# Part II

## Geothermal Resources and Applications in India

Chapter 2

# Where Is the Heat? Exploring India's Subsurface Geology

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***More than one-quarter of India's extraordinary and diverse topography could be used for either geothermal power or direct-use heat. This chapter pinpoints the regions across the nation with the most promising geothermal resources, including the high-potential Himalayan fields, western rift systems, and eastern-central fault-controlled basins.***

India's diverse terrain is well suited to geothermal energy development, but the resource remains largely untapped. India has more than 11,000 gigawatts of direct-use industrial heat potential (with a 100°C cutoff temperature down to 3,500 metres) and more than 1,500 gigawatts of geothermal cooling potential. It also has technical potential for roughly 450 gigawatts of electricity generation (down to 5 kilometres) today and more than 8,000 gigawatts of electricity (down to 7 kilometres) as technology improves.[1]

Despite this potential, efforts to develop large-scale geothermal projects have faltered due to high costs of exploratory drilling and detailed geophysical investigations. To address these issues, we assessed India's geothermal resources using a weighted overlay analysis of geological data sets. This approach focuses time, effort, and expenditures on areas with the most potential, enabling more efficient planning and decision-making, while drilling and on-site investigations remain essential for confirming resource viability.[2,3] Our method integrates multiple geological, geophysical, and tectonic data sets—including data covering proximity to thermal springs, fault systems, seismicity, lithology, heat flow, Moho depth (the boundary between Earth's crust and its mantle), and shear wave velocities—to identify favourable zones for geothermal energy production. The analysis classifies geothermal potential by application type, identifying areas suitable for high-temperature power generation, potential power generation, direct use and direct heating, low-temperature industrial heating and cooling, and geothermal heating and cooling.

***Of these areas, northern, western, and northeastern India all demonstrate potential for geothermal electricity, with promising prospects in the states of Ladakh, Himachal Pradesh, Uttarakhand, Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Sikkim, Arunachal Pradesh, and Meghalaya. All of these regions exhibit favourable subsurface thermal regimes and geotectonic conditions that make them excellent candidates for geothermal exploitation.***

Strikingly, more than one-quarter of India's land area shows potential for geothermal electricity generation, direct use, and direct heating, with significant moderate-temperature resources, while a smaller proportion contains high-temperature geothermal resources suitable for power generation.

This analysis confirms that geothermal energy is a crucial pillar in India's future renewable energy mix and provides a scientifically grounded way to prioritise target areas. It also underscores just how much geothermal can accelerate India's development of a resilient, renewable, and non-polluting energy system, ultimately improving both national energy security and grid stability.

This chapter provides a comprehensive assessment of India's geothermal potential. A weighted overlay analysis integrating eight geological and geophysical parameters was used to generate information about application potential across India (**Figure 2.1**). The analysis and resulting categorisation were then cross-checked against real-world observations, including thermal springs, to confirm the model's validity. The resulting map shows geothermal potential by application type, identifying areas suitable for high-temperature power generation, potential power generation, direct use and direct heating, low-temperature industrial heating and cooling, and geothermal heating and cooling.

## GEOTHERMAL APPLICATION POTENTIAL ACROSS INDIA, CLASSIFIED BY APPLICATION TYPE

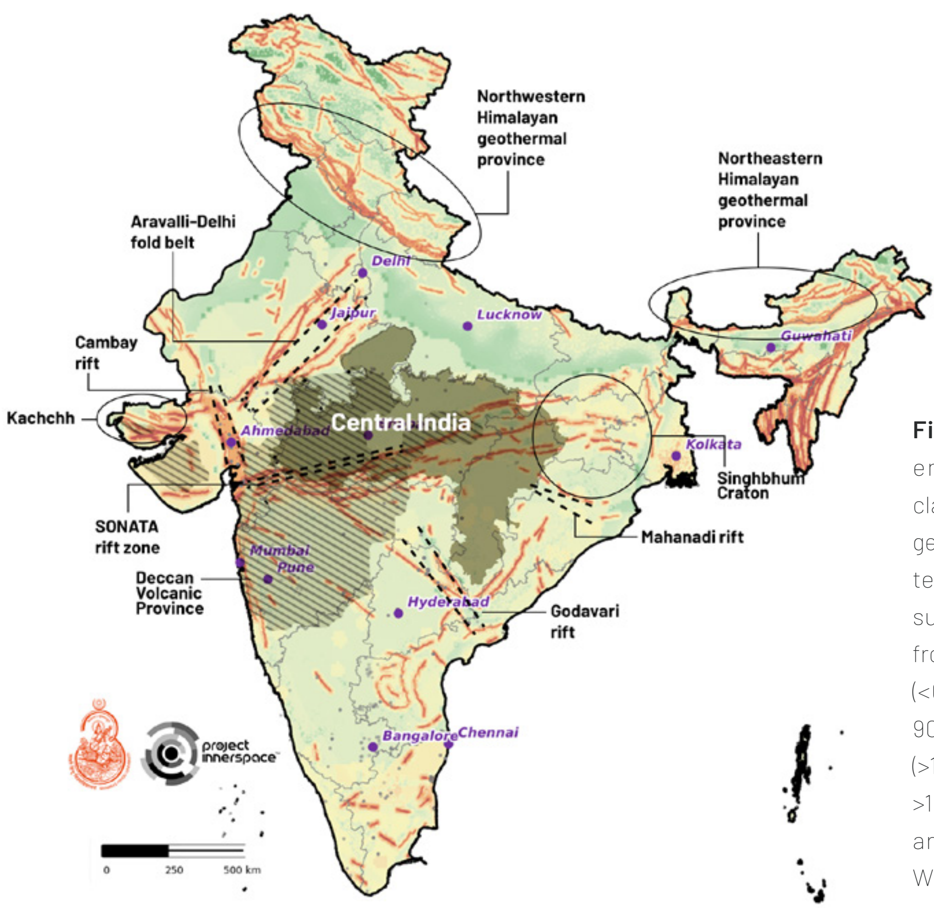



**Figure 2.1:** Summary of geothermal energy potential across India, classifying each land pixel by its optimal geothermal use type based on subsurface temperature, depth to resource, and surface constraints. Categories range from ground-source heat pump suitability (<60°C) through district heating (60–90°C) to electricity generation potential (>150°C). Exclusion zones include slopes >15° and IUCN Category Ia/Ib protected areas. Source: Project InnerSpace Weighted Overlay Analysis (WOA).

Regions with the highest potential for electricity generation include the Himalayan geothermal province (both the northwestern and northeastern segments), the Aravalli Delhi Fold Belt, the Kachchh and Cambay rifts, the SONATA rift zone, select zones of the Deccan Volcanic Province, the Singhbhum Craton, central India, and segments along the western coast, as well as the Mahanadi and Godavari rift systems (**Figure 2.1**). All of these areas display physical and thermal characteristics that make them excellent prospects for generating geothermal electricity.

## GEOLOGY OF INDIA

The Indian subcontinent has a long and complex geodynamical evolution spanning billions of years and characterised by the association of stable Archean cratonic blocks, Proterozoic mobile belts, intracratonic sedimentary basins, and extensive Phanerozoic volcanic provinces (**Figure 2.2**). Architecturally, these cratons are underlain by thick, refractory, and buoyant lithospheric keels that extend into the subcontinental mantle lithosphere, giving it significant thermomechanical stability. These lithospheric roots serve as tectonic anchors, rendering the cratonic interiors less susceptible to subsequent deformation.[4] During the Proterozoic era, the Indian continental crust experienced multiple inter-cratonic collisions, giving rise to prominent suture and mobile belts such as the Aravalli Delhi Fold Belt (ADFB), the Eastern Ghats Mobile Belt (EGMB), and the Satpura Mobile Belt (SMB; **Figure 2.2**).[5,6] These mobile belts are tectonic imprints of Proterozoic orogenesis and serve as fundamental structural discontinuities.

As a result of this complex geotectonic history, the Indian subcontinent has developed a substantial number of thermal springs—more than 300—that serve as surface manifestations of deeper hydrothermal geothermal systems (**Figure 2.3**). These thermal springs are largely concentrated along the Proterozoic mobile belts, rift zones, and major suture zones that define the lithospheric architecture of the Indian subcontinent (**Figure 2.2**). Similarly, geothermal provinces such as the Himalayan geothermal belt, the Sohana and Cambay grabens, the Godavari and Mahanadi rifts, the West Coast region, and the SONATA lineament zone are aligned along structurally weak zones and tectonic discontinuities, as expected (**Figure 2.2**).

Past initiatives by the Geological Survey of India (GSI) have helped characterise these zones through heat flow mapping, fluid geochemistry, and reservoir temperature estimations. Detailed geophysical and geochemical investigations have also revealed high geothermal gradients and subsurface thermal anomalies, particularly in regions such as Puga-Chumthang (Himalayas), Tatapani (Chhattisgarh), and Unai (Gujarat), indicating the presence of significant hydrothermal geothermal reservoirs.

Today, these hydrothermal geothermal systems embedded within ancient cratons, mobile belts, and active collision zones hold immense promise for sustainable energy development, and they should be a high priority for advanced structural, thermal, and geophysical modelling.

## GEOLOGY, GEODYNAMICS, AND TECTONICS OF INDIA

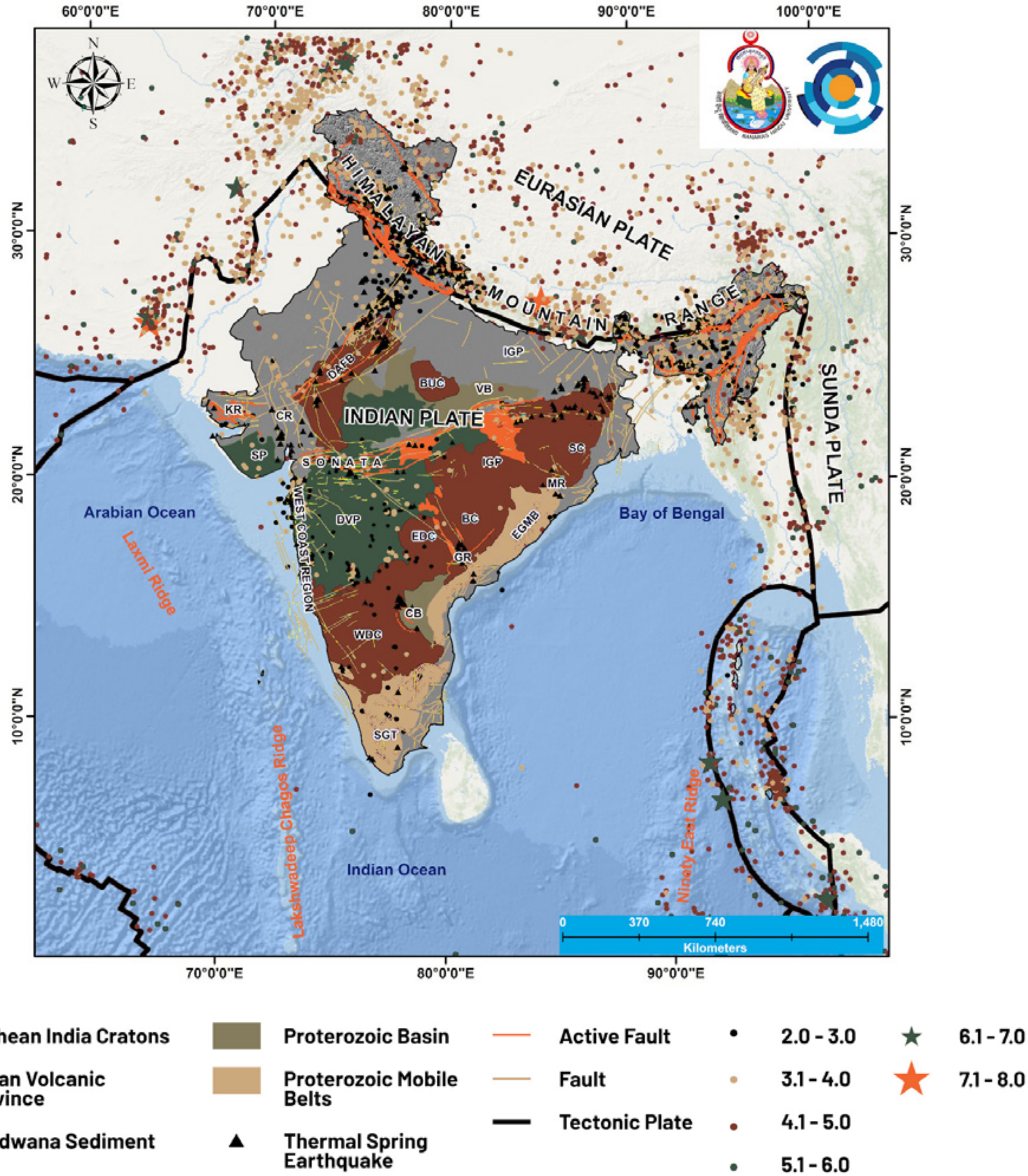



**Figure 2.2:** This figure shows the geological and tectonic framework of India, highlighting the Precambrian cratons, volcanic regions, the Proterozoic basins, and the nearby Cenozoic basins. Shallow earthquakes (at depths of less than 10 kilometres) in India and its neighbouring regions are shown. ADFB = Aravalli Delhi Fold Belt; BC = Bastar Craton; BUC = Bundelkhand Craton; CB = Cuddapah basin; CR = Cambay rift; CTB = Chhattisgarh Basin; DVP = Deccan Volcanic Province; EDC = Eastern Dharwar Craton; EGMB = Eastern Ghats Mobile Belt; GR = Godavari rift; IGP = Indo-Gangetic Plain; KR = Kachchh rift; MR = Mahanadi rift; SC = Singhbhum Craton; SGT = Southern Granulite Terrain; SHP = Shillong Plateau; SP = Saurashtra peninsula; VB = Vindhyan Basin; WDC = Western Dharwar Craton. Sources: Hasterok, D., Halpin, J. A., Hand, M., Collins, A. S., Kreemer, C., Gard, M. G., & Glorie, S. (2022). New maps of global geologic provinces and tectonic plates [Preprint]. *Earth Science Reviews*. EarthArXiv; National Center for Seismology. (2023). Data portal. Ministry of Earth Sciences, Government of India.

# AN OVERVIEW OF THE MAP LAYERS

This section provides details of each map layer's variation and suitability score classification.

## Proximity to Thermal Springs

Thermal springs represent the most direct and observable surface expression of underlying geothermal systems, as they reflect the accessibility of deep-seated heat to the surface through permeable geological structures. Productive geothermal systems are closely associated with these springs so long as the two are in close proximity. Empirical studies conducted in northern Japan indicate that approximately 97% of geothermal wells are located within a 4 kilometre radius of thermal springs.[7] Similar geothermal assessments across Iran and Africa have likewise found that areas within 5 kilometres of thermal springs have the highest geothermal potential. In this study, proximity to thermal springs was reclassified into six suitability classes, with locations within 2 kilometres receiving the highest score (5) to indicate that they were the most suitable for geothermal and those beyond 6 kilometres classified as the least suitable (score = 0; see also **Figures 2.3** and **A.3**).

## Proximity to Active Faults

Active faults play a critical role in geothermal systems by acting as high-permeability conduits for the migration of heat and hydrothermal fluids from deeper crustal levels to the surface.[8,9] Their presence significantly enhances a region's geothermal potential, particularly where recent

### GEOTHERMAL SUITABILITY BASED ON PROXIMITY TO THERMAL SPRINGS

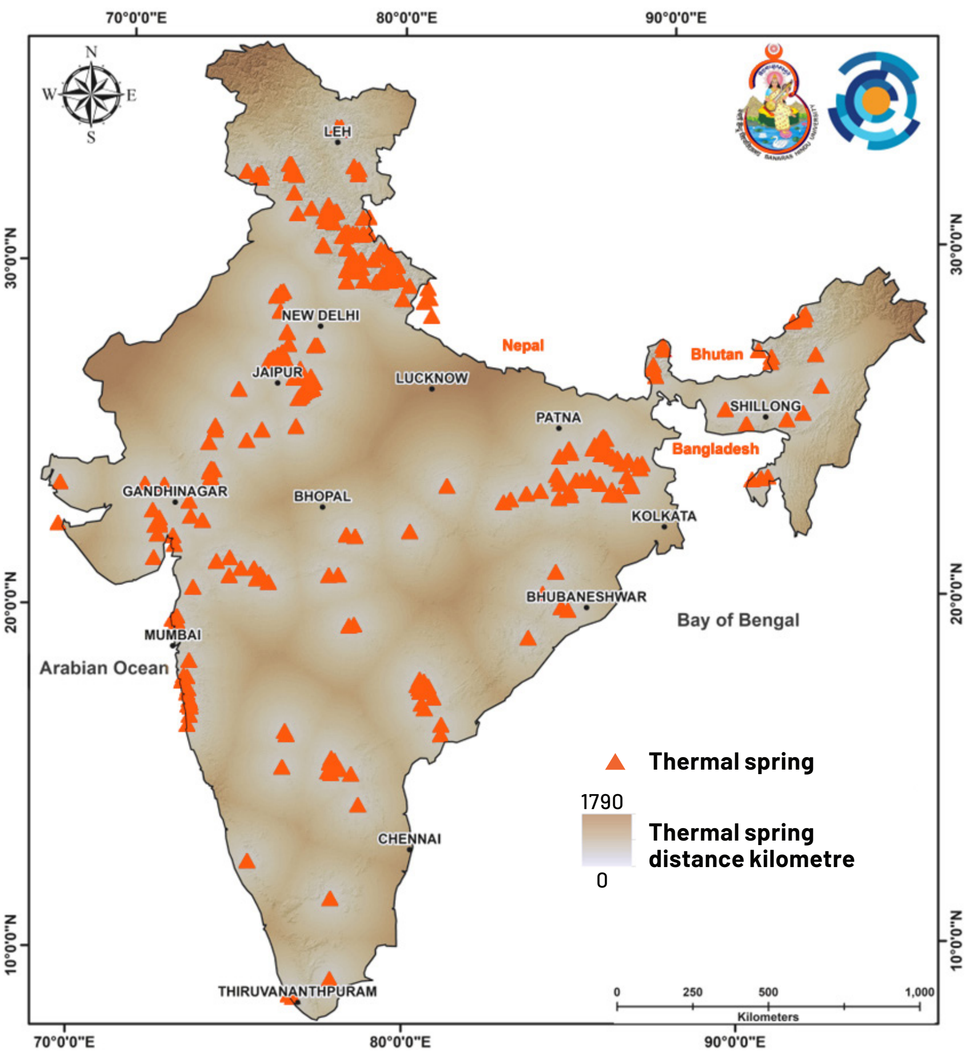


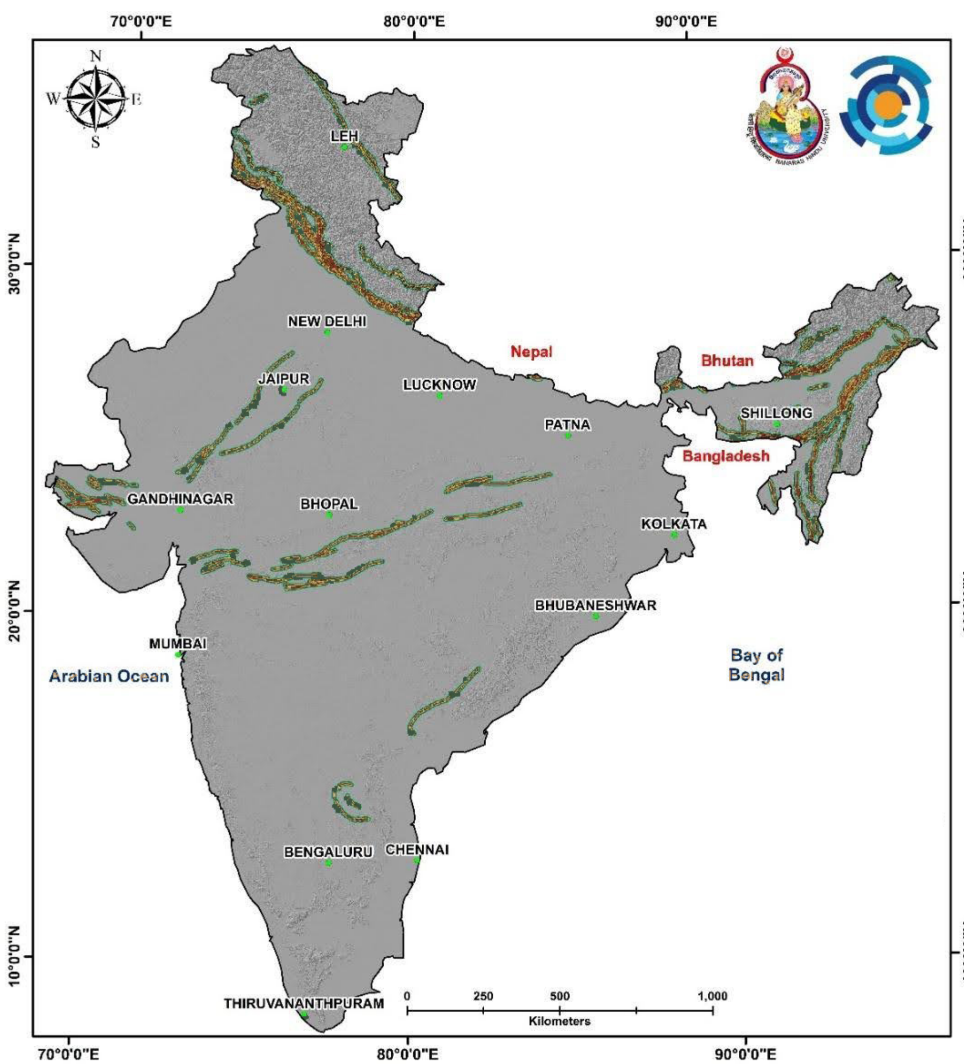

**Figure 2.3:** Proximity to geothermal springs. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace; Tamburello et al., 2022; Craig et al., 2013; Das et al., 2022; Sinha, 1980; Dhirendra et al., 1992; Bajpai & Narayan, 2005; Singh et al., 2014; Gurav et al., 2015; Dutta et al., 2023; Pandey & Raymahashay, 1981. (See full source information in the conclusion to this chapter.)

tectonic activity maintains fracture connectivity and fluid circulation.[10,11,12] Areas in close proximity to active faults are therefore prioritised in geothermal suitability mapping, as they facilitate enhanced convective heat transfer. Empirical studies have also consistently shown that geothermal manifestations such as thermal springs and fumaroles are frequently aligned with active fault traces due to their structural permeability.[13] India exhibits a good distribution of active faults along the Himalayan arc, in northeast India, and in isolated segments across the central (along SONATA), western (along the Kachchh rift and ADFB), and southern regions—areas that coincide with higher geothermal gradients and thermal spring occurrences (**Figure 2.4**). In this study, zones within 2 kilometres of active faults were assigned the highest suitability score (5), while regions located beyond 10 kilometres received the lowest score (0), reflecting their diminished influence on geothermal fluid migration (**Figures 2.4** and **A.3**).

## Proximity to Major Fault Lines

The circulation of water from atmospheric precipitation (such as rain) through fault and fracture networks is a fundamental mechanism that influences the formation and sustainability of geothermal reservoirs.[14,15,16] These structural discontinuities act as high-permeability channels that allow deep-seated geothermal fluids to ascend and accumulate, thereby playing a pivotal role in heat and mass transport within the crust.[17,18] In geothermal provinces, the spatial association between thermal manifestations and major fault zones is well documented, highlighting the importance of fault proximity

### PROXIMITY TO ACTIVE FAULTS




**Proximity to Active Fault**

| Kilometre | Rank |
|---|---|
| 0 - 2 | 5 |
| 2 - 4 | 4 |
| 4 - 6 | 3 |
| 6 - 8 | 2 |
| 8 - 10 | 1 |
| > 10 | 0 |

**Figure 2.4:** Proximity to active faults classified from 0 (least favourable for geothermal) to 5 (most favourable for geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

## PROXIMITY TO MAJOR FAULTS

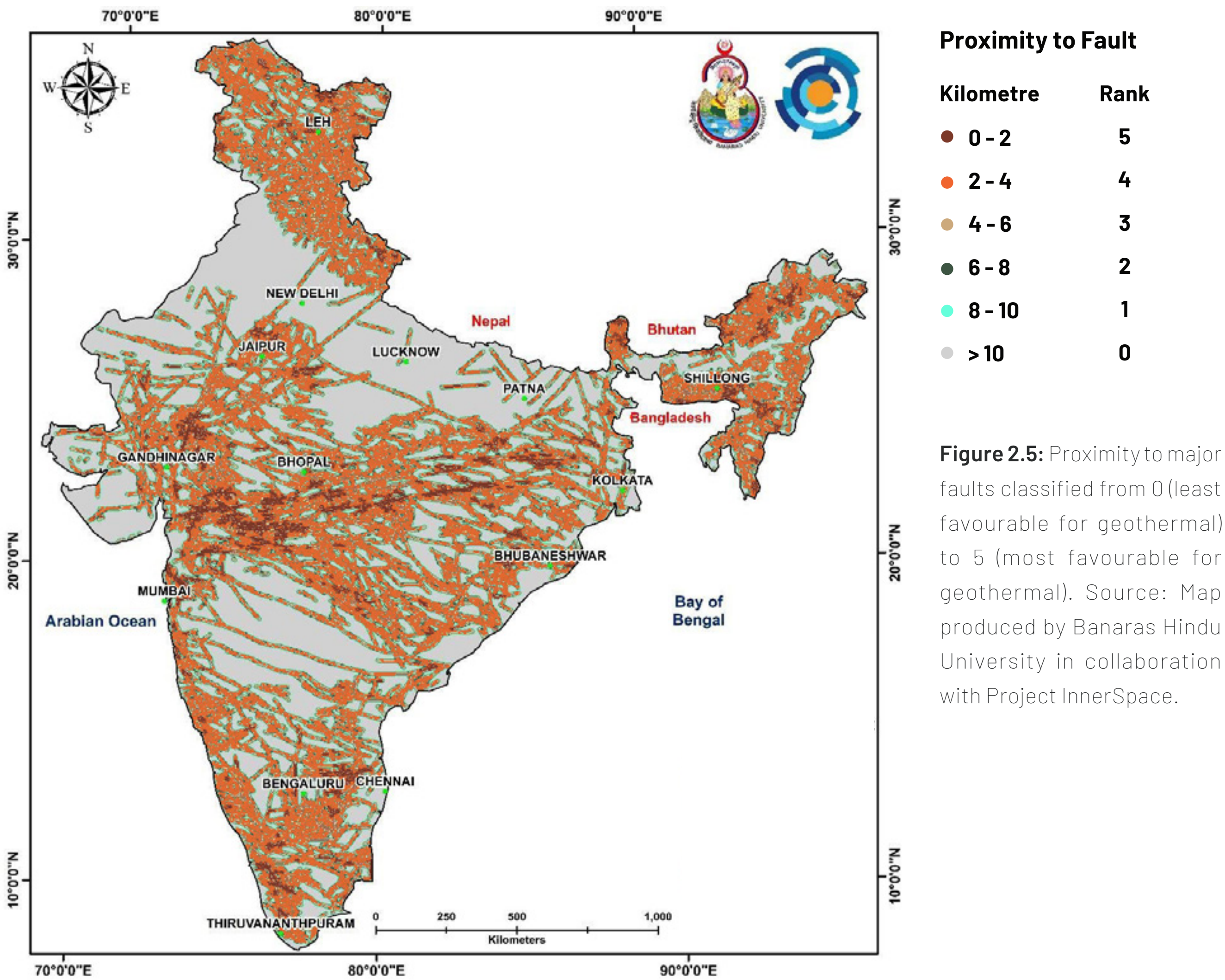


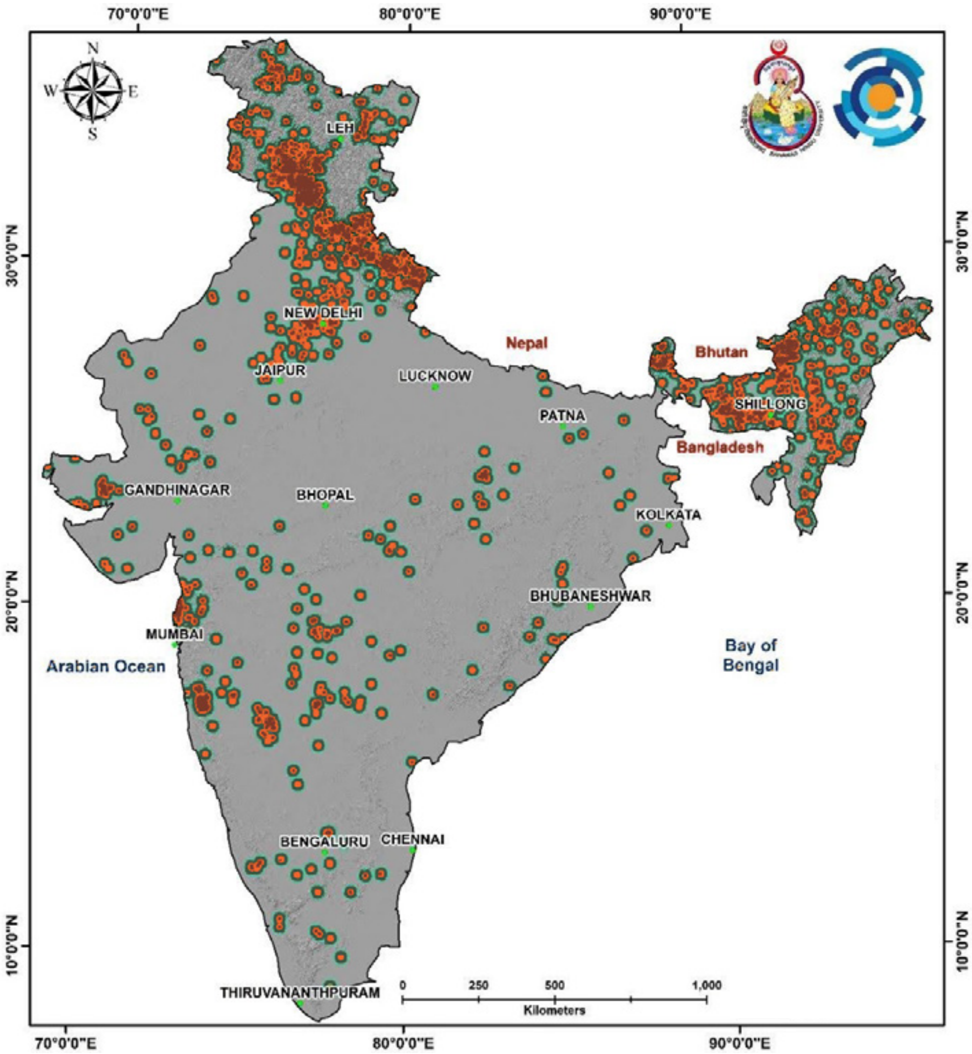

**Figure 2.5:** Proximity to major faults classified from 0 (least favourable for geothermal) to 5 (most favourable for geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

as a key criterion in geothermal potential assessment.[19] Observations from this study confirm that a significant number of thermal springs are situated near fault structures (**Figure 2.5**), indicating a strong structural control of fluid migration pathways. Previous research, particularly in tectonically active regions such as Japan, has demonstrated that more than 95% of geothermal wells are located within 6 kilometres of major fault traces.[20] Based on this empirical evidence, fault proximity was integrated into the weighted overlay model as a critical factor. Distances of less than 2 kilometres from major faults were assigned the highest suitability score (5), recognizing their enhanced permeability and geothermal favourability, while regions situated beyond 10 kilometres were considered the least favourable, with a suitability score of 0 (**Figure 2.5**).

### Proximity to Shallow Seismicity

Geothermal resources are frequently discovered in areas where earthquakes occur within fault zones. In this study, we have integrated the National Centre for Seismology earthquake catalogue covering 1900 to 2022 to identify high-density seismic zones such as the Himalayas, the ADFB, the Kachchh and Cambay rifts, northeastern India, and western coastal areas that are likely to have increased geothermal potential and tectonic activity (**Figure 2.6**). A previous study by Elbarbary and colleagues used earthquakes with depths of less than 10 kilometres for the geothermal potential zonation of Africa.[21] Following this study, we have used only earthquakes with less than 10 kilometres of focal depth and have taken a similar approach to faults in seismicity. Shallow earthquakes (depths of

## PROXIMITY TO SHALLOW SEISMIC EVENTS




**Proximity to Shallow Seismicity**

| Kilometre | Rank |
|---|---|
| 0 - 5 | 5 |
| 5 - 10 | 4 |
| 10 - 15 | 3 |
| 15 - 20 | 2 |
| 20 - 25 | 1 |
| > 25 | 0 |

**Figure 2.6:** Proximity to shallow seismic events, classified from 0 (least favourable to geothermal) to 5 (most favourable to geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace. Data from National Center for Seismology. (n.d.). *Data portal*. Ministry of Earth Sciences, Government of India.

less than 10 kilometres) suggest the presence of active crustal deformation and enhanced permeability, both of which support geothermal activity. As a result, locations within 5 kilometres of such events are scored highest (5), while those beyond 25 kilometres are considered the least favourable for geothermal (score 0; **Figures 2.6** and **A.3**).[22]

## Geological Framework

India's geological framework is a complex assemblage of rocks dating from the Precambrian to the Cenozoic eras (**Figure 2.7**). The northern region is dominated by the tectonically active Himalayan orogen, which emerged from the ongoing convergence between the Indian and Eurasian plates.[23,24] This region hosts several major active fault systems, such as the Karakoram and Kishtwar faults, and accounts for nearly 50% of India's thermal springs, highlighting its geodynamic significance.[25,26] South of the Himalayas, the Indo-Gangetic plains are underlain by thick Cenozoic sedimentary sequences, with basin fill thickness reaching up to 8 kilometres, predominantly derived from Himalayan orogenic processes.[27] The central and southern regions of the Indian subcontinent are composed mainly of Precambrian and Mesozoic formations, where key cratonic blocks (the Aravalli-Bundelkhand, Bastar, Chhotanagpur-Singhbhum, and Dharwar) are bounded by mobile belts and interspersed with rift systems including the SONATA, Godavari, Mahanadi, Cambay, and Kachchh (**Figure 2.7**). These tectonic and lithological features play a critical role in influencing geothermal gradients, heat flow, and reservoir characteristics.

## DISTRIBUTION OF MAJOR GEOLOGICAL FORMATIONS BY ERA

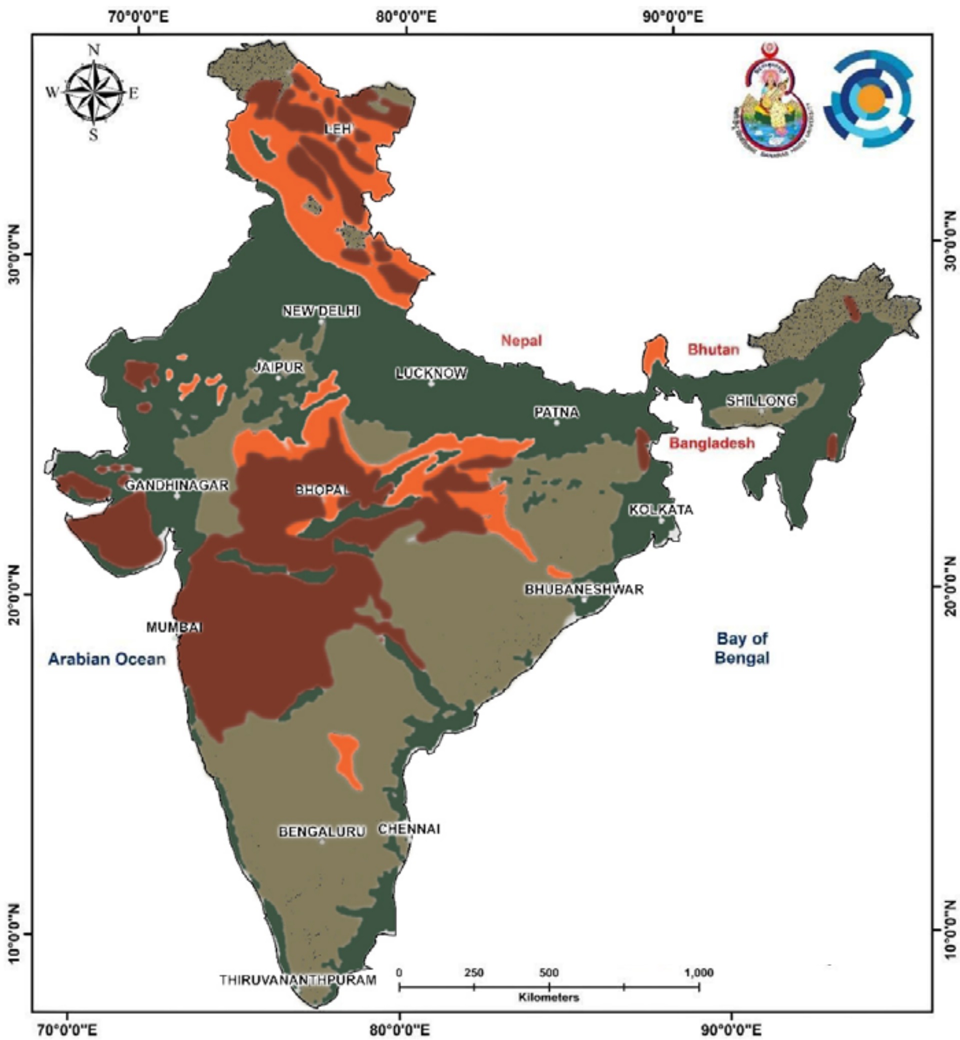



**Figure 2.7:** Distribution of major geological formations by era: Cenozoic, Mesozoic, Palaeozoic-Mesozoic, and Precambrian. Classified from 0 (least favourable to geothermal) to 5 (most favourable to geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

Mesozoic terrain—which is often associated with volcanic activity, high heat-retaining capacity, and a large number of thermal springs—has the highest geothermal suitability score (5). Paleozoic-Mesozoic terrain has the second-highest score (4), followed by Precambrian (3), and finally the less favourable Cenozoic sequences (1; **Figures 2.7** and **A.3**).

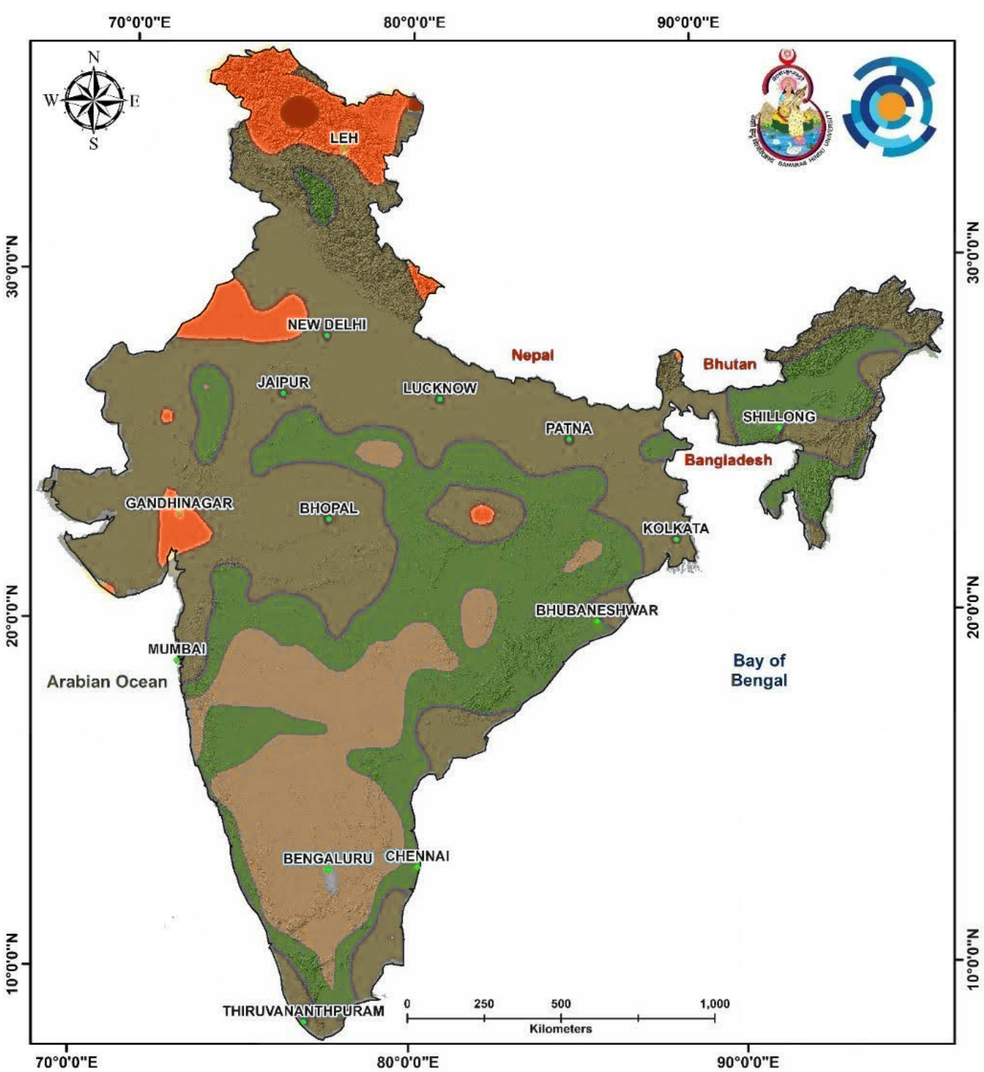
### Proximity to Heat Flow

Heat flow is a critical geophysical parameter for identifying zones of high geothermal potential, as it directly reflects the subsurface thermal regime and indicates the presence of anomalously high temperatures at shallow depths.[28] Heat flow data provide insights into the conductive and convective heat transfer mechanisms within the Earth's crust, which can help geothermal developers identify regions with a sustained thermal energy source—an essential condition for viable geothermal systems.[29] In our study, heat flow is assigned the highest weight (20%) among all input layers due to its crucial role in determining geothermal resource viability. High heat flow values have been observed in the northwestern Himalayan zone, the Cambay rift, and the Saurashtra peninsula, all of which are favourable zones for geothermal potential (**Figure 2.8**).[30] Areas that exhibit heat flow values exceeding 100 milliwatts per square metre are considered the most favourable for geothermal and are assigned the maximum suitability score (5). Conversely, regions with heat flow below 30 milliwatts per square metre are deemed the least suitable for geothermal, receiving a score of 0. Intermediate heat flow ranges are classified into graduated suitability classes, which indicates a continuum of geothermal favourability in the weighted overlay framework (**Figures 2.8** and **A.3**).

## Moho Depth Variation

Crustal thickness plays a pivotal role in modulating heat flow, as it directly influences the efficiency of heat conduction from the underlying mantle to the Earth's surface.[31] Globally, crustal thickness—also known as Moho depth, or the boundary between Earth's crust and its mantle—varies significantly across different tectonic domains, averaging 35 kilometres in stable continental interiors, thinning to 7 kilometres in oceanic settings, and exceeding 70 kilometres in active orogenic regions such as the Himalayas. In the context of geothermal potential zonation, Moho depth is a critical geophysical parameter. Shallower Moho depths are typically associated with higher heat flow due to reduced lithospheric thickness and enhanced mantle heat flux.[32] These regions promote vertical heat transport, which makes them more likely to form geothermal reservoirs. Accordingly, areas with Moho depths shallower than 30 kilometres are classified as highly favourable to geothermal and assigned the maximum suitability score (5), while zones with Moho depths greater than 50 kilometres—reflecting thicker, more thermally resistive crust—are considered the least suitable for geothermal exploitation and are scored the lowest (0; **Figures 2.9** and **A.3**).

### GEOTHERMAL SUITABILITY BASED ON HEAT FLOW DISTRIBUTION

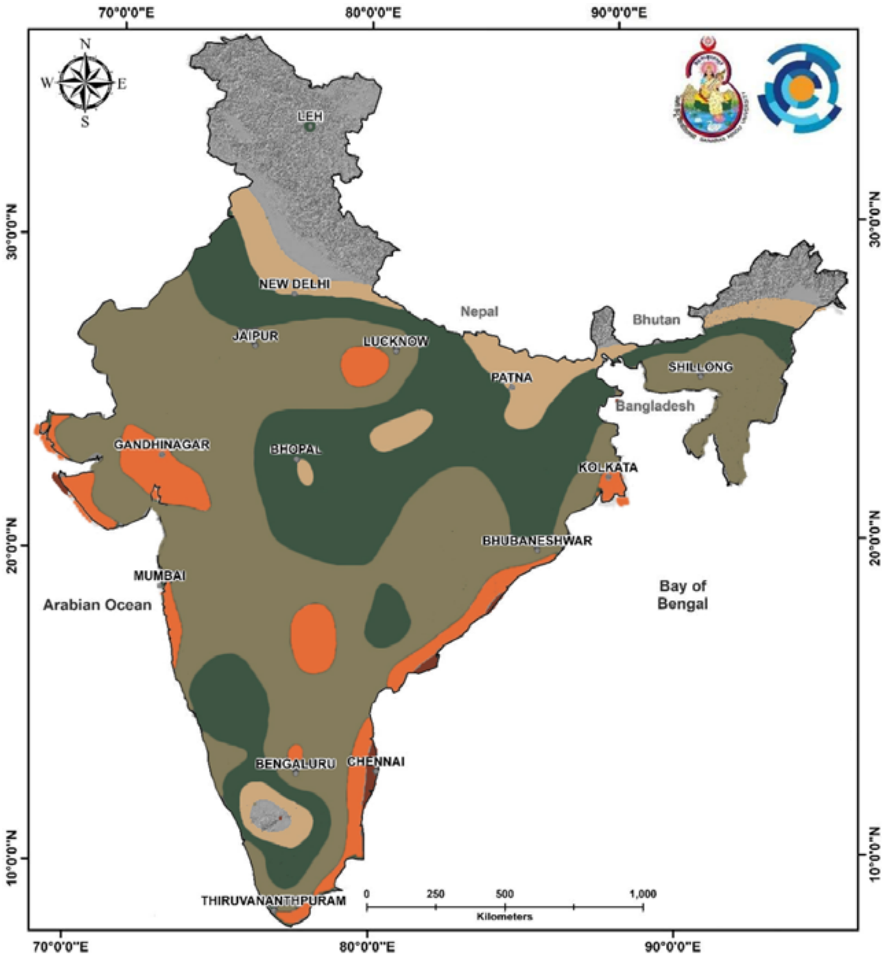



**Proximity to Heat Flow**

| mW/m² | Rank |
|---|---|
| < 30 | 0 |
| 30 - 50 | 1 |
| 50 - 60 | 2 |
| 60 - 75 | 3 |
| 75 - 100 | 4 |
| > 100 | 5 |

**Figure 2.8:** Terrestrial heat flow distribution classified from 0 (least favourable for geothermal) to 5 (most favourable for geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

## GEOTHERMAL FAVOURABILITY BASED ON MOHO DEPTHS




**Proximity to Moho Depth**

| Kilometre | Rank |
|---|---|
| < 30 | 5 |
| 30 - 35 | 4 |
| 35 - 40 | 3 |
| 40 - 45 | 2 |
| 45 - 50 | 1 |
| > 50 | 0 |

**Figure 2.9:** Moho depth distribution classified from 0 (least favourable for geothermal) to 5 (most favourable for geothermal). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

### Average Shear Wave Velocity Variation

When assessing geothermal potential, average shear wave velocity within the upper mantle (specifically between 110 kilometres and 150 kilometres deep) serves as a critical proxy for subsurface thermal conditions.[33] Lower shear wave velocities typically correspond to elevated temperatures, partial melting, or the presence of fluids, all of which are conducive to geothermal activity.[34] Regions exhibiting velocities below 4.1078 kilometres per second are classified as highly favourable to geothermal and assigned the maximum suitability score (3). Conversely, velocities exceeding 4.4189 kilometres per second suggest colder, more rigid mantle conditions and are considered the least suitable (assigned a score of 1). Intermediate velocity ranges are progressively scored to reflect decreasing geothermal favourability, thereby allowing for refined integration into the weighted overlay framework (**Figures 2.10** and **A.3**).

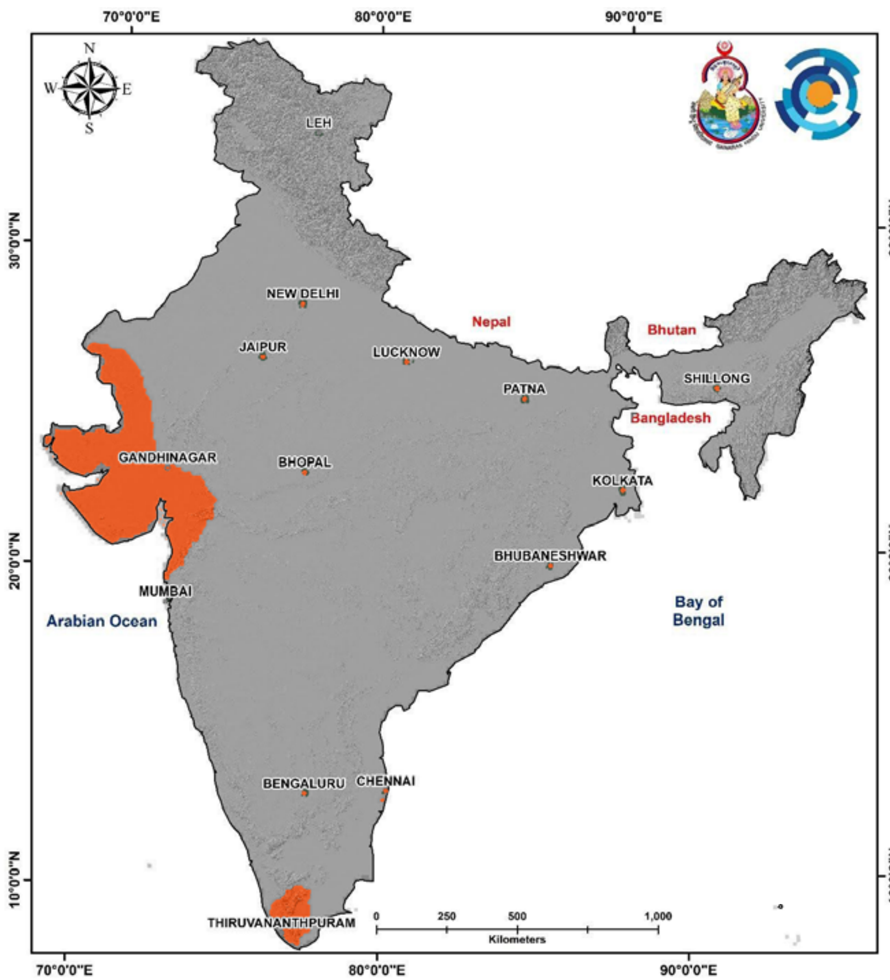
## REGIONAL AND STATE ANALYSIS OF GEOTHERMAL POTENTIAL

India has technical potential for roughly 450 gigawatts of electricity generation (down to 5 kilometres) today and more than 8,000 gigawatts of electricity (down to 7 kilometres) as technology improves.[36] These geothermal regions occupy three main tectonic domains:

- The Himalayan collision zone associated with active continental convergence.
- The Aravalli Delhi Fold Belt (ADFB).
- Stable peninsular India, particularly near the Cambay, Kachchh, and SONATA rift systems; the Gondwana sedimentary basins; and the thermally active belts along the eastern and western coasts.

For the purpose of regional analysis, we divided the Indian geothermal landscape into five zones corresponding to

## GEOTHERMAL FAVOURABILITY BASED ON SHEAR WAVE VELOCITY




**Shear Wave Velocity**

| m/sec | Rank |
|---|---|
| 4.2633 - 4.3411 | 2 |
| 4.3411 - 4.4189 | 1 |
| > 4.4189 | 0 |

**Figure 2.10:** Average shear wave velocity between 100 kilometres and 150 kilometres. Regions exhibiting velocities below 4.1078 kilometres per second are classified as highly favourable to geothermal and assigned the maximum suitability score(3). Conversely, velocities exceeding 4.4189 kilometres per second suggest colder, more rigid mantle conditions and are considered least suitable(assigned a score of 1). Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

## ROBUSTNESS AND LIMITATIONS OF THE ANALYSIS

The study integrates eight geoscientific data sets (shown earlier; see the appendix for details). To ensure the robustness of this analysis of geothermal potential, the results were cross-validated against existing geoscientific literature and previously identified geothermal provinces. This approach confirmed that our assessment was accurate in its findings that high-potential zones could be found in the northwestern Himalayas, eastern and western India, and northeastern provinces—findings that correspond closely with previous studies.[35]

That said, geothermal potential mapping is subject to inherent uncertainties, primarily due to limitations in the availability and resolution of input data sets. One significant constraint is the sparse and uneven nature of heat flow measurements across India, which may affect the spatial accuracy of potential zones. Likewise, seismic data sets generally span the past two centuries, so earlier seismicity remains partially undocumented. Thick sedimentary covers, particularly in the Indo-Gangetic Basin and other alluvial regions, can also make it challenging to accurately identify structural features such as active and major faults. This issue introduces additional uncertainty, especially in rifted domains where geothermal activity is structurally controlled. Finally, there are several discrepancies among global data sets such as Moho depth and shear wave velocity, which creates additional uncertainty. As more high-resolution geophysical, geological, and geochemical data become available—particularly heat flow measurements, detailed seismicity catalogues, and refined fault maps—this new information can be integrated to further enhance the map's inputs and resulting precision.

administrative divisions: northwestern, northeastern, western, eastern, and southern Indian states.

## Northwestern Indian States

The northwestern Himalayas, located within the Trans-Himalayan tectonic belt, are rich in seismic faults and possess nearly half of India's thermal springs (more than 100; **Figures 2.3**, **2.4**, and **2.5**). The geothermal reservoirs are primarily located in post-Tertiary gneissic, granitic, and schistose formations, overlain by a thick layer of sedimentary deposits.[37,38] These granitoid intrusions act as significant heat sources, with high reservoir temperatures (above 250°C), anomalously high geothermal gradients (greater than 100°C per kilometre), and surface heat flow exceeding between 150 and 200 megawatts per square metre (**Figure 2.8**).[39,40] Magnetotelluric surveys in the Puga geothermal field have revealed low-resistivity zones corresponding to high-temperature fluid circulation at depth and the existence of an active magmatic system at a depth of between 5 kilometres and 7 kilometres.[41,42,43] Together, these measurements confirm there is considerable geothermal energy potential within the Ladakh region, with Puga, Chumthang, and the Nubra Valley emerging as key target zones for future development. Recent drilling operations undertaken by the Oil and Natural Gas Corporation provide empirical validation of the region's geothermal exploration potential, underscoring the strategic importance of this region for this exploration. **Figure 2.11** shows that northwestern India—particularly Ladakh, Jammu and Kashmir, Himachal Pradesh, and Uttarakhand—has extensive zones with high-temperature geothermal potential for power generation, along with broader areas of moderate potential.

In Himachal Pradesh and Uttarakhand, the most prospective zones fall within the Central and Lesser Himalayan domains, where several thermal springs exhibit

### GEOTHERMAL POTENTIAL ZONES IN THE NORTHWESTERN INDIAN STATES

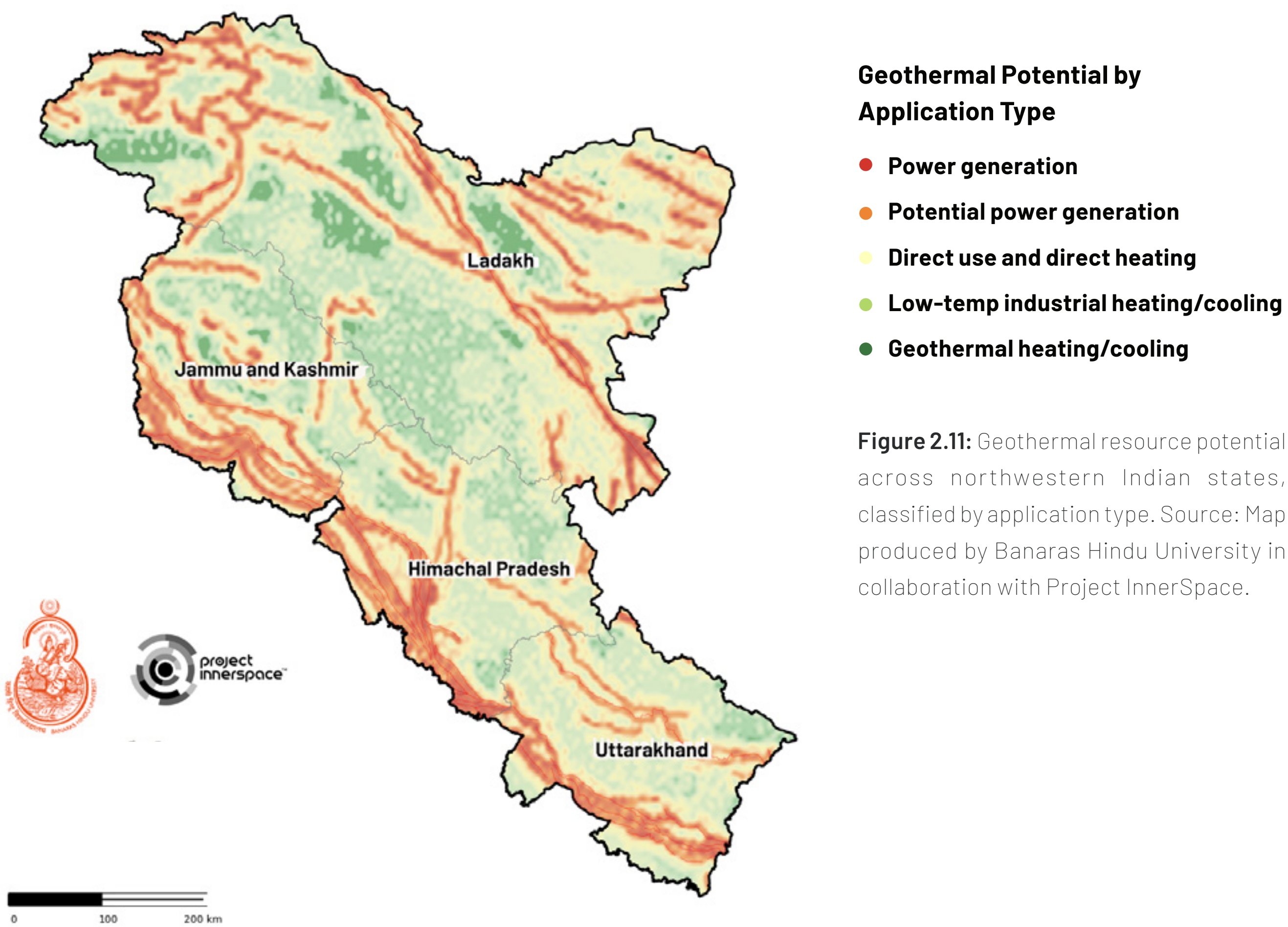



**Figure 2.11:** Geothermal resource potential across northwestern Indian states, classified by application type. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

very high temperatures. Notably, the Manikaran hot spring in Himachal Pradesh reaches a discharge temperature of 97°C, with inferred reservoir temperatures of between 80°C and 110°C.[44,45] In Uttarakhand, the Badrinath and Tapoban springs record even higher subsurface temperatures of between 122°C and 142°C.[46] The combination of high surface and reservoir temperatures with high geothermal potential indices makes these systems among the most promising for future energy development in the Indian Himalayas.

By contrast, parts of eastern and southern Jammu and Kashmir within the Central Himalayan zone also host geothermal springs, but with lower surface (42°C–53°C[47]) and subsurface (41°C–85°C[48]) temperatures, making them more suitable for direct-use heating and cooling rather than power generation.

From a population perspective, many of these high-potential zones lie in sparsely populated mountainous areas, which limits immediate large-scale grid integration but offers strong opportunities for localised power and heat supply to tourism hubs, remote communities, and strategic installations. Moderate-potential zones in more accessible valleys and foothills are closer to population centres, providing attractive targets for direct-use applications and smaller-scale geothermal projects.

## Northeastern Indian States

The map shows that northeastern India—particularly Arunachal Pradesh, Sikkim, Meghalaya, Assam, and parts of Manipur, Mizoram, Nagaland, and Tripura—hosts extensive zones with high and moderate geothermal potential (**Figure 2.12**). In Sikkim, five documented thermal springs have surface temperatures ranging between 38°C and 59°C,[49] with our model indicating higher prospectivity in the surrounding zones. The western part of Arunachal Pradesh has particularly strong geothermal signatures, with more than 30 thermal springs and reservoir temperatures estimated to reach up to 200°C,[50,51] highlighting this region as a priority for future

### GEOTHERMAL POTENTIAL ZONES IN THE NORTHEASTERN INDIAN STATES

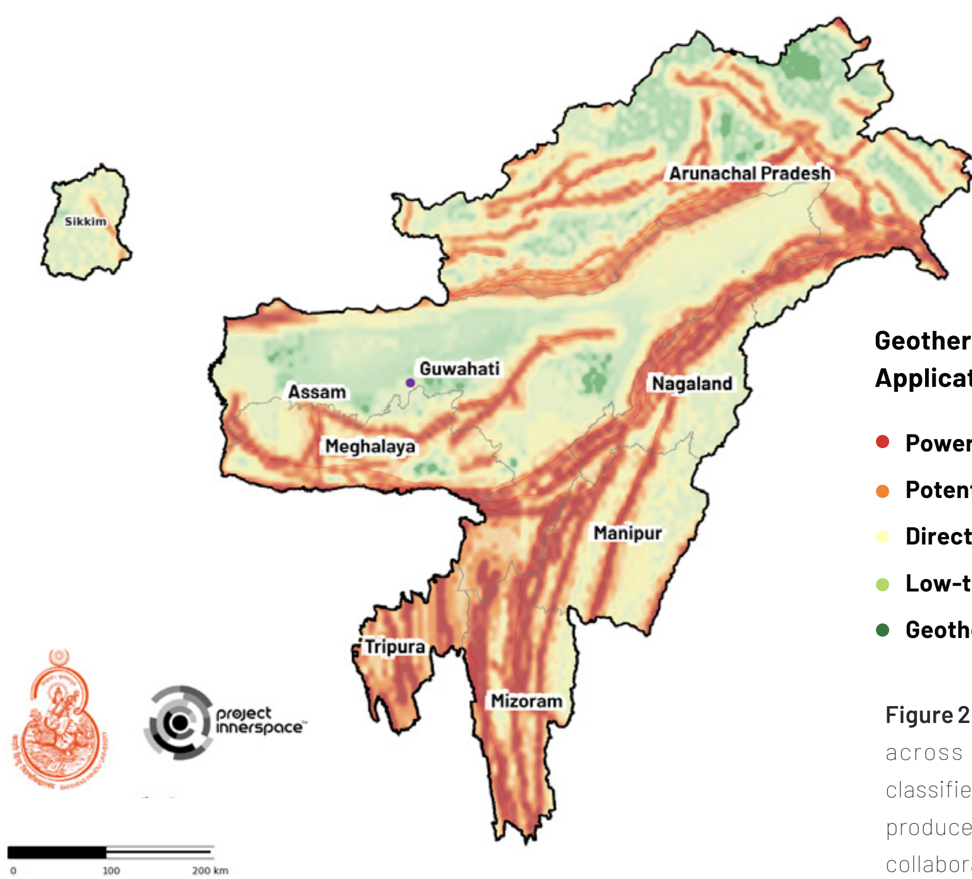



**Figure 2.12:** Geothermal resource potential across northeastern Indian states, classified by application type. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

geothermal development. In 2023, the Arunachal Pradesh government formalised a memorandum of understanding with GSI, the Government of India, and the Norwegian Geotechnical Institute to conduct a comprehensive geoscientific assessment aimed at evaluating the feasibility of geothermal energy exploitation from the state's thermally active hydrothermal systems.

In Meghalaya, the East Garo Hills host between 10 and 20 thermal springs (**Figure 2.3**), and investigations by the Bhabha Atomic Research Centre in India's Department of Atomic Energy have reported surface temperatures between 28°C and 48°C and reservoir temperatures as high as 300°C.[52,53] This high heat flow is linked to uraninite-bearing granitoid intrusions of the Archean Shillong Plateau that exhibit enhanced natural radioactivity.[54] Despite relatively modest surface temperatures, the deep thermal regime reflects significant geothermal potential.

Assam, Manipur, Nagaland, Mizoram, and Tripura also display geothermal prospectivity, though with fewer documented thermal springs (**Figure 2.3**). In the Upper Assam Basin, well log data from 17 boreholes reveal five wells with significantly elevated heat flow, highlighting promising sites for geothermal energy applications.[55]

From a population perspective, many of the zones with the greatest potential—particularly in Arunachal Pradesh, Mizoram, and Nagaland—are in remote, sparsely populated terrain, favouring decentralised off-grid systems for local communities, tourism hubs, and strategic installations. In contrast, prospects in Assam and Meghalaya are closer to major population centres and industrial corridors, making them more suitable for grid-connected power generation and direct-use heating and cooling.

Overall, the combination of high estimated reservoir temperatures, heat flow anomalies, and favourable tectono-magmatic settings confirms that northeastern India is a strategically important frontier for geothermal energy exploration.

## Western Indian States

In the western states, high geothermal potential exists in Rajasthan and Haryana along the ADFB (**Figure 2.13**), which hosts several low- to moderate-temperature thermal springs, with discharge temperatures between 35°C and 47°C and estimated reservoir temperatures of between 60°C and 80°C.[56] This zone is structurally controlled by northeast-southwest trending strike-slip faults, which have been active since the Precambrian era and serve as primary conduits for the ascent of deep-circulating geothermal fluids.[57] Thermal anomalies in this region are likely driven by heat-producing alkaline intrusions and high-thermal-conductivity silicic lithologies, which enhance the subsurface geothermal regime.[58] Thermal fluid discharge in the Sohana area is linked to groundwater percolation through a structurally induced depression formed by the downward displacement of a central crustal block flanked by two uplifted ridges of the Delhi Mobile Belt.[59] This tectonic configuration facilitates gravity-driven infiltration of meteoric water along fractures and faults, where it is subsequently heated during deep circulation.

The Kachchh rift, Cambay rift, and Saurashtra peninsula regions of Gujarat are all characterised by high geothermal potential. Among these areas, the Cambay rift stands out as the most promising area for geothermal exploration. A majority of the thermal springs are spatially associated along the boundary fault of the Cambay rift, and surface temperatures of thermal springs in this region are generally moderate to high (40°C–93°C), from the Dholera spring (40°C–45°C) up to the Tuwa (93°C).[60,61] In the Unai geothermal system, surface and reservoir temperatures are reported at approximately 50°C to 55°C and 120°C, respectively (**Figure 2.13**).[62] Reservoir temperature estimations also suggest high geothermal gradients, with inferred subsurface temperatures of 150°C on the eastern margin of the rift and between 70°C and 90°C on the western margin.[63] Magnetotelluric investigations at the Chabsar hot springs also indicate high fluid saturation along the western boundary fault, which likely serves as a conduit for ascending geothermal fluids.[64]

Along with the aforementioned regions, the central segment of the seismically active Kachchh rift also holds considerable geothermal potential, although it hosts only a single known thermal spring (**Figure 2.13**). Geophysical investigations—including gravity, magnetotelluric, and seismic studies—have revealed the presence of intrusive bodies in the upper crust and a partially molten magma chamber at mid- to lower-crustal depths.[65] These subsurface features indicate a viable heat source and suggest that the Kachchh rift may support geothermal energy development, contingent on further exploratory efforts.

The SONATA megatectonic lineament, extending across southern Gujarat, northern Maharashtra, and central Madhya Pradesh, reveals the presence of a structurally significant corridor with considerable geothermal exploration potential. The Salbardi and Anhoni thermal springs (in the northern region of Maharashtra and the southern region of Madhya Pradesh, respectively) are spatially aligned with the western segment of this major tectonic feature (**Figure 2.13**). Surface discharge temperatures at the Salbardi thermal springs range between 44°C and 47°C, while subsurface reservoir temperatures have been estimated at approximately 150°C.[66,67] In the Anhoni geothermal zone, the surface temperature is around 45°C, with reservoir temperatures estimated at nearly 100°C.[68,69] The high heat flow in this region is thought to result from the presence of partial melts and associated fluids at mid- to lower-crustal depths. Geophysical and petrological evidence further suggests the existence of high-density mafic intrusions and magmatic underplating at the base of the crust, which may serve as significant heat sources driving hydrothermal circulation.[70]

Our analysis also found high geothermal potential along the coastal tract of Maharashtra (**Figure 2.13**), where abundant thermal springs (**Figure 2.3**) show surface temperatures ranging from 47°C to 72°C.[71,72] These thermal manifestations are primarily governed by deep-seated tectonic structures like the West Coast Fault and are associated with fluid migration through the Deccan Traps.[73] The Rajapur hot spring is particularly significant, as its thermal waters circulate through granitic basement rocks underlying the basalt cover, suggesting a complex hydrothermal system with both volcanic and plutonic contributions.

Given their favourable tectonic setting, elevated geothermal gradients, and robust surface and reservoir

## GEOTHERMAL POTENTIAL ZONES IN THE WESTERN INDIAN STATES

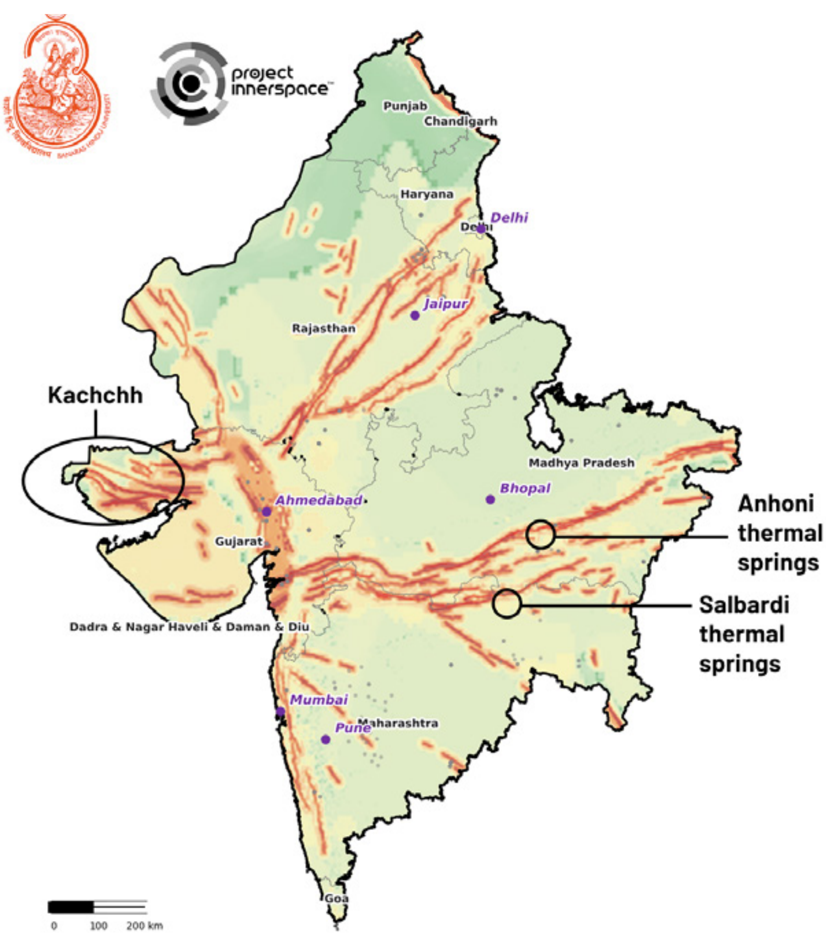



**Figure 2.13:** Geothermal resource potential across western Indian states, classified by application type. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

temperature profiles, the Cambay rift and the SONATA lineament zones collectively should be high-priority targets for geothermal resource development in western India.

## Eastern Indian States

The eastern region of India is geologically diverse, featuring major tectonic and crustal units such as the Indo-Gangetic Plain, Singhbhum Craton, Mahanadi rift, and Bastar Craton (**Figure 2.2**). Within this tectonic framework, our analysis shows high geothermal potential in the Rajgir geothermal province of Bihar (**Figure 2.14**). This zone is spatially associated with the Munger-Saharsa Ridge fault system, a prominent tectonic feature that facilitates deep fluid circulation. Several thermal springs have been documented within this structurally controlled corridor, exhibiting surface discharge temperatures ranging from 30°C to 65°C. Reservoir temperature estimates suggest subsurface values reaching up to 100°C.[74,75] These temperatures position the Bihar state as a promising candidate for low- to medium-enthalpy geothermal resource development in eastern India.

Multiple thermal spring occurrences have been identified in the western part of West Bengal and the adjoining eastern region of Jharkhand (**Figure 2.14**). Previous investigations by Ravi Shanker and colleagues have documented anomalously high geothermal gradients in this region, reaching up to 90°C per kilometre.[76] High geothermal gradient values are thought to result from deep-seated geodynamic processes, including possible mantle upwelling and mafic intrusions, particularly in the Bakreswar and Tantloi areas, as supported by regional gravity anomaly data.[77] Furthermore, the thermal regime is influenced by the occurrence of vein-type uranium-bearing mineralization (brannerite and uraninite) hosted in Paleoproterozoic quartz-chlorite schist within the tectonically active Singhbhum Shear Zone.[78,79] (In other words, the radioactive decay produces heat.) As a result, these states should be designated as a high-priority target for further geothermal exploration and resource development.

### GEOTHERMAL POTENTIAL ZONES IN THE EASTERN INDIAN STATES


**Geothermal Potential by Application Type**

- Power generation
- Potential power generation
- Direct use and direct heating
- Low-temp industrial heating/cooling
- Geothermal heating/cooling

**Figure 2.14:** Geothermal resource potential across eastern Indian states, classified by application type. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

In northern Chhattisgarh, the Tatapani geothermal system is structurally situated between two prominent east-west-trending fault zones, spatially associated with the SONATA megatectonic lineament to the north and the Tapi lineament to the south. This fault-bounded configuration plays a crucial role in facilitating subsurface fluid migration. Previous investigations by Chandrashekharam and Antu and by Minissale and colleagues have reported surface discharge and reservoir temperatures ranging from 60°C to 80°C and 205°C to 217°C.[80,81] Studies attributed the geothermal anomalies in the region to deep fluid circulation along these fault-controlled conduits, enabling efficient heat transport from mid- to lower-crustal levels.[82] The high geothermal potential identified in this zone, in conjunction with the state's favourable geological framework and thermal regime, reaffirm Chhattisgarh as a strategically significant zone for advanced geothermal resource exploration, assessment, and sustainable exploitation.

The state of Odisha (**Figure 2.14**) exhibits a broad spatial distribution of thermal springs (**Figure 2.3**), with surface discharge temperatures ranging from 32°C to 67°C and inferred subsurface reservoir temperatures estimated between 90°C and 130°C.[83] These thermal characteristics are indicative of low-enthalpy geothermal systems, underscoring the region's potential for moderate-temperature geothermal resource development.

## Southern Indian States

Compared with the rest of the country, the southern Indian states show comparatively lower geothermal potential (**Figure 2.15**). Very localised geothermal prospective zones have been identified in the southern part of Karnataka, with geo-structural and lithological conditions similar to those seen in the coastal Maharashtra region, particularly with regard to thermal regime and fault-controlled hydrothermal fluid migration. The Godavari rift zone, extending across the northern and eastern regions of Telangana and Andhra Pradesh, represents a prominent exception, exhibiting high geothermal prospectivity. Within this tectonically active northwest-southeast trending graben structure, more than 15 thermal springs have been documented (**Figure 2.3**), with

### GEOTHERMAL POTENTIAL ZONES IN THE SOUTHERN INDIAN STATES


**Geothermal Potential by Application Type**

- Power generation
- Potential power generation
- Direct use and direct heating
- Low-temp industrial heating/cooling
- Geothermal heating/cooling

**Figure 2.15:** Geothermal resource potential across southern Indian states, classified by application type. Source: Map produced by Banaras Hindu University in collaboration with Project InnerSpace.

surface discharge temperatures ranging from 36°C to 62°C and reservoir temperatures inferred to be between 80°C and 120°C.[84,85,86] The bounding fault systems of the rift act as conduits, facilitating the ascent of thermally altered fluids from deeper crustal levels to the surface.

## CONCLUSION

India's diverse topography—ranging from high mountain ranges to extensive river basins and coastal plains—contains a wealth of geothermal resources. The Himalayan region, with its rugged terrain and high-altitude geothermal springs, presents logistical challenges but offers immense potential for energy generation. In contrast, the western and central parts of India have more accessible geothermal reservoirs due to their relatively stable geological settings.

Our integrated and systematic assessment offers vital insights into the geological, geophysical, and thermal characteristics that underpin India's geothermal resources and highlights a number of extremely promising areas for exploration across a diverse set of tectonic and lithological settings.

In eastern and central India—including the Rajgir geothermal group in Bihar, the Jharkhand–West Bengal corridor, and the Mahanadi Rift Basin in Odisha—there are extensive geothermal resources thanks to heat-producing lithologies and structurally controlled spring systems. In particular, the Tatapani geothermal field in northern Chhattisgarh is one of India's most promising reservoirs, with temperatures exceeding 200°C and deep fluid circulation along major fault alignments.

The Godavari rift system in Telangana and Andhra Pradesh, as well as isolated zones in Karnataka, are also strong geothermal targets thanks to a combination of rift tectonics, magmatic intrusions, and thermal fluid pathways. In the northwestern Himalayan corridor, the Ladakh region's Puga, Chumthang, and Nubra valleys collectively possess significant subsurface heat reservoirs. Likewise, the geothermal systems in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand—exemplified by sites like Manikaran, Tapoban, and Badrinath—show high reservoir temperatures and strong hydrothermal circulation linked to deep-seated fault systems and granite-hosted radiogenic heat sources, making all of them excellent candidates for geothermal energy production.

In western India, the geothermal provinces of Haryana (Sohana region), Rajasthan (ADFB), Gujarat (Cambay and Kachchh rifts), and coastal Maharashtra are good candidates for both low- and medium-enthalpy geothermal systems, with fault-mediated hydrothermal pathways facilitating deep fluid migration.

In the northeastern Himalayan, provinces such as Sikkim, Arunachal Pradesh, and Meghalaya remain underexplored but exhibit surface thermal anomalies and spring systems that merit targeted geoscientific investigations.

Going forward, we recommend additional high-resolution subsurface investigations—using magnetotelluric imaging, seismic tomography, heat flow measurements, isotopic hydrochemistry, and 3D geothermal modelling—to produce an even deeper understanding of subsurface characteristics and thermohydraulic regimes, with an eye toward identifying extractable energy potential. These studies will make geothermal resource assessments more accurate and will contribute to the design of both exploration strategies and pilot-scale projects.

This work is crucial to allowing India to take advantage of its exceptional geothermal resources. With its minimal land footprint and significant baseload generation capacity, geothermal energy can help India meet both its urgent national energy security needs and multiple United Nations Sustainable Development Goals. Our investigation provides a foundational scientific basis for future exploration, development, and policy planning.

The electricity generation potential and industrial heat potential numbers were calculated using methodology that expresses electricity estimates in gigawatts-electric down to 5,000 metres and all heat applications for industrial use (with a 100°C cutoff) down to 3,500 metres in gigawatts-thermal per square kilometre.

## Additional Figure Source Information

**Figure 2.3:** Tamburello, G., Chiodini, G., Ciotoli, G., Procesi, M., Rouwet, D., Sandri, L., Carbonara, N., & Masciantonio, C. (2022). Global thermal spring distribution and relationship to endogenous and exogenous factors. *Nature Communications*, *13*, 6378; Craig, J., Absar, A., Ghat, G., Cadel, G., Hafiz, M., Hakhoo, N., Kashkari, R., Moore, J., Ricchiuto, T. E., Thurow, J., & Thusu, B. (2013). Hot springs and the geothermal energy potential of Jammu & Kashmir State, N.W. Himalaya, India. *Earth-Science Reviews*, *126*, 156–177; Das, P., Maya, K., & Padmalal, D. (2022). Hydrogeochemistry of the Indian thermal springs: Current status. *Earth-Science Reviews*, *224*, 103890; Sinha, R. K. (1980). Some thermal springs in Kameng District, Arunachal Pradesh. *Journal of the Geological Society of India*, *21*(9), 464–467; Dhirendra, K., Bajpai, R. K., & Sengupta, B. (1992). Geochemistry and geothermometry of the thermal springs of Resubelpara, East Garo hills, Meghalaya, India, and their bearing on uranium exploration. *EARFAM*, *5*, 53–62; Bajpai, R., & Narayan, P. K. (2005). Natural analogue study of Resubelpara Group of thermal springs at Garo Hills, Meghalaya for demonstration of safe geological disposal of nuclear waste. *Current Science*, *88*(6), 986–989; Singh, H. K., Garg, G. C., Chandrasekharam, D., Trupti, G., & Singh, B. (2014). Physicochemical evolution of the thermal springs over the Siwana Ring Complex, western Rajasthan. *Journal of the Geological Society of India*, *84*, 668–674; Gurav, T., Singh, H. K., & Chandrasekharam, D. (2015). Major and trace element concentrations in the geothermal springs along the west coast of Maharashtra, India. *Arabian Journal of Geosciences*, *9*, 44; Dutta, A., Thapliyal, A. P., Singh, P. K., Rohilla, S., & Gupta, R. K. (2023). Geological setup and physicochemical characteristics of Munger Groups of thermal springs along Munger-Saharsa Ridge Fault, Bihar, India: A conceptual hydrogeochemical model. *Journal of Earth System Science*, *132*, 12; Pandey, G. C., & Raymahashay, B. C. (1981). Studies on some low-temperature East Indian hot springs. *Chemical Geology*, *34*(1–2), 113–129.

# APPENDIX: DATA AND METHODOLOGY

## Data

The data sets employed in this study are derived from a range of authoritative sources, including peer-reviewed scientific literature, government agencies, and publicly available geoscientific databases. The spatial distribution and attributes of thermal springs were obtained from the Geological Survey of India, conducted by the Government of India. Geological frameworks, including major and active fault systems and crustal heat flow data, were sourced from Project InnerSpace's GeoMap.[87,88,89,90,91] The earthquake catalogue, comprising seismic events with focal depths shallower than 10 kilometres between 1900 and 2023, was acquired from the National Centre for Seismology within the Government of India. A detailed summary of all data sets used is presented in **Figure A.1**.

Using QGIS-based spatial analysis, continuous variables were standardised, reclassified, and combined through a weighted overlay analysis informed by expert-derived significance scores. The resulting composite geothermal potential index identifies priority zones across India with the highest favourability for future geothermal exploration and development.

## Tools Used for Thematic Map Preparation

All thematic layers in this study were generated and processed within QGIS using its advanced spatial analysis capabilities. The proximity analyses—including distances to thermal springs, fault lines, and shallow earthquake epicentres—have been computed using the "Proximity (Raster Distance)" tool in the QGIS Processing Toolbox. This tool calculates the distance from each raster cell to the nearest vector feature, producing continuous distance raster where lower values indicate spatial closeness to the geologic features of interest, which are considered critical in geothermal prospecting.[92]

For the heat flow distribution, interpolation was conducted using the inverse distance weighting (IDW) method, available through the QGIS interpolation tool set (**Figure A.2**). IDW is a deterministic spatial interpolation technique that estimates unsampled values based on the proximity-weighted average of known data points. The power coefficient in the IDW function modulates the influence of nearby points, ensuring that interpolated values remain bounded within the range of observed heat flow measurements and reflect spatial continuity.

## SUMMARY OF DATA SETS USED FOR THE STUDY

| S. No. | Data | Source | Other Details |
|---|---|---|---|
| 1 | Thermal springs | Geological Survey of India, Government of India | 340 Thermal springs |
| 2 | Active fault | Project InnerSpace database | Scale: n/a |
| 3 | Major fault | Project InnerSpace database; Geological Survey of India, Government of India | Scale: n/a |
| 4 | Shallow seismicity (<10 kilometres) | National Centre for Seismology, Government of India | Duration: 1900–2023 AD |
| 5 | Geology | Project InnerSpace database | Scale: n/a |
| 6 | Heat flow | Project InnerSpace database | Resolution: n/a |
| 7 | Moho depth | Mooney et al. | Resolution: 1° x 1° |
| 8 | Average shear wave velocity between 110 kilometres and 150 kilometres | Schaeffer & Lebedev | Resolution: 0.5° x 0.5° |

**Figure 2.A.1:** Summary of the data (source, scale, resolution, and number of points) used in this study. Sources: Geological Survey of India, 1991; Geological Survey of India, 2025; National Center for Seismology, n.d.; Mooney et al., 2023; Schaeffer & Lebedev, 2013; Markwick et al., in preparation; Fuchs et al., 2023; Dou et al., 2024; Smithsonian Institution, n.d., *Holocene Volcano List*; Smithsonian Institution, n.d., *Pleistocene Volcano List*. (See full source information at the end of this appendix.)

## METHODOLOGY FOR MAPPING GEOTHERMAL POTENTIAL ZONES

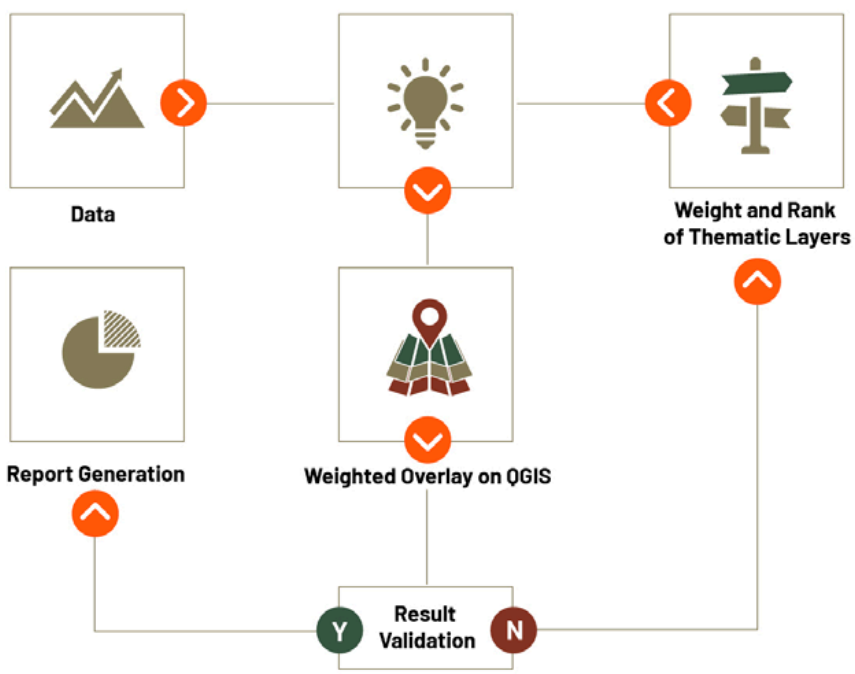



**Figure 2.A.2:** Flow chart of the methodology used for mapping of geothermal potential zones in India. Source: Chouhan, A. K., Kumar, R., & Mishra, A. K. (2024). Assessment of the geothermal potential zone of India utilizing GIS-based multi-criteria decision analysis technique. *Renewable Energy, 227*, 120552.

## WEIGHTED OVERLAY ANALYSIS SCORES

| S. No. | Layers | Unit | Weights | Suitability Score | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 4 | 5 |
| 1 | Proximity to thermal springs | km | 20 | > 6 | 5–6 | 4–5 | 3–4 | 2–3 | < 2 |
| 2 | Proximity to active fault | km | 10 | > 10 | 8–10 | 6–8 | 4–6 | 2–4 | < 2 |
| 3 | Proximity to major fault | km | 10 | > 10 | 8–10 | 6–8 | 4–6 | 2–4 | < 2 |
| 4 | Proximity to shallow seismicity | km | 10 | > 25 | 25–20 | 20–15 | 15–10 | 10–5 | < 5 |
| 5 | Geology | Era | 10 | n/a | Cenozoic | n/a | Precambrian | Palaeozoic | Mesozoic |
| 6 | Heat flow | (mW/$m^2$) | 20 | < 30 | 30–50 | 50–60 | 60–75 | 75–100 | > 100 |
| 7 | Moho depth | km | 10 | > 50 | 50–45 | 45–40 | 40–35 | 35–30 | < 30 |
| 8 | Average shear wave velocity between 110 and 150 km | (km/sec) | 10 | > 4.4189 | 4.3411–4.4189 | 4.2633–4.3411 | 4.1856–4.2633 | 4.1078–4.1856 | < 4.1078 |

**Figure 2.A.3:** Weights and suitability scores of the thematic layers for the mapping of geothermal potential zones of India. Source: the authors.

Reclassification of continuous raster layers—such as proximity to thermal features, fault zones, seismic activity, and interpolated heat flow—was carried out using the "Reclassify by Table" tool. This process involved discretising the continuous data into ordinal suitability classes based on thresholds informed by geoscientific domain knowledge and relevant published literature. Each class represents the degree of favourability with respect to geothermal potential (**Figure A.3**).

Subsequently, a weighted overlay analysis was performed to integrate the standardised thematic layers and derive a composite geothermal potential index. Each layer was assigned a relative weight, reflecting its significance in geothermal resource localisation, as determined through expert consensus and prior studies. The integration was operationalised using the QGIS "Raster Calculator" tool, where each reclassified raster was multiplied by its respective weight, and the resulting layers were aggregated to produce a final geothermal potential map. This composite output represents a continuous spatial surface depicting relative geothermal favourability across the study area, thereby enabling the identification of priority zones for detailed geothermal exploration and potential development.

## Weights for the Layers

To delineate geothermal potential zones, eight layers have been analysed based on their geoscientific significance and relevance to geothermal processes. Each layer is mapped and ranked from 0 to 5, where 5 represents the most favourable geothermal conditions and 0 the least favourable for that respective layer (**Figure A.3**). Each layer is then weighted (ranging from 0% to 100%) in accordance with its relative influence on geothermal potential (details have been provided in this appendix). The combined weighted layers provide a single, summary weighted overlay analysis, which provides a robust assessment of overall subsurface geothermal favourability.

## Additional Figure Source Information

**Figure A.1:** Geological Survey of India. (1991). *Geothermal atlas of India*. Government of India; Geological Survey of India. (2025). *BHUKOSH*. Government of India; National Center for Seismology. (2023). *Data portal.* Ministry of Earth Sciences, Government of India; Mooney, W. D., Barrera-Lopez, C., Suárez, M. G., & Castelblanco, M. A. (2023). Earth Crustal Model 1 (ECM1): A 1° x 1° global seismic and density model. *Earth-Science Reviews*, 243, 10449; Schaeffer, A. J., & Lebedev, S. (2013). Global shear speed structure of the upper mantle and transition zone. *Geophysical Journal International*, *194*(1), 417–449; Markwick, P. J., Paton, D. A., & Mortimer, E. J. (in prep). An update for the North American continent based on the previous work of Markwick, P. J., Paton, D. A., & Mortimer, E. J. (2021). *Reclus,* a new database for investigating the tectonics of the Earth: An example from the East African margin and hinterland. *Geochemistry, Geophysics, Geosystems, 22*(11), e2021GC009897; Fuchs, S., Norden, B., Neumann, F., Kaul, N., Tanaka, A., Kukkonen, I. T., Pascal, C., Christiansen, R., Gola, G., Šafanda, J., Espinoza-Ojeda, O. M., Marzan, I., Rybach, L., Balkan-Pazvantoğlu, E., Ramalho, E. C., Dědeček, P., Negrete-Aranda, R., Balling, N., Poort, J., ... Verdoya, M. (2023). Quality-assurance of heat-flow data: The new structure and evaluation scheme of the IHFC Global Heat Flow Database. *Tectonophysics*, *863;* Dou, H., Xu, Y., Lebedev, S., Chagas de Melo, B., van der Hilst, R. D., Wang, B., & Wang, W. (2024). The upper mantle beneath Asia from seismic tomography, with inferences for the mechanisms of tectonics, seismicity, and magmatism. *Earth-Science Reviews*, *255*, 104841; Smithsonian Institution. (n.d.). *Holocene Volcano List* [Database]. Global Volcanism Program; Smithsonian Institution. (n.d.). *Pleistocene Volcano List* [Database]. Global Volcanism Program.

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