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Spring Rehabilitation at Gaurikund, Central Himalaya, India

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Abstract

The geothermal spring at Gaurikund is located in Himalayan Geothermal Belt in the Garhwal Region of Uttarakhand, India. Gaurikund town is situated along the trekking route to the famous Kedarnath temple, which was severely affected by a flood disaster in 2013, which caused huge damage to infrastructure and loss of more than 5000 human lives. Rehabilitation of Gaurikund geothermal spring is a priority due to religious beliefs, balneotherapic values and the opportunity it offers to understand the hydrological and geothermal characteristics of the region. To justify these aspects, an integrated study on geology, hydrogeology, hydrochemistry, geophysics, and remote sensing was taken up at Gaurikund. The geological studies indicate that the geothermal spring is recharged by steep, southerly dipping joints in granite gneiss. Subsequenetly, the deep percolated water heats up due to high geothermal gradient and advection to finally emerge along the Vaikrita Thrust and its sympathetic minor fault-thrust system. Four outlets of the spring were inventoried, with discharge varying from 7.46 to 95.54 L/min. Two dimensional Electrical Resistivity Tomography using Wenner, Schlumberger and Gradient configurations revealed two low resistivity zones proximal to the geothermal spring, on the right bank of Mandakini river. Maximum kinetic temperature images generated using the normal emissivity model using the pre and post-disaster satellite data shows positive correlation between land surface temperature and spring discharge variation. Engineering interventions by bank protection and construction of small gully plugs in the catchment area is recommended along Gaurikund-Sonprayag section on the right bank of Mandakiniriver.

Keywords

Geothermal spring; Himalayan geothermal belt; Electrical resistivity tomography; Normal emissivity model; Fluoride; River bank protection; Gully plugs.

Introduction

The Himalayan Geothermal Belt (HGB) spanning from the north-western part of India (Ladakh) to the north-eastern part (Assam) is inundated by numerous hot springs [1]. It is one of the highest heat flowing regions with a thermal gradient over 200°C/km [2]. One of the famous hot springs of the region Gaurikund is located at 30.65N and 79.02E, in Rudraprayag district of northern state of Uttarakhand in India. It lies very close to the surface expression of the Main Central Thrust (MCT) of Himalaya at an altitude of 1995 m on the right bank of Mandakini river. It has a lot of local significance as it is considered as the gateway to the famous Kedarnath shrine, which is visited by over a million people every year. The place derives its name from the geothermal spring and the trekking route of 16 km starting from Gaurikund reaches Kedarnath through small hamlets of Jangalchatti, Rambara and Lencholi. In the disaster of 2013, major part of Gaurikund town, temple complex and geothermal springsource were severely damaged or buried under debris. As it is an important geothermal spring of the region and has a lot of religious sentiments and balneotherapic values, there was wide-spread concern (including Green Tribunal intervention) and demand to revive the spring and restore the surroundings. Primarily the task was assigned to Central Ground Water Board (CGWB), the national organization, which in collaboration with other organizations has carried out investigations with the prime objective to understand the geological set up the region, spring geohydrology and hydrochemistry, locate the buried geothermal spring source using geophysical techniques and finally suggest remedial measures that would sustain the flow of geothermal spring and minimize damage in future. Realizing the importance of satellite remote sensing in this inaccessible terrain, images from past and recent time have been utilized. A satellite image of the area in and around Gaurikund, generated using fused LISS-IV and Cartosat-2 Indian Remote Sensing data (in Normal Colour Composite) shows the location with terrain attributes (Figure 1). The study has attempted to develop a comprehensive strategy for revival and rotation of geothermal springs of Himalaya which are very important to understand the geothermal characteristics and rock and water interaction in an active tectonic regime and have immense medicinal and religious values.

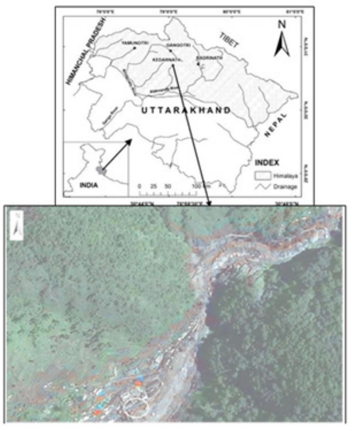

Figure 1: Satellite image of GauriKund and upstream section of Mandakini River (study area shown in white circle (Data Source: Merged Cartosat-2 and LISS-IV in normal colour composite).

Impact of the Kedarnath Disaster, 2013

Mandakini valley and many parts of Uttarakhand received unusual high precipitation of 300 to 400 mm during 15-17th June 2013, which was accompanied by high snow melt run off in higher reaches of Himalaya and caused unprecedented flooding, bank erosion, landslides, Landslide Lake Outburst Floods (LLOFs) and

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Glacier Lake Outburst Flood (GLOF) in valleys and downstream areas [3-6]. It was a wide spread event that affected approximately 30,000 km2 in Himachal Pradesh and all hill districts of Uttarakhand. As the time period coincided with tourist/pilgrimage season, the total death toll was over 5000 and most of the victims were classified as missing as per the Indian law. Precipitation data obtained from Tropical Rainfall Measuring Mission shows an enormous rise of 346% in the rainfall of June compared to previous 5 years average monthly rainfall of June [7-9]. The only operational rain gauge located in the upper slope region of Kedarnath had shown precipitation of 325 mm during past 24 hours measured at 5.00 PM on 16th June [4]. The enormous volume of water originating from melting of glaciers and steep side slopes of high mountains in the upstream region followed by Glacial Lake Outburst Flood (GLOF) of the Gandhi Sarovar or Chorabari Tal, up slope of Kedarnath temple caused maximum devastation in Mandakini valley [10,11]. The major impact of disaster was due to landslides, bank erosion and Chorabari Tal breaching on 16th and 17th June 2013 and has been explained by various workers [4-6,12]. There were precisely two catastrophic events: 1st one occurred in the evening of 16th June, which was attributed to mainly landslides and LLOFs that destroyed some parts of Kedarnath, Rambara and Gaurikund followed by GLOF on 17th morning which wiped out large parts of Kedarnath and downstream areas up to 120 km, affecting localities proportionate to their distance from the source region [13].

The devastating flood that destroyed Gurikund spring and adjoining areas on the right bank of Mandakini River is primarily attributed to narrowing of the river course slightly upstream of Gaurikund. During the fateful event, the left bank of Mandakini River (opposite slope of Gaurikund) experienced severe erosion and bank failure followed by a huge landslide (400-425 m wide, ~85 m wide), which partially blocked the river course [4]. As a result, the flow was diverted towards Gaurikund and subsequently destroyed and buried the geothermal springsource and bathing complex, part of the temple complex and surrounding areas including an iron bridge. The river had severely affected areas up to 40 m from the right bank where most of the structures were situated. Field photograph of the pre-devastation scenario is shown in Figure 2 whereas the post-devastation scenario is shown in Figure 3. The High Flood Level (HFL) of Mandakiniriver during the disaster is shown in Figure 4 which is approximately 30 m from the original river bed. In fact, in most part of the upper reaches of Mandakini river, the HFL (2013) was around 20-30 m from the river bed, which resulted in two to four times increase in river width in narrow valleys causing bank erosion and landslides.

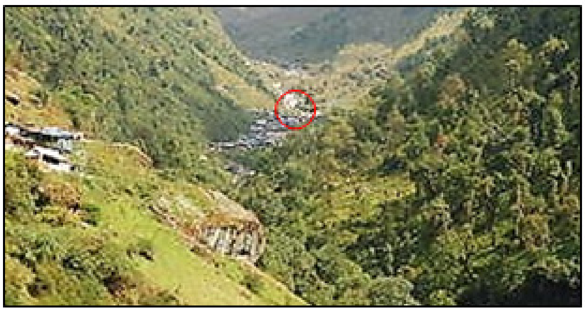

Figure 2: Pre-disaster scenario of Gaurikund (in red circle), view from Rambara.

Figure 3: Post devastation scenario of Gaurikund (spring in red circle).

Figure 4: High flood level (red arrow) of Mandakini river at Gaurikund.

Geological Set up of the Region

Geologically the area lies to the north of Main Central Thrust (MCT) forming the "Central Crystalline Group", a complex of metamorphic and granitic rocks consisting of two major thrust bound litho-tectonic units [14,15]. These are exposed along Gaurikund - Kedarnath foot track, both upstream and downstream of Mandakiniriver. The upper unit (Vaikrita Group) is separated from the lower unit by the Vaikrita Thrust (VT) also known as MCT-I. The Gaurikund Formation (equivalent of Joshimath Formation) of upper unit comprises of garnetiferous gneiss, schist, quartzite and migmatite [16]. The gneisses are greyish coloured, moderately to highly foliated and weathered. During field survey, it was observed that general strike of the country rocks varies from N40°E-S40°W to N55°E-S55°W with variable dip of 38° to 51° towards NW. The regional geological map from Chorabari glacier to the south of Gaurikund shows another prominent structural feature, the Pindari Thrust which shows strike slip offset of a mega lineament, along which Mandakini river flows in a linear valley (Figure 5). Similar minor strike slip offset is also observed across Vaikrita Thrust just south of Gaurikund. The entire stretch from south of Gaurikund to Kedarnath can be considered as a structurally disturbed fault zone with multiple thrusts, faults and lineaments. The steep slopes closer to Mandakini river valley is covered by colluvium and glacio-fluvial deposits (Figure 6). Therefore, the highly deformed rocks and quaternary deposits are prone to failures on steep mountain slopes.

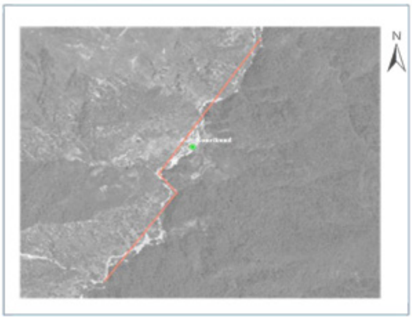

Figure 5: Offset by the major lineament (along which River Mandakini flows) due to thrust near GauriKund (Source: Corona Image, 24-11-1973).

The Vaikrita thrust separates high-grade metamorphic rocks of Vaikrita group (Gaurikund Formation) from the lower grade metamorphic rocks of Kalimath Formation (equivalent to Munsiyari Formation). The Vaikrita Thrust is marked by a topographical break to the south of Gaurikund and is elongated across the valley with a minor displacement of a major lineament. Due to structural complexities attributed to interaction of mainly three sets of joints and fault system, a relatively gentle slope and wide valley is developed at Gaurikund in the downstream side compared to the upstream section of Mandakiniriver. Relatively wide valley with meandering nature of Mandakini river is also observed on Corona satellite image of 1973 (Figure 5). Sudden widening of Mandakini valley to the south of Gaurikund is a geomorphic evidence of proximity of the area to a tectonic contact [16]. In Gaurikund, three prominent joint systems are conspicuous along the river section, which includes a) prominent set defined by bedding joint or schistosity plane dipping N-NNE-NW at 30°-45°, b) steeper joint set dipping S-SSW and c) a third major joint set across the earlier two sets, dipping steeply (>75°) and oriented N-S to NNE-SSW, along which Mandakini river flows. Regional structural map of the area showing prominent fault and thrust system is shown in Figures 6 and 7.

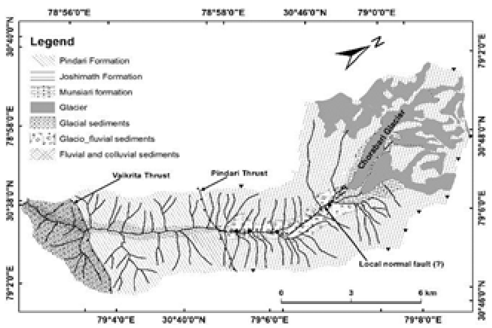

Figure 6: Regional geological map of GauriKund and surrounding areas (Source: Dobhal et al.)..

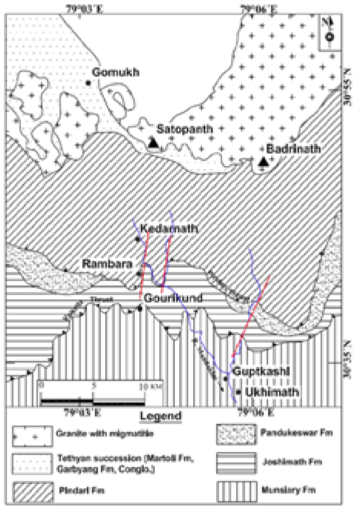

Figure 7: Regional structural map of the area in and around GauriKund (Source: Dobhal et al.).

Evolution and Mode of Occurrence of Geothermal Spring

The geothermal spring at Gaurikund is located on the hanging wall of the Vaikrita thrust and has been categorized as a fault spring [17]. Based on geological mapping, it is interpreted that the geothermal springgets its recharge mostly though the steep, southerly dipping joints and after reaching substantial depth (a few kms), the surface water is heated up due to high geothermal gradient caused by Sonprayag Granitoid and advection in the upper crustal region. Finally it reaches the northerly dipping Vaikrita Thrust and/or other faults related to this thrust. The Vaikrita Thrust is a structurally weak zone, through which groundwater emerges as numerous hot springs. As the area is within the HGB, the high heat flow (>100 mW/m2) which is attributed to shallow crustal melting along the seduction zone [18,19] and high radioactivity of the leucogranites and gneisses [20,21] is primarily responsible for the high temperature of thermal springs. Secondly as the area is very close to the Vaikrita Thrust, also known as the MCT-I, high thermal gradient and rock water interaction significantly influences the geothermal spring and its geochemistry. It is noteworthy to mention that the geothermal gradient in HGB is highest in India that is around 2000 C/km compared to around 1000 C/km for other geothermal belts of India. Therefore, in such area, water need not travel too deep to be heated up much and a distance of 1-2 km would be sufficient for formation of hot springs under appropriate hydrogeological conditions [16].

An analysis of heat discharged by thermal fluids along the 3000 km long Himalayan Geothermal Belt (HGB), mostly in the Tibet region shows that heat transfer is concentrated along 30- to 50-km-wide ‘heat bands’ which are associated with at least 600 geothermal systems in both Himalaya and Trans Himalayan region including Tibetan plateau [18]. The bands have been interpreted as segments of major, concentric slip lines caused by plastic deformation of the ductile crust within the Asian plate resulting from plate collision. The same can also be extended to areas south of Indo-Tsangpo Suture Zone (ITSZ) mostly involving Indian crust at the collision boundary. Anomalously low 3 He/4 He ratios in thermal fluids rule out the possibility that the heat is derived from upwelling hot mantle material or mantle melts. Meteoric water as the main source of hot springs in MCT zone is also inferred by [16] from their model based on metamorphic CO2 degassing through geothermal springs in Garhwal Himalaya. In a similar observation, [22] has also reported decarbonation and dehydration reactions in the subducted Lesser Himalaya sediments produce CO2-H2O fluids at 10–20 km depth, where resistivity data indicates the presence of a fluid phase [23]. CO2-rich fluids migrate up where they are entrained in local meteoric hydrothermal circulation driven by steep geothermal and topographic gradients close to MCT zone in similar terrane in the Narayani basin, Nepal Himalaya. The CO2 degassing occurs closer to hotsprings and it plays an important role in its consumption by chemical weathering of silicate rocks [22]. Therefore, comprehensive assessment CO2 requires detailed analysis of the same closer to hot springs in the Himalaya. Studies have shown that the net impact of Himalayan orogenesis on the carbonate-silicate geochemical cycle is not large-scale drawdown of CO2 because the weathering sink is substantially offset or even exceeded by the metamorphic source.

Overall, all low and intermediate temperature systems derive their heat by advective sweeps of infiltrated meteoric water from the hot, brittle upper crust. High standing, cooling granitic plutons are probably the heat sources for a few systems with temperatures as high as 300°C at 1.5 km depth e.g., Yangbajing in Tibet [18] and similar granitic plutons and granitoids are present in the Indian side of Himalayan Geothermal Belt, probably contributing to the high temperature of the Gaurikund spring.

In MCT zone, it has been observed that most of the geothermal spring sources are located on the hanging wall side of the main thrust or its sympathetic faults. The north-south oriented lineament (third set of lineament) is also interpreted to have facilitated emergence of hot water mostly along the river valley though such deep-seated extensional joints with relatively high fracture aperture. Therefore, the geothermal spring is largely depended on the recharge scenario on the northern part of Gaurikund along the Mandakini valley. In the recharge area, precipitation is through snow and rainfall and any change in the climatic conditions would alter the recharge condition of hot springs in the vicinity of Vaikrita Thrust or MCT-I. A schematic diagram showing the mechanism of formation of Gaurikund geothermal springis given in Figure 8. Similar topography and structure driven meteoric water circulation model has been proposed by [22] while studying degassing near surface producing 13°C enriched hot springs in Narayani basin, Nepal in the Central Himalaya very close to MCT zone. Helium isotope data further support a crustal origin for the volatiles in the Nepal hot springs close to MCT [24] reported very low helium isotope ratios 3 He/4 He, which clearly indicated a crustal source for the volatiles, with little or no mantle input. Similar observations have been made by that south of the Indus Tsangpo Suture Zone, fluids carry only crustal helium.

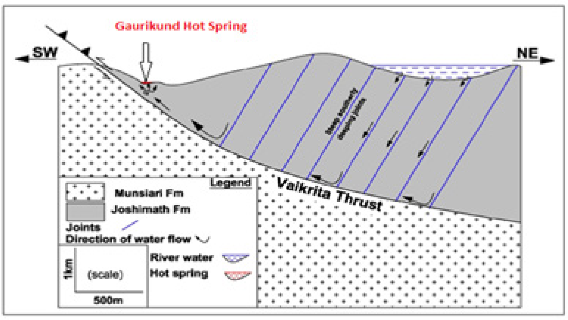

Figure 8: Role of thrust and joint system in formation of hot spring at Gaurikund.

In a similar observation in Nepal Himalaya [25] have summarized that majority of Himalayan hot springs are found along large incised valleys, in zones of steep river reaches and rapid fluvial down cutting. Most are located within or near the MCT zone and are associated with strong gradients in range-front topography and river profiles. The position of springs is consistent with the view that heat is supplied to the meteoric system by tectonic advection of hot rock, deep within the crust. Advection of rocks along the MCT zone in Indian Himalaya since ~2 Ma has been reported [26,27] which gives credence to origin of geothermal springs as postulated in the present study.

Onsite Investigation and Analysis

Hydrogeological investigations

Hydrogeological investigation of the Gaurikund geothermal spring was carried out adjacent to the old location of geothermal spring and nearby temple complex situated on the right bank of Mandakini river. It was found that the geothermal spring outlet was burried during the Kedarnath disaster of June 2013 by big boulders and debris generated by landslide and flash flood in Mandakini river. The rock outcrops about 10 m north of the damaged and buried geothermal spring were identified as banded and streaky gneiss and porphyritic granite gneiss with intricately folded and deformed bands of felsic materials. A retaining wall has been constructed at the back side of the major outlets of the hot spring, as shown in Figure 9. Prominent landslide zones were observed on left bank of Mandakini river opposite to Gaurikund. During field survey, four outlets of the original (pre-2013) geothermal spring were identified and labelled as Outlet 1 to Outlet 4. Due to construction of the RCC retaining wall and accumulation of debris, the geothermal spring has taken various paths below the debris cover and oozes out at most favorable locations (Figure 10). All four outlets of the spring were surveyed using GPS and in situ measurements on spring discharge, EC, pH, water and atmospheric temperature were taken. Location and other details of spring outlets are given in Table 1.

Figure 9: Big boulders strewn near taptkund, RCC retaining wall in the background.

Figure 10: Field photographs of primary outlets of hot spring (Clockwise from Top Left: Outlet 1, Outlet 2, Outlet 3 and Outlet 4 in which discharge measurement was not possible).

Field data shows Outlet 1 has highest temperature of 58°C with discharge of 9.0 L/min and is considered to be closer to the main source. Outlet 2, which is situated just down slope of the RCC retaining wall and adjacent to Gaurikund temple, is the main source of the geothermal spring showing highest discharge of 95.54 L/min. It shows relatively low temperature of 43°C mainly due to disturbances to the outlet due to debris cover and construction of the retaining wall. Outlet 3 shows discharge of 7.46 L/min and temperature of 35°C mainly due to intermixing of geothermal spring water either with cold groundwater or with base flow of Mandakini river. Mixing of hot and cold spring water indicates hydraulic connectivity in the fractured rock aquifers locally developed in the high-grade granite gneiss, quartzite and migmatite of Gaurikund Formation.

Table 1: Location and other details of spring outlets at Gaurikund.

Point No.	Location	Altitude (m)	Discharge (L/min)	Temp. (°C)	
				Water	Air
1	Located ~10 m north of ladies bathing room, about 15 m from river course on the right bank of Mandakini river 30.6539N 79.0278E	1972	9.00	58.0	20.0
2	Located near the base of RCC retaining wall, ~25 m west of river course, main source of geothermal spring with three sub-outlets 30.6542N 79.0275E	1972	95.54	43.0	20.0
3	Located ~8 m downslope of Gauri Mata mandir, natural outlet ~5 m from the base of RCC retaining wall, ~20 m west of river course, on the right bank of Mandakini river 30.6536 N 79.0272E	1983	7.46	35.0	20.5
4	Located ~3 m south of ladies bathing room, ~20 m west of river course, on the right bank of Mandakini river 30.6538N 79.0277E	1966	NA	45.0	20.0

Due to very feeble discharge and non-channelized flow of hot water at Outlet 4, the discharge measurement and sample collection could not be carried out. However, temperature, EC and pH were measured. A single natural outlet of hot spring, marked by characteristic reddish-brown outcrops at the base of the outlet, was observed on the left bank of Mandakini river. Close field inspection of this outlet was not possible due to inaccessibility. Additionally, several minor discharges of geothermal spring water were also observed further on the upstream side marked by reddish-brown colour of adjoining boulders on the river bed.

Hydrochemical study

During ground survey, Electrical Conductivity (EC) and pH of spring water was measured in situ using HM Digital waterproof, portable EC and pH meter. Three water samples collected from Outlet 1, 2 and 3 were analyses at Central Ground Water Board, Chandigarh (NABL Accredited Lab). The results of chemical analysis are given in Table 2.

Table 2: Chemical analysis of water samples collected from hot spring, Gaurikund.

Sample No.	pH	EC (µS/cm)		Concentration (mg/L)						
		Field	Lab	NO3	F	Cl	Ca	Mg	Na	K
Gaurikund-Outlet-1	6.40	1300 (at 58°C)	1185	BDL	1.78	31	184	17	59	16
Gaurikund-Outlet-2	6.41	1200 (at 43°C)	895	0.20	1.35	24	139	16	45	14
Gaurikund-Outlet-3	6.39	400 (at 35°C)	394	0.72	0.4	10	55	10	14	7

The data shows that the geothermal spring water has relatively high EC at Outlet 1. High fluoride was reported from Outlet 1 and Outlet 2, which exceeds the acceptable limit of 1.0 mg/L for fluoride. Fluoride concentration at Outlet 1 even exceeded the permissible limit of 1.5 mg/L. High fluoride in spring water is attributed to fluoride bearing minerals in the granitoids around Gaurikund and Sonprayag. The EC, temperature and fluoride concentration in groundwater at Outlet 3 are much less as compared to Outlet 1 and Outlet 2 mainly due to mixing with the base flow of the river. Concentrations of other constituents like nitrate, chloride, calcium and magnesium were within the acceptable limit. High sodium and potassium in spring water is attributed to rock-water interaction. Sodic and calcic plagioclase in the granitoids act as the source of relatively high sodium and potassium in Gaurikund hot spring. Overall it is observed that Outlet 1 is closer to source compared to Outlet 2, which is partially disturbed due to debris cover and Outlet 3 is contaminated with base flow of the river or local groundwater. Outlet 1 and 2 indicate intermediate temperature category in comparison to major geothermal springs of the HGB. Overall, low pH indicates the source as meteoric water percolated down through fractures in the country rock, which reappears at the contact of major faults of the region.

Electrical Resistivity Tomography

Two-dimensional Electrical Resistivity Tomography (ERT) was carried out on the right bank of Mandakini river in open land adjacent to the buried geothermal spring source and temple complex using ABEM Terrameter-LS Earth Resistivity Meter. Two dimensional (2-D) ERT survey was carried out along profile line (P1-P2-P3) of 120 m oriented in NNE-SSW direction. This was the longest and most feasible profile line available in the region. Satellite image of the area with ERT profile line is shown in Figure 11 and field photograph of ERT survey is shown in Figure 12. Topographically corrected model resistivity sections using Wenner, Schlumberger and Gradient configurations are shown in Figures 13-15 respectively. The figures show subsurface electrical resistivity distribution up to a depth of ~25 m from ground surface. Based on ERT results, two low resistivity zones having resistivity varying from 20 to 50 ohm.m were identified at a depth of 5 to 15 m. One zone is located towards the northern side while the other was located to the east of Outlet 2, which is the main source of present-day hot spring. The low resistivity zones are interpreted as weak zones through which hot water flows in subsurface channels.

Figure 11: Image of the area showing the profile line (P1-P2-P3).

Figure 12: ERT survey on the right bank of Mandakini river, Gaurikund.

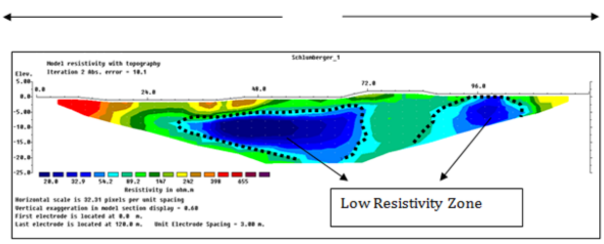

Figure 13: 2D ERT section along the profile line P1-P2-P3 using the Wenner configuration.

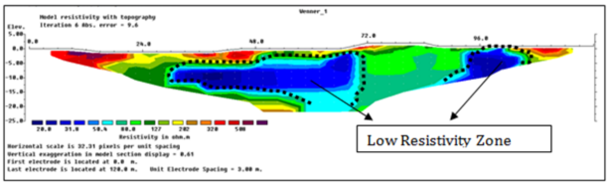

Figure 14: 2D ERT section along the profile line P1-P2-P3 using the Schumberger configuration.

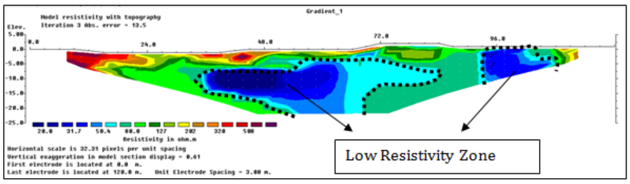

Figure 15: 2D ERT section along the profile line P1-P2-P3 using the Gradient configuration.

Thermal Remote Sensing Study

ASTER Thermal Infrared (TIR) data sets were processed to detect thermal anomaly in Gaurikund area. The Land Surface Temperature (LST) map was generated using ASTER TIR data acquired on 22.9.2012 (pre-disaster) and 3.11.2014 (post-disaster). The maximum kinetic temperature image for September 2012 was generated from multispectral data of ASTER TIR sensor using the Normal Emissivity Model (NEM), which is shown in Figure 16. The 2012 thermal data shows high temperature region (>29°C) just north of Gaurikund town, which coincides with geothermal springsource. As the thermal image pre-dates the Kedarnath disaster of 2013, the anomaly related to geothermal spring is compatible with the thermal signature as shown in Figure 16. The figure shows high kinetic temperature (24°C to 31°C) in Gaurikund area, which correlates very well with the pristine condition of the hot spring. Thus, the maximum kinetic temperature map prepared using the TIR technique supports the ground-based hydrogeological survey which measured in situ spatial distribution of land surface and water temperature in and around Gaurikund. The thermal image of the area after the 2013 Kedarnath disaster has been generated using ASTER TIR and the maximum kinetic temperature image for post-monsoon (November 2014) using the NEM is shown in Figure 17. Interpretation of the image shows absence of high kinetic temperature zone in and around the geothermal spring source. The anomalous distribution of modelled temperature in and around Gaurikund is attributed to reduced spring discharge due to burial of original geothermal spring after the 2013 Kedarnath disaster. The substantial decrease in spring discharge is attributed to diffused and non-channelized flow of geothermal springin November 2014. The reduced spring flow measured during post-monsoon ground survey validates the analysis of thermal image of the area using ASTER TIR data of November 2014.

Restoration through Engineering Intervention

During the devastating flood of June 2013, there was severe erosion along both the banks of Mandakini river in the vicinity of Gaurikund, which was mainly attributed to very high bed load from upstream area in the river due to erosion of moraine deposits and fluvio-glacial and colluvial deposits along hill slopes and narrow section of Mandakini river near Gaurikund town. In order to restore the geothermal spring and minimise damage to life and property and control the erosion by Mandakini river, it is suggested to implement riverbank protection, restoration and reconstruction of the geothermal springoutlet and a storage pond for socio-religious activities.

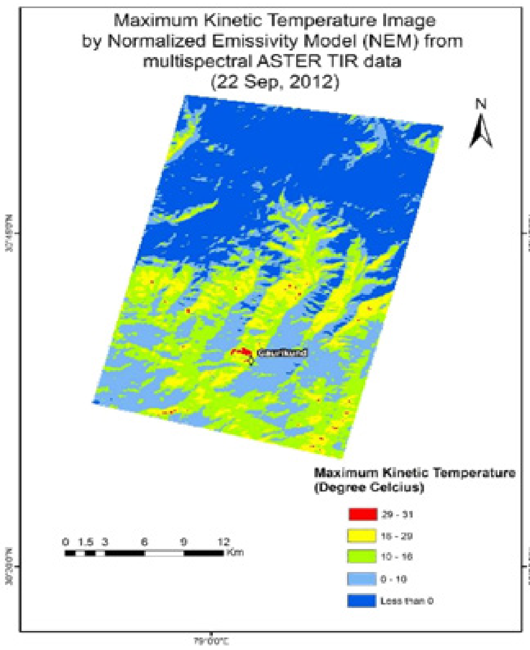

Figure 16: Maximum kinetic temperature image of Gaurikund and surrounding area before 2013 Kedarnath Disaster. Highest temperature is shown at GauriKund. Data Source: ASTER TIR Image dated 12-9-2012.

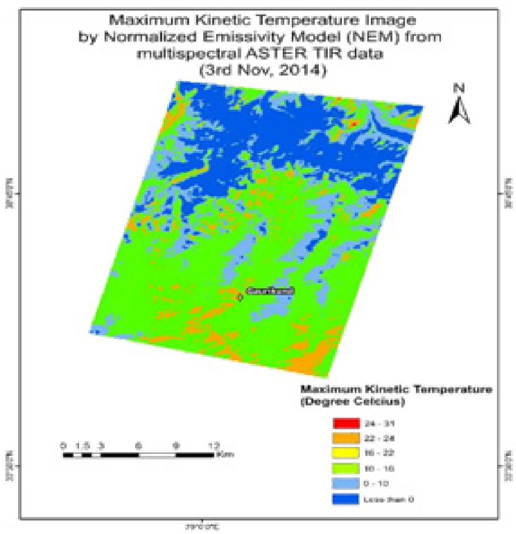

Figure 17: Maximum kinetic temperature image of Gaurikund and surrounding area. Highest temperature zone (in red) is absent near Gaurikund post-2013 Kedarnath disaster.

Sustainable land reclamation and flood protection measures are required in the upstream and downstream of river Mandakini near Gaurikund. During the 2013 disaster, the river developed avulsion towards west. Bank protection is therefore required to reclaim area keeping adequate waterway for passing excess flood water in future. To minimize future flood hazard and increase bank stability through riverbank protection, Flood Protection Wall (FPW) needs to be constructed on both banks of the river covering the entire stretch (~300 m) of Mandakini starting from north of Gaurikund to the south of the iron bridge on Gaurikund-Sonprayag road. The western side i.e. the right bank where important outlets of hot spring, temple and human settlement are located will get double protection from the envisaged structure and the existing retaining wall. Field investigations have shown that the flood water had reached approximately 30 m above the river bed in 2013. Therefore it is essential to make two tier flood protection wall for minimizing the damaging effect of future extreme events.

The second most important intervention is related to the channelization and collection of water from geothermal spring outlets. Currently, the geothermal spring water is un-channelized due to construction of retaining wall and debris cover during 2013 disaster. Therefore, we propose that the spring sources flowing beneath the retaining wall are to be diverted into a new storage tank/bathing complex for religious activities. In order to reduce the loss of discharge from hot spring, it is also proposed to drill and provide horizontal perforated pipes to collect water in a large pond. A schematic diagram of the proposed FPW, renovated geothermal spring and bathing complex is shown in Figure 18. In this endeavor, it is also proposed to collect water from Outlet 1 and 2 together to the proposed pond, which will increase the flow and maintain the high temperature of the water; and Outlet 3 being of lower temperature and contaminated with base flow is not considered. However, attempts should be made in future to source other outlets of primary source in near vicinity and channelize the flow to the proposed pond. Small gully plugs are suitable to arrest torrential monsoon flows in addition to water conservation during non-monsoon period. River bank protection along Gaurikund-Sonprayag section will be achievable by construction of a series of gully plugs (height 1.5-2.0 m, base width 2.0-3.0 m) along with the Flood Protection Wall on the right bank of Mandakini. Monitoring of river flow (stage, discharge, silt content) along with study of variation in cross section of river bed should be done at regular intervals to assess the changes in surface flow regime. Periodic monitoring of discharge and water quality will help in assessing the variation in hydrological-hydrogeological regime of Gaurikund area, which is a pre-requisite for implementing sustainable spring rehabilitation, disaster management and mitigation programs. Recharge areas for the hot spring are located upstream of Gaurikund and in the catchement of Mandakini river. Thus appropriate water conservation measures and monitoring of spring discharge and spring water chemistry are required at regular intervals.

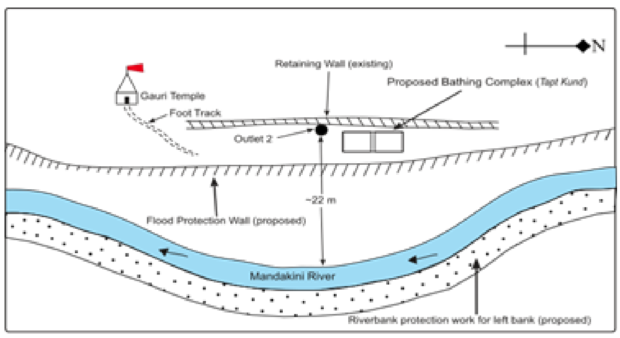

Figure 18: Schematic of rehabilitation plan, Gaurikund hot spring.

Conclusion

The geothermal sources of Himalaya are very important due to religious and medicinal values and their geochemical signature of host rock and water interaction. Additionally, these play a significant role in assessment of global climate due to degassing of CO2. A very detailed study of hot springs in the Indian HGB region is lacking today, which calls for preservation of such sites for future studies. Present study was focused on rejuvenation of geothermal spring at Gaurikund, Higher Himalaya which was buried due to landslide and river borne materials. The Kedarnath disaster of 2013 has significantly affected terrain slope, river bank of Mandakini and local hydrological regime around the Gaurikund geothermal spring. Hydrogeological set up of the area suggests that the recharge zone of Gaurikund spring is to the north of the town. The Mandakini river flowing in a valley marked by lineaments, joints and fractures act as main conduit for recharge followed by deep percolation and emergence along the fault-thrust system developed around Gaurikund. Channelized flow of hot spring water has been facilitated by faults/thrusts in the brittle part of the upper crust associated with the Vaikrita thrust, a part of the Main Central Thrust system. The source of heat is the higher geothermal gradient developed in this part of the Himalayan Geothermal Belt of the Indian subcontinent. Thermal remote sensing using Normal Emissivity Model has indicated anomalous distribution of modelled temperature in and around Gaurikund. This is attributed to reduced spring discharge post-disaster due to burial of original geothermal spring source under the thick debris cover observed during the present study. Measurement of cumulative spring discharge and assessing the total volume of spring water available for utilization should be the prerequisites to assess the impact of spring rehabilitation at Gaurikund. Assessment and comparison with the dimensions of the pre-disaster pond (kund) suggests that the storage volume for rehabilitation of the spring is sufficient, considering an uninterrupted flow.

In addition to increasing cumulative discharge of Gaurikund spring through removal of debris cover, the most immediate intervention would be to construct Flood Protection Walls on both banks of Mandakini river and drilling on the right bank adjacent to the temple complex, as revealed by electrical resistivity tomography. A series of gully plugs need to be constructed along the seasonal streams (khudds and gads), that flows into Mandakini river in the upstream section of Gaurikund temple complex. The gully plugs arrest the monsoon run-off, helps in water conservation and facilitates shallow recharge that will lead to deep percolation for rejuvenation of the hot spring source. High fluoride in Gaurikund spring water is a potential health hazard that requires periodic assessment on temporal variability in fluoride and possible balneotherapic value of the hot spring. The integrated geologic-hydrogeologic-chemical-geophysical-remote sensing-engineering approach to study Gaurikund geothermal spring can be replicated in the HGB where spring rehabilitation is a necessity for sustaining the livelihood of people.

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