IDENTIFICATION OF SOURCE AND CAUSES OF THE GUSHING WATER IN THE PREMISES OF JAYPEE COLONY IN THE NIGHT OF 02 JANUARY, 2023

Submitted to

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(USDMA)

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IDENTIFICATION OF SOURCE AND CAUSES OF THE GUSHING WATER IN THE PREMISES OF JAYPEE COLONY IN THE NIGHT OF 02 JANUARY, 2023

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Introduction

The present study was carried out in the Joshimath region of Uttarakhand, which has faced enhanced rate of subsidence during last few months, followed by the emergence of a new spring in the premises of Jaypee Colony and development of cracks in houses. Being close to the holy shrine of Shri Badrinath, Shri Hemkund Sahib, the Valley of Flowers and Auli, the city is also important in terms of pilgrimage and tourism. The town of Joshimath is located at an altitude of approximately 1875 m in Higher Himalayas, along a narrow gorge at the confluence of River Dhauliganga and Alaknanda. Joshimath town had a human population of 16,709 (Census, 2011) and might have reached at least 18630 as per 11.5% population growth. The region is situated over paleo landslide deposits (Mishra, 1976) and is highly vulnerable in view of enhanced erosion due to unprecedented human activities and intensified monsoonal rainfall. Geomorphologically, the terrain around Joshimath encompasses both glacial and glacio-fluvial landforms. The slopes are dominated by precipitous slopes covered with gigantic fans and cones of active and stabilized landslide debris. Tectonically, Joshimath is bounded in the north by a North West-South East (NW-SE) trending Pindari Thrust and the north dipping Main Central Thrust (MCT) in the south west (Heim and Gansser, 1939; Valdiya, 1998). The area around Joshimath is seismically very active with an exhumation rate of ~2 mm/yr (Vance et al., 2003; Tyagi et al., 2009). Lithology of the area is comprised of highly jointed gneisses with interlayers of schistose rockmass. High relief around the MCT acts as an orographic barrier to the northward moving moisture laden winds of the Indian Summer Monsoon (ISM), which accounts for around 80% of the annual precipitation between June and September. Some precipitation is also received during winters through western disturbances, and partly by local convection in pre-monsoon season.

The NW Himalaya has witnessed ~51 % of all the landslides in India during the years 1800 to 2011 (Parkash 2011). However, in Joshimath area land subsidence has started from 1960's, which formed the basis of constitution of Mishra Committee in 1976. As evident from the report of Uttarakhand State Disaster Management Authority (USDMA) on "Geological and Geotechnical Survey of Land Subsidence Areas of Joshimath Town and Surrounding Regions, Uttarakhand", cases of land subsidence in different areas of Joshimath have been reported during last couple of years. However, the subsidence occurred during the first week of January, 2023 was intense, different from other events and drew the attention of people from different sections of the country. Sudden subsidence in large part of Joshimath was noticed in the night of 2nd Jan, 2023 with appearance of gush of water near badminton court of Jaypee colony in

Marwari area (Fig. 1 &2). This incidence coincided with land subsidence in a pattern, with bottom near Jaypee colony main gate and top near Sunil ward of Joshimath (Fig. 3). Most of the subsidence cases occured in Western part of the Joshimath town.

Fig. 1: Photograph of the site of gushing water at Jaypee Colony (Date: 08.01.2023)

Fig. 2: Photograph of land subsidence very close to the gushing water site in the Badminton court of Jaypee Colony

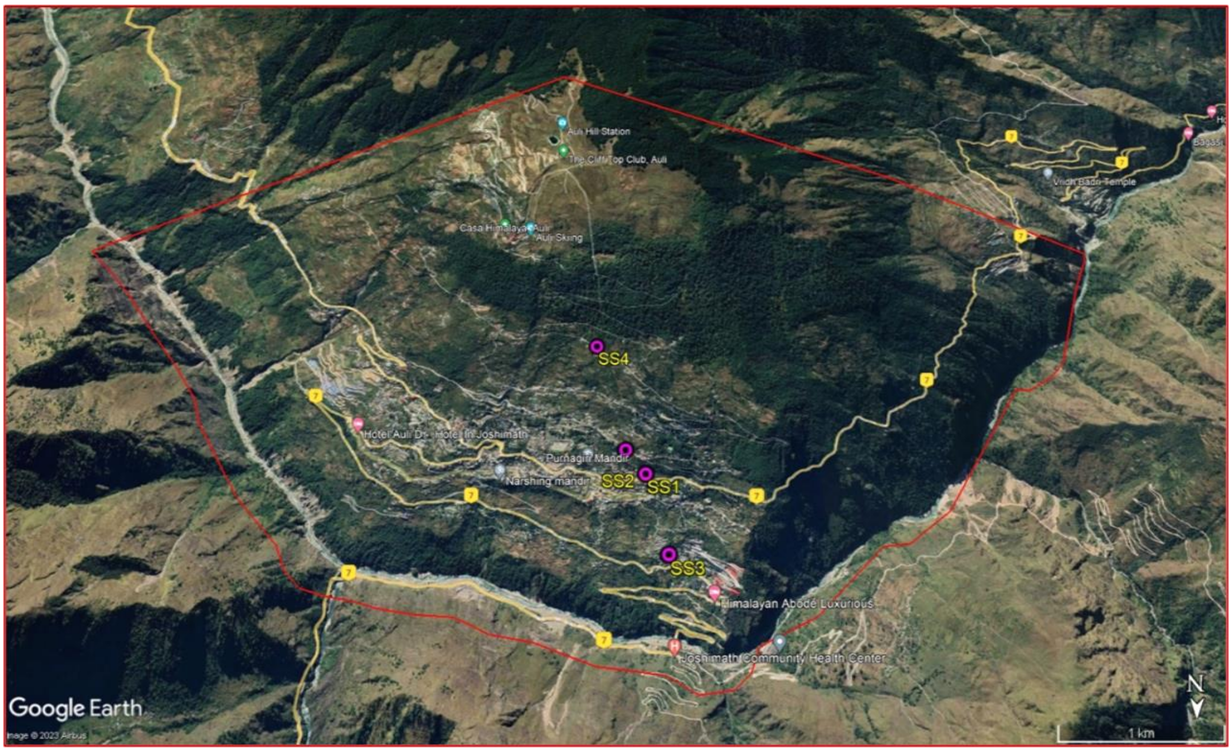

Fig. 3: Pattern of the subsidence (concentrate in Western part of Joshimath town) as observed during the visit of 08-09 Jan, 2023

Drainage Network of the Area

The drainage network of the region was delineated from the SOI toposheet no. 53N/10 (Fig. 4 &5). Most of the streams originats from the NW-SE trending ridge Auli area and flows parallel to each other and joining the main river Alkananda almost *perpendicularly* and displays trellised drainage pattern. No drainage network was observed in Singhdhara, Manohar Bagh, Sunil Ward and JP Colony area in the toposheet (Fig.5), which indicated the possibility of presence of subsurface channels, which normally dispose-off the water coming from the upper reaches (Auli areas). This possibility is supported by the fact that a drainage line marked in SoI toposheet, above the Manohar Bagh (Adjacent to the West of the top of the Sunil ward) of Joshimath disappears after travelling for some distance (Fig. 5). This indicates that water coming from steep slopes get opportunity to infiltrate in this area due to change of slopes or soil material properties or both. Disappeared water may flow in the form of a subsurface channels, which either feeds the local springs or directly discharges to the river/streams as a base flow. However, detailed resistivity survey can be helpful to captured the moisture signature in the area to demarked the path of subsurface channels.

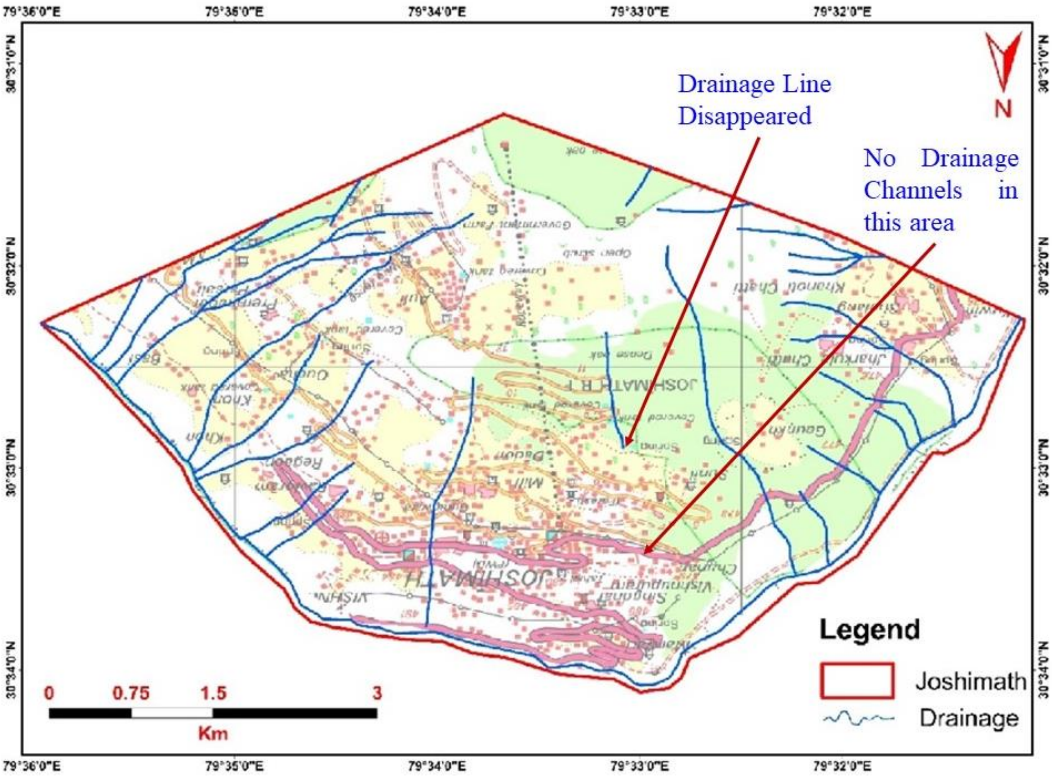

Fig. 4: Drainage network extracted from toposheet (53N/10) of Survey of India

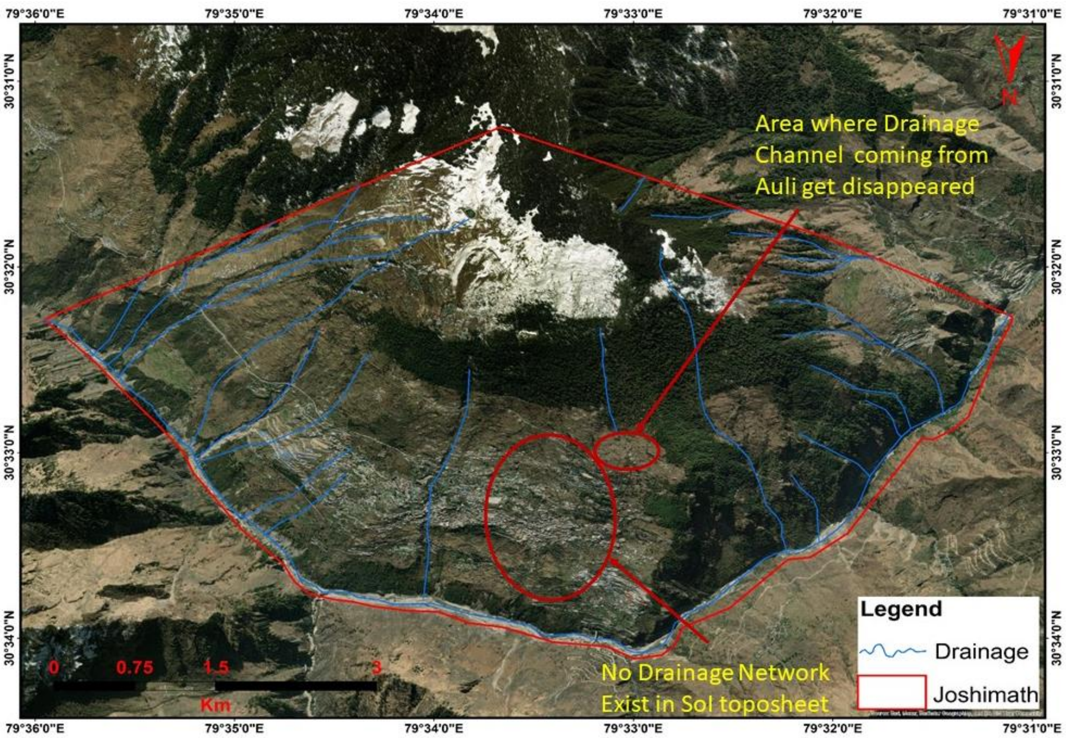

Fig. 5: Location of disappeared drainage channel and area where drainage channel network is absence on the google earth satellite imagery

Digital Elevation Model (DEM) of the area was downloaded from High Mountain Asia web portal (8m resolution) (HMA, 2023) and depicted in the Fig. 6. The altitude of the area of interest varies from about 1300 m (river at bottom) above mean sea level (amsl) to about 3200 amsl (peak of Auli) (Fig. 6). A large part of the region has steep (25-35°) to very steep (>35°) slopes (Fig. 7) with major slope in Northwest, Northeast, North and West directions (Fig. 8). The slopes are covered with debris of gigantic active and inactive/stabilized landslides.

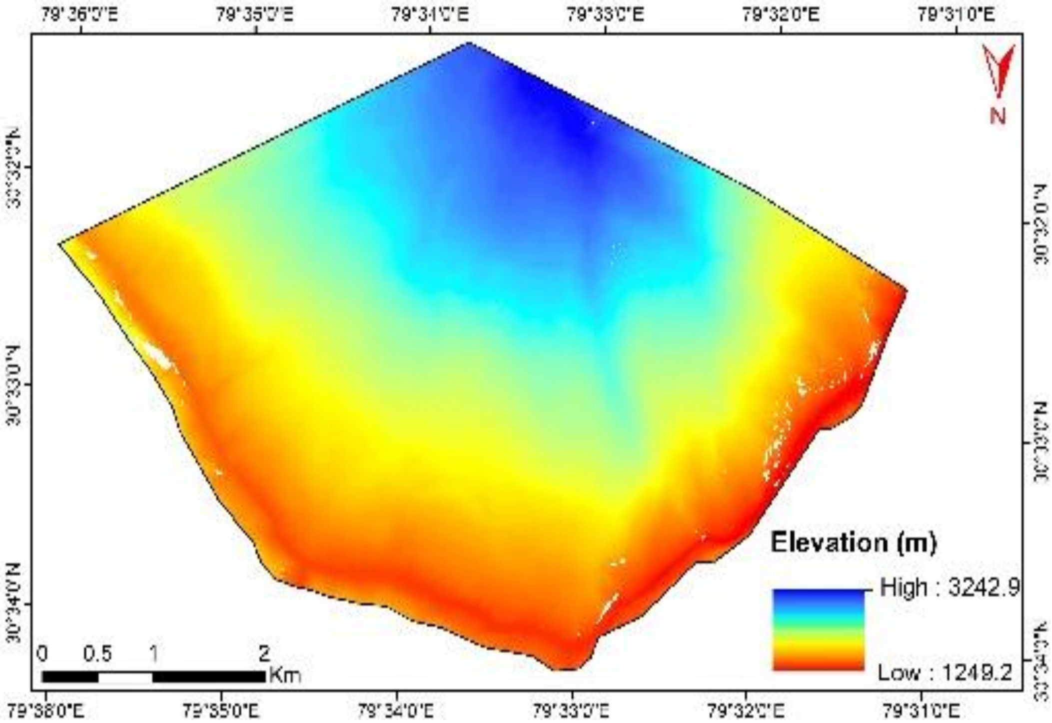

Fig. 6: DEM of the study area (8m resolution)

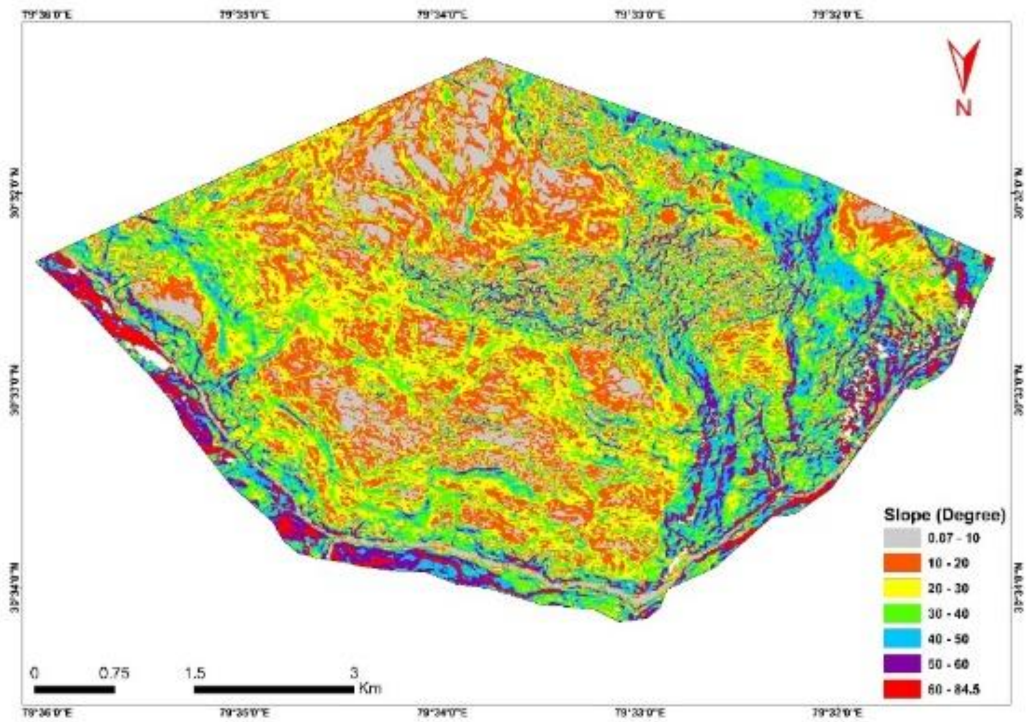

Fig. 7: Slope map of the area derived from DEM

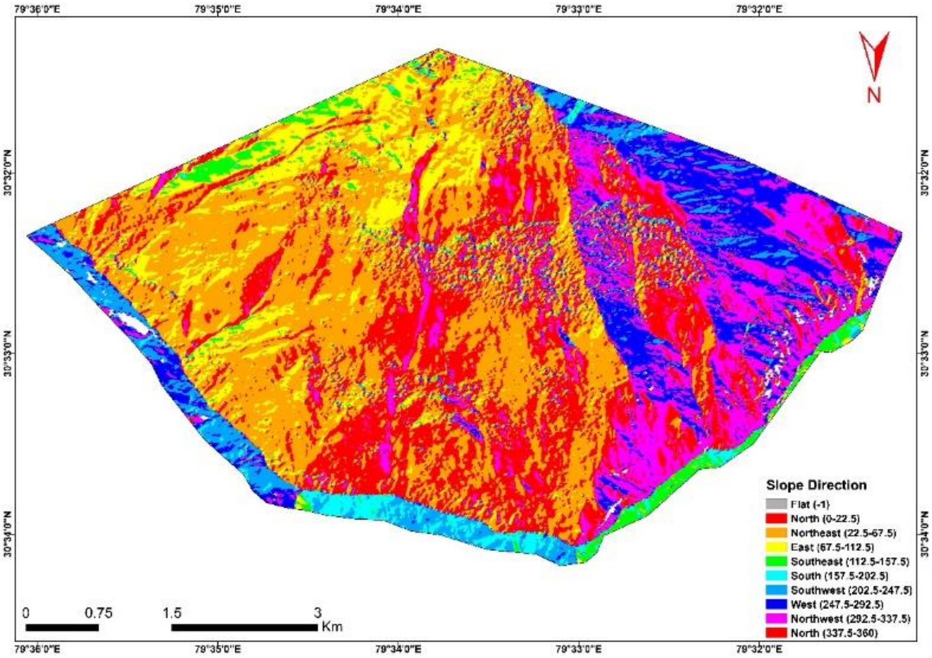

Fig. 8: Aspect map of the area derived from DEM

Drainage network have been also extracted from the DEM by considering 0.20 km^2 as the threshold value of channel initiation in this region as per experiences and depicted in Fig. 9.

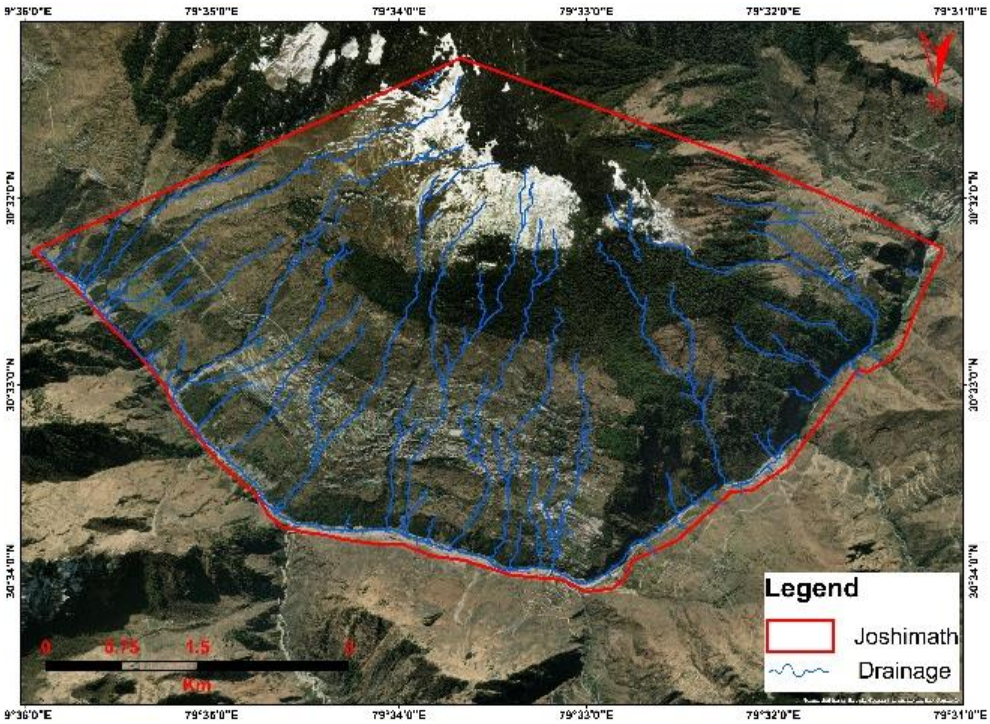

Fig. 9: Extracted drainage network in Joshimath region from the DEM

Developed drainage maps suggested that there has to be the presence of channels in the western side of Joshimath to dispose-off the surface runoff generated during the rain or snowmelt from the upper reaches.

Mapping of Springs in the Joshimath Area

Total six (06) springs reported in SoI toposheet were digitized and are shown in Fig. 10a. All the springs located in SoI toposheets were physically verified to confirm the chances of disappear of any springs after the event of 02 January, 2023.

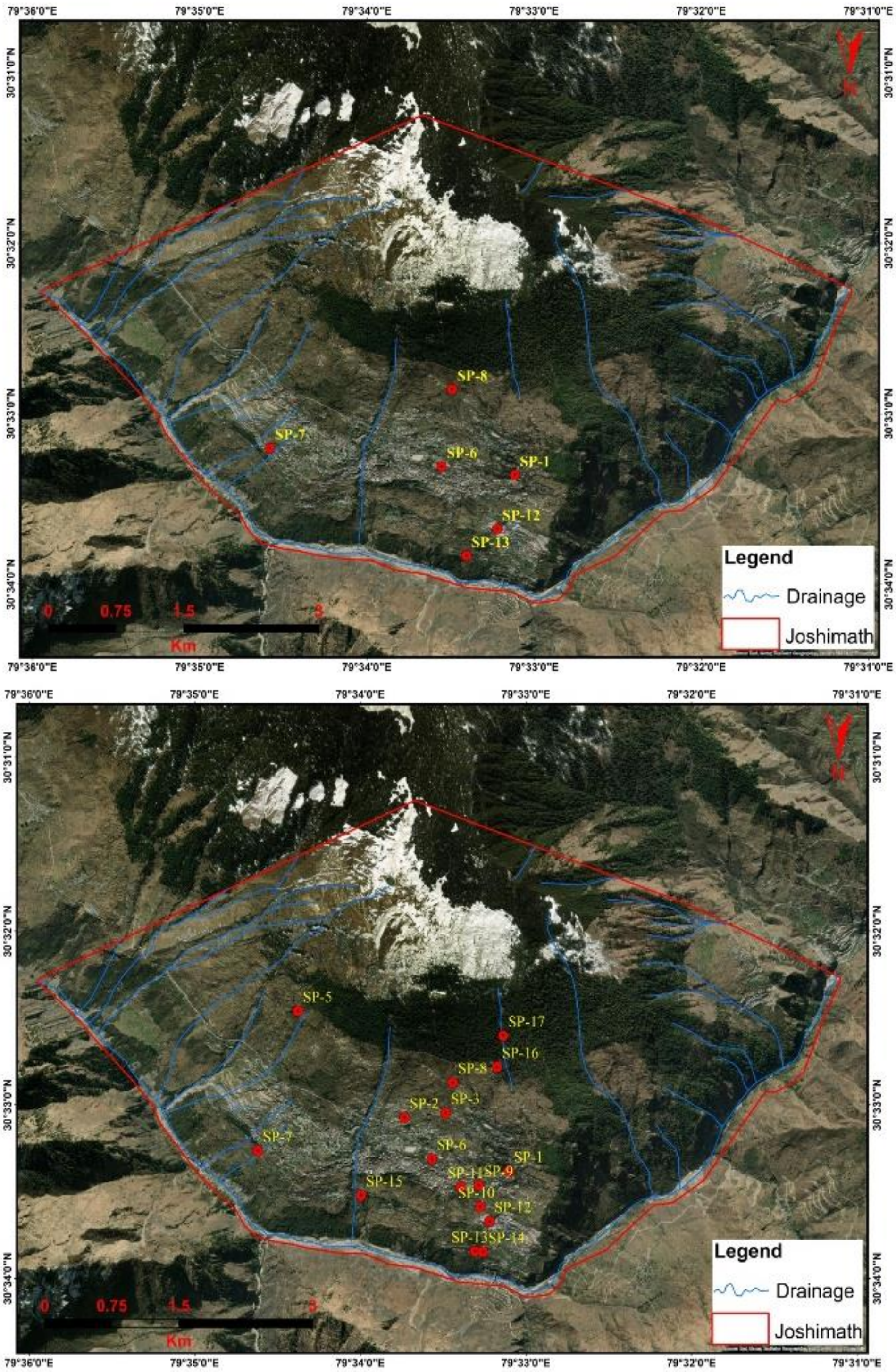

Fig. 10: Location of springs (a) as per SOI toposheet, and (b) identified during field excursions

However, total 16 nos. of springs have been identified in the vicinity of Joshimath during the field visits performed on 18 to 19 January, 2023. It was observed that most of the springs lie in the Western side of Joshimath i.e., Sunil Ward, Manohar Bagh, Singhdhar, Marwari and JP colony (Fig. 11). The details of the springs identified in the area is given in Table 1. It is noticed that that most of the springs have been obsereved in the area of Subsidence (Fig. 3 & Fig.10b).

Table 1: Details of the springs identified in Joshimath area

SN	Sample Id	Location	Latitude (ºN)	Longitude (ºE)	Elevation (m,amsl)	pH	EC (μS/cm)	Temp (˚C)	Discharge (LPM)
1	SP-01	Below Jangalat Gate	30.5564	79.5517	1946	7.92	114	11.4	2.50
2	SP-02	Dadon	30.5512	79.5622	2053	8.01	68	10.0	≈750
3	SP-03	Sunil Dhara (46)-1	30.5508	79.5581	2106	7.98	105	10.7	1.22
4	SP-05	Manoti	30.5410	79.5729	2359	7.79	138	9.4	20
5	SP-06	Jyotirmath	30.5552	79.5595	1943	7.08	219	12.5	5
6	SP-07	Near Swadeshi Dhaba	30.5544	79.5770	1785	7.74	271	13.5	5
7	SP-08	Sunil Ward	30.5478	79.5574	2272	7.5	69	9.6	11.29
8	SP-09	Singhdhara	30.5577	79.5548	1858	7.5	172	-	-
9	SP-10	Above JPVL	30.5598	79.5546	1752	7.58	162	-	-
10	SP-11	Singhdhara Gopaldhar	30.5579	79.5566	1856	7.18	203	-	-
11	SP-12	JP Colony Gushing Water)	30.5612	79.5537	1662	7.47	123	12.88	NA
12	SP-13	Marwari	30.5640	79.5551	1543	6.94	275	15.46	6.25
13	SP-14	Marwari	30.5641	79.5543	1549	7.26	276	14	12.5
14	SP-15	Kamed	30.5587	79.5666	1699	7.53	288	12.7	18.82
15	SP-16	Sunil Forest (Dry)	30.5463	79.5530	2400	-	-	-	-
16	SP-17	Sunil Forest	30.5434	79.5523	2490	7.89	43	3.1	40

Fig. 11: Photographs of Springs in Joshimath area

Flow Behavior of Gushing Water

Discharge data of gushing water (new spring) have been measured by Jaypee Company twice a day (8:30 AM and 5:30 PM) since 06.01.2023 and hydrograph of the gushing water is depicted in Fig. 12. The discharge on 06.01.2023 was 540 LPM, which decreased to 17 LPM on 02.02.2023. Hydrograph of the gushing water shows recession trend except for few observations. Fig. 12 shows sudden rise in discharge of gushing water during Jan 19 to 20, 2023, which is due to rainfall followed by snowfall during that time in Joshimath area. This indicated that the possibility of source is very near and the gushing water is feed by a shallow subsurface channel. It can be seen from the Fig. 12 that after 01.02.2023, the discharge is almost constant (about 17 LPM). It was estimated that 10.66 million liters of water have been discharged from the gushing water before coming to its steady state (as on 02.02.2023). Now, as per discharge data, it has become a spring having discharge about 17 LPM. This spring may be kept in the Sixth category (0.1-1 LPS) based on Meinzer Spring classification. As per the Table 1, most of the springs emerging in the Joshimath area comes under Sixth category according to Meinzer Spring classification. However, long term spring discharge and rainfall data (at least one complete hydrological year) will be helpful to understand the behavior of this new spring emerged in the night of 02.01.2023 at Jaypee colony.

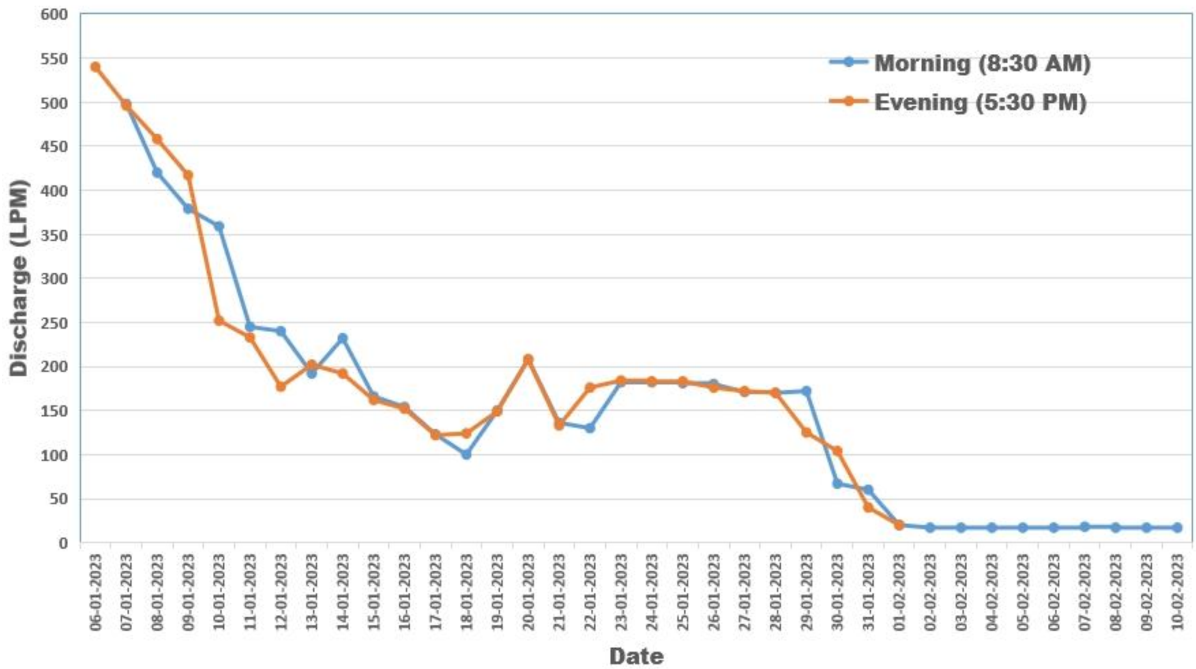

Fig. 12: Graph showing discharge variability of gushing water in the premises of Jaypee colony

Sample Collection in the Field

Three field excursions were carried out during 06 Jan, 2023; 08-09 Jan, 2023; and 18-19 Jan, 2023 by the team of National Institute of Hydrology, Roorkee (Fig. 13). A total of 05 water samples during first visit, 08 samples during second visit and 27 samples during the third visit were collected. The samples were collected from springs, drains, and river to study the chemical characteristics through on-site measurements of physico-chemical parameters [i.e., pH, temperature, Electrical Conductivity (EC) and Dissolved Oxygen (DO)]. The physico-chemical parameters were measured onsite using portable measuring kits of Hach, USA make HQ40d handheld multiparameter kit. The analysis of major ions and trace metals in collected water samples have been carried out in the laboratory and details are provided in water quality section. The samples were filtered through 0.45 µm nylon filter paper for the analysis of major ions and trace metal concentration. In addition, identification of source of water has been carried out at NIH Roorkee through stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD).

Fig. 13: Survey of various water sources for onsite investigations and collection of samples for laboratory analysis

Stable Isotope Analysis

A total of 40 samples (22 no. of samples collected from springs; 3 from hand pumps; 11 samples from drains; 5 samples from NTPC sites) were collected from Joshimath area in 3 field visits and analysed for stable isotopes. Stable isotopes (δD and $\delta^{18}O$) in water were analysed using GV-Isoprime Dual-Inlet Isotope Ratio Mass Spectrometer (DI-IRMS) with precision of measurement for δD is ± 1‰ and that for $\delta^{18}O$ is ± 0.1‰. The results of these samples are presented in Fig 14. and Fig. 15. Based on the analysis results, the recharge sources are identified.

Samples were analysed for stable isotopes ($\delta^{18}O$ and δD) and are shown in Fig. 14 . Some inferences (based on analysis of $\delta^{18}O$**)** are given as below:

- High depleted values of $\delta^{18}O$ in spring and drains indicate a possible recharge from snow or glacial melt water.
- $\delta^{18}O$ values of springs in the range of -9.4 to -10.2‰ indicate recharge source as melt water from higher reaches (or recharge source may be intermittent rains) flowing in the form of drains (-9.4 to -10.2‰) with slight enrichment and $\delta^{18}O$ values are further enriched in the groundwater samples taken from hand pumps (-8.9 to -9.7‰).
- The slope and intercept of the groundwater samples $\delta D = 7.45\delta^{18}O + 9.14$ is closer to the Global Meteoric Water Line (GMWL) $\delta D = 8\delta^{18}O + 10$ clearly showing that groundwater is formed from the rainfall.
- The slopes and intercepts of the drain and springs are less than the GMWL suggesting origin from different source than the rainfall.

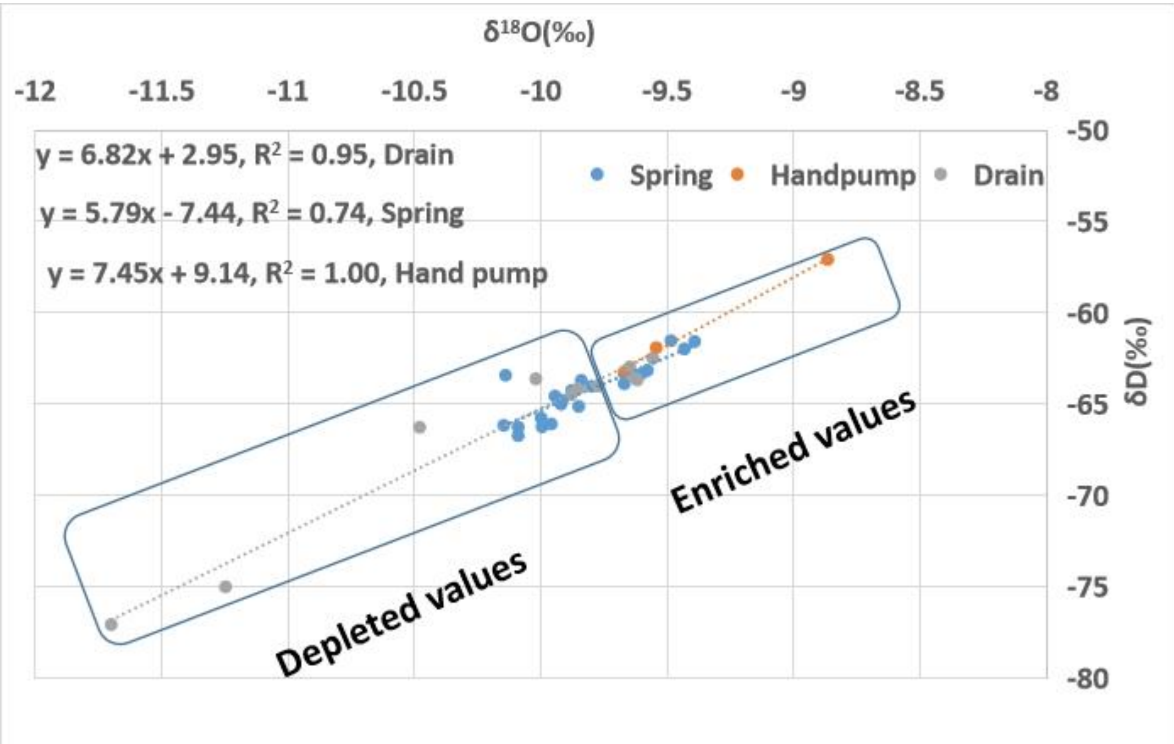

Fig. 14: $\delta^{18}O$ v/s δD for the samples collected during the field visit.

Interaction of seepage water near JP site with the NTPC water samples

In order to find the interaction between seepage water and NTPC water samples, 5 samples from inside and around the NTPC site were collected and plotted with the other analysed 40 samples including the sample collected from seepage water near JP site (SP-12). A plot between EC and $\delta^{18}O$ was drawn Fig. 15.

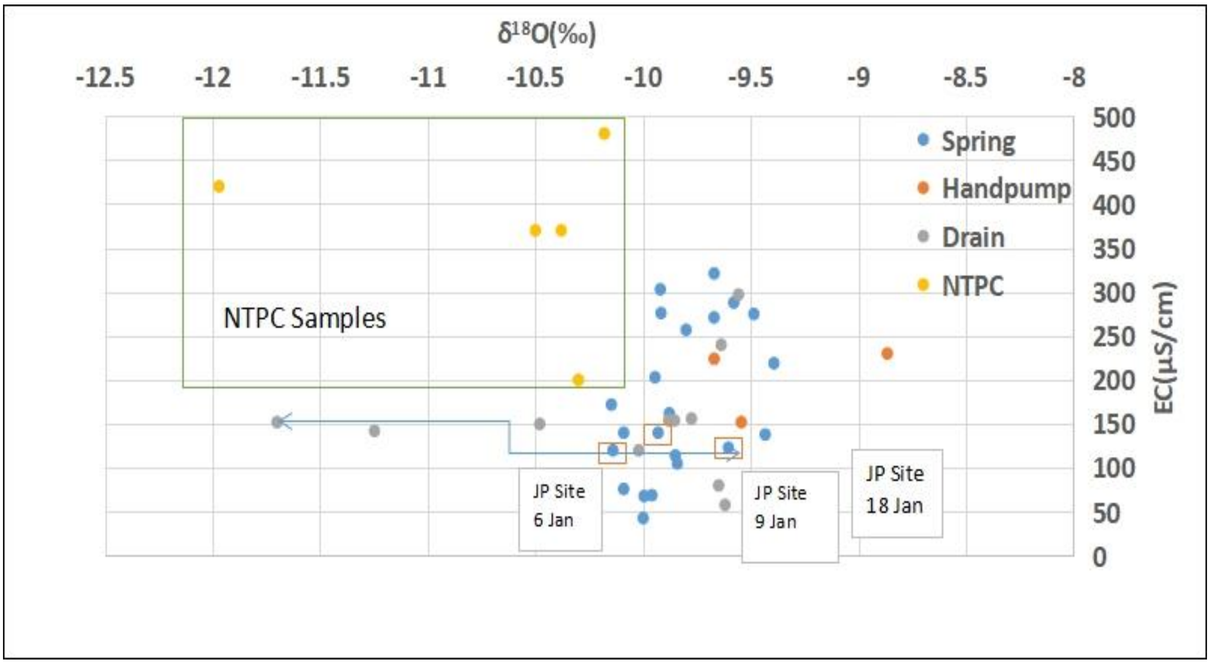

Fig. 15: EC v/s $\delta^{18}O$ of the samples collected around Joshimath area and NTPC sites

$\delta^{18}O$ values of NTPC sites samples ranged between -10.3 to -12‰ with an average value of -10.7‰ showing highly depleted values, while the $\delta^{18}O$ value of seepage water near JP site (SP-12) was found -9.9‰, which is isotopically enriched and if the same water is reaching to the JP site then the EC values do not support any interaction. The samples collected from NTPC sites have EC values in the range of 280 to 480 µS/cm with an average value of 368 µS/cm while the EC values of the seepage water (SP-12) was found 140 µS/cm which is much lower than (< 163%) the values of NTPC sites water samples. These values do not support the interaction since the EC values increase due to the dissolution of minerals on the way after covering a significant distance. Thus, it is clear that there is no interaction between the water samples from the NTPC sites to the gushing water near JP site (SP-12) and same can found in Fig. 15, where the samples collected from NTPC are lying in isolation to the samples collected from Joshimath area.

Water Quality

Sampling and analysis

The spring and drain water samples were collected in polypropylene (PP) bottles (500 mL) using dip/grab sampling method, and for trace metals in PP bottles (125 mL) after acidification to pH <2 with HNO_3. The samples were transported in an ice box to the laboratory and kept at 4 ºC in a cold cabinet till the analysis of samples. All the chemicals used for preservation and analysis were of analytical grade (Merck).

The pH, EC, and temperature of the samples were measured in situ with the help of a multi-parameter analyzer calibrated in the field before sampling. The major cations (Li, NH_4, Ca, Mg, K, and Na and anions (F, Cl, NO_3, NO_2, and SO_4) were analyzed using Ion Chromatograph (Metrohm 930 Compact IC Flex) with a conductivity detector, and the alkalinity (HCO_3) was determined by the acid titration method (APHA 2017). The trace metals were analyzed by ICP-MS (Agilent 7850 ICP-MS). The Ion chromatograph and ICP-MS were calibrated for the intended use using Certified Reference Materials (CRMs) traceable to NIST (Merck) and the standards/blank were also run after a periodic interval during the analytical run for the continuing calibration verification (CCV). The analysis run was accepted if the percentage recovery in CCV run was within ±10%. All the parameters were analyzed in triplicate for quality control and the analysis correctness was checked by anion-cation balance and the analyses were accepted with the difference of ±5%.

Statistical analysis

The descriptive analysis for minimum, maximum, range mean, standard deviation, and Pearson’s correlation coefficient (r) for different chemical and physical parameters and the Hierarchical Cluster Analysis (HCA) in the study was conducted by SPSS version-22 software. HCA is a statistical technique that classifies different objects into groups in such a way that the similarity between two objects is maximal if they belong to the same group and minimal otherwise.

Major Ions & Trace Metals

Thirty-Seven (37) samples covering springs, drains, rivers and groundwater were collected from Joshimath in sampling expeditions during Jan 06-09, 2023 and Jan. 18-19, 2023. The results of major ions and trace metals in the collected water samples is provided in Table 2 and 3, respectively. The water quality parameters (such as pH, TDS, F, Cl, NO_3, SO_4, HCO_3, Ca, and Mg) of the water samples were found within the limits prescribed by BIS (2012) for drinking water.

The results of trace metals analysis indicate that most of the trace metals in the collected water samples were within the acceptable limit prescribed by BIS (2012) for drinking water. The Al content in one sample collected from a spring at JP Site (JM-SP-12) was 68.6 µg/L exceeded the acceptable limit of 30 µg/L, however, was with the permissible limit of 200 µg/L. Similarly, Fe concentration in the spring at JP site, Mn concentration in the handpump sample at Radha Krishan Mandir, Marwari exceeded the maximum permissible limit of 300 µg/L. Hg concentration exceeded the maximum permissible limit (1.0 µg/L) in the samples collected from Sunil dhara (JM-SP-03) and Jogidhara (JM-D-05). Zn concentration in the samples collected from Handpump near Sunil house exceeded the acceptable limit (5000 µg/L).

Hierarchical Cluster Analysis (HCA) of Hydrochemical Data

To improve the understanding of the geochemical characteristics of the study area and to identify the source of the new spring that appeared near JP company, the hierarchical cluster analysis of 11 water quality parameters was performed using Ward's method. HCA analysis classified the water samples of the study area into five distinct groups, namely Cluster 1, 2,3 4, and 5 (Fig.16). Cluster 1 comprises the lowest values of EC, TDS, and alkalinity, whereas, cluster 5 sample (NTPC tunnel) was having highest TDS, F, SO_4, Ca, and HCO_3. Cluster 2 samples were having all the parameters higher (around double) than cluster 1 samples. Cluster 3 samples were having higher TDS, F, Ca, and HCO_3 and lower Cl, NO_3, and SO_4 as compared to Cluster 1 samples. Cluster 4 sample (Vishnuprayag) was having TDS and SO_4 higher than Cluster 1,2, and 3 and lower than cluster 5. The HCA analysis clearly indicates that the source of water in the new spring appeared near JP company is in Cluster 1: Spring and is not linked to the water in the NTPC tunnel.

Table 2: Concentration of Major ions in the collected samples

Date of Sampling	Location	Sample Code	Source	pH	EC	TDS	Turbidity	F	Cl	NO_3	SO_4	HCO_3	Na	K	Ca	Mg
				--	(µS/cm)	(mg/L)	(NTU)	(mg/l)								
Jan 06-08, 2023	Vishnugad (NTPC-Inlet)	JM-NTPC-4	Drain	-	370	271	35.80	1.1	2.3	0.3	86.5	147.4	9.3	6.6	57.4	9.2
	Vishnugad (NTPC-Outlet)	JM-NTPC-5	Drain	-	370	264	41.60	1.2	2.2	0.3	83.0	155.7	9.8	7.4	58.3	9.6
	J P Company (Joshimath)	JM-SP-12	New Spring	-	120	78	>800	0.2	1.9	3.4	19.9	41.3	3.6	5.4	13.7	3.5
Jan 08-09, 2023	Below Jangal Gate	JM-SP-01	Spring	-	140	70		0.1	3.7	8.1	9.9	40.2	4.1	4.1	12.7	4.6
	Jyotirmath-53	JM-SP-06	Spring	-	257	118		0.1	16.1	15.0	13.6	62.0	10.5	4.9	17.3	9.7
	Near Swadeshi Dhaba	JM-SP-07	Spring	-	303	151		0.1	15.8	35.3	16.2	59.4	11.3	14.3	21.3	7.4
	Sunil Dhara (47)-2	JM-SP-08	Spring	-	76	38		0.1	4.2	0.5	2.4	29.2	2.7	3.0	6.8	3.4
	JP Site	JM-SP-12	Spring	-	140	70		0.1	1.6	3.4	22.5	33.2	3.2	6.1	12.3	4.14
	Marwari-1	JM-SP-13	Spring	-	321	149		0.1	19.0	19.8	20.7	71.1	11.0	7.2	23.6	10.9
	JP Nala	JM-D-01	Drain	-	152	76		0.2	5.0	7.6	14.4	38.2	5.6	2.9	15.2	3.7
	Vishnuprayag	JM-R-01	River	-	283	156		0.1	0.6	1.0	65.8	73.3	3.7	1.9	31.9	10.4
Jan 18-19, 2023	Below Jangal Gate	JM-SP-01	Spring	7.92	114	75		0.1	4.9	8.8	1.6	49.2	4.8	4.7	16.3	4.6
	Dadon	JM-SP-02	Spring	8.01	68	41		0.9	2.5	3.5	7.2	15.9	2.7	3.4	7.0	2.2
	Sunil Dhara (46)-1	JM-SP-03	Spring	7.98	105	53		0.2	7.2	3.9	4.6	24.7	4.9	4.2	7.5	4.3
	Manoti	JM-SP-05	Spring	7.79	138	97		0.2	3.2	2.0	9.8	75.2	3.2	3.8	26.2	3.7
	Jyotirmath-53	JM-SP-06	Spring	7.08	219	115		0.2	14.7	15.3	13.0	42.3	9.3	5.4	17.2	9.0
	Near Swadeshi Dhaba	JM-SP-07	Spring	7.74	271	162		0.7	16.3	39.6	15.6	58.0	11.8	14.8	12.7	7.5
	Sunil Dhara (47)-2	JM-SP-08	Spring	7.5	69	41		0.2	4.9	0.6	2.4	26.4	2.8	3.6	5.6	3.3

Date of Sampling	Location	Sample Code	Source	pH	EC	TDS	Turbidity	F	Cl	NO_3	SO_4	HCO_3	Na	K	Ca	Mg
				--	(µS/cm)	(mg/L)	(NTU)	(mg/l)								
	Singhdhara	JM-SP-09	Spring	7.5	172	109		0.1	11.2	19.7	13.8	42.7	8.9	5.1	14.7	5.6
	Above JPVL	JM-SP-10	Spring	7.58	162	105		0.1	8.7	15.5	17.3	42.3	7.4	5.7	14.8	5.4
	Singhdhara Gopaldhar	JM-SP-11	Spring	7.18	203	109		0.1	1.9	18.0	16.5	49.6	8.5	5.3	17.4	7.2
	JP Site	JM-SP-12	Spring	7.47	123	82		0.9	1.8	3.2	24.2	35.7	3.2	6.2	12.5	3.8
	Marwari-1	JM-SP-13	Spring	6.94	275	142		0.1	19.1	2.3	19.6	71.8	11.9	7.4	23.6	11.1
	Marwari-2	JM-SP-14	Spring	7.26	276	145		0.1	18.2	14.4	18.9	67.6	13.9	8.5	22.7	1.5
	Kamed	JM-SP-15	Spring	7.53	288	161		0.2	17.8	24.8	13.6	81.3	12.9	1.8	26.1	8.7
	Sunil Forest	JM-SP-17	Spring	7.89	43	29		1.0	0.9	1.3	4.5	16.4	1.8	1.9	4.0	1.9
	JP Nala	JM-D-01	Drain	7.63	142	77		0.2	6.3	1.8	13.6	38.6	6.3	3.5	14.2	3.8
	Dawil/Dadon	JM-D-02	Drain	7.99	154	64		0.2	13.3	4.7	8.7	17.8	1.4	3.7	13.8	3.5
	Sunil Dhara (48)-3	JM-D-03	Drain	7.3	58	36		1.0	3.3	0.7	2.3	24.4	2.5	2.7	4.9	2.9
	Parsari	JM-D-04	Drain	8.39	154	93		0.7	1.5	4.4	6.8	73.0	1.7	2.4	28.1	2.6
	Jogidhara	JM-D-05	Drain	8.11	80	44		0.1	1.9	1.8	3.1	29.2	3.0	2.9	8.8	2.8
	Kamed	JM-D-06	Drain	8.16	297	139		0.1	20.0	15.7	16.4	65.5	12.9	7.0	13.2	8.2
	Kamed Nala-2	JM-D-09	Drain	8.26	156	119		0.1	11.3	13.9	20.0	48.1	8.9	6.2	16.6	5.8
	Manoti	JM-D-10	Drain	8.34	240	132		0.7	3.4	3.5	6.3	113.8	2.9	3.6	39.7	4.5
	Radha Krishan Mandir, Marwari	JM-HP-01	Handpump	6.38	230	112		0.1	12.2	0.5	3.4	85.7	7.5	5.4	19.5	9.4
	O Bend Petrol Pump	JM-HP-02	Handpump	5.99	224	126		0.9	1.4	26.7	15.3	54.2	7.4	6.9	21.2	7.3
	Sunil	JM-HP-03	Handpump	7.55	152	65		0.2	6.8	0.1	2.3	55.5	4.8	4.3	8.2	5.9

Table 3: Concentration of trace metals in the collected samples

Date	Sample Code	Source	Be	B	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Sr	Cd	Ba	Hg	Pb	U
Jan 18-19, 2023	JM-SP-01	Spring	0.0	0.0	4.8	0.7	0.8	4.8	0.4	1.7	8.1	0.5	0.1	26.9	0.2	15.3	0.3	0.5	0.2
	JM-SP-02	Spring	0.0	0.0	4.8	0.5	0.6	4.2	0.0	1.4	9.2	0.1	0.1	16.7	0.3	1.5	0.6	0.5	0.1
	JM-SP-03	Spring	0.0	0.0	6.1	0.6	0.8	5.8	0.3	2.3	17.8	0.2	0.1	19.4	0.4	16.9	13.3	0.7	0.2
	JM-SP-05	Spring	0.1	0.0	2.8	0.2	0.3	3.1	0.2	2.8	16.9	0.1	0.4	49.3	0.3	32.4	0.3	0.2	0.8
	JM-SP-06	Spring	0.0	0.0	1.8	0.5	0.5	1.6	0.0	0.9	8.0	0.6	0.0	51.2	0.2	3.3	0.2	0.1	0.1
	JM-SP-07	Spring	0.0	3.4	2.8	0.7	0.3	5.1	0.0	1.7	12.1	2.5	0.2	58.9	0.3	32.4	0.8	0.3	0.4
	JM-SP-08	Spring	0.0	0.0	3.5	0.7	2.8	3.3	0.0	0.9	35.6	0.5	0.0	12.4	0.1	1.5	0.1	0.3	0.5
	JM-SP-09	Spring	0.0	0.0	8.5	0.5	1.4	6.4	0.0	0.6	11.7	0.4	0.3	3.6	0.2	15.3	0.8	0.2	0.7
	JM-SP-10	Spring	0.0	0.0	29.2	0.3	0.5	3.3	0.0	0.8	5.3	0.6	0.6	31.5	0.1	15.1	0.1	0.9	0.4
	JM-SP-11	Spring	0.0	0.0	2.9	0.4	0.6	4.2	0.0	0.4	2.3	0.3	0.2	33.6	0.1	2.9	0.7	0.2	0.5
	JM-SP-12	Spring	0.1	0.0	68.6	1.1	15.8	713.6	1.1	2.5	11.6	0.7	0.9	42.7	0.2	26.6	0.8	1.1	0.1
	JM-SP-13	Spring	0.0	0.0	2.2	0.6	0.5	4.8	0.0	1.6	13.5	0.1	0.0	63.9	0.2	35.9	0.1	0.4	0.5
	JM-SP-14	Spring	0.0	0.0	3.2	0.5	0.5	4.8	0.0	2.4	7.4	0.7	0.0	61.4	0.2	3.9	0.5	0.3	0.6
	JM-SP-15	Spring	0.0	7.2	0.1	0.2	0.2	0.5	0.2	1.5	1.7	0.6	0.9	76.0	0.2	63.6	0.1	0.1	0.2
	JM-SP-17	Spring	0.0	0.0	2.6	0.4	0.4	5.7	0.0	0.3	11.8	0.1	0.2	1.4	0.1	7.0	0.1	0.3	0.4
	JM-D-01	Drain	0.0	6.4	12.7	0.6	1.7	19.6	0.3	1.8	12.1	3.5	0.2	29.2	0.3	13.9	0.2	0.7	0.7
	JM-D-02	Drain	0.0	0.0	13.7	0.8	0.7	5.8	0.2	2.3	14.4	0.3	0.0	29.4	0.4	15.9	0.9	1.3	0.2
	JM-D-03	Drain	0.0	0.0	1.8	1.6	0.7	23.5	0.0	1.8	35.0	0.1	0.0	15.0	0.3	8.4	0.2	0.4	0.6
	JM-D-04	Drain	0.0	0.0	6.0	0.3	0.7	5.3	0.2	1.6	11.7	0.7	0.3	53.6	0.2	17.5	0.9	0.3	0.2
	JM-D-05	Drain	0.0	0.0	6.5	0.4	0.9	13.9	0.4	2.3	14.7	0.3	0.0	2.4	0.3	13.5	18.8	0.7	0.1
	JM-D-06	Drain	0.0	0.0	4.7	0.2	0.3	2.4	0.0	1.5	7.0	0.8	0.0	9.1	0.2	3.7	0.8	0.1	0.7
	JM-D-09	Drain	0.0	0.0	2.8	0.2	0.2	3.3	0.0	1.1	5.8	0.8	0.1	41.4	0.1	17.1	0.1	0.1	0.3
	JM-D-10	Drain	0.0	0.0	5.1	0.4	0.4	6.2	0.0	1.4	8.8	0.8	0.0	64.9	0.2	23.1	0.1	0.4	0.1
	JM-HP-01	Handpump	0.0	0.0	0.4	0.1	633.9	2.6	0.0	0.4	56.5	0.5	0.0	54.5	0.1	26.4	0.5	0.2	0.3
	JM-HP-02	Handpump	0.0	0.0	0.6	0.4	19.3	1.6	0.0	1.3	63.7	0.2	0.2	55.5	0.2	22.8	0.5	0.9	0.3
	JM-HP-03	Handpump	0.0	0.0	0.8	0.2	44.0	5.0	0.2	0.8	5726.4	0.5	0.3	18.2	0.7	18.4	0.1	0.1	0.3

Note: All values are in μg/L

SITES	SITE NAME	SITES	SITE NAME
1	NTPC (inlet)	20	Above JPVL
2	NTPC (outlet)	21	Singhdhara Gopaldhar
3	JP company	22	JP Site
4	Below Jangal Gate	23	Marwari-1
5	Jyotirmath-53	24	Marwari-2
6	Near Swadeshi Dhaba	25	Kamed
7	Sunil Dhara (47)-2	26	Sunil Forest
8	JP Site	27	JP Nala
9	Marwari-1	28	Dawil/Dadon
10	JP Nala	29	Sunil Dhara (48)-3
11	Vishnuprayag	30	Parsari
12	Below Jangal Gate	31	Jogidhara
13	Dadon	32	Kamed
14	Sunil Dhara (46)-1	33	Kamed Nala-2
15	Manoti	34	Manoti
16	Jyotirmath-53	35	Mandir, Marwari
17	Near Swadeshi Dhaba	36	O Bend Petrol Pump
18	Sunil Dhara (47)-2	37	Sunil
19	Singhdhara		

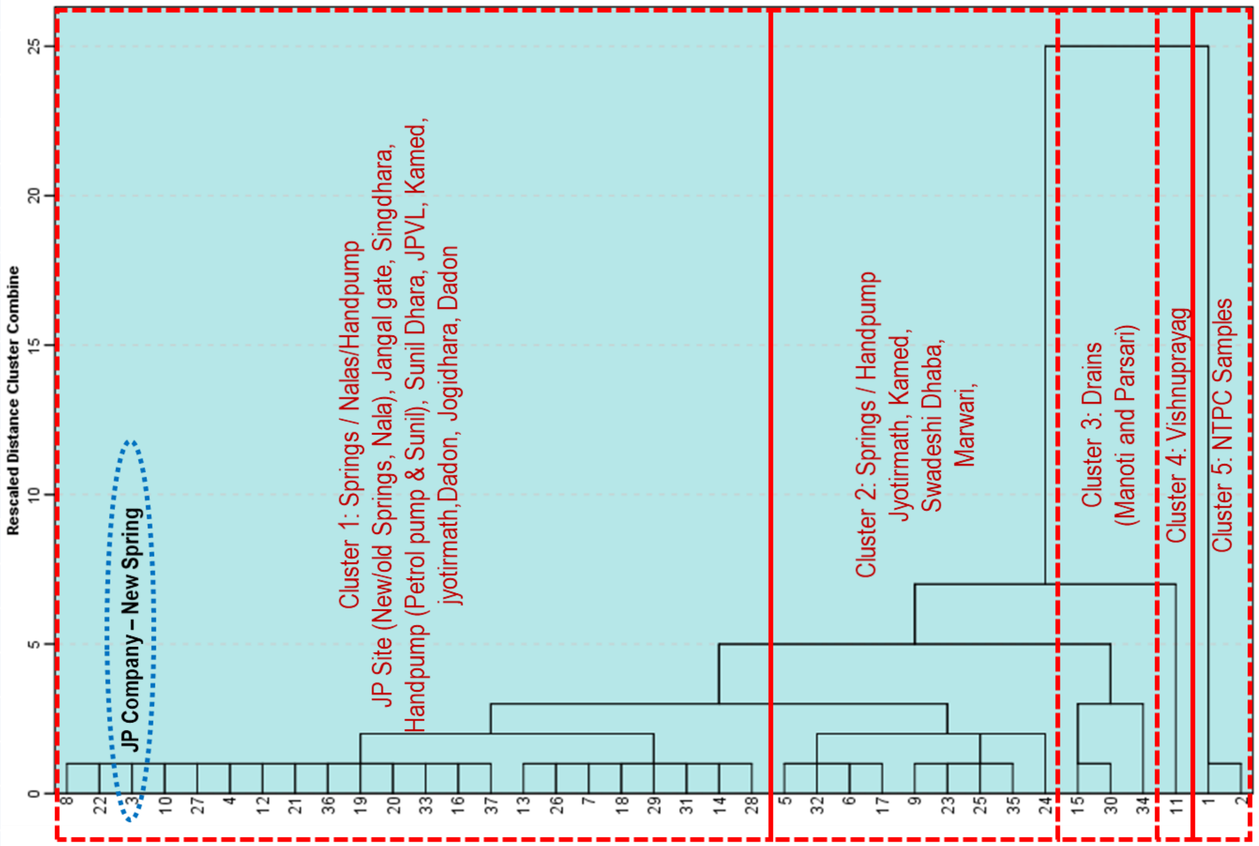

Fig. 16: Hierarchical Cluster Analysis (HCA) of Samples

Bacteriological Analysis

Bacteriological analysis was performed for the gushing water from Jaypee colony and some nearby drainages and springs and the results are presented in Table 4. It was found that the Total Coliform count in the gushing water was detected 2 MPN/100 ml and E. Coli was absent in the sample. It can be concluded that the gushing water is separated from the nearby drains through geological formations.

Table 4: Results of bacteriological test of gushing water and nearby springs and drains

S.N.	Location	Sample code	Date of Collection	Total Coliform (MPN/100 ml)	E. coli. (MPN/100 ml)
1	JP Site (Gushing water)	JM-SP-12	18-01-2023	2	ND
2	JP Site Nala	JM-D-1	18-01-2023	120330	3654
3	Marwari Spring	JM-SP-13	18-01-2023	230.6	ND
4	Davil Nala	JM-D-2	15-01-2023	54750	19863
5	Kamed Nala	JM-D-6	19-01-2023	17329	4352

The presence of coliforms and E Coli bacteria in drain water indicate the mixing of faecal matter in the freshwater sources of the Joshimath region may be due to leakage in the sewerage network/septic tanks. However, E. Coli was absent in the spring water and is safe for human consumption.

Concluding Remarks

Various spring, drainage network, areas of subsidence maps infer that land subsidence and subsurface water in the Joshimath area may have some connections. The Western part of the Joshimath has numerous springs which indicates good subsurface storage and transmitting capacities. Unfortunately, the topography (cascade of flat and steep terrain from top to bottom) and geological setting (presence of thick layers of galacio-fluvial and non-cohesive materials) of this part is in such a way which creates unfavourable condition for the development of permanent surface channels to dispose-off the water coming from upper reaches. Therefore, water moves in shallow subsurface channel (disappeared Channel shown in SoI toposheet) from upper reaches (after Sunil forest) to the lower reaches of the mountain and these channels also feed some springs in the area. The isotopic analysis also suggested that the origin of the gush water in Jaypee colony is from the upper reaches (Sunil forest and Auli area). Further, the gush water, local springs and drains fall in a similar cluster as per Hierarchical Cluster Analysis (HCA) of hydrochemical data. It also indicated the origin of springs and gush water in Jaypee colony is same i.e., from Sunil forest and Auli area. The isotopic and water quality signature of the samples taken from NTPC sites differs from the JP site as well as drains and springs in the nearby area of Joshimath. The bacteriological analysis also suggested that the gush water is fresh water and not contaminated by the local drains.

There may be a possibility that some temporary storage has been created due to the blockage of any sub-surface channel(s), which eventually burst from the weak point of strata when the hydrostatic pressure of stored water exceeded the soil-water bearing capacity of the area. The stored water got emptied by 01 February, 2023 and now it appears as a spring (discharge about 17 LPM) feed by a shallow subsurface channel. However, long term time series discharge and rainfall data will be helpful to develop an understanding regarding the hydro-geological behaviour of the new spring as well as the subsurface channel, which is feeding this spring. Based on the discharge data provided by Jaypee Company, a storage of 10.66 million litres is estimated, which got emptied in about one month. It can be roughly estimated that 12 to 15 month time may required to store such amount of water, if it is assumed that the channel(s) are blocked, which feed the new springs (discharge about 17 LPM) at present. Nevertheless, the reasons are still unknown, but the possibility of heavy rainfall (190 mm in 24 hours) occurred in October 2021 (about 15 months before the start of gushing water) (USDMA, 2022) might be one of the prominent reasons for changing the soil/rock geomechanical and geotechnical properties that may created obstacle in the path of subsurface channels. USDMA team had also empathized in its report of August, 2022 that the pace of land erosion had accelerated that year, with residents attributing this to heavy rainfall in October 2021 and catastrophic flash flooding earlier in the same year.

Land subsidence is one of the most common geomechanical and geotechnical consequences of the loss of a significant amount of groundwater. In general, when large amounts of water are withdrawn, the subsoil compacts, thus reducing in size and open pore spaces in the soil previously held water. Globally, ground subsidence resulting from rock mass drainage ranges from a few centimetres to several meters (maximum reported subsidence is 14.5 m). Joshimath has its locational disadvantage as it settles down on an old landslide deposit at the mid of the hillslope, which is having excellent recharge area in the form of gentle slopes, huge depressions and thick forest in the upper reaches (Auli area). Water move from upper reaches to lower reaches in the form of subsurface flow due to a special kind of topography and geological setting which always weaken the soil stability on the steep hill slopes. Furthermore, this slope instability is exacerbated by unplanned and rampant construction in and around the town and natural calamities (extreme weather events as well as frequent earthquakes).

Recommendations

Joshimath region particularly north facing slope is lying on a sliding zone where regular monitoring of features with instrumentations is a must and calls for a need of controlled and regulated development system. As the saying goes, 'you can't manage what you don't measure'. Recently, satellite radar interferometry (InSAR) has contributed to significant progress in monitoring and determining the spatio-temporal land subsidence distributions worldwide. Application of such techniques will be immensely helpful to understand the compaction nature of the aquifer system beneath the city. In addition, the density of Continuously Observed Reference System (CORS) should be increased in the Himalayan regions, which are prone to subsidence as well as landslide. Such data should be shared with the R& D organizations for modelling such subsidence and development of alarming system.

Safely dispose-off the water coming from the upper reaches and waste of town should be the top priority. However, the water requirement of local people and flora and fauna must be kept in mind before channelization of the water. There is a need to identify the towns having Joshimath like topographical locations as well as geological settings. These towns should be well equipped with the desired instruments so that precautionary measures can be taken in advance.

Natural water springs (act as natural piezometers) are good indicators for any change in the groundwater in the mountainous area. Therefore, there is an urgent need to inventories all springs located in the vicinity of Joshimath like towns in the entire Indian Himalayan Region (IHR). Their periodic monitoring will be a good tool for detecting any such events in advance in the mountainous regions.

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