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ORIGINAL ARTICLE

Assessment of Geothermal Renewable Energy with Reference to Tapoban Geothermal Fields, Garhwal Northwest Himalaya, India

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ABSTRACT

The energy potential of geothermal resources at Tapoban Geothermal Field, situated in the orogenic region of the Chamoli district of Uttarakhand state in the Himalaya, is investigated based on physical parameters, reservoir temperature, borehole depth, and geochemical indicators. It is a prospective field of geothermal water exploitation for both electrical and non-electrical usages. The anomalous geothermal gradient due to the active Main Central Thrust (MCT) zone plays a significant role. To explore the feasibility of exploitation, the surface water temperature and pH from existing geothermal springs is calculated, which ranged from 45°C-93°C and 6.2-7.3, respectively. The study based on dissolved silica geothermometry shows an average reservoir temperature of ~125 ± 2.0°C. The springs emerge from the prominent joint/ weak zone in the country-rock with the discharge of hot waters up to 300 liter minute^{-1}. The total geothermal heat energy of the reservoir is estimated as ~874.35 x 10^{11} KJ. The energy estimated for the binary power geothermal plant is ~1.02 MWe and 0.71 MWe for 20 years and 30 years, respectively. This energy can be increased manifolds by operating binary cycle power plant technique at multiple sites for an electric generation. The heat capacity from two dominant hot springs from Tapoban geothermal resource was found to be ~0.84 MWt, which can be harnessed by the local people for direct usage. The annual energy use from this reservoir is ~15.89 TJ per year with a capacity factor (CF) of ~ 0.60, indicating that the energy reserve of the Tapoban geothermal field can be used for low to moderate scale energy production to partially meet the energy gap and future requirements.

INTRODUCTION

The availability of energy is one of the critical aspects for the development of a society (Anderson and Rezaie, 2019). Fossil fuels meet 80% of the global energy requirement: 34% crude oil, 25% coal, and 21% natural gas (Vedachalam et al., 2015), which produce not only the greenhouse gas but have limited reserve (Gupta and Roy 2006; Sain and Gupta 2012; Tiwari and Sain, 2021). The concentration of CO_2 in the atmosphere has increased tremendously over the past century from 280 to 400 ppm, which is 142% higher than the pre-industrial era, with net growth of 2ppm/year in the last decade (WMO, 2015; 2016). Though coal is not an environment-friendly fuel, it provides ~72% of India's electricity requirement (Kumar et al., 2020). India produces only 30% of its total energy requirement and spends a significant amount on importing the remaining (Sain, 2017; Tiwari and Sain, 2021).

The worldwide energy consumption is expected to attain 20679 million tons of oil equivalent (Mtoe) in the year 2040, which is 56% more than in 2010. This scenario envisages that the conventional energy resources may continue to supply ~80% of the global energy demand not more than another 2.5 to 3 decades (Vedachalam et al., 2015). By that time, the CO_2 emission may reach 45 million metric tons (MMT), a 46% increase over the 2010 level (Leahy et al., 2013). Thus, there is strong need for developing green and renewable energy resources such as geothermal, solar, wind, biofuels, etc., for our country's energy security. Other sources of the world's energy demand are 12% renewable energy and 8% nuclear energy. Geothermal is a clean, uninterrupted, and naturally available renewable energy resource, which is still untapped.

The word 'geothermal' comes from a Greek word, which consists of geo (Earth) and therme (heat). Earth heat is derived within the earth's sub-surface, whereas geothermal resource is a reservoir of hot water at varying depths and temperatures beneath the earth's surface (Tiwari and Sain, 2021; Bates and Jackson, 1987). Geothermal spring is the manifestation of convecting water in the upper crust within a confined space, where it transfers heat from a source to sink, usually the free surface (Hochstein et al., 1990). A geothermal field or reservoir may contain heat in the fluids and the solid rock that fills the pore and fracture space within the rock (Gupta and Roy, 2006). This reservoir can be found in regions of higher geothermal gradient and is mainly found around the plate margins or in the tectonically active unit (Tiwari and Sain, 2021). A well can be drilled into the geothermal reservoir to trap the steam and heated water. It can be brought to the surface for several applications such as electricity and/or direct usage. A geothermal field contains three main constituents: a heat chamber, a reservoir, and a fluid that transfers the geotherm heat to the near-surface. Each geothermal spring has unique characteristics reflected in the geothermal fluids' geochemistry (Tiwari et al., 2016; 2020). The potential of harnessing geothermal energy depends on its chemistry, temperature, and discharge. The criterion for classifying geothermal resources depends on the enthalpy of fluid that works as a carrier, transporting heat from the deep hot rock to the surface. Further, the enthalpy is considered proportional to temperature and is used to define the heat content (thermal energy) of fluid. The geothermal resources are mainly characterized into three categories, i.e., low (<125°C), medium (125-225°C), and high (>225°C) enthalpy (Hochstein et al., 1990).

Huge geothermal fields are naturally available in the Indian Himalayas. These are situated in deeply incised river valleys along the mega thrust zone like the Main Central Thrust (MCT) and Indus Tsangpo Suture Zone (ITSZ) (Tiwari, 2014). The medium enthalpy hot springs are mainly found in the younger intrusive granites, i.e., in the orogenic belt of the Himalayas, and tectonically active belts like rifts and grabens, while low enthalpy hot springs are linked with the Tertiary and Neotectonic active belts (Chandrshekharam and Chandrashekhar, 2010). More than 300 geothermal springs are documented in the Indian subcontinent, which can be utilized as renewable energy resources (GSI 1991, 2001; Gupta, 1974; Gupta, 1980; Guha, 1986; Gupta and Roy, 2006; Tiwari and Sain, 2021). Further, ~40 geothermal springs are situated in the Garhwal and Kumaun regions of the Uttarakhand state, many of which have great potential to generate energy. Geothermal sites of the Garhwal and Kumaun regions are associated with high heat flow (~150 mW/m) and high geothermal gradient (~100°C/km) (Rai et al., 2015; Tiwari and Sain, 2021). The capital cost for establishing a geothermal power plant for producing electricity is more than a hydroelectric power plant, but the operating or maintenance cost is minimal. Further, the estimated cost for generating electricity from geothermal energy is one-third of that produced from hydroelectric power (Smith, 2007; Friedman, 2011: Younger and Gluyas, 2012; Craig et al., 2013).

GEOLOGICAL SETUP OF THE STUDY AREA

The present study deals with the geothermal resource assessment at Tapoban geothermal fields of Dhauliganga river valley in the Uttarakhand state. The work is mainly focused on possible geothermal energy reserve estimation, which measures the amount of geothermal energy extracted at a profitable rate from the geothermal reservoir for at least 30 years. The surface discharge and downhole data is evaluated to illustrate the physio-chemical characteristic of the Tapoban geothermal field. The study also aims to quantify geothermal energy resources that could be harnessed up to a certain period with well-defined fluid characteristics.

The Tapoban geothermal field falls in Survey of India toposheets no. 53N/11, and is situated in Chamoli district of Uttarakhand state. Physiographically, the study area comes under the Alaknanda river, consisting of the Gangotri-Badrinath-Kedarnath complex and higher Himalayan crystalline (HHC) sequence and displays the radial drainage pattern. The Tapoban geothermal field is bounded by two mega thrusts of northwest Himalaya, i. e., the Main Central Thrust (MCT) to the south and the Vaikrita thrust (VT) to the north (Tiwari, 2014). The study area is located near the Tapoban village, ~14 km from Joshimath towards the Malari road.

Geological settings and rock exposed along the Alaknanda river valley is described in detail by Auden (1937). The rocks of HHC are exposed in the study area, which is thrusted over the Garhwal group of rocks (Chamoli and the Pipalkoti Formations) along a northerly dipping major tectonic discontinuity known as the MCT zone passing through the Tapoban area. The HHC sequence consists of highly metamorphosed schist, gneiss, quartzite, and calc silicates rocks. The gneisses are the dominant rock type in the Tapoban area. The stratigraphic sequence of the study area is briefly given in Fig. 1 and Table 1 based on previous studies (Auden, 1937; Agrawal and Mukhopadhyaya 1975; Valdiya et al., 1999; Tiwari 2014) made in the study area.

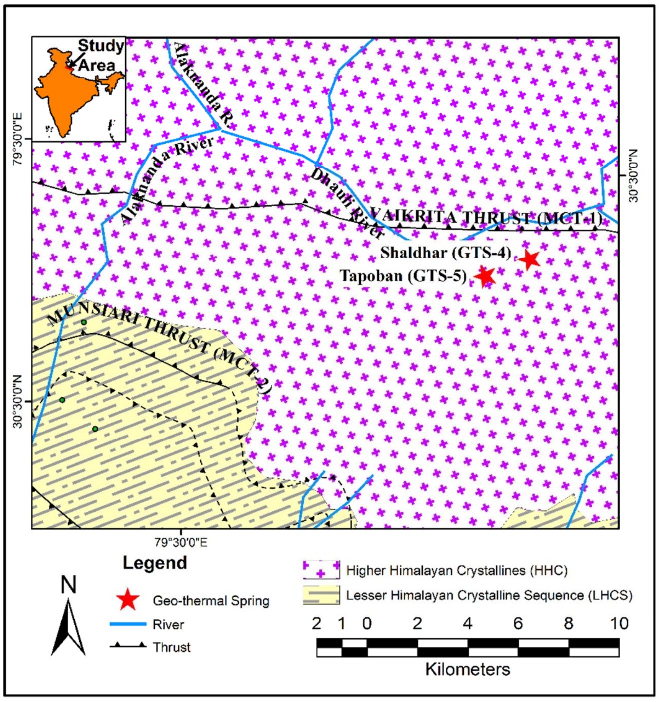

Fig. 1. Geological map of the Tapoban Geothermal Field (modified after Valdiya et al., 1999) showing the Vaikrita thrust, rivers, and geothermal springs (GTS).

Table 1. Geological setting of Tapoban geothermal reservoir in Chamoli district, Uttarakhand

Group	Formation	Rock type	Lithological setup
Higher Himalayan Crystalline Sequence	Helang	Gneiss and Schist	Biotite augen-gneiss and schist with a small band of amphibolite and calcareous rock
		Quatrzite	Greyish white and seicitic quartzite
		Gneiss and Schist	Augen gneiss and schist

MATERIAL AND METHOD

The in-situ parameters (pH, TDS, surface temperature) were measured during the fieldwork by adopting the methodology given by Tiwari et al. (2020). The profound geothermal energy was estimated using the volumetric method based on reservoir and reference temperature and geometrical characteristics (i.e., reservoir area and depth). The reference temperature of the Tapoban reservoir equals to the minimum temperature of the geothermal fluids emerging from the reservoir. The configuration of the Tapoban reservoir is almost conical, with an area of ~3 km^2. The medium depth springs ranging from 291 to 728 m depth (Panday and Negi, 1995) have been investigated. Therefore, the effective depth of reservoir for thermal water can be considered up to ~500 m. The following equations are used to calculate the thermal energy from liquid dominated Tapoban geothermal field (Muffler, 1978).

$$H_r = A * h\,[\rho_r * C_r * (1 - \phi) * (T_i - T_f)] \qquad \text{(i)}$$

$$H_w = A * h\,[\rho_w * C_w * \phi * (T_i - T_f)] \qquad \text{(ii)}$$

$$H = H_r + H_w \qquad \text{(iii)}$$

Where H = total thermal energy (KJKg^{-1}); H_r = heat energy in rock (KJKg^{-1}); H_w = heat energy in water (KJKg^{-1}); A = area of the reservoir (m^2); h = average thickness of the reservoir (m); C_r = specific heat of rock at reservoir condition (KJKg^{-1}); C_w = specific heat of water at reservoir condition (KJKg^{-1}); ρ_r = density of rock (Kgm^{-3}); ρ_w = density of water (Kgm^{-3}); ϕ = porosity; T_i = average temperature of the reservoir (°C); T_f = final temperature (°C).

Table 2. Parameters used to estimate geothermal energy for electric and non-electric uses

S. No.	Parameter	Unit	Value	References
1	Area of the reservoir (A)	m^2	3000	
2	Average thickness of the reservoir (h)	m	500	
3	Specific heat of rock at reservoir condition (Cr)	$KJKg^{-1}°C^{-1}$	0.796	
4	Specific heat of water at reservoir condition (C_w)	$KJKg^{-1}°C^{-1}$	4.18	
5	Density of rock (ρ_r)	Kgm^{-3}	2560	
6	Density of water (ρ_w)	Kgm^{-3}	957.8	
7	Porosity (ϕ)	%	70	GSI (2001)
8	Average temperature of the reservoir (T_i)	(°C)	114	Pandey and Negi (1995)
9	Final temperature (T_f)	(°C)	135	Pandey and Negi (1995)
10	Recovery factor (R_f)	%	30	GSI (2001)
11	Plant efficiency (P_e)	%	6	GSI (2001)
12	Maximum flow rate	$Kg\ s^{-1}$	10	Tiwari et al. (2020)
13	Average flow rate	$Kg\ s^{-1}$	6	Tiwari et al. (2020)

The maximum temperature of geothermal springs in the Tapoban field is 65°C, which also matches the previous study (Pandey and Negi, 1995). The parameters used to calculate the geothermal potential from the Tapoban geothermal fields are given in Table 2. The fracture porosity of the Tapoban field is ~70%, which is measured based on rock composition and tectonic manifestation like a fractured rock (GSI, 2001). The geothermal energy for 20 years and 30 years have been calculated for electricity and direct usages at a large scale.

Power plant capacity is a measure of the total energy of a power plant for a particular supply of electricity. This was evaluated using the following equations proposed by Muffler (1978):

$$P = H * R_f * P_e \tag{iv}$$

where P = power potential (MWe); H = total thermal energy (MWe); R_f = Recovery factor; and P_e = plant efficiency.

The geothermal energy can be utilized for various non-electrical (direct) uses. The heat capacity (Q_c), energy use (Q_u) and capacity factor (CF) of the Tapoban geothermal field are calculated by using the following relations:

$$Q_c\ (\text{MWt}) = \textit{Max flow rate} * (T_i - T_f) * 0.0042 \tag{v}$$

$$Q_u\ (TJY^{-1}) = \textit{Avg. flow rate} * (T_i - T_f) * 0.0322 \tag{vi}$$

$$CF = Q_u / Q_c \tag{vii}$$

RESULTS AND DISCUSSION

Worldwide Review on Geothermal Energy

The geothermal energy resources are classified worldwide as high enthalpy (T > 200 °C, depth >1000 m) and low enthalpy (T < 150°C, depth < 1000 m) reservoirs (Kazmarczyk et al., 2020, Dávalos et al., 2021). The world's first geothermal potential plant with a capacity of 20 KW was established in 1905 at Larderello in Italy (Singh et al., 2016). Several geothermal fields were explored and exploited in the recent decade to generate electricity and other direct uses. Till 2010, about 24 countries potentially stepped up to generate electric power, amounting to 67,246 GWh from geothermal sources, especially from hot springs (Bertani, 2012). The generation of geothermal energy after 2010 has been found in the growing phase exponentially, amounting to> 15 GWe, mainly due to the establishment of medium to low geothermal projects worldwide. It has been expected to be 21 GWe geothermal energy. The United States produces the largest electricity from the GTE (capacity~ 3102 MWe in 2011), followed by Italy (capacity~ 843 MWe) and Germany (capacity~ 50 MWe) (Bertani, 2012, 2016; Zarrouk, 2014). Some other countries like Iceland, New Zealand, Kenya, Mexico, and the Philippines have explored geothermal energy from hot springs and fumaroles (Datuin and Troncaales, 1986; Hunt, 1998; Bertani, 2016). Iceland's power supply based on geothermal energy covers significant energy needs (~80%) (Reinsch et al., 2017). In Kenya, the GTE from hot springs, geysers, and fumaroles is utilized directly or indirectly for numerous purposes like space heating and cooling, agriculture, aquaculture, etc. (Teklemariam, 2008). A large-scale house heating uses the GTE in the spa region of Abano in north-eastern Italy (Carella, 1985). In New Zealand, ~17% is achieved by GTE from hot springs (Hunt, 1998; McNamara, 2016). In a couple of years, about 40 countries may be 100% geothermally powered, which is a good sign for reducing CO_2 load by about 1000 million tons per year from the atmosphere (Bertani et al., 2016).

The literature archive shows that India has a large number of geothermal potentials in the form of hot springs of low to medium enthalpy in the orogenic (Himalayas) and a non-orogenic belt (Peninsular region). The GSI identified ~340 geothermal fields and classified them as seven major geothermal provinces: Himalayas, Cambay basin, Son-Narmada-Tapti (SONATA) lineament belt, Sahara valley, West Coast Godavari basin, and Mahanadi basin (Table 3). The surface temperature of these hot springs ranges from 37 to 90 °C over the geothermal provinces of India. Most of the geothermal springs (~50%) existed in the orogenic belt of the Himalayas (Craig et al., 2013). The Puga geothermal field in the western Himalayas has 100 hot sprigs, showing the greatest enthalpy GTE source (surface temperature: 30-84°C) to develop an electric power potential of ~5000 MWh (Craig et al., 2013). Published records stated that India, especially the Himalayan regions, has an estimated geothermal power potential of 10,600 MW, which is still untapped (Shankar, 1988; Shankar, 1998; Craig et al., 2013; Tiwari and Sain, 2021). Even though, the first step to utilizing GTE was under evaluation in Gujarat (Chandrashekharam and Chandrashekhar, 2010). Towards this, some noteworthy efforts by the organizations like Geological Survey of India (GSI), National Geophysical Research Laboratory (NGRI), Centre of Excellence for Geothermal Energy (CEGE), Wadia Institute of Himalayan Geology (WIHG), and Thermax, etc. At present, the Ministry of New & Renewal Energy (MNRE) has been keeping an eye to explore and exploit the GTE of 1000 MW capacity in the primary phase and further potentialize it to ~10000 MW by 2030. For this, the GSI has suggested three sites in the Ladakh region (Chumathang and Puga in the Indus valley and Panamik in the Nubra Valley), which have massive potential to generate

Table 3. Geothermal provinces in India, identified based on heat flows, geothermal gradient, and tectonic settings (GSI, 1987; Chandrashekharam and Chandrashekhar, 2010)

S. No.	Geothermal Provinces	Reservoir temperature (°C)	Surface temperature (°C)	Thermal gradient (°C Km^{-1})	Expected heat flow (mWm^{-2})
1	Himalayas	260	>90	100	468
2	Cambay	150-175	40-90	70	80-93
3	West Coast	102-137	46-72	47-59	75-129
4	SONATA	105-217	60-95	60-90	120-290
5	Godavari	175-215	50-60	50	93-104
6	Sohana	100	24-47	41	100
7	Mahanadi	180	28-58	-	-

References: GSI (1987, 1991); Chandrashekharam and Chandrashekhar (2000, 2010); Singh et al. (2016), Sircar and Yadav (2017)

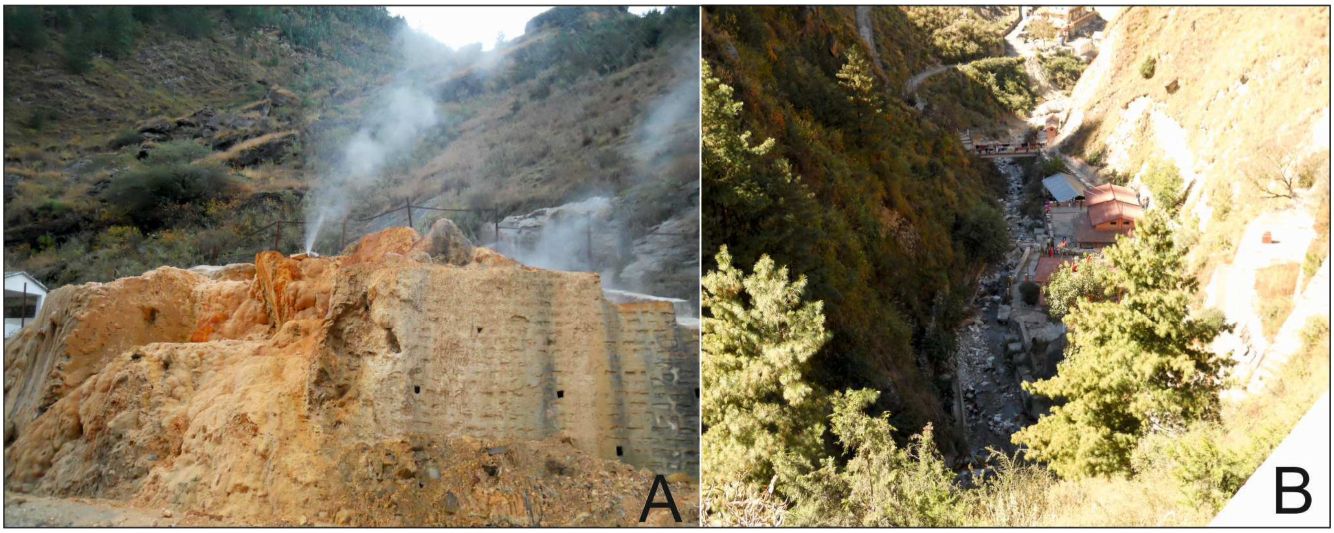

Fig. 2. (A) Field photograph of Tapoban (Shaldhar) Geothermal Field, **(B)** Geothermal field along the Ringi Nala, Tapoban.

thermal power with a capacity between 3 and > 20 MWe (Craig et al., 2013).

Physio-Geochemistry and Thermometry

The potential of geothermal fields can be seen in several geothermal springs over 3 km between Tapoban and Ringi villages (Tiwari, 2014). Four geothermal springs are situated on the left bank of the Dhauliganga river towards Malari. Out of four geothermal springs, two geothermal springs are located on the hill slopes about 1.6 km east of Tapoban village, the third one occurs on the left bank of Ringi nala, and the last one is in temple premises (Fig. 2). The surface water temperature of all the geothermal springs ranges from 45°C to 93°C, measured in the field using the multiparameter kit, Hach made (USA). The springs emerge from the country-rock's prominent joint/ weak zone with the discharge of hot waters up to 300 lit/min, and travertine (Yellowish white to brown material) can be seen around the spring (Tiwari and Sain, 2021).

The pH of all four geothermal springs varies from 6.2 to 7.3, whereas Total dissolved solids vary from 261 to 572. Tiwari et al. (2020) and Tiwari and Sain (2021) presented further details of geochemical data. Bicarbonate (HCO_3^-) is the most dominant among all anions, and Ca and Mg are more abundant than Sodium and potassium. The thermal fluids of the geothermal field all in the category of Ca-Mg-HCO_3 type, which suggests the contribution of meteoric water and fast percolation of precipitation up to shallow depth. The stable isotopic study also conforms to the meteoric water recharge source in the Tapoban geothermal field (Tiwari and Sain, 2021). The reservoir temperature of Tapoban geothermal field was estimated to be 125 ± 2.0°C based on dissolved silica geo-thermometry. The data of reservoir temperature for the present study is adopted from Tiwari and Sain (2021).

Thermal Energy of Tapoban Geothermal Field

The high-temperature gradient (160-580 °C km^{-1}) of the Tapoban geothermal reservoir offers the harnessing of the geothermal potential for electrical and non-electrical purposes. The result shows that the total estimated geothermal energy from the Tapoban field is ~874.35 x 10^{11} KJ. Considering the conical manifestation of the Tapoban field, the total energy for 20 and 30 years was found to be ~170.37 x 10^{11}KJ and 117.30 x 10^{11}KJ, respectively. Establishing a binary power plant and its capacity depends on potential geothermal fields, recovery factors, and plant efficiency. The energy of the geothermal power plant over this reservoir is estimated at ~1.02 MWe and 0.71 MWe for 20 years and 30 years, respectively. This potential of the power plant can be enhanced by drilling three or four wells in the Tapoban fields and using advanced production techniques.

Further, deep drilling may be a hope to produce substantial electric power. In recent years, a binary cycle power plant may be an efficient and eco-friendly tool for producing electric energy at a profitable rate because of the low loss of heat energy and quick recycling process. This method requires a low-cost working substance (ammonia-water mixture, HCFs gases, etc.) that gets converted into the gas at or below the steam temperature, which is provided by the flow of geothermal water. The massive steam created in the circulating track spins the turbine to generate electricity. In addition, This technique does not allow CO_2 or other hazardous pollutant emissions from the hot waters. This method has essentially operated using the low enthalpy geothermal resources worldwide (Bertani, 2016; Yasukawa et al., 2018).

This geothermal energy can be utilized directly in non-electrical applications, such as space heating and cooling, food, and agricultural fields (Yadav and Sircar, 2019) near the Tapoban field. The maximum flow rate through the hot spring in the Tapoban geothermal field may vary from 80-300 liter $minute^{-1}$ (Tiwari et al., 2020). Thus, considering two prominent springs, we find a maximum flow rate ~ 10 Kg s^{-1} with an average of 6 Kg s^{-1}. The heat capacity of two sources from Tapoban geothermal energy was found to be ~0.84 MWt, which can be utilized for direct purposes for local people. The annual energy use from this source is ~15.89 TJ per year. The capacity factor (CF) of the Tapoban geothermal field is observed at ~ 0.60, which implicates the potential applications of GTE. The worldwide average value of a CF is reported at about 0.40. The geothermal field of lower value of CF was harnessed for geothermal heat pump (GTHP) applications, while the geothermal field of higher CF was utilized in continuous works and industrial purposes (Lund and Freeston, 2001). Considering multiple resources from the Tapoban field, this geothermal potential is augmented manifolds. It can be used for individual space heating, fish and animal farming, agriculture drying, bathing, swimming, greenhouses, industrial processes, etc. Direct applications of the GTE are site-specific; for example, the thermal water emerging from Manikaran geothermal field is utilized for cooking and bathing (used as therapeutic) by local people (Chandrasekharam and Chandrashekhar, 2010). Most of the locations in and around the Himalayan region fall under low-temperature zone (i.e., < 25°C); therefore, the GTE can be suitably harnessed for heat applications and fulfill several local demands.

PROSPECTS OF GEOTHERMAL ENERGY POTENTIAL FOR FUTURE

Presently, our country stands on the fifth position in the line amongst all the nations exhausting maximum energy, which is expected to rise much more by the year 2023 (Kumar et al., 2020). It is important to understand that, although we can achieve short-term gain from conventional energy resources, it can be life-threatening and can damage the environment and biological diversity. The present phase necessitates focusing on the geothermal resource of renewable energy, which maintains the environmental standards.

Out of many renewable energy resources, the GTE is one of the eco-friendly, nonconventional, and sustainable energy sources that can produce electricity manifolds higher than solar or wind because of the higher load factor. The geotectonic settings of India favor the exploitation of the GTE at a large scale to reduce the power deficit in the future. Considering the geothermal energy potentials, India can reduce CO_2 emissions to the level recommended by the Kyoto protocol; therefore, it emerges as a carbon credit earner by opting clean development mechanism (CDM). The negative mass balance of the Himalayan glaciers could be a far-reaching challenge to the hydro-ecosystem by fluctuating monsoon patterns across south Asia. The receding rate of the Gangotri glacier is reported as ~ 22 m per year (Bisht et al., 2020). Under these circumstances, the utilization of the geothermal domain can preserve the pristine ecosystem of the high mountain Himalayas (Chandrasekharam and Chandrasekharan, 2010). Since the hydropower projects in the Himalayan region are generally not efficient, particularly in the winter season, geothermal potential can accomplish the baseload needs around the river basin.

Many sectors such as the food processing, infrastructure (residential and commercial), and industrial field attain power deficits from coal field-based power plants, which provides extra pressure on the country's revenue. If India only implements low enthalpy GTE as a form of ground source heat pump, the load of natural resources like coal would be reduced, and these sectors would grow at a fast rate. Thus, the GTE can serve as a bridge between demands and supply of power for a long time and with proven technology, and it can substantially contribute to the country's revenue.

CONCLUSIONS

Here, the utilization of abundant geothermal energy resources for electric and non-electric usages in India has been emphasized. For this, the geothermal energy from an in-situ and reported dataset from Tapoban geothermal field in Chamoli district in the state of Uttarakhand has been calculated. This study has explored the knowledge gap about renewable energy and offered a valuable database for harnessing geothermal energy resources. The present study stresses implementing a permissible policy for developing an effective and environment-friendly geothermal exploitation. As per the country's needs, the government and policymakers should step up and reconstruct an adequate institutional framework for geothermal energy production over a longer period.

The lack of geothermal data and knowledge on such renewable energy remains a crucial barrier to defining geothermal resources' sustainability. Hence, we suggest that data sharing policies among the agencies and nodal centers and awareness of local people about non-electrical uses of geothermal energy would be a positive sign to accomplish the future demand of energy.

The methods and results of the Tapoban geothermal field would be relevant to improve our understanding of different geothermal regions (orogenic or non-orogenic) of India. The insights and raw data may be used as key parameters to achieve information about the geothermal potential in India. Other exploration methods like resistivity and electromagnetic would help to provide information about the depth of thermal reservoir to ensure the resource quality and quantity by appropriate drilling. The thermal energy from the deep-seated reservoir (i.e., 1 to 3 km) must be critically assessed to develop potential power plants. As a developing country, we highly urge that India may be a leading contributor to renewable energy by harnessing cost-effective geothermal energy.

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