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Energy from Geothermal Resources and Scope of its Utilization in India

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Abstract

Demand of energy is increasing day by day worldwide. Also the use of non-renewable energy resources has created serious problems like global warming and air pollution. At the same time, these resources are fast depleting. Thus we have to look on renewable energy resources to meet the future energy needs. Geothermal energy resources are very versatile renewable energy resource, and have wide range of potential use to fulfill the energy need of rural and urban society in and around the regions of its availability. The present work critically examines the energy from geothermal resources and scope of its utilization in India. There are about 400 known thermal areas in India, each represented by hot spring. The potential geothermal resources exist all around these hot springs. The temperatures of these springs range from 34 °C to 96 °C. Based on cation's and anion's study, the water types are mostly $NaHCO_3Cl$, $NaCaHCO_3Cl$, $CaMgHCO_3$, and $NaHCO_3ClSO_4$. The geothermal fluids from the shallow wells at Puga have been effectively applied to the refining of borax and sulfur as well as experimental space heating. India's first power plant to produce estimated output power of 250MW will be setup at Puga. The helium content in the hot gases from Bakreswar geothermal sites varies from 1-3% v/v. Helium exploration field stations were established in the above mentioned sites. The geothermal gradient varies from 0.7 °C/m to 2.5 °C/m at Chhumathang geothermal field indicating the powerful geothermal region. There exists great scope to use this versatile resource for electrical as well as non-electrical applications in India.

Keywords: *Energy, geothermal, resources, utilization, geothermal gradient.*

1. Introduction

Geothermal energy is the energy that is encapsulated under the earth's crust [1]. For practical utilization of these resources for the benefit of society, the depth of these resources should not exceeds the limit of economic exploitation. The essentiality for the geothermal resources is Earth natural active heat source [2]. The basic systems of geothermal energy resource utilization include hydrothermal convection systems, dry hot rocks, active volcanic vents, direct utilization of magma lakes, and deep sedimentary basins [3, 4].

Utilizing geothermal resources should be seen as an energy replacement for the limited capital energy resources such as natural gas, fuel oil, or coal, to better utilize those resources elsewhere, where they are needed most and cannot be replaced. An essential component of energy conservation policies should be the use of geothermal energy as a direct heat source. Due to the strong thermodynamic link between the availability of medium and low temperature geothermal resources and direct heat end uses, using these resources encourages conservation, which aims to increase resource utilization efficiency [5].

Art of geothermal exploration has to pass through many phases to be recognized as a potential geothermal resource. These phases include reconnaissance survey, prospect investigation (geological studies, geochemical studies, shallow temperature gradient and heat flow studies, and geophysical surveys), slim hole/exploratory hole drilling, proving of the field and evaluation, economic feasibility study, and geophysical monitoring of a field under exploration. Geophysical surveys include the surface electrical methods, macro-seismic survey, gravity survey, magnetic survey, and seismic surveys [6, 7]. The Hot Spring Committee, constituted by Government of India in 1966, along with Geological Survey of India (GSI) and National Geothermal Research Institute, Hyderabad (NGRI) successfully studied these phases and identified some multi-disciplinary geothermal exploration projects. A systematic geothermal exploration and experimental utilization on a pilot scale were initiated in 1973. Since then eight multi-disciplinary geothermal exploration projects, i.e. the Puga-Chhumathang Geothermal Project in Jammu & Kashmir, the Parbati Valley, the Beas Valley, and the Sutleg Valley Geothermal projects in Himachal Pradesh, the Sohna Geothermal Project in Haryana, the Alaknanda Valley Project in Uttar Pradesh, the West Coast Geothermal Project in Maharashtra, and the Tattapani Geothermal Project in Madhya Pradesh are investigated. The deepest exploratory bore holes have been sunk to a depth of 385 metres at Puga; 220 m at Chhumathang; 700 m at Manikaran; 728 m in Tapoban; and 620 m at Tattapani [8].

According to the 2019 data, there are 15.4 gigawatts (GW) of installed geothermal generating capacity globally, of which 3.68 GW, or 23.9%, are located in the United States [9]. El Salvador, Kenya, the Philippines, Iceland, New Zealand, and Costa Rica are nations that get more than 15% of their electricity from geothermal sources [10]. The world's largest geothermal energy resource, estimated to be 29,000 megawatts (MW) in Indonesia, with an installed capacity of 1,800 MW in 2017. The potential geothermal provinces in India have the capacity to generate 10,600 MW of electricity [6, 11], which is a respectable amount in energy budget.

The present work analyzes and evaluates the understanding and developments for location and evaluation of potential geothermal energy resources for eventual utilization for the benefit of society as an alternative to fast depleting fossil fuel resources.

2. Geothermal energy resources in India

Considering the geotectonic and igneous history of India, there is ample scope to develop geothermal resources. There are about 400 known thermal areas in India, each represented by hot/warm spring. The potential geothermal resources exist all around these hot springs. Based on the art of geothermal exploration study, carried by the Geological Survey of India, the detected provinces in India for exploitation of geothermal energy are shown in figure 1, and are briefly described below.

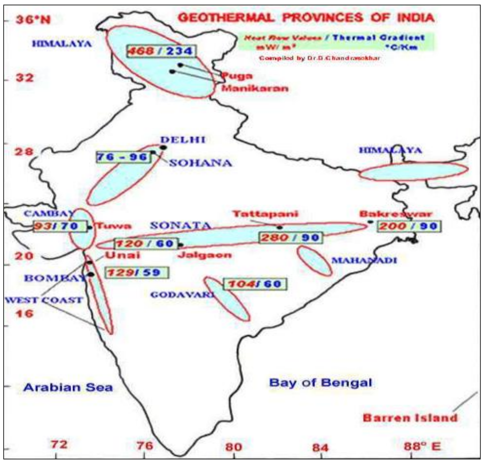

Figure 1. Potential geothermal provinces of India (source: geological survey of India Indiaenergyportal.org).

2.1. N.E Himalaya provinces

2.1.1. Puga geothermal field

It is the region having approximately one hundred thermal springs with draining capacity of more than 190 tons of thermal water per hour and surface temperatures of up to 90 °C. These resources are associated with moderate enthalpy reserves [12]. It is that part of the country where most frequent earthquakes are observed and seismically very sensitive due to the existence of Indo-Eurasian plate boundary. The magneto-telluric recordings have been used to characterize the geothermal springs with depth in range from 1 to 3 km [13-15}. The study at Puga, traced an unusual conductive zone with resistivity less than 10 Ohm m (figure 2), which may be connected to the local geothermal source. The anomalous conductive portion and the surface low resistive region are divided by a basement layer that has a high resistance. At the top of the conductive section, the minimum temperature is thought to be around 250 °C [16].

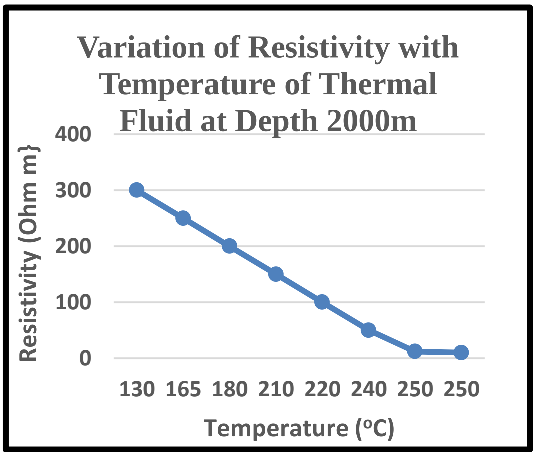

Figure 2. Variation of resistivity with temperature of thermal fluid at Puga (depth, 2000 m).

The Geological Survey of India has successfully carried out experiments on space heating using thermal discharge from these thermal springs as well as for refining naturally occurring sulphur and borax. Currently, work is being done to extract Cesium from geothermal fluid using a resin called resorcinol formaldehyde (RF) and ammonium 12-molybdo-phosphate (AMP). According to computer-based reservoir simulation exercises [17], even if the Puga valley experiences temperatures of 170 °C, only 2 MW of electricity could be generated using an exhaust-to-atmosphere plant in a location where it is desperately needed.

Another study found that a binary cycle power plant capable of producing 1.7 MW of electricity can be supported by the shallow geothermal reservoir supplying the current boreholes. It is intended to use iso-butane as the working fluid, and its inlet and outlet temperatures are taken at 120 °C and 92 °C, respectively. The outlet water can be used for non-electrical purposes like space heating and greenhouse growing [18].

The main findings of the Puga thermal fields are described in table 1, and a geothermal activity is shown in figure 3.

Figure 3. Geothermal activity at Puga (courtesy: Wikimedia commons).

Table 1. Measuring parameters, observations, and inferences at Puga geothermal field.

Measuring parameters	**Observations**	**Inferences**
Thermal manifestation	Hot springs and pools, Sulphur condensates Borax evaporates having areal extent of about 4 Kms.	Naturally occurring Sulphur and Borax may be refined.
(a) Temperature range (b) Discharge rate	(a) 30 °C to 84 °C (b) 300 L/min, with maximum discharge from a single spring–5 L/s	Refrigeration (lower temperature limit), animal husbandry, and space heating (buildings and greenhouses). greenhouses heated by a combination of space and hot beds, mushroom cultivation, warm water for year-round mining in cold locations, swimming pools, biodegradation, fermentations, de-icing, and fish spawning.
Resistivity (Geophysical surveys)	2 – 10 Ohm meter	Existence of nearly neutral to weakly alkaline thermal water in the sub-surface.
pH value	6 – 8.3	Nearly neutral to weakly alkaline
Major cations contents	Na, K, Cs, Li, Mg, Rb, Fe (in decreasing order)	(a) Longer lived thermal waters indicating intensive water-rock interaction. (b) Deeper layers may include thermal fluids with temperatures between 220 °C and 260 °C.
Major anions contents	HCO_3, Cl, SiO_2, B, SO_4, As, and NH_3 (in decreasing order)	Water type: $NaHCO_3Cl$
Temperature gradient	0.35 – 2.5 °C/m	Thermal logging of the geothermal wells
Minimum heat flow	13 FHU	Basis of the thermal gradient data that is currently available and a few determinations of thermal conductivity
Boreholes (34) at depth range 28.5 m–384.7 m	Mixture of steam-water from shallow reservoir	(a). Yield on the average 12.5% of steam at 140 °C and of 2 to 3 kg/cm^2 pressure. (b). Total water-steam mixture discharge of 190 tonnes per hour (c). A drill hole can discharge up to 30 tonnes per hour.

2.1.2. Manikaran geothermal field

The Manikaran geothermal field stretches for roughly a 3 km in an east-west direction from the Harihar temple at the village’s entrance to the point where the Pārbati River and the Brahmaganga Nala meet. At Manikaran, thermal springs typically erupt either through the terrace gravel deposits or joints in quartzite’s. The springs have pools and spouts with temperatures as high as 96 °C. Some springs exhibit bubbling activity as well. Aragonite deposits covered in iron oxide have grown up around the majority of the springs. The thermal springs also appear in Kasol, where they are formed by quartzite and debris. The water from the hottest spring is 76 °C in temperature. Around several of the springs, there is visible calcium carbonate encrustation and ferruginous colouring of the bedrock joints. With a temperature of 34 °C, only one thermal spring can be seen erupting through jointed quartzite in Jan. In the spring, there is a lot of gas activity. In and around the spring, deposits of ferruginous materials are seen. The sole thermal spring is located at Khirganga, 25 kilometers upstream of Manikaran, on a hilltop around 100 m above river level. Manikaran, Kasol, Jan, and Khirganga all have hot springs with surface temperatures up to 96 °C, with Manikaran having the warmest springs [19, 20, 21]. Geothermal activity in the Pārbati Valley may be seen in these hot springs. The Khirganga thermal spring is the only one in the Parbati Valley that is not within 10 m of the river level. Most of them release from places that are extremely close to the river's level.

The Pārbati Valley's thermal springs can be divided into two groups based on their location [20, 21]. Firstly, steam escapes from the springs, which seem to have its genesis in river terrace sediments. The majority of them contain significant travertine deposits. across the vents, and secondly, having extremely hot water flows that may be observed going up directly onto a steep rocky joint and have temperature in range 70–80 °C. However, no steam release is seen in these flows. There isn't any obvious deposition near the mouths of these flows, in contrast to the first category.

The main findings of the Manikaran geothermal field are described in table 2 and a geothermal activity is shown in figure 4.

Table 2. Measuring parameters, observations, and inferences at Manikaran geothermal field.

Measuring parameters	Observations	Inferences and techniques
Hot spring temperature range	34 °C–96 °C (right bank of Pārbati River) and 28 °C – 37 °C (left bank of Pārbati River)	Geo-physical surveys
Resistivity	Low 30–100 Ohm meter	High conductivity zone
pH	7.5–8.1	Water is feebly alkaline
Type of water	(a) $NaHCO_3Cl$ (b) $NaCaHCO_3Cl$	On the bases of dominant cations and anions (Based on major ion chemistry)
Sub-surface water temperature	110 °C–130 °C	Geo-chemistry study
Boreholes (9)	(a). Temperature ranges from 45 °C to 96 °C (b). Highest discharge rate from a single bore: 7 L per s (c). Cumulative discharge rate: 100 Tonnes per hour	Drying stock fish, intense deicing operations, domestic green house, milk pasteurization, refrigeration by low temperature, manure and poultry processing, mushroom growing and food processing.
Heat flow	100 mW/m^2	Because shallow magmatic processes are still happening and newer granites are present.
Geothermal temperature gradient	100 °C/Km	Happening of shallow magmatic process

Figure 4. Apple cold stores and food processing, Manikaran geothermal field.

2.1.3. Chhumathang geothermal field

The Chhumathang geothermal provinces, which are located around 150 km from Leh Ladakh and 40 km north of Puga Valley, are another of the Himalayan region's most well-known areas [21, 22]. The majority of this field is located about 4300 m above the mean sea level in the Northwest Himalayan hills beside the river Indus and spread in about 1 km^2 area. The activity, takes the form of hot springs, stained soil and travertine deposits. The region has a granitic basis and a thick sequence of river debris to shallow sea deposits [22]. In Chhumathang, there have been discovered to be 73 geothermal provinces, most of which are represented by hot spring deposits, with temperatures ranging from 30 °C to 87 °C and H_2S emission. The discharge rate of all springs is about 200 l/min. Chhumathang's geothermal spring, which has a discharge of 1.5 l/s, has a maximum temperature of 87 °C [23, 24]. In this region, the recorded water pH values range from 6.9 to 8.6. The water has low percentages of Cl, Na, HCO_3, and K and the greatest SO_4 content. In this region, sodium bicarbonate and sulphate make up the majority of the fluid. Na-K, Na-K-Ca, and SiO_2 thermometry have been used to measure the base temperatures. The observed base temperature is 145-166 °C using Na-K, 160-184 °C using Na-K-Ca, and 148-174 °C using SiO2 thermometry. Geothermal energy was successfully used at Chhumathang for space heating and greenhouse harvesting. An air temperature of 20 to 25 °C may be maintained within the greenhouse even when the outside ambient temperature is -35 to -40 °C. They produced numerous vegetables [25-27]. The main findings of the Chhumathang geothermal field are described in table 3, and a geothermal activity is shown in figure 5.

Table 3. Measuring parameters, observations, and inferences at Chhumathang geothermal field.

Measuring parameters	**Observations**	**Inferences and techniques**
Resistivity	Low resistivity zones–13 to 30 Ohm meter up to a depth of 300 m. Deposits of carbonate plateaus up to diameter 100 m and height 6–10 m.	Much vigorous thermal activity in the past
Hot springs temperature range	30 °C–87 °C	Stock fish drying Intensive de-icing operations, space heating, cooling, animal husbandry, greenhouses (space and hot bed heating), mushroom growth, soil warming, swimming pools, biodegradation, fermentations, warm water for year-round mining in cold locations, de-icing, and fish hatching.
Cumulative discharge and discharge rate	200 L/min 1.5 L/s	Existence of thermal fluid in the reservoir of about 150 °C temperature (geochemical studies)
Boreholes (06) at depth range 20 – 221 m	Temperature of flowing water in the wells recorded about 109 °C	(a). Steam-heated re-equilibrated fluids (b). Deep reservoir temperature of 150 °C (c). The total discharge from 4 flowing wells is approximately 50 tones per hour.
Temperature gradient	very high 0.7 °C–2.5 °C/m	Thermal logging of the geothermal wells. Powerful geo-thermal region.
pH	Higher than Puga, i.e. greater than (6 – 8.3)	More sulphate contents
Origin	meteoric	Based on stable isotope studies on oxygen and hydrogen

Figure 5. Carbonate deposited at Chhumathang geothermal field.

2.1.4. Tapoban geothermal Field

Based on physical factors such as reservoir temperature, depth of the borehole, and geochemical markers, the energy prospective of geothermal resources at the Tapoban geothermal field is examined. This field is located in the orogenic region of the Chamoli district in the Himalayan state of Uttarakhand. Exploiting geothermal water has the potential to be used for both electrical and non-electrical purposes. A key factor is the abnormal geothermal gradient caused by the Main Central Thrust (MCT) zone, which is now active. Calculations were made of the pH levels and surface water temperatures from the known hot springs, which varied from 6.2 to 7.3, and 45 °C to 93 °C, respectively, to examine the viability of extraction. The investigation using dissolved silica geo-thermometry reveals an average reservoir temperature of 125.2 °C. Up to 300 l/min of hot water can be discharged from the springs, which originate from a noticeable joint or weak zone in the surrounding rock. The reservoir is expected to have $874.35x10^{11}$KJ of geothermal heat energy in total. The estimated energy for the binary power plant is 1.02 MWe and 0.71 MWe for the periods of 20 years and 30 years, respectively, which may be multiplied by using this method at several different locations for power generation. It was discovered that the two prominent hot springs have a combined heat capacity of roughly 0.84 MWt, which the locals can use directly. With an annual energy consumption from this reservoir of 15.89 TJ and a capacity factor (CF) of 0.60, it can be used to produce energy on a small to moderate scale to help close the energy gap and fulfil future demands [28-30]. The main findings of the Tapoban geothermal field are described in table 4, and a geothermal activity is shown in figure 6.

Figure 6. Geothermal activity at Tattapani geothermal field.

Table 4. Measuring parameters, observations and inferences at Tapoban geothermal field.

Measuring parameters	**Observations**	**Inferences & Techniques**
Surface manifestation	Over a one-kilometer stretch, there are five hot springs.	Expected heat energy of reservoir is 874.35 x 10^{11} KJ.
Base temperature Discharge rate	65 °C 0.83–9.22 L/s	Geo-chemical study
pH	6.9–7.2	Neutral
Resistivity	Low about 100 Ohm meter extending up to 165 m depth	Electrical method
Cat ions and anions	Ca, Mg, Na, K (in decreasing order of concentration) & F, B, Cl, SO4, SiO_2, HCO_3 (in increasing order of concentration)	Water type: Ca-Mg-HCO3
Boreholes (04)	(a). Artesian conditions (b). Due to the rapid precipitation of silica, the water samples' base temperature of about 150 °C, as determined by silica thermometry, has decreased to about 90 °C. Similarly, with the drop in temperature, ratios of Ca, Na, and K have also changed significantly	(a). cumulative discharge 150 tons/h (b). Highest temperature 92 °C (c). Gas sample collected at one spring containing 78.6% CO_2, 18.96% N_2, and 2.4% O_2

2.2. Cambay and West Cost province

This province is a component of the Cambay basin and lies above the well-known Deccan flood basalts in a failed arm of a rift. It contains more than 15 thermal springs with surface temperatures between 40 and 90 °C and releasing rate from these geothermal wells is more than 125 m^3/hr. Higher reservoir temperatures as recorded at Tuwa and Tulsi Shyam are more than 150 °C. The Cambay region is one of the primary oil and gas producing zones in India, which has Tertiary sediment layers above straightforward lava flows. By drilling numerous deep wells, this basin has been intensively investigated for the extraction of hydrocarbons. It has been discovered that the Moho is located here at a shallow depth [31]. In the northern section of the region, where temperature gradients in certain zones exceed 70 °C/km, there is a high amount of heat distribution [32]. During the drilling of boreholes Cambay-15 and Kathana-4, hot water and steam were seen. The steam discharge rate at a depth of 3 km was estimated to be roughly 3000 m^3 per day. On the basis of information from the drilled hole, *in situ* temperatures have been estimated to reach 175 ± 25 °C. To ascertain the existence of geothermal prospects in the Gandhar area of the Ankleswar district, the Centre of Excellence for Geothermal Energy(CEGE), Pandit Deendayal Petroleum University, Gandhinagar, and the Polish geophysical exploration company PBG collaborated on a thorough Magnetotelluric survey [33]. According to the results of the MT survey, there are incredibly conductive regions at shallow to medium depths, up to 2 kilometers. In the studied area, CEGE had already carried out magnetic and gravity surveys to identify sub-surface irregularities.

2.2.1. West Coast province

This province is one of the most attractive areas for exploitation since it is situated within the Cretaceous-aged Deccan flood basalts and benefits from a thin lithosphere of 18 km thickness. The salinity of the thermal discharges is around 1%. The corrected reservoir temperatures, after considering saline impact, range from 102 to 137 °C. The thermal waters are found to have a temperature in the range of 120-200 °C. The measuring parameters, observations, and inferences at West Coast hot spring belt are given in table 5.

Table 5. Measuring parameters, observations, and inferences at West Coast hot spring belt.

Measuring parameters	**Observations**	**Inferences and tTechniques**
Thermal water springs (60)	Alkali Chloride type except at Rajapur where thermal water is bicarbonate type Fluorine content: 1–3 ppm	It is suggested by the clearly different range of chloride content that there is no connection between the presence and flow of thermal water and the hydrologic cycle of the neighbouring cold water.
Cl/B ratio	High	Independent geothermal systems
Minimum reservoir temperature	110 °C-130 °C	May be used in; sugar refining by evaporation, fresh water by distillation, extraction of salts by evaporation and crystallization, drying and curing of light aggregate cement slabs, and concentration of saline solution
Boreholes (12)	The Sativli, Tural-Rajwari, Unhavrekhed, and Ganeshpuri-Akloli, thermal spring locations can produce enough hot water by drilling shallow production wells.	Use of hot water save the sizeable amount of fossil fuel. Development of hot water bath and Sauna bath.

2.3. SONATA (Son-Narmada-Tapi) province

This province extended from Bakreswar in the east to Cambay in the west. The heat flow and geothermal gradient in this province is very high. It contains the Tattapani geothermal resource with an area of about 80 km^2 and having 24 thermal springs with surface temperatures varying from 60 °C to 95 °C. The pressure of the thermal discharge is 5 kg/cm^2. Based on thermal gradient and experimental results, it was discovered to contain a reservoir with a maximum temperature of 217 °C at a distance of 3 km from the earth's surface. The Geological Survey of India has bored five production wells, each of 6 inches' diameter, in order to commission a 3.17 MW pilot power plant with a lifespan of approximately 20 years. [34].

The main findings of the SONATA geothermal field are described in table 6, and a geothermal activity is shown in figure 6.

Table 6. Measuring parameters, observations, and inferences at Tattapani geothermal field.

Measuring parameters	Observations	Inferences and techniques
Manifestation	Hot spots, hot water pools, and a marshy land in 0.05 Sq. Km area	(a). White to dirty white deposits that have been identified as silica (b). Moderate to low gas activity.
Temperature range Sub-surface temperature Cumulative discharge rate	50 °C–98 °C 120-150 °C 60 L/min	(a). Drying of wool, organic materials, stock fish, seaweed, grass, and vegetables. (b). Extreme de-icing activities, animal husbandry, space heating, mushroom cultivation, refrigeration (lower temperature limit), and greenhouses heated by both hot beds and space.
Nature of zone	Conduction zone near the area of the hot springs in the sub-surface	Hot water bearing formation
Water types	(i). Ca-Mg-HCO3 (ii). Na-HCO3-Cl-SO$_4$	Identified on the basis of proportion of Cat ions and anions Low TDS and high Fluoride content
Boreholes (26)	100 m-620 m depth	(a). Shut in temperature of the thermal fluid–112 °C (b). Cumulative discharge–1600 L/min

2.4. Bakreswar province

This province connects the SONATA and Singbhum shear zones as it stretches throughout the districts of Bengal and Bihar. Based on the study carried out in all the thermal discharges, it has been found that this province is rich in Helium gas. The temperature and helium profiles of Bakreswar geothermal province are presented in figure 7. Distances are measured from Agni Kunda, which is taken at 0 Km.

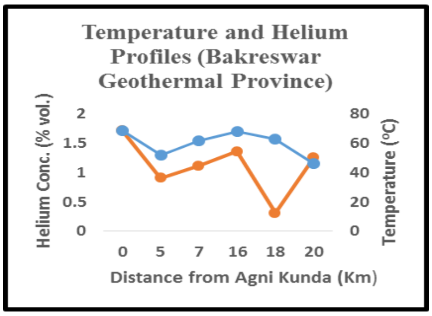

Figure 7. Temperature and helium profile, Bakreswar geothermal province. Agni Kunda is taken at 0 Km.

The Helium concentration in vol. % at Bakreswar Agni Kunda, Reserve Tank, Bhairab Kunda, Khar Kunda, Surya Kunda, and Brahma Kunda are 1.72, 0.91, 1.12, 1.36, 0.31, and 1.26 respectively. Therefore, it is suggested to set up a pilot plant to collect helium from this area's thermal materialisation.

The measured Temperature at Bakreswar Agni Kunda, Reserve Tank, Bhairab Kunda, Khar Kunda, Surya Kunda, and Brahma Kunda are 69°C, 52°C, 62°C, 68°C, 63°C and 46°C respectively. It was anticipated that the energy would be produced from a source of power ranging from 38 to 76 MW, considering all the sources of heat production inside the reservoir system. The development of a Kalina cycle-based geothermal power plant with an ability to harness power of 9.88 MW to 40.26 MW in the study area could be facilitated by the use of the right technology for energy production [35,36,37]. The main geothermal features of Bakreswar Geothermal Province are presented in table 7.

Table 7. Main geothermal features of Bakreswar geothermal province.

Measuring parameters	Observations	Inferences and techniques
Manifestation	Presence of a sub-surface fault that strikes almost north-south and allows hot water to escape through springs. A cluster of hot springs characterized by varying temperature and similar chemical composition	Helium gas concentration
Temperature range Reservoir temperature Boreholes depth	35 °C–71 °C 130 °C 1155 m	(a). Drying of wool, organic materials, stock fish, seaweed, grass, and vegetables, (b). extreme de-icing activities, animal husbandry, space heating, mushroom cultivation, refrigeration (lower temperature limit), and greenhouses heated by both hot beds and space.
Nature of zone	Conduction zone near the area of the hot springs in the sub-surface	Hot water bearing formation
Water types	Na-HCO3	Chemically, the water from the shallow aquifer is of the Na-HCO3 type, with a pH that is almost neutral and minimal F.
Temperature gradient	90 °C/Km	High amount of heat distribution.

2.5. Godavari province

Godavari province in Andhra Pradesh contains 13 thermal discharges. The surface temperature of these springs varying from 50 °C to 60 °C, and pH ranges from 6.5 to 7.3. The reservoir temperature ranges from 175 °C to 215 °C as per study carried out using geochemical thermometers [37]. According to the hydrogeochemistry of the geothermal waters, they are of the Na-Ca-SO_4-HCO_3 to Ca-HCO_3 type. The fluids of the research area are richer in SO_4^{2-} and Cl^- as a result of interactions with pyrite-containing Gondwana deposits and granitic gneiss underlying rocks. Additionally, the enrichment of Ca^{2+}, Mg^{2+}, and an improved HCO_3/Cl ratio in geothermal water is caused by the interchange and/or blending process that takes place due to interaction of rock and water at a high temperature while rising towards the surface. Studies on the geochemistry of geothermal gas suggest that the crust's geothermal fluids circulate deeper than previously thought and that helium, a thermal gas that can be exploited commercially, is highly concentrated. Thermal set down in a bore-well with a depth varying from 50 to 1000 m shows that the geothermal gradient and heat flow in the Manuguru area are both higher than the regional norm, ranging from 22.5 to 105.5 °C/km and 83 to 388 mW/m2, respectively.

Therefore, the Manuguru geothermal area of the Godavari valley can generate 38MW of power using the Organic Rankine Cycle (ORC). This cycle has also been used for thermal analysis using different organic fluids [39].

2.6. Barren island

This Island is in the Bay of Bengal and forms a part of the Andaman-Nicobar Island. In 1991, high volcanic activity has been recorded in this Island, indicating high temperature steaming ground and thermal discharges. An investigation in 2009 [40] discovered that the seawater around this structure was between 60 and 70 degrees Celsius, indicating the island's enormous geothermal potential. It generates enormous amount of steam and volcanic gases through fumaroles–openings on the surface. The temperatures were found to vary from 100 °C to 500 °C, and they might be used as a clean energy source. Barren Island is currently a well-liked tourist destination. Warm seas nearby make for a fantastic scuba-diving experience, enabling divers to explore ancient lava structures and magnificent coral reefs. In Iceland, geothermal energy is currently used to heat nearly 90% of dwellings. Additionally, hot gases that were generated as a result of drilling operations in the volcano on the Reykjanes Peninsula have been used to power electric turbines.

2.7. Sohna geothermal region

This geothermal region is situated around 25 kilometres south of Gurugram, in the Haryana state. The geology of the region is characterised by Precambrian meta-sediments from the Delhi Super group (figure 1). At Sohna, quartzite's, schists, siliceous limestone's, slates, and phyllites are the most prevalent types of rock. The Sohna Fault, a N-S-oriented seismic fault, extends from Sohna to the Delhi Ridge, west of New Delhi [20, 41]. To explore the potential of geothermal energy, a thorough exploratory study was conducted in 1973–1974. Geothermal water in this area has a temperature range of 24 to 46 °C which has been observed in many boreholes that have been dug up to a depth of 547 m. In these holes, a maximum temperature of 55 °C was noted. A temperature of 100 °C is said to exist in the reservoir [42].

3. Scope of utilization of geothermal energy resources

The geothermal fluids from the shallow wells at Puga have been effectively applied to the refining of borax and sulphur as well as experimental space heating. 500 kg of borax could be refined daily at the refinery, while 1 tonne of borax ore could be processed daily at the extraction plant. The Puga experiment on space heating has been quite successful. With the help of thermal fluids, a prefabricated hut that measured 5 metres by 5 metres by 2.5 metres could be heated to a temperature that was 20 °C higher than the surrounding air. The GSI and RRL, Jammu have also carried out successful experimental space heating, greenhouse farming, and poultry farming projects. The RRL, Jammu, has grown mushrooms in a hut on a 500 m^2 area using thermal water that have been used for poultry hatching. The amount of cesium in Puga fluid (10 mg/l) is the highest in the entire world. With the help of the resin created by BARC, Mumbai, efforts were made to separate this valuable metal from geothermal fluid. On a small scale, this field has the ability to generate either binary cycle power or primary cycle power. Reservoir modelling studies, however, have indicated the potential for producing more than 3 MW of electrical power if deeper depths, at least up to 500 m are examined. On February 06, 2021, a

Memorandum of Understanding (MoU) has been signed to set up India's first power plant between Oil and Natural Gas Corporation Energy Centre, Union Territory of Ladakh and Ladakh Autonomous Hill Development Council-Leh. The agreement will be implemented in three phases. To access the steam and hot sulphur water that the geysers spew out, ONGC would drill up to 500 m deep in the first phase. It would be useful for running the one megawatt power plant. Drilling would go a little deeper in the second phase to investigate the thermal reservoir's potential, and a commercial facility would be built in the third phase. The power output is estimated to be 250 MW.

Excellent opportunities exist for the indirect (power generation) and direct uses of thermal discharges (recreation, agriculture, space heating, cold storage, food processing, greenhouse farming, etc.) at the Manikaran geothermal field. An NH_4-absoption system-based cold storage facility with a 7.5-ton capacity was erected. Also put to the test was a binary cycle (ISO-Butane) powered 5 KW pilot power plant. Additionally, the area's geothermal resources could also be used to create a tourist complex with hot tubs, spas, and other attractions.

Geothermal energy was successfully used at Chhumathang for space heating and greenhouse cultivation. It is feasible to keep the greenhouse at a temperature of 20 °C to 25 °C even when the ambient temperature is as low as -35 °C to -40 °C. In this regard, a demonstration project on Space Heating utilising Geothermal Energy was established in 2015, and it began operating in 2017. The Geological Survey of Iceland (ISOR), the Norwegian Geotechnical Institute (NGI), the Wadia Institute of Himalayan Geology, Dehradun, and the National Institute of Technology, Hamirpur are contributing their technical expertise to the project, which is financed by the Department of Science and Technology, Government of India. Vegetables of all most all kinds were grown.

According to a paper [18], Ladakh consumes 50,000 L of diesel each day to power generators that generate 17 MWe, which costs the Indian government 2.92 billion rupees annually (based on the current price of diesel).

In Ladakh, there is a 53 MW total demand for power. In industries like food processing and greenhouse agriculture, the geothermal version reduces operating costs by 8% and fuel costs by 80% when compared to conventional energy.

A significant chemistry change has taken place at the Tapoban Geothermal Field. It has been noted that the temperature drops by 34 degrees within 1.5 meters of the bore hole. Because silica precipitated so quickly, the water samples' base temperature of about 150 °C, as determined by silica thermometry, has decreased to about 90 °C. Similar to how the temperature drop has drastically altered the Ca, Na, and K ratios. The energy reserve of this field can be utilised for low-to-moderate scale energy generation to partly satisfy the energy gap and future needs. The annual energy utilisation from this reservoir is 15.89 TJ with a capacity factor (CF) of 0.60. The further applications are still being researched.

It is conceivable to envision the large-scale development of "Sauna baths," greenhouses, poultry farming, animal husbandry, and fresh water farming of fish, for an increase in the production of vegetables and mushrooms under controlled circumstances through a number of crops. These initiatives would not only save a sizable amount of fossil resources but also strengthen the nation's economy.

The installation of a 300 kWe binary cycle power plant is a collaborative project between ONGC-GSI-MPUVN (Madhya Pradesh Urja Vikas Nigam), based on the total thermal water discharge of 1600 L/min (100 °C) from five wells drilled at Tattapani. It is crucial to use the hot fluids for non-electrical applications due to the area's remoteness. Thermal waters can be utilised for food preparation and cold storage. Additionally, it can be used for spa development, boiling cocoons to extract silk thread, and tourism development.

The energy was anticipated to be produced from the source of power of 38 to 76 MW utilizing the suitable technology, taking into account the combined source of heat generation inside the Bakreswar reservoir system. The development of a geothermal power plant with a Kalina cycle that can generate between 9.88 and 40.26 MW of electricity in the research region may be made possible by the use of power technology for power generation. The amount would probably rise, when the He emanations from additional hot springs and Bakreswar's enormous surface area (soil gas) were factored into this assessment. Additionally, it is suggested to set up a pilot plant to recover helium from this area's thermal materialisation.

Sohna thermal spring is of Na(Ca)–HCO_3(Cl) type. It is endowed with electrical conductivity of 1,500 μS/cm, pH of 7.1, and discharge thermal water at 42 °C. It is at the intersection of alluvion with the Alwar quartzite and all the elements present here have low concentrations.

Additionally, the hot springs are well-known for their therapeutic benefits, which can treat a variety of skin ailments.

Geothermal energy, therefore, obviously replaces the use of other forms of energy, particularly fossil fuels. Benefits include reduced reliance on imported fuels for India and many other nations, as well as global pollution reduction from greenhouse gases and particulate matter.

4. Results and discussion

The demand of energy is increasing worldwide. In order to meet the future energy demand, for sustainable development, it become essential to explore the all possible sources of energy with the consideration of minimizing CO_2 and pollutants emission. Thus we have to explore possible existing renewable source of energy [43]. India is a country having rich geothermal potential. There are about 400 known geothermal areas, each represented by hot springs. The wide temperature range (34 ^oC –96 ^oC) in low and medium enthalpy region make them suitable for various applications including the generation of electric power. The estimated potential for generation of electric power is 10600MW. The observed reservoir temperature in high enthalpy region, need deep exploration of these regions in order to precisely know the potential ingredients of the resources. The enrichments of these resources by Helium, Borax, Sulphur, Cesium, etc. make geothermal more exciting to explore and use for the benefit of society.

India has made considerable progress in utilization of geothermal resources. The geothermal fluids from the shallow wells at Puga have been effectively applied to the refining of borax and sulphur as well as experimental space heating. Also work is being done to extract Cesium from Puga geothermal fluid. A binary cycle power plant capable of producing 1.7 MW of electricity can be supported by the shallow geothermal reservoir supplying the current boreholes. At Manikaran, an NH4-absoption system-based cold storage facility with a 7.5-ton capacity was erected. Also put to the test was a binary cycle (ISO-Butane) powered 5 KW pilot power plant. Geothermal energy was successfully used at Chhumathang for space heating and greenhouse harvesting. With an annual energy consumption from Tapoban reservoir of 15.89 TJ and a capacity factor (CF) of 0.60, it can be used to produce energy on a small to moderate scale to help close the energy gap and fulfil future demands. For hot water baths, Ganeshpuri hot springs (west coast province) and Barren Island are currently, the well-liked tourist destination and already drawing a sizable number of tourists and strengthening the nation's economy. The development of a geothermal power plant with a Kalina cycle that can generate between 9.88 and 40.26 MW of electricity in the research region may be made possible at Bakreswar reservoir system. The hot springs at Sohna are well known for their therapeutic benefits, which can treat a variety of skin ailments.

Thus as far as, the geothermal resources are concerned, India is well placed. Also it is certain that, the sustainable development requires renewable energy. So need of the time is to put sustained efforts for utilization of geothermal energy for generation of electric power. There exit some technical as well as financial constraints, need to be addressed.

5. Conclusion

Most of the exploited resources are hydrothermal in nature and state of art of their exploration and utilization has been established and developing fast. Based on the work carried out so for, it can be seen that geothermal energy has the potential to provide long-term and secure source of energy. An area of great potential exists in agriculture, aquaculture and food processing. The concrete findings are as follow:

(i). The geothermal fluids from the shallow wells at Puga have been effectively applied to the refining of borax and sulphur as well as experimental space heating. The amount of cesium in Puga fluid (10 mg/l) is the highest in the entire world. With the help of the resin created by BARC, Mumbai, efforts were made to separate this valuable metal from geothermal fluid. On a small scale, this field has the ability to generate either binary cycle power or primary cycle power. Reservoir modelling studies, however, have indicated the potential for producing more than 3 MW of electrical power if deeper depths, at least up to 500 m are examined. The power output capacity of this region is estimated to be 250 MW.

(ii). An NH_4-absoption system-based cold storage facility with a 7.5-ton capacity was erected at Manikaran geothermal field. Also put to the test was a binary cycle (ISO-Butane) powered 5 KW pilot power plant. In Ladakh, there is a 53 MW total demand for power. In industries like food processing and greenhouse agriculture, the geothermal version reduces operating costs by 8% and fuel costs by 80% when compared to conventional energy [19].

(iii). The annual energy utilisation from Tapoban reservoir is 15.89 TJ with a capacity factor (CF) of 0.60. It can be used to produce energy on a small to moderate scale to help close the energy gap and fulfil future demands.

(iv). The Bakreswar reservoir system has the capacity to produce 38 to 76 MW taking into account the combined source of heat generation. Also this province is rich in Helium, whose demand is on increasing trend due to wide applications. It is suggested to set up a pilot plant to recover helium from this area's thermal materialization.

(v). Geothermal energy was successfully used at Chhumathang for space heating and greenhouse harvesting.

(vi). The Geological Survey of India has bored five production wells, each of 6 inches' diameter, in order to commission a 3.17 MW pilot power plant with a lifespan of approximately 20 years at Tattapani.

(vii). At Manuguru geothermal area of the Godavari valley can generate 38MW of power using the Organic Rankine Cycle.

(viii). Barren Island is currently a well-liked tourist destination due to warm seas.

(ix). The Hot Springs at Sohna are also known for their medicinal values which help to cure many skin ailments.

(x). The estimated high reservoir temperature in most of the geothermal province indicate potential reservoirs and need deep drilling investigations.

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