केंद्रीय भूमि जल बोर्ड,

जल संसाधन नदी विकास और गंगा संरक्षण विभाग,

जल शक्ति मंत्रालय,भारत सरकार

Central Ground Water Board,
Department of Water Resources, River Development and Ganga Rejuvenation,
Ministry of Jal Shakti, Government of India

जलभृत मानचित्रण और प्रबंधन योजना

बिलासपुर, हमीरपुर और सोलन जिला (भाग)

हिमाचल प्रदेश

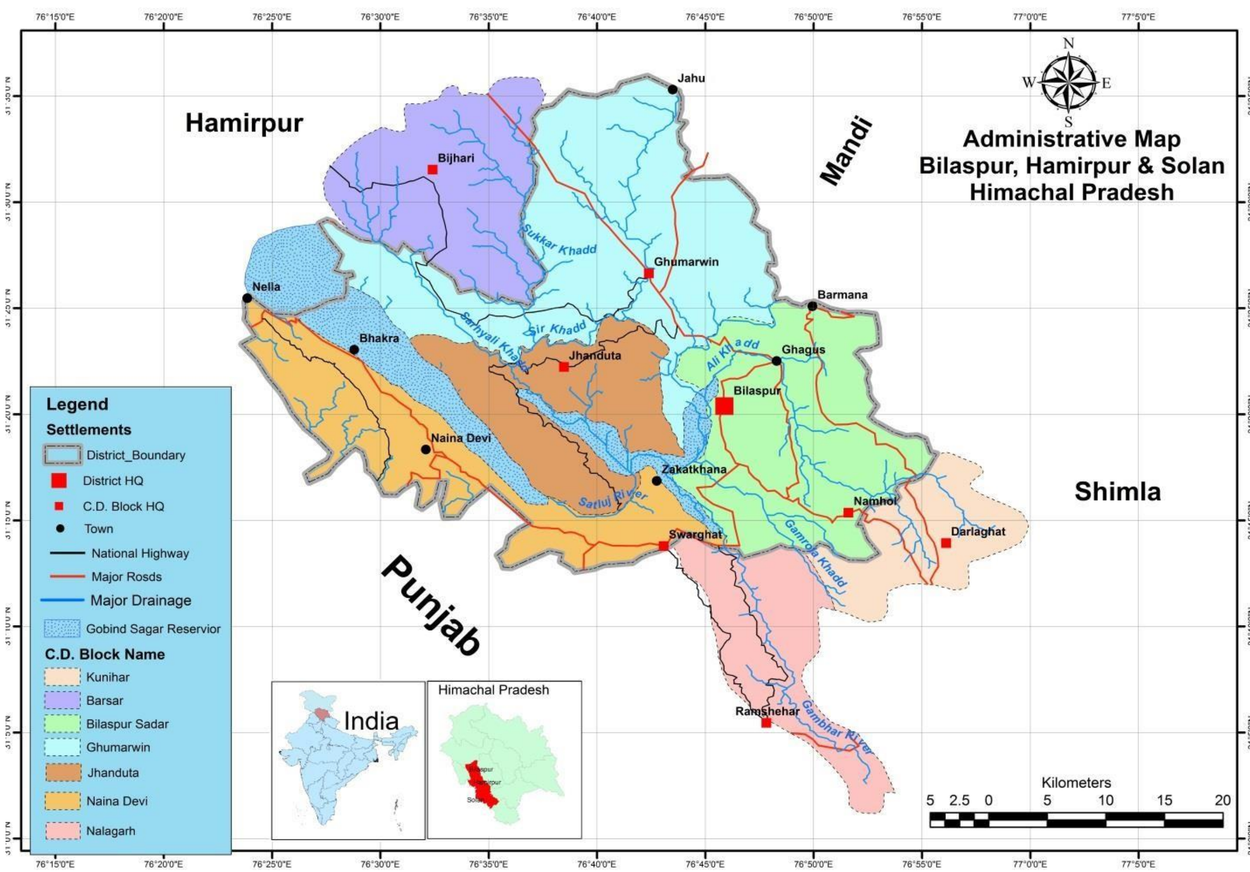
Aquifer Mapping & Management Plan
Bilaspur, Hamirpur & Solan Districts (Parts)
Himachal Pradesh

उत्तरी हिमालयन क्षेत्र, धर्मशाला

Northern Himalayan Region, Dharamshala

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, RD & GR
CENTRAL GROUND WATER BOARD,

Aquifer Mapping & Management Plan Bilaspur, Hamirpur & Solan Districts (Parts), Himachal Pradesh



Administrative division of the study area

Northern Himalayan Region, Dharamshala
2020

CONTENTS

AQUIFER MAPPING AND MANAGEMENT PLAN OF Bilaspur, Hamirpur, Solan Districts (Parts), Himachal Pradesh

1. INTRODUCTION

Aquifer mapping is a process wherein a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses are applied to characterize the quantity, quality and sustainability of ground water in aquifers. There has been a paradigm shift from "groundwater development" to "groundwater management". An accurate and comprehensive micro-level picture of groundwater in India through aquifer mapping in different hydrogeological settings will enable robust groundwater management plans at the appropriate scale to be devised and implemented for this common-pool resource. This will help achieving drinking water security, improved irrigation facility and sustainability in water resources development in large parts of rural India, and many parts of urban India as well. The aquifer mapping program is important for planning suitable adaptation strategies to meet climate change also. Thus the crux of NAQUIM is not merely mapping, but reaching the goal – that of ground water management through community participation.

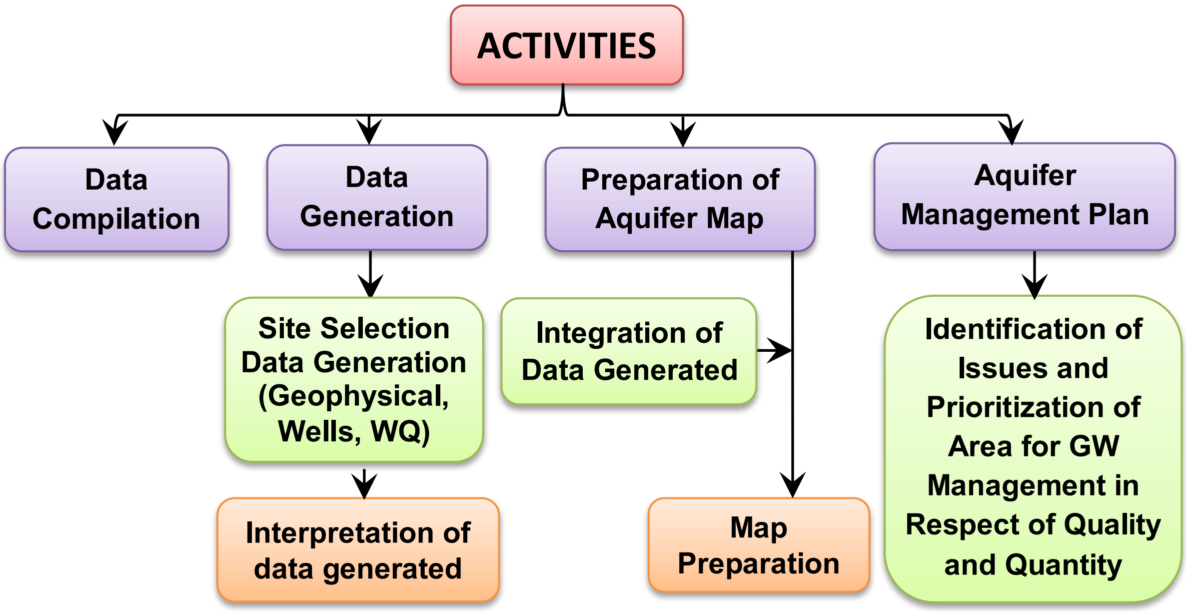
1.1 Objectives

The primary objective of the Aquifer Mapping Exercise can be summed up as "Know your Aquifer, Manage your Aquifer". Demystification of Science and thereby involvement of stake holders is the essence of the entire project. The involvement and participation of the community will infuse a sense of ownership amongst the stakeholders. This is an activity where the Government and the Community work in tandem. Greater the harmony between the two, greater will be the chances of successful implementation and achievement of the goals of the Project. As per the Report of the Working Group on Sustainable Ground Water Management, "It is imperative to design an aquifer mapping programme with a clear-cut groundwater management purpose" This will ensure that aquifer mapping does not remain an academic exercise and that it will seamlessly flow into a participatory groundwater management programme. The aquifer mapping approach can help integrate ground water availability with ground water accessibility and quality aspects.

With these aims, Aquifer Mapping Study is carried out in parts of Bilaspur, Hamirpur and Solan Districts of Himachal Pradesh under the Annual Action Programme 2016-17. These surveys are carried out to integrate the information on the scenario of groundwater occurrence, availability and utilization in terms of quality and quantity along with exploratory drilling, monitoring of water levels with quality, spring monitoring (discharge and quality), pumping tests, infiltration tests, geophysical surveys etc. Development of aquifer mapping at the appropriate scale and formulation of sustainable management plan will help in achieving drinking water security, improving the sustainability of water resources development through springs. It will also result in better management of vulnerable areas. During this study, 56 key observation points, both Dug wells (34 Nos.) and springs (22 Nos.) were established. Subsequently, all the available data on ground water from the earlier studies are compiled and integrated with these studies to bring out the ground water scenario, lateral and vertical characteristics of the aquifers and better management plan of ground water in a scientific manner.

1.2 Methodology

Various activities of NAQUIM are as follows:



1.3 Location, Extent and Accessibility

The study area forms an elongated oval shape and cover Bilaspur districts and parts of Hamirpur and Solan Districts. The total area covered under study is 1522 Sq km. and covers South central part of the state extending from SE to NW direction. The study area comprises 91% geographical area of Bilaspur district (1066.33/1167 Sq. Km), around 18.5% area of Hamirpur districts (205.94/1118 sq. km) and around 13.19% area of Solan district (255.45/1936 sq. km). The areal extent of the areas is between Northern latitudes of 31°35' to 31°01' and eastern longitudes of 76°25' to 76°59' which falls in the Survey of India Toposheet no. 53 A/06, A/07, A/10, A/11, A/12, A/14, A/115 and 53 A/16. The area is delimited between Bhakra Dam in the west, Punjab state boundary in south west, Block Boundary of Nalagarh and Ghumarwin bloc in south and north direction respectively and Kunihar in east direction. All the area encompasses the Shiwalik hills throughout the area. The area is well connected by tar roads and is traversed by NH 20 and NH 88 in east-west and north south direction through heart of the area. Bilaspur, a district headquarter is located in the central region of the study area. Administrative map and other important places and features are given in Base map. (Fig 1)

1.4 Administrative Divisions and Demographic Particulars

Administratively, area comprises of three districts in parts viz. Bilaspur, Hamirpur & Solan. The study area comprises of 7 Blocks viz., Bijhari, Bilaspur Sadar, Ghumarwin, Jhanduta, Naina Devi, Nalagarh, Kunihar. Administrative divisions are shown in the Fig.1. The study area boundary is hydrogeological in nature and does not coincide with administrative boundary of the blocks/tehsil and districts. The study encompasses the catchment areas of Sutlej River and its tributaries (refer watershed map). During compilation of the demographic data on the study area, the data has been compiled on the block boundary basis as the basic requirement of the study is to analyse trends and patterns. The administrative divisions of the study area are given in fig-1

Socio-Economic Conditions: The study area is moderately populated. The total population in 7 blocks is 718150 as per Census 2011. The average density of the study area is 290 persons per sq. km which is significantly higher than the state average of 123 persons per sq. km. The area shows a population growth of 1.02 % per year. (Decadal growth: 10.2% approx.). Around 24% of the population in area belongs to scheduled cast community and around 4% belongs to the scheduled tribe community. Majority of the population lives in villages. The work force constitutes about 55% of the total population. Agriculture is the backbone of the area's economy.

Table 1: Demographical details of the area

Sr. No	District	Block	Area Sq. Km	Total Population	Male	Female	SC	ST	Density (psqkm)	Total Worker
1	Hamirpur	Bijhari	273.62	91724	43496	48228	21637	362	335	46099
2	Bilaspur	Bilaspur Sadar	276.83	94827	48519	46308	24188	482	354	43412
3		Ghumarwin	279.89	127330	62596	64734	31066	1395	455	69425
4		Jhanduta	307.52	89190	44916	44274	25278	2500	290	56912
5		Naina Devi	245.05	45480	23622	21858	12766	5957	186	25942
6	Solan	Kunihar	393	90631	45954	44677	25733	359	231	54537
7		Nalagarh	703.8	178968	94614	84354	44558	20467	892	100919
			Total	**718150**	**363717**	**354433**	**185226**	**31522**	**290**	**397246**

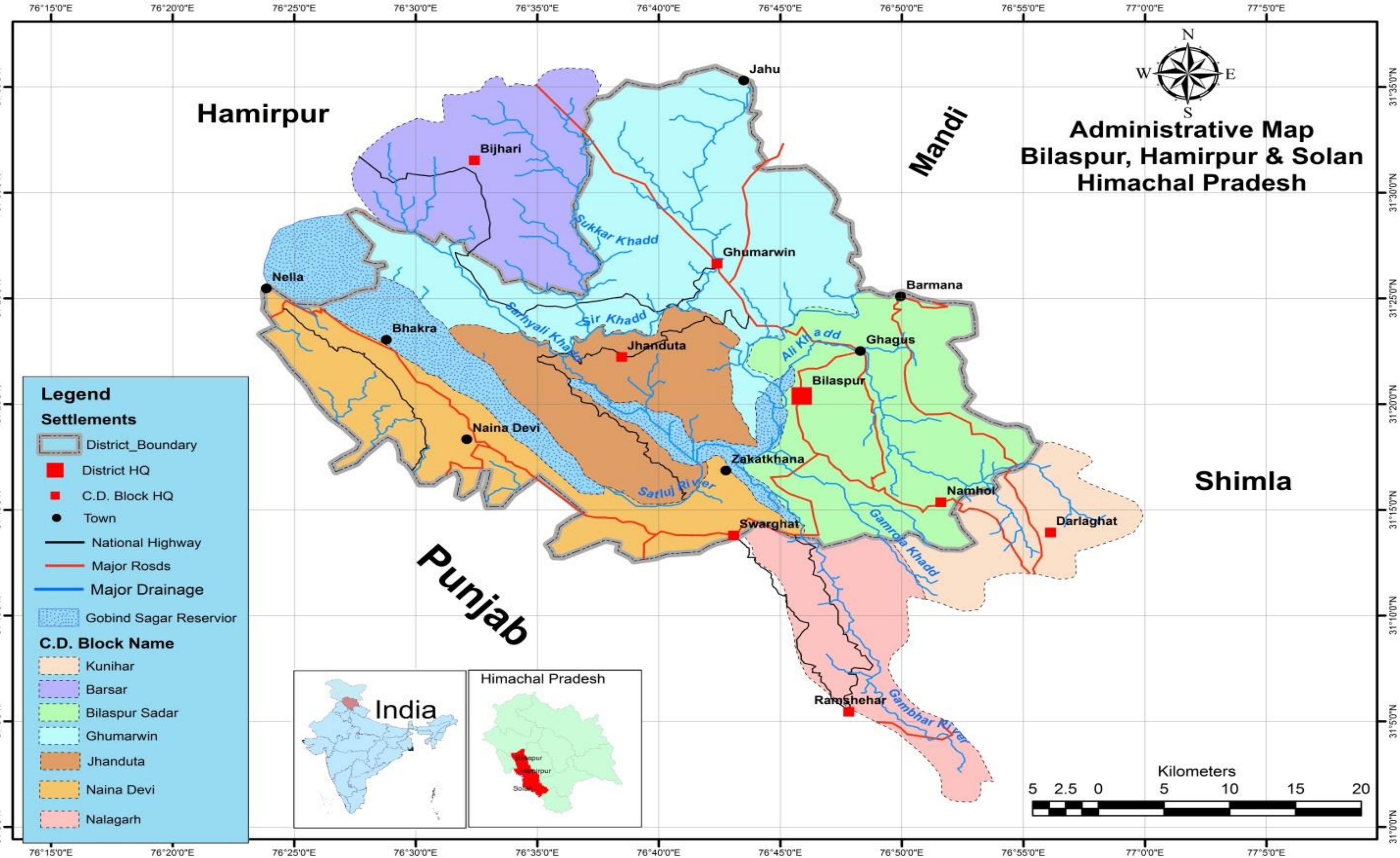


Fig. 1: Administrative division of the study area.

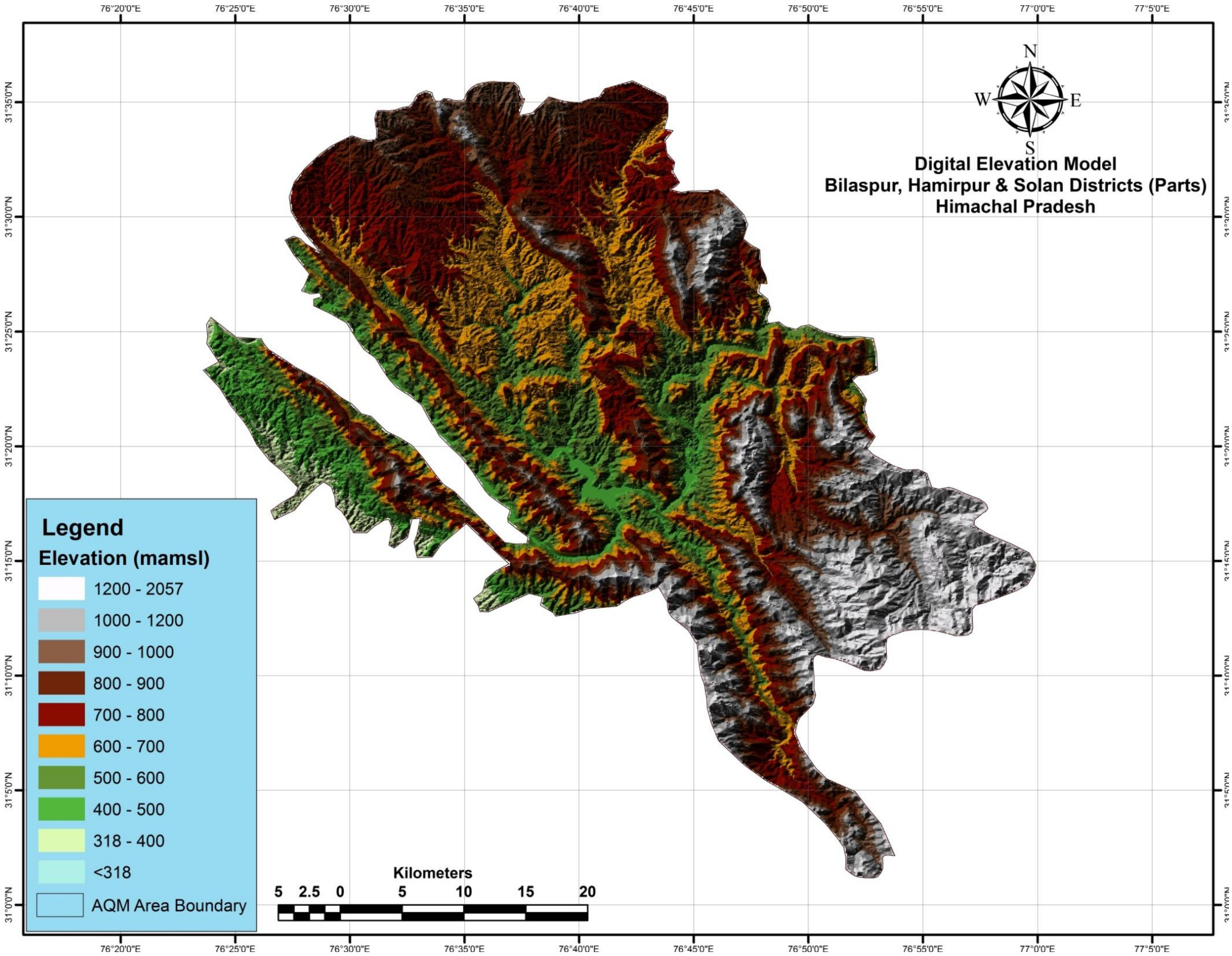


Fig 2: Digital Elevation Map of the study area.

1.5 Land Use: The topography of the study area is hilly having slopes ranging from less than 5% in some areas to more than 60%. Having a large part of the utilizable land rendered unusable due to slope, a relatively large population is dependent on small lands. Majority of the farmers are marginal and small having average land holding less than 2 hectares. The land use / land cover map was prepared using Survey of India topographic sheets and IRS P6 LISS – III satellite imagery. The Land use and land cover features in the study area Dense Forest, Land with scrub, Plantation and River. Similarly Forest Area map was prepared with the help of processed satellite imagery; the same has been shown in **Fig. 2**. The breakup of land use is give in table 2 & 2.1 below

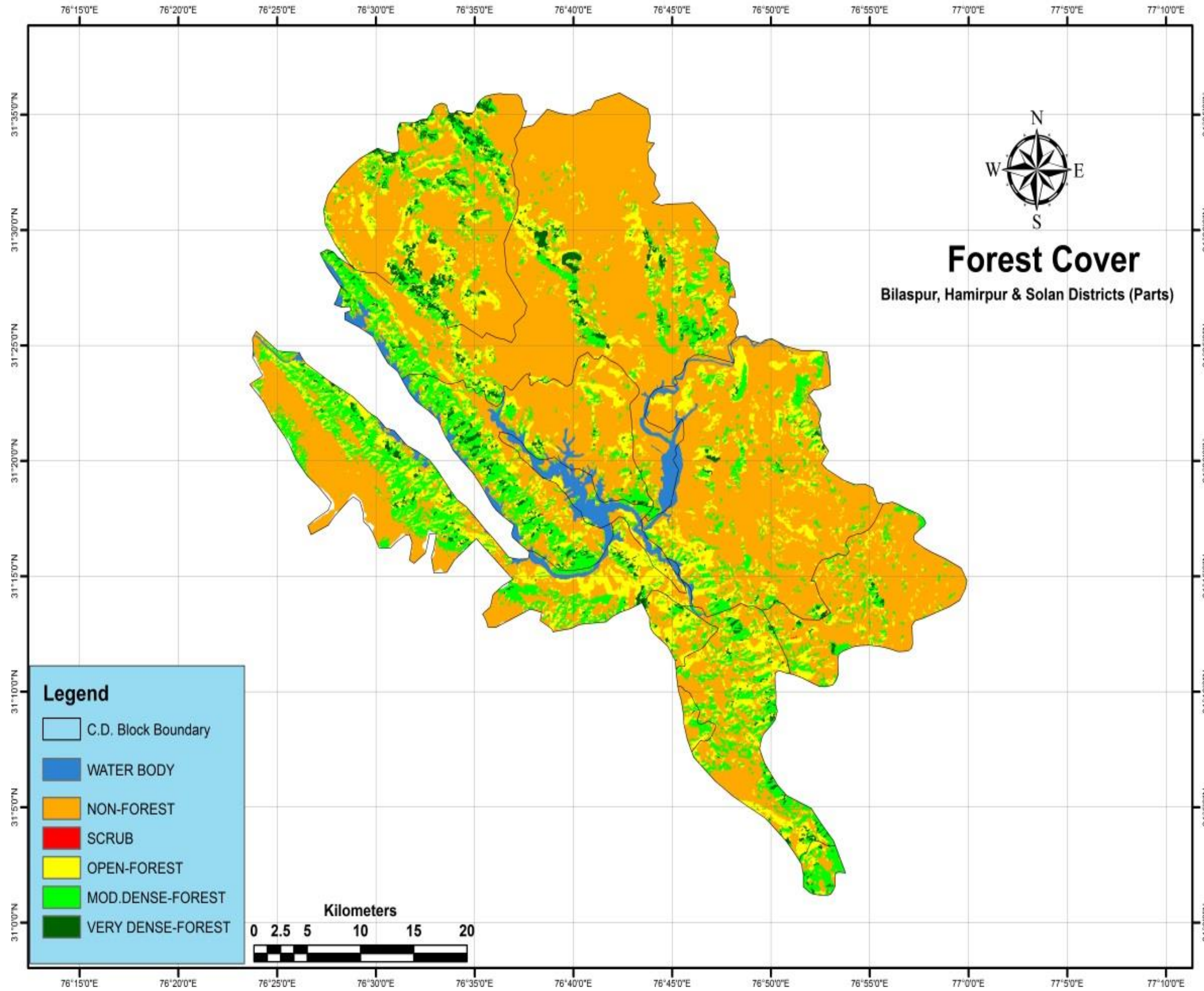


Fig-3: Forest cover map of the study area.

Table 2: Category wise Land use/Land Cover in the study area (contd..)							
Sr. No.	**District**	**Block**	**Forest**	**Land Put to Non-Agri Use**	**Barren Land**	**Permanent Pastures**	**Misc. Tree & Grooves**
1	Hamirpur	Bijhari	8876	2624	1432	1648	0
2	Bilaspur	Bilaspur Sadar	1922	3805	515	10837	13
3		Ghumarwin	3674	2456	1523	6455	95
4		Jhanduta	5364	6626	1002	8795	8
5		Naina Devi	3766	2858	663	12298	17
6	Solan	Kunihar	6941	1406	1253	19127	37
7		Nalagarh	2733	3898	1925	6720	125
		Total	**33276**	**23673**	**8313**	**65880**	**295**
Source: District Revenue Officer of respective districts & District Statistical Abstracts of respective districts for the Year-2017-18. (Figures in Hectares)							

Table 2.1: Category wise Land use/Land Cover in the study area										
Sr. No.	**District**	**Block**	**Cultivable Wasteland**	**Other Fallow**	**Current Fallow**	**Net Sown Area**	**Area sown more than once**	**Gross Sown**	**Net Sown/ Total Sown**
1	Hamirpur	Bijhari	2876	1521	1585	6907	6034	12947	53.1
2	Bilaspur	Bilaspur Sadar	1930	133	1438	7237	7860	13218	54.8
3		Ghumarwin	1619	242	505	11720	11393	18777	62.4
4		Jhanduta	1744	232	302	6964	6846	13816	50.4
5		Naina Devi	836	154	205	3430	3324	7274	47.2
6	Solan	Kunihar	1290	278	221	8850	7287	16137	54.8
7		Nalagarh	5410	712	372	11131	6784	17915	62.1
		Total	**15705**	**3272**	**4628**	**56239**	**49528**	**100084**	**56.2**
Source: District Revenue Officer of respective districts & District Statistical Abstracts of respective districts for the Year-2017-18. (Figures in Hectares)									

1.6 Cropping patterns: Agriculture is main economic activity in the area. The net area sown is around 56239 hectares in 7 CD Blocks with 49528 hectares area sown more than once. The cropping intensity of the area is 178%. The principal crops of area are Wheat and Maize. In Khariff season in addition to Maize, Paddy, Fruits, Vegetables, Spices are also cultivated over small area. During Rabi season Wheat is principal crop along with potato, fruits, onions and fodders etc.

Table 3: Block-wise breakup of area cropped under each crop type in study area

			Rabi		Khariff		others	
Sr. No	**District**	**Block**	**Wheat**	**Vegetables**	**Maize**	**Paddy**	**Fruits**	**Fodder**
1	Hamirpur	Bijhari	6500	13	6265	4	11	94
2		Bilaspur Sadar	6636	359	6540	184	1960	125
3	Bilaspur	Ghumarwin	11154	619	10220	941	2042	48
4		Jhanduta	6500	141	6570	15	2205	188
5		Naina Devi	3210	245	3600	32	1797	25
6	Solan	Kunihar	6707	604	6429	492	164	27
7		Nalagarh	8395	540	6619	897	9	607
		Total	**49102**	**2521**	**46243**	**2565**	**8188**	**1114**

Source: District Revenue Officer of respective districts & District Statistical Abstracts of respective districts for the Year: 2017-18. (Figures in Hectares)

1.7 Irrigation

The area is blessed with sufficient Monsoon Rainfall and Non Monsoon rainfall. The irrigation sources in area are Mainly *Kuhl/* Channels, Tube wells, Dug well and lift Irrigation Schemes and one Medium irrigation Scheme. Except Changar Irrigation Scheme by IPH which provide assured irrigation to approx. 2300 hectares in area, there are no assured irrigation facilities in area. There are around 150 FIS & LIS in the area. The source wise breakup of irrigation in area is given below:

table 4: Irrigation pattern in study area

Sr. No	**District**	**Block**	**Kuhl/ Canal**	**Pond**	**Wells/TW**	**other**	**Total Irrigated**	**% of Net wn**
1	Hamirpur	Bijhari	77	0	6	33	116	1.8
2	Bilaspur	Bilaspur Sadar	1082	0	164	0	1246	17.2
3		Ghumarwin	745	0	207	196	1148	9.8
4		Jhanduta	222	0	202	0	424	6.1
5		Naina Devi	183	0	810	0	993	29.0
6	Solan	Kunihar	862	0	0	219	1081	12.2
7		Nalagarh	2261	0	2065	535	4861	43.7
		Total	**5432**	**0**	**3454**	**983**	**9869**	17.5

Source: District Revenue Officer of respective districts & District Statistical Abstracts of respective districts for the Year: 2017-18. (Figures in Hectares)

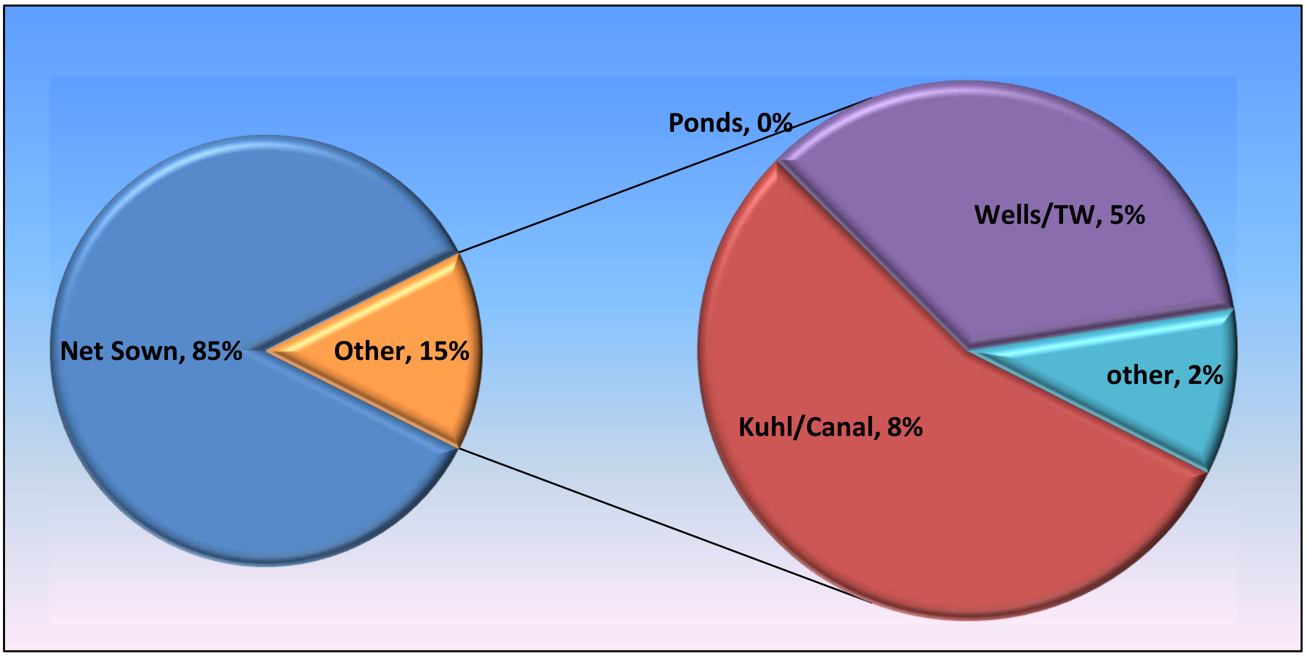


Fig : Source wise irrigation pattern in study area.

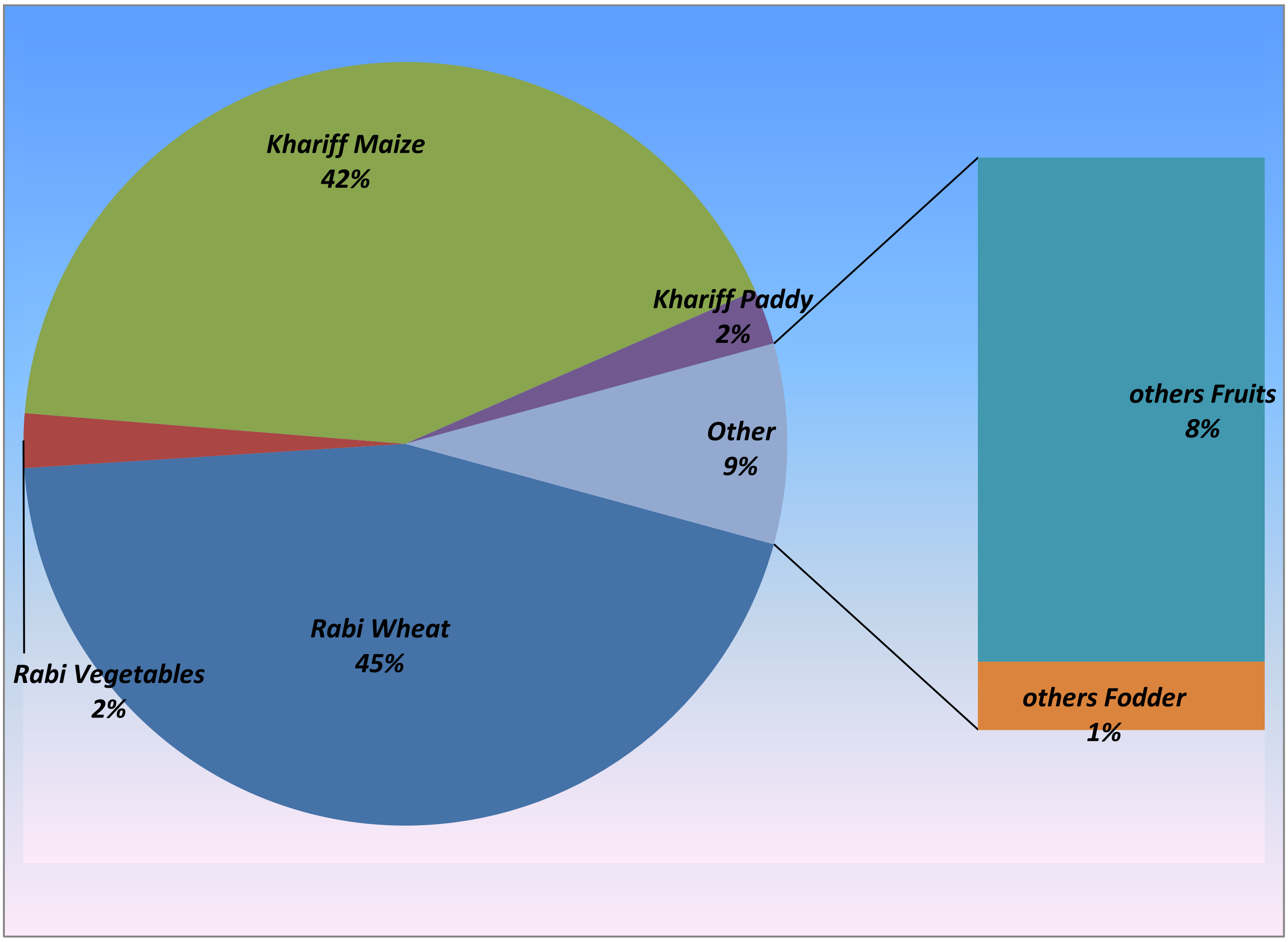


Fig 4 : Season wise major crop in the study area

1.8 Climate: Climate of the district is tropical to temperate in nature in area. Summers in Bilaspur and Hamirpur are more severe compared to Solan districts where weather remains pleasant throughout the year. Summers of Bilaspur are hot and humid; the temperature usually ranges 22°C to 38°C. in the month of April to June. The terrain is mountainous particularly in the portion in area south western of Satluj. The year may be divided into four seasons. The summers are from March to end June. The south west monsoon starts thereafter and lasts till 3rd week of September. October and November constitute the post monsoon season and the period from December to February is the cold season. The area receive more than 75% of annual rainfall during Monsoon season only. No. of rainy days vary from 60 to 65 aver the area. The Normal average rainfall for three districts is given in Table4. For preparing the Isohyet map of the area, Arithmetic mean of last 20 to 30 years rainfall has been considered for selected station in and around the area. Details are given in Table 5.

Table 5: District-wise monthly rainfall in study area. (mm)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bilaspur	34.2	65.9	60	29.8	48.4	120.9	301.9	299.8	151.3	20.6	14.3	29.6	**1176.7**
Hamirpur	36.5	70.6	57.3	33.1	49.7	153.9	352.9	374	138.2	25.8	12.7	30.3	**1335**
Solan	71.7	66.1	62.6	27.9	48.8	130.3	368.4	331.8	169.6	44.1	12.9	32	**1366.2**
Average	47.5	67.5	60.0	30.3	49.0	135.0	341.1	335.2	153.0	30.2	13.3	30.6	**1292.6**

Source: *(Source: http://www.imd.gov.in/section/hydro/distrainfall/webrain/hp/una.txt)*
All figures in millimeters.

Table 6: Weather station wise monthly rainfall in study area. (mm)

Sr. No.	District	Weather Station	Lat	Long	Mean (mm)	Median(mm)
1.	Bilaspur	Ghumarwin	31.43	76.71	1192	1058.9
2.		Berthin	31.41	76.62	1093.6	1040.8
3.	Hamirpur	Bhoranj	31.68	76.52	1315	1279.1
4.		Hamirpur	31.70	76.5	1313.2	1322.4
5.	Mandi	Sarkaghat	31.70	76.74	1540.3	1497
6.		Sundarnagar	31.53	76.9	1278.6	1302.9
7.	Solan	Arki	31.15	76.97	1065.8	1006.5
8.	Una	Una	31.48	76.28	1065.9	1025

Source: Department of Agronomy, Forages and Grassland Management, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur.

Temporal distribution of rainfall in the study areas: The month wise rainfall in study area can be summarized as:

- **74% of total annual rainfall occurs during Monsoon Season only (June to September)**
- **Average no. of rainy days (days having rainfall more than 2.5mm in 24 hours) in year are 65.**
- **965 mm rainfall (75% of annual rainfall) occurs over 42 days.**

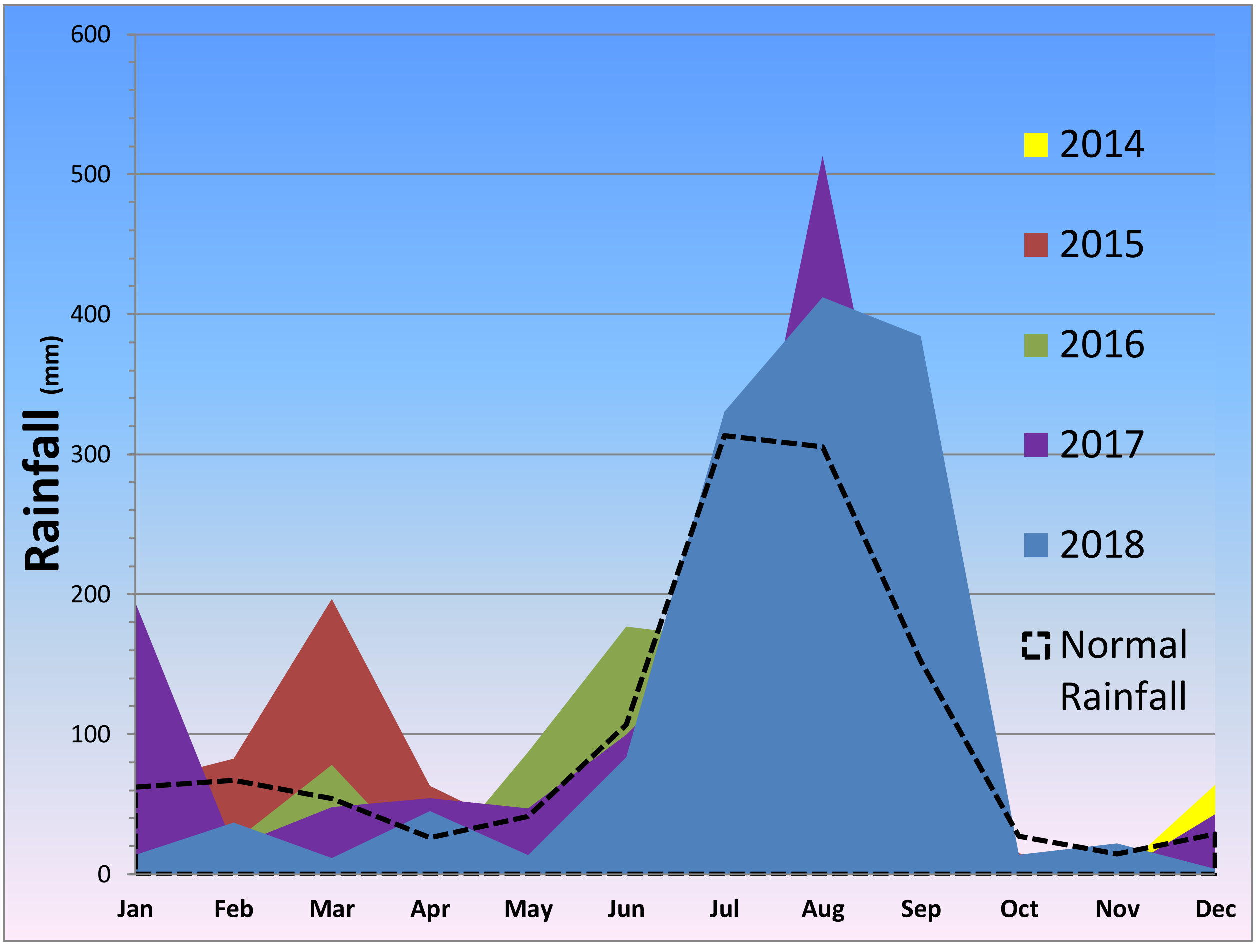


Fig 5: Temporal Distribution of Rainfall in Study Area

1.9 Physiography

The area is entirely hilly and located at an altitude ranging between 318 metres above the mean sea level to 2057 mamsl. It comprises several sub-mountains (Dhars) and of which Naina Devi ki Dhar, Kot ki Dhar, Ratanpur Dhar, Bahadurpur Dhar, Chhaiawan Dhar, Dangwil Dhar, Bandla Dhar, Tuini Dhar, Jhanjhiar Dhar and Sariun Dhar is important. The Satluj is the main river which enters the study area from the east near Barmana in Bilaspur district and after flowing for about 90 kms, it crossing over the district boundary of Bilaspur, enters the State of Punjab. Several tributaries like Sir, Sukar, Ali, Gambhar and Sarhyali join it at different places in the study area. The whole study area is verdant and fertile, bounded by low hills, forests, grazing lands, rivulets and streams. Geomorphology

The geomorphological map was interpreted from survey of India topographic sheets and IRS P6 LISS - IV satellite imagery. The geomorphic units represented in the study area are Structural hills and river alluvium shown in fig 4.

Hills: The area is entirely hilly and located at an altitude ranging between 318 metres and 2057 metres above the mean sea level. Bahadurpur Dhar attains a maximum height of 1,879 metres in this region. The region has many low hill ranges known as Dhars. These are Dhar Naina Devi, Dhar Kot, Dhar Tuini, Dhar Bandla, Dhar Jhinjiar, Dhar Ratanpur and Dhar Bahadurpur.

Valleys: The hill system just described has given rise to the formation of various smaller or bigger vales and dales as also to the watersheds of river or streamlets. Nevertheless whatever smaller or bigger valleys have been formed are comparatively, especially in their extremities, more fertile, better cultivated and more populated than the summits, shoulders and sides of the hills.

1.10 Drainage: Satluj River is the only river which passes through the area. It enters the study area near Barmana in Bilaspur in the north-east part of the study area. Principal tributaries that join it from the south-east are Ali, Gamrola and Gambhar streams. On the other bank i.e. from the north-west, Moni and Seer streams are its tributaries. The Satluj is joined by several tributaries from both sides. The main three tributaries are Ali Khad, Gamrola khad and Seer had. The length of Ali khad is about 26 kms. It rises in the Shimla district and after passing through Bahadurpur Dhar joins the river Satluj at Bilaspur. Its water is utilized for irrigation and running gharats at various places. Gamrola khad also rises in the Shimla district and after draining the Ratanpur Dhar joins the river about 5 kms. from Bilaspur town. Seer Khad takes its origin at Awah Devi 10 kms. from Sarkaghat in Mandi district. After draining Kot ki Dhar and a greater portion of Ghumarwin tehsil it joins Satluj river at village Serimatla 15 kms. from Bilaspur town. Two other khads Sukar and Saryali rise in the Hamirpur district and join this khad at village Balgar after draining the western portion of the study area. Moni khad and Gambhar Khad are tributaries of the river. Moni khad chiefly flows in Mandi district and join the river at a place in Mandi. Gambhar khad rises in Solan district. The river bed is deep and is not used for irrigation. The major drainage of the area is depicted in **Fig 5**

1.11 Soil Types

For the preparation of the soil map, the soil atlas of the Himachal Pradesh, prepared by C.G.W.B. Northern Himalayan Region is used as the primary source and then updated with satellite imagery **(fig 6).**

The description of soil types is available at

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf

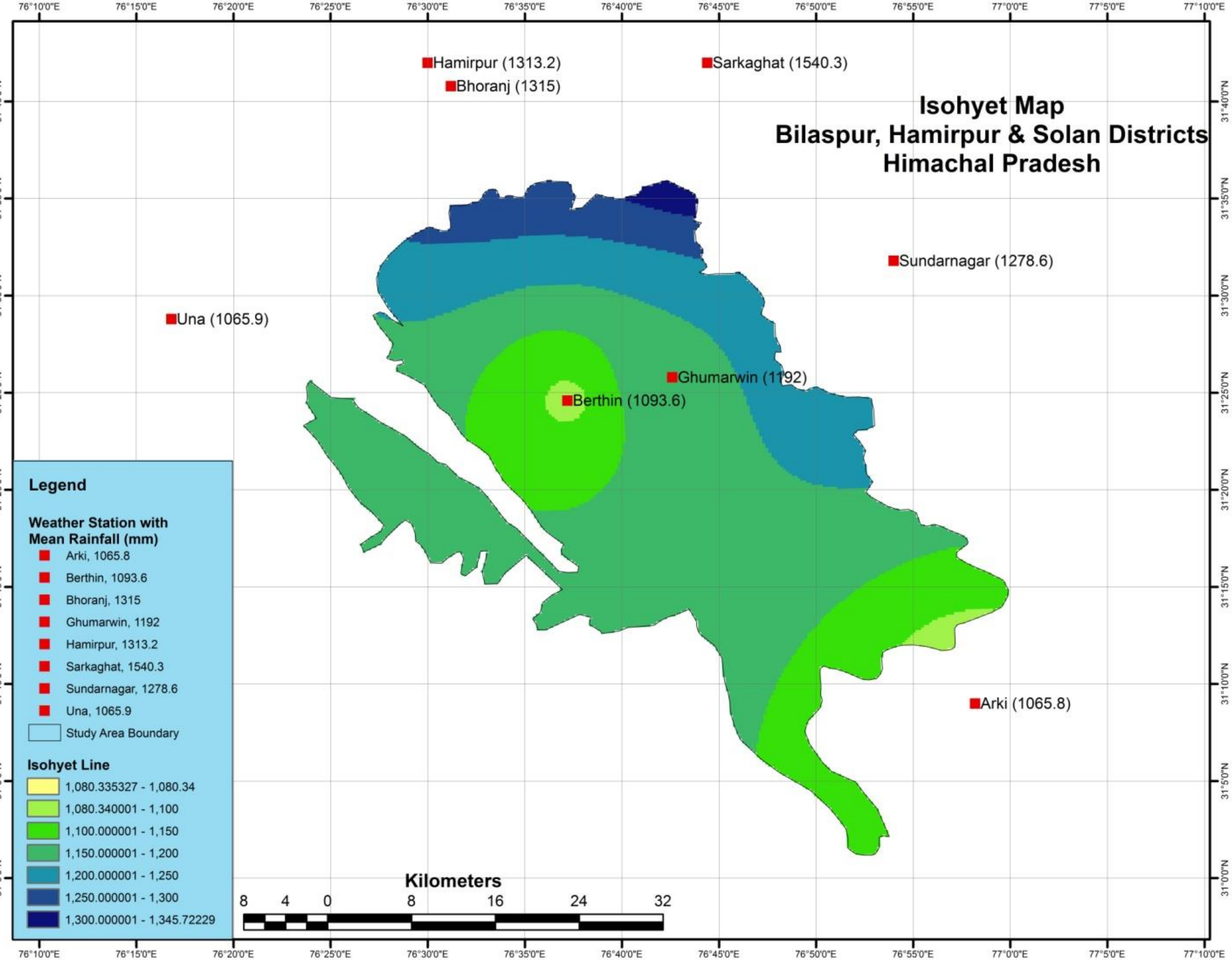


Fig 6: Rainfall Distribution in the study areas

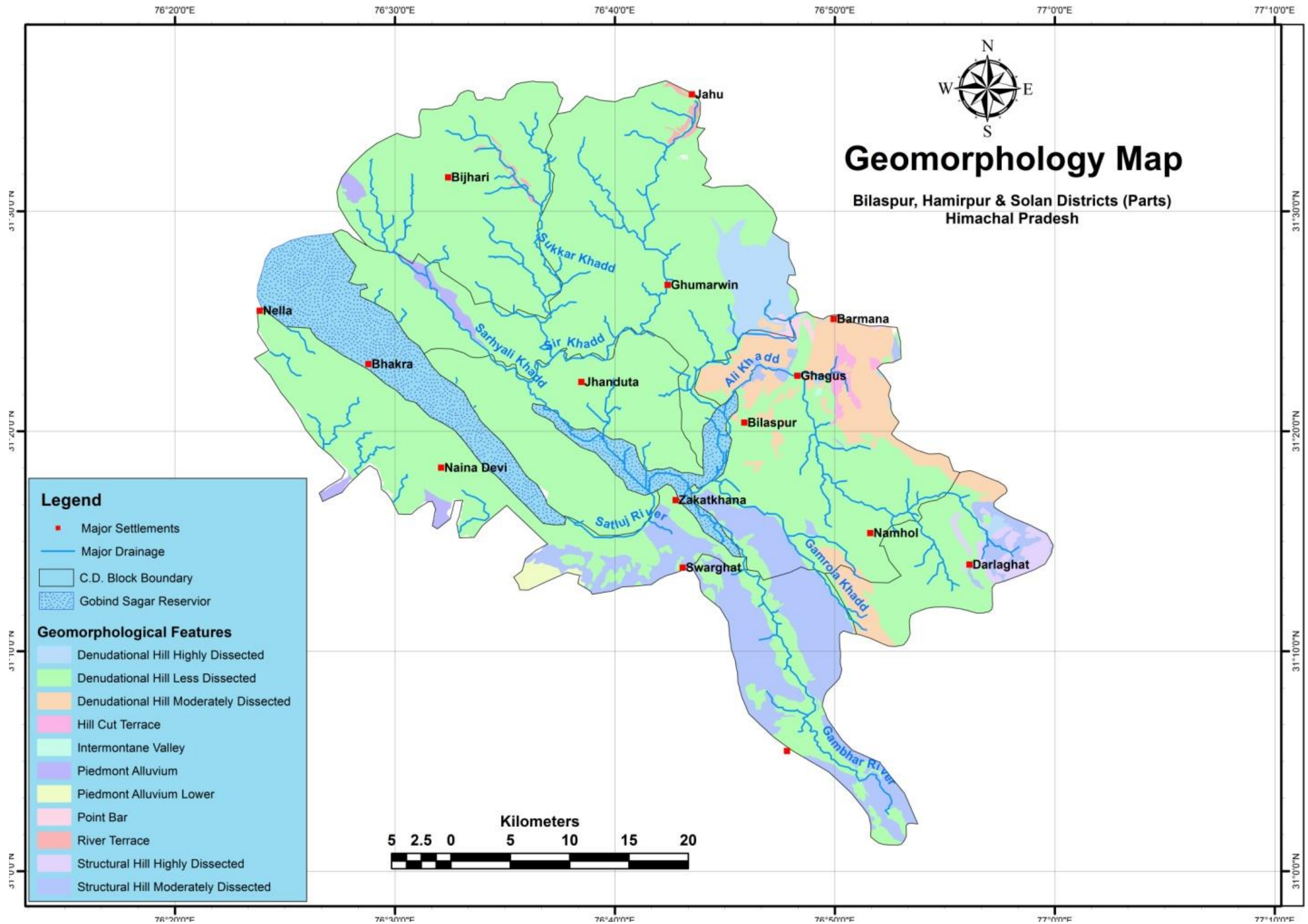


Fig 7: Geomorphological map of the study area.

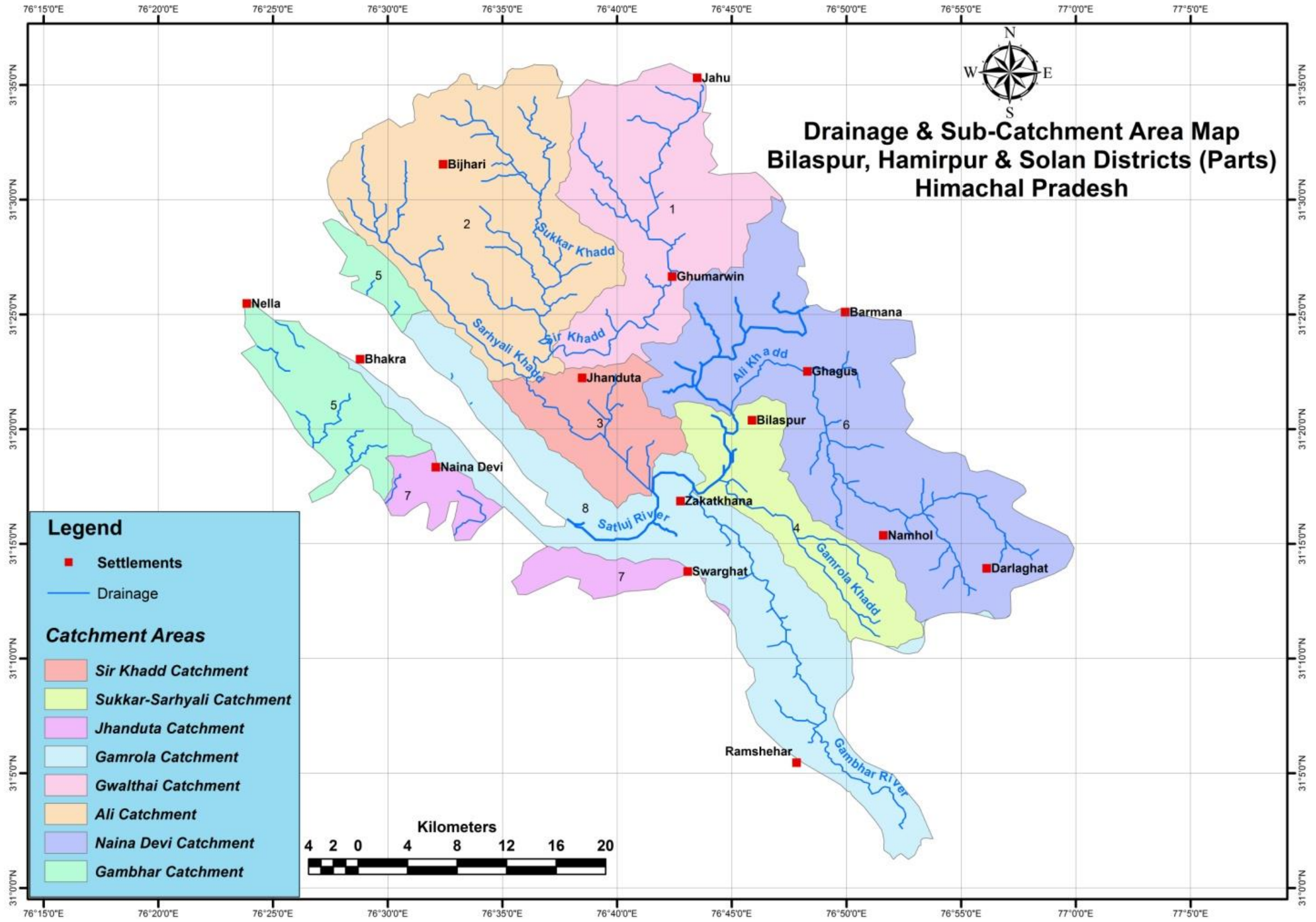


Fig 8: Major Drainage and sub catchment map of the study area

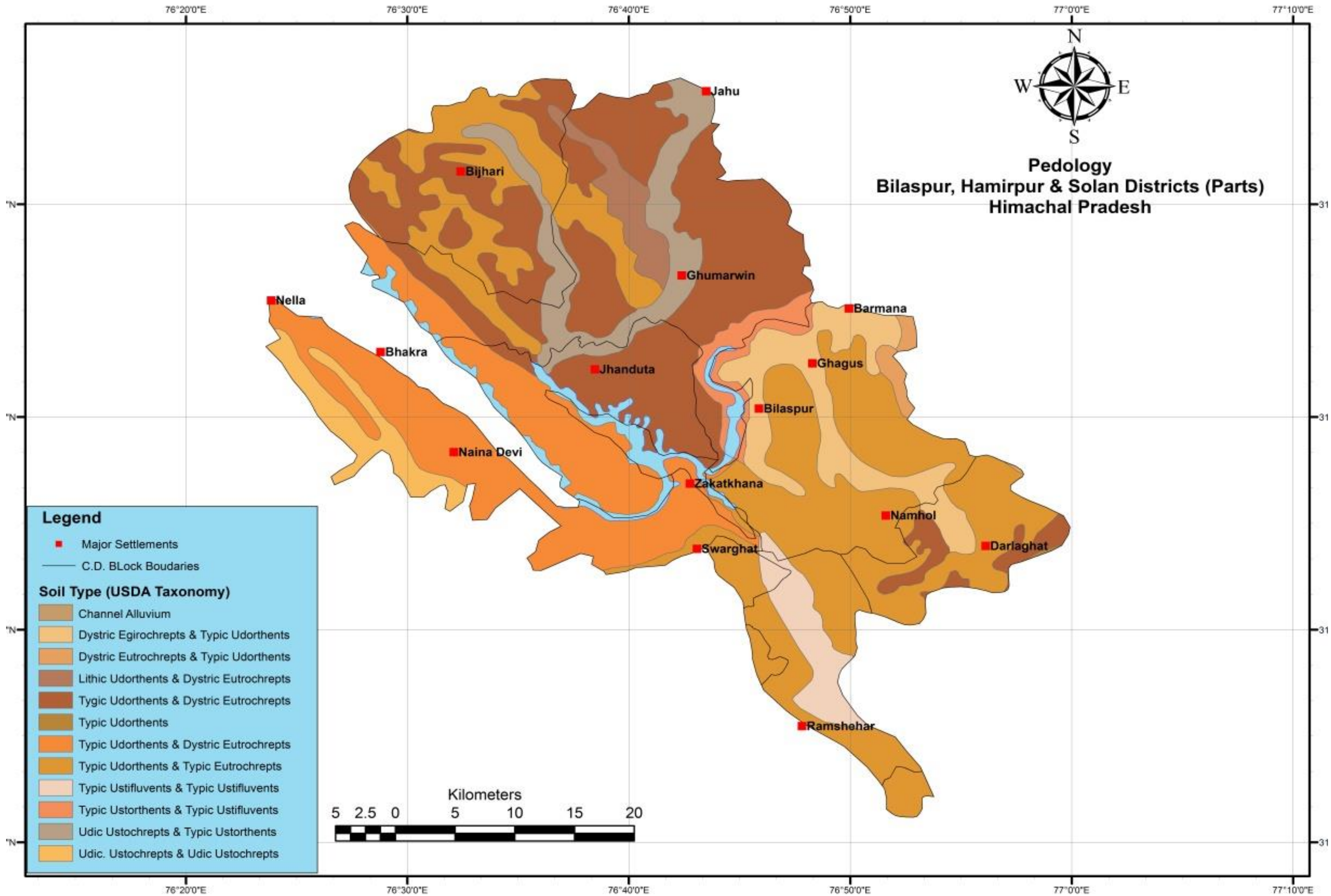


Fig 9: Pedological map of the study area

1.12 Data Adequacy & data gap analysis

The Data gap analysis was done on the basis of NAQUIM & EFC guidelines in Aquifer Mapping Study area of 1488 sq. kms in Bilaspur, Hamirpur and Solan Districts of Himachal Pradesh. The study area falls in Survey of India Topo sheets No.53 A/06, A/07, A/10, A/11, A12, A/14, A/15 and A/16 covering full or partial area of 32 quadrants (Figure -1.2 -Toposheet Index Map). The Data Gap analysis of all the attributes is given in Table 1.1.

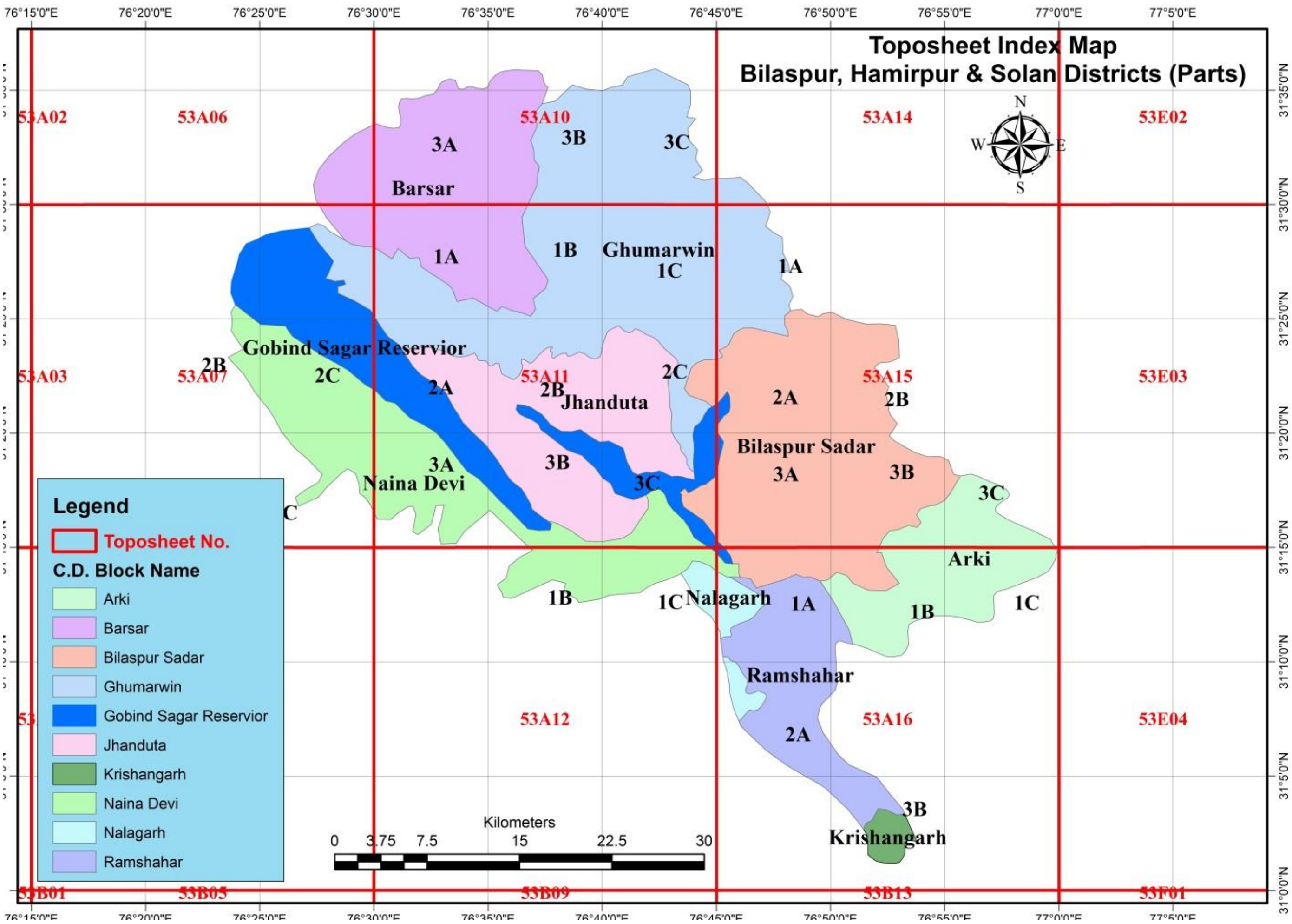


Fig.10: Topo sheet Index Map – Study Area

1.12.1 Exploratory Data

The Data gap Analysis indicates the required Ground Water Exploration sites, sets of exploratory and observation wells to ascertain the aquifer parameters, in the area as per the EFC and the existing number of sites in the area and the Gap is indicated where ever the required number of sites is higher than the existing number of sites. If the number of existing exploratory wells is higher than the required exploration sites, the gap is considered as zero and the existing structures were taken as fulfilling the norms. On the basis of data gap analysis, quadrant-wise existing and recommended sites is presented and shown as square diagram in the figure-1.3 and Table No.1.1

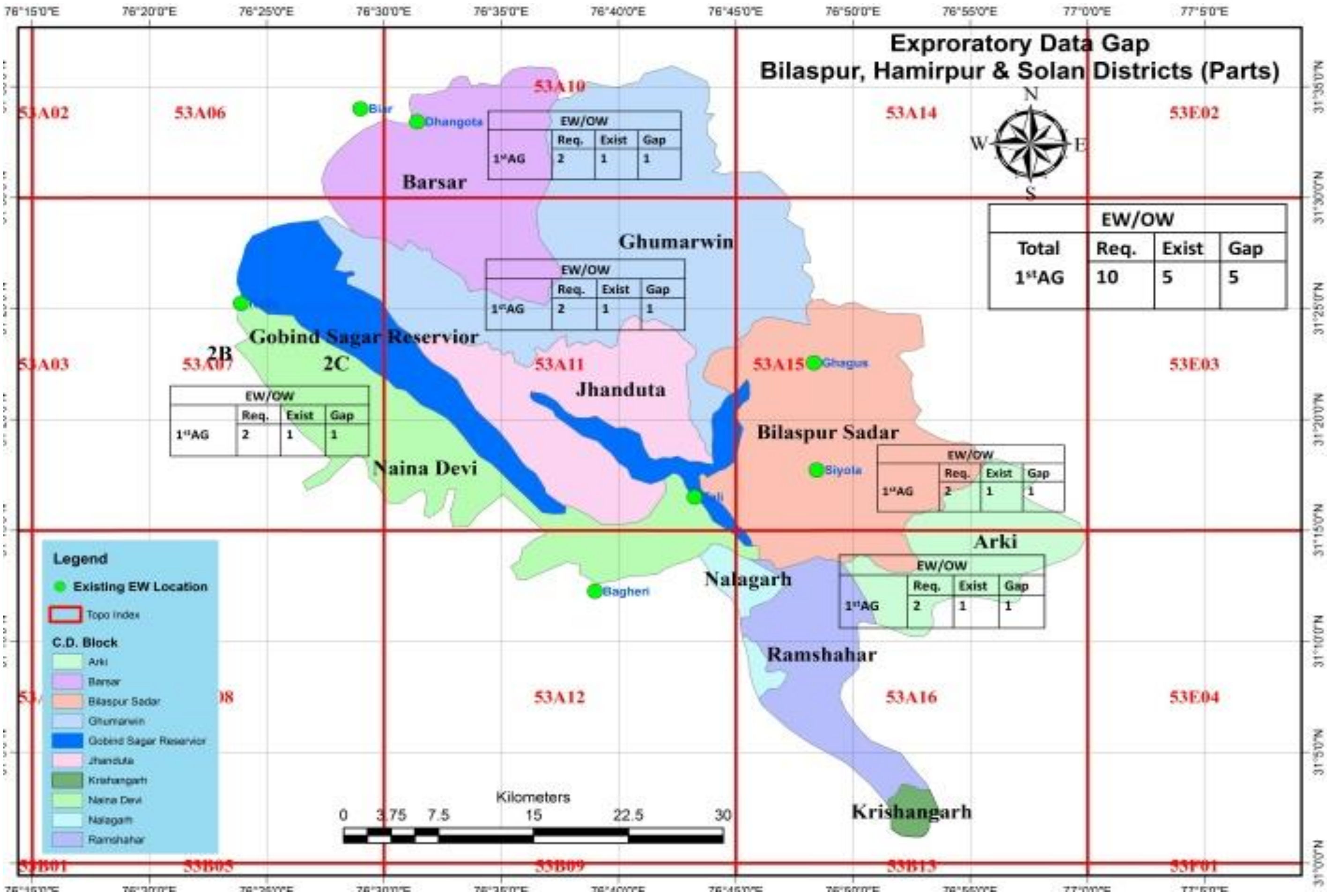


Fig.11: Exploratory Data Required Map in the study area, Bilapsur, Hamirpur & Solan Districts.

1.12.2 Geophysical Data

The Vertical Electrical Soundings (VES) is required for lithological interpretation to a depth of 300 m but due to hilly terrain the adequate spread may not be available, therefore, TEM is also recommended for lithological interpretation to a depth of about 100 m. For the study area, no VES data is available with CGWB and state agencies. On the basis of data gap analysis, the required no. of VES are 30 Nos. The quadrant-wise existing and recommended VES sites is presented and shown as square diagram in the figure -1.4.

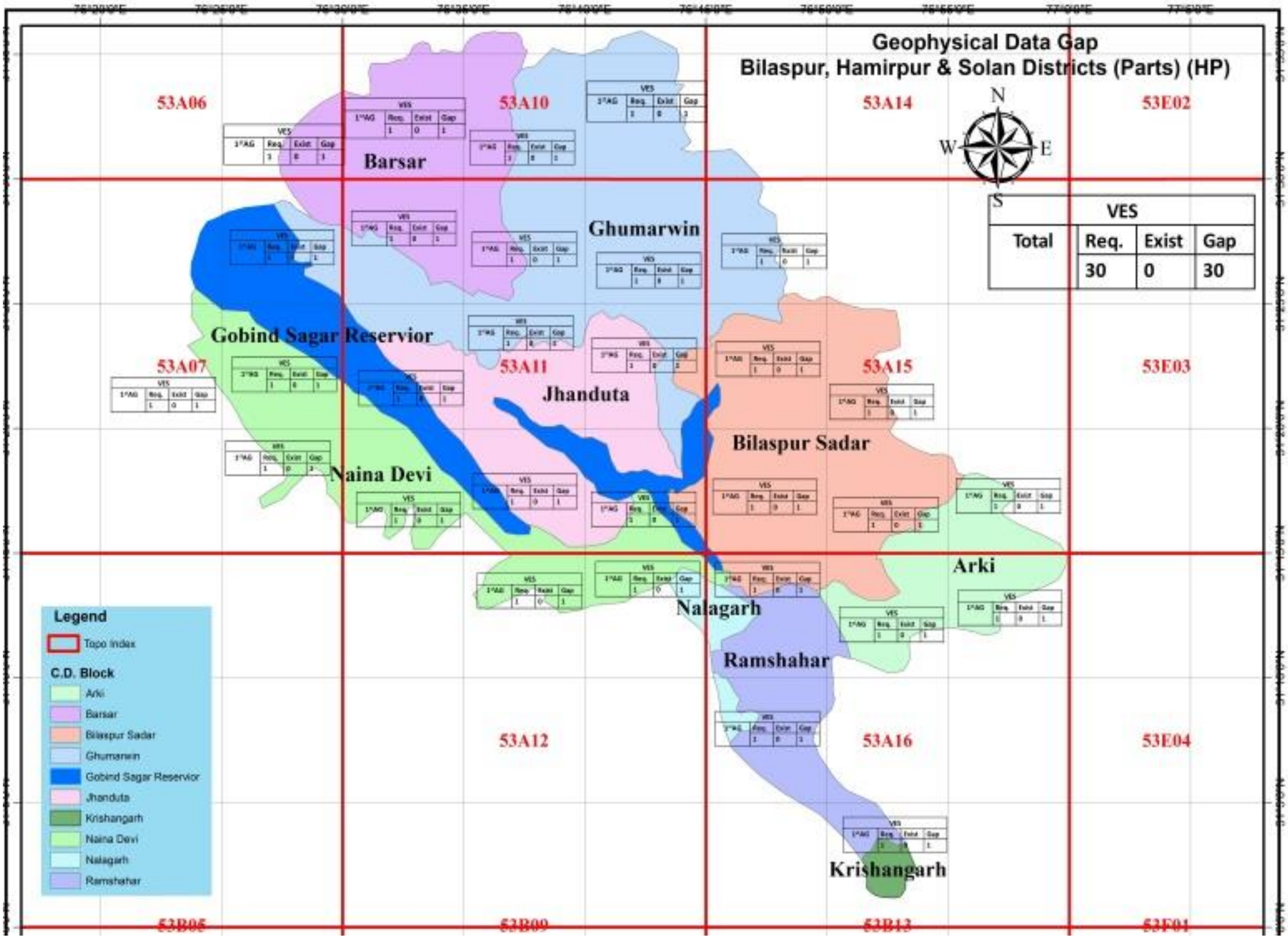


Fig.12: Data Gap Analysis of Surface Geophysical Surveys in Bilaspur, Hamirpur & Solan Districts (Parts)

1.12.3 Ground Water Monitoring Stations (GWMS)

The ground water monitoring NHS and Key well observation stations in the area tap the unconfined aquifer. Wells constructed by CGWB and hand pumps by State agencies which tap the deeper and shallow aquifers are utilised for drinking water supply instead of monitoring the piezometric head in the deeper and shallow aquifers. On the basis of data gap analysis, quadrant-wise and aquifer-wise existing and recommended ground water monitoring stations is presented and shown as square diagram in the figure -9

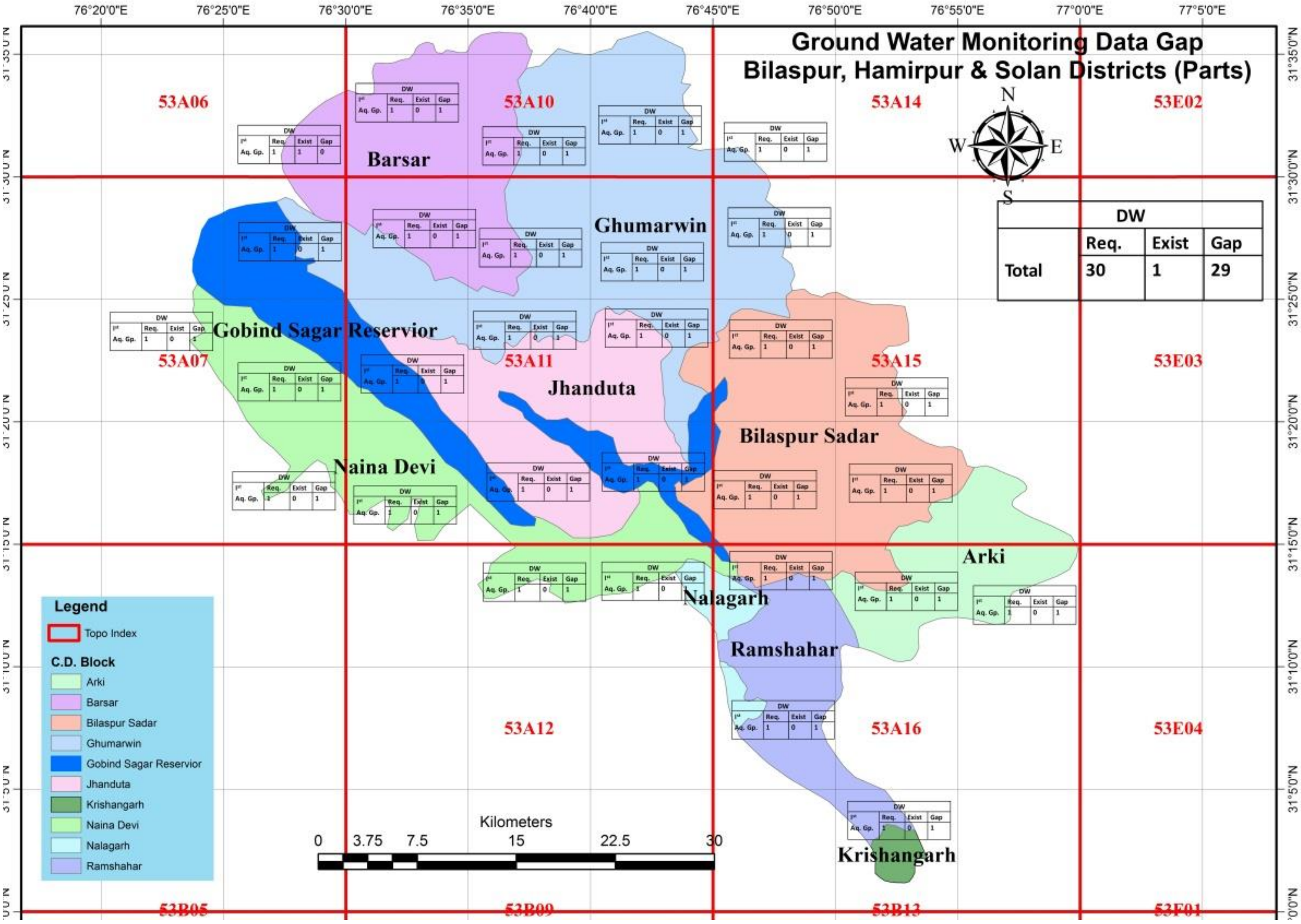


Fig.13: Data Gap Analysis for Ground Water Monitoring

1.12.4 Ground Water Quality Monitoring Stations (GWQMS)

Most of the ground water quality monitoring NHS and Key well observation stations in the area taps the unconfined aquifer. Wells constructed by CGWB and hand pumps by the state agencies tapping the deeper and shallow aquifers are utilised to monitor the quality of ground water in the deeper and shallow aquifers. On the basis of data gap analysis, 55 additional GWQMS were required and were to be monitored for two years including Key well observation stations, hand pumps, existing and proposed E/Ws, and Pzs. The quadrant-wise and aquifer-wise existing and recommended ground water quality monitoring stations are shown as square diagram in the fig 10.

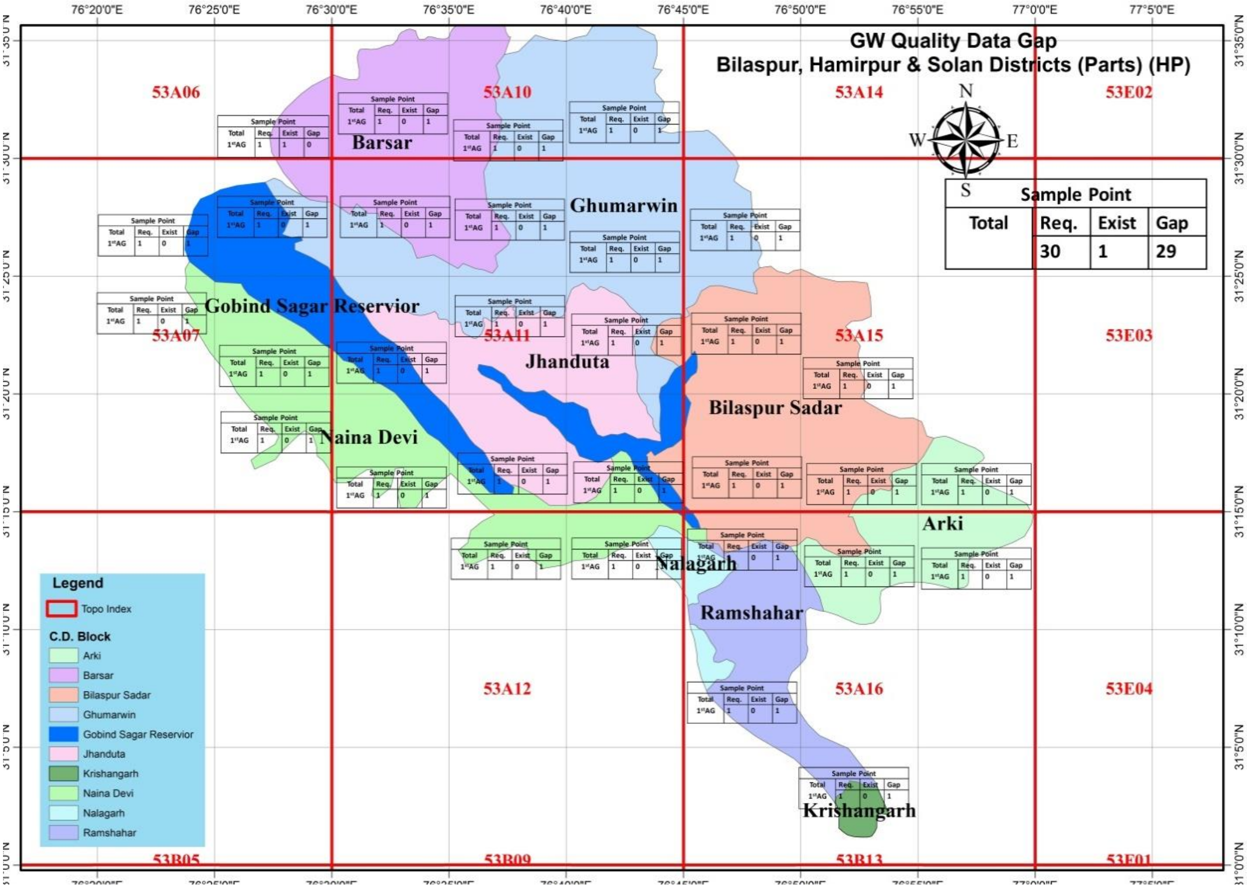


Fig.14: Existing Ground Water Quality Locations in study area.

1.12.5 Rate of Infiltration

The amount of recharge to ground water depends on the infiltration rates of the soils. No infiltration tests have been conducted in previous surveys by CGWB and even this data is not available with state agencies. To know the infiltration characteristics of the soil in the study area, 39 nos. of infiltration tests are required. On the basis of data gap analysis, quadrant-wise existing and recommended infiltration tests are presented and shown as square diagram in the figure -11

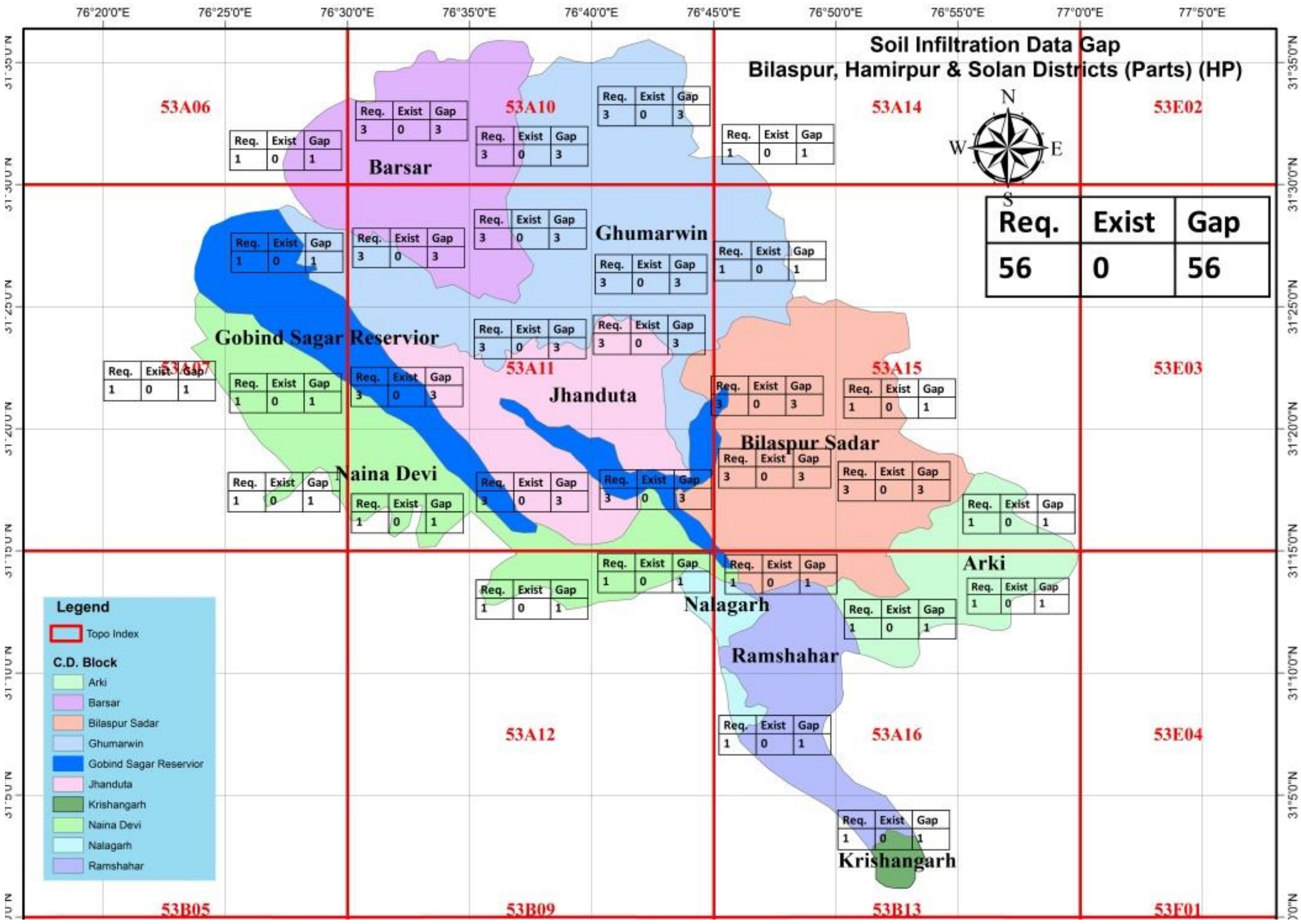


Fig.15: Data Gap Analysis for Soil Infiltration Studies – Bilaspur, Hamirpur & Solan District

1.12.6 Spring discharge

The spring monitoring (discharge and quality) is essential to know the inflow and outflow of the water in the study area and its quality for domestic and other use. In the study area, 22 Nos. springs have been located.

1.13 Previous Work and Present Status of Data

Central Ground Water Board, NHR, Dharamshala has brought out district reports, ground water management studies reports, ground water exploration reports periodically on all districts of Himachal Pradesh. The systematic surveys and reappraisal hydro geological surveys were carried out by CGWB in area during various field seasons. Central Ground Water Board, NHR, Dharamshala has also carried out ground water exploration studies in the area.

CGWB NHR, Dharamshala is monitoring ground water levels from National Hydrograph Network observations and aquifer mapping wells (Table 1.3) since 1977 in all valleys of Himachal Pradesh four times a year in the months of, May, August, November and January. The ground water quality is being studied by CGWB once in a year from the samples collected from those observation wells during the month of May.

Table 9: National Hydrograph Network observations falling in the study area are tabulated below:

Sl.No	Name of Village/site	Latitude	Longitude	Estt. Date	RL (mamsl)	Total Depth of DW (mbgl)	Type (DW/)	Measuring Point (magl)
1	Bijhari	31.522722	76.53941667	6/11/2014	789	15	DW	0.5

Table 7: Data Gap Analysis Table for all parameters Bilaspur, Hamirpur & Solan (216-17)								
Quadrant no.	**No. of additional EW's Required**		**No. of additional OW's Required**		**No. of additional VES/TEM Required**	**No. of additional water level monitoring Stations (DW/Spring) Required**	**No. of Soil Infiltration test Required**	**Remarks**
	Aq- I	**Aq- II**	**Aq- I**	**Aq- II**	**Aq- II**	**Aq- I**		
53A06/3C					1	1	1	
53A07/1C					1	1	1	
53A07/2B	1		1		1	1	1	
53A07/2C					1	1	1	
53A07/3C					1	1	1	
53A10/3A					1	1	3	
53A10/3B					1	1	3	
53A10/3C	1		1		1	1	3	
53A11/1A					1	1	3	
53A11/1B	1		1		1	1	3	
53A11/1C					1	1	3	
53A11/2A					1	1	3	
53A11/2B					1	1	3	

53A11/2C					1	1	3	
53A11/3A					1	1	1	
53A11/3B					1	1	3	
53A11/3C					1	1	3	
53A12/1B					1	1	1	
53A12/1C					1	1	1	
53A15/1A					1	1	1	
53A15/2A					1	1	3	
53A15/2B					1	1	1	
53A15/3A					1	1	3	
53A15/3B	1		1		1	1	3	
53A15/3C					1	1	1	
53A16/1A					1	1	1	
53A16/1B	1		1		1	1	1	
53A16/1C					1	1	1	
53A16/2A					1	1	1	
53A16/3B					1	1	1	
Total	**5**		**5**		**30**	**30**	**56**	

Chapter II

2.1 Geology

Geologically, the rock formations occupying the study area range in age from Proterozoic to Quaternary. The detailed geological succession encountered in the area is given below in table 8:

<table>
<tr><th colspan="6">Table 8:Geological Succession in study area.</th></tr>
<tr><th>Era</th><th>Period</th><th>Group</th><th>Formation</th><th colspan="2">Description of Lithology</th></tr>
<tr><td rowspan="2">Post Tertiary</td><td>Recent</td><td></td><td>Alluvium</td><td colspan="2">Grey to dark grey iron stained fine to coarse sand with pebble and clay</td></tr>
<tr><td>Pleistocene</td><td></td><td>Older Alluvium</td><td colspan="2">Multiple fill cyclic sequence of medium to coarse grained grey sand and grit with pebble of sandstone and lenses of clay</td></tr>
<tr><td rowspan="6">Tertiary</td><td rowspan="3">Pliocene – Middle Miocene</td><td rowspan="3">Siwalik system</td><td>Upper Siwalik</td><td colspan="2">Sand stone, boulder conglomerate, clay and grit stone</td></tr>
<tr><td>Middle Siwalik</td><td colspan="2">Grey sandstone, gravel beds, shale, clay</td></tr>
<tr><td>Lower Siwalik</td><td colspan="2">Micaceous sandstone, purple clay, mudstone</td></tr>
<tr><td rowspan="3">Lower Miocene-Oligocene</td><td rowspan="3">Subathu group</td><td>Kasauli</td><td colspan="2">Grey sandstone, shale, clay;</td></tr>
<tr><td>Dagshai</td><td colspan="2">Grey/green sandstone, red nodular clay</td></tr>
<tr><td>Subathu</td><td colspan="2">Grey/green splintery shale, sandstone and limestone bands</td></tr>
<tr><td rowspan="17">Pre Tertiary</td><td rowspan="3">Upper Proterozoic-III</td><td rowspan="3">Krols</td><td>Krol</td><td colspan="2">Sand stone, red shale, dolomite;</td></tr>
<tr><td>Infra Krol</td><td colspan="2">Carbonaceous shale, slate, greywacke;</td></tr>
<tr><td>Blaini</td><td colspan="2">Tillitoids, shale, slate, quartzite, dolomitic limestone.</td></tr>
<tr><td rowspan="4">Lower Proterozoic –III</td><td rowspan="4">Simla Group /Jaunsar Group</td><td>Sanjauli</td><td>Shale, siltstone, slate, greywacke, quartzite, sandstone, conglomerate,</td><td rowspan="4">Undifferentiated jaunsar quartzite, slate, phyllite, conglomerat, greywacke, limestone, dolaomite and metavolcanics</td></tr>
<tr><td>Chhaosa</td><td>Shale, siltstone, quartzite, greywacke;</td></tr>
<tr><td>Kunihar</td><td>Shale, siltstone and limestone</td></tr>
<tr><td>Basantpur</td><td>Limestone, shale, quartzite and sporadic conglomerate</td></tr>
<tr><td rowspan="7">Proterozoic-II</td><td rowspan="5">Shali Group</td><td>Parnali</td><td colspan="2">Cherty dolomite, quartzite, limestone</td></tr>
<tr><td>Makri</td><td colspan="2">Purple/pale greenish and grey shale, slate, quartzite and cherty dolomite</td></tr>
<tr><td>Tattapani</td><td colspan="2">Pink and grey dolomite, phylitised shale</td></tr>
<tr><td>Sorghawari</td><td colspan="2">Pink and grey limestone, sporadic shale</td></tr>
<tr><td>Khaira</td><td colspan="2">Pink and white quartzite with a thin band of red shale along the upper contact</td></tr>
<tr><td>Sundernagar</td><td>Sundernagar</td><td colspan="2">Shale, slate, phyllite, quartzite and meta-volcanices,</td></tr>
<tr><td rowspan="3">Proterozoic-Undifferentiated</td><td rowspan="3">Jutogh Group</td><td>Bhotli</td><td colspan="2">Shale, phyllitc, garnetiferous, schist, staurolite quartzite, dolomite and amphibolite</td></tr>
<tr><td>Manal</td><td colspan="2">Pale white to grey quartzite, schist, carbonaceous dolomite</td></tr>
<tr><td>Panjerli</td><td colspan="2">Carbonaceous slate, phyllite, schist with limestone and quartzite.</td></tr>
</table>

Source: Geological Survey of India

Stratigraphically, majority of the study area is underlain by the tertiary formations. Structurally these formations are highly disturbed. The rock types of the area can be broadly grouped into two tectonic zones striking and trending NW-SE direction. Their position from North to South is as follows; Belt of lower and middle tertiary occurring along the NW flank of the area (Para-autochthonous) and Belt of upper tertiary confined to the Middle and northern part of the areas and along its SW flank (Autochthonous). The contact of these zones is marked by a major fault (Main Boundary Thrust).

Tectonically, the area is highly disturbed, major thrust trending NW-SE are, Main Boundary Thrust, Jwalamukhi Thrust and Drang thrusts. Jawalmukhi Thrusts separates Lower Shiwalik to middle Shiwalik whereas Drang Thrust and MBTs separates Upper Shiwaliks and other older rock formations. The Geology/ lithology map of the study area was prepared with the help of Himachal Pradesh Geological map on 1:50000 scale. Figure 12.

Lithology: Lithology wise, the area has extremely varied lithology. Rocks in area varies from Recent alluviums to crystalline formation of Proterozoic, through Shiwaliks of tertiary. Major lithology of the area is Sandstone, Conglomerate, Limestone, Dolomites, clay and other clastic sediments. Lithology map of the area is given in Fig 13.

Lineament: Due to tectonic activity in the area, the lineament development is very prominent in the areas. All these lineament provide necessary weak zones for infiltration as well as movement of groundwaterThe lineament map of the area has been prepared from National Geological Lineament Map on 1:50000.(Source: Geological Survey of India) Fig 14

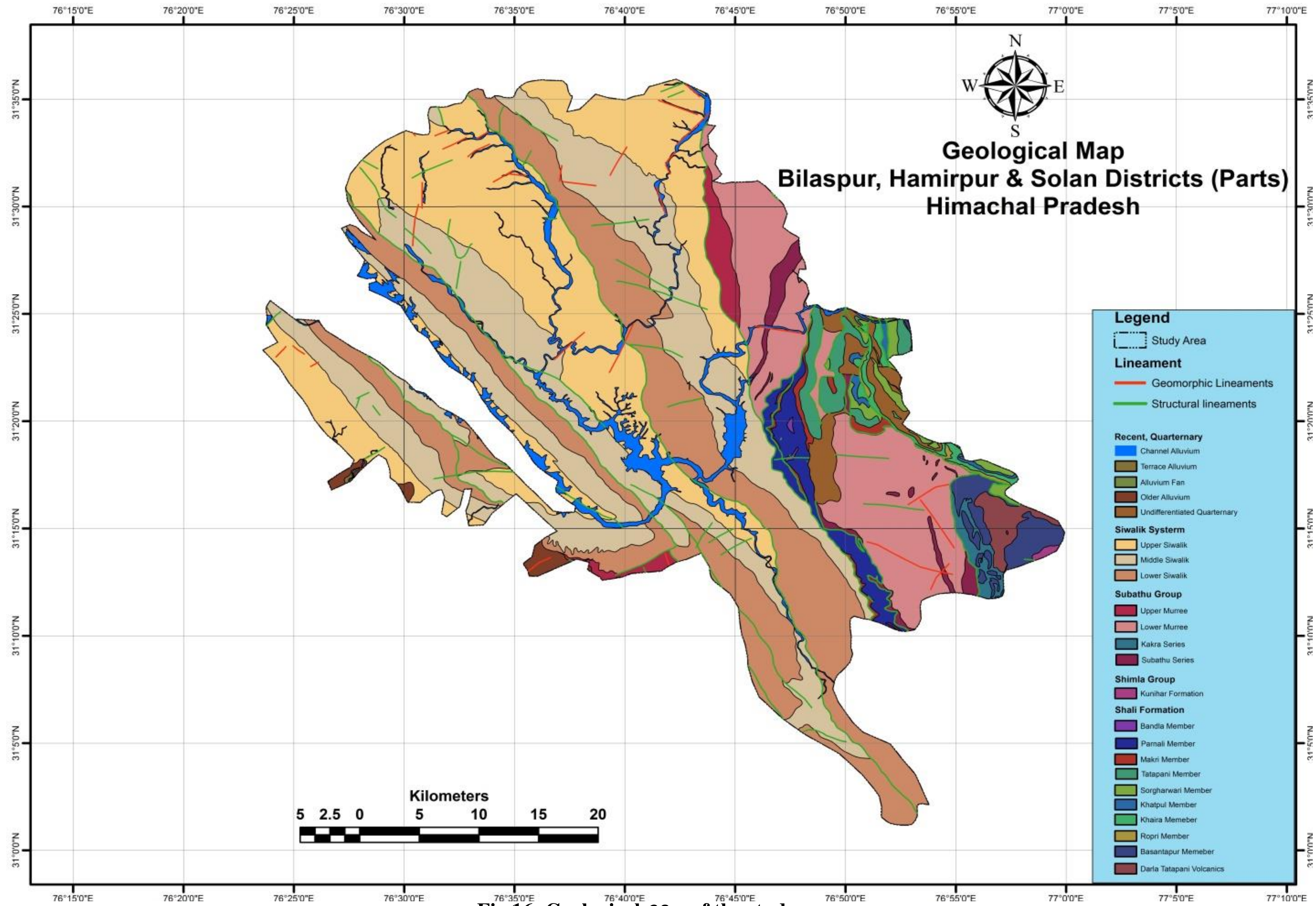


Fig 16: Geological map of the study area

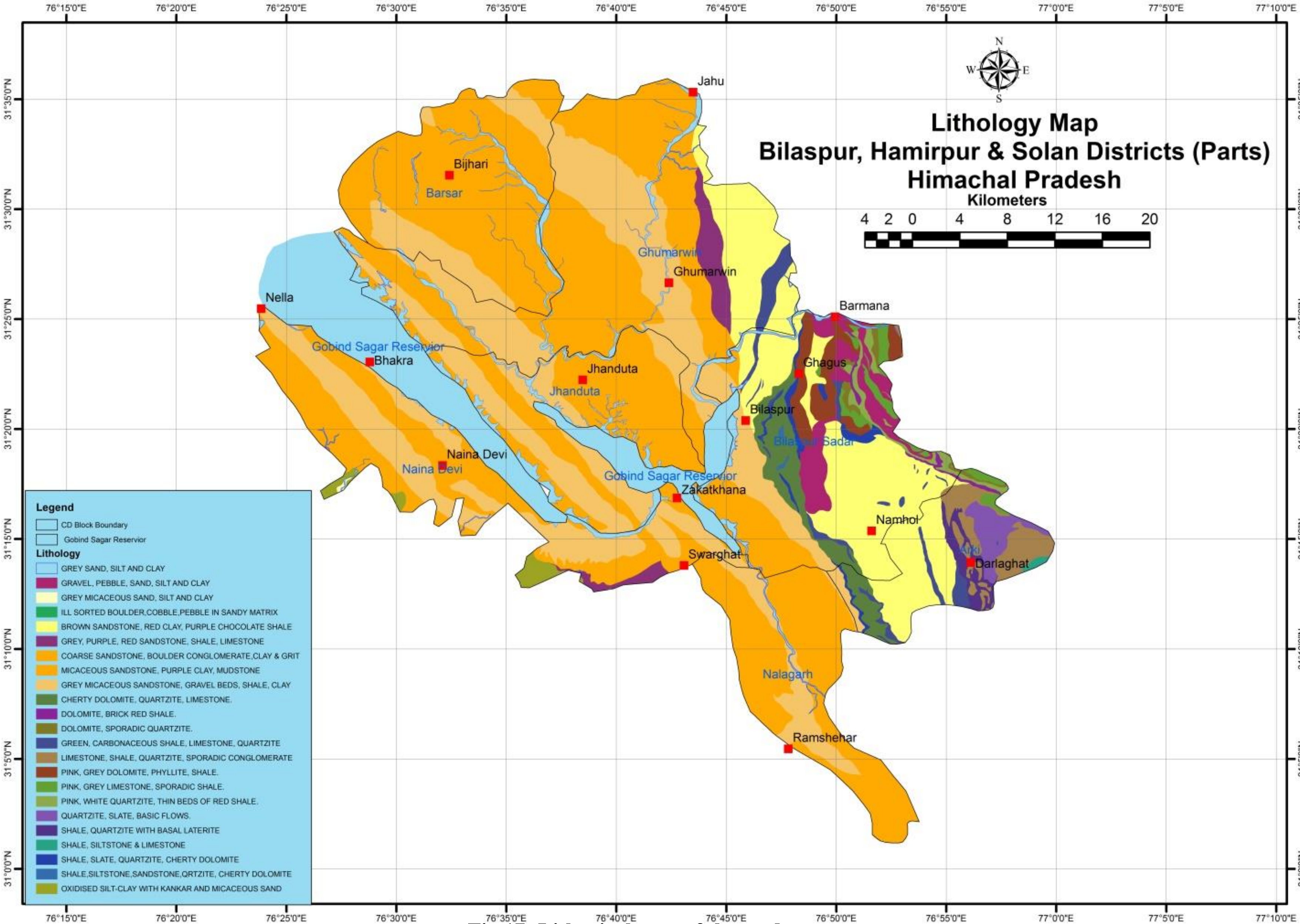


Fig 17: Lithogical map of the study area

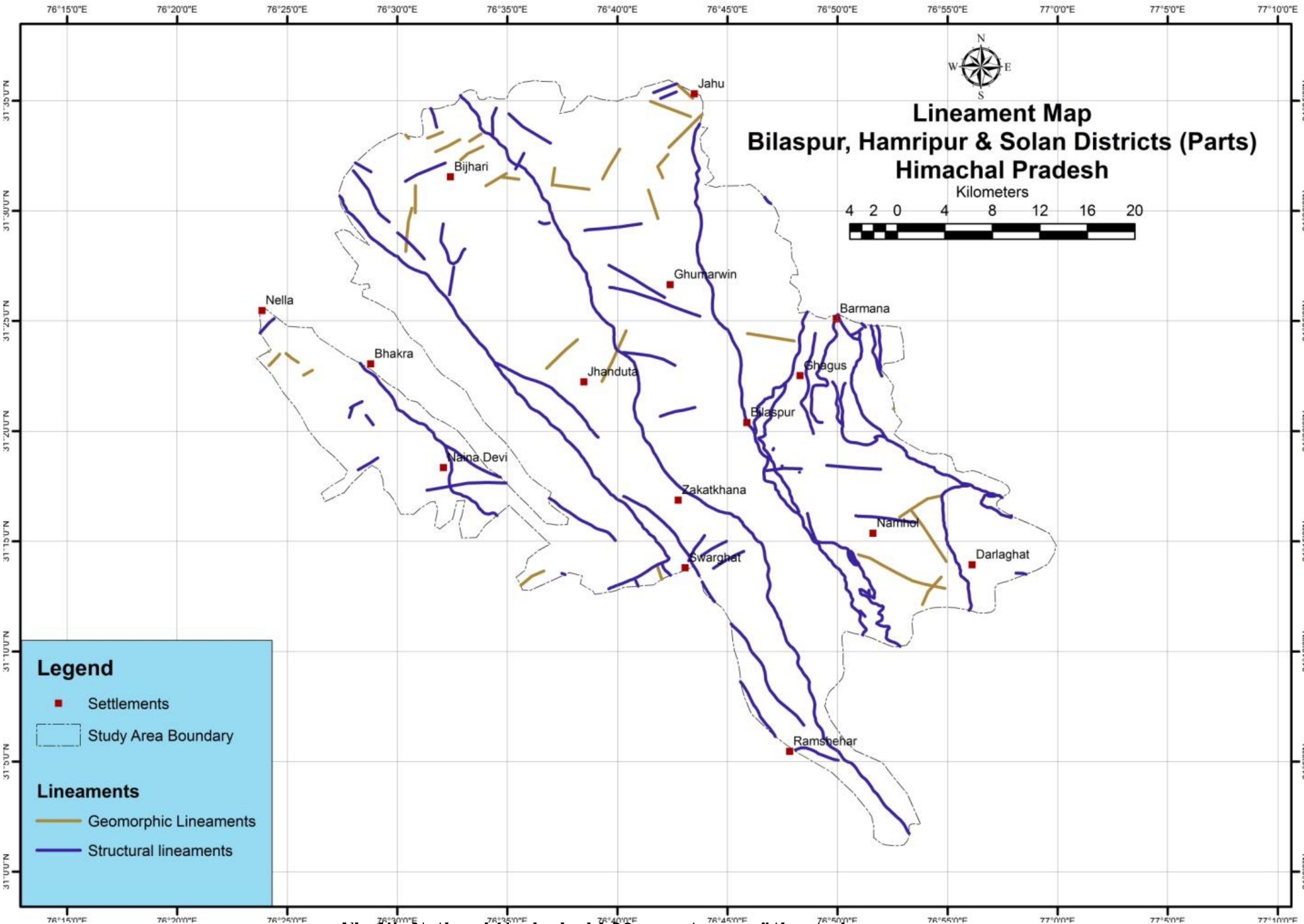


Fig 18: National Geological Lineament map of the study area

2.1 Hydrogeology

In area of this study, the ground water occurs in porous unconsolidated alluvial formation (intermountain valley fills) comprising, sand, silt, gravel, cobbles/pebbles etc. Ground water occurs both under phreatic & confined conditions. The thickness of such deposits is again restricted to 60 to 100 m below ground level.

The ground water in the valley also occurs under perched water table conditions at places. Water table rises after monsoon period and intersects the ground surface giving rise to a number of springs at suitable locations. However, the water table falls with the advent of summer and these springs used to dry. Intersection of water table in various tributary khads at suitable places maintained their perennial flow. All the four major khadds are mainly ground water fed river during the non-monsoon period. Ground water intersects these Khadd's bed near point of origin and the whole length further downstream upto lower reaches the confluence with Sutlej River is effluent in nature. All the khads show effluent of ground water in their beds and are perennial in their lower reaches in the study area and drains into Sutlej River (Fig. 5).

Dug wells, tube wells and springs are the main ground water abstraction structures. Whereas dug well and tube wells are prominent structures in the Northern and North Western part of the study area, springs make the major groundwater sources in south and southeastern part of the study area. Ground water is being developed in the area by medium to deep tube wells, dug wells, and dug cum bored wells. Depth of open dug wells and dug cum bored well in area ranges from 10.00 to 35.00 m bgl wherein depth to water table varies from near ground surface to more than 18 m bgl. Yield of unconfined aquifer is moderate with well discharges up to 10 lps.

Deeper semi-confined aquifers are being developed by tube wells ranging in depth from 65 to 120 m tapping 25-35 m granular zones. The well discharges vary from about below 1 lpm to 20 lps. Central Ground Water board has drilled/constructed > 6 exploratory wells in the valley fill area in the depth range of 44.00 to 180 m bgl. Static water level of the tube wells ranges from 1.2 to 36.55 mbgl and discharge ranged from below 1 lpm to to1245 lpm for drawdown of 1.5 to 43.19 m. Transmissivity ranges from $2.6x10^{-5}$ m^2/day to 1218.21 m^2/day.

Table 8: Aquifer parameters delineated through Exploratory drilling

Location	LATITUDE	LONGITUDE	SWL	Discharge	Drawdown	Transmissivity	Depth
Panjgain	31.38866667	76.83425333	1.65	90	23.7	8.47	104.6
Harkukar	31.43952778	76.71838889	4.46	90	-	$2.6x10^{-5}$	101
Dehra Malkota	31.58729	76.719055	1.93	90	-	$3.15X10^{-6}$	104.7
Dobat	31.30086111	76.46650833	17	NIL	NIL	NA	92.3
Kikerwala	31.227547	76.59178	18.45	740	1.5	493.3	103
Siyola	31.295217	76.807578	36.55	833	6.11	147	115
Ghagus	31.375827	76.805592	3.03	1245	2.6	1218.21	31.8
Tali	31.275	76.72083333	NA	1	NIL	NA	74

The recharge to the aquifers in the area is chiefly affected through the influent stream seepage and percolation of surface precipitation and irrigation waters. Influent stream seepage occurs mainly in the upper higher portions of the valley adjacent to foothills, their large quantities of water from the streams percolate down into the porous and highly permeable valley-fill deposits.

The discharge of ground water is both natural and induced. Natural discharge is chiefly affected through evapo-transpiration and effluent seepage into the major streams. The induced discharge is mainly through draft from the open wells used for domestic, irrigation and industrial water supplies. The Hydrogeological map of the area is shown in Fig. 16 on next page. Further the information on various aquifer parameters. Aquifer disposition etc. has been given in Chapter 3 on Data Integration.

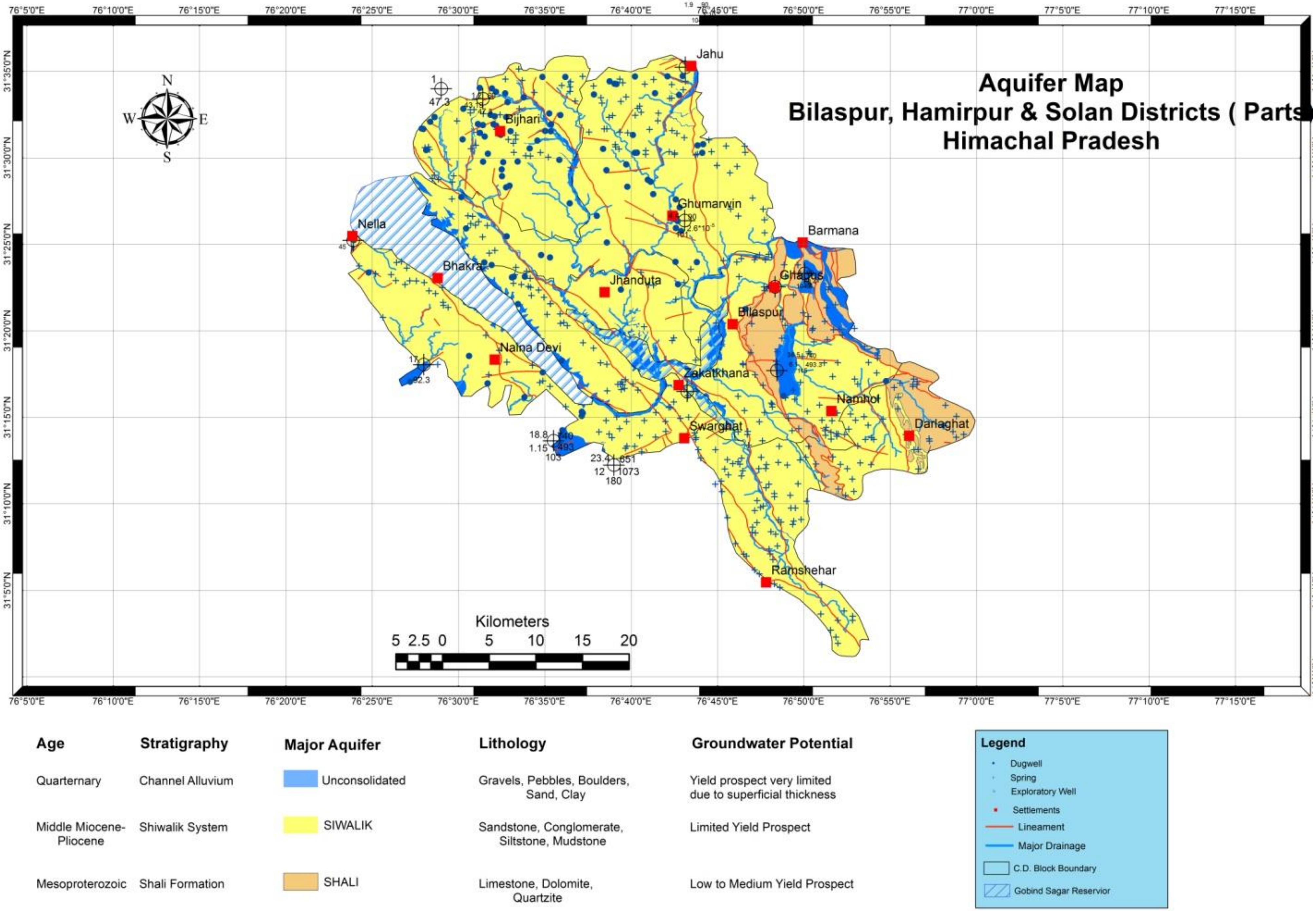


Fig 19: Aquifer Map of the study area in Bilaspur, Hamirpur and Solan Districts (Parts)

III DATA COLLECTION AND GENERATION

3.1 Hydrogeological Data

Water Level Behavior: To know the water level and its behavior with respect to time and space, 34 dug wells have been inventoried for Ground Water Management Studies all over the area. The dug wells are mainly located in Hamirpur and Bilaspur districts. The water levels were taken during the month of May, August, November and January of 2016, 2017 & 2018 and on the basis of these data, pre-monsoon, post monsoon and seasonal fluctuation map have been prepared for the study area. The hydrogeological data of the inventoried dug wells are given in Table 10

In Study area, depth to water level shows wide variation. During pre-monsoon period (May 2016) it ranges from 0.84 mbgl (Hatwar) to 18.09 mbgl (Mehre) (Fig.17) and post monsoon period (Nov.2016) ranges from 1.62 to 17.51mbgl. (Fig.18). In major parts of study area, Seasonal Water Level Fluctuation ranges between less than 0.08 to 2.8 m. Whereas in pre-monsoon period of (May 2017) it ranges from 1.09 to 18.09 m bgl (Fig.19) and post monsoon period (Nov.2017) ranges from 0.8 to 16.77 m bgl (Fig.20) and Seasonal Water Level Fluctuation ranges between -0.1 to 5.2m bgl. Similarly, Spring discharge varies from 0 to 120 lpm during pre-monsoon to 0 to 90 lpm during post monsoon season.

Table 10: Water level spring discharge data (May & Nov 2016 and May & Nov 2017) GWMS and Aquifer Mapping Wells of Bilaspur, Hamirpur & Solan Districts Himachal Pradesh

Location	Latitude	Longitude	Water Level, 2016 (mbgl)		2016 Fluctuation (m)	Water Level, 2017 (mbgl)		2017 Fluctuation (m)
			May 2016	Nov. 2016		May 2017	Nov. 2017	
Dagwar	31.567278	76.520472	1.5	1.98	0.48	1.71	1.55	0.16
Sahari	31.541417	76.530778	3.22	4.58	1.36	7.71	4.14	3.57
Bijhari	31.522722	76.539417	1.99	2.67	0.68	2.96	2.05	0.91
Dhangota	31.532167	76.589361	6.56	8.52	1.96	7.85	6.9	0.95
Chakrana	31.521861	76.668417	1.25	2.02	0.77	1.09	0.95	0.14
Ghandalwin	31.571361	76.650694	4.73	4.1	0.63	4.5	3.35	1.15
Hatwar	31.528222	76.464444	0.84	1.62	0.78	1.55	0.8	0.75
Mehre	31.578417	76.701806	18.09	17.51	0.58	18.09	16.77	1.32
Maruda	31.462139	76.502694	1.19	1.77	0.58	3.19	1.45	1.74
Tambari	31.424333	76.5465	5.6	5.97	0.37	6.09	5.6	0.49
Ghandhir	31.406361	76.579778	4.97	5.65	0.68	5.89	1.73	4.16
Jhanduta	31.373083	76.656806	6.41	8.11	1.7	NA	6.35	NA
Sanihara	31.385528	76.564056	1.81	2.92	1.11	3.13	0.95	2.18
Goind	31.396722	76.532	4.84	3.92	0.92	6.3	1.3	5
Ghandhir	31.403917	76.588389	6.12	7.01	0.89	7.33	5.96	1.37
Berthin	31.418361	76.643278	9.76	8.21	1.55	11.58	6.3	5.28
Chauki	31.456111	76.607389	9.97	7.1m	2.87	6.85	1.9	4.95
Naswal	31.465028	76.688008	2.04	2.31	0.27	5.43	2.65	2.78
Ghumarwin	31.429389	76.715056	2.2	3.21	1.01	4.85	1.9	2.95
Amarpur	31.399722	76.709528	14.06	14.87	0.81	NA	15.5	NA
Geharwin	31.354306	76.777222	3.41	3.59	0.18	3.87	2	1.87
Brahmpukhar	31.270667	76.813722	1.26	1.85	0.59	1.75	1.48	0.27
Malothi	31.284806	76.912806	2.7	2.62	0.08	2.7	2.6	0.1

Jerakh	31.377361	76.838361	8.47	7.18	1.29	8.2	6.4	1.8
Nella	31.42075	76.398972	5.93	8.1	2.17	6.55	5.8	0.75
Springs								
Location	**Latitude**	**Longitude**	**Discharge, 2016 (lpm)**		**2016 Fluctuation (lpmm)**	**Water Level, 2017 (lpm)**		
			May 2016	Nov 2016		May 2017		
Dalhi	31.38553	76.77086	120	90	30	90	60	30
Binaula	31.37564	76.79492	90	51	39	60	60	0
Badkishan	31.30397	76.8065	0	0	0	0	0	0
Namhol	31.25542	76.86142	0	0	0	0	0	0
Bhararighat	31.24728	76.88331	2	9	7	1.25	10	8.75
Ghundan	31.22881	76.90089	8.5	18	9.5	5	12	7
Darlaghat	31.21897	76.94386	1.7	1.5	0.2	0	6	6
Tepra	31.23183	76.86519	0	0	0	0	1	1
Markandey	31.32622	76.81239	0	1.5	1.5	0	0.1	0.1
Solag	31.34711	76.83783	0	0	0	0	0.1	0.1
Tuhnu	31.32486	76.85622	0	0	0	0	0.1	0.1
Bhedali	31.22331	76.78008	1.5	6	4.5	48	0.1	47.9
Jarlu	31.25008	76.72222	0	0	0	0	0.1	0.1
Kiarian	31.26486	76.70792	0	12	12	12	0.1	11.9
Bhini	31.18572	76.74792	0.9	6	5.1	0	05	5
Barog	31.11639	76.77803	2	9	7	0	0.1	0.1
Chiachi	31.06056	76.84981	0.5	0	0.5	0	0.1	0.1
Bahlam	31.19842	76.77447	0	0	0	0	0.1	0.1
Mayoth	31.26038	76.60359	0	0	0	0	0.1	0.1
Mandhiyali	31.30319	76.54675	0	0	0	0	10	10
On Road	31.32897	76.5265	0.5	12	11.5	0	12	12
Tursuh	31.38753	76.43492	0	0	0	0	0.1	0.1

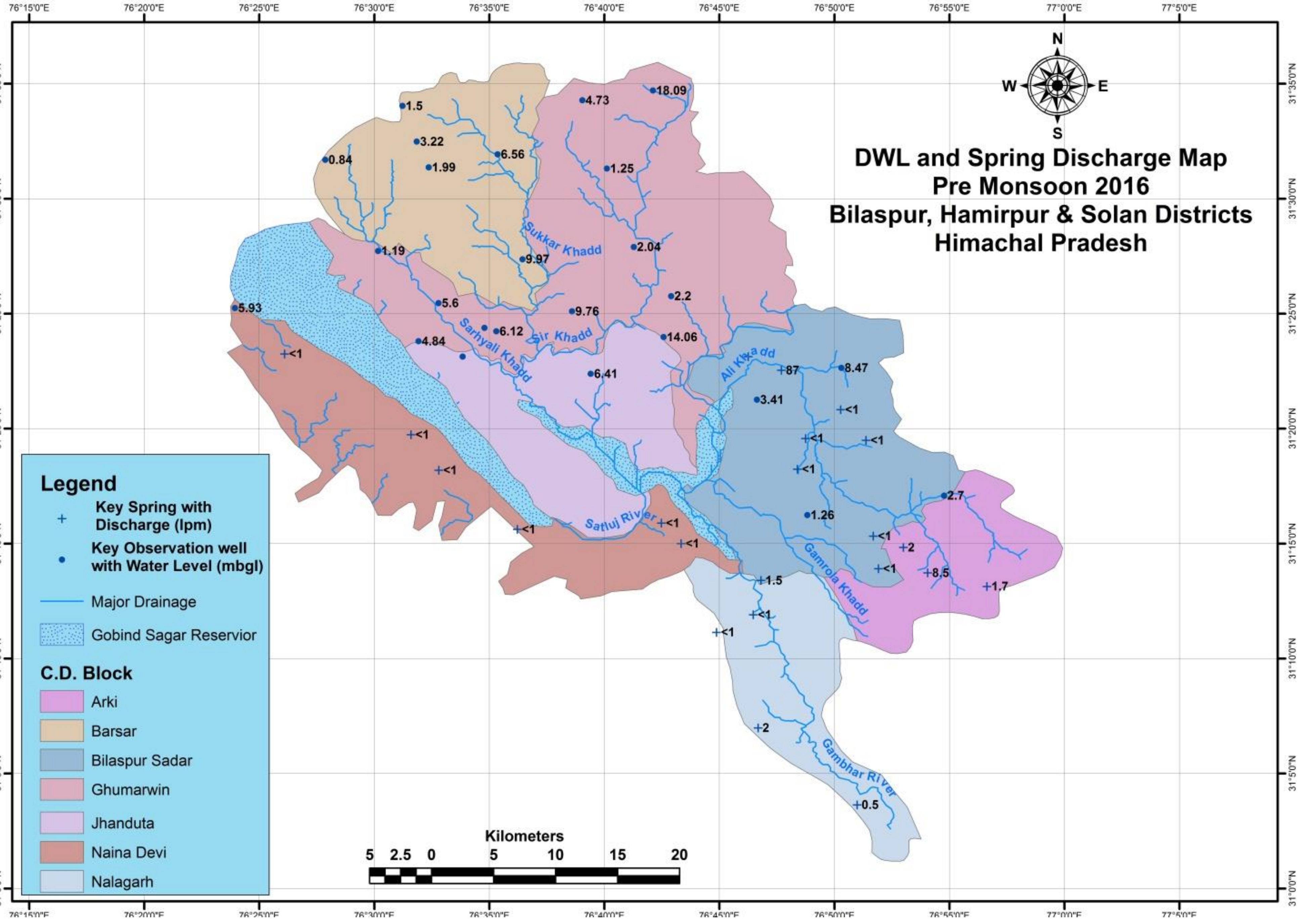


Fig 20: Depth Water Level – May 2016 in study area

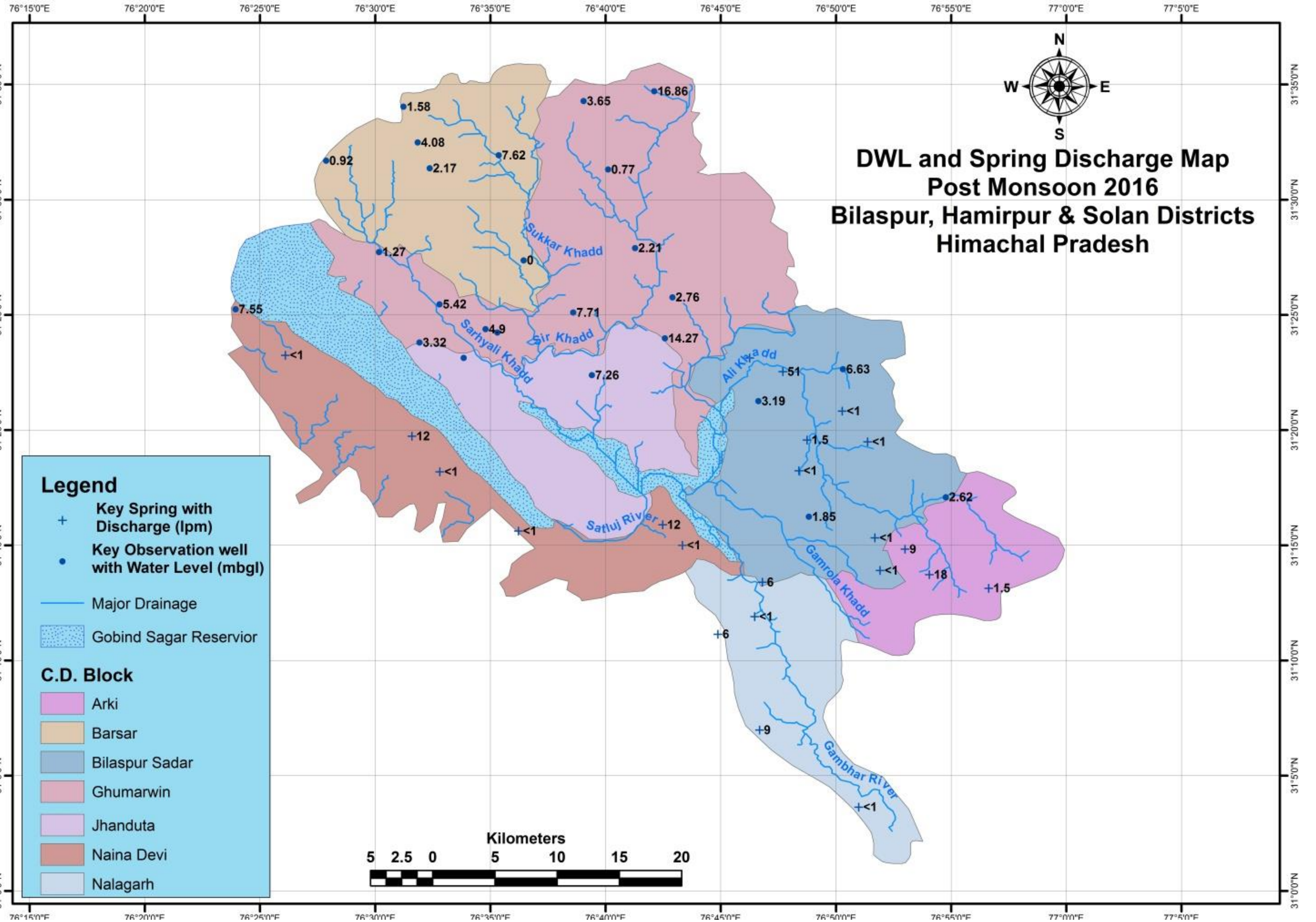


Fig 21: Depth Water Level – Nov 2016 in study area

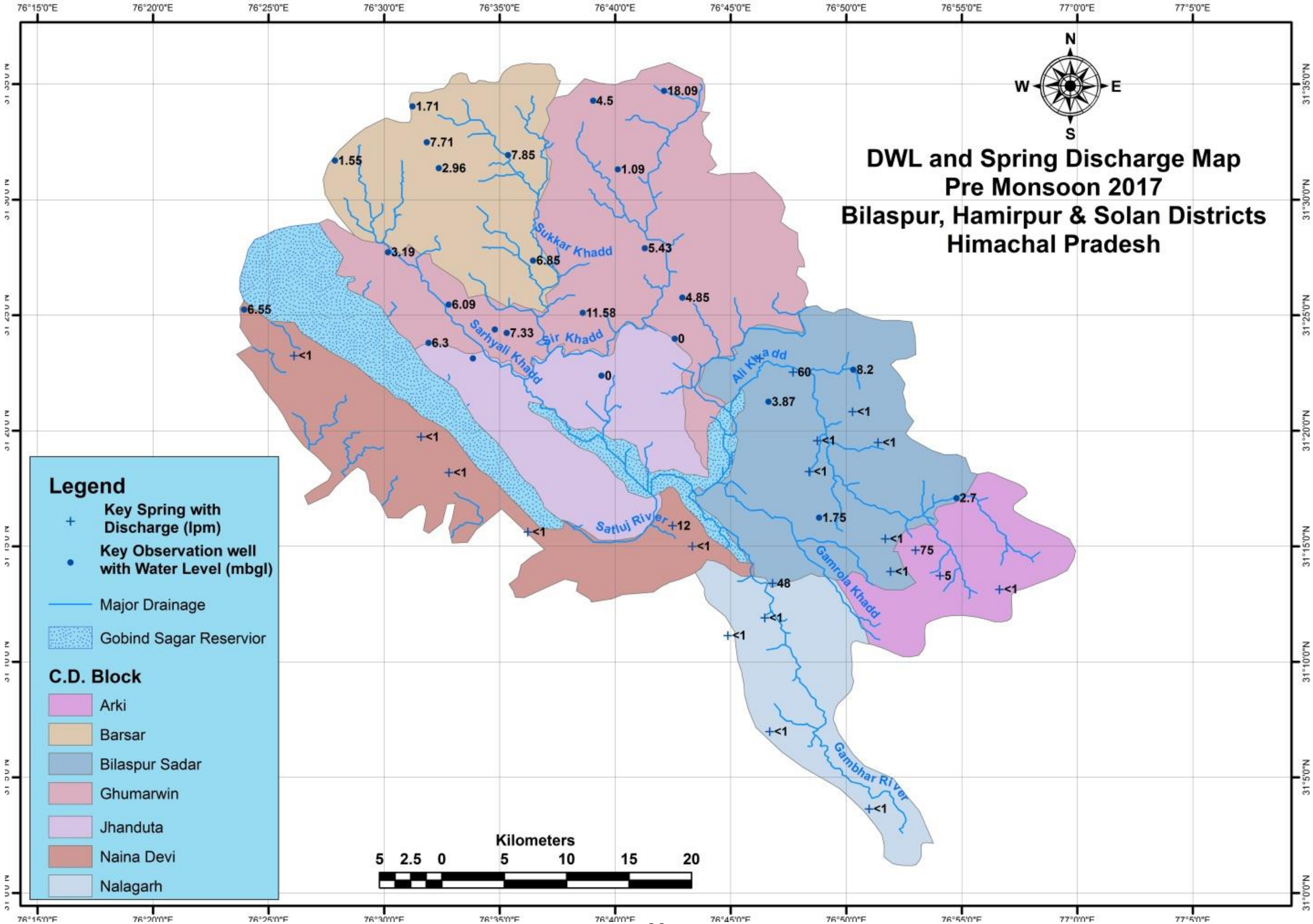


Fig 22: Depth Water Level – May 2017 in study area

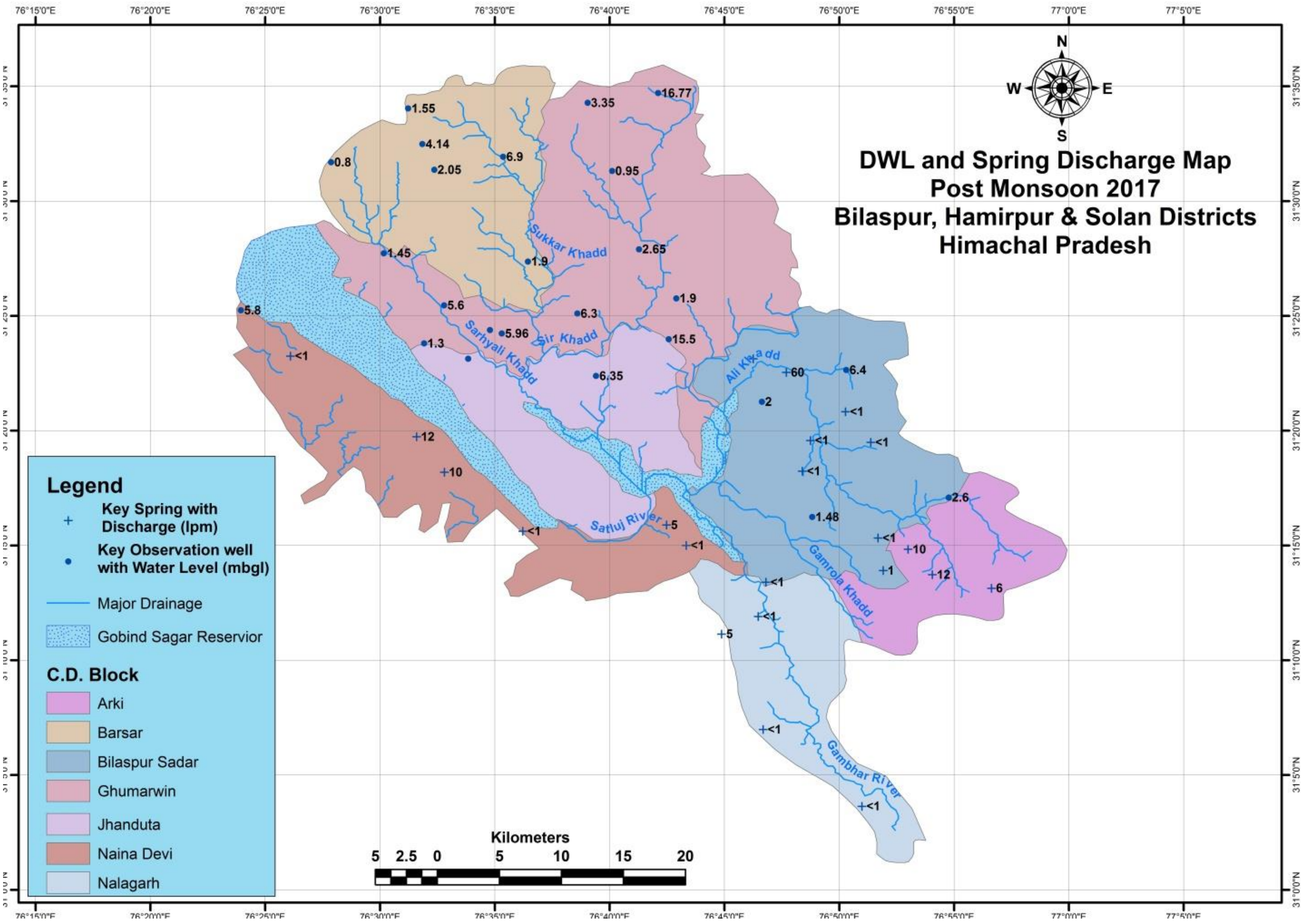


Fig 23: Depth Water Level – Nov 2017 in study area

3.2. Exploratory Drilling – CGWB & I& PH Wells

The Lithologs of 12 Nos. of Exploratory Well of CGWB has been compiled and those supported electrical logs have been used to validation for preparation of aquifer maps. One number of deeper well data of CGWB is available for some parts in study area. The details are shown in 11. The composite logs derived from lithologs and geophysical well loggings have been taken as reliable data base.

Table 11: Data availability of exploration wells in Parts of Bilaspur, Hamirpur & Solan District.

Table of Wells in study Area			
Agency	**Well Depth (meters)**		
	<100	**100-150**	**>150**
CGWB	5	6	1
I & PH	-	-	-
Total	**5**	**6**	**1**

3.3 Ground Water Quality

The water quality standards are laid down to evaluate suitability of water for intended uses and to safeguard water from degradation. These recommended limits form the basis of treatment needed for improvement in quality of water before use. In the formulation of water quality standards, the selection of parameters is considered depending upon its end use. Two types of standards are referred in India decipher the quality of water suitable for drinking purposes, namely Bureau of Indian Standards (BIS) and World Health Organisation (WHO) Standards.

Drinking Water

The BIS has laid down the standard specification for drinking water during 1983, which have been revised and updated from time to time. In order to enable the users to exercise their discretion, the maximum permissible limit has been prescribed especially where no alternative sources are available. It is medically established fact that water with concentration beyond permissible limits cause short term or permanent adverse health effects.

Standards for Chemical Parameters

The water quality standards as laid down in BIS standard (IS-10500, 1991), First Revision, 2003-2009 and WHO (2008) standards are summarized in Table 12 and Table 13 respectively. In addition separate standards for the use of Surface water i.e. lakes and rivers for drinking purposes have been laid down by BIS and have been given in table 14.

Table 12: Drinking water Standards - BIS (IS-10500, 1991)			
S. No.	**Parameters**	**Desirable limits (mg/l)**	**Permissible limits (mg/l)**
Essential Characteristics			
1	Colour Hazen unit	5	25
2	Odour	Unobjectionable	-
3	Taste	Agreeable	-
4	Turbidity (NTU)	5	10

5	pH	6.5 - 8.5	No relaxation
6	Total Hardness, $CaCO_3$	300	600
7	Iron (Fe)	0.3	1
8	Chloride (Cl)	250	1000
9	Residual Free Chlorine	0.2	-
10	Fluoride (F)	1	1.5
Desirable Characteristics			
11	Dissolved Solids	500	2000
12	Calcium (Ca)	75	200
13	Magnesium (Mg)	30	100
14	Copper (Cu)	0.05	1.5
15	Manganese (Mn)	0.1	0.3
16	Sulphate (SO_4)	200	400
17	Nitrate (NO_3)	45	100
18	Phenolic Compounds	0.001	0.002
19	Mercury (Hg)	0.001	No relaxation
20	Cadmium (Cd)	0.01	No relaxation
21	Selenium (Se)	0.01	No relaxation
22	Arsenic (As)	0.01	No relaxation
23	Cyanide (CN)	0.05	No relaxation
24	Lead (Pb)	0.05	No relaxation
25	Zinc (Zn)	5	15
26	Anionic Detergents (as MBAS)	0.2	1
27	Hexavelant Chromium	0.05	no relaxation
28	Poly Nuclear Hydrocarbons (as PAH)	-	-
29	Alkalinity	200	600
30	Aluminium (Al)	0.03	0.2
31	Boron (B)	1	5
32	Pesticides	Absent	0.001
33	Mineral Oil	0.01	0.03
34	Radioactive Material		
	Alpha Emmiters, Bq/l	-	.0.1
	Beta Emmiters, pci/l	-	1

NTU = Nephelometric Turbidity Unit

Table 13: Drinking Water Standards, WHO (2008)

S. No.	Parameters	Guideline value (mg/l)	Remarks
1	Aluminium	0.2	
2	Ammonia	-	NAD
3	Antimony	0.005	
4	Arsenic	0.01	For excess skin cancer risk of 6×10^{-4}
5	Asbestos	-	NAD
6	Barium	0.3	
7	Beryllium	-	NAD
8	Boron	0.3	
9	Cadmium	0.003	
10	Chloride	250	
11	Chromium	0.05	
12	Color	-	Not Mentioned
13	Copper	2	ATO
14	Cyanide	0.07	
15	Dissolved Oxygen		NAD
16	Fluoride	1.5	Climatic conditions, volume of water consumed, and

			intake from other sources should be considered when setting national standards.
17	Hardness		NAD
18	Hydrogen Sulfide		NAD
19	Iron		NAD
20	Lead	0.01	It is recognized that not all water will meet the guideline value immediately; meanwhile, all other recommended measures to reduce the total exposure to lead should be implemented.
21	Manganese	0.5 (P)	ATO
22	Mercury (total)	0.001	-
23	Molybdenum	0.07	-
24	Nickel	0.02	-
25	Nitrate (as NO_3) Nitrite (as NO_2)	50	The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1.
26	Turbidity		Not Mentioned
27	pH		NAD
28	Selenium	0.01	-
29	Silver		NAD
30	Sodium	200	
31	Sulfate	500	
32	Inorganic Tin		NAD
33	TDS		NAD
34	Uranium	1.4	
35	Zinc	3	

NAD - No adequate data to permit recommendation

ATO - Appearance, taste or odour of the water

Table 14: Surface Water Quality Standards -BIS

Characteristic	Tolerance Limit				
	Class A	**Class B**	**Class C**	**Class D**	**Class E**
pH value	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Dissolved Oxygen (mg/l), min.	6	5	4	4	--
BOD (5-days at 20° C, mg/l, min.	2	3	3	--	--
Total Coliform Organism, MPN/100ml, max	50	500	5000	--	--
Colour, Hazen units, max.	10	300	300	--	--
Odour	10	300	300	--	--
Taste	Tasteless	--	--	--	--
Total dissolved solids, mg/l, max.	500	--	1500	--	2100
Total hardness(as $CaCo_3$), mg/l, max.	300	--	--	--	--
Calcium hardness (as $CaCO_3$), mg/l, max.	200	--	--	--	--
Magnesium hardness (as $CaCO_3$), mg/l, max.	100	--	--	--	--
Copper (as Cu), mg/l, max.	1.5	--	1.5	--	--
Iron (as Fe), Mg/l, max.	0.3	--	0.5	--	--
Manganese (as Mn), mg/l, max.	0.5	--	--	--	--
Chlorides (as Cl), mg/l, max.	250	--	600	--	600
Sulphates (as SO_4), mg/l, max.	400	--	400	--	1000
Nitrates (as NO_3), mg/l, max.	20	--	50	--	--
Fluorides (as F), mg/l, max.	1.5	1.5	1.5	--	--
Phenolic compounds (as C_6H_5 OH), mg/l, max.	0.002	0.005	0.005	--	--
Mercury (as Hg), mg/l, max.	0.001	--	--	--	--
Cadmium (as Cd), mg/l, max.	0.01	--	0.01	--	--
Salenium (as Se), mg/l, max.	0.01	--	0.05	--	--

Arsenic (as As), mg/l, max.	0.05	0.2	0.2	--	--
Cyanide (as CN), mg/l, max.	0.05	0.05	0.05	--	--
Lead (as Pb), mg/l, max.	0.1	--	0.1	--	--
Zinc (as Zn), mg/l, max.	15	--	15	--	--
Chromium (as Cr^{6+}), mg/l, max.	0.05	--	0.05	--	--
Anionic detergents (as MBAS) mg/l, max.	0.2	1	1	--	--
Polynucleararomatic hydrocarbons, (as PAH	0.2	--	--	--	--
Mineral oil, mg/l, max.	0.01	--	0.1	0.1	--
Barium (as Ba), mg/l, max.	1	--	--	--	--
Silver (as Ag), mg/l, max.	0.05	--	--	--	--
Pesticides	Absent	--	Absent	--	--
Alpha emitters, uC/ml, max.	10^{-9}	10^{-9}	10^{-9}		
Beta emitters, uC/ml, max.	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}
Free ammonia (as N), mg/l, max.	--	--	--	1.2	--
Electrical conductance at 25° C, mhos, max.	--	--	--	1000×10^{-6}	2250×10^{-6}
Free carbon dioxide (as CO), mg/l, max.	--	--	--	61	--
Sodium absorption ratio	--	--	--	--	26
Boron (as B), mg/l, max.	--	--	--	--	--
Percent sodium, max.	--	--	--	--	--

*Explanation for Symbols:

A: Drinking water sources without conventional treatment but after disinfection.

B: Organized outdoor Bathing.

C: Drinking water sources with conventional treatment followed by disinfection.

D: Propogation of wild life and Fisheries.

E: Irrigation, industrial cooling and controlled water disposal.

Standards for Bacteriological Parameters

Faecal contamination is widespread in most of the Rural Areas. The major bacteriological contamination and their limits are given below:

E. Coli is the more precise indicator of faecal pollution. The count of thermo-tolerant, coliform bacteria is an acceptable method however, if necessary, proper confirmatory tests of the sample should be carried out. As per Indian standard for drinking water - specification (First Revision) IS-10500:1991 BIS, ideally, all samples taken from the distribution system including consumers' premises should be free from coliform organisms. In practice, this is not always attainable. The following standard of water collected in the distribution system is therefore recommended when tested in accordance with IS 1622:1981.

a) 95 percent of samples should not contain any coliform organisms in 100 ml;

b) No sample should contain E. coli in 100 ml;

c) No sample should contain more than 10 coliform organism per 100 ml; and

d) Coliform organism should not be detectable in 100 ml of any two consecutive samples.

WHO has also suggested guidelines for bacteriological parameters are as follows (Table 2.10)

Table 15: Bacteriological quality of drinking water (WHO, 2008)

Organisms	**Guideline Value**
All water intended for drinking	
E. Coli or thermo-tolerant coliform bacteria	Must not be detectable in any 100/ml sample.
Treated water entering the distribution system	

E. Coli or thermo-tolerant coliform bacteria	Must not be detectable in any 100/ml sample.
Total coliform bacteria	Must not be detectable in any 100/ml sample.
Treated water in the distribution system	
E. Coli or thermo-tolerant coliform bacteria	Must not be detectable in any 100/ml sample.
Total coliform bacteria	Must not be detectable in any 100/ml sample. In the case of large supplies, where sufficient samples are examined must not be present in 95% of sample taken throughout any 12 month period.

The detrimental effect of various pesticides/ organic compounds cannot be ignored.

The ground water sampling was carried out in the study areas through Ground Water Observation Wells in every year pre-monsoon period by CGWB. The water samples for both pre monsoon and post monsoon were collected during the year 2016-17 & 2017-18. To assess the impact of ground water quality, 56 numbers of water samples were collected from the study area of in 2016-17 and 2017-2018, as per the list below:

Sr.No	Type of Source	Total Nos.
1	Dug Well	34 Nos.
3	Spring	22 Nos.

Table 16: Details of Water Samples for Ground Water Quality in Parts of Bilapsur, Hamirpur & Solan District.

S.No.	District	Location	Lat	Long	Source	Depth	Measuring Point	Depth Zone	Temp. (Celsius) Sample/ Atm	Analysis
1	Hamirpur	Dagwar	31.56728	76.52047222	Dugwell	05m	0.4	Shallow	21/22	Basic
2	Hamirpur	Sahari	31.54142	76.53077778	Dugwell	15m	0.5	Shallow	21/22	Basic
3	Hamirpur	Bijhari	31.52272	76.53941667	Dugwell	15m	0.5	Shallow	24/26	Basic
4	Hamirpur	Dhangota	31.53217	76.58936111	Dugwell	9m	0.9	Shallow	21/24	Basic
5	Bilaspur	Chakrana	31.52186	76.66841667	Dugwell	10	1.25	Shallow	25/26	Basic
6	Bilaspur	Ghandalwin	31.57136	76.65069444	Dugwell	6	0.45	Shallow	22/31	Basic
7	Bilaspur	Hatwar	31.52822	76.46444444	Dugwell	7.5	0.7	Shallow	24/28	Basic
8	Hamirpur	Mehre	31.57842	76.70180556	Dugwell	25	0.65	Shallow	22/30	Basic
9	Hamirpur	Maruda	31.46214	76.50269444	Dugwell	6	0.5	Shallow	21/31	Basic
10	Hamirpur	Shah Talai	31.45278	76.51747222	Handpump	NA	NA	Shallow	22/30	Basic+Heavy Metal
11	Bilaspur	Tambari	31.42433	76.5465	Dugwell	10	0.55	Shallow	22/28	Basic
12	Bilaspur	Ghandhir	31.40636	76.57977778	Dugwell	10	0.75	Shallow	22/32	Basic
13	Bilaspur	Jhanduta	31.37308	76.65680556	Dugwell	10	0.85	Shallow	22/32	Basic+Heavy Metal
14	Bilaspur	Sanihara	31.38553	76.56405556	Dugwell	6	0.75	Shallow	21/24	Basic
15	Bilaspur	Goind	31.39672	76.532	Dugwell	8	0.6	Shallow	24/26	Basic
16	Bilaspur	Ghandhir	31.40392	76.58838889	Dugwell	10	0.4	Shallow	22/28	Basic
17	Bilaspur	Berthin	31.41836	76.64327778	Dugwell	22	0.5	Shallow	24/30	Basic
18	Hamirpur	Chauki	31.45611	76.60738889	Dugwell	13.7	0.5	Shallow	21/22	Basic
19	Bilaspur	Dadhol kalan	31.48861	76.66008333	Handpump	NA	NA	Shallow	26/30	Basic
20	Bilaspur	Naswal	31.46503	76.68800833	Dugwell	10	0.2	Shallow	24/26	Basic+Heavy Metal
21	Bilaspur	Ghumarwin	31.42939	76.71505556	Dugwell	7	0.45	Shallow	22/28	Basic
22	Bilaspur	Kularu	31.42128	76.72225	Handpump	NA	NA	Shallow	24/28	Basic
23	Bilaspur	Amarpur	31.39972	76.70952778	Dugwell	16.7	0.6	Shallow	22/30	Basic
24	Bilaspur	Geharwin	31.35431	76.77722222	Dugwell	12.1	0.4	Shallow	24/28	Basic
25	Bilaspur	Brahmpukhar	31.27067	76.81372222	Dugwell	5	0	Shallow	26/28	Basic

26	Bilaspur	Malothi	31.28481	76.91280556	Dugwell	3.5	0	Shallow	25/29	Basic
27	Bilaspur	Jerakh	31.37736	76.83836111	Dugwell	10	0.55	Shallow	22/28	Basic
28	Bilaspur	Bassi	31.32478	76.85625	Handpump	NA	NA	Shallow	24/29	Basic
29	Bilaspur	Kiarian	31.2715	76.70475	Handpump	NA	NA	Shallow	26/28	Basic
30	Solan	Dolru	31.17961	76.78386111	Handpump	NA	NA	Shallow	27/29	Basic
31	Bilaspur	Bohai	31.23475	76.66936111	Handpump	NA	NA	Shallow	25/31	Basic
32	Bilaspur	Janali	31.24711	76.61988889	Handpump	NA	NA	Shallow	27/31	Basic
33	Bilaspur	Panj Pojra	31.28175	76.57605556	Handpump	NA	NA	Shallow	29/31	Basic
34	Bilaspur	Nella	31.42075	76.39897222	Dugwell	10.66	0.55	Shallow	27/30	Basic+Heavy Metal
Springs						Discharge (LPS)				
35	Bilaspur	on Road/ Dalhi	31.38553	76.77086111	Spring	2		Shallow	18/31	Basic
36	Bilaspur	Binaula	31.37564	76.79491667	Spring	1.45		Shallow	24/32	Basic
37	Bilaspur	Badkishan	31.30397	76.8065	Spring	Meagre		Shallow	18/21	Basic
38	Bilaspur	Namhol	31.25542	76.86141667	Spring	Meagre		Shallow	18/24	Basic+Heavy Metal
39	Solan	Bhararighat	31.24728	76.88330556	Spring	0.3		Shallow	19/24	Basic
40	Solan	Ghundan	31.22881	76.90088889	Spring	0.14		Shallow	20/24	Basic
41	Solan	Darlaghat	31.21897	76.94386111	Spring	0.2		Shallow	22/31	Basic
42	Bilaspur	Tepra	31.23183	76.86519444	Spring	Meagre		Shallow	20/28	Basic
43	Bilaspur	Markandey	31.32622	76.81238889	Spring	Meagre		Shallow	22/28	Basic
44	Bilaspur	Solag	31.34711	76.83783333	Spring	Meagre		Shallow	21/28	Basic
45	Bilaspur	Tuhnu	31.32486	76.85622222	Spring	Meagre		Shallow	21/29	Basic
46	Bilaspur	Bhedali	31.22331	76.78008333	Spring	0.2		Shallow	22/28	Basic
47	Bilaspur	Jarlu	31.25008	76.72222222	Spring	Meagre		Shallow	21/24	Basic
48	Bilaspur	Kiarian	31.26486	76.70791667	Spring	Meagre		Shallow	21/24	Basic
49	Solan	Bhini	31.18572	76.74791667	Spring	0.90lpm		Shallow	22/26	Basic
50	Solan	Barog	31.11639	76.77802778	Spring	0.3		Shallow	19/24	Basic+Heavy Metal
51	Solan	Chiachi	31.06056	76.84980556	Spring	Meagre		Shallow	21/24	Basic
52	Bilaspur	Bahlam	31.19842	76.77447222	Spring	Meagre		Shallow	21/24	Basic
53	Bilaspur	Mayoth	31.26038	76.60358611	Spring	Meagre		Shallow	24/28	Basic
54	Bilaspur	Mandhiyali	31.30319	76.54675	Spring	0.1		Shallow	23/28	Basic
55	Bilaspur	on road	31.32897	76.5265	Spring	0.1		Shallow	24/28	Basic
56	Bilaspur	Tursuh	31.38753	76.43491667	Spring	Meagre		Shallow	24/24	Basic

All the collected samples are to be analyzed at chemical laboratory of CGWB, North Western Himalayan Region, Jammu, (J&K), by adopting Standard methods of analysis (APHA)

pH

The pH is a numerical scale which express the degree of acidity or alkalinity of solution and represented by the equation $pH= \log 1/aH^{+} = -\log aH^{+}$ or in other words pH may be defined as negative logarithmic of Hydrogen ion concentration.

Electrical conductivity

Electrical Conductivity can be defined as the ability of a solution to conduct an electric current and measured in micromhos /cm and reported at 25°C. Electrical Conductivity is a function of concentration of ions, charge and ionic mobility Electrical Conductivity is approximately indicative of ionic strength.

Chloride

Chloride is one of the most common constituent in groundwater and very stable as compared to other ions like SO_4, HCO_3, NO_3 etc.

Nitrate

Nitrate is one of the important pollution related parameter. Nitrate is the end product of the aerobic oxidation of nitrogen compounds. Mainly it is contributed by nitrogenous fertilizers, decomposition of organic matter in the soil, fixation of nitrogen by bacteria etc. Human and animal excreta may also add nitrate to water by bacterial decomposition. For drinking water maximum permissible limit of nitrate is 45 mg/l as per BIS 1991-Rev-2007.

High concentration of nitrate causes infant methaemoglobinaemia (Blue baby disease).Very high concentration of Nitrate causes gastric cancer and affects central nervous and cardiovascular system.

Fluoride

Fluoride is an important water quality parameter for accessing the water quality for drinking purpose. Fluoride is more abundant than chloride in the igneous and as well as sedimentary rocks. Fluoride differs from other halogen members due to high electronegative character.

Calcium

The calcium is a major constituent of various rocks. The precipitates (limestone) contain about 27.2% of calcium ions. It is one of the most common constituent present in natural water. Calcium minerals associated with sodium, aluminium, silica, sulphate, carbonate and Fluoride. Maximum permissible limit for calcium is 200 mg/l (Fig-2.25).

Magnesium

Magnesium is the 8^{th} most abundant element in the solar system. It is available in various rocks .The maximum concentration of Magnesium, 4.53 % is found in the evaporates of sedimentary rocks. The concentration of Magnesium in natural water is mainly controlled by dissolved CO_2.

The concentration of Magnesium in springs, Ground Water Aquifers (Shallow & Deep) are within the maximum permissible of BIS (100 mg/l) for drinking water.

Sodium

Sodium is the abundant of the alkali element in the earth's crust. Most of the Sodium occurs in the Feldspars, Mica, amphiboles and Pyroxenes.

Potassium

Potassium in sedimentary rock is more abundant than Sodium. The main potassium minerals containing silicates are Orthoclase, micas. Evaporate beds may contain potassium salts.

Total Hardness (TH)

High concentration of carbonates, bicarbonates of calcium and magnesium, in ground water causes hardness. It causes scaling in water supply lines. High concentration of hardness in ground water is social economic problem; hence it is also an important water quality parameter. Hardness of water is the capacity to neutralize soap and is mainly caused by carbonates and bicarbonates of calcium, magnesium.

The results of chemical analysis of water samples collected during study are awaited from Chemical Lab. The results and spatial distribution thereof will be updated in the report as soon as the results are received.

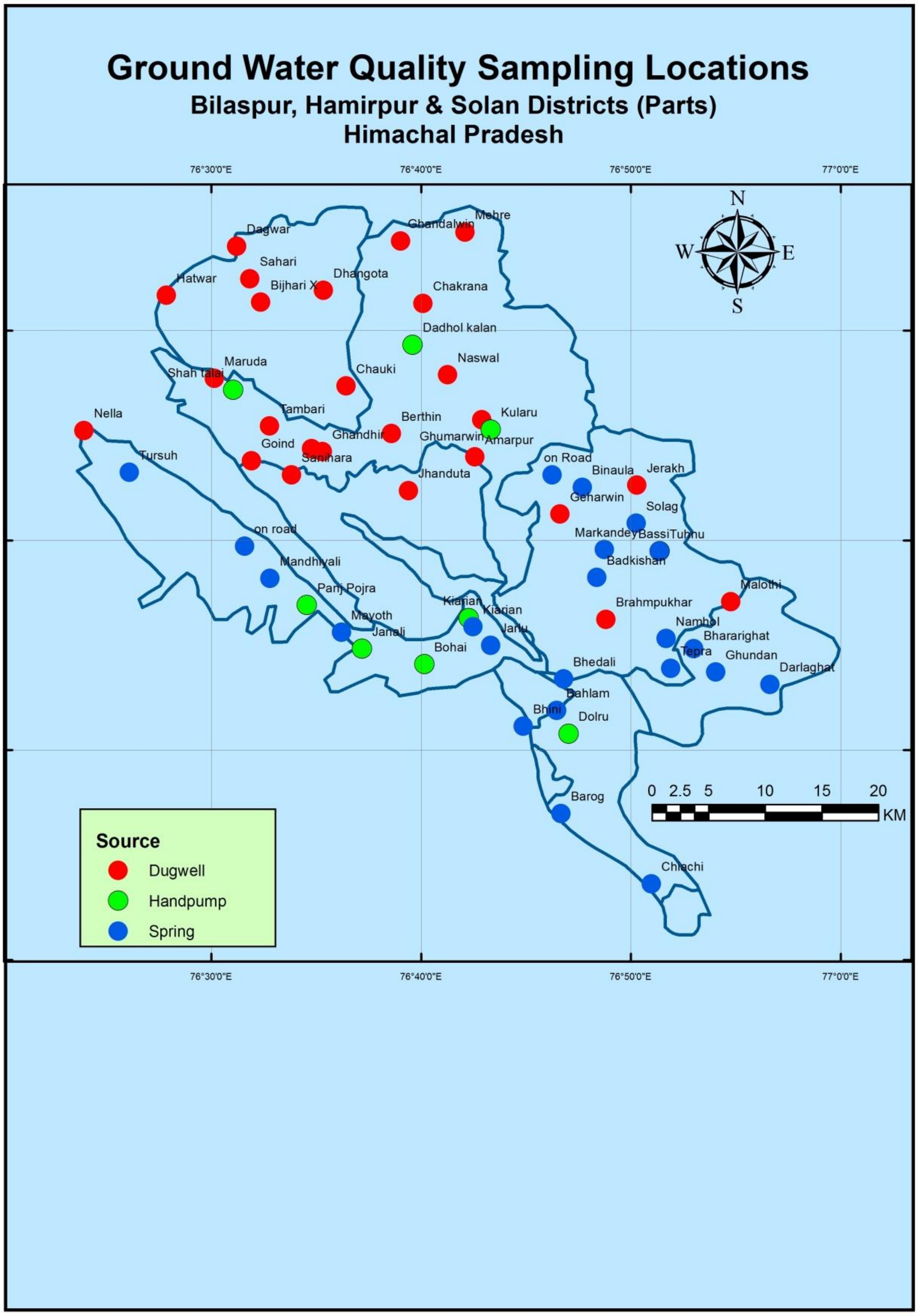


Fig. 24: Locations of GWMS in study area.

3.4 Geophysical Data:

The objectives of geophysical surveys were

- ❖ To ascertain sub-surface information and aquifer deposition up to 300m depth in softrock and 200m depth in hard rock,
- ❖ To provide detailed site-specific recommendations based on survey results for drilling or not-drilling the boreholes at the sites proposed and given for the survey, and also,
- ❖ To provide tentative aquifer water quality inferred from VES interpretation.

3.4.1Geophysical Investigations

The surface geophysical methods sense the subsurface remotely. Therefore the depth and dimension of the subsurface target, its position with respect to the sensor at the surface, physical property contrast of the target with the surrounding and scale and orientation of measurement controls the response. The resolution reduces with depth and to obtain a resolvable response from deeper target, it is also necessary that the deeper target has distinct resistivity contrast and an adequate dimension. To reduce the ambiguities, constrain the interpretation and enhance precision, it is necessary to design the data acquisition procedure to a possible extent which could sense the variations in physical properties of the deeper target and the surrounding. The incongruity in data acquisition and the target character brings in non-uniqueness in inversion and thus ambiguity creeps in hydrogeological transformation of geophysical response. Coming out with a positive solution satisfying the conditions is quite a difficult geophysical task and hence the approach becomes a complex geophysical endeavour. For example, to estimate the weathered zone thickness a vertical electrical sounding with conventional current electrode spacings is adequate, but to qualitatively estimate the depth of saturated fractured zone aquifers, a close spacing observation is essential, and even that too may not suffice to yield the desired results. Thus, the success in geophysical investigations for weathered and fractured zone aquifer mapping in hard rocks depends on a number of factors. They are

- Local terrain and hydrogeological conditions vis-a-vis point of demand,
- Approachability to the area/site for survey, cultural noise, scale and quantum of measurements,
- Geophysical method and technique used and their inherent limitations, and
- Standardization of geophysical parameters and defining the geophysical signatures for hydrogeological transformation

The geophysical exploration method of electrical resistivity, having direct bearing on the presence of groundwater, has been used widely in hard rock, to identify the weathered zone and saprolite, their thicknesses and aquifer characteristics, depth to compact formation, saturated fractured zones, their lateral extension and orientation and other structures like basic dyke and quartz reef controlling the groundwater conditions and delineation of granular zones and clays. In Deccan Trap basaltic terrain having a good number of stacked basalt flows it is used to delineate the weathered zone, vesicular and fractured basalts and the massive basalts. However, as already mentioned, it is extremely difficult to delineate the deeper relatively less resistive saturated fractured zones, which are hardly a metre thick and surrounded by highly resistive compact rock and the productive vesicular and fractured basalts underlying the massive basalts. In soft rock the method is used to delineate the granular aquifers and the clays. The method is also used to qualitatively assess the aquifer water quality in terms of salinity. In the present investigation, Vertical Electrical Sounding (VES) technique of resistivity method was used to delineate the aquifers. It is explained below.

3.4.2 Vertical Electrical Sounding (VES)

The Vertical Electrical Soundings (VES) were carried out using Schlumberger configuration (Figure 21). The only modification made in sounding data collection was to increase the current electrode spacings at a smaller increment of 5 m up to AB/2:100 m, increment of 10 m up to AB/2 : 200 m and there after it was 20 m and the potential electrode spacing was increased at the minimum to avoid static shifts. In general where there is no space constraint, the VES were spread in strike direction of the formation or structure. The curves were interpreted for the layered-earth model as well as for fracture depth determination using empirical methods of 'current increase', 'curve –break' and 'factor-method' wherever required.

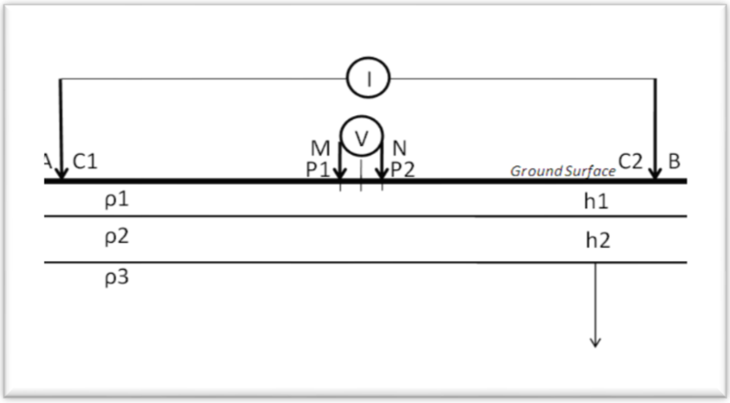


Figure 25: The Schlumberger configuration of collinear electrodes used for conducting vertical electrical sounding (VES). AB separation is increased in a sequence of close increments up to 600 to 1000 m. MN collinear with AB is kept fixed at the centre of the configuration at a maximum spacing of AB/5. MN is changed when the potential values measured are too low for the instrument.

3.4.3 Field Procedure

The maximum current electrode spacing (AB) used was 600 to 700 m for the Schlumberger configuration of electrodes. The VES were carried out using indigenous instruments CRM AUTO-C 500 Resistivity Meter, Pune. In Schlumberger VES, the potential electrodes symmetrically placed at the centre of configuration with a spacing equal to 1/5th the current electrode spacing are kept fixed and the measurements are made by successively increasing the current electrode spacing to increase the depth of investigation. The potential electrode spacing is increased when the potential value drops substantially compared to the measurement accuracy of the instrument. The apparent resistivity values for each current electrode spacing is calculated by multiplying the resistance 'R' (δV/I) by Geometric Factor for that current and potential electrode spacings of Schlumberger configuration. The apparent resistivity values thus obtained with increasing values of current electrode separation are plotted as graphs and interpreted to estimate the thickness and resistivity of the sub-surface layers.

3.5 VES Data Processing and Interpretation

Vertical Electrical Sounding (VES)

The VES field curves comprise apparent resistivity (ρa) values plotted against half current electrode separations (AB/2) on 62.5 mm double-log transparent graph paper. The distorted curves, if any, were smoothened manually. The quantitative interpretation of VES field curves to determine the thickness and resistivities of the sub-surface layers is done at two stages. First it is manually interpreted and then the curves are interpreted on computer by IX1D software using the layer model generated through manual interpretation as initial guess. The curves can also be interpreted directly using Occam's inversion and few-layer inversion schemes. For the present study computer based direct inversion was adopted. The techniques of inversion of VES using the computer software are described below.

Computer Based Inversion

This method is based on computer based technique, which provides more flexibility to compare different scenarios. In this method, sounding data are analyzed with computer based automatic iterative curve fitting technique. It is a forward and inverse modeling program for interpreting resistivity sounding data in terms of layered earth (1D) model. The field VES data as apparent resistivity (pa) versus spacing (AB/2) and an initial guess model of layer parameters obtained from manual interpretation are entered. The curve generated from guess model is compared with the field curve. In case the field curve and the computer generated curve based on guess model are not matching with RMS difference value more than 5%, the layer parameters of the guess model are automatically modified to get the best fit within the defined RMS value. It is an iterative process and continues till a satisfactory fit is obtained. The method is also used for forward modeling to generate synthetic VES curves from borehole electrical resistivity log data. It is used to assess the types of field VES curve expected from the area and also the limitations of VES in resolving the layers under prevailing subsurface conditions in the area. Generally the resistivity log presents a large number of layers. Therefore, selected sequence of layers observed in the log is combined through computation of transverse resistance and longitudinal conductance and a mean resistivity for the combined layer is obtained. Since computation of true resistivity from log is a tedious process, for small diameter borehole and fresh water formations, the 64" Normal apparent resistivities against the layers are taken as the true resistivities for computation of combined-layer mean resistivities. In this way the log is reduced to 'few-layer' model. The resistivity of surface layer which is not obtained from log is taken from nearby field VES. The synthetic VES curve is generated from the 'few-layer' model so obtained from the log. The synthetic curve is compared with

the smoothened VES field curve and if matches satisfactorily with RMS difference within limit (less than 5%), the log generated layer model are correlated with the field VES generated layer model and the litho units encountered in the borehole are assigned with the resistivity ranges obtained from VES. The layer resistivities obtained from VES are weighted average and also the general direction of current flow is different from logging, therefore VES generated model need not always match with the layer model obtained from log data. For the present study the computer based interpretation was done using IX1D v3 software from Interpex Ltd. (Golden, Colorado, USA). The static shifts in the VES curve segments for shorter and longer potential electrode spacing were considered while using the software. The inversion was carried out through ridge regression technique. For smooth model eneration Occam's inversion was used. For direct inversion, i.e., automatic estimation of layered model, Koefoed's approach was applied. It is worth mentioning that the geoelectrical layer interfaces thus obtained need not always match with the hydrogeological or geological layer interfaces. The major problem encountered in interpretation was of transitional resistivity and equivalence. The transition from weathered zone to saprolite and then the compact formation is characterized by a transitional increase in resistivity with depth without clear cut indication of resistivity interfaces in the VES curve. In such cases, where such transition was expected, a layer with intermediate resistivity was introduced, obviously after studying the nearby VES and *priori* local hydrogeological information. The equivalence occurs in the intermediate relatively thin geoelectrical layers. Equivalence means that the thickness and resistivity of the intermediate geoelectrical layer(s) can be changed over a certain range without noticing any change in the VES curve. This indicates that an intermediate layer can be assigned several combinations of thickness and resistivity within a certain range and hence the interpretation becomes non-unique. The equivalence problem cannot be removed without the support from other geophysical methods. It can be minimized using local hydrogeological information. The provision of equivalence analysis provided by IX1D software after multiple iterations was used to determine the range of intermediate layer parameters wherever found necessary. A point to be noted is that in hard rock areas, while conducting VES, once the compact formation or bed rock is sensed with increasing AB/2, the VES curve starts showing a 45^{o} positive slope with abscissa and for further increase of current electrode spacing, the same slope continues. From the VES curve segment with 45^{o} slope no further information on layering can be extracted for the layered earth interpretation. In such a situation, providing precise layered-earth information up to 200 m depth by increasing the spread of VES becomes unrealistic, except that the compact resistive formation continues to depths.

Fractured Zone Identification from VES

Besides the layered earth interpretation, the VES were interpreted for fractured zone identifications using curve break and factor methods. The reduction in resistivity gradient between a pair of consecutive AB/2 values with increase in current input was considered as an indication of fracture presence. It was proved at a few VES locations. For this the conventional resistivity meter or a constant voltage source resistivity meter is more effective. In case of constant current source resistivity meter, the increase in current input is not effectively picked up. For factor analysis of the curve, the ratio of the apparent resistivity at a particular AB/2 to the sum of apparent resistivities of the preceding AB/2s is computed and plotted at that AB/2. The flat portion of the factor curve indicates the presence of fractured zones. A commonality in the occurrence of the breaks or kinks in the VES curve and flat factor curve supports the presence of fractured zone. It is mostly effective for AB/2 less than 100 m. However, in the present investigation the analyses were made up to 200 m AB/2. To use these empirical methods two points are essential. They are: the VES measurement has to be with smaller increment in current electrode spacing and with minimum number of shift or no shift of potential electrode positions. Both these were attempted for the present investigation.

3.6 Hydrogeological inferences from geophysical interpretation

With the help of existing borehole lithological logs wherever available, the estimated layer parameters obtained from the VES data interpretation were standardized and resistivity ranges were generalized for different lithological predominance at the VES sites. It is likely that there will be overlaps in the resistivity ranges because of deviations from these ranges at local level. These ranges were to be considered as a guide and to be ascertained or modified for the local subsurface hydro-geological situations. VEs has been carried out by WAPCOS as in house survey was not possible. The district wise findings are as follows:

Hamirpur

In district Hamirpur only 3 VES were conducted over W-E stretch of 12 km between the Rivers Man and Kunah which are tributaries to River Beas. The area is beween 2 NW-SE trending thrusts –Barsar Thrust towards west of River Man and Gambhar Thrust towards east of River Kunah. The area is occupied by Middle and Lower Siwalik sediments comprising sandstone and clay. The Upper Siwaliks are exposed towards west of Barsar Thrust up to the NW-SE fault passing through Thesar –Lathiyani and Naloi.

The VES 15, 16 and 17 are at elevations 757, 844 and 693 m amsl. The cross-section through these 3 VES reveals the presence of moderately high (94 ohm.m) resistivity at VES 15 and 16 up to 161 m and 59 m respectively. It is underlain by layers of still higher resistivity. At VES 17, a sand clay layer is present upto 24 m depth underlain by high resistivity layer. The high resistivity deeper layer represents the compact sandstone. The considerably thick layer of 94 ohm.m resistivity at VES 15 located near Man river may form aquifer.

Three VES were conducted in Hamirpur district. They are in a line between Barsar and Gambhar Thrusts. With the limited information available from 3 VES it can be said that the site near Man river and Barsar Thrust appears better compared to that near Gambhar Thrust. Besides, the VES 16 located between these thrusts is at a higher elevation, though hold a layer of 94 ohm.m and 49 m thickness may not be suitable because of higher elevation and on water divide. The VES site specific recommendations are given in interpretation table.

Bilaspur

Bilaspur district is southeast of Una and south of Hamirpur districts. A total of 10 VES were conducted within North Latitudes 31° 14’ 05” and 31° 28’ 17” and 76° 24’ 11” and 76° 54’ 51” in the blocks of Sri Naina Deviji, Bilaspur Sadar, Ghumarwin and Jhandutta The surveyed area also encompasses Govind Sagar reservoir area. The area is mostly occupied by highly folded and thrusted Siwalik sequence of (Upper, Middle and Lower) sediments. The VES 1, 3, 4, 5, 6, 7 and 9 are in Siwaliks and VES 2, 8 and 10 are in the contact zone of Lower Tertiaries (Subathu and Dagshai) and the metasediments.

There are 4 boreholes viz., Dobat, Kikerwala, Harkukar and Panjgain located near VES 9, 3, 6 and 2 respectively.

The Dobat BH (DD: 92.3 m) encountered clay throughout the depth with minor mixing of boulder at the top and sand at the bottom. The VES 9 is located about 7 km east of the BH close to NWSE fault passing through Thesar – Lathiyani and Naloi. The VES 9 does not show any presence of clay. A thick (144 m) layer of resistivity 70 ohm.m with bottom at 155 m is delineated. It is underlain by highly resistive compact sandstone. In all probability the VES is in Middle Siwalik while the BH is in Upper Siwalik.

The BH Kikerwala (DD: 103 m) is located very close to VES 3. The BH encountered boulder and gravel at the top, followed by clay up to 12 m, coarse sand up to 18 m, sand with clay up to 36 m, clay with sand up to 57 m , sand and clay up to 63 m , boulders up to 66 m and clay with sand up to 103 m. The VES 3 delineates sands with 49 ohm.m resistivity up to 53 m and then sediments of 35 ohm.m resistivity. The sands and mixing of clays is inferred from VES results and the layers hold potential aquifers.

The Harkukar BH (DD: 101 m) reveals the presence of clay with minor sand throughout the depth drilled. The VES 6 is located about 1.5 km NE of the BH. The VES infers high resistivity (102 ohm.m) sand and boulder up to 48 m depth. It is underlain by a thick (103 m) layer of 40 ohm.m resistivity with bottom depth 151 m. Further down the layer commencing at 151 m depth is with resistivity 81 ohm.m. The VES does not represent the lithological conditions encountered in the BH. First of all, the BH is at 670 m elevation and VES is at 697 m elevation. The BH is located in the alluvium locally deposited by the Seer Khadd (stream). It is supported by the results of VES 5 which is located very close to Seer Khadd. The VEs 5 infers the presence of a layer with 25 ohm.m resistivity in the depth range 12-54 m. It is supported by the lithological information obtained from Harkukar BH.

The Panjgain BH (DD: 104.6 m) is located near VES 2. The VES is located about 3 km SW of BH. The BH encountered clay and sand throughout the depth drilled. Beyond 50 m depth it is totally clayey. VES 2 does not reflect any presence of clay. Instead a layer of 80 ohm.m resistivity is delineated in the depth range 4 to 33 m. It may form aquifer. Overall the VES-BH correlation has revealed that though the lithological logs of BH may help define the litho-resistivities but it is necessary to conduct spot VES at the proposed drilling site to understand the possible lithological conditions and decide on the suitability of the site for drilling.

Chapter-IV

4.0 DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

All the available data have been validated and optimized for consideration to generate the aquifer map in study area. The wells optimization part is done based on the maximum depth & litholog The deepest well in each quadrant is selected and plotted on the map of 1.50000 scale with 5’X5’grid (9 x 9km) and is shown in Fig-3.0.

4.1 Aquifer Parameter Ranges

In study area the exploration drilling was carried out by CGWB, the aquifer parameters range extracted and given in below Table-2.13.

Table 17: Summary of exploration and hydraulic details in study area

Location	LATITUDE	LONGITUDE	SWL (m)	Discharge (lpm)	Drawdown (m)	Transmissivity (m^3/day)	Depth (m)
Panjgain	31.38866667	76.83425333	1.65	90	23.7	8.47	104.6
Harkukar	31.43952778	76.71838889	4.46	90	-	$2.6x10^{-5}$	101
Dehra Malkota	31.58729	76.719055	1.93	90	-	$3.15X10^{-6}$	104.7
Dobat	31.30086111	76.46650833	17	NIL	NIL	NA	92.3
Kikerwala	31.227547	76.59178	18.45	740	1.5	493.3	103
Siyola	31.295217	76.807578	36.55	833	6.11	147	115
Ghagus	31.375827	76.805592	3.03	1245	2.6	1218.21	31.8
Tali	31.275	76.72083333	NA	1	NIL	NA	74

3.2 Aquifer Geometry

To understand the lithological frame work and aquifer disposition in the sub surface aquifers, the litholog data of wells drilled by CGWB are used to compile, optimized and modeled into 2D (Fig. 26-29) & 3D synoptic picture(Fig. 30 & 31) by using the Surfer and Corel Draw software. Along with the lithological data, VES data have been also used to identify the prospect zones in areas. The lithological model has been prepared along with positions of exploratory wells, shown in Fig-26-29. The 3D lithological fence diagram has been prepared along with distribution of wells are shown in Fig-30 & 31

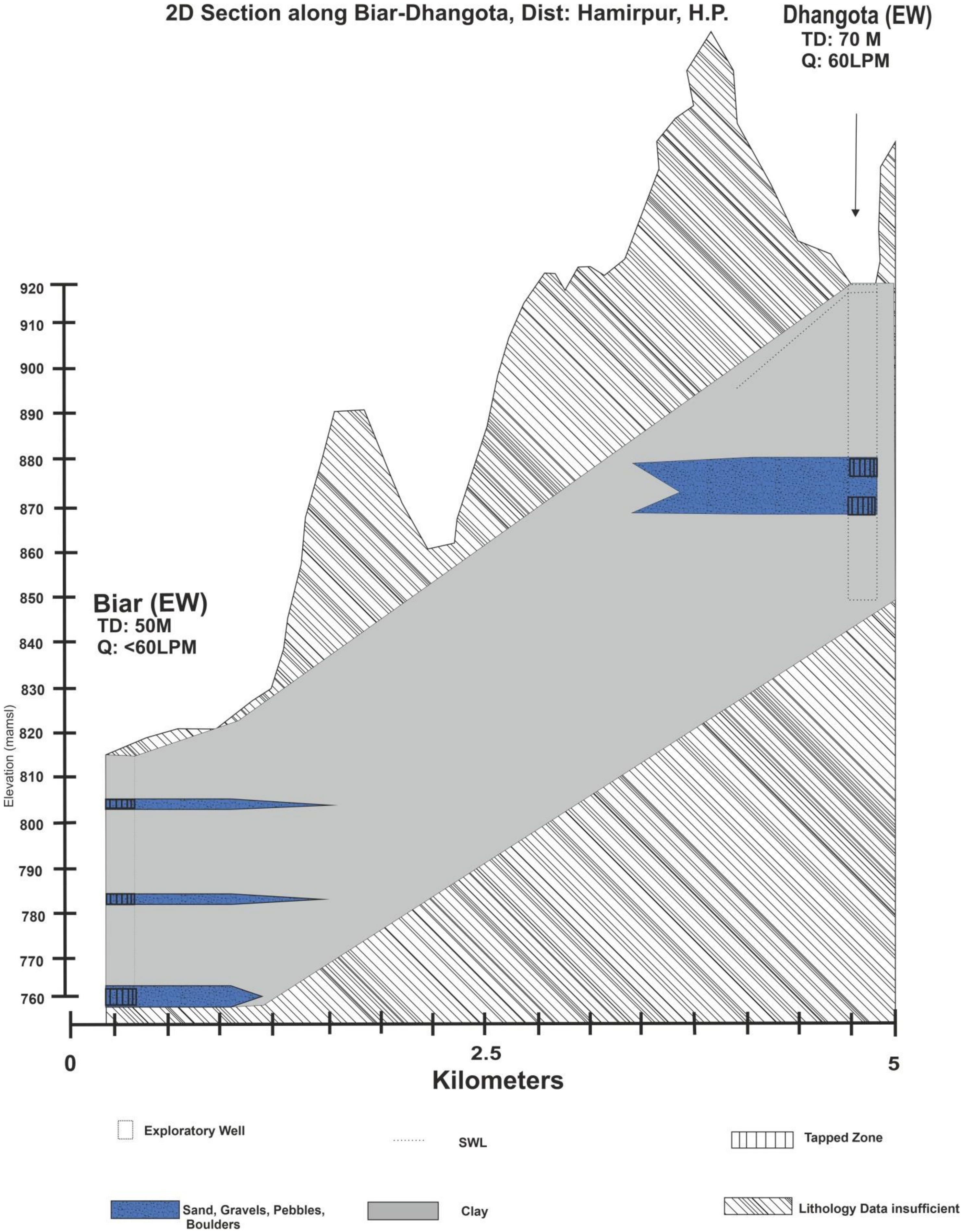


Fig: 26: Two cross section between Biar & Dhangota EW

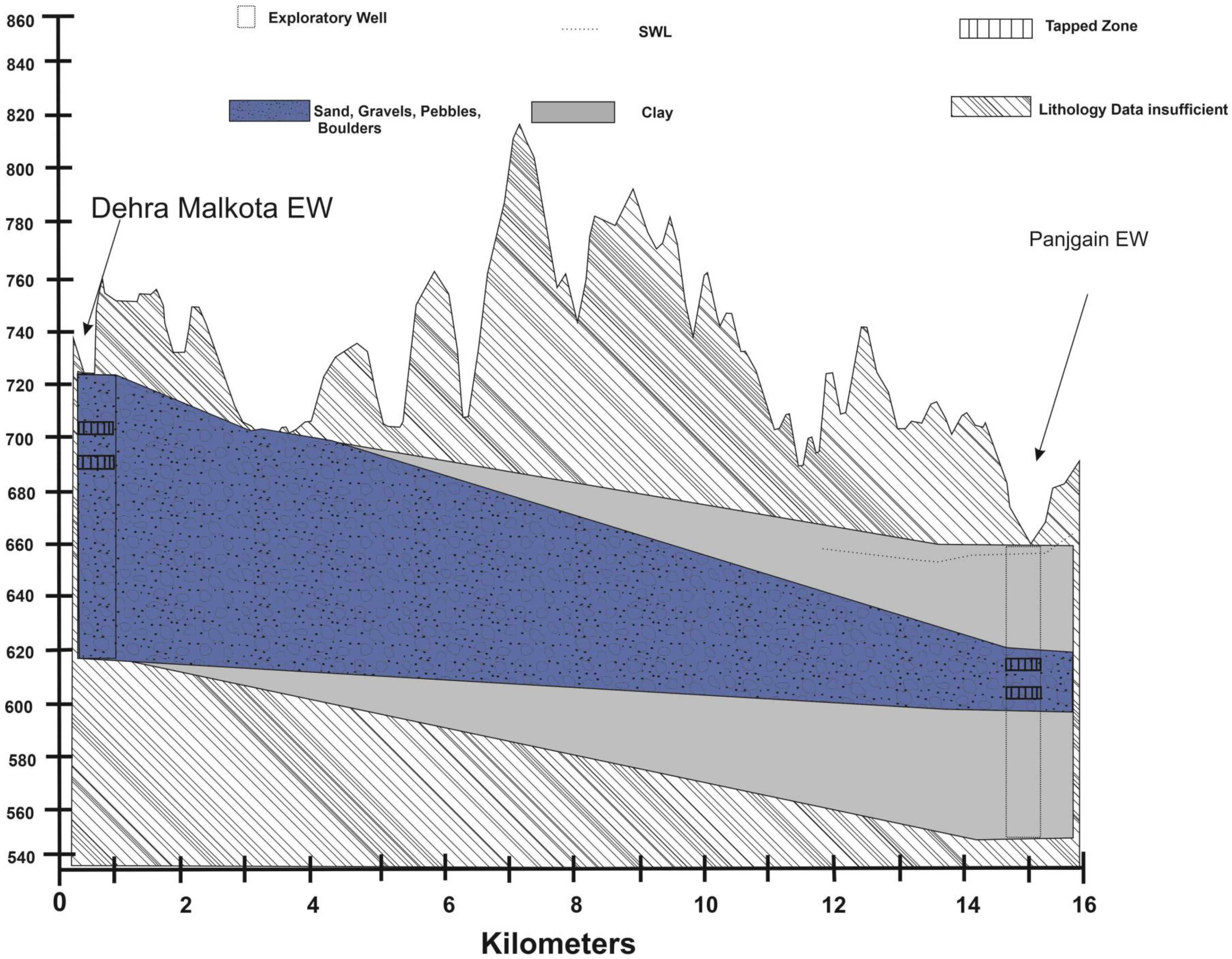


Fig 27: Cross Section alongDehra Malkota- Panjgain EW

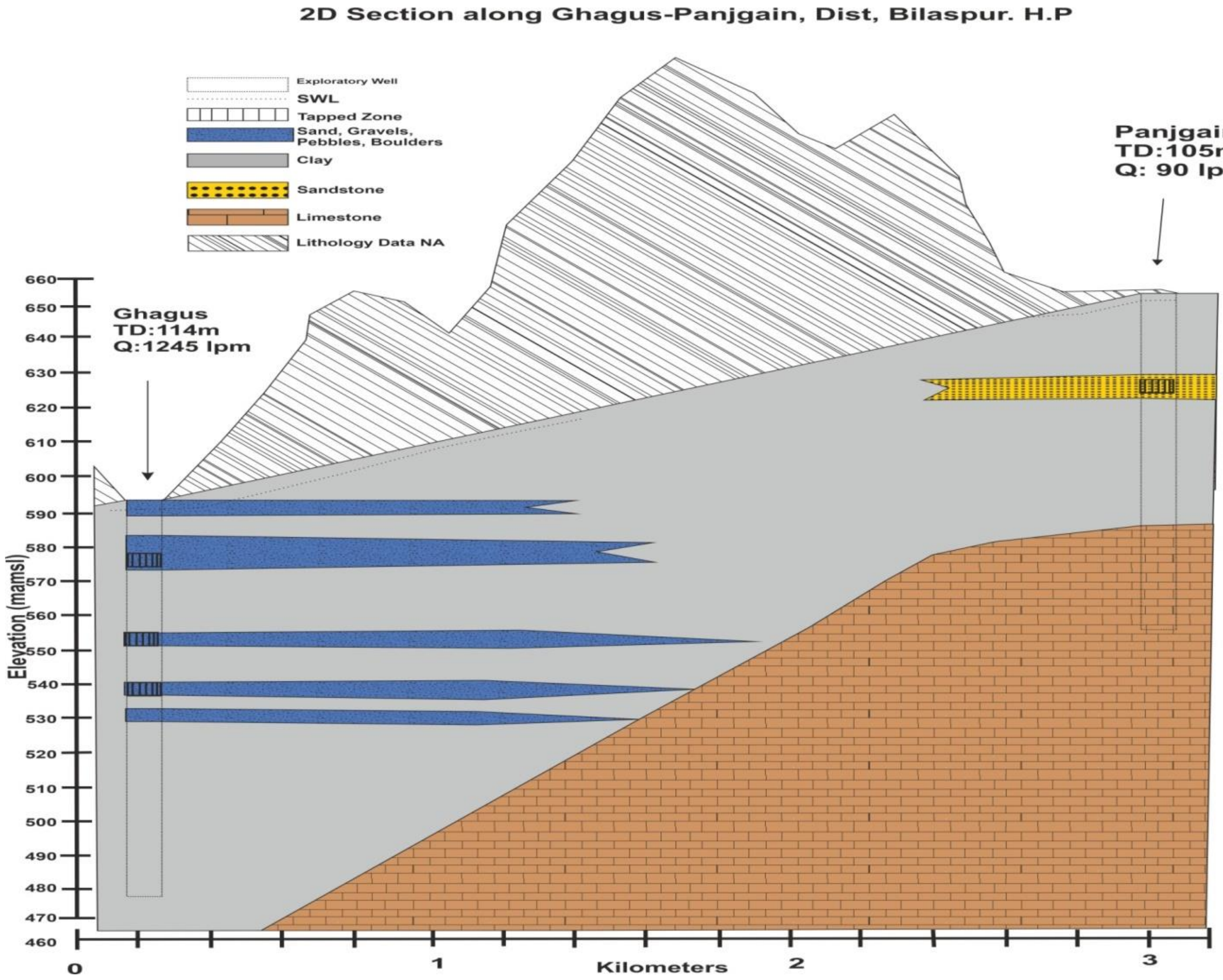


Fig 28: Two dimensional cross section along Ghagus-Panjgain EW

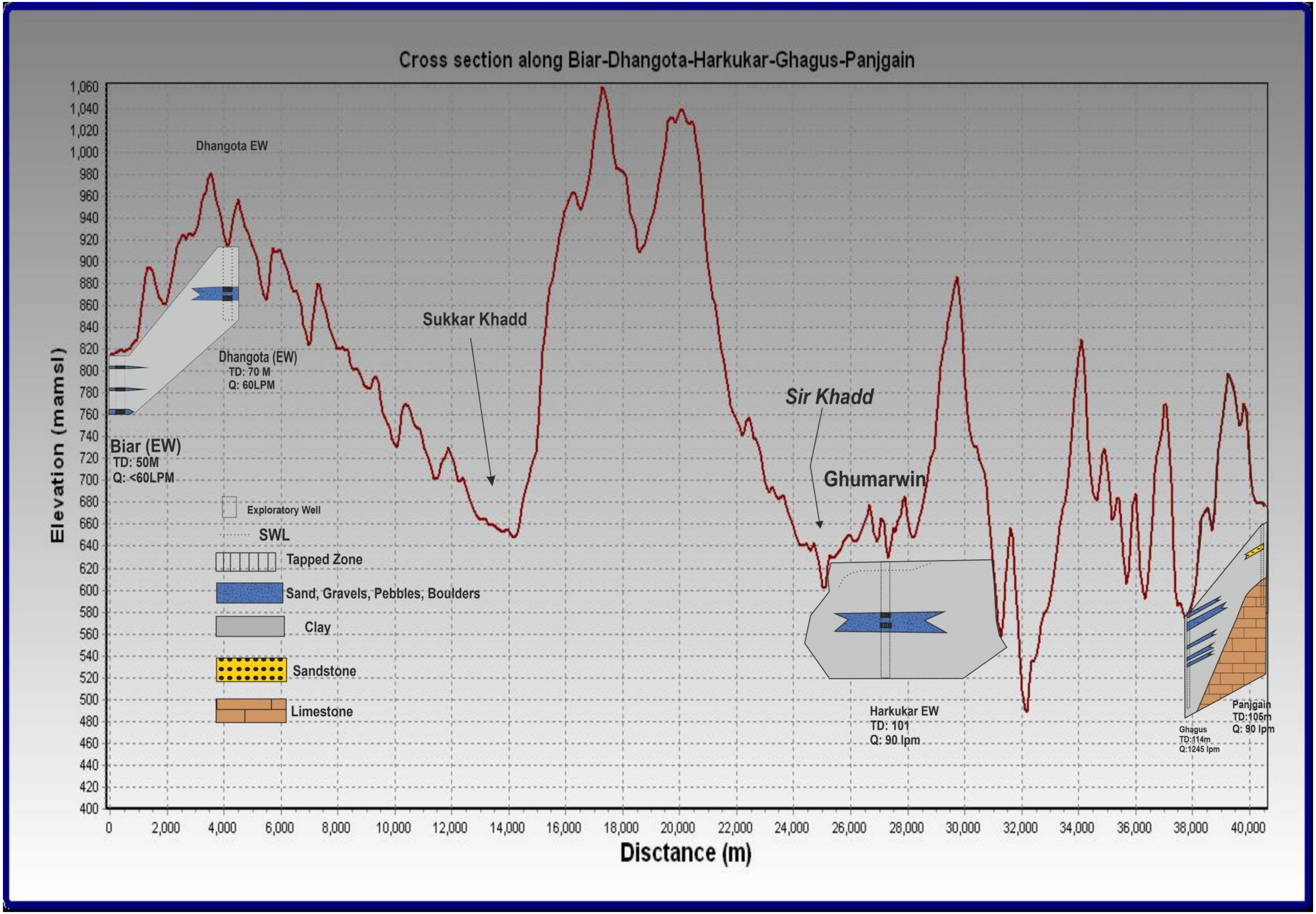


Fig 28: An overview of the 2D cross section plotted against the elevation profile in the study area

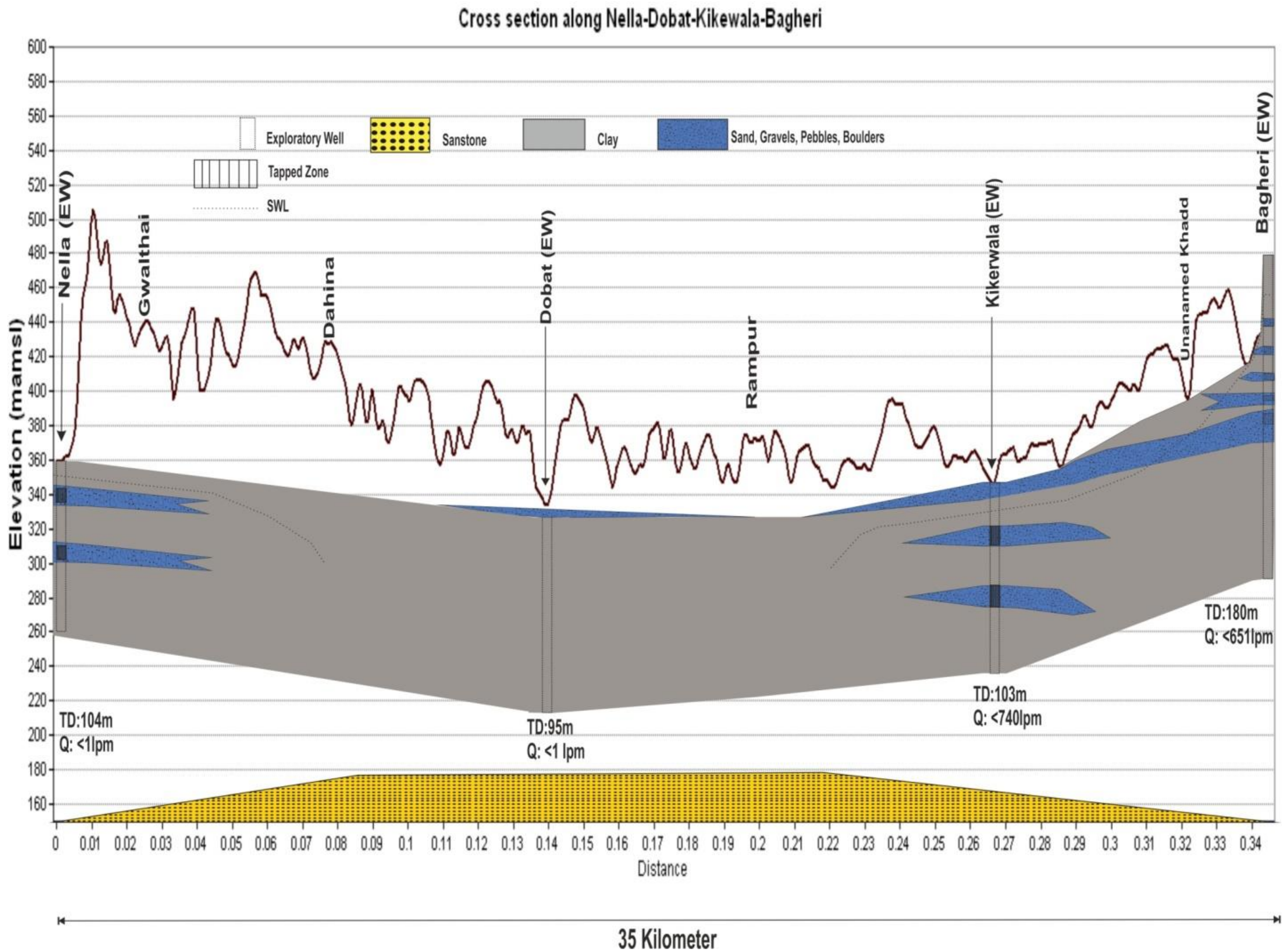


Fig 29: Two dimensional Cross section along the Nella-Dobat-Kikerwala-Bhgheri

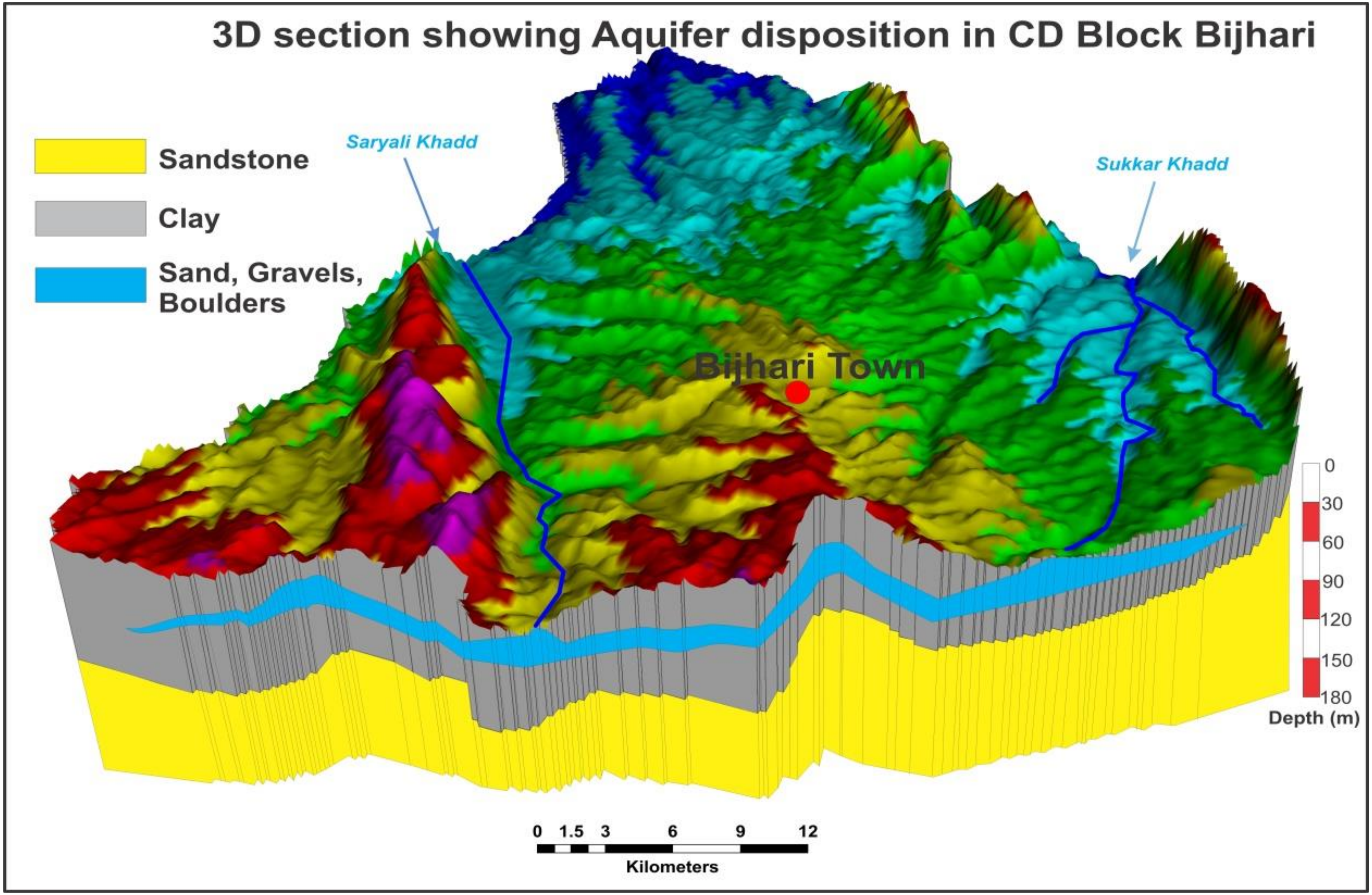


Fig 30: A three dimensional image showing aquifer disposition for CD Block Bijhari

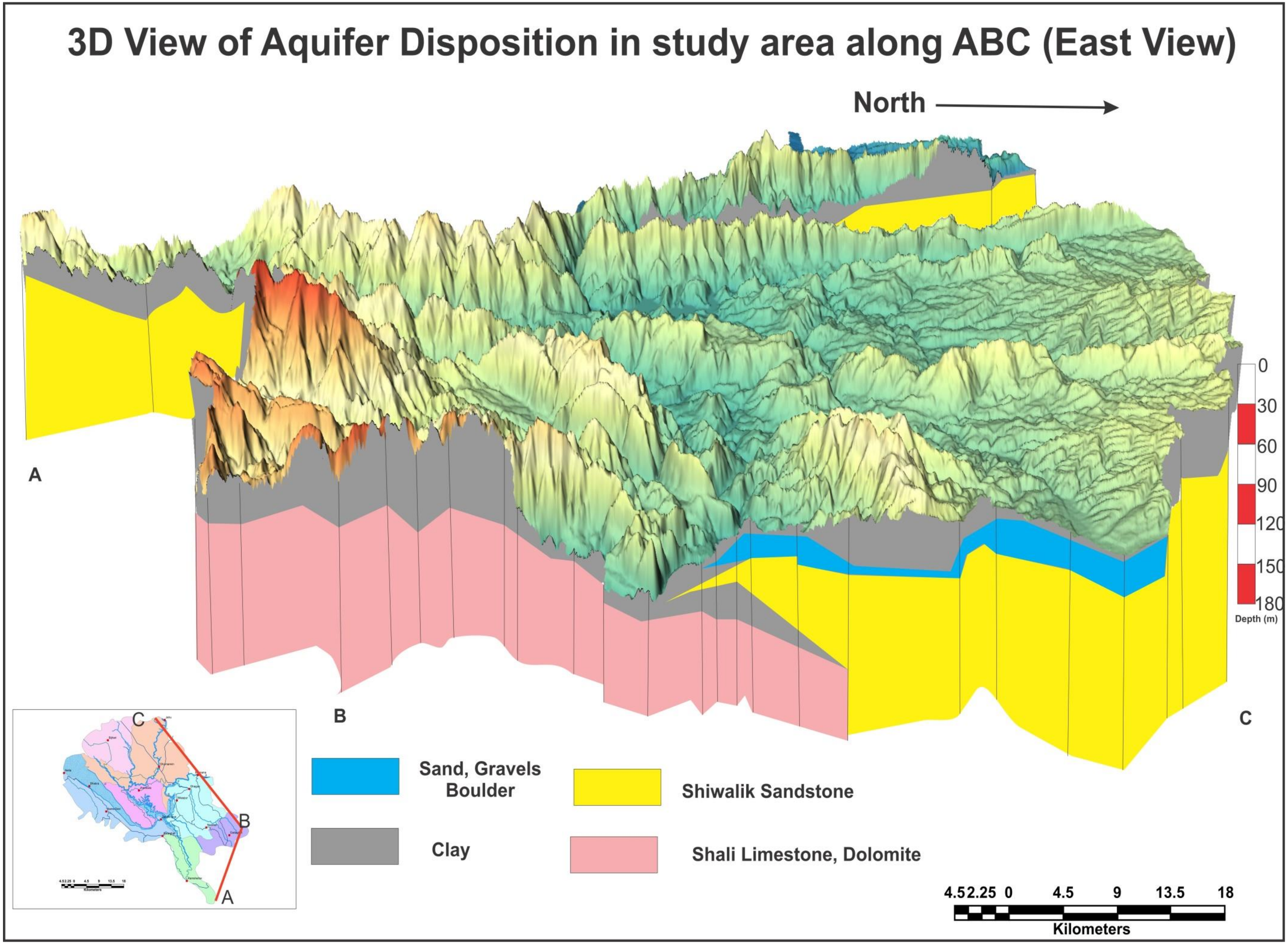


Fig 31: A three dimensional image showing aquifer disposition of all three major aquifer in the study area

4.3 Aquifer Disposition: The lithology data of bore wells drilled under NAQUIM and previously drilled borehole was compiled. The lithological data is available for shallow aquifers only as most of these bore wells were drilled up to 180 meters only. Further, the VES data has been interpreted using Computer inversion technic to mark the boundaries of potential zone in areas. The 3-D llitho-models prepared using Surfer and Corel Draw shows disposition of clay, sand and aquifer layers. The Lower Part (Southern part of study area), the encountered strata are mostly clay only.. The discharge of bore wells from this area is very low (>1 lpm). The subsurface layers in eastern part of the area are chaotic mixtures of rocks ranging from sedimentary to crystalline in origin. As evident from the 2-D cross section, the aquifers in the area are separated by a thick clay layer of roughly 30-35 meters. A no. of bore wells tapping different aquifers is showing different level of discharge. Water level in the area is generally following the surface topography. Interpretation from VES carried out district wise is as follows:

Bilaspur: In parts of Bilaspur district 10 VES were conducted. The interpreted results of VES reveal the presenc e of thick sand/sandstone layer at VES 6 and 9 located on either side of Govind Sagar Reservoir. The layer with 40 ohm.m resistivity in the depth range 48-151 m at VES 6 and the layer with 70 ohm/m resistivity in the depth range 12-155 m at VES 9 are expected to form potential aquifers.

Hamirpur: Three VES were conducted in Hamirpur district. They are in a line between Barsar and Gambhar Thrusts. With the limited information available from 3 VES it can be said that the site near Man river and Barsar Thrust appears better compared to that near Gambhar Thrust. Besides, the VES 16 located between these thrusts is at a higher elevation, though hold a layer of 94 ohm.m and 49 m thickness may not be suitable because of higher elevation and on water divide.

Solan: The VES are mostly located along the NW-SE trending Sirsa and Nalagarh Thrusts. Near Nalagarh a group of VES indicates the localized presence of thick clay extending to depths beyond 200 m. The lithological logs of boreholes and their correlation with the existing nearby boreholes indicate that the layer resistivities less than 20 ohm.m are associated with predominance of clay. The layer resistivities which are indicative of the presence of sand zone aquifer could be up to about 80 ohm.m. The layer resistivities higher than 80 ohm.m, occurring at depths are indicative of sandstones and attempts may be made to drill test borehole deeper through the sandstones.

4.4 GROUND WATER RESOURCES

Rainfall is the major source recharge to the groundwater body apart from the influent seepage from the rivers, irrigated fields and inflow from upland areas. The discharge from ground water mainly takes place from wells and tube wells; effluent seepages of ground water in the form of springs and base flow in streams.

Most of the study area is havinf more than 20% slope. Based on SRTM, slope map of the area was prepared and areas having more than 20% slope were excluded. Out of 7 CD bLock in the study area, only three block can be assessed for Ground Water Resource Estimation. Details are as below:

Table 18: Ground Water Resource in the study areas (As per GEC-15) (Continued)

Block	Recharge from Rainfall (monsoon)	Recharge from Other Sources (Monsoon)	Recharge from Rainfall (Non-monsoon)	Recharge from Other Sources (Non Monsoon)	Total Recharge	Provision for Natural Discharge	Net Ground water availability
Bijhari	3201	13	1241	26	4481	448	4033
Ghumarwin	10748	274	1840	549	13410	1341	12069
Naina Devi	1947	45	675	89	2755	275	2479

Table 19: Ground Water Resource in the study areas (As per GEC-15)

Block	Net Ground water availability	Gross Irrigation draft	Domestic+ Industrial Draft	Draft of All uses	Domestic requirement upto 2025	Net GW availability for future irrigation	Stage of GW development
Bijhari	4033	155	338	493	1441	2437	**12%**
Ghumarwin	12069	3292	819	4111	2353	6424	**34%**
Naina Devi	2479	534	243	777	1680	265	**31%**

(All figures in Hectare meter)

The stage of ground water development of the entire three blocks assessed falls under **"Safe Category".** This suggests that further ground water development can take place in the study area.

5.0 GROUND WATER RELATED ISSUES

Major ground water related issues and their manifestation in area are:

1) Siltation of surface Water Bodies
   - Due to excessive runoff, topography of the area, and anthropogenic change of land use in areas, all the surface water bodies are receive high level of silt. This siltation hamper the rate of ground water recharge form these bodies as well increase the maintenance cost of these water bodies
2) High degree of rainfall runoff
   - Due to sloping topography of the areas, type of soil, concentrated period of rainfall, most of the precipitation is lost as surface runoff without significant contribution to infiltration
3) Drying of Springs
   - Majority of the springs in the area are losing discharge, especially during lean season. The man culprit behind drying of springs is Energization nearby groundwater abstraction structures to cope with the increasing demand, Change in land use pattern in the watershed as well as recharge area of he springs and ecological degradation caused by human activities.
4) Low Stage of Ground Water Development
   - Ground water development in study areas is very low. In few of the blocks, stage of groundwater extraction is less than 15%. Most of the population is dependent on surface water for both domestic as well as irrigation use. It si manly due to reason that groundwater potential in the area is lo to moderate.

6.0 AQUIFER MANAGEMENT PLAN

An outline of the Aquifer Management Plan includes details regarding population, rainfall, average annual rainfall, agriculture and irrigation, water bodies, ground water resource availability, ground water extraction and water level behavior. Aquifer disposition and various cross sections have also been given.

Plans for Sustainable Management of the Resource

Broad outline of management plan is as follows:

Sr. No	GW Related Issues in Area	Suggested Solution
1.	Low Groundwater Potential	Check runoff thorough various surface storage type recharge structure
2.	Siltation of Surface Water Bodies	Watershed treatment through plantation, restoration/revival and de-silting of existing ponds/tanks etc.
3.	High Degree of Runoff	Surface water storage structures i.e. dams/ponds, NB, Gabions structures etc,
4.	Drying of Springs	A program similar to Dhara Vikas Spring Rejuvenation in Sikkim, India
5	Low Stage of Groundwater Development	Promoting Irrigation through TW/DW in valley areas/ potential zones

In the study area, huge volume of water goes waste as surface runoff every year. Computation of rainfall runoff has been carried out using various empirical methods are results are as below:

Table: Computation of Rainfall run off in study area (in ham)

Sr. No	Block Name	Strange's Method*	Khosla's Formula	Inglis & Dsouza Formula**
1	Bijhari	7851.5	8405	8220.5
2	Ghumarwin	10947.3	11292.16	36090
3	Jhanduta	4668.3	4815.36	15390
4	Bilaspur Sadar	7616.7	7856.64	25110
5	Naina Devi	5705.7	5885.44	18810
6	Nalagarh	5211.4	6390	15194
7	Arki	4147.1	5085	12091

Keeping view of the available fallow and cultivable wasteland in study area, quantum of rainfall runoff, stage of Ground water extraction, irrigation practices and hydrogeological regime, the basic tenets of management plan for the study area are

1. Promotion of irrigation through tube wells/ bore wells through PMKSY.
2. Conservation of huge surface runoff through surface storage technics

3. Developing fallow and cultivable wasteland for productive uses to increase grain production.

All above steps will result into increase in income of marginal farmers, as presently, major agriculture practice is rain fed only.

The details of management plan are as follows:

Demand side interventions: Under demand side intervention, it is suggested to:

1. Increase the area under assured irrigation through:
   a. Construction of shallow depth tube wells under PMKSY. Based on the groundwater resource estimation in the areas 3787 number of tube wells can be constructed having discharge 3-4 lps,which can be pumped for 12 hours a day for 120 days in an year. (Number and discharge figures have been calculated to strictly keep the area under SAFE category)
   b. Around 25% area of the study area is under cultivable wasteland/fallow land. This area can be put to productive use by strengthening the network of Kuhls and drilling of shallow depth tube wells (Point a) This will result into additional demand of *10166 ham* of water for irrigation use. This demand can be met through supply side interventions.
   c. This will result into production of additional 30122 metric tons of Maize & Wheat.
   d. Total cost of supply side intervention comes at 208.2 crores, whereas it will result into production of additional grains worth 55.7 crore per year.

Supply side management: As mentioned earlier, the area is witnessing huge volume of rainwater going waste as runoff. The figures arrived at through various empirical formulas is around 20076 ham (Strange's method). See details below:

Table: ESTIMATION OF BLOCKWISE SURPLUS RUNOFF IN NAQUIM AREA					
Blocks	**Total area (Km^2)**	**Normal Monsoon rainfall (mm)**	**Runoff Generated During Monsoon (Ham)**	**Non-committed Run-off (%)**	**Surplus surface runoff (Ham)**
Bijhari	**205**	**1335**	**7851.5**	**50**	**3925.75**
Ghumarwin	**401**	**1204.5**	**10947.3**	**50**	**5473.65**
Jhanduta	**171**	**1204.5**	**4668.3**	**50**	**2334.15**
Bilaspur Sadar	**279**	**1204.5**	**7616.7**	**50**	**3808.35**
Naina Devi	**209**	**1204.5**	**5705.7**	**50**	**2852.85**
Nalagarh	**142**	**1366.2**	**5211.4**	**50**	**2605.7**
Arki	**113**	**1366.2**	**4147.1**	**50**	**2073.55**
				Total	**20076.00**

The surplus runoff can be harvested using various surface storage type technics for irrigation use as well as groundwater recharge.

a. It is proposed to construct 13824 Gabion structures of capacity 0.5 ham at the cost of Rs. 50000/structure
b. It is proposed to construct 965 check dams of 2 ham capacity at the rate of Rs. 15 lac per structure
c. Hill slope treatment through contour trenching 446 km trench work @ 357 per trench to harness 246 ham of rainwater
d. Modification of 259 already existing tanks/ponds having 2 ham capacity.

Total cost of proposed supply side intervention comes at 74742 crore. The Cost benefit ration comes at around Rs. 0.12 for every one liter.

For sustainable ground water management in area, following additional suggestion should also be considered:

- There is need to protect traditional water harvesting structures like ponds, tanks, talavs to utilized these for rain water harvesting and recharging shallow aquifers.
- In hilly and mountainous terrain, traditional ground water sources viz., springs, *bowries* etc needs to be developed and protected for better health and hygiene with proper scientific intervention.
- Proper development of springs is essential as it is observed that most of the spring in the district does not have collection chamber or tanks from where water can be distributed under gravity. The objective of spring development should be to collect the flowing water underground, to protect it from surface contamination and store it in sanitary spring box for supply. Similarly, seepage springs along hill sides also need to develop for harnessing ground water in such areas.
- Roof top rainwater harvesting practices can be adopted in hilly areas and urban areas, since the district receives fair amount of rainfall. Construction of roof top rain water harvesting structures should be made mandatory in all new construction and rain water harvesting in rural areas should be promoted. Traditional water storage systems need to be revived.
- In north western part of the area, for the households, IPH department supplies water, so the people put their dug wells abandoned without using it. These unused and abandoned dug wells can be used as rainwater harvesting and artificial recharge structure to recharge ground water.
- People's participation is a must for any type of developmental activities. So proper awareness for utilization and conservation of water resources is required.
- Constrictions of bore well near to spring source in hilly area should be avoided as this could lead to drying of the natural water sources.
- Recharge structures feasible in hilly areas are check dams, Gabion structures and staggered contour trends at suitable locations.

Principal Contributors

Head of Office:	**Sh. J. N. Bhagat** **Scientist 'D'**
Report Compiled and Prepared:	**Sh. Vipin Kumar** **Scientist 'B'**
Report Edited:	**Sh. Sanjay Pandey** **Scientist 'B'**

References

1. Pilot Reports on Aquifer Mapping
2. GEC 2015 Report
3. Ground Water Brochures publishe by BHR Dharamshala
4. Bhukosh- Geological Survey of India
5. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-non?qt-science_center_objects=0#qt-science_center_objects
6. The Advanced Land Observing Satellite-2- JAXA
7. Ground Water Yearbook 2016-17 & 2017-18
8. Himachal Pradesh Council For Science,Technology & Environment, Shimla
9. Source: http://www.imd.gov.in/section/hydro/distrainfall/webrain/hp/una.txt
10. Department of Agronomy, Forages and Grassland Management, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur.