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Geothermal Appraisal of Bhimband, Eastern India

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ABSTRACT

Bhimband, a geothermal hotspot lies along the vast stretch of Munger- Saharsa Ridge fault zone bounded by the latitude 24.5:25.5N and longitude 85.0:86.75E of Eastern India. It has a geothermal potential of 60–65-degree Celsius with the highest surface manifestations temperature range with a cumulative flow rate of 1.2 to 5.5 l/sec. Our research focuses on the geochemical and geophysical surveys conducted in this region. The data obtained by conducting geochemical survey in the region suggests the presence of several elements and oxides in ppm. Bhimband is also distinguished by the presence of some trace elements like Cu, Zn, Pb and Ba in ppb. The pH of water in this region is 6.3 which suggests its slight acidic to neutral nature. The TDS is very low in the region. Based on this data some plots have been plotted in this research to elucidate the purpose of the suitability of the utilization of geothermal water. These plots include, Piper plot, Wilcox and Durov plots. The geophysical survey in this study includes the acquisition and interpretation of gravity, magnetic and electrical resistivity data which shows the variation of density, magnetic susceptibility and conductivity respectively. In this research, the contour maps of the gravity and magnetic surveys shows the presence of four-way closure and doubly plunging saddle like features are indicative of geothermal reservoir. The gravity data varies from 3.6 to 7.2 mgals and the magnetic data varies from 37.3 nT to 71.9 nT. The electrical resistivity survey in the study area has been conducted using a 1-D resistivity meter, Wenner survey method at a depth of 90 meter inferring the conductivity of the subsurface. By integrating all these surveys an integrated subsurface model can be prepared for a better understanding of the subsurface. Since, it can be observed that the area is a low- enthalpy geothermal zone, so, thermodynamic cycle like binary cycle can be incorporated by utilizing a suitable working fluid in this geothermal system to generate power which can further be transmitted to the grid. In this process mechanical energy is converted into electrical energy. The existing literature suggests that the water present in this region is of mixed type as it includes the mixing of meteoric water with the parent water. Hence, the study suggests that Bhimband has sufficient potential for geothermal energy exploration and exploitation.

1. INTRODUCTION

Coal, oil and natural gas-based energy sources have become a major threat to the environment due to high greenhouse gas emissions, mainly CO_2. These emissions lead to air pollution and climate change globally Das et al. (2016). In addition to that, price of fuel also directly affects the cost of energy generation from those fossil fuel-based power plants, which makes it economically volatile Das et al. (2016). On the other hand, renewable energy sources, including solar, wind cleaner sources, and geothermal energy, offer sustainable alternatives that are not impacted by fuel cost changes Moeck (2014). Geothermal energy, among them, is an eco-friendly and cost-effective resource that can be used for power generation space heating, bathing, fish farming, and others. Surface thermal springs are important markers of geothermal energy reservoirs that can be harnessed in these areas. Geothermal system is a geological setting in which the thermal energy of the Earth is extracted and carried to the application point by the naturally circulating or artificially induced fluids Sarkar and Basu (1982). The most important surface manifestations of geothermal energy are volcanoes, fumaroles, geysers, steaming grounds and hot springs. The key elements of a geothermal system are a heat source, circulating fluids, a fluid reservoir, and a fluid conduit. The productivity of such a system is determined by three main variables: the strength heat source and crustal heat flow, the permeability of faults and geological formations, and fluid flow patterns. Since regional plate tectonics largely controls these, a basic knowledge of tectonic activity is necessary to assess the geothermal potential of an area Dutta et al. (2023).

The Geological Survey of India identified Indian geothermal resources GSI (1991) based on surface temperatures to be grouped into medium-enthalpy geothermal provinces (75°C to 100°C) and low-enthalpy geothermal provinces (35°C to 75°C), respectively GSI (1987). Among these geothermal systems, the Rajgir–Munger metasedimentary springs (an example of a continental rift geothermal system) in the Indian state of Bihar was previously suggested as free from active volcanic activity with little tectonic activity GSI (1989). The region is characterized by faults related to the late-phase Himalayan orogeny Miocene to Pleistocene GSI (2016). The metasedimentary belt consists of isoclinally folded quartzites with phyllites interbedded between them, associated with formations of sub-metamorphic rocks from central India's Son and Narmada valleys Mazumdar (1988). The MSR fault zone contains the largest concentration of thermal springs and provides conduits for near-surface geothermal fluids to reach the surface through faulted and fractured rock formations Mazumdar (1988).

The Bhimband, the main geothermal hotspot at the eastern Indian Munger–Saharsa Ridge fault zone, is located between 24.5°N and 25.5°N, and between 85.0°E and 86.75°E Roy et al. (1987). This geothermal system has a surface temperature of 60°C to 65°C and a total discharge rate of 1.2 to 5.5 L/s Roy et al. (1987). Geological limitations cause the geothermal system at Bhimband to have slower discharge rates compared to the Tattapani geothermal system, where sedimentary insulation extends up to intrusive granites at depths of 2 km Neuendorf et al. (2005).

This study represents the first multi-disciplinary investigation of a major geothermal hotspot in Bhimband geo-thermal field. This study comprises (a) geochemical analyses of water sample at the hotspot, Dutta et al. (1982) (b) geophysical surveys using gravity, magnetic and electrical resistivity to characterize the subsurface structure, (c) all geophysical data plotted and interpreted, and (d) a strategic discussion and determined the feasibility of power generation using thermodynamics cycles to exploit geothermal energy. The research aims to provide better knowledge of the geothermal resources of the Bhimband area along with the possibility for sustainable energy production by utilizing these analytical methods.

2. METHODOLOGY

The methodology includes onsite data collection of temperature, pH, and TDS, followed by water sample collection from hotspot for geochemical analysis. Results of the geochemical analysis were interpreted and the geothermal resource was assessed with the help of potential analysis. Afterward, geophysical surveys like gravity, magnetic, and electrical resistivity surveys were conducted to gather greater insight into the subsurface characteristics. So that it can conduct a reservoir estimation by integrating interpretations of all those surveys. Such integrated subsurface model can be made by integration of the geophysical subsurface plots, aiding in a detailed assessment of the geothermal reservoir.

2.1 Geochemical survey

A geochemical survey of the Bhimband hot spring was carried in a systematic approach with due attention to each step, from sampling to analysis. The collected water samples were all taken in air-tight High-Density Polyethylene (HDPE) bottles, which are designed to prevent contamination and to maintain the integrity of the sample. Each bottle was cleaned before collection; each bottle was rinsed with acetone followed by distilled water and had been dried in a hot dry oven at 30 °C. This cleaning method reduces the risk of introducing an external contaminant that would alter the results Pandey (1975). The hotspot lying in Bhimband, Bihar is shown in Figure 1. The figure also depicts the various parameters temperature, pH and TDS which are being collected on-site.

Prior to the sampling, the bottles were pre-contaminated by rinsing them three times with hot spring thermal water at the sampling site. This is an important step, since it allows for equilibration between the bottle interior and the water being sampled, thus minimizing the potential for contamination. Water samples were acidified with ultra-pure concentrated nitric acid (HNO_3) post-sampling, preventing the alteration of trace metal concentrations during transportation to the laboratory for analysis Singh et al. (2015b).

2.1.1 Physicochemical Parameters Measurement

- On-site measurements of key physicochemical parameters were performed using specialized meters:
- Temperature: Measured in degrees Celsius.
- pH: Indicates the acidity or alkalinity of the water.
- Total Dissolved Solids (TDS): Reflects the concentration of dissolved substances in water.
- The results of these measurements are summarized in Table 1.

Figure 1. Analysis of temperature, pH and TDS from the Geothermal hot spring of Bhimband, Bihar.

Table 1 Physicochemical parameters of the sample collected from the hotspot.

Parameters	Result
pH	6.2 - 6.4
TDS	30 ppm
Temperature	62 - 65 °C
Total Hardness (mg/l)	64 - 70
$HCO3^-$ (mg/l)	30 - 40
Cl^- (mg/l)	10 - 13
$NO3^-$ (mg/l)	1 - 3
SO_4^{2-} (mg/l)	14 - 18
Ca^{2+} (mg/l)	10 - 20
Mg^{2+} (mg/l)	5 - 10
Na^+ (mg/l)	1
K^+ (mg/l)	<1

2.1.2 Interpretation of Results

The physicochemical data show that the Bhimband hot spring's water is slightly acidic, with a pH range from 6.2 to 6.4, which is common for geothermal waters influenced by volcanic activity. The TDS level of 30 ppm indicates relatively modest mineralization, implying that while some minerals exist, they are not extremely concentrated. The variation in temperatures ranging from 62°C to 65°C indicates the presence of thermal springs. The water is relatively hard due to the presence of calcium and magnesium ions, with total hardness values ranging from 64 to 70 mg/l over time.

The mean levels of bicarbonates (30-40 mg/l) and sulfates (14-18 mg/l) reflect that these ions are major elements in the chemical composition of ground water. The variation in elemental compositions is due to the dissolution of mineral present in the geological formation with the ground water. The Cl- (10-13 mg/l) and NO3 (1-3 mg/l) concentrations are relatively low, indicating the anthropogenic influence or pollution to this natural setting.

2.1.3 Potential Analyses

Having established these physicochemical parameters, there are a variety of different graphical plots that can be made to show the relationships between these variables. Additionally, plots like Wilcox plots can determine the classification of water based on its ionic constitution and ternary plots can represent the proportion of major ions in the water samples. These analyses play a crucial role in comprehending hydrochemical processes and assessing possible applications of the hot spring's water as a therapeutic, or any other indirect or direct applications of geothermal water.

Overall, this comprehensive methodology serves as a valuable foundation for subsequent geochemical analysis and interpretation of thermal waters in the Bhimband region, yielding crucial data for academic and practical applications alike.

2.2 Geophysical Surveys in the Bhimband Area

The geophysical surveys were conducted in the Bhimband area to determine its potential for power generation by harnessing the geothermal energy and the feasibility of power generation. The techniques employed includes the gravity, magnetic and electrical resistivity surveys. In practice, resource estimation is done based on the result from these surveys and further Monte Carlo simulation is done for the probabilistic assessments about resource availability calculation.

2.2.1 Gravity Survey

The gravity survey is conducted at different latitude and longitude by using an instrument called as Gravimeter. We used the scintrex CG 5, autograv gravimeter for our data collection. Using the gravity (mGals), the density of subsurface is calculated. The variation in gravity is between 3.7 and 7.1 milligals as shown in Table 2. This survey helps in elucidating the geological attributes of the subsurface which is essential for evaluating the geothermal potential.

Table 2 Variation in Gravity (mGals) at different points in the hotspot region.

Latitude	Longitude	Gravity
25.0642	86.39706	3.738391
25.06421	86.39706	3.834083
25.06426	86.39697	4.584104
25.06408	86.39704	4.717438
25.0641	86.39694	4.732957
25.06409	86.39706	4.954786
25.06421	86.39699	4.985886
25.06433	86.39694	5.017165
25.06416	86.39702	5.052015
25.06431	86.39699	5.054985
25.06421	86.39696	5.055218
25.06425	86.39702	5.055557
25.06428	86.39694	5.055833
25.06417	86.39697	5.055984
25.0646	86.3967	5.253857
25.06455	86.39664	6.766633
25.06452	86.39661	6.840842
25.06443	86.39676	6.870676
25.0644	86.39684	6.959599
25.06439	86.39689	7.109371
25.06437	86.39702	7.194207

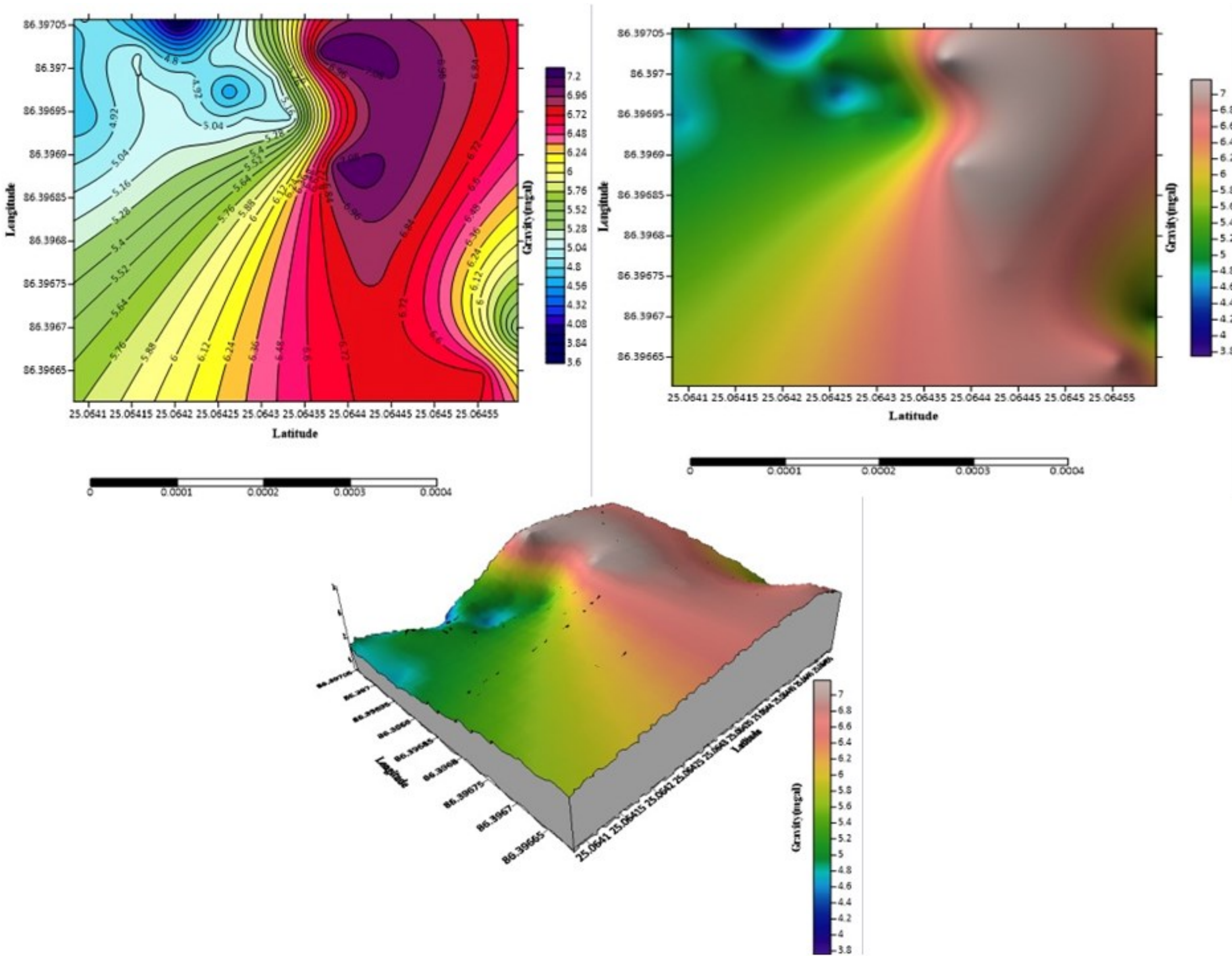

Figure 2. Interpretation of gravity data. a.) Gravity contour map b.) Gravity colour relief map c.) Gravity 3 D surface map.

Interpretation of Gravity Data

The different values of gravity are interpreted by the gravity contour map, colour relief map and the 3 D surface map as shown in Figures 2 a, b and c respectively. The change from structural lows to structural highs toward the southeast reflects changes in subsurface density. Indicating different types of geological formations, which could hold hints of geothermal resources. Higher values of gravity may be associated with denser rocks or thermal energy reservoirs, while lower values may represent less dense materials or voids.

Two small antiforms that appear nested within larger ones suggest the geology folded complexly in the region. The results show that these antiforms can have a strong influence on the flow of fluids and the dispersion of heat, both of which are crucial to the production of geothermal energy. These large fault or fracture systems can resist geothermal fluid flow and act as traps, therefore increasing the potential for geothermal fluid accumulation.

These gravity closure data set represents significant constancy, indicating some structural complexity, while the absence of the four-way closure data set indicates the significant lack of determination of subsurface structure. Three-way closure can be observed in the contour maps. This may also mean that while promising features indicative of geothermal potential exist, additional data collection and analysis is needed to determine the extent and configuration of these structures.

<u>2.2.2 Magnetic Survey</u>

The Magnetic Survey is carried out at each point of different latitude and longitude coordinates using Magnetometer (Proton- Precision) in nano Tesla. The magnetic data corresponds to the measure of magnetic susceptibility of the subsurface as a result of the interpretation of the data acquired. The different magnetic values are shown in the Table 3. The results of magnetic data from the Bhimband area (3.7–7.1 nano Tesla) corroborates with the gravity data obtained from the same region and indicate an overall systematic plan which is contributing towards better understanding of the geological features associated with the geothermal hotspot.

Table 3 Variation in Magnetic (nT) values at different points in the hotspot region.

Latitude	Longitude	Magnetic(nT)
25.0642	86.39706	37.38391
25.06421	86.39706	38.34083
25.06426	86.39697	45.84104
25.06408	86.39704	47.17438
25.0641	86.39694	47.32957
25.06409	86.39706	49.54786
25.06421	86.39699	49.85886
25.06433	86.39694	50.17165
25.06416	86.39702	50.52015
25.06431	86.39699	50.54985
25.06421	86.39696	50.55218
25.06425	86.39702	50.55557
25.06428	86.39694	50.55833
25.06417	86.39697	50.55984
25.0646	86.3967	52.53857
25.06455	86.39664	67.66633
25.06452	86.39661	68.40842
25.06443	86.39676	68.70676
25.0644	86.39684	69.59599
25.06439	86.39689	71.09371
25.06437	86.39702	71.94207

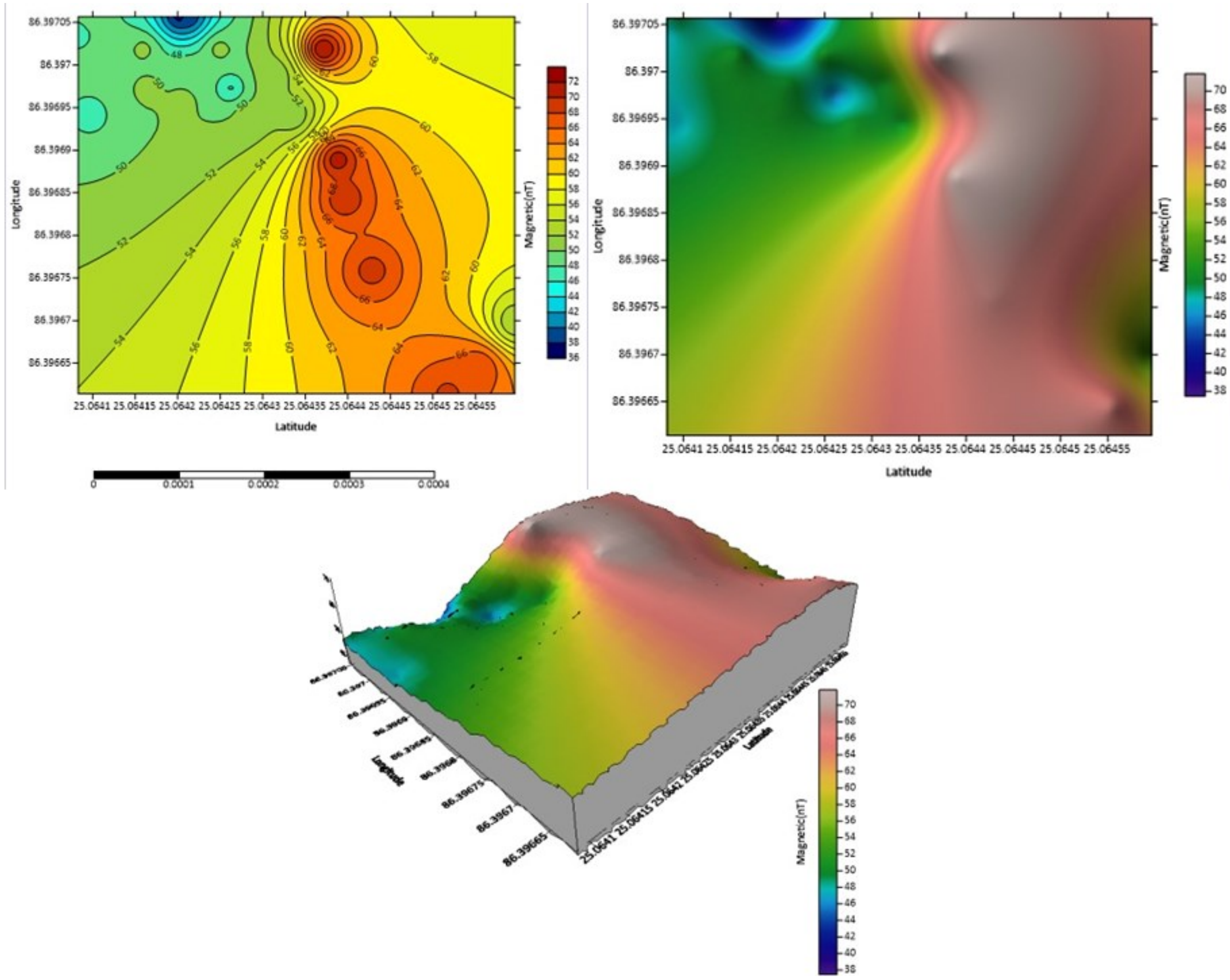

Figure 3. Interpretation of magnetic data. a.) Magnetic contour map using inverse distance to power method b.) Magnetic colour relief map c.) Magnetic 3 D surface map.

Interpretation of Magnetic Data

The magnetic data is interpreted by the contour map (plotted using inverse distance to power), colour relief map and 3 D surface map as shown in Figure 3 a, b, and c respectively.

Geological Significance: The co-occurrence of magnetic anomalies with structural highs and lows could suggest the presence of igneous intrusions or fault systems essential for geothermal resource accumulation. These features enable the pathways for fluid movement and increase the possibility of extracting geothermal energy.

Correlation Between Magnetic and Gravity Data: The correlation between the magnetic and gravity data indicates that the two datasets display similar subsurface features. Differences in magnetic signature could be explained by variations in the composition of the rock or the distribution of magnetic minerals that are also found in the regional geology with a similarly unique signature seen in the gravity data.

2.2.3 Electrical Resistivity Survey

The electrical survey was conducted using a 1 D resistivity meter. The interpretation of the acquired data as shown in Figure 4 gives the apparent resistivity of the subsurface in ohm- meter. The inverse model of resistivity section is interpreted using the measured and calculated apparent resistivity. The apparent resistivity of the subsurface helps us to know the conductivity of the zone. The apparent resistivity values obtained from the electrical resistivity survey in the Bhimband area range from 17.2 ohm-meter to 329 ohm-meter. This variation provides critical insights into the subsurface geological characteristics and potential geothermal resources.

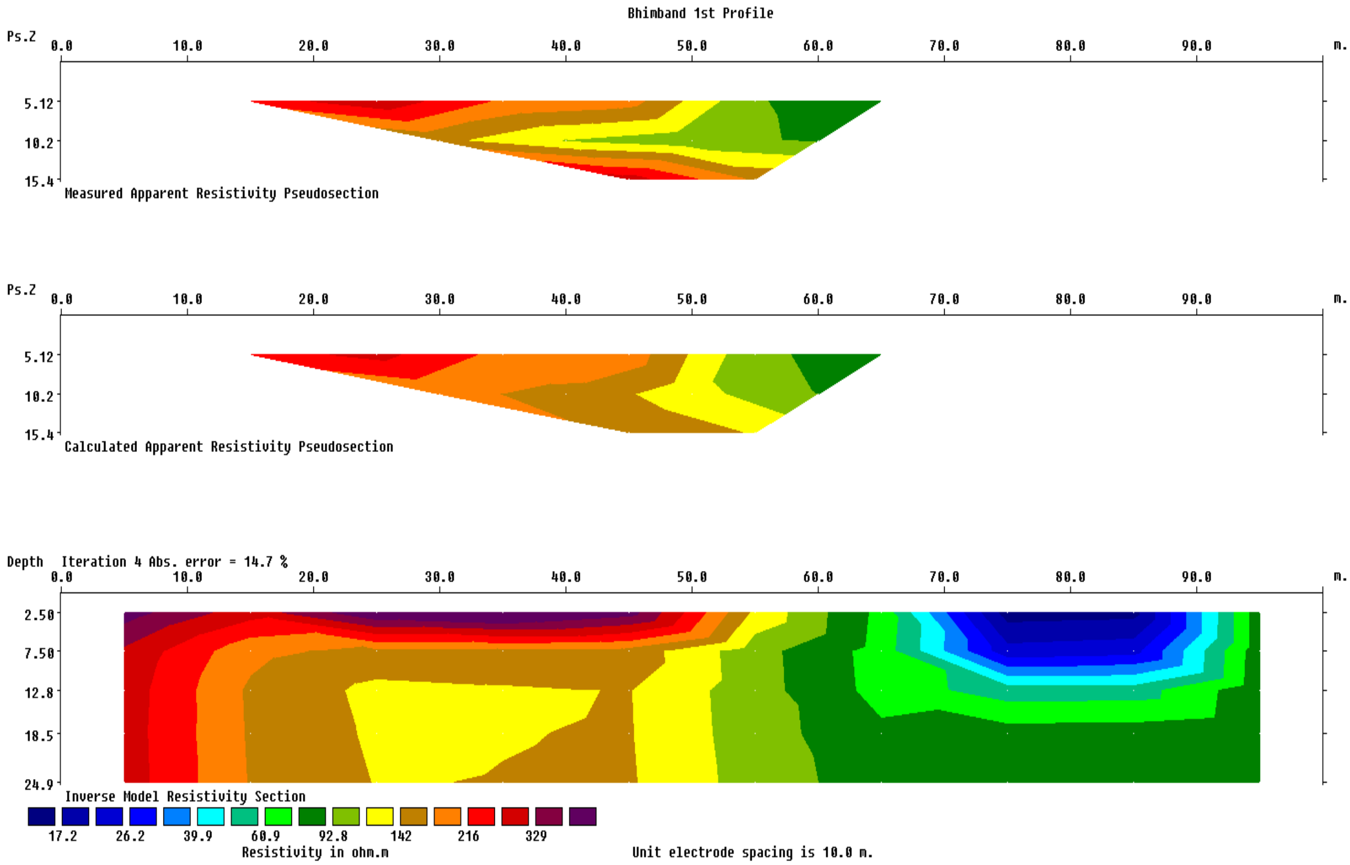

Figure 4. Interpretation of Electrical Resistivity data.

Interpretation of Electrical Resistivity Data

Low Resistivity Values (17.2 ohm-meter): The lower end of the resistivity range suggests resistive materials that could be water-saturated zones, clay-rich sediments, or mineralized areas. These conditions are typically associated with geothermal reservoirs where dissolved ions can increase the conductivity of thermal fluids.

High Resistivity values (329 ohm-meter): High resistivity values indicate less conductive materials like dry rocks or volcanic formations. This may represent places of lower fluid saturation or more crystalline rock types that would tend to be at greater depths or at sites less significantly affected by geothermal heat.

This compares well with similar investigations in geothermal areas and the variations in resistivity highlights the geothermal systems with high efficiency, as also seen in results from other geothermal hotspots. These methods correlate with the results found in Bhimband and indicates that focused exploration guided by resistivity measurements is the key to providing relevant information on the geothermal prospect of the region.

3. DISCUSSION AND WAY FORWARD

The results of chemical analysis of Bhimband hot spring water show that it is slightly acidic with pH in the range of 6.2−6.4. The TDS of 30 ppm indicates mild mineralization, where calcium and magnesium cations constitute the hardness of the water (64–70 mg/L); major anionic components were bicarbonates (30–40 mg/L) and sulfates (14–18 mg/L); and chloride (10–13 mg/L) and nitrate (1–3 mg/L) were low, which indicate minimal anthropogenic influence. The observed 62°C–65°C temperature variations indicate an active low to medium enthalpy Chandrasekharam and Bundschuh (2008) geothermal system in the region.

Geophysical surveys, such as gravity, magnetic, and electrical resistivity studies, help to characterize the subsurface geological structures of the Bhimband geothermal system. Differences in these measurements suggest possible geothermal reservoirs underground. low resistivity zones may represent fluid reservoirs for geothermal energy extraction. Conversely, high-resistivity zones could represent impermeable features or suggest areas that might necessitate deeper wells to reach resources. Geothermal potential of the study area is also enhanced by structural complexities like antiforms and fault closures.

Monte Carlo simulations can be run for resource estimation, offering a more precise understanding of geothermal reservoir potential. This targeted approach helps to strategically choose the sites for power plants by aiding in optimal siting of wells and predicting long-term sustainability. It indicates that through the study area, suitable plants can be established to explore and exploit this power of renewable energy. The resource estimation will also help to estimate the feasibility of the ORC- based power plant by determining the CAPEX and OPEX of the exploitation of geothermal energy.

A parametric well can be drilled in Bhimband to utilize the geothermal resource. After the well is drilled, one production well and one injection well can be installed in the reservoir for the extraction and reinjection of the geothermal water as indicated in Figure 5 Singh (2020). The extracted geothermal water will be be used to run a closed-loop binary thermodynamic cycle. An organic rankine cycle (ORC) can be used with a suitable working fluid for power generation. And the electricity harvested could be plugged in to a micro-grid, distributed nearby to secure energy supply and sustainability in the rural area.

Considering all above, the geochemical and geophysical reports indicate the geothermal potentiality of Bhimdand region. Geothermal power generation feasibility is supported by employing advances in resource estimation techniques and thermodynamic cycle modeling. This renewable resource has the potential for future research and pilot projects to optimize drilling strategies and convert energy into efficiencies for optimal benefit.

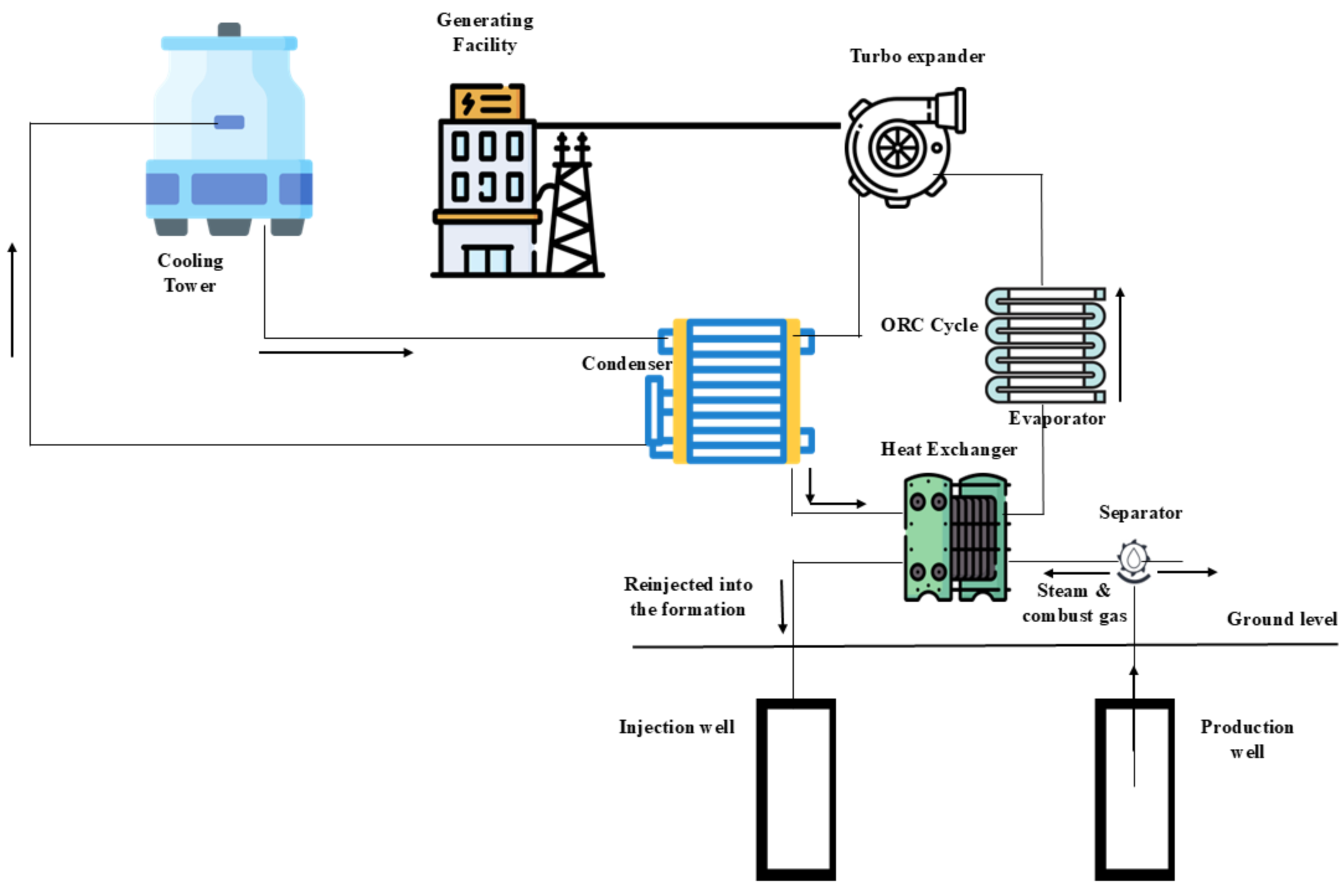

Figure 5. A conceptual model for hypothetical power plant set up in Bhimband, Bihar Singh (2020).

4. CONCLUSION

Geothermal energy is a renewable and sustainable energy option with the capacity for power generation on a large scale. Geothermal potential of Bhimband, a hot spring in Bihar, eastern part of India is a low- to medium-enthalpy zone, with surface temperature variation from 62 °C to 65 °C. Geochemical and geophysical investigation was conducted as a part of feasibility of geothermal energy utilization. Geochemical analyses suggest the groundwater interaction with formation minerals by dissolution, contributing to the chemical signature of geothermal springs.

Geophysical surveys including the geophysical surveys (gravity, magnetic, and electrical resistivity) are used to identify the density, magnetic susceptibility, and conductivity of the subsurface material. This will help derive potential geothermal reservoirs through integration of the acquired data into an integrated subsurface model. Also, Monte Carlo simulations can be used for resorce estimation, which facilitates a probabilistic risk assessment of resources. This method allows to predict CAPEX (capital expenditure) and OPEX (operational expenditure), which are critical for determining whether a geothermal power plant is economically viable.

A conceptual power production model based on an organic Rankine cycle (ORC) has been created to efficiently convert geothermal heat into electricity. The generated power can be fed into a microgrid, ensuring efficient distribution and consumption. This study's findings indicate geothermal energy's potential as a sustainable power source in the region. Future research should focus on optimizing drilling procedures, increasing energy conversion efficiency, and undertaking extensive economic evaluations to improve the feasibility of large-scale geothermal power deployment.

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