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SPATIAL DISTRIBUTION OF HOT-SPRINGS IN INDIA: AN OVERVIEW

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ABSTRACT

Hot-springs, the heterogeneous presence of rising water with usually higher temperature than the immediate surrounding, have attracted the human kind and simultaneously arose curiosity to know the underlying causes behind their presence in certain locality. In this paper, an attempt has been made to map the distribution of hot-springs in India at the one hand and to find a relation with certain geological phenomena like presence of fault lines, heat flow regions of the continental crust, geothermal provinces, tectonic movements of lithosphere and vertical displacement as a result of plume-lithospheric interactions and geological hot-spots.

Keywords: Fault lines, heat flow regions, geothermal provinces, hot-spots, plume-lithospheric interactions and hot-springs.

1.1 Introduction

Springs are a part of natural landscape, gifting a significant character to one space over the other. Heterogeneous presence of rising water with temperature above the immediate surrounding have fascinated the world over and arose the curiosity to understand the flow mechanism and its composition. A hot water springs or a hydrothermal spring is a place where warm or hot groundwater comes out from the earth on a regular basis for at least a periodical part of the year and is significantly above the ambient ground temperature (Bisht et al., 2011). They emerge in most of the ecosystems on earth, including a wide range of subaerial terrestrial settings and as subaqueous discharge from the floors of freshwater and marine body of water (Springer et al., 2008). Water coming out from the springs are either fresh groundwater or marine water which get heated by various heat flow mechanisms prevailing in its system. The water present within cracks and crevasses in rock, sand, clay, gravel or in spaces between particles of materials also add to it (Thompson et al., 2003).

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Hot-springs are highly concentrated in the areas of modern volcanic activities and fault zones that allow circulation of thermal fluids. The possible reasons of thermal nature of springs have been found varying, depending upon its location and phyico-chemical nature of fluids. Warm springs near the town of Hot-springs, South Dakota, USA owe its warmth to the presence of partially cooled magma at shallow depth (Hildenbrand and Kucks, 1981). The source of heat for the springs near Urugano volcano, Indonesia comes from the intrusive body of andesite to diorite rocks (Saibi et al., 2016). Hot-spring at Barkeshwar, India exists as a result of volcanic or tectonic activities belonging to Chhotanagpur gneiss (Chaudhary et al., 2017). In Japan, most of them are related to volcanic eruptions (Zaizen et al., 2017). Few springs are in extensional geothermal systems, concentrated at fault tips and in fault interaction zones where porosity and permeability are dynamically maintained (Curewitz and Karson, 1997; Faulds et al., 2010 and Glen et al., 2013). Springer et al. (2008) have also calculated the density of hot-springs in Orogen (0.018 springs/km^2) and Arizona (0.017 springs/km^2) in western USA. Many more examples are found in different parts of the globe.

Most of the hot-springs forms a part of the geothermal systems prevailing on the earth's surface. In these systems, other than volcanoes, mainly two types of underground heat transfer mechanism can be considered: conduction from inside the deep earth and convection of underground fluid. In general, heat transfer of underground water is more efficient than heat transfer inside rocks. Therefore, hot springs exist in areas that have high geothermal gradient (Zaizen et al., 2017). Heated by geothermal gradients (Pradhan and Jena, 2016), water in the springs comes out either following the fault line, joints, interspaces from sedimentary rocks (Young et al., 2007; Gupta et al., 2017 and Gautam et al., 2018), along faults through hot igneous and metamorphic rocks (Pradhan and Jena, 2016), caverns or point of intersection between piezometric level and ground surface (Gautam et al., 2018). The possible causes of high geothermal gradients include the presence of partially cooled magma at shallow depth (Hilderbrand and Kucks, 1981), high heat production from disintegration of radioactive elements (Guha, 1970 a & b), transport of heat and fluids from depth in a cyclic system (Singh et al., 2015) and exothermic reactions (Pradhan and Jena, 2016; Gupta et al., 2017 and Gautam et al., 2018) produced by chemical weathering (Hilderbrand and Kucks, 1981).

Aquifer lithology also controls the spring temperature (Shi et al., 2017). At Rajgir, Singh et al. (2015) suggests the presence of granite as the source of heat to the circulating fluid. In the Kargding and Batang geothermal field (China), the springs exposed in the crystallized limestone, crystalline dolomite limestone and schist show lower temperature than those exposed to granite (Shi et al., 2017).

The scientific communities have tried to understand the hot-spring ecosystem throughout the world but their approach of study has been largely regional rather systematic. The earlier studies

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are concerned with the regional sources of water and heat for a group of springs prevailing in that region. Geological setting of the whole country or region has not been looked upon in details to analyze the spatial distribution of hot-springs in the regions. With this background, the present study tries to give a reasoned account of the spatial pattern of hot-springs in the geographical boundary of India. A systematic analysis has been considered for this purpose as many of the hot-springs have common genesis. Their locational settings are associated with the geological and tectonic set up of the country. They are present along most of the fault lines. Spring zones coincide with the geothermal provinces, which in turn are related to the lithospheric heat flow of the subcontinent. The distribution of mantle-plume and hot-spots which have shaped the Indian subcontinent are also related to the locational setup of the hot-springs. Therefore, the main aim of this study is to analyses the spatial distribution of hot-springs in India.

1.2 The Study Area

India is located in the eastern part of northern hemisphere of the globe, extending from 8^{o}4’ N to 37^{o}6’ N and 68^{o}7’ E to 97^{o}25’ E. Neighbours include Pakistan, Afghanistan, China, Nepal, Bhutan, Myanmar and Bangladesh on land and Maldives and Sri Lanka in the Ocean. Physiographically and culturally, India is home to almost all the geomorphic structures, societies, races and linguistic families. Extending from mighty Himalaya to Indian Ocean, the nation is crisscrossed with mountains, hills, plateaus, plains, rivers, lakes, mineral deposits, vegetation, faults and the core of the present study i.e. hot-springs.

1.3 Database and Methodology

The systematic analysis of hot-springs in India is based on the secondary sources of data. The database for the locational set up of most of the hot-springs along mountains, hills and plateau regions, fault lines, geothermal provinces and heat flow map of India have been taken from Geothermal Atlas of India (1991). For mapping the plume affected areas and mobile belts, the map of Rawal and Veeraswamy (2003) has been considered as the base map for further analysis. The relationship between hot-springs with each of physiography, fault lines, heat flow regions, geothermal provinces and mantle-plumes lithospheric interaction have been analysed with the help of overlay technique using ArcGis 10.2 software.

1.4 Result and Discussion

For the perennial flow of hot-springs, two major sources are prominent; source of water to feed the springs and source of heat to provide thermal nature. If the flow is discontinuous, the springs have seasonal character whereas if the flow stops permanently at some point of time, the springs may be extinct. The perennial flow along fault lines may also get affected by obstruction on the

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stream flow path due to natural and anthropogenic reasons; less flow of water, blockage on spring mouth due to landslide or human construction (Gautam et al., 2018).

The source of water in these springs differs from site to site. If the springs are located at the foothills of mountains and hills, then the source could be rain or snow that penetrates the surface and combine with groundwater to flow along the slopes and come out at various points. *Sahastradhara* near Dehradun, India can be the best example where thousands of such streams emerge from the foothills. If the springs are at the foothills of old mountain chain, then along with rain water, groundwater follow the fault lines developed in the sedimentary and metamorphic rocks. The overlying pressure on the aquifer may also force them to rise up through caverns and come out in the form of springs. Suction effect due to high pressure gradient along the cavity can also be one of the reasons for emerging groundwater in the springs. Apart from these, springs can also emerge at the point where piezometric level of groundwater and ground surface meet.

Similarly, there can be various sources of heat to these springs: (i) The flowing water reacts with the surrounding metals present and heat is released as a result of exothermic reaction. This heated water further reacts with Sulphur Dioxide present in most of the mountains, increasing its temperature and granting curative property. This negates the common belief that spring water get heated due to the presence of Sulphur. Under normal conditions, Sulphur do not react with cold water. (ii) The presence of radioactive elements present in the rocks also adds heat to the groundwater. (iii) Groundwater may pass through volcanic zone or partially cooled magmatic zone having high thermal nature i.e. through geothermal provinces.

1.4.1 Factors Affecting the Sites of Hot-Springs

Hot-springs are not homogenous to the physical landscape of India but follow a certain pattern. They are in synchronization with some of the earth's geological characters such as high lands (mountains, plateaus and hills), fault lines, geothermal provinces, internal heat flow and plume-lithospheric interaction.

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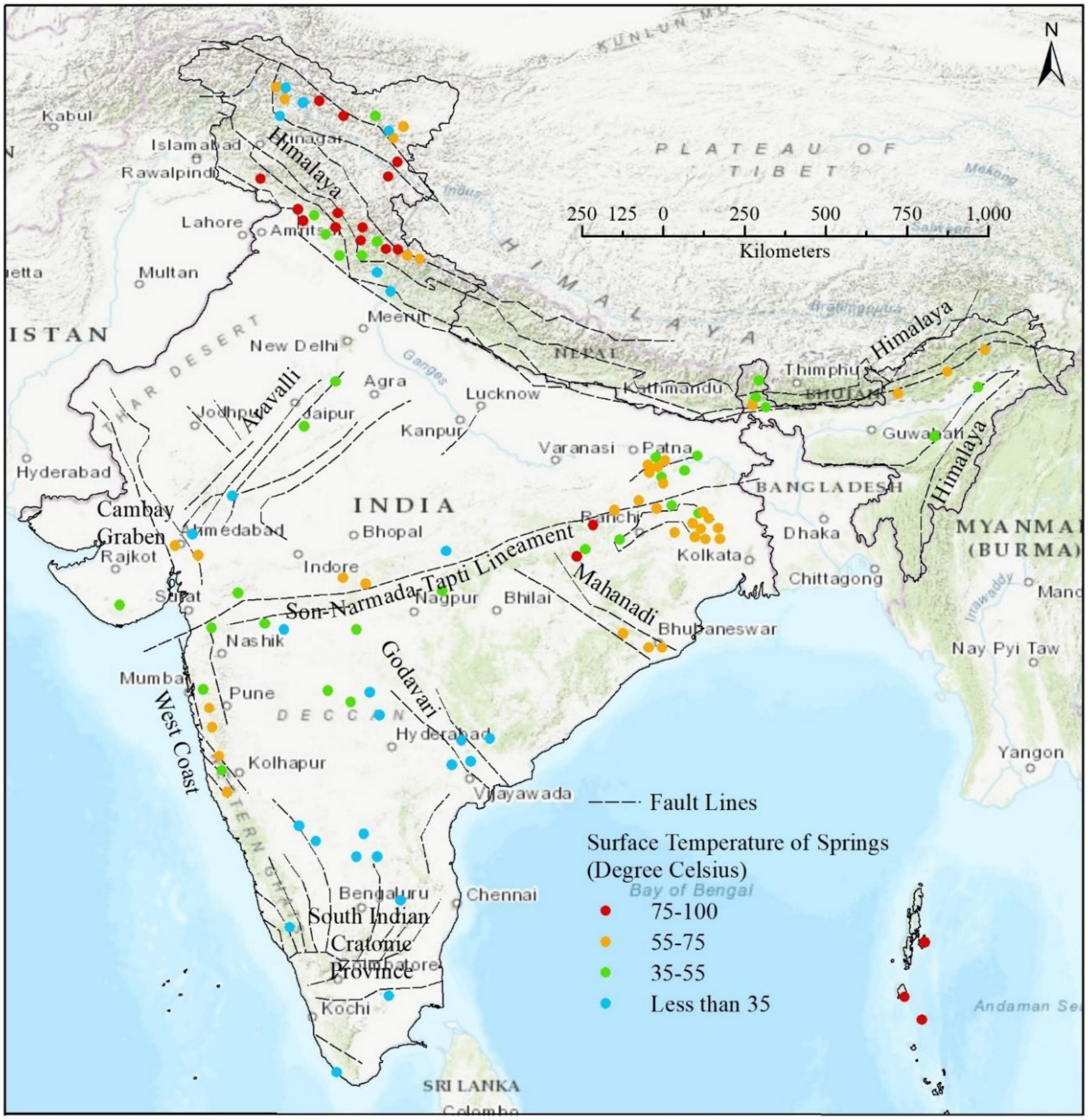

Fig 1: Spatial Distribution of Hot-Springs along Fault Lines in India

(i) Physiography

Hot-springs are located on the specific physiographic division of India. They are at the foothills of major mountain chains (Himalayan arc, Vindhyan Range, Aravalli range, western Ghats and grabens of Eastern Ghats) and plateaus (Chhotanagpur Plateau and Peninsular India). They are highly correlated with the high topography (Fig 1). From this map, it becomes crystal clear that no springs are found in the plains of India.

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(ii) The Presence of Fault Lines

Geotectonic activities have given rise to various faults in the mountain systems of India. These lithospheric cracks give passage to the groundwater and percolated rain water to emerge as springs. With respect to lithospheric setting of the Himalaya, they occur along major thrust. Other places such as Aravalli, Son-Narmada-Tapti lineament of Vindhyan Range, Western Ghats, Godavari and Mahanadi grabens of Eastern Ghats have developed various faults in their sedimentary and metamorphic rocks through which springs sprout (Fig 1).

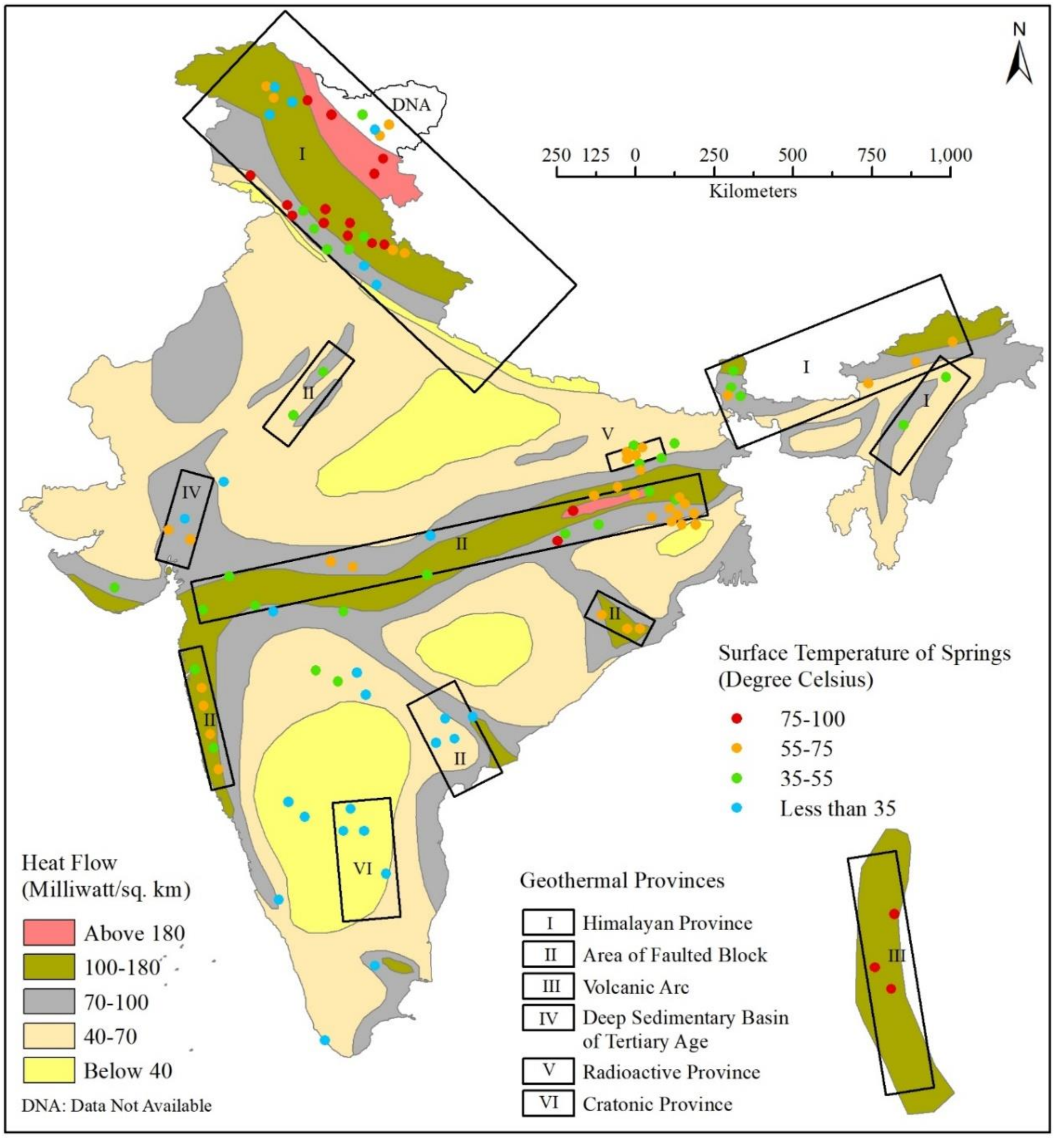

Fig 2: Hot-Springs, Geothermal Provinces and Heat Flow Regions of India

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(iii) Heat Flow Regions of India

In hot-springs areas, the conductive transfer of heat is predominant (Roy and Rao, 2000). The knowledge of surface heat flow is an important parameter to understand the thermal state of earth's crust. These affect the hotness of the spring water in great way. In the Himalayan Province, the heat flow is above 70 milliwatt per km^2 along which most of the hot-springs are located. This high heat flow is the result of continuous continental convergence between Indian and Eurasian plates. The magmatic actions in various geological periods have contributed to this heat. Apart from Himalayan belt, the central zone of India along with Andaman and Nicobar Volcanic arc, northern part of Western Ghats, and few patches in Mahanadi and Godavari graben too have heat flow between 100^{o}C to 180^{o}C. These are the places where most of the hot-springs have surface temperature between 35^{o}C to 75^{o}C. Geothermal provinces of deep sedimentary basin of tertiary age, radioactive elements and cratonic belt have internal heat flow below 70^{o}C and hot-springs with surface temperature below 55^{o}C. Heat in the cambay graben is due to faulted area with late tertiary reactivation, plutonism and recent seismicity (Shankar et al., 1991). The places where the heat flow is above 180 milliwatt per km^2 give way to those springs whose surface water temperature is above 100^{o}C (Fig 2). Hence, it can be seen that almost all the springs with surface temperature above 35^{o}C are situated along the surface where the internal heat flow is above 70 milliwatt per km^2.

(iv) Geothermal Provinces

Geothermal provinces are the manifestation of spatial distribution of heat-flow in the Indian Lithosphere. From the overlay map of hot-springs and geothermal provinces (Fig 2), it can be ascertained that these geothermal provinces are associated with the thermal nature of spring water. The water present either as magmatic, connate or meteoric, gain their thermal character from these geothermal provinces which emerge at places in the form of springs. On the basis of sources of heat, the geothermal provinces have been categorized into six i.e. Himalayan province, area of faulted blocks, deep sedimentary basin of tertiary age, radioactive province, and cratonic provinces.

(v) Plume-Lithospheric Interaction

The source of heat for the heat flow map of India and the geothermal provinces are related to the tectonic processes which have given India its present shape. Earth's interior is not stable. Hence, the lithosphere, floating on the asthenosphere are continuously modified. This modification is the result of plume-lithospheric interaction whose surface manifestation is the geological hot-spots. They have played a major role in separating Indian subcontinent from Gondwana and giving the present shape of peninsular India. Broadly, four geological hot-spots have shaped Indian Peninsula i.e. Marion, Kerguelen, Crozet and Reunion. Eastern parts were shaped by Kerguelen

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and Crozet hot-spots whereas western boundary got its shape from Marion and Reunion hot-spots along which Madagascar and Seychelles have been separated from western boundary. Reunion hotspot has given way to the formation of Western Ghats, Cambay Graben and Son-Narmada-Tapti Lineament (Vindhyan Range). Crozet gave way to Mahanadi Valley and Kerguelen separated Meghalaya hills form Chhotanagpur Plateau (Rawal and Veeraswamy, 2003).

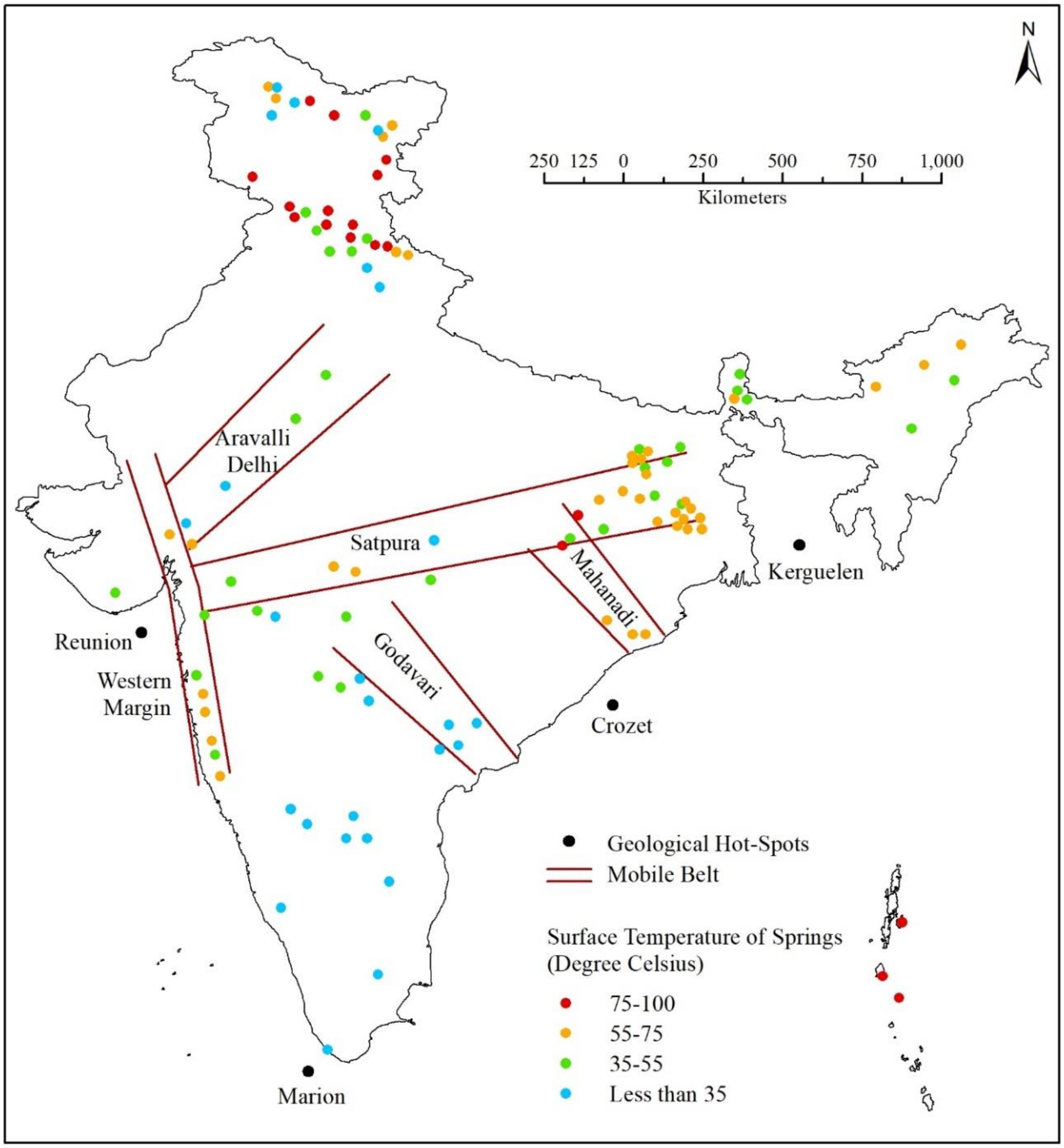

Fig 3: Hot-Springs of India along Geological Hot-Spots and Mobile Belts

The heat from these mantle-plumes causes rocks in the lower lithosphere to melt. This loose lithosphere is known as hot mobile belts. In the flood basaltic eruption, the mobile belts probably form major corridors of large scale magmatism. Cambay graben, western margin, Son-Narmada-Tapti lineament converge at Reunion hot-spot giving rise to the junction of mobile belts (Aravalli Delhi Mobile Belts, Satpura Mobile Belts and Western Margin Mobile Belts) in all three directions (Fig 3). This junction is still weaker and continuously provide the heat to the areas. Apart from these mobile belts, Godavari and Mahanadi mobile belts are responsible for the heat flow in the eastern region as they are also associated with mantle plume and hot-spots. Hence, the source of heat for springs in these regions is largely the result of this plume-lithospheric interaction. Fig 3 depicts the zone of mobile belts, which coincide with the spatial distribution of hot-springs having high surface temperature.

1.4.2 Spatial Distribution of Hot-Springs

The fascinating hot-springs are not solitary to one place but are spread in most of all the mountainous regions of the world. Within the limits of India itself, they are found more frequently in some areas than the other. The actual sites where they are present are of considerable varieties in their physical surroundings. They exist in the depths of the sea, in the beds of rivers, in low-lying alluvial tracs where no rock is exposed, in the strata of many different formations, and at elevations varying from the low depths up to those which are 4877 m above it (Ball, 1893-1896).

Many of the springs present in India were heard of and recorded by travelers through the regions where they occur. There are more than 300 known thermal spring localities in India. Of which, 112 are present in north-western Himalayan States of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. The localities extend over a stretch of about 700 km in a north-west to south-east direction. The eastern extension of Himalaya also manifests a number of thermal springs in the states of Sikkim and north-eastern states. Over 30 hot-springs are located in Subansiri and Kamala valleys in the northern part of Arunachal Pradesh (Shankar et al., 1991). Hot-springs like Nattha Waree, Pai are present in Andaman and Nicobar arc. The thermal springs with not very high temperature and discharge are also found near Cambay in Gujarat along the dimension of 200 km length and 50 km width. The Kathiawar peninsula has one in Tulsishyam with temperature 56^{o}C. Few other present in Eastern Gujarat are Unai, Tuwa, Dholera, Chabsar, Gandhar etc. Few hot-springs like Tatapani, Suraj kund, Sita kund, Brahma kund and others are present in the central India aligning with the Son-Narmada-Tapti alignment up to Chhotanagpur Plateau parallel to Vindhyas in the states of Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, Jharkhand, Bihar and West Bengal. West coast of India along Maharashtra is also characterized with a series of thermal springs in Unkeshwar, Akoli, Khadgaon etc. The springs of low temperature and discharge are also found in Haryana at Sohna, at the foothills of Aravalli

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range. Godavari and Mahanadi valley also nurtures some of the springs in India along with few in Tamil Nadu.

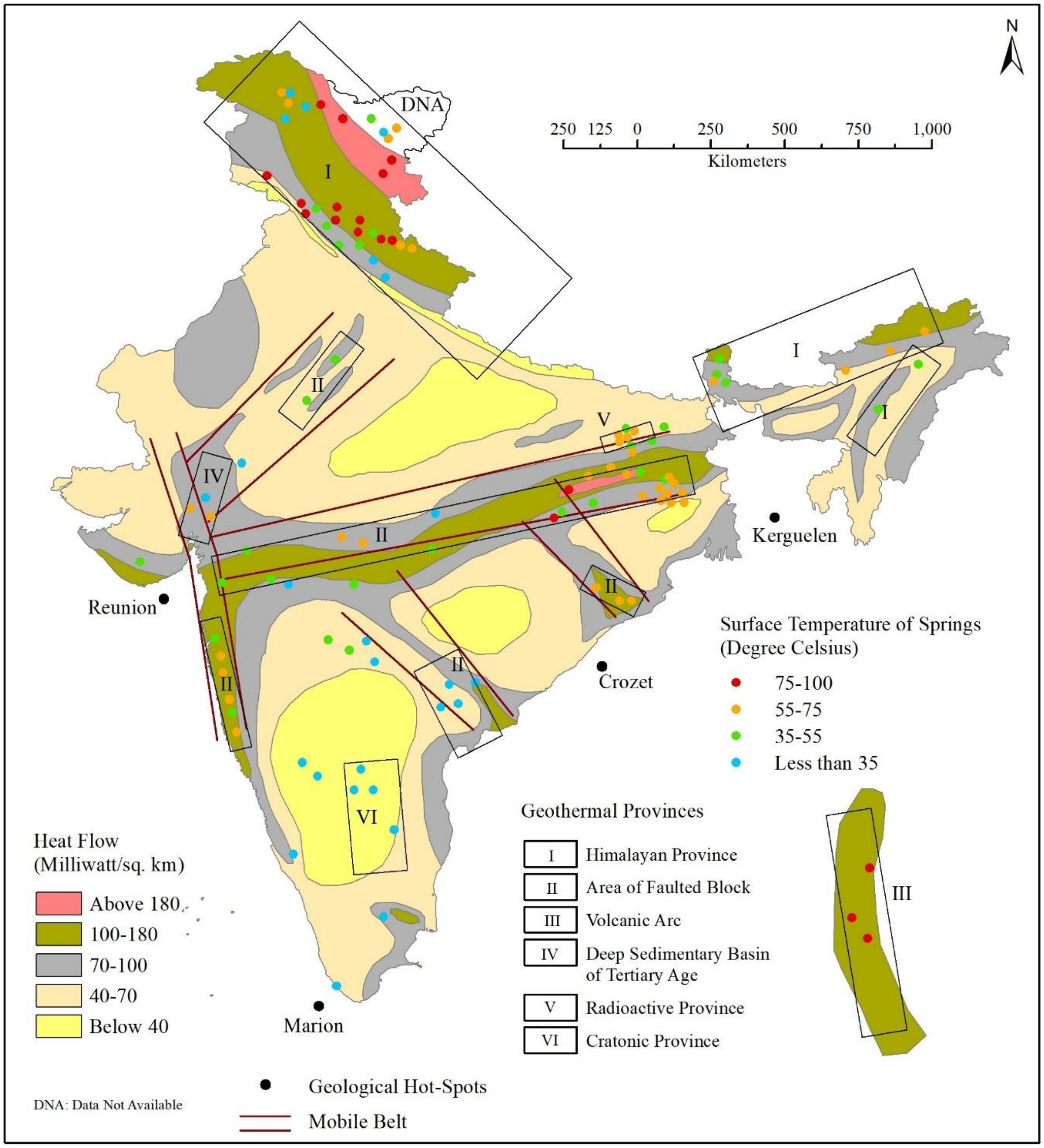

Fig 4: Spatial Distribution of Hot-Springs along Geothermal Provinces, Heat Flow Regions, Geological Hot-Spots and Mobile Belts

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The hot-springs of India are not of same surface temperature but differ with each other, which depend upon its place of existence. The hot-springs with temperature more than 75^{o}C are present in just three zones i.e. North-western Himalaya, Eastern ends of Son-Narmada-Tapti lineament and Andaman and Nicobar arc (Fig 1). The hot-springs with surface temperature ranging between 55^{o}C and 75^{o}C are present in north-western Himalaya, Cambay region of Gujarat, west coast of Maharashtra, Son-Narmada-Tapti geothermal belt and Mahanadi basin of Odisha. This region is also characterized with few hot-springs having surface temperature between 35^{o}C and 55^{o}C. Other areas in this category include the springs of Aravalli range of Haryana, Naga-Lushai region of north-east India and Godavari basin of Maharashtra and Andhra Pradesh. All the Dravidian states manifest thermal springs less than 35^{o}C.

The thermal nature of hot-springs are the pointers to the presence of geothermal regimes in various domains. They are highly correlated with the geothermal provinces which showcase the internal heat of the earth. These act as the source of heat for the circulating fluid. Based on geographical locations, geotectonic setting and geothermal characteristics, the hot-springs have been categorized into six provinces: (i) Himalayan province (ii) Area of faulted blocks (iii) Volcanic arc (iv) Deep sedimentary basin of tertiary age (v) Radioactive Provinces, and (vi) Cratonic Provinces (Fig 4).

Hot-springs in the Himalayan provinces are characterized by the tertiary orogenic belt with tertiary magmatism. It includes most of the land uplifted by the crustal-crustal lithospheric convergence of Eurasian and Indian plate, during which the sediments underlying the Tethys sea uplifted to form mountains. This took place in various geological time frame giving rise to various horizontal fault lines. Most of the springs of this province lie along these fault lines. In this process, water of Tethys sea may have accumulated in voids and spaces during the orogeny which along with percolated meteoric water emerge as springs at various places. Magmatic actions along with the orogeny are source of heat to these springs.

Springs in the area of faulted blocks include Aravalli, Naga-Lushai, west coast, Son-Narmada-Tapti Lineament and Mahanadi and Godavari grabens on eastern coast. Except Naga-Lushai thermal springs which has similar nature as observed in the foothills of Himalaya, all other physical structures are geologically related and have been formed long ago. With the time, faults have developed along which springs have found their way. Hot-springs of temperature higher than 35^{o}C are found in this province. Eastern parts of Son-Narmada-Tapti lineament have also reported few springs having surface temperature above 100^{o}C whose thermal nature is added by the presence of radioactive metals and rocks such as dolomite. After Himalaya, this province manifests maximum number of hot-springs in India. The source of heat for this province varies with the location as they are found in 5 patches over India i.e. Son-Narmada-Tapti lineament, West Coast, Aravalli range, Mahanadi and Godavari grabens (Fig 4). The heat in springs along

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Son-Narmada-Tapti Lineament is attributed by Satpura mobile belt. Springs along West Coast, Aravalli Range, Mahanadi and Godavari grabens get their heat from Western Margin mobile belt, Aravalli Delhi mobile belt, Mahanadi mobile belt and Godavari mobile belt respectively. They all have acquired their heat from mobile belts associated with Geological hot-spots as a result of plume lithospheric interaction.

In India, Andaman and Nicobar Islands are the only land formed by volcanic activities. Here, the springs are of more than 200^{o}C of surface temperature. Springs at Cambay basin have originated along faults in deep sedimentary basin of tertiary age. Their surface temperature ranges below 75^{o}C. Few springs at the foothills of Rajgir (Bihar) owe its heat to the presence of radioactive elements in its geothermal system. They too are along the fault line developed in their age old formed rocks. Heat in the Cratonic provinces are due to the presence of Dharwar carton which was once a part of Gondwana super-continent separated by the action of geophysical forces.

1.5 Conclusion

The understanding about spatial distrubution of hot springs in India reveals that these springs are broadly the result of natural phenomena affected by the heat underneath; in the lithosphere. This heat is the result of geotectonic activities and thus a pattern is followed on the localisation of these springs. Most of all have their existence on the high topography and fed by either groundwater, sea water or rain water. The location of these springs coincides with the fault lines, geothermal provinces, heat flow regions and hot mobile belts of the Indian lithosphere. Hence, it can be stated that mantle-lithospheric interaction in the form of plume affceted areas, geological hot-spots and mobile belts affect the distribution and shaping of mountains, hills, geothermal provinces and heat flow regions directly, and hot-springs are the cumulative outcome, originating out of systematic interaction between the geological (mantle-lithospheric interactions, mantle plume, geogogical hot-spots, mobile belts and minerals present in rocks), geomorphic (physiography, fault lines and piezometric levels) and geothermal (internal heat flow and geothermal provinces) settings on the planet earth.

This systematic analysis of spatial distribution of hot-springs also provide a clue to understand the geological framework in which the present landmass has acquired its shape and geomorphic structure, through their sources of water and heat. Hence, the hot-springs are not only the fascinating feature of landscape but also account for understanding the lithological characteristics and geological history of the landmass.

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REFERENCES

Ball, V. 1893-1896. On the Volcanoes and Hot Springs of India, and the Folklore connected therewith, Proceedings of Irish Academy, 3: 151-169.

Bisht, S. S., Das, N. N. and Tripathi, N. K. 2011. Indian Hot-Water Springs: A Birds Eye View. Journal of Energy, Environment and Carbon Credits, 1(1): 1-15.

Chaudhary, B., Chowdhary, T. and Chattopadhyay, B. 2017. Comparative Analysis of Microbial Diversity in two Hot Springs of Barkeshwar, West Bengal, India. *Geonomics Data* (12): 122-129.

Curewitz, D. and Karson, J. A. 1997. Structural Setting of Hydrothermal Outflow: Fracture Permeability Maintained by Fault Propagation and interaction. *Journal of Volcanology and Geothermal Research*, 79(3-4): 149-168.

Faulds, J. E., Coolbaugh, M. F., Bouchot, V., Moek, I. and Oguz, K. 2010. Characterizing Structural Control of Geothermal Reservoir in the Great Basin, USA and Western Turkey: Developing Successful Exploration Strategies in Extended Terranes. *Proceedings World Geothermal Congress*, 11p.

Gautam, A., Rai, S. C. and Shekhar, R. 2018. Hot-Springs of Rajgir: Spatial Re-distribution and Conservation. *Sree Journal of Spatial Perspectives*, 2(1): 1-9.

Glen, J. M. G., Egger, A. E., Ippolito, C. and Athano, N. 2013. Correlation of Geothermal Springs with Sub-Surface Faults Terminations revealed by High Resolution, UAV-Acquired Magnetic Data. Proceedings of Thirty-Eighth workshop on Geothermal Reservoir Engineering, Stanford: Stanford University.

Guha, S. K. 1970. Report on Drilling and Thermal Logging Around Hot-Springs of Rajgir Area, Bihar. GSI Unpublished Report.

Guha, S. K. 1970. Some Aspects of Studies on the Thermal Springs of Rajgir Area, Bihar, Records of papers on groundwater potential in hard rock area. *Geol. Sci. Ind.* – Ind. Stand. Inst., New Delhi.

Gupta, B. K., Prakash, P. and Ahmad, M. F. 2017. Water Quality of Rajgir Hot Springs, Nalanda Bihar. *International Journal Emerging Trends in Science and Technology*, 04(8): 5447-5464.

Hildebrand, T. G. and Kucks, R. P. 1981. Gravity and Magnetic Features and their Relationship to the Geothermal System in Southwestern South Dacota. United States Department of the Interior Geological Survey.

ISSN: 2455-8834

Volume:04, Issue:02 "February 2019"

Pradhan, B. and Jena, R. 2016. Spatial Relationship between Earthquake, Hot-Springs and Faults in Odisha, India. Earth and Environmental Science, (37) pp 1-13.

Raval, U. and Veeraswamy, K. 2003. Modification of Geological and Geophysical Regimes due to Interaction of Mantle Plume with Indian Lithosphere. *Journal of the Virtua Explorer*, 12: 117-143.

Roy, S. and Rao, R. U. M. 2000. Heat Flow in the Indian Shield. *Journal of Geophysical Research*, 105: 587-604.

Saibi, H., Setyawan, A., Aboud, E., Barianto, D. H., Nishijima, J. and Ehara, S. 2008. Relationship between the Locations of the Hot-Springs and the deducted Subsurface Structure from Gravity Data Analysis in Urgaran Volcano (Indonesia). *Geophysics*, pp 167-173.

Shankar, R., Guha, S. K., Seth, N. N. and Mathuraman, K. 1991. *Geothermal Atlas of India*. Special Publication, Geological Survey, India.

Shi, Z. Liao, F., Wang, G. Xu, Q. Mu, W. and Sun, X. 2017. Hydrogeochemical Characteristics and Evolution of Hot Springs in Eastern Tibetan Plateau Geothermal Belt, Western China: Insight from Multivariate Analysis. *Geofluids*, Hindawi.

Singh, H. K., Chandrashekharan, D., Trupti, G, and Singh, B. 2015. Geochemistry of Rajgir Munger Metasedimentary Springs of Bihar, India. World Geothermal Congress, Melbourne, Australia.

Springer, A. E., Stevens, L. E., Anderson, D. E. Partnell, R. A., Kreamers, D. K., Levin, L. A. and Flora, S. 2008. A Comprehensive Springs Classification System. Integrating Geomorphic, Hydrogeochemical and Ecological Criteria; In, Stevens, L. E. and Meretsky, V. J. (eds.) *Aridland Springs in North America*, Tukson: University of Arizona Press and the Arizona-Sonora Desert Museum, 49-75.

Thompson, C. 2003. Tonopah: Its water under the Bush. *The Arizona Republic*, p 12.

Young, M. C. 2007. *Hot Springs and Hot Pools of the Southwest Publisher: Aqua Thermal Access*, Volume 4, pp 8.

Zaizen, T., Fujmitsu, Y. and Nighijima, J. 2017. Subsurface Structure in Oita, Hot-Spring Area Inferred from Gravity Data, Eastern Kyushu, Japan. *Proceedings 2nd Workshop on Geothermal Province Engineering*, Stanford University, Stanford, California.

