A Hydrogeological Investigation Report on Land Subsidence in Joshimath Town, Chamoli District, Uttarakhand

By

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1.0 Introduction

In context of recent land subsidence at Joshimath, a four-member committee namely Sh Prashant Rai, Scientist- E, Dr Vikas Tomar, Assist. Hydrologist from CGWB, Dehradun and Dr Shashikant Singh, Scientist- C, Sh Aniruddh Singh, Assist. Geophysicist, CGWB, Lucknow visited the area from 09.01.2023 to 19.01.2023 to carry out Hydrogeological and Geophysical survey to decipher the water saturated zone, nature of geological formation and extent of cracks.

Joshimath, also known as **Jyotirmath**, falls in Toposheet No 53 N/10 and comes under Alaknanda Basin. (Figure- 1) River Alaknanda makes the northern boundary of the study area. The Dauliganga river confluences with Alaknanda at Vishnuprayag. Mostly dendritic pattern is observed in the area. High peaks, cliffs, steep slopes, deep and narrow valley is characteristic of the study area.

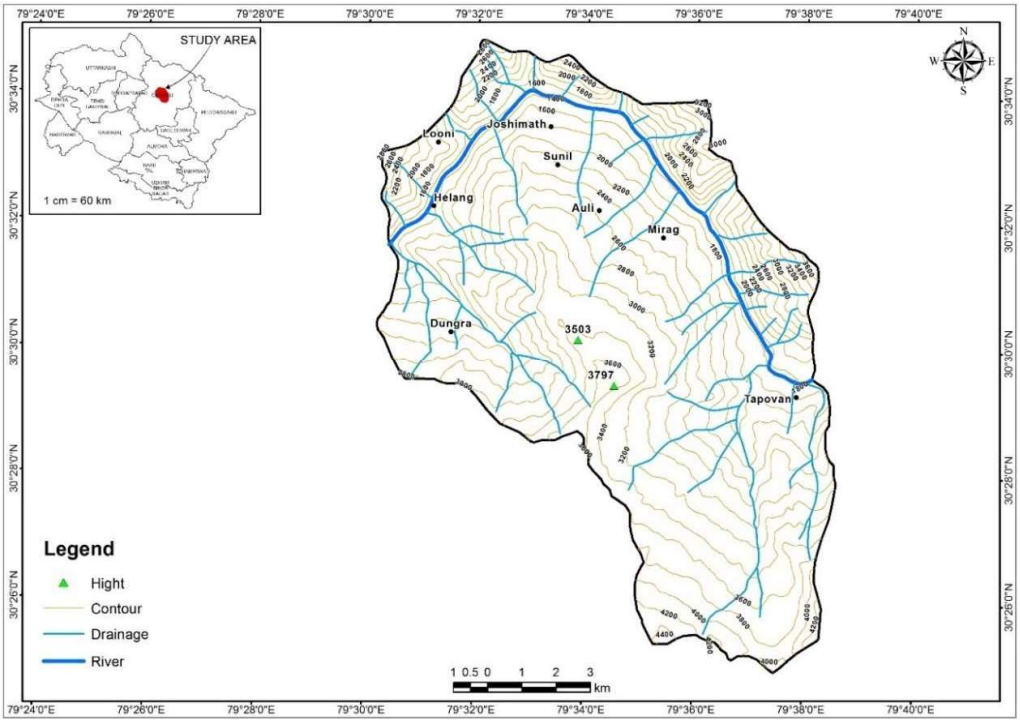


Figure – 1 Location Map of Joshimath Town, Alaknanda Basin, Chamoli District, Uttarakhand

It is a Tehsil and Block Headquarter of Chamoli district in Uttarakhand state. The town is located at a height of 6150 feet (1875 m) in mighty Himalayan Mountain Chain and falls in seismic zone IV to V. The average annual rainfall of Joshimath is 1337 mm with 80 days of duration. The average lowest and highest temperature ranges from 9 ^{o}C to 19 ^{o}C (Source IMD 1971-2001).

As per 2011 census, total population is 16709 and density 1454 person/sq km. It is a gateway to several Himalayan mountain climbing expeditions, trekking trails and pilgrim centres like Badrinath. To accommodate the floating population, large numbers of buildings like hotels, home stay are constructed in a small-town area of 11.49 sq km.

2.0 Present Land Subsidence- Sequence of Events

In conversation with the local people in Manoharbagh area, it comes to know that the cracks in the agricultural land of Sh Suraj Kaparuwan was noticed on last week of November 2022. It was very less in its extent. Cracks in the residential building have been observed at about 9 PM on 2/ 3rd Jan 2023 as told by Sh Salig Ram Prajapati, employ of J P Power Project (Photo - 1). In the morning of 03 January 2023, the moderate to intensive land subsidence was observed just below Auli, Sunil Village upto Marvadi Village.(Photo-2) The Cracks developed in North – South direction having average width of 10-15 m. Further, water burst out in JP residential premise in Marwari Village. Initially, discharge was about 650 lpm which is reducing with time upto to the tune of 225 lpm.

Photo -1 House of Sh Salig Ram Prajapati, JP Colony, Joshimath

(A) Badminton Indoor Stadium, J P Colony

(B) Sudden Gush of Water nearBadminton Indoor Stadium, J P Colony

(C)Vertical Cracks (about 3 ft) at Manohar Bagh

(D) Cracks Devloped in House of Sh Vinod Saklani, Sunil Village

Photo- 2 Cracks developed at Different Location in Joshimath Town, Chamoli District

3.0 Geology

Geologically, the Joshimath belongs to the Higher Himalayas and occupied by Central Crystalline Group (Vaikrita Group) i.e Mesoproterozoic to Neoproterozoic rocks. It represents the higher-grade metamorphism of the Higher Himalaya pervasively penetrated by young Tertiary granite. The rocks comprising, this group, are micaceous schists, talcose rocks, phyllites and gneisses overlying mainly the granite gneisses. The Vaikrita group rocks are overlain by morainic deposits. These morainic deposits are composed of irregular boulders and clay of varying thickness. These morainic deposits are less cohesive and susceptible to land slide/subsidence.

The Main Central thrust (MCT) traverse in southern part of the study area. Beside this there are number of weaker plains present in the area. The area along these weaker plains is highly vulnerable for landslides/land subsidence. (Figure- 2). Geological succession is furnished in Table -1

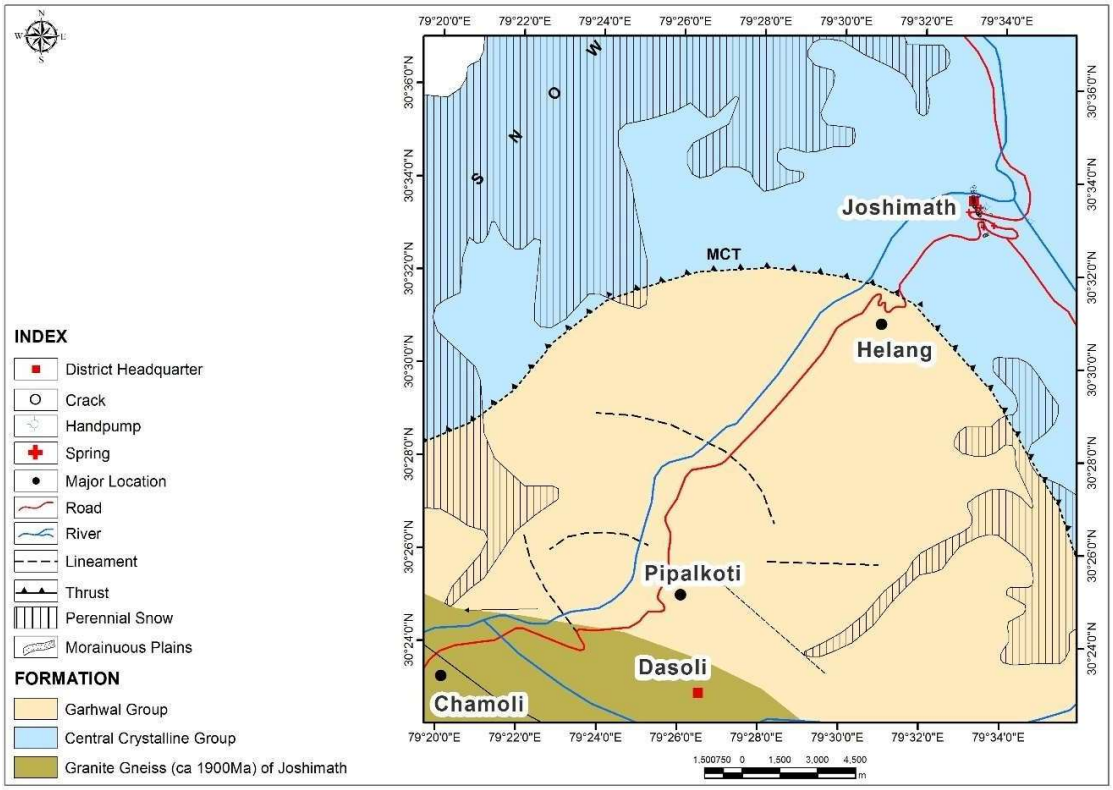


Figure- 2 Geology of Joshimath Area, Chamoli District

Table- 1 Geological Succession in Joshimath Area, Chamoli District

Group/ Formation	Lithology
Quaternary Formation	Loose Morainic Sediment with large boulders
----------	----------
Central Crystalline Group (Vaikrita Group)	Kyanite rich gneiss with Garnet-Biotite schist
----------	Main Central Thrust----------
Munsiary Formation	Mylonitised gneisses of ganitic composition, schist

4.0 Hydrogeological Study

CGWB traced the subsidence zone and its detail. Springs and the Ground Water abstraction structures such as hand pump are demarcated. Depth of water level, discharge and temperature of ground water are also monitored.

A total of 46 cracks/subsidence zones are observed which are oriented in North-West to South-East direction (Figure- 3 A) (Annexure- I). The slope direction of the study area is South to North. (Figure- 3 B) The crown of the subsidence marks at house of Sh Vinod Saklani, Village Upper Sunil and extend upto JP township at Marwari village. The intensity of the cracks is increasing from south to north and it maximum observed in Manohar Bagh area where one of the hotels building lean over adjoining hotel building. The depth of the cracks observed in the agriculture land is upto 03 ft deep and 1-2 ft wide.

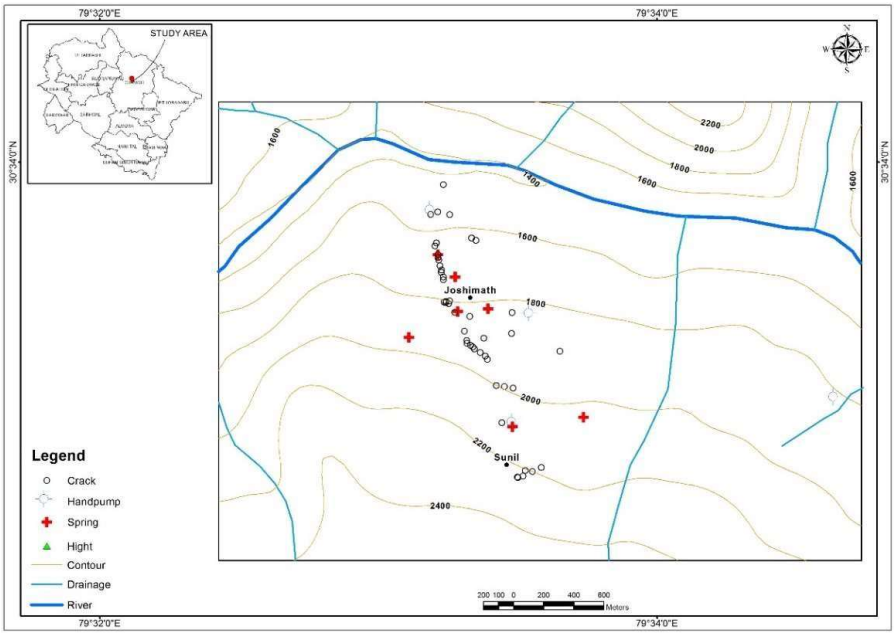


Figure- 3 A Location of Cracks, Springs and Hand pumps in the Joshimath Town, Chamoli District, Uttarakhand.

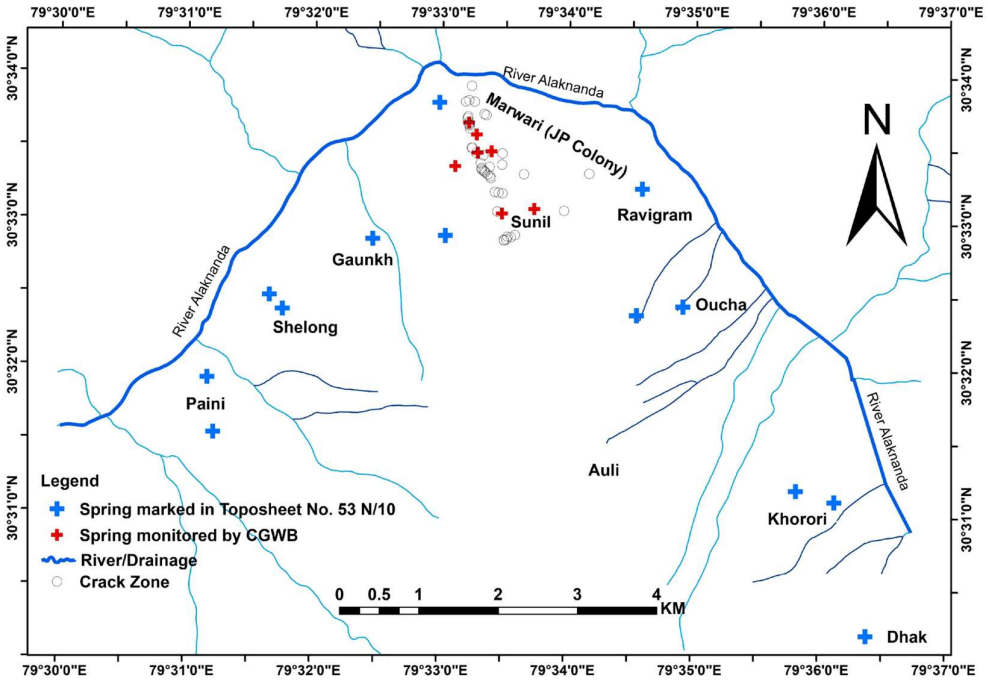


Figure- 3 B Location of Spring Monitored during CGWB Survey and Marked in Toposheet 53 N/10 in and around Joshimath Town, Chamoli District, Uttarakhand.

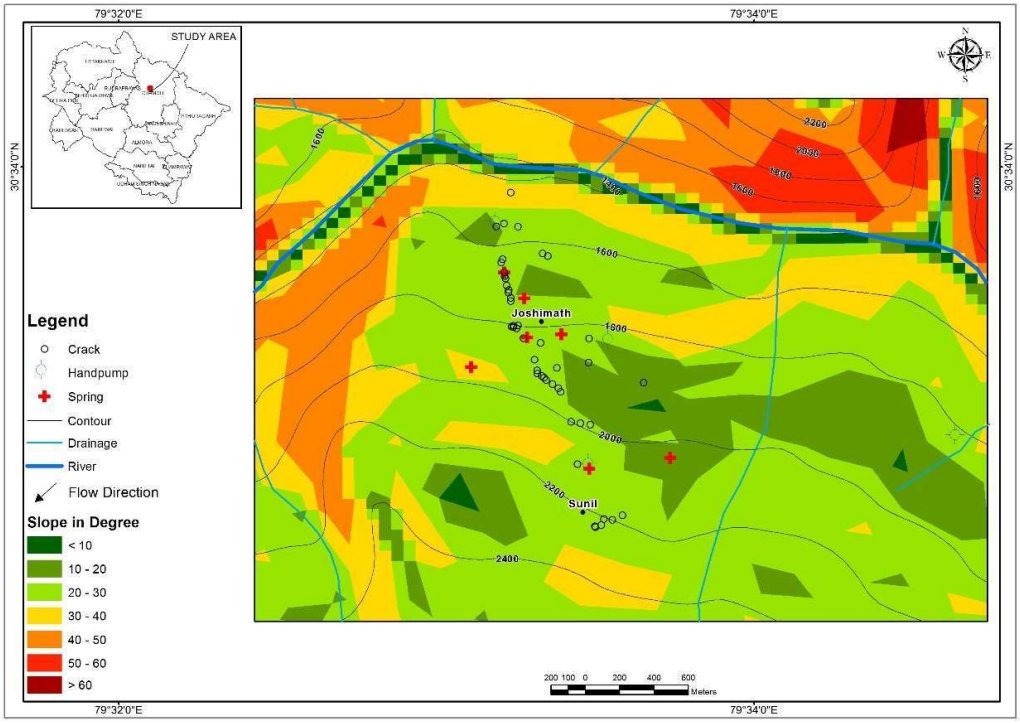


Figure- 3 C Slope Configuration in the Joshimath Town, Chamoli District, Uttarakhand.

Joshimath town is situated on morainic deposit, comprising thick Quaternary loose sediment. Big boulders are embedded in this deposit. The morainic deposit is both porous and permeable and hence suitable for groundwater development. The ground water is mainly developed through handpumps. The topography is highly undulating and geological formations are moderately to steeply dipping. Due to frequent undulations of high magnitude a continuous water table doesn't exist. However, permeable formation overlays an impermeable one, the water table exists, its extension depends upon the distribution of the aquifer forming rocks and topography. A total of 04 number of handpumps are present in the study area (Figure 3 A & 3 B) and as per the data available with Jal Sansthan, Joshimath, the handpump are drilled upto the depth of about 80 m and the zone tapped ranges from 65-80 m bgl. The depth of water level in these handpumps ranges between 18 to 48 m. Daily depth of water level has been monitored and it is observed that water level is declining in Singhdhar area, with various rate. 20- 60 cm per day, (Figure- 4) while in other handpumps the water level is almost content. (Table-2) The decline in Singhdhar handpump indicates that water bearing strata is linked with the land subsidence. Land subsidence may be extended in and around Singhdhar Handpump. The discharge of these handpumps was taken manually which is 17.65-20.27 lpm

Table- 2– Hydrogeological Detail of Handpump, Joshimath Town, Chamoli District

S. N	Location	Long	Lat	11 Jan	13 Jan	14 Jan	18 Jan	Temp	Discharge(lpm)
1	Singhdhar	79.5590	30.5574	47.03	47.92	48.4	51.2		
2	Ravigram	79.5773	30.5523	20.52	20.52			15	17.65
3	Marwari-GREFP	79.5531	30.5635	22.8	22.73			15	
4	Sunil	79.5580	30.5509	18.37	18.22	18.15		13	20.27

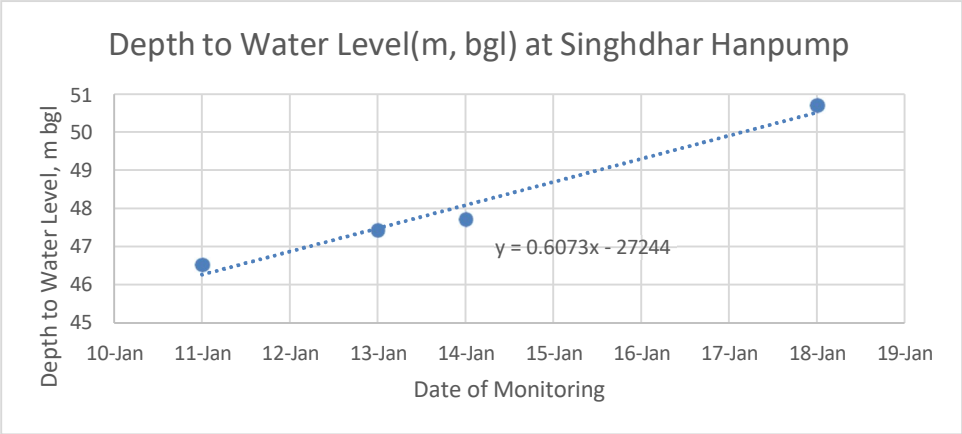


Figure 4 – Hydrograph of Singhdhar Handpump Joshimath Town, Chamoli District

The occurrence of springs is a common phenomenon in Joshimath area. The moving groundwater emerges on ground in form of springs at the contact of different rock types and through joints/fractures etc. The topographic breaks also are the favourable location for spring formations. Many springs has been shown in Toposheet No 53 N/10 (published year 1963) where present land subsidence occurred. One of the springs marked in toposheet at Marwari village where J P residential colony situated, another spring present near Hotel Auli, Ravigram. During the investigation eight spring are also marked. (Figure 3B) Most of these springs are depression and contact type. Discharge of these springs vary from 1 lpm to 600 lpm and temperature is about 13^0 C. (Table-3)

Table – 3 - Detail of Spring in and around Joshimath Town, Chamoli District

S,No	Location	Long	Lat	Discharge (lpm)	Temp (deg C)	Remarks
1	JPVL-Marvadi	79.55356	30.56113	250-650	13	Badminton Hall-Inside Campus
2	Tapowan Hot spring	79.65706	30.4887	---	88	
3	Nauganga	79.56227	30.55141	600	12	Sunil-Jal Sansthan Water supply tank
4	Sunil	79.55802	30.55085	1	13	Near ITBP Campus
5	Dronagiri	79.55183	30.55618	35.8	13	
6	Singhdhar	79.55475	30.55773	28.91	13	Near Bhatt House
7	Lower Singhdhar	79.5546	30.55978	---	12.5	Just above JPVL
8	Singhdhar-Gopaldhar	79.55656	30.55789	35.29	13	Near Panchvati Hotel

Photo – 3 A Spring Monitoring at Singhdhar, Joshimath

Photo – 3 B Water Level Monitoring at HP Ravigram, Joshimath

As large number of pilgrims for Chardham Yatra and tourists comes every year, to provide accommodation ample number of hotels, home stay are constructed in the area. Some of them are constructed in spring zone or at the emergence point of springs. Construction of buildings in spring zone did cessation of spring flow. Cessation of spring flow increases the pore pressure which ultimately rendered the burst of ground water in form of spring in JP residential premise. In nutshell, construction in spring zone may be the reason for recent land subsidence.

5.0 Hydrochemical Study

During the present study, Electrical Conductivity (EC) and pH of the spring water were measured on the spot using waterproof, portable EC and pH meters. A total of twenty-two (22) water samples were collected in and around Joshimath town spring, had pump, river and naula for basic and trace metal analysis which were sent to the Chemical Lab, North Western Region, Chandigarh for basic analysis of major inorganic constituents. Water samples for tritium analysis were also collected and sent to NIH Roorkee for analysis. The results of chemical analysis are summarized in Table 4 A and 4 B.

Table- 4 A Basic Chemical Analysis of Water Samples in and Around Joshimath Area, Chamoli District

S. No.	Location	EC (uS/cm) at 25° C	pH	HCO3 (mg/l)	Cl (mg/l)	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Ca (mg/l)	Mg (mg/l)	TH as CaCo3 (mg/l)	Na (mg/l)	K (mg/l)
1	JP Premise-Joshimath	145	7.55	55	11	5.48	40	0.15	16	11	85	4.84	8.3
2	Marwari-HP	217	7.25	128	11	BDL	28	0.14	20.04	18	125	8.01	7.7
3	Singhdhar-spring	178	7.77	61	11	17	45	0.13	14	16	100	9.76	7.36
4	Ravigram-HP	222	6.98	79	11	25	35	0.11	22	13	110	8.34	9.7
5	Nauganga-spring	78	7.90	37	3.9	3.87	14	0.15	10	5	45	2.47	4.3
6	Dronagiri-spring	127	7.70	49	7.4	9.31	50	0.13	14	15	95	4.55	6.5
7	Sunil- HP	135	6.88	92	7.4	BDL	BDL	0.14	8	11	65	4.76	6.2
8	Sunil-Spring	110	7.73	55	11	4.19	30	0.14	8	15	80	4.72	5.7
9	Auli - Naula	147	8.08	92	1.8	1.58	25	0.10	32	5	100	0.89	3.5
10	Alaknand River – JP Power	207	7.89	116	3.9	1.57	52	0.14	30	18	150	3.82	2.9
11	Tapovan-Hot Spring	415	8.07	268	11	0.38	32	0.45	36	30	20	12.6	215

Table- 4 B Trace Metal Chemical Analysis of Water Samples in and Around Joshimath Area, Chamoli District

S.No	Location	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Pb	U
		mg/L (ppm)						micro mg/L(ppb)				
1	Ravigram-HP	0.001	0.017	0.793	0.001	0.003	0.277	0.233	0.032	0.045	0.938	0.052
2	JPVL-Marvadi		Due to sediment particles sample was not run in the instrument (ICP-MS)									
3	Marwari-GREFP-HP	0.001	0.807	6.236	BDL	0.045	1.433	0.079	0.006	0.156	4.684	0.109
4	Sunil ITBP(HP)	0.007	0.078	12.44	0.002	0.009	12.8	0.137	0.014	0.75	52.16	0.133
5	Singhdhar Spring	0.001	BDL	0.002	BDL	0.001	0.005	0.338	0.023	0.015	BDL	0.011
6	Tapowan Hot Spirng	BDL	0.209	2.015	BDL	BDL	0.044	66.58	0.004	0.006	0.115	0.039
7	Nauganga	0.001	0.001	0.113	BDL	BDL	0.009	0.166	0.016	0.03	0.503	0.05
8	Sunil Spring	0.001	0.002	0.277	BDL	0.001	0.017	0.127	0.001	0.065	1.168	0.053
9	Auli Naula	BDL	BDL	0.002	BDL	BDL	0.003	1.862	0.02	0.003	BDL	0.049
10	Dronagiri	0.001	0.001	0.109	0.001	0.001	0.015	0.332	0.032	0.048	0.724	0.056
11	Alaknanda River	0.001	0.002	0.132	0.001	0.002	0.015	0.305	0.032	0.05	0.853	0.03

A perusal of the chemical analysis data shows that Nitrate content in the new source, JP premise is 5.48 mg/l which shows that sewage is not contributing to sudden gushing of water. PO_4 and SiO_2 are not detectable in all water samples. Hot spring water at Tapovan has relatively high EC and arsenic. High iron content has been reported in water sample of all hand pump, it may be due to very less use of the handpump and rusting of pipe. Barring this concentration of all inorganic constituents is below the acceptable limit- this indicating absence of contamination in the spring source

6.0 Geophysical Study

The 2D electrical resistivity tomography (ERT) technique has been carried out in Joshimath area, District Chamoli, Uttarakhand to know the horizontal and vertical variation in lithology and presence of weaker zone or ground water saturated formation. Precise subsurface two-dimensional (2D) model is obtained in electrical resistivity tomography technique as changes in the resistivity value observe in vertical as well as horizontal directions along the survey line. A typical 1D resistivity sounding usually 10 to 20 measurements in 100 m stretch are obtained while in 2D imaging surveys techniques higher data density (100 to 500) measurements in same stretch are recorded. Data collection is fast with an automated multi-electrode resistivity meter. ERT profiles consist of a modelled cross-sectional (2-D) plot of resistivity (Ω·m) versus depth.

Methodology and layout

For carrying out 2-D electrical imaging/tomography surveys large number of electrodes, connected to a multi-core cable. A microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. Multi-electrode Resistivity system (ABEM Terrameter LS) was used for automatic data collection with 1 to 36 electrodes spaced at 3, 5 and 10 m intervals as per availability of space. Wenner and Gradient array were used for data acquisition of Resistivity. The layout of electrodes for 2D-Imaging survey and sequences of measurement are presented in Fig. 5.

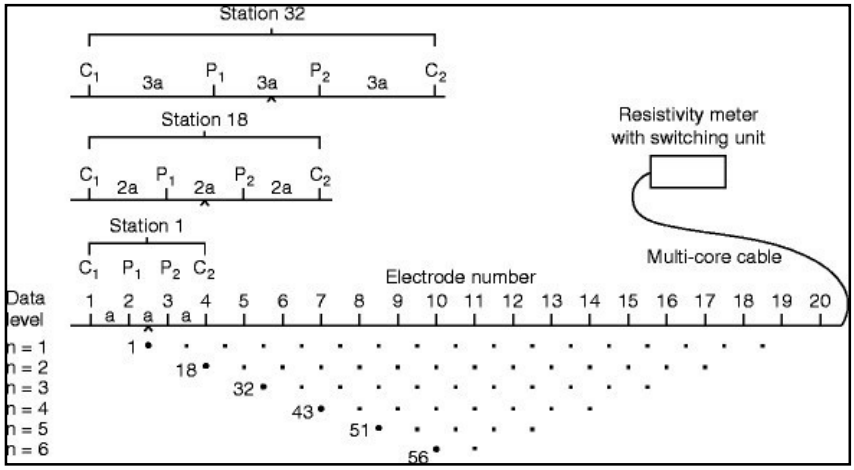


Figure -5: Schematic diagram of 2D resistivity imaging/ERT survey

This equipment is capable of running self-checks for connectivity of electrodes and generates warnings on bad contacts. Bad contacts were resolved by pouring water around the electrode. Normally a constant spacing between adjacent electrodes is used. The multi-core cable is attached to an electronic switching unit, which is connected to the resistivity imaging system. The sequence of measurements to take, the type of array to use and other survey parameters (such the current to use) is normally entered into a text file which can be read and fix in the instrument. After reading the control file, the instrument program then automatically selects the appropriate electrodes for each measurement. In a typical survey, most of the time- consuming process in the data acquisition is the laying of the multi core imaging cables and electrodes. After that, the entire profile line connection is checked automatically by the instrument for noise and bad connection. Once all the electrode connection is proper, then the equipment is ready to take measurements. Data acquisition for each set of measurement is made automatically with constant current supply and stored in the system. The acquired field data is then down loaded to the computer and then processed by using RES2DINV software.

Results and Discussions

In the present study area, ERT profile lines are conducted at five locations across the cracks zone (Fig. 6 A & 6B). As the open land in Joshimath town is very limited, the spread for the ERT profiles varies from 105 m to 360 m. All efforts were done to locate the profile linear to cracked line/subsidence area and with a maximum space availability using two types of electrode configurations i.e., Gradient and Wenner configurations for maximum data and comparative study in NW-SE direction. The coordinates of profile line are given in Table 5. The data have been processed using RES2DINV software. On the basis of ERT results, low resistivity zones were identified i.e. weak zones which may be the cause of cracks/subsidence due to steep gradient of groundwater flow towards north. Overall, the two electrode configurations have yielded almost same the results. Topographically corrected model resistivity sections using Wenner and Gradient are shown Fig. 7 (A & B), 8 (A & B), 9 (A & B), 10 (A & B), 11 (A & B) respectively.

Table 5: The coordinate details of the ERT profiles, Chamoli District

S. No.	Location	Start of Profile		Centre of Profile		End of Profile		Length of ERT Profile
		Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	
1	ERT-1 (Sunil Village)	79.557561	30.54826	79.55808	30.54807	79.55859	30.54787	105
2	ERT-2 (Manohar Bagh)	79.554235	30.5557	79.55515	30.55568	79.55612	30.55565	180
3	ERT-3 (Behind JP Colony)	79.552702	30.56014	79.55381	30.56014	79.5551	30.56013	230
4	ERT-4 (Auli Road)	79.554666	30.54678	79.55611	30.54641	79.55812	30.5457	350
5	ERT-5 (Auli Road)	79.557638	30.54588	79.5588	30.5455	79.56002	30.54501	250

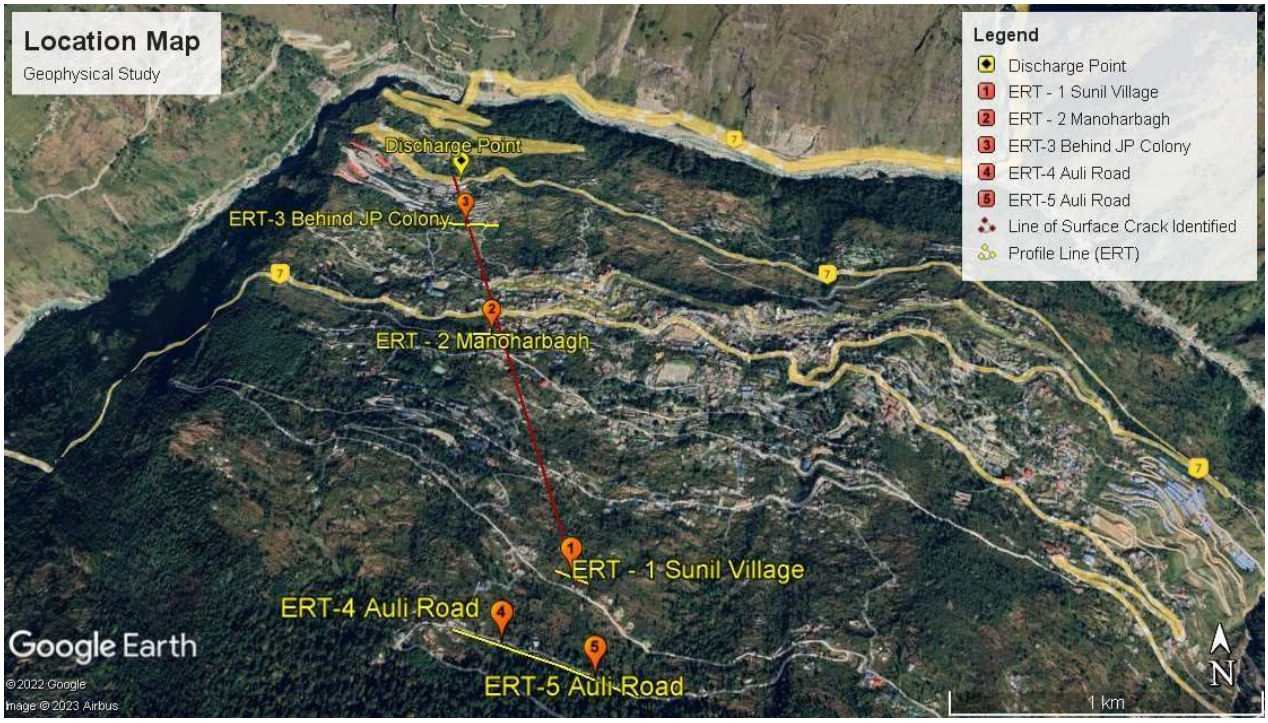


Figure 6 A: Location map of the study area along with ERT Profile line and Crack Zone, Joshimath, Chamoli District

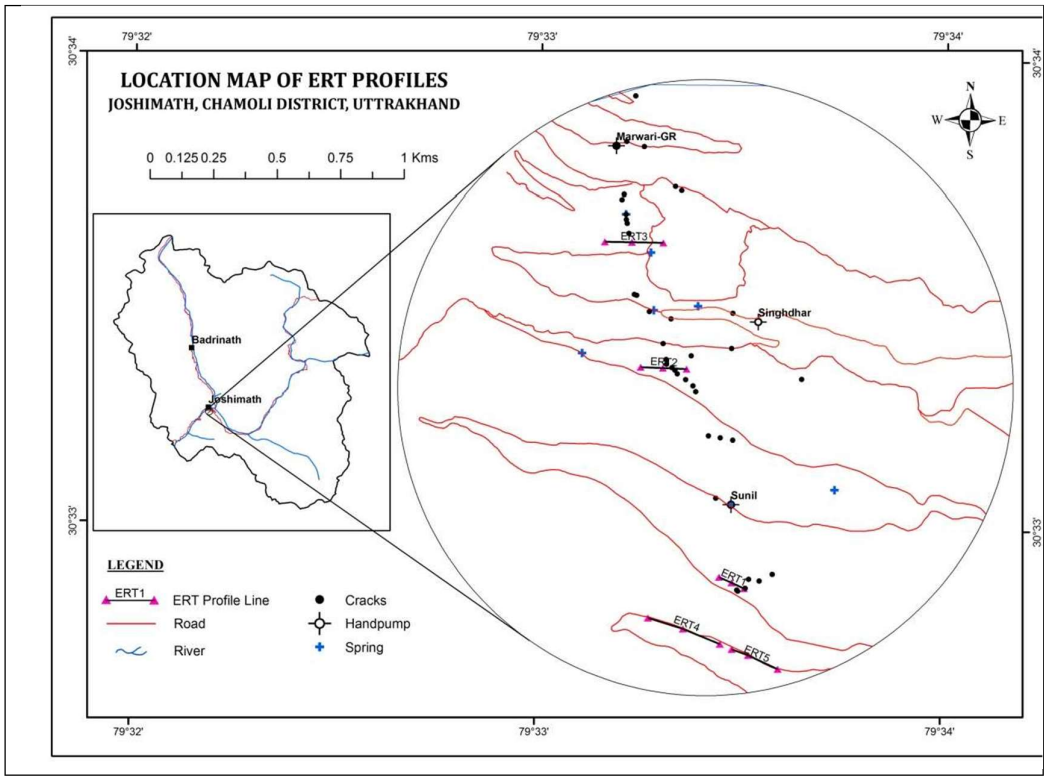


Figure 6 B: Key map of the study area along with ERT Profile line and Crack Zone Joshimath, Chamoli District

Site-1 (ERT-1): In agricultural land of Sh Vinod Saklani, Upper Sunil, Joshimath, Chamoli District

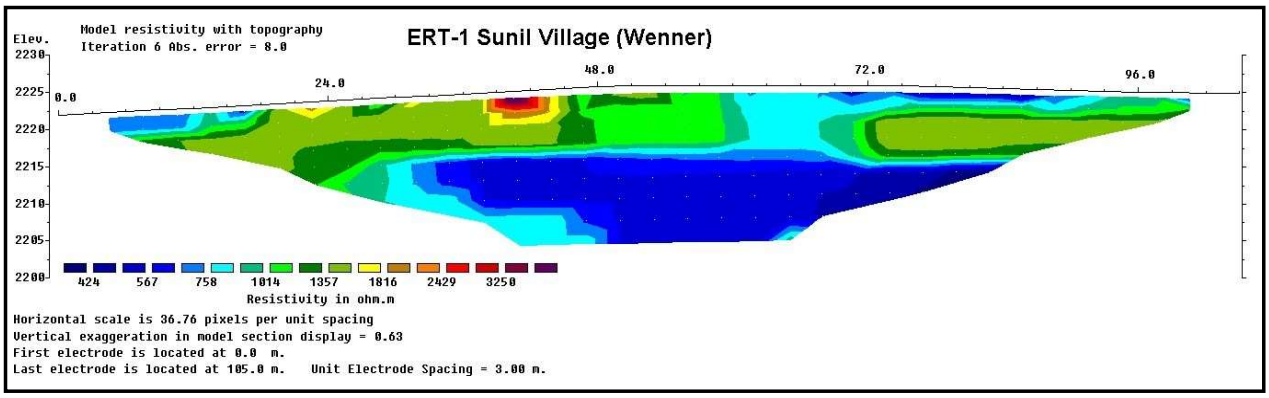


Figure 7 A: 2-D Electrical Resistivity Tomography Section (Wenner) at Upper Sunil Village, Joshimath (ERT-1), Chamoli District

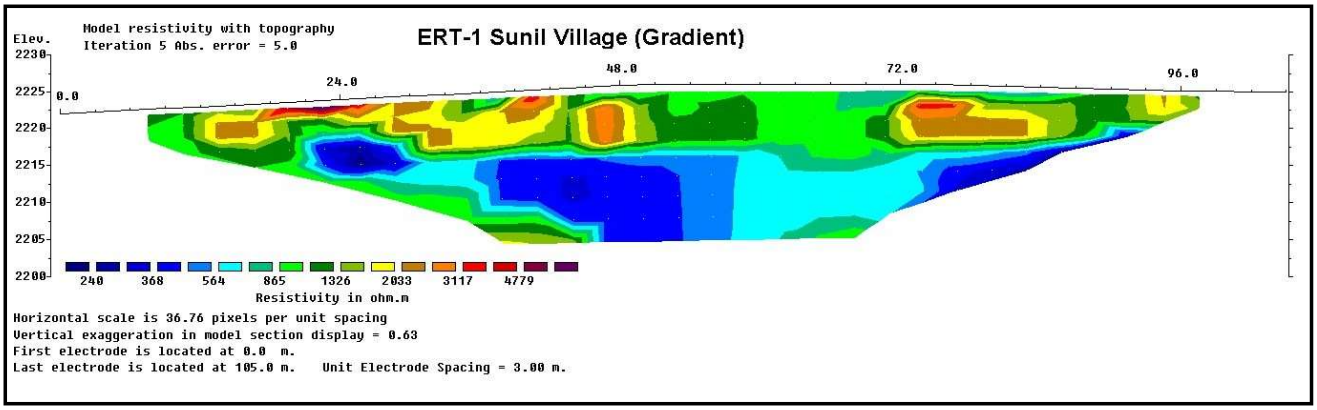
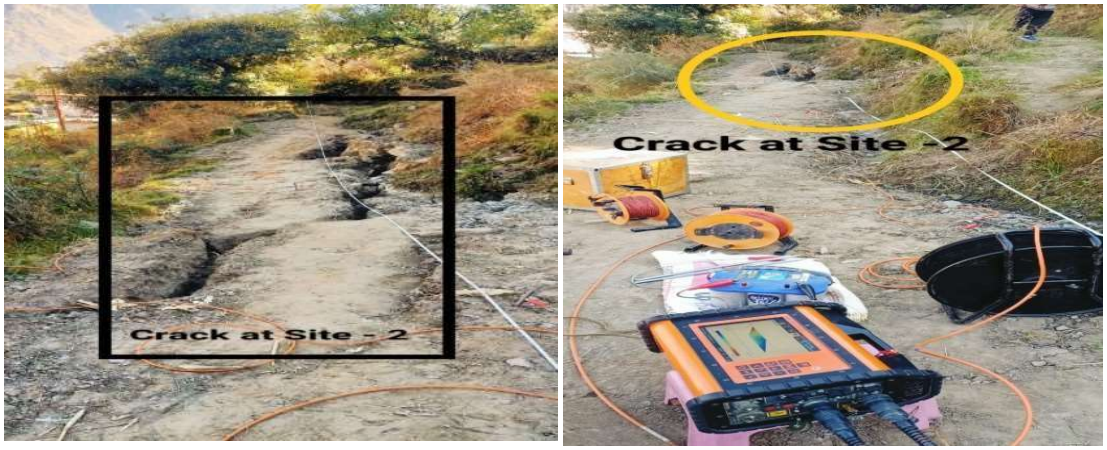


Figure 7 B : 2-D Electrical Resistivity Tomography Section (Gradient) at Upper Sunil Village, Joshimath (ERT-1), Chamoli District



Site-2 (ERT-2): In agricultural land of Village Manoharbagh, Joshimath, Chamoli District

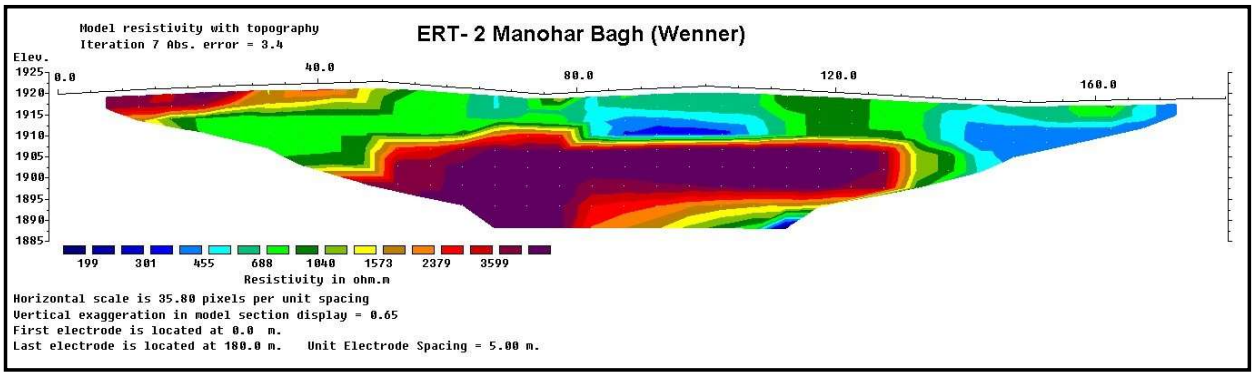


Figure 8A: 2-D Electrical Resistivity Tomography Section (Wenner) at Manohar Bagh, Joshimath (ERT-2), Chamoli District

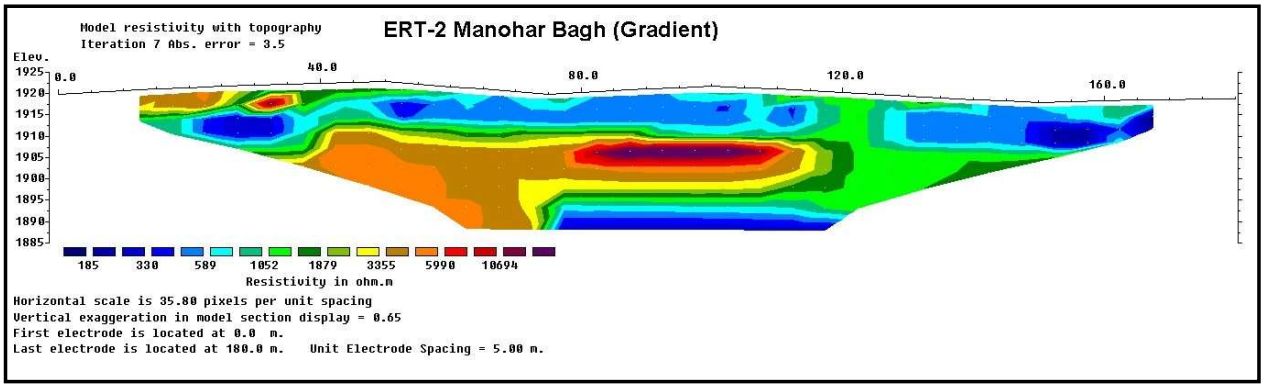


Figure 8B: 2-D Electrical Resistivity Tomography Section (Gradient) at Manohar Bagh, Joshimath (ERT-2), Chamoli District

Site-3 (ERT-3): In open land, between Singhdhar and JP Premise, Joshimath, Chamoli District

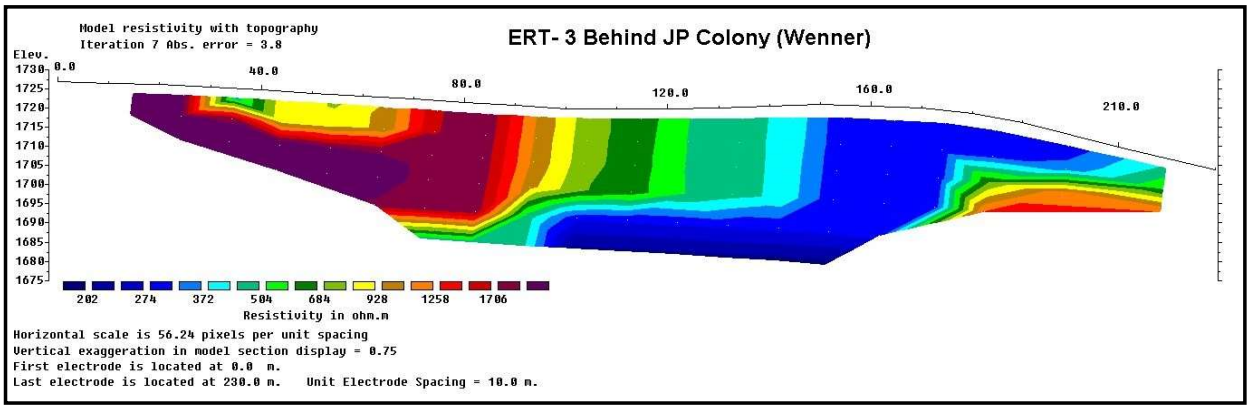


Figure 9 A : 2-D Electrical Resistivity Tomography Section (Wenner) between Singhdhar and JP Premise, Joshimath (ERT-3), Chamoli District

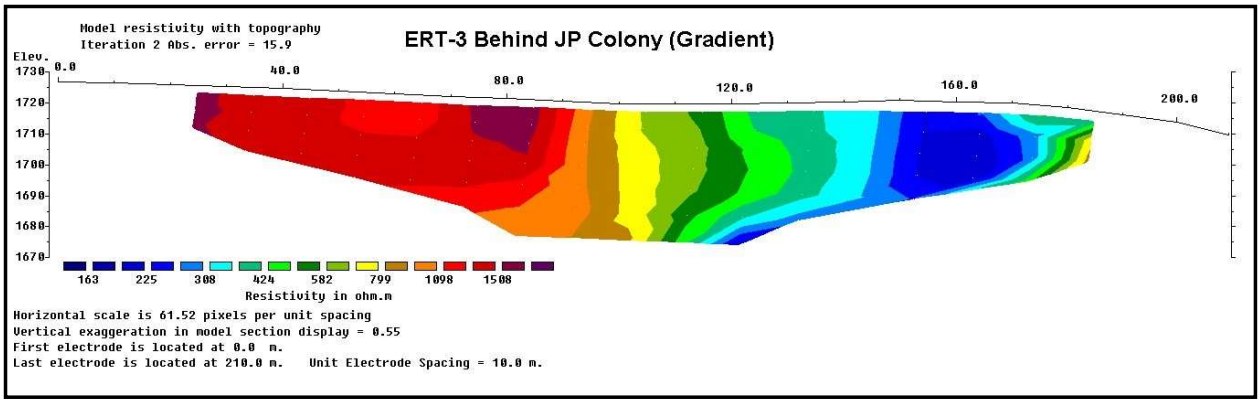


Figure 9 B : 2-D Electrical Resistivity Tomography Section (Wenner) between Singhdhar and JP Premise, Joshimath (ERT-3), Chamoli District

Site-4(ERT-4): Just above the Upper Sunil Village towards Auli Joshimath, Chamoli District

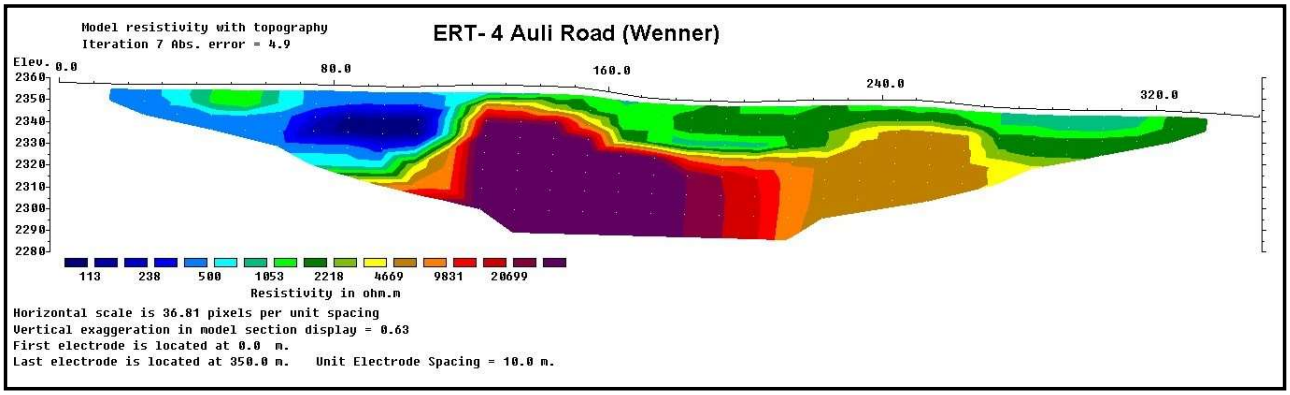


Figure 10 A: 2-D Electrical Resistivity Tomography Section (Wenner) at Auli Road above the crown of subsidence, Joshimath (ERT-4)

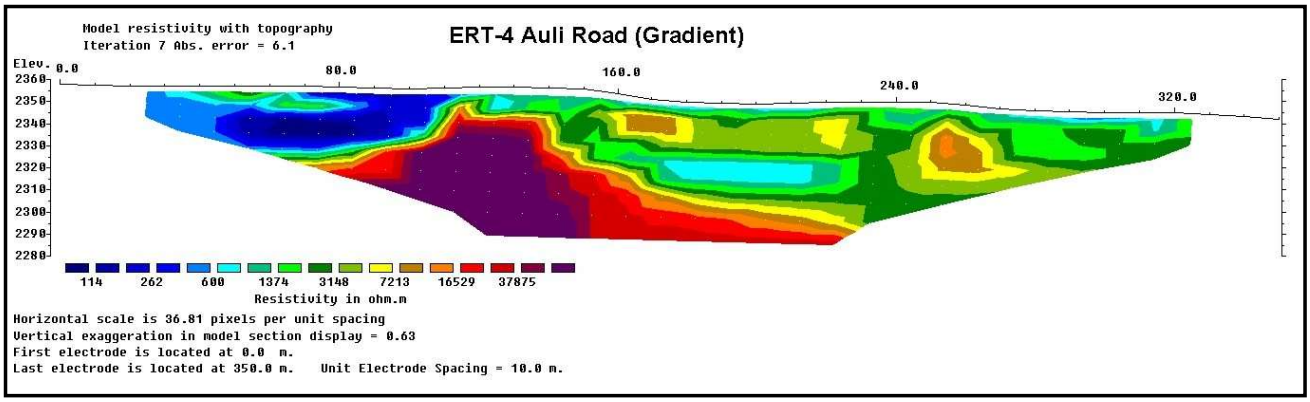


Figure 10 B : 2-D Electrical Resistivity Tomography Section (Gradient) at Auli Road above the crown of subsidence, Joshimath (ERT-4), Chamoli District

Site-4(ERT-5): Just above the Upper Sunil Village towards Auli Joshimath, Chamoli District

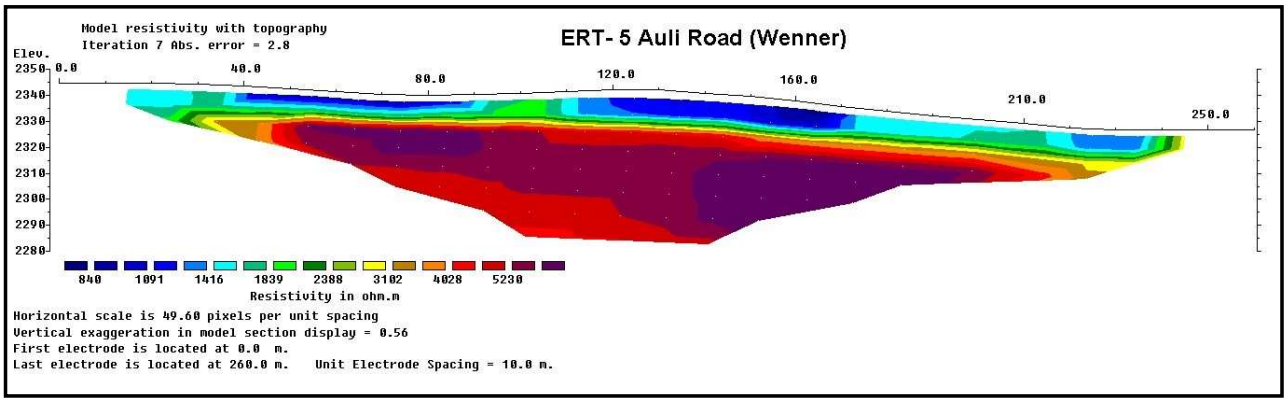


Figure 11 A: 2-D Electrical Resistivity Tomography Section (Wenner) at Auli Road above the crown of subsidence, Joshimath (ERT-5), Chamoli District

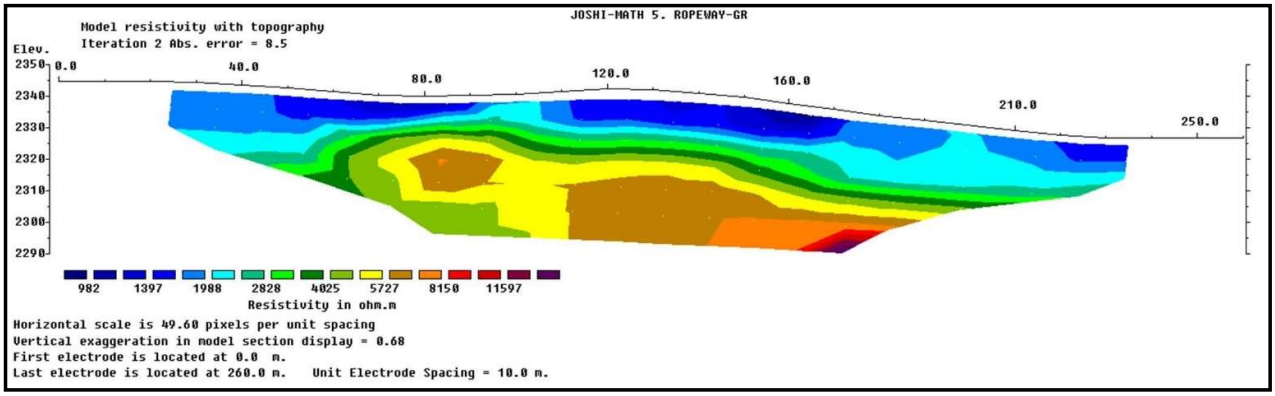


Figure 11 B: 2-D Electrical Resistivity Tomography Section (Gradient) at Auli Road above the crown of subsidence, Joshimath (ERT-5), Chamoli District

First 2D electrical resistivity tomography (ERT-1) has been carried out across the cracks developed in agricultural land of Sh Vinod Saklani Joshimath area, District Chamoli, Uttarakhand. Length of ERT profile was 105 m. Resistivity value received during ERT indicates that boulders are embedded into loose sediments. Saturated formation occurs at a depth of 15 m below ground level (Figure 7A & 7 B).

Second ERT has been conducted at Manohar Bagh area of Joshimath town where intensity of cracks is maximum. Length of ERT profile was 180 m and maximum depth of investigation is about 35 m bgl. Altitude of the ERT point is 1920 m amsl and it is about 500 m distance towards north from ERT-1. The ERT results shows that the loose formation and boulders are present under saturation with water below the depth of 30 m bgl (Figure 8A & 8 B).

Third ERT was conducted 200 m south of the spot where sudden gush of water occurred on 2 / 3rd of January 2023. Here, the spread of ERT profile was 230 m and maximum depth of investigation was about 50 m (Fig.9A & 9B). ERT-3 results shows that area lying west of the cracks zone is consolidated in nature. East of the cracks zone have resistivity values in range of 200 – 300 ohm.m at a depth of 10 m to 50 m bgl which indicates the formation encounter in this depth range is saturated with water on the ERT profile between distance 100 and 170 m. It has the 70 m in horizontal extends which may act as path of the subsurface water flow.

ERT-4 carried out along the Auli road in NW-SE direction about 200 m towards SW of the Sunil Village (Fig. 10 A & 10 B). A patch of low resistivity (100-300 ohm.m) was observed on the ERT-4 profile line between the distance of 50 and 100 m indicates the presence of saturated loose formation with boulders up to depth of about 25 m bgl.

ERT-5 conducted as a roll along of ERT-4 towards east covering profile length of 250 m distance (Fig. 11A & 11 B). A patch of relatively low resistivity (800-900 ohm.m) was also observed compared to the surrounding resistivity values (more than 2000 ohm.m) on ERT-5 profile between 120 and 170 m distance on profile line. It may be indication of fracture in consolidated rock up to the depth of about 10 m bgl.

All ERT carried out across the cracks line and almost parallel to each other to decipher the subsurface lithology as well as path of groundwater flow. The low resistivity zones having resistivity values between 100 and 300 ohm.m indicates the presence of ground water saturated loose sediment in which large boulders are embedded.

The low resistivity patches observed on ERT-4 & ERT-5 lie above cracks zone and on ERT – 1 to ERT 3 (Sunil Village-Manohar Bagh – behind JP Colony) are interconnected. This low resistivity zone follows the direction of maximum crack zone observed in NW- SE which may be the zone of groundwater flow with steep hydraulic gradient towards north.

On the basis of geophysical and hydrogeological survey, lithological sections from J P colony in North to about 300 m away from Sunil Village on Auli Road are prepared (Figure- 12 A, 12 B, 12 C and 12 D).

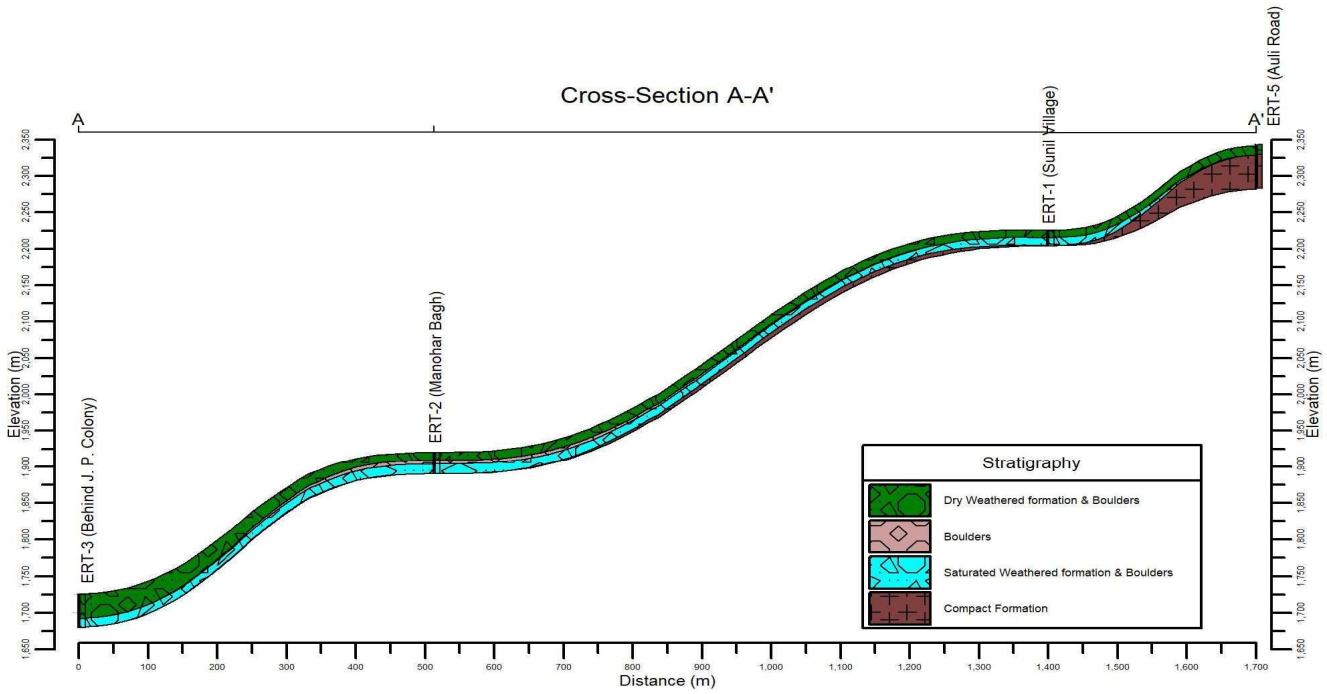


Figure – 12 A - lithological section from J P colony in North to about 300 m away from Sunil Village, Joshimath, Chamoli District

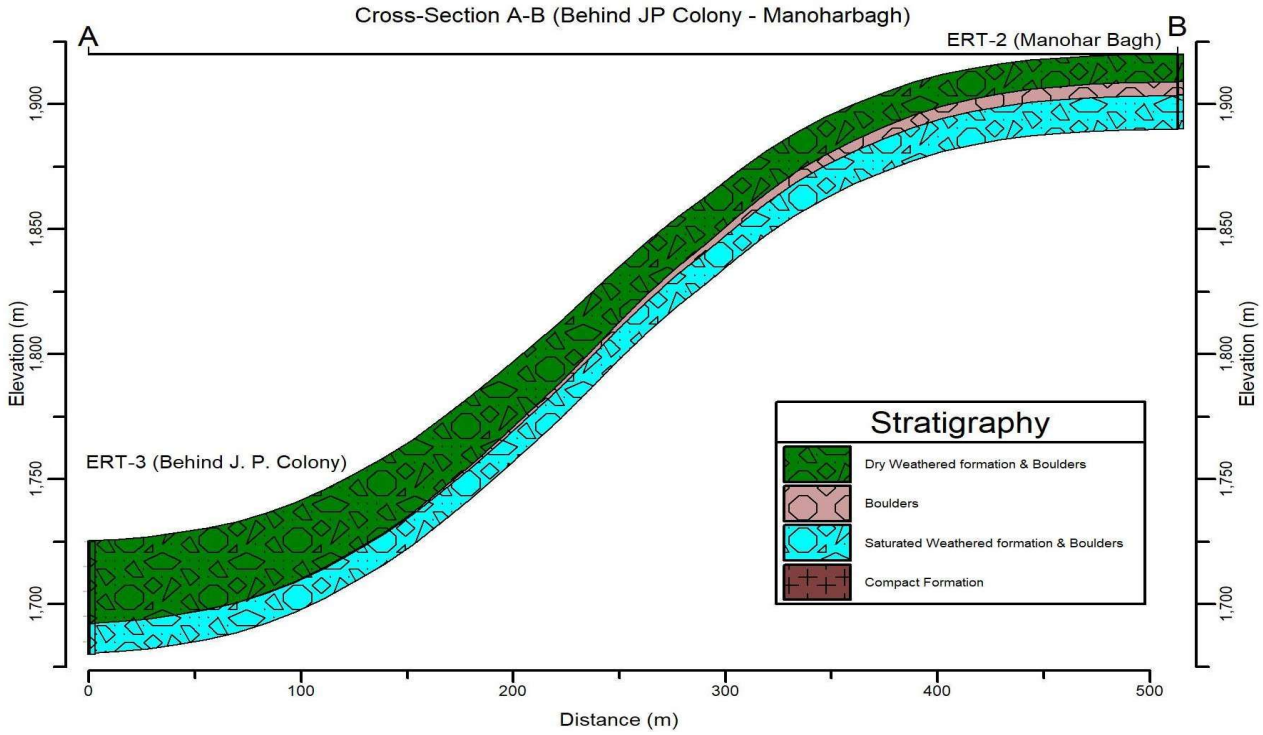


Figure – 12 B- lithological section from J P colony to Manohar Bagh, Joshimath, Chamoli District

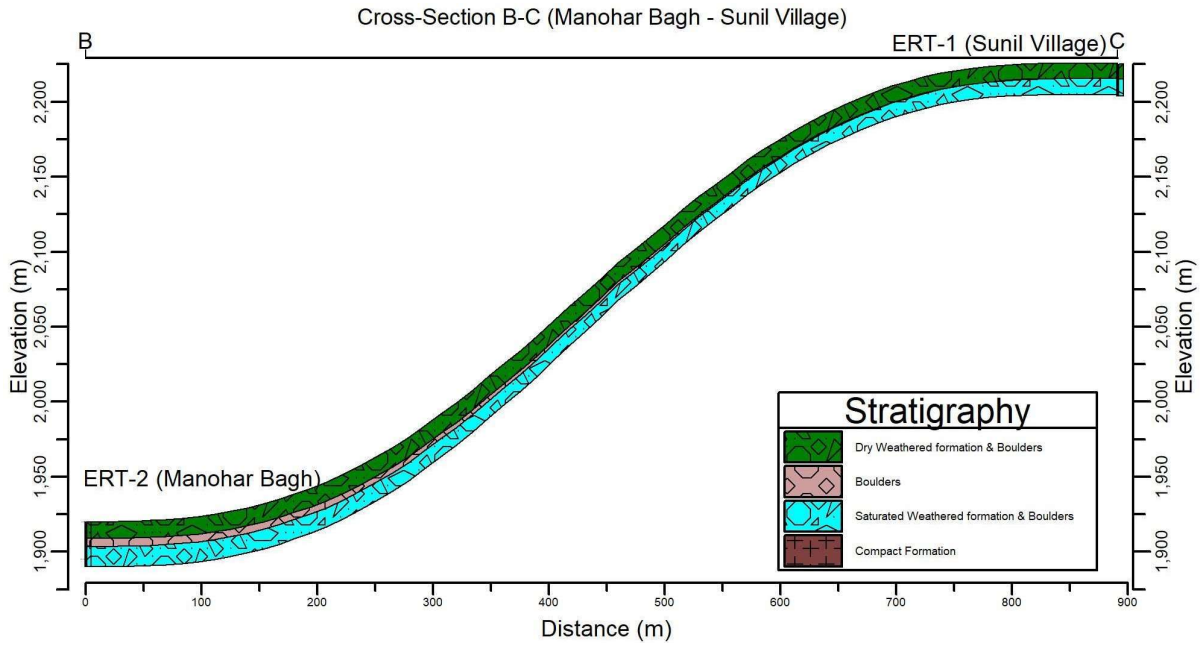


Figure – 12 C- Lithological section from Manohar Bagh to Sunil Village, Joshimath, Chamoli District

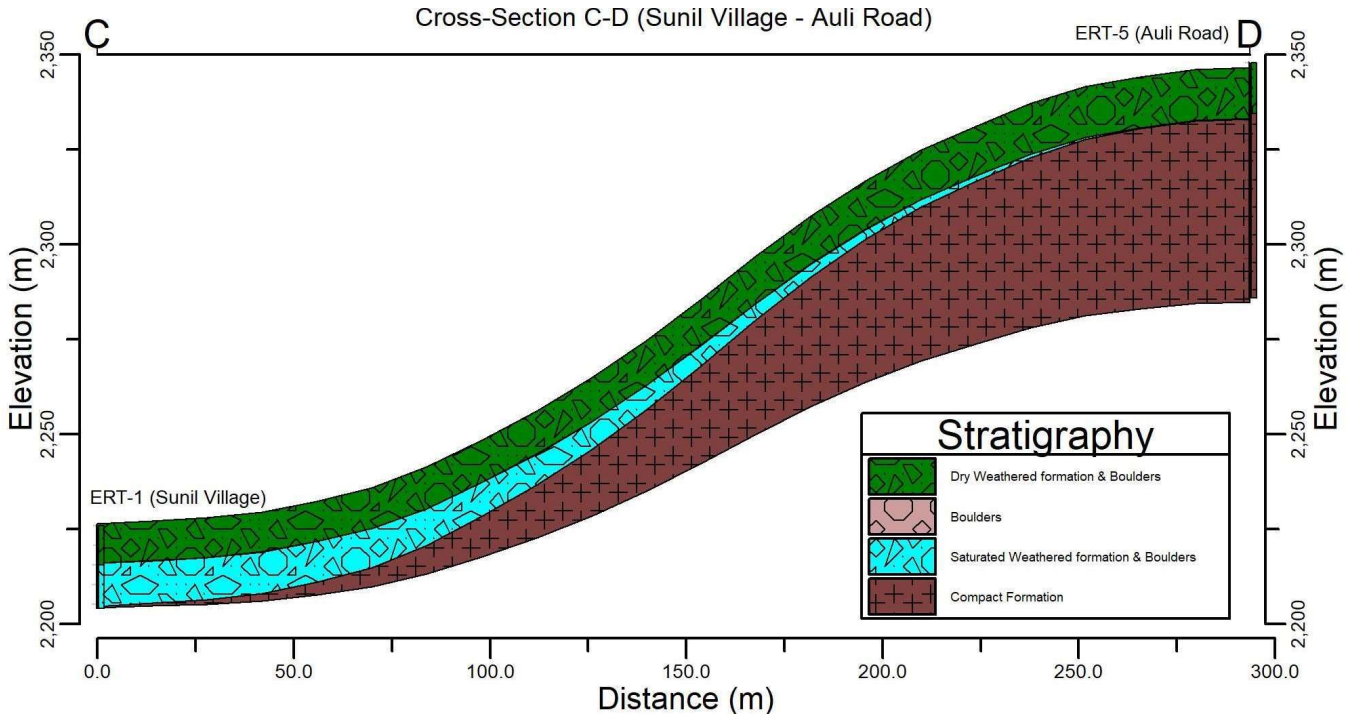


Figure – 12 D- Lithological section from Sunil Village to Auli Road, Joshimath, Chamoli District

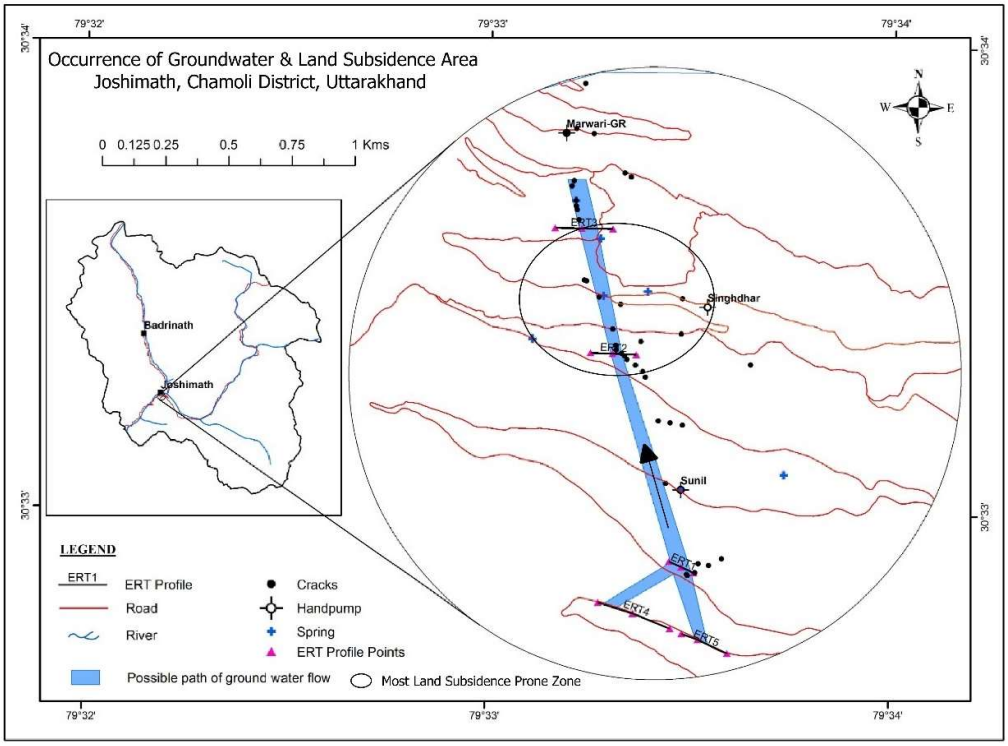


Figure – 13- Occurrence of Groundwater and Land Subsidence Area, Joshimath, Chamoli District

On perusal of the Figure 12 A, it is observed that thickness of the unconsolidated material increasing from Auli Road to J P Colony. Occurrence of water saturated formation becomes deeper from Auli Road to J P Colony. Ground water flows towards North direction (Fig 13). Large boulders are embedded in loose material especially in and around Manohar bagh. Findings of hydrogeological and geophysical studies conducted in the area reveals that the thickness of overburden (loose material) and saturated zone are comparatively more in Manohar Bagh-Singhdhar area, which may causes this area becomes susceptible to land subsidence. Further, the crack and subsidence in the area have relation with low resistivity shallow zones with groundwater flow occurring within 50 m depth.

5.0 Conclusion and Recommendation

- Joshimath Town is characterised by high peaks, valley, cliff and moderate to steep slope.
- Joshimath town is situated on loose sediment embedded with large boulders which overlain the metamorphic rocks. These sediments are deposited by glacial and fluvioglacial action duringQuaternary period. The slope of the basement in the area ranges between 30 to more than 60 degrees. After deposition of the morainic deposit, the slope become gentler but it still lies between 10- 20 degree. Unconsolidated deposits are less cohesive and steep slope also aggravates the stability of the landscape.
- Main Central Thrust (MCT), Vaikrita thrust and many lineaments, fractures

traversed through the area. The rock masses along the weaker zones are highly vulnerable to land subsidence.

- Cracks, spring location and handpumps constructed in the area are plotted (Figure 3 A and 3 B). It is observed that they are aligned in the same zone. Occurrence of all three in the same zone may indicate that strata saturated with the ground water may prone to land subsidence. In the area, zone tapped for handpump is 65 -80 m below ground level which indicates that formation saturated with ground water may located at a depth of 65 -80 m bgl. The decline in depth to water level at Singhdhar handpump indicates that water bearing strata is linked with the land subsidence. Land subsidence may be extended in and around Singhdhar Handpump.
- Many springs has been shown in Toposheet No 53 N/10 (published year 1963) where present land subsidence occurred. During the investigation eight spring are also marked. As large number of pilgrims for Chardham Yatra and tourists comes every year, to provide accommodation ample number of hotels, home stay are constructed in the area. Some of them are constructed in spring zone or at the emergence point of springs such as one of the springs marked in toposheet at Marwari village where J P residential colony situated, another spring present near Hotel Auli, Ravigram. Construction of buildings in spring zone did cessation of spring flow. The study conducted in respect of hydrogeological and geophysical survey indicated that the natural discharge of the earlier existing springs in the area were severely affected and due to the cessation of spring flow, it ultimately increases the subsurface pore pressure which result in sudden gush of ground water in form of spring at JP residential premise. The sudden release of ground water reduces the existing pore pressure and the fluctuation in pore pressure renders the land subsidence in the area. In nutshell, construction in spring zone triggered with seismic activities may be the reason for recent land subsidence.
- The cracks, spring and handpumps present in the area are aligned in the same zone. Occurrence of all three in the same zone indicates that strata are saturated with the ground water. Ground water saturated zone may accelerate the land subsidence. The significance of geophysical survey is very important as it reveals the subsurface lithology. The ERT has been conducted at five places with different length of spreading (100- 240 M). The ERT data shows that loose sediment embedded with large boulder exists upto 35 -40 m bgl. In addition, the outcome of the geophysical study infers that low resistivity zone i.e., water saturation zone occurs all along the cracks zone. Ground water flows towards north with steep hydraulic gradient. At some places of ERT, low resistivity zone occurs below high resistivity zone which indicate that big boulders are embedded within unconsolidated water saturated sediment and due to sudden gush of water, balance of boulders are also disturbed. As these boulders supports many constructed structures, disbalance in the boulder causes the cracks in the structures.

- It is suggested that trench along with the retention wall may be constructed at different topographic level so that ground water pressure may be dissipated and cracks in futures will be cease. Construction activities in spring zone area should be immediately stopped. Emergence point of the springs which are covered with any concrete material should be cleared immediately.