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Geomorphotectonics of the Kathiawar (Saurashtra)-Kutchch outlier: A spatial statistical approach

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Abstract
The present work explores the geomorphotectonics of the Kathiawar (Saurashtra)-Kutchch Outlier in Gujarat, India north of the SONATA lineament. Using spatial statistics, the author explores intricate links between spatially resolved data, reveal patterns and correlations that drive the region's geological history. The work addresses an underlying issue, i.e., that of finding the spatial position of entities under study, which is a central issue in spatial analysis. The methodology combines several spatial analytic methods in order to derive a detailed representation of the geomorphotectonics of the area. Results of this study would make an important contribution to the ongoing task of understanding the geological history of the Kathiawar (Saurashtra)-Kutchch Outlier, providing insight to the complex processes that have created this peculiar geological unit.
Keyword: Indian Subcontinent, Peninsular, Ex-Peninsular, Kathiawar-Kutchch, Outlier, Lothal

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I. Introduction

Spatial analysis, or geospatial analysis in the context of the present topic, encompasses several tools and analytic approaches, particularly spatial statistics. Spatial statistics is concerned with the analysis of data that has a spatial (location) attribute. This form of analysis searches for patterns or correlations in recorded data of a process that occurs across a distance. Spatial analysis presents complex challenges, many of which are neither well defined nor entirely answered yet serve as the foundation for current research. The most fundamental of them is the challenge of determining the spatial location of the entities under investigation. The classification of spatial analytic techniques is complex because of the enormous number of diverse fields of research involved, and the numerous fundamental approaches that might, the several core methodologies that can be used, as well as the numerous forms that data can take.

Spatial statistics are utilised in a variety of research, such as pattern analysis, shape analysis, surface modelling and prediction, spatial regression, statistical comparisons of spatial datasets, statistical modelling and prediction of spatial interaction, GIS approaches, and others. Spatial statistics are grouped into five types: descriptive, inferential, exploratory, geostatistical, and economic.

Background Information of Study

The current study is an outgrowth of the study conducted on spatially dependent multivariate geothermal hot spring data from two regions with different geologic- monumental settings a 2400 km-long arcuate belt in the tectonically active Extra-Peninsular Himalayan region and Late- Precambrian or Proterozoic mobile belts in the Central Highland in an else stable mainland or guard of Peninsular India, which were subjected to robust multivariate statistical analyses and collected in the book: Geostatistics applied to fluid geochemistry of geothermal fields in peninsular and extra-peninsular India (Amitabha Roy, 2024; ISBN 979-8-89222-356-0).

The geological regions of India generally follow unique physical features: 1) The extra-Peninsula, often known as the Himalayas, are large crescent-shaped mountain ranges with a significant southerly convexity that surround the whole northern edge of the Indian Subcontinent; 2) Indo-Gangetic Alluvium Plain; 3) The Peninsular shield-shaped in the form of a vast inverted triangle, bounded on the west by the Arabian Sea, on the east by the Bay of Bengal, and on the north by the Vindhya and Satpura ranges; and 4) two outliers: Shillong or Meghalaya plateau is in the east, and the Kutchch-Kathiawar plateau is to the west.

Association of Geothermal Fields and Tectonic Settings: There are around 340 hot springs dispersed across two litho-tectonically diverse regions of India: the peninsular and extra-peninsular India. Geothermal fields and tectonic settings have a remarkable link, whether in the extremely active Extra-Peninsular region or the stable late Precambrian Proterozoic mobile belts in the Central Highlands of the Peninsular Shield. The GPS

coordinates of every geothermal spring were placed on a Google map. The geothermal overlay map was then layered on the geologic-tectonic map of India (Fig. 2B), which was used as the basis map.

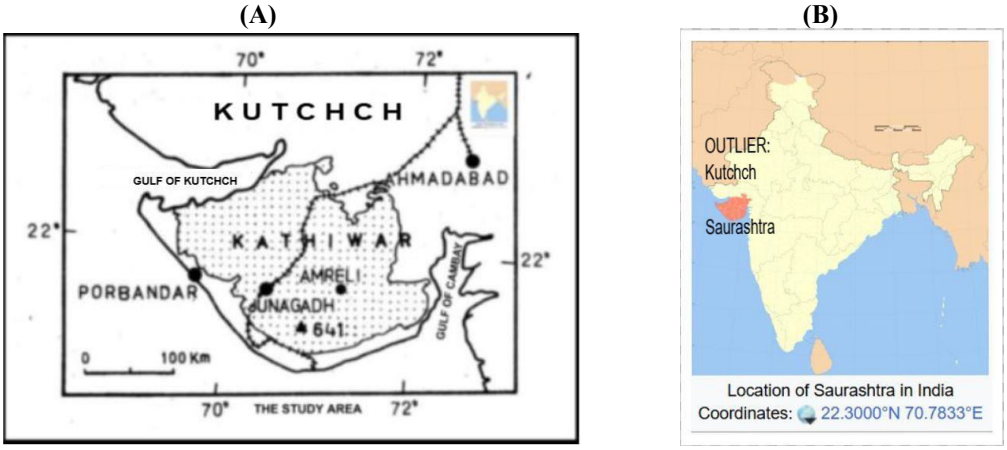
The study's goal was to use a comprehensive statistical/mathematical model study to provide insight into identifying two suites of separate geothermal systems between two diverse geotectonic settings in India's Peninsula and extra-Peninsula. Statistical analyses separate non-magmatic thermal sources as alkaline K-Na-HCO_3 from magmatic thermal sources as acidic Cl-HCO_3-SO_4-Na in Extra-Peninsular springs. There is variety in both lithological and multidirectional tectonic contexts, which affects fluid geochemistry.

The current study using the knowledge gained, would be an amalgamation of geotectonic settings, their striking correlation with the disposition of hot springs, and fluid geochemistry in determining the tectonic environment of the Kutchch-Kathiawar outlier, which, in terms of statistics, is a data point (currently geospatial) that differs significantly from other prevalent observations.

The Study Area

Fig. 1. Location Map

(A) **(B)**

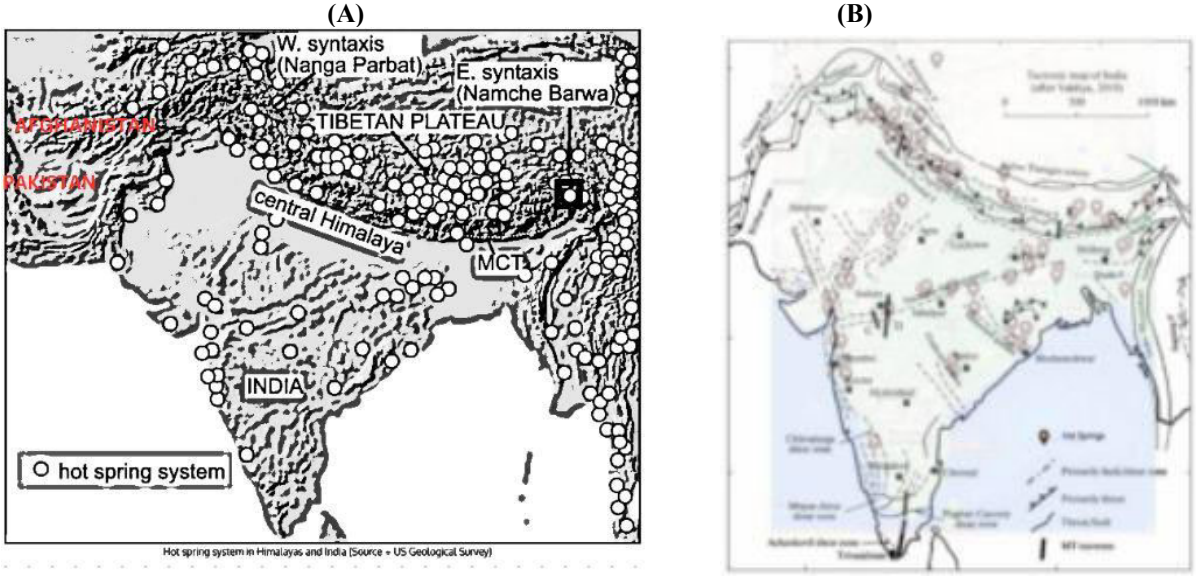


The Saurashtra (Kathiawar) outlier (Fig. 1), is located in southwestern Gujarat state, west-central India, and is bordered by the Little Rann (marsh) of Kachchh (Kutch) to the north, the Gulf of Cambay to the east, the Arabian Sea to the southwest, and the Gulf of Kachchh to the northwest. It has a narrow neck in the northeast that links to the Gujarat mainland. The settlement of Kathiawar dates back to the third millennium BC. Archaeological relics of the Harappan civilisation can be found in Lothal and Prabhasa Patan (Patan Somnath), named after the Harappa village in Pakistan.

Geospatial Association of Geothermal Hot Springs and Tectonic Settings

Fig. 2. Indian subcontinent's Queen's hot spring necklace : Geothermal Map overlay on Tectonic Map

(A) **(B)**



(C): Juxtaposition of Sulaiman-Kirther-Hindukush and Kutchch-Kathiawar arcate

The Himalayan system, which consists of large crescent-shaped mountain ranges with a noticeable southerly convexity, surrounds the whole northern margin of the Indian subcontinent. The world's highest and youngest mountain ranges span 2400 km, from Nanga Parbat (8114 m) in the west to Namcha Barwa (7755 m) in the east, south of the Indus Valley.

The Himalayas bend dramatically near the western end to meet the Karakoram-Hindukush Ranges of Pakistan and Afghanistan. The mountain ranges join the north-trending Indo-Myanmar Arc, represented by the Naga Hills and the Arakan Yoma, with a similarly severe bending at their eastern end. All throughout its lengthy stretch of tectonic belt, geothermal hot springs arestudded with hot springs, presenting a sparkling image of the Indian subcontinent's Queen's Necklace in Central Asia (Fig.2A).

II. Geomorphotectonics of the Kathiawar (Saurashtra)-Kutchch Outlier

Several researchers were recently of the opinion that the Kutchch Kathiawar plateau, though an extension of the Peninsular plateau (because Kathiawar is made of the Deccan Lava and there are tertiary rocks in the Kutch area), is now treated as an integral part of the Western Coastal Plains as they are now levelled down. The Journal of Geophysical Research: Solid Earth, published by Wiley and the American Geophysical Union (Earth Scences. Online ISSN-2169-9356; Print ISSN: 2169-9313) considered the region as an extension of the Indian Peninsula and proposed block faulting based on the plateau's geometric shape

In geographic statistics, an outlier is an observation that differs significantly from other values in a random sample of a population. Using the same approach, Kathiawar-Kutchch is an outlier located or isolated from any evident connection with the Indian Peninsula plateau.

The Sabarmati plains, Saurashtra, and Kutch terranes differ significantly in many ways, including volcanism and magmatism (Girnar Hill granites), litho-tectonic pattern (mini-arcate Nagar Parker fault in the north and north Kathiawar-Saurastra fault in the south), which resembles the western extension of smaller arcs of the Himalayan extension in central and south Asia (Karakorams-Hindukush and its southern extension, Sulaiman-Kirther hills in Pakistan). Orthophragminids foraminifera from the Bartonian Fulra Limestone in Kutch, India, and the coeval or contemporary units in the Sulaiman Range in Pakistan reveal a high number of endemic species in the Indian subcontinent (Eastern Tethys) (Ercan Özcan et al., 2018). The Girnar hills, Gujarat's tallest mountain (1070 m or 3506 ft), are located in the Kathiawar outlier, east of the town of Junagadh, 64 kilometres north of the Arabian Seacoast, and are a classic example of an igneous plutonic complex. The Girnar laccolith was intruded into a thick layer of late Cretaceous or early Eocene basalt in Kathiawar, and elevated up in the form of a dome-shaped upper surface and a flat base, fed by a conduit from below. The Laccolith of acidic rocks, the concordant body with a flat bottom and convex upward dome-shaped hills, also occurs in the Great Himalayan Mountain in the north, Karakoram-Hindukush, its southern extension in the Sulaiman-Kirthar highlands in Pakistan, and and Pir Panjal Range, Eastern Mountain range or The Purvanchal range (Arakan in Maynmer). The northern Kutch region is particularly active and earthquake-prone, while the middle region has some activity in terms of current deformation and periodic earthquakes, which may be linked to the Himalayan orogen. A closer look at Fig. 2C within the rectangle shows the juxtaposition of the Kathiawar-Kutchch (blue) and Sulaiman-Kirther-Hindukush-Karakoram (brown) arcuate features in Pakistan, indicating that Kathiawar-Kutchch is geotectonically more akin to the Great Himalayan Orogeny than neither the Indian Peninsula nor an integral component of the Western Coastal Plains, as stated by other scholars.

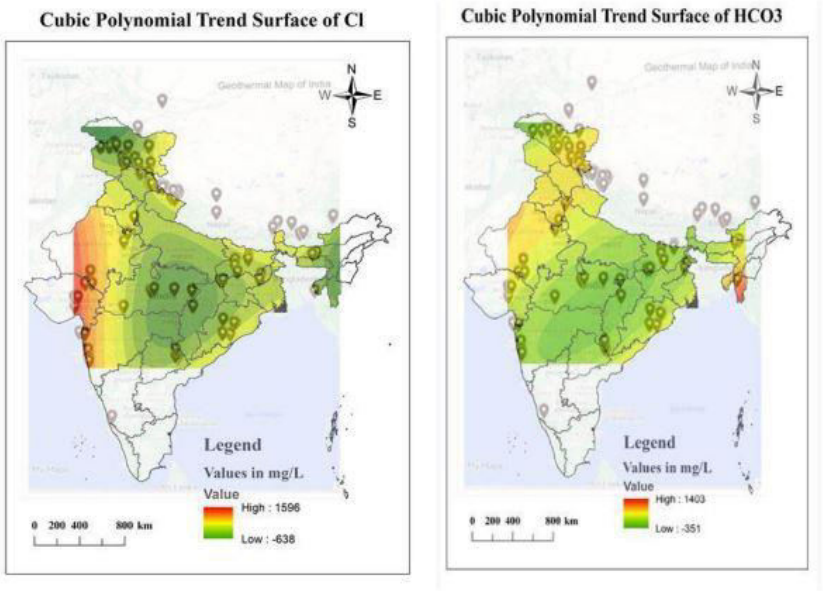
III. GIS MAPPING PROCEDURES

The notion of trend surface modeling is demonstrated by a very visible geographical distribution of fluid geochemical variables, chloride (Cl) and bicarbonate (HCO3). The trend surface mapping of raw data was performed with the help of a GIS tool. While mapping, the polynomial power was set to 3, or cubic, resulting in a more identifiable pattern than the original raw data.

RESULTS AND VISUALIZTION OF TREND SURFACE MAPS

The figures below depict the true distribution of fluid geochemical variable values within a study area. The litho-tectonic patterns that resemble the Himalayas distinguish the Sabarmati plains, Saurashtra, and Kutch terranes. The Sabarmati plain in Gujarat conceals a 50-kilometer-wide N-S trending graben (K. S. Valdiya et al., 2017). Cenozoic strata of this graben contain petroleum and gas deposits and form a northerly extension of the Cambay Basin. Geothermal map overlays on the trend surface maps (Fig.3) below confirm the litho-tectonic structure in both the Peninsula and ExtraPeninsula regions.

Fig.3. Trend Surface Maps



IV. CONCLUSIONS

Following the same statistical definition of an outlier—an outlier is an observation that differs significantly from other values in a random sample of a population—the author disputes the widely held belief that the Kutchch-Kathiawar outlier is an extension of the main Indian Peninsula, despite its distance from the unit under consideration. Kathiawar and Kutch terranes differ significantly in many ways, including litho-tectonic pattern, volcanism and magmatism (Girnar Hill granites), Girnar laccoliths, concordant body with a flat bottom and convex upward dome-shaped hills, mini-arcuate east-southeasterly convexity, and active seismicity resembling the western extension of smaller arcs of the Himalayan extension in central and south Asia (Karakorams-Hindukush and its southern extension, Sulaiman-Kirther hills in Pakistan), and Orthophragminids foraminifera from the Bartonian Fulra Limestone in Kutch, India, and the coeval or contemporary units in the Sulaiman Range in Pakistan, all of these distinguishing features of the Kuchch-Kathiawar outlier strongly support its outlier status and genesis as synonymous with the Great Himalayan Orogeny, as opposed to the widely held belief that it is an extension of the main Indian Peninsula, despite its remote location. Finally, the spatial statistical technique used in this study adds sophistication to the analysis, allowing for a better understanding of the geological dynamics at play in the Kathiawar (Saurashtra)-Kutchch anomaly.

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