Prospective Geothermal Resources in the Deccan traps terrains: Case study from Unai, Tulsishyam and Savarkundla, Gujarat

Introduction

Geothermal energy is a form of renewable energy that is environment-friendly and reliable for electric power generation. As per the Geological Survey of India's estimation, India can generate 10 GW of power from existing geothermal resources. However, the energy resource remains in the nascent stage of development with only 7.1% share in the total renewable energy supply due to limited knowledge, technology readiness, and policy framework constraints. To achieve its objectives of energy independence and net-zero carbon emission, India needs to look towards harvesting geothermal energy resources through extensive geophysical exploration and exploitation in the prospective locations.

Gujarat is an Indian state located on the western coast of the country. Multiple exploration activities previously carried out in the state suggest positive indications of geothermal systems at the top of Deccan trap terrains. With the formation at the end of the Cretaceous period 65 million years ago, The Deccan trap is one of the greatest volcanic features on Earth's surface and spans more than 500,000 km2 in the Indian sub-continent. The geology of Saurashtra and the southern regions of Gujarat exhibit numerous such horizontal volcanic features with varying thicknesses. In the traps, confined to semi-confined conditions exist in intertrappeans and vesicular basalt units between two successive layers of compact basalts, under unconfined conditions in weathered/fractured mantle at a shallower depth, and under unconfined conditions in joints and fault/fracture zones within massive basalt units. Groundwater can migrate vertically under in-situ hydraulic pressure through faults, fracture zones, and joints connected to the constrained deeper aquifer, manifesting itself as springs on the surface (Kumar et al., 2011).

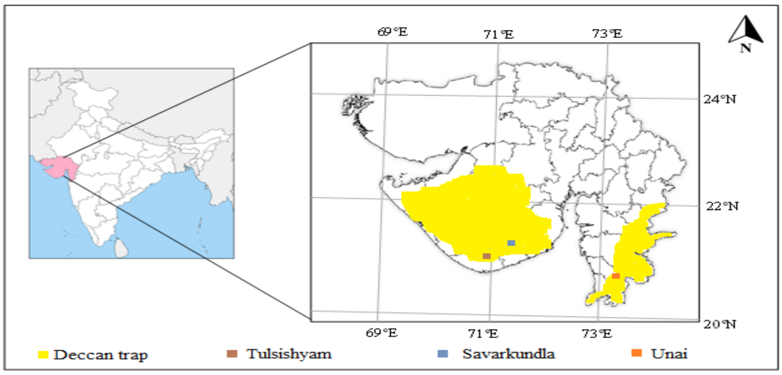

Figure 1 *location of Tulsishyam, Savarkudla, Unai and Deccan traps in the map of Gujarat, India*

The present study pertains to three such geothermal hotspots in the state of Gujarat (Figure 1) that are located at the Deccan trap dominated subsurface geology. These areas include Unai a village in the hilly terrains of southern Gujarat, Tulsishyam, and Savarkundla in the Saurashtra region of the state. The average temperature of hot spring in Unai goes up to 70 ℃ and nearly 40 ℃ at Tulsishyam and Savarkundla. An extensive geophysical exploration carried out including 2D- 3D Magneto-telluric, Gravity, and Magnetic survey were conducted to delineate the shallow and deep conductivity in the subsurface of Unai. The outcomes suggest a large geothermal aquifer system with a heat source, heat flow path, and a trapping system (Sircar et al., 2017). Later on, a parametric well was drilled at the prospective locations which produce water with a temperature above 60 ℃ and a 4 lit/sec flow rate. An extensive Gravity and Magnetic survey carried out at Tulsishyam and Savarkundla shows a peaked gravity (mGal) and magnetic susceptibility (nT) anomaly as shown in Figure 2 (a), (b), (c), and (d). The investigated contrast in gravity and magnetic field intensity values at the surveyed areas implies a high possibility of them being a geothermal water aquifer with an active heat source. For the calculation of heat in the subsurface of the hot springs stochastic thermal heat calculation method is applied. This method refers to the estimation of heat stored in the rock and the fluid which can be extracted by using factors like reservoir temperature, base reservoir temperature, and specified reservoir volume. All outcomes for aquifer volume, porosity, water saturation, etc. are derived using the Monte Carlo method using a cumulative distribution function for the total heat in place. The study attempts to assess the geothermal hotspots with a probabilistic approach that differentiates the total thermal energy stored in the form of minimum (P90), High likely (P50), and Maximum (P10) as mentioned in PRMS (Petroleum Resource Management System) guidelines. These prospective geothermal hotspots can be a tremendous source of power generation from the heat of the earth which will be environmentally sustainable and economic.

Method

Gravity Survey

A direct geophysical investigation tool called gravity includes estimating the acceleration brought on by the Earth's gravitational pull. In the underlying rocks, lateral density changes are what create gravity fluctuations. The tools used in gravity surveys to determine changes in gravity are called gravimeters. The unit of gravity measurement is mGal, where 1 Gal equals 1cm/s2. The gravity fluctuations brought on the sediments and basement are shown by the Bouguer gravity measurements gathered across a certain grid. The survey looks for abnormalities in density that stand out from the surrounding population. After making the necessary modifications, the Bouguer gravity is split into regional and residual components. Residual gravity can be used to explain geophysical anomalies and short wavelength features.

In gravity surveys, gravimeters are used to measure both absolute and relative gravity at certain station locations. The two types of gravimeters are absolute and relative gravimeters. The direction of the falling mass is measured by the absolute gravimeter, which employs a laser beam to calculate the precise value of gravity. The second type of gravimeter measures the comparative gravity (mGal) fluctuations between two station sites, while the absolute type gravimeter achieves a precession of 0.001 mGal. This mechanism uses a mass at the end of the spring that extends towards the higher G region. This type of gravimeter determines gravity with a 0.01mGal precision in around 5-7 minutes.

In order to identify possible geothermal discovery sites, this technique is usually utilised to find dense or less dense subsurface abnormalities. The boundaries of subsurface fault lines can also be found by using the gravity concept. These faults are perfect drilling locations since their density is substantially lower than that of the nearby features. Groundwater level fluctuations can be estimated and identified using gravity surveys.

Magnetic Survey

Finding and describing areas of the Earth's crust and core with abnormal magnetizations is the magnetic survey's main goal. Because of their high sensitivity to the susceptibility of subsurface geology, magnetic methods of exploration are perfect for investigating the intricate basement. Although volcanic formations beneath the sediments respond primarily, the susceptibility of sedimentary rocks is relatively modest. Together with the voids, near-surface fault, igneous dykes, and other underground ferromagnetic materials, this non-harmful technique is utilised for engineering as well as environmental investigations. Together with structural and stratigraphic features, magnetic surveys can be used to map geological boundaries that exhibit magnetic contrast. The two main types of rock magnetization are induced magnetization (abbreviated "Mi"), where the formation follows the direction of the ambient earth's magnetic field, and permanent magnetization (abbreviated "Mp"), which primarily occurs in igneous rocks and is dependent on those rocks' properties and formation histories. The unit of measurement for magnetic field strength is the nano Tesla (nT), where 1 nT equals 1 kg/AS2. The shift in magnetization results in a local or regional disruption in the magnetic anomaly. The anomalous body's position, qualities, shape, and formation history all affect how the exploration field is magnetised.

Magnetotelluric Survey

The magnetotelluric survey is a passive electromagnetic technique that detects differences in electrical conductivity across subterranean strata that are brought on by conductive substances such metals, minerals, molten rocks, graphite, aqueous fluids, and conductive minerals (Chaves and Jones, 2012; Munoz, 2014). It gauges the erratic changes in the Earth's surface's inherent magnetic and electrical fields in an orthogonal direction (Chaves and Jones, 2012). The time variation is monitored along the induced electric field as well as the magnetic field in the magnetotelluric survey.

The study examines how the induced magnetic and electric fields change over time. MT data is often captured at frequencies between 10 kHz to 0.001 kHz, or even as low as 0.0001 Hz (Vozoff, 1991). The results of the magnetotelluric survey reveal resistivity anomalies that are connected to the presence of cap rock, faults, geothermal structure, and knowledge of the thermal gradient at various depths (Everett and Hyndman, 1967). Geological materials typically have low conductivity and poor electrical conductivity.

Examples

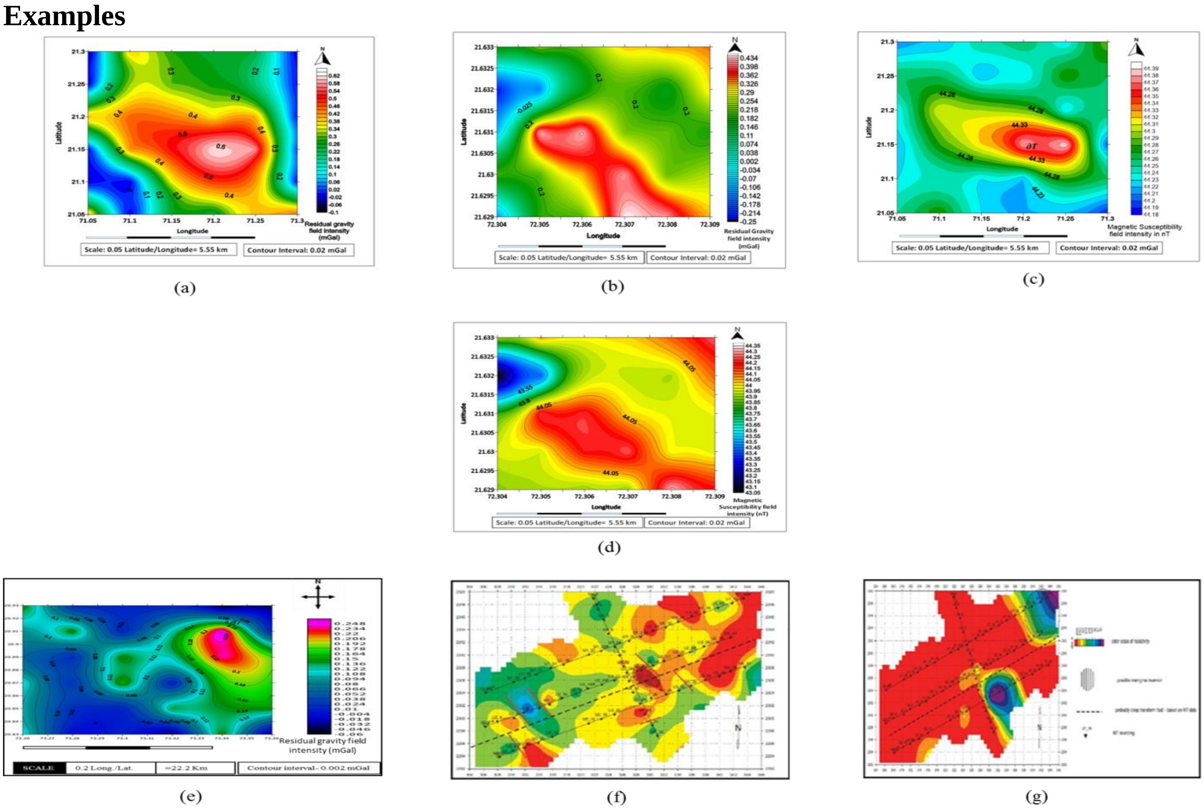

Figure 2 *(a) Residual gravity field intensity(mGal) map of Tulsishyam (b) Residual gravity field intensity(mGal) map of Savarkundla (c) Magnetic Susceptibility field intensity(nT) map of Tulsishyam (d) Magnetic Susceptibility field intensity(nT) map of Savarkundla (e) Residual gravity field*

intensity(mGal) map of Unai (Sircar et al., 2017) (f) resistivity distribution at the depth of 3.5 km bsl (g) resistivity distribution at the depth of 15 km bsl (Sircar et al., 2017)

Conclusion

After the end of the reconnaissance survey, a regional and residual gravity separation was done graphically and for each three locations a contour map showing residual gravity field intensity in mGal was prepared as shown in Figure 2 (a), (b) and (e). Residual gravity curve shows variation in anomalies ranging from 0.003- 0.0201 (mGal). The curve suggests the presence of gravity high which is also geologically supported by magnetic susceptibility anomaly map shown in Figure 2 (c) and (d). This high gravity four way closure can be a possible geothermal zone which is existing in the central part of the map.

Resistivity distribution map at the depth of 3.5 km bsl for Unai is shown in Figure 2(f). The demarcated zone with black boundary shows most likely location of hot spots with low resistive and high conductive values. There is also presence of transform faults at some places which leads the flow of hot water to the surface. There are low-resistivity anomalies at depth 15 km below sea level as shown in Figure 2(g). This may be associated with magma which is heating of rocks lying above this reservoir. So they are the possible location of the hot spots on surface.

A volumetric method was utilized for estimation and assessment of these resources. The simulation of the calculation procedure was done by the stochastic method of Monte-Carlo simulation. According to a triangular distribution, it was determined that hotspot at Tulsishyam contains 5.157E+16 J, 7.896E+16 J, and 11.427E+16 J as the minimum (P90), highly probable (P50), and maximum (P10) energy in joules. For the similar type of distributions the values stood at 3.630E+11 J (P90), 8.824E+11 J (P50) and 1.260E+12 J (P10) for the hotspot at Savarkundla. Unai a place located in the southern part of Gujarat holds 3.0088E+16 J (P90), 4.50773E+16 J (P50) and 5.50016E+16 J (P10) of energy in the form of heat. The numbers shows that the state of Gujarat has got tremendous potential to generate power from its geothermal resources. It can be said that Unai and Tulsishyam look more promising in comparison of Savarkundla for the purpose power generation due to more storage of heat in the hotspots. The heat produced from these resources can be utilized in multiple direct and indirect socio-economic applications.

References

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