2+} vs HCO_3^- plot shows dominance of silicate or carbonate weathering in the study area (Rajmohan and Elango 2004). The equiline in the plot indicates presence of both silicate and carbonate weathering, while points plot near Ca^{2+}+Mg^{2+} indicates carbonate weathering and plots near HCO_3^- axes indicates silicate weathering. Ca^{2+}+Mg^{2+} vs HCO_3^- plot (Fig. 4.24b) shows surface water and few locations of shallow and deep groundwater at few location lying on equiline indicating prevalence of both silicate and carbonate weathering. While, rest of the shallow and deep groundwater plot near HCO_3^- axes indicates dominance of silicate weathering at these locations. Source for Ca^{2+} and Mg^{2+} ions can be deciphered using the Ca^{2+} vs HCO_3^- and SO_4^{2-} plots. When calcium and bicarbonate originates from calcite Ca^{2+}: HCO_3^- will be 1:2 and if it is from dolomite the ratio will be 1:4 (Garrels and Mackenzie 1971; Holland 1978). Similarly, the ratio of Ca^{2+} and SO_4^{2-} will be 1:1 when these components are derived from gypsum (Das and Kaur 2001). The Ca^{2+} vs HCO_3^- plot (Fig 4.24d) indicates dissolution of calcite and dolomite with the sampling points plot near HCO_3^-. Higher concentration of Ca^{2+} in Ca^{2+} vs SO_4^{2-} (Fig. 4.24c) indicates absence or negligible amount of gypsum in the study area. Presence of SO_4^{2-} in some locations might be due to usage of fertilizers and pesticides.

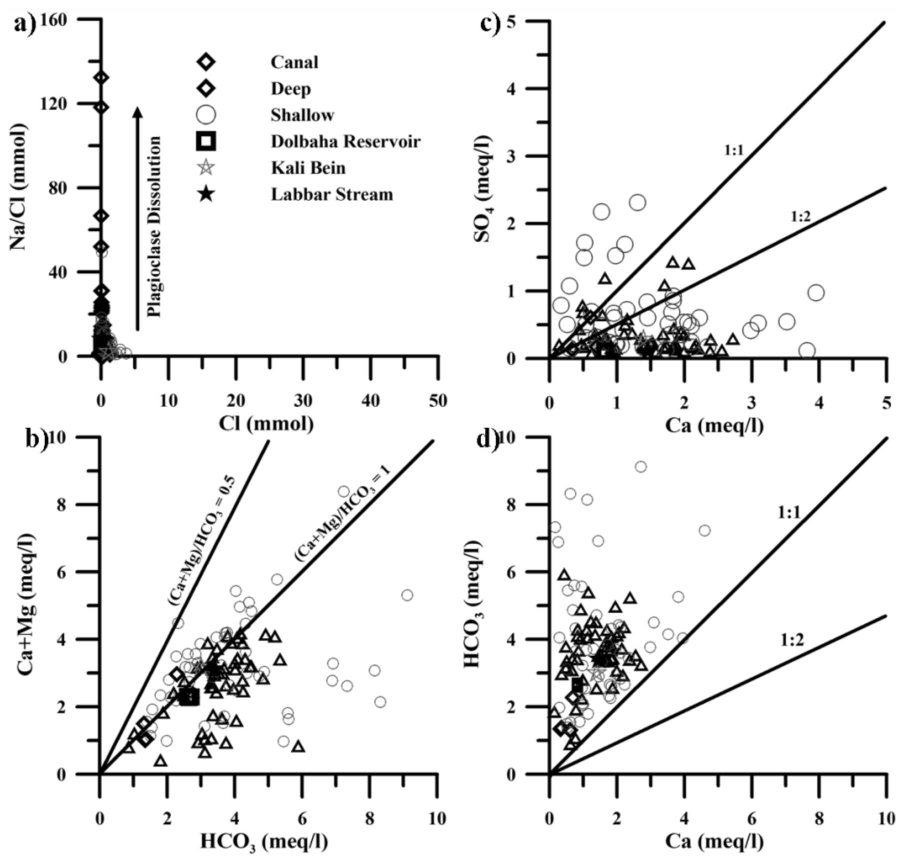

Figure: 4.24: Plots showing the weathering and dissolution processes taking place in the study area

4.4.3 Ion- Exchange Processes

The elements in ionic form are adsorbed on crystal lattices of minerals such as clay minerals. When these minerals come into contact with groundwater the adsorbed ions in mineral lattice are replaced by the ions in groundwater. The exchange reaction takes place till an equilibrium position is reached. To determine type of exchange, i.e. from rock to groundwater and its host environment or vice versa, Schoeller (1965, 1977) suggested 2 chloro alkaline indices CAI1 and CAI2. These indices are calculated using the formula:

$$CAI1 = Cl^- – (Na^+ + K^+/Cl^-)$$

$$CAI2 = Cl^- – (Na^+ + K^+/Cl^-) / (HCO_3^- + SO_4^{2-} + NO_3^{2-})$$

all values are in Meq/l. The indices are positive, indicating base-exchange reaction, during which Na^+ and K^+ ions in water are exchanged with Mg^{2+} and Ca^{2+} ions in host rock, whereas negative indices indicate chloro-alkaline disequilibrium. The negative indices of both CAI1 and CAI2 in waters in study area shows reverse exchange reaction indicating exchange of Mg^{2+} and Ca^{2+} from water with Na^+ and K^+ of rock.

4.4.4 Water Quality for Drinking Purpose

Chemical parameters of waters in the region are compared with WHO (WHO, 2004) and Indian standard (BIS, 1991). The surface waters in the region exhibits good quality, with major ion concentrations lying below desirable limits. Shallow groundwater shows high cation

Table 4.4: Water quality of major ions in the study area

Ions	Shallow	Deep
Ca^{2+} (>75mg/l)	Rahon, Badesaron	All samples within permissible limit
Mg^{2+} (>30mg/l)	Goraya, Noormahal, Rahon, Saidpur Jhinni, Nakodar, Nawanpind	
Na^+ (>200mg/l)	Phillaur, Sadiqpur	
K^+ (>10mg/l)	Begowal, Maliyakalan	
F^-		
Above desirable limit (0.6-1.2mg/l)	Busowal, Darwesh, Jandiala, Khurdpur	Darwesh, Malliankalan, Arjanwal, Phuller
Above permissible limit (>1.2mg/l)	Jalandhar	Behram
NO_3^- (>45mg/l)	Nussi, Nakodar, Goraya, Nawanpind	All samples within permissible limit

Values in parenthesis indicate drinking water quality (BIS & WHO) concentration (above desirable/ permissible limit) at few locations (Table 4.4) with deep groundwater showing good quality. Except fluoride and nitrate, all other anions are within permissible limits in both shallow and deep groundwater. Higher Nitrate concentration in shallow groundwater is due to influence of fertilizers.

4.4.5 Water Quality for Irrigation Purpose

Excess concentration of sodium in water affects soil property by replacing cations in soils and hence it is an important criterion in irrigation-water classification. The extent of this replacement is estimated by Sodium Adsorption ratio (SAR), Residual Sodium carbonate (RSC) and sodium percentage (Na %) (Table 4.5).

Table 4.5: Classification of water for irrigation purposes in Bist- Doab region

Parameters	Range	classification	Surface waters	Shallow	Deep
				(Number of samples)	
SAR	<10	Low	9	51	52
	11-18	Medium			
	18-26	High			
	>26	Very High			
Salinity Hazard (EC) (µS/cm)	<250	Low	2		
	250-750	Medium	7	17	44
	750-2250	High		34	8
	>2250	Very High			
RSC	<1.25	Good	9	35	33
	1.25-2.50	Doubtful		7	16
	>2.50	Unsuitable		9	3

Sodium Adsorption Ratio

The SAR index quantifies proportion of sodium (Na^{+}) to calcium (Ca^{2+}) & magnesium (Mg^{2+}) ions in a sample. Sodium hazard of irrigation water can be well understood by knowing SAR and is calculated by using the equation (Richard, 1954).

$SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2}$

Where, concentrations are in meq/l. The waters of Bist- Doab region shows low amount of sodium absorption ratio indicating very good nature (Table 4.4).

Salinity vs. Sodium Hazard

Water quality for irrigation can be classified using the salinity and sodium hazard diagram (USSD, 1954). The diagram is divided in to C1 to C4 with increase in salinity hazard and S1 to S4 with increase in SAR (Fig. 4.25). The salinity hazard, a measure of TDS expressed in terms of EC, reduces osmotic activity of plants and thus infers with adsorption of water and nutrients from soil (Saleh et al. 1999; Subba Rao et al., 2012). High salt content forms saline soils, which is the major cause of crop loss. Whereas, sodium hazard in water renders it suitability for soils (Subba Rao et al, 2012).

The SAR vs EC plot (Fig. 4.25) exhibits medium quality for irrigation in shallow groundwater at most of the locations and at two locations in deep groundwater. Rest of the shallow & deep groundwater locations exhibits good quality for irrigation.

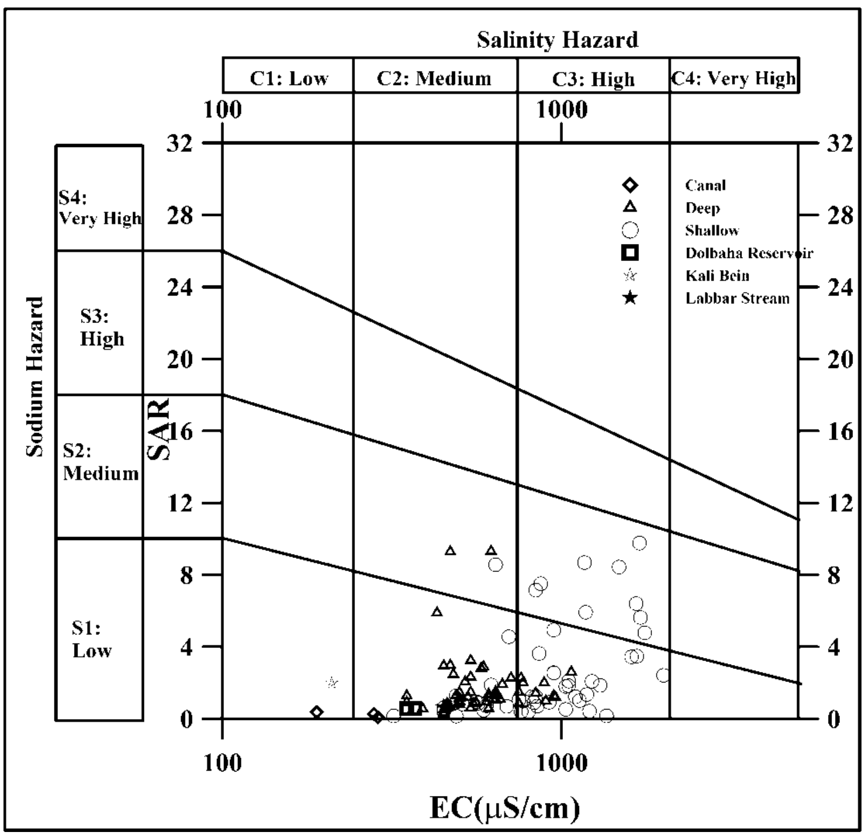

Figure 4.25: Water Classification According to SAR and EC

Sodium Percentage

The role of sodium in the classification of groundwater for irrigation was emphasised because of the fact that sodium reacts with soil and results in clogging of particles, thereby reducing permeability (Todd, 1980; Domenico and Schwartz, 1990). Wilcox (1955) proposed classification of irrigation waters based on sodium percentage using the formula given below.

$$Na\% = (Na^{+}+K^{+})*100/ (Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$$

According to this classification water samples are divided into five types 1) Excellent to Good, 2) Good to permissible, 3) Permissible to Doubtful, 4) Doubtful to Unsuitable and 5) Unsuitable. Surface waters show excellent nature for irrigation purposes. Deep groundwater exhibits Excellent to permissible nature in almost all locations with only two locations exhibiting Permissible- Doubtful nature. In case of shallow groundwater almost half of the locations exhibit Permissible to Doubtful nature for irrigation purposes (Fig. 4.26).

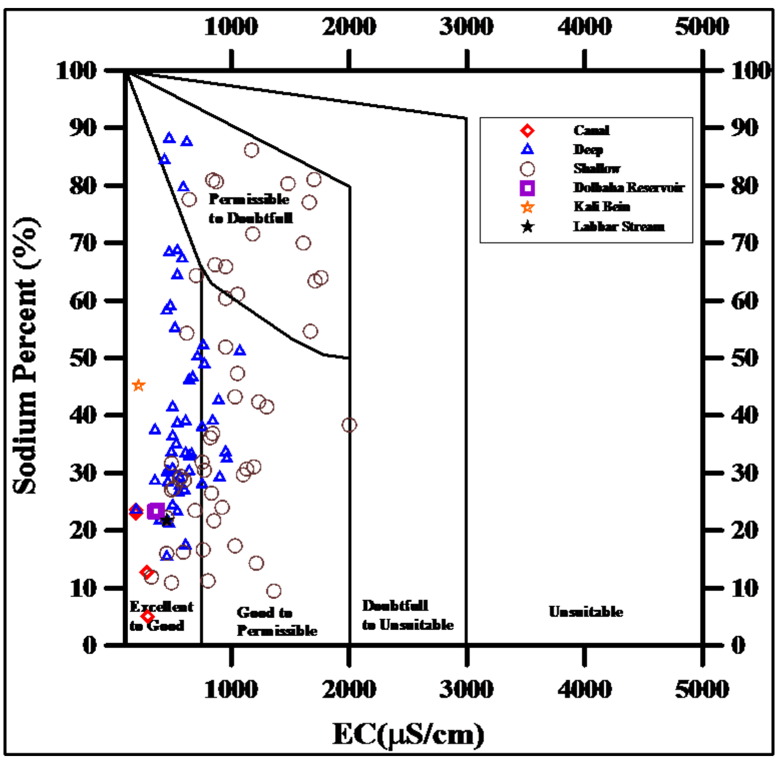

Figure 4.26: Classification of Irrigation Waters

Residual Sodium carbonate

Relative abundance of sodium with respect to alkaline earths & boron, and quantity of bicarbonate & carbonate in excess of alkaline earths, influences suitability of water for irrigation. Above excess carbonate is denoted by 'Residual sodium carbonate' (RSC). Water with high RSC has high pH and lands irrigated by such water become infertile, owing to deposition of sodium carbonate (Eaton, 1950). RSC can be calculated using the formula:

$$\text{Residual sodium carbonate (RSC)} = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+})$$

where, samples are in Meq/l. Most of the locations show low RSC values exhibiting good quality of groundwater and surface water. Almost 30% of the locations show doubtful to unsuitable nature (Table 4.4) for irrigation purposes in deep and shallow groundwater.

4.4.6 Factor Analysis

Groundwater in the study area has been statistically analysed using principal component analysis (PCA). Principal components are sequentially extracted in the way that greatest variance of observed data is accounted by first component, the second greatest variance by second component, and so on. Principal components can also be understood as interplay of different observed variables which represent a common process that is causing these variables to link.

A preliminary analysis of the groundwater chemistry data exhibits correlated dominant components (ion concentrations). Bartlett's sphericity test, a test for independence of 18 variables, has been used to determine whether correlation matrix R is an identity matrix (Fung and Le 1987; Feng 2003; He and Meng 2002 and Mrklas et al. 2006). The vector of eigen values (λ) of R matrix represents variance of each component. The Eigen value >1 was considered for the analysis.

Shallow groundwater showed total four factors (Table 4.6) with eigen value greater than 1. The first factor (PC1) with higher loadings, explains the natural component governing water chemistry. The EC, Na^+, HCO_3^- and Cl has highest loading in PC1 indicating that these elements are derived naturally. The PC2 explains negative loading of Ca^{2+}, Mg^{2+}, K^+, HCO_3^- and Cl^-, indicating that these elements are derived by weathering and dissolution (Ranjan et al. 2012). F^- with positive loadings in PC3 indicates a possible anthropogenic and natural source. Positive loadings of SO_4^{2-}, NO_3^{2-} and Mg^{2+} in PC4 suggests anthropogenic source of these elements.

Table 4.6: Loadings of experimental variables on the first four PCs for the shallow groundwater data set

	Factor 1	Factor 2	Factor 3	Factor 4
pH	0.29	-0.33	0.56	0.49
HCO_3(Meq/l)	0.80	-0.46	0.24	0.07
Cl(Meq/l)	0.47	-0.49	-0.44	0.45
SO_4(meq/l)	0.21	0.03	-0.01	0.76
NO_3(meq/l)	0.03	-0.04	-0.06	0.78
F(meq/l)	0.06	-0.28	0.67	-0.01
Ca(meq/l)	-0.11	-0.90	0.10	0.00
Mg(meq/l)	0.25	-0.62	0.03	0.54
Na(meq/L)	0.95	-0.05	-0.04	0.24
K(meq/l)	-0.33	-0.81	0.11	-0.05
EC	0.55	-0.53	0.07	0.46
Eigen Value	7.27	3.19	1.91	1.15

Deep groundwater also has four factors with eigen values > 1. Similar to shallow groundwater, Na^+ and HCO_3^- show high positive loading in PC1 (Table 4.6). F^- also shows positive loading in this factor indicating a possible natural source for fluoride in the study area.

Table 4.7: Loadings of experimental variables on the first four PCs for the Deep groundwater data set

	Factor 1	Factor 2	Factor 3	Factor 4
pH	-0.05	0.13	0.06	-0.95
HCO_3(Meq/l)	0.61	-0.61	-0.37	-0.01
Cl(Meq/l)	0.24	-0.35	-0.69	0.20
SO_4(meq/l)	0.19	-0.16	-0.91	-0.05
NO_3(meq/l)	-0.02	-0.82	0.15	0.21
F(meq/l)	0.48	-0.31	0.06	-0.03
Ca(meq/l)	-0.09	-0.79	-0.28	-0.13
Mg(meq/l)	-0.02	-0.78	-0.53	0.07
Na(meq/L)	0.92	-0.11	-0.26	0.08
K(meq/l)	0.09	-0.79	-0.16	0.16
EC	0.41	-0.66	-0.16	-0.48
Eigen Value	7.12	3.50	1.54	1.27

PC2 shows negative loadings of HCO_3^-, NO_3^{2-}, Ca^{2+}, Mg^{2+}, and K^+, indicating influence of dissolution and weathering in groundwater chemistry (Table 4.7). PC3 with negative loading of

Mg^{2+}, Cl^- and SO_4^{2-} indicates dissolution of calcium/ magnesium rich rocks as a source for these elements. Insignificant negative loadings in PC4 indicate negligible anthropogenic influence in chemistry of deep groundwater.

MANAGEMENT MEASURES AND ARTIFICIAL RECHARGE OF GROUNDWATER

MANAGEMENT MEASURES

The results from stable isotope investigations of surface water and groundwater (figures) has clearly indicated that the major recharge zone for shallow to deep aquifer is spread along the Kandi-Siwalik region. In the plains, recharge through Bist Doab canal is occurring to a marginal extent to shallow aquifer and deeper aquifer are almost not getting recharged in the entire plains of Doab region. River Satluj is also working as gaining type and is not recharging the Doaba region. River Beas to some extent is recharging the Doaba region to a distance upto few kilometers. Groundwater that is getting recharged in Kandi-Shivalik region is reaching to the central plains of Doab region in few decades. Municipal and agricultural waste water are occupying the dried zones of shallow and deep aquifers contaminating the groundwater and recharging fresh water. Due to slow movement of groundwater, poor recharge conditions, high rate of withdrawals and recharge of contaminant water, overall conditions of groundwater in the Bist Doab region is deteriorating rapidly. If the situation continues without taking any management measures the health and economy of the Doab region will get affected and may become irreversible. A few management measures are suggested in the present chapter. However, detail study, rigorous exercise and collective efforts are required to overcome the situation.

The groundwater in the Doab region can be rejuvenated by reducing the growing pressure of groundwater withdrawal through conjunctive use of surface and groundwater (multi-aquifer management), by preserving the monsoon run-off and flood water storage wherever possible, by artificially enhancing the recharge to shallow and deep aquifers, by taking measures on quality controls in the solid-waste & waste water disposal, implementation of modern agricultural technology to enhance the water use efficiency, regular monitoring of the situation and mass awareness & Govt-public-private partnership programmes.

On the point of entry into the Doab region at Rupnagar, the river Satluj water gets distributed to Bist Daob canal and Sir Hind Canal leaving a minimum flow in the river Satluj. Over the passage of thie minimum flow in the Satluj river between the stations Ropar to Harike, a fraction of the discharge is lost as evaporation and that contributing as recharge from flood plain to groundwater and, a small fraction gets added to the discharge as base flow component.

Since the river Satluj falls in the lower elevation in the Bist Doab it mainly receives the base flow component of the groundwater recharged in the Bist Doab plains (through precipitation, canal seepage, irrigation return flow etc). Moreover, since the discharge in the river is also very low the river hardly recharges its flood plain and there is no flow towards interior into the Doab plains. Canals of the Doab region (Bist Doab canal, Kandi canal and drains of Kandi dams) carry discharge only during the irrigation demand period. In rest of the season, the stagnated canal flow receive the local garbage & waste and these canals are therefore highly contaminated in the remaining periods. The only perennial source in the Bist Doab region is the River Beas. In most of the period in the year, it carries bank-full discharge from Mukerian to Harike as it does not have any outlets from it from Mukerian (after the Kandi canals debouching from it at Mukerian) to up to Harike. Thus, possibilities that exists to make the central Bist Daob region perennial are: (i) by transferring a component of the Beas river water to central Bist Doab region by connecting the Kandi canal with the Bist Doab canal (ii) creating an additional feeder link from Beas river to Doab canal between Mukerian to Harike and (iii) creating additional surface water storage structures to store the surface run-off from the ephemeral monsoon torrents. To examine the first two possibilities, the smallest distance between the Kandi Canal and Bist Doab canal with sufficient elevation difference between the two canals has been looked at and, in a similar way a possible shortest route from Beas river to Kandi canal with sufficient elevation difference between the two points have been identified. For the possibility given in (iii) joining points of ephemeral rivulates in the Kandi region have been marked. These locations normally have good basement to hold to develop water storage structure and receive sufficient water during monsoon periods. Structures at such locations are also useful in flood controls measures and in distribution of water through natural rivulets in dry periods. With this background for the above surface water development measures the following measures are arrived at:

The Kandi canal is a lined contour canal and carries Beas river all along the foot hill outline upto the village Balachore. The Balachore site is only a few kilometer distance away from Bist Doab canal and this site is also at much higher elevation compared to the main branch of the Doab canal. Thus, a part of the Beas river water can be easily be transferred to Bist Doab canal by developing a link canal at Balachaore site. The bypassing of Beas river water through the Doaba canal will help maintain the Doaba canal perennial round the year and will also help to recharge the local groundwater. After end of the distribution through all its distributaries the tail end discharge (canal and groundwater as baseflow) will ultimately join at Harike for its conveyance to remaining parts of Punjab and Rajasthan. The transfer of Beas water through Doab canal and its distribution in the central Bist Doab region where groundwater problem is the most severe will pressure on groundwater for irrigation, industrial and drinking requirements of this region. In addition to the Kand canal- Doab canal link additional links to connect the Beas river with the canals of central Doab region are possible. With this background four viable links are identified (Figure 5.1):

Link1&3: for surface water support in western parts

Link 2: For surface water support in south central region

Link 4: To increase the surface water potential of white Bein/Doab canal

1) With the construction of a link canal 1 & 3, the river Beas water can be discharged through the Kali Bein to distribute its water to western parts of the Doab region. The total canal length required to be constructed is around 5 km.
2) Once the Kali Bein becomes perennial (by the construction of the link 1 & 3), a fraction of the Kali Bein water can be transferred to the Doab canal by constructing the link canal (labeled as 2 in the figure). The link canal 2 will provide surface water support to the central-west zone of the Doab region.
3) The elevation altitude of Kandi canal is much higher compared to the White Bein and Doab canal. The tail end of Kandi canal can be linked with White Bein/ Doab canal by developing a link canal from Balachaur. Out of the several ephemeral natural streams that are there in this region, a suitable one can be used to develop such link.

   The above links will not only reduce the groundwater pressure in the central Doab region but will also make the two important streams Kali Bein and White Bein perennial. Bunds on these streams can also be developed to increase their discharge capacity and to use these drains as support to the existing canal systems.
4) The local and major dams (like Maili, Dolbaha, Pong dam etc.) can be judiciously used for keeping the Kandi canal perennial.

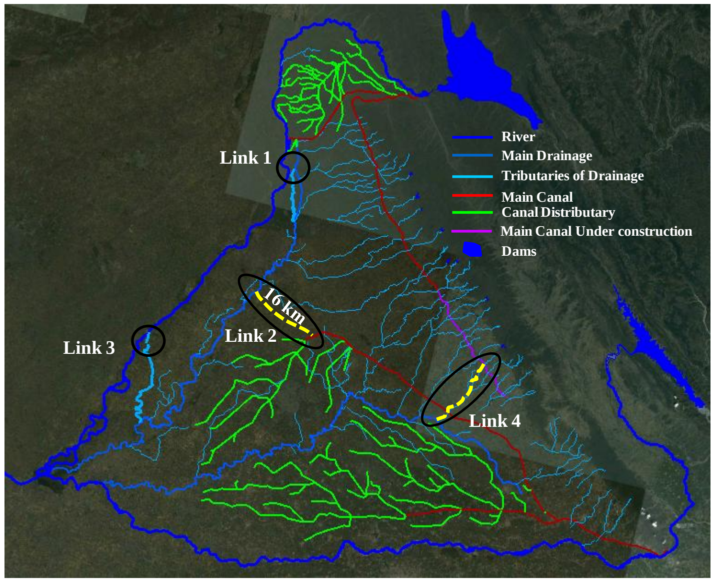

Figure 5.1: Proposed Links from River Beas to Central part of Bist- Doab Region

5) The Kandi canal and the Bist Doab canal along their path passes from recharge zones. The groundwater potential at these zones can be developed for utilization of drinking water supply. Some such locations are shown in the figure 5.2 a.

6) Small size surface water bodies/tanks can be developed along the joining points of ephemeral streams along the Kandi/plain interface region to store the monsoon run-off. Some such locations for developing surface water structures are marked in the figure 5.2b. In the absence of the proper structure the discharge from these streams during monsoon is getting spread out haphazardly creating water logging problems and also damaging the roads coming on their ways. In the entire Bist Doab region, maximum rain fall occur in the Siwalik-Kandi region. By developing the surface water bodies as shown in the figure 5.2b most of the surface run-off can be preserved for the use during dry periods and also for recharging the groundwater.

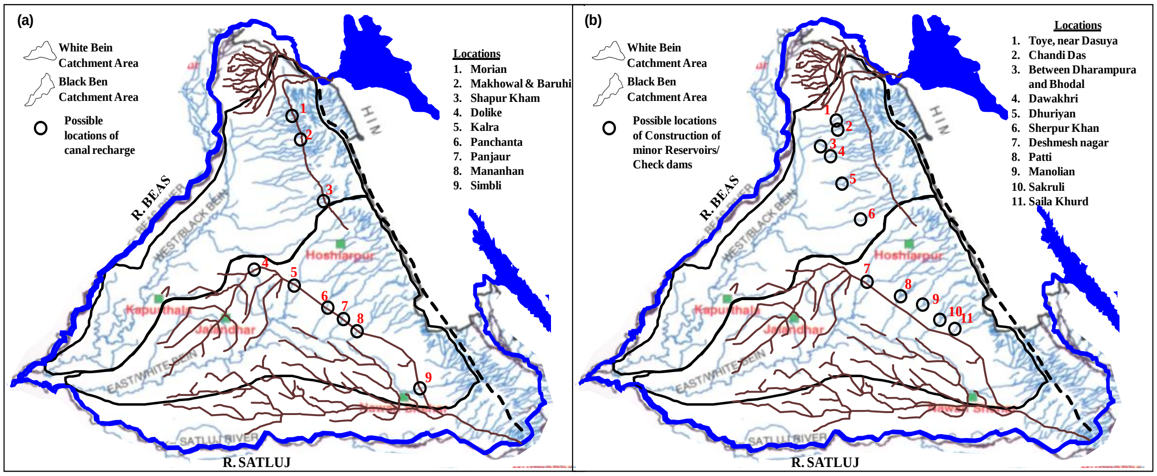

Figure 5.2 Locations identified for artificial recharge measures in Bist- Doab Region (a) Enhancement of groundwater recharge using canal; (b) Locations identified for construction of check dams

Other than specific management steps as detailed above several general measures can also be taken up to improve the water resources of the Bist Doab region. Some such steps are given below.

1) Use of flood plain aquifers: The large and thick aquifers of Beas river flood plains that mainly contain sand deposits can be used as a natural storage space for water. During monsoon, the flood plain gets recharged naturally on their own. Therefore, these aquifers prior to the monsoon can be used for various needs. The dewaterd aquifer, during the monsoon will naturally get recharged. A simple calculation for amount of water that can be gained through 1 meter depth of water level withdrawal from 10% of the flood plain can be computed. The length of the river Beas in the Bist Doab region is over 140 km. Even if the flood plain width is considered as half a kilometre on either side of the river, this translates to the flood plain area 70 sq km on either side. Dewatering to a depth of 1 meter from even 10 % of the flood plain region for assumed specific yield of 15% corresponds to the total water of (10% of 70km2 x 1 meterx0.15) 1.05MCM/yr. Since the withdrawal can be extended from pre-monsoon to the entire monsoon season much higher withdrawal that 1.05MCM can be made. The dewatered aquifer subsequently gets recouped naturally during monsoon flooding.

2) Depending upon the sub-surface geology, the seasonal streams can be developed (by developing bund & check dams) for recharge to groundwater or for the purpose of storage of surface run-off.
3) Collecting rain-water in topographical depressions zones and transferring it to deeper aquifers
4) In the areas where groundwater is not suitable, groundwater can be used after mixing with canal water. This would help in evacuating the un-suitable water and freshening of the dewatered zone with fresh precipitation recharge in the next monsoon. The repeated such cycle over long period can ultimately change the groundwater quality from bad to good. In the brackish ground water zone areas, salt resistant crops can be sown.
5) Groundwater utilization is pre-dominantly done by the agriculture sector. Therefore, any water savings in irrigation can have large effect on the overall groundwater savings. The crops consuming less quantity of water may be grown in the over exploited blocks while crops like paddy that demand mode water can be grown in water logged regions or where plenty water is available. Farmers have adopted paddy cultivation due to its profitability and incentives from Government. However, with the depleting groundwater reserve the extent of profit is decreasing. The farmers therefore can go for rotating cropping pattern as per the prescribed guidelines (depending upon fertilizers/nutrients requirement, market demand, water availability, financial constraints, minimization of pest build-up, diversification risk etc).
6) Paddy sown in the month of May requires more evapotranspiration than paddy shown after 15th June. Thus a lot of water can be saved by timely plantation of Paddy. Farmers should be made be aware of timely plantation of paddy. Alternately, a direct seeding rice (DSR) technique may be used. The traditional method involves planting seeds in a nursery and later transplanting the saplings to the main cultivation area, while in DSR technique, there is no need to clear the stubble, prepare a paddy nursery, or even puddling of the field before sowing. The technique can save not only fields from burning but also 40 per cent on water consumption and Rs 5,000 per hectare on cultivation cost. The technique works on laser level lands and seeding using power tiller operated seeder. Farmers can take up paddy cultivation at any time, as there is no requirement or delay of raising a nursery.

7) Modern agricultural management techniques, removing land undulation by laser leveling, use of regulated deficit irrigation or partial root zone drying wherever applicable, drip irrigation, sprinklers etc can help to increase the water use efficiency without severe yield reductions.
8) The abandoned dug wells and mined areas may be cleaned and used rainwater harvesting or for run-off storage for the case of mines (if the basement strata is impervious).
9) In the hilly terrains, the recharge zones of springs can be identified (using isotope, GIS/RS techniques) and these recharge zones can be developed for the sustainability of springs which is the main source of drinking water in such areas.
10) Appropriate surface water storage structures and groundwater recharge measures should be adopted in hilly terrains where maximum rainfall goes off as runoff, and a very small quantity contributes towards ground water replenishment.
11) Mapping the recharge zones and recharge sources and their maintenance for artificial recharge measures.
12) Use of scientific methods for solid waste and wastewater treatment and disposals specially in cities like Jalandhar, Kapurthala etc. Water treatment plant of sufficient capacity (considering future requirement) should be installed in all the cities. Part of the treated waste water that is suitable for irrigation needs can be recycled to the nearby lands.
13) Roof top rainwater harvesting, may be promoted by imposing bye-laws especially in overexploited blocks.
14) Mass awareness towards water conservation and conjunctive use of Surface & ground water to overcome the over exploitation and aquifer management practices should be given at all levels (village to state level).
15) To control over the deteriorating water quality mapping of the area of water contaminated zone, saline groundwater zone, identification of cause and remedial or management measures of such conditions should be done at regular intervals.
16) In critical areas, network for water quality and water level monitoring should be done.
17) Canals and drains may be interconnected to keep their flows for more time in a year.

The above specific and general recommendations if implemented can help in rejuvenating the groundwater resource of the Bist Doab region and also in areas where similar problem is getting faced.

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List of Publications (Journls)

S. No.	Authors	Title of the paper	Name of the Journal	Vol	Pages	Year
1	Krishan, Gopal, Lohani, A.K., Rao, M.S. and Kumar, C.P.	Prioritization of groundwater monitoring sites using cross-correlation analysis	NDC-WWC Journal	3(01)	28-31	**2014**
2	Rao, M. S., P. Purushothaman, Gopal Krishan, Y. S. Rawat and C. P. Kumar	Hydrochemical and Isotopic Investigation of Groundwater Regime in Jalandhar and Kapurthala Districts, Punjab, India	*International Journal of Earth Sciences and Engineering*	7 (01):	6-15	**2014**
3	Sharma, Manishi, M. S. Rao, D.S. Rathore, Gopal Krishan	An integrated approach to augment the depleting ground water resource in bist- doab, region of Punjab, India	*International Journal of Earth Sciences and Engineering*	7 (01):	27-38	**2014**
4	P. Purushothaman, M. S. Rao, B. Kumar, Y. S. Rawat, Gopal Krishan, S. Gupta, S. Marwah, A. K. Bhatia, Y. B. Kaushik, M. P. Angurala and G. P. Singh	Drinking and Irrigation Water Quality in Jalandhar and Kapurthala Districts, Punjab, India: Using Hydrochemsitry	International Journal of Earth Sciences and Engineering	05, No.06	0974-5904	2012
5	P. Purushothaman, M. Someshwar Rao, Y. S. Rawat, C. P. Kumar, Gopal Krishan, T. Parveen	Evaluation of hydrogeochemistry and water quality in Bist-Doab region, Punjab, India	Environmental Earth Sciences	DOI:10.1007/s12665-013-2992-9		2013

List of Publications in Conferences

S. No.	Authors	Title of the paper	Name of the Conferences	Pages	Year
1.	P. Purushothaman, M. S. Rao, Gopal Krishan, Y. S. Rawat, C. P. Kumar	Hydrochemical and Isotopic Investigation of Groundwater Regime in Jalandhar and Kapurthala Districts, Punjab, India	International Conf. on Advances in Water Resources Development & Mangement held at PU, Chandigarh	P: 42	Oct. 23-27,2013
2.	Sharma, Manishi, M. S. Rao, D.S. Rathore, Gopal Krishan	An integrated approach to augment the depleting ground water resource in bist- doab, region of Punjab, India	International Conf. on Advances in Water Resources Development & Mangement held at PU, Chandigarh	P: 47	Oct. 23-27, 2013.
3.	Purushotaman, P,	A study on surface	International conference on	P: 1-5	25-27 July

	Rao, M.S., Rawat, Y.S., Krishan, Gopal, and Kumar, C.P.	water and groundwater interactions in Bist-Doab region, India	"Integrated Water, Waste Water & Isotope Hydrology IC-WWISH Bangalore, India		2013
4.	Krishan Gopal, Lohani, A.K., Rao, M.S. and Kumar, C.P.	Optimization of groundwater monitoring network in Bist-Doab, Punjab	International conference "India Water Week 2013- Efficient Water Management: Challenges and Opportunities" (IWW-2013) New Delhi, India	Pp: 274	08-12 April 2013
5.	Parveen Tabassum, Rao M.S., Rawat, Y.S. and Krishan Gopal	Ground water crisis and remediation in Punjab.	1st International Conference on Interdisciplinary Engineering & Sustainable Management Sciences at Madurai, India	Pp: 101	22-23 February, 2013
6.	M.S. Rao, P. Purushothaman, Y.S. Rawat, and C. P. Kumar	Use of isotopic techniques in identification of groundwater recharge sources: Some case studies from India.	National Seminar on Hydrology "HYDROCARE 2012@GRI-DU" with special colloquium on "Geomatics in Water Resources"	Pp: 59-60	11-12 December, 2012
7.	Kumari, Saroj, Rao, M.S, Krishan, Gopal, Lal, Shyam and Singh, Padma.	Impact of recharge sources on isotopic composition and microbiological quality of groundwater- a case study from Punjab, India.	International SWAT conference at IIT-Delhi.	Pp. 22	July 18-20, 2012
8.	Anju Pant, M.S. Rao, Y.S. Rawat, P. Purushothaman and Gopal Krishan	Assessment of groundwater resources and quality in Bist Doab region, Punjab, India	International SWAT Conference at IIT-Delhi.	Pp: 69	18- 20 July 2012
9.	P. Purushothaman, M.S. Rao, Y.S. Rawat	Mapping the groundwater flow regime in bistdaob region, punjab, india using environmental tritium.	National Seminar on Applications of Isotopes and Radiation Technology for Societal Benefits (AIRTS- 2012) Bangalore, India		21- 23 June, 2012
10.	M.S. Rao, P. Purushothaman, Y.S. Rawat	Potential Application of Nuclear Techniques in Water Resource Sector- A Status and Future Prospects	India Water Week 2012 at Delhi		10-14 April, 2012
11.	P. Purushothaman, M.S. Rao, Bhishm Kumar, Y.S. Rawat, GopalKrishan	Stable Isotopic Characterisation of Groundwaters in Bist-Doab Region, Punjab.	National Conference in Recent Advanced Techniques in Civil Engineering "RACE-2011." Banaras Hindu University, India		14-16 Oct 2011
12.	P. Purushothaman, M.S. Rao, Bhishm Kumar, GopalKrishan, Y.S. Rawat,Sushil Gupta,	Identification of the source of salinity in the groundwater of BIST-DOAB region, Punjab- using Electrical	Regional Workshop on Ground water Salinity: Assessment, Management and Mitigation CSSRI, Karnal, Haryana		March 18-19, 2011

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13.	M.S. Rao, P. Purushothaman, Bhishm Kumar, Gopal Krishan, Y.S. Rawat, Vishal Gupta and P. Garg	Isotopic Characteristics of waters of Bist- Doab and their Hydrological Significance	Regional Workshop in Proceedings Water Availability and Management in Punjab at Chandigarh, India	Pp: 1-6	13-15 Dec. 2010
14.	Rao, M.S.; Gupta, A.K., Krishan, Gopal; Kumar, Bhishm. Rawat, Y. S., Marwah, Sanjay and Gupta, Sushil	Assessment of water quality in groundwater in Bist-Doab region.	Regional workshop on Water Availability and Management in Punjab (WAMIP-2010) in PU, Chandigarh	Pp: 59-65	13-15 Dec. 2010
15.	M.S.Rao, Bhishm Kumar, P. Purushothaman, Gopal Krishan	Isotopic analysis of Nitrates: Methodological and Applications in pollution studies	5th International Nitrogen Conference at New Delhi, India	Pp: 619	3- 7 Dec. 2010
16.	Rao, M.S.; Kumar, Bhishm; Kumar, Sudhir; Krishan, G.; Rawat, Y. S.; Gupta, A.K.; Gupta, Vishal; Garg, Pankaj; and Verma, S.K.	Impact of Land-Use Change on Groundwater Resources: A Case Study from Beas-Satluj Interfluve Region of Punjab	AOGS 2010 at Hyderabad, India		5-9 July 2010

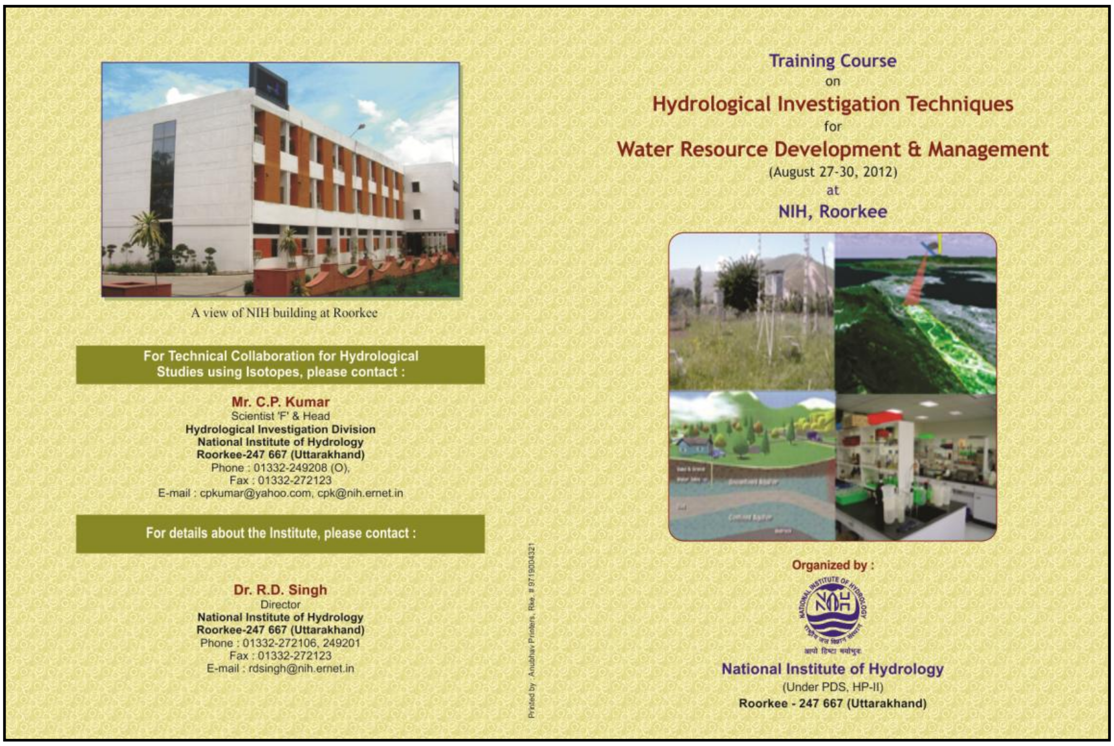

Photo: Training Course

Photo: Awareness Programmes