*IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*
*e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 13, Issue 3 Ser. I. (May-June 2025), PP 01-07*
*www.iosrjournals.org*

# Multivariate Geospatial Heat Map Analysis for Interpretation of India's Peninsular and Extra-Peninsular Hot Springs

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***Abstract***
*This study presents a comprehensive multivariate geospatial heat map analysis of India's Peninsular and Extra-Peninsular hot springs, focusing on geothermal geochemistry. Heat maps serve as an effective tool for visualizing complex numerical data, allowing for the identification of patterns, trends, and anomalies in geothermal variables across diverse geotectonic settings. The research utilizes a dataset comprising 182 observations and 11 variables, including geographic coordinates and various geochemical parameters. By employing Excel's heat map functionalities, the study illustrates the spatial distribution of geothermal geochemistry, revealing significant insights into the acidic and alkaline assemblages prevalent in the Himalayan and Peninsular regions, respectively. The findings align with previous research while simplifying data interpretation, making it accessible for broader audiences. This analysis underscores the importance of heat maps in geospatial studies, facilitating a clearer understanding of geothermal resources and their potential applications in energy development.*

**Keywords:** Heatmaps, multivariate, geospatial, geothermal geochemistry, Himalayan and Peninsular hot springs, India

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Date of Submission: 03-05-2025 Date of Acceptance: 14-05-2025

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## I. INTRODUCTION

A heatmap is a graphical representation of numerical data, where each data point is represented by a distinct colour. The primary advantage of heatmaps is that they condense complex numerical data into visualisations that are easy to understand at first glance. Geospatial heat maps use colour to depict the intensity levels of a spatial event on a map, typically based on region or coordinates.

Heat maps simplify data and provide visually appealing data analysis, making them useful for a variety of applications. Heat maps are used for a variety of applications, including business analysis, financial/stock market analysis, crime mapping, cybersecurity,election results, population studies, urban planning, sports, exploratory data analysis, biology or bioinformatics (pattern identification in DNA, RNA, gene expression), MRI analysis, neuroscience, CT scan analysis, and Geospatial visualisation,.

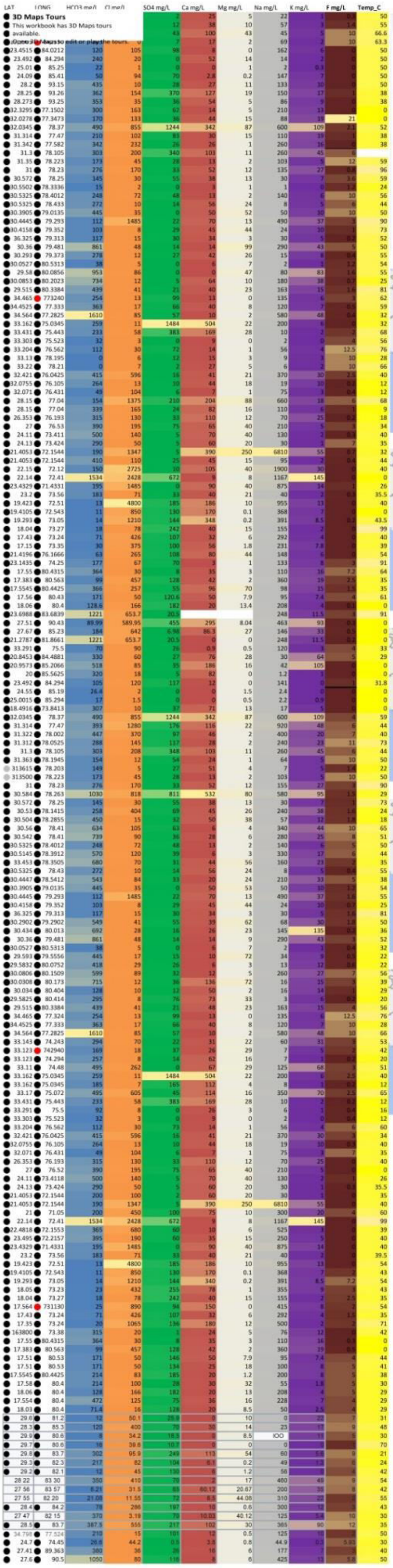
The fundamental advantage of using heat maps is that they make previously uninteresting or impenetrable data understandable. Making data science available in this way allows more people across its operations to understand how users engage with your online application.

### History of Heat Maps

Heat maps initially appeared in the late 1900s, when accountants and mathematicians manually coloured in early spreadsheets to show areas of interest. This approach had been out of style for nearly a century until being reintroduced in 1993 for usage in the software industry. Cormac McKinney, an entrepreneur, devised heat maps as a data visualisation tool to identify trends in financial markets. Heat maps have grown to be one of the most popular data visualisation and website design tools since its inception.

### Software choice

The next step is to choose the software that will be used to create the heatmap. There are several options dependent on their accessibility, including web tools like Google Maps or Tableau, desktop software like ArcGIS or QGIS, and computer languages like R or Python. Personally, in this study, I created my heat maps using mapping functions in Excel version 2021 using the built-in Heat Map option.



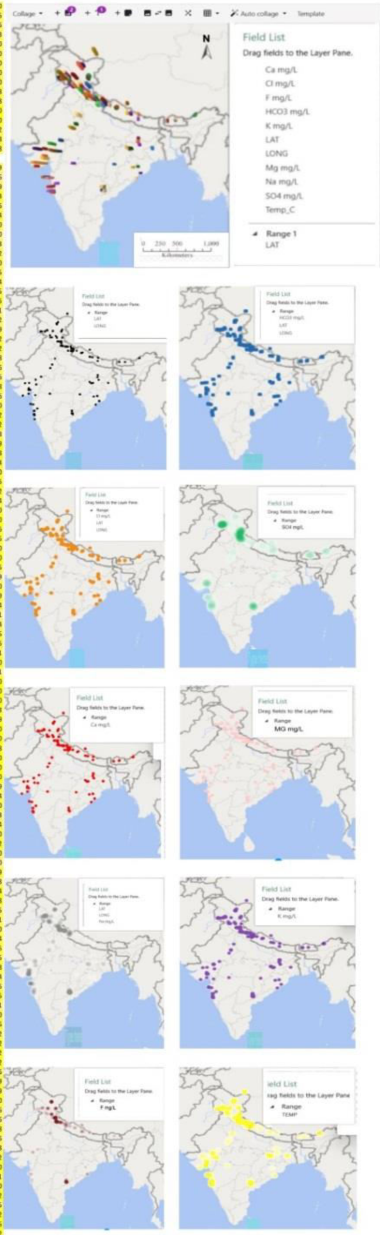



Fig.1. Multivariate Geospatial Heat Map Analysis of Geothermal Geochemistry in India's Peninsular and Extra-Peninsular (Himalayan) Hot Springs: Heat Chart (Left), Heat Map with all layers on (Right Top), and Individual Layer Maps (Below, Individual Heat Maps),

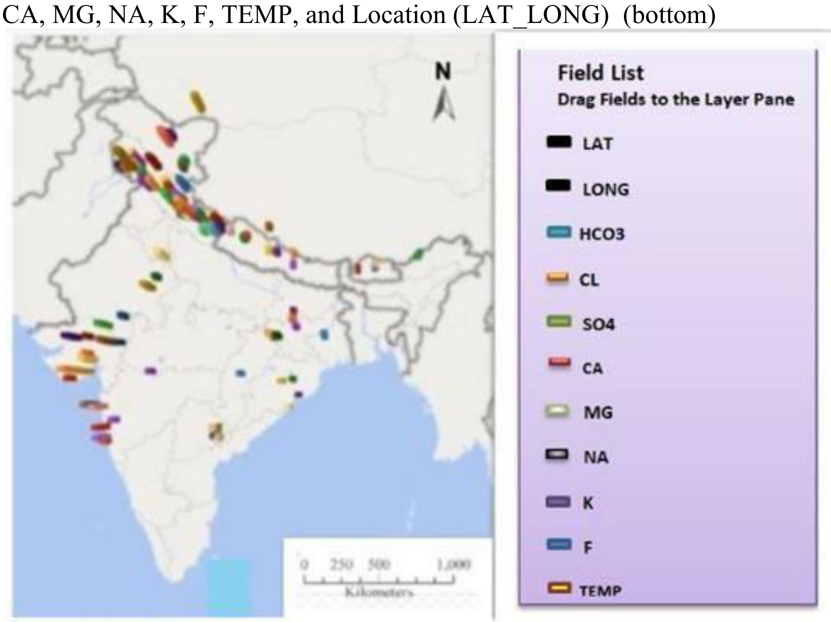
**How to Create Heat Maps in Excel**

1. A heat map is fundamentally based on a two-dimensional data matrix, with columns representing variables or categories and rows representing observational values.
2. Open Excel and enter your data matrix.
3. Click Insert > Data > Options. 1) text/csv, online, or table/range > browse > File > open > click > Import > GTHREV and LAT_LONG will be displayed. Click on LAT > a table will open up > Load > Table containing variable names and observations will open up.
4. Choose the dataset for which you wish to create a heat map.
5. Select Model > 3D > a globe with 'Open 3D Map'.
6. Click on the globe > Flat Map > click > Full View of Map with a Field List.
7. Add Layers (in succession): 1, 2, 3, 4,……
8. Add Field starting with Location:LAT and LONG > Categories > Filter > Layer option
9. Cick on layer option > colour scale (custom) > size
10. Lock current scale
11. Coditional formatting for colour scale of Heat Chart: a) for LAT_LONG > select columns > select black colour filed circle from icon sets > OK, and b) for variables or categories > New Rules > Format all cells based on their values (custom) > select cells > colour > chose from standard colours that correspond to custom colours of layers > click OK
12. Repeat 7 to 11 for other variables or categories
13. Add layers sequentially: 1, 2, 3, 4, …. 9.
14. Add a field with Location:LAT and LONG, then select Categories, Filter, and Layer options.
15. Select layer options > colour scale (custom) > size.
16. Lock the current scale.
17. Formatting for Heat Chart Colour Scale: a) for LAT_LONG > choose columns > select black colour filled circle from icon sets > OK; and b) for variables or categories > New Rules > Format all cells according to their values (custom) > Select cells > Colour > Choose from standard hues that correspond to the custom colours of layers. Click OK.
18. Repeat steps 7-11 for different variables or categories.

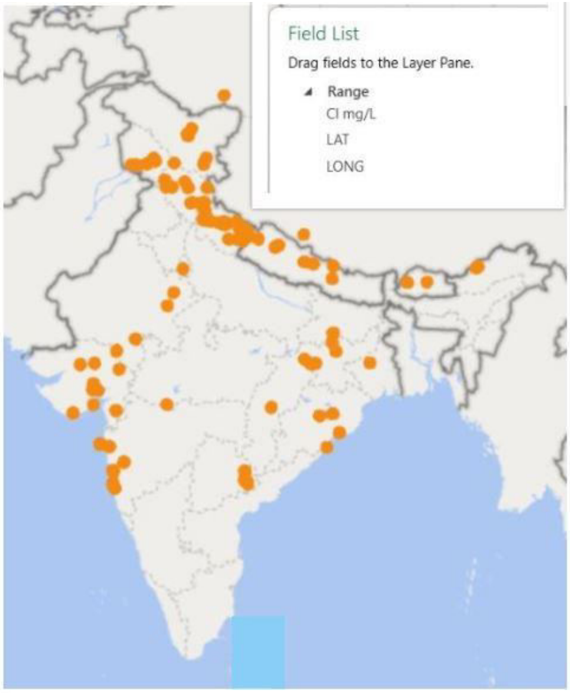
## II. Multivariate Geospatial Heat Map Analysis

A geospatial heatmap, also known as a geo heatmap, displays data points on a map to depict areas of intensity or overlay of intensity values on maps, usually by region or geographical coordinates of a certain parameter (in the current study, for example, geothermal geochemistry variable values). Multivariate Geospatial Heat Map Analysis encodes multiple variables in each cell by varying the colour, size, form, and annotation. The first step in creating a heat map is deciding the data matrix or dataset to show and examine. The geospatial heat map analysis requires two types of data: a spatial variable, such as geographic coordinates (latitude and longitude), and numeric variables, which describe the value of each data point (Fig. 1, and Fig. 2)

Figure 2. A multivariate geothermal heat map with all layers turned on (top) and individual heat map layers for $HCO_3$, CL, $SO_4$, CA, MG, NA, K, F, TEMP, and Location (LAT_LONG) (bottom)




Field List
Drag fields to the Layer Pane.
Range
HCO3 mg/L
LAT
LONG


Field List
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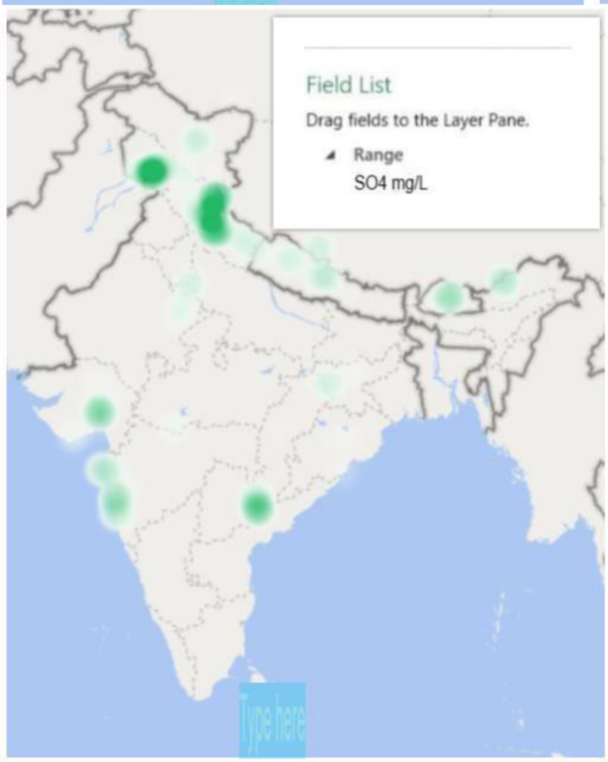
Range
Cl mg/L
LAT
LONG


Field List
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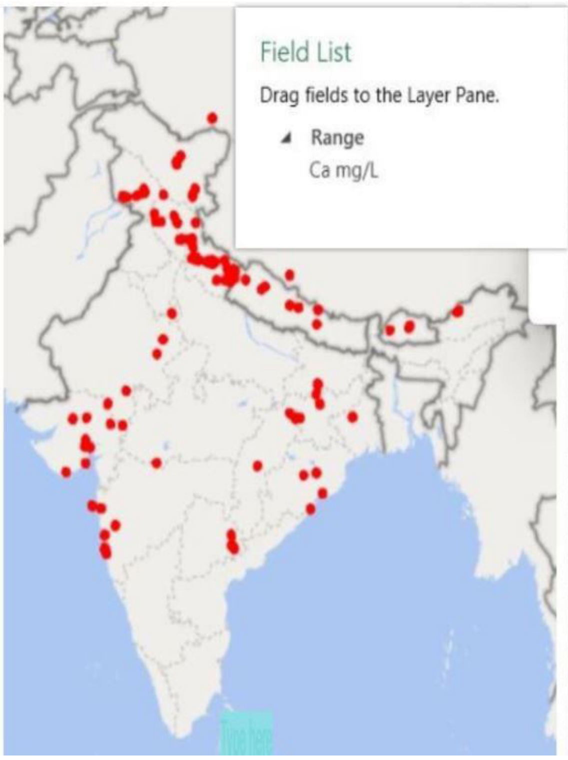
Range
SO4 mg/L
Type here


Field List
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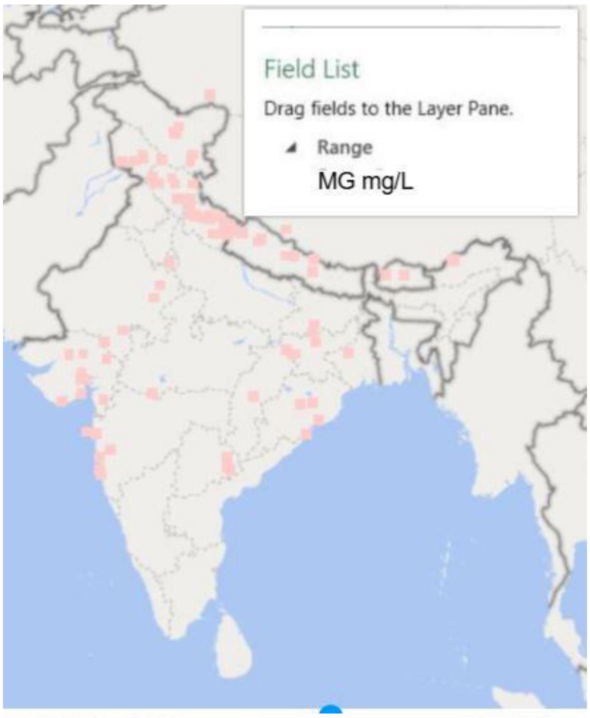
Range
Ca mg/L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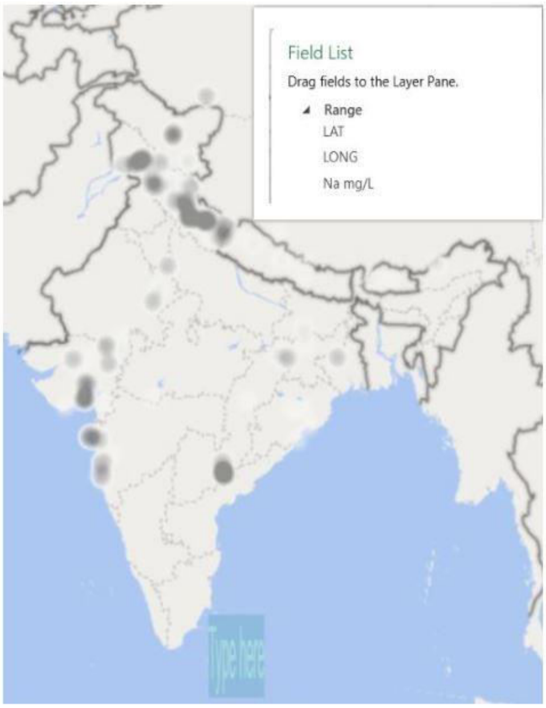
Range
MG mg/L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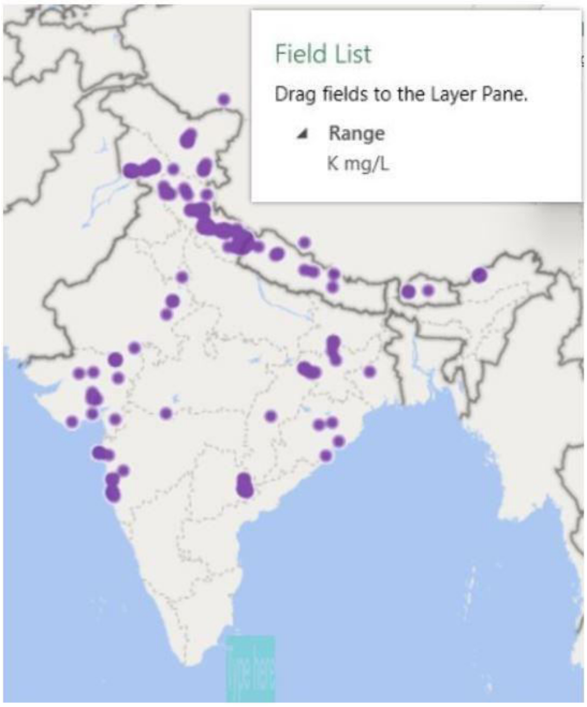
Range
LAT
LONG
Na mg/L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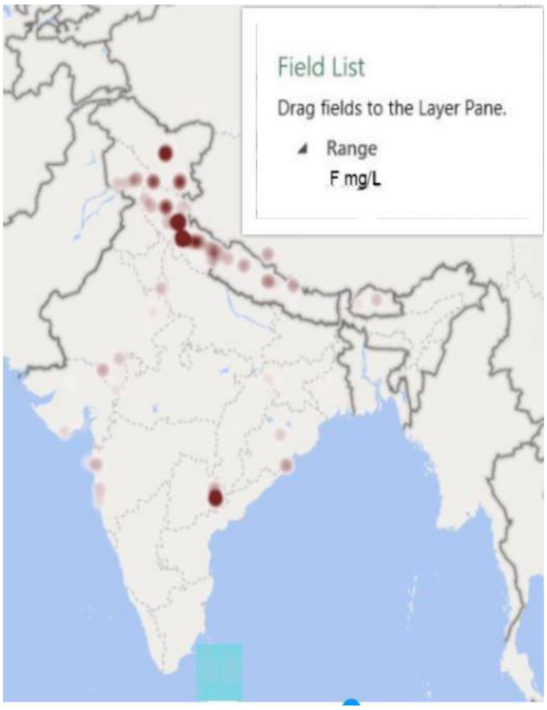
Range
K mg/L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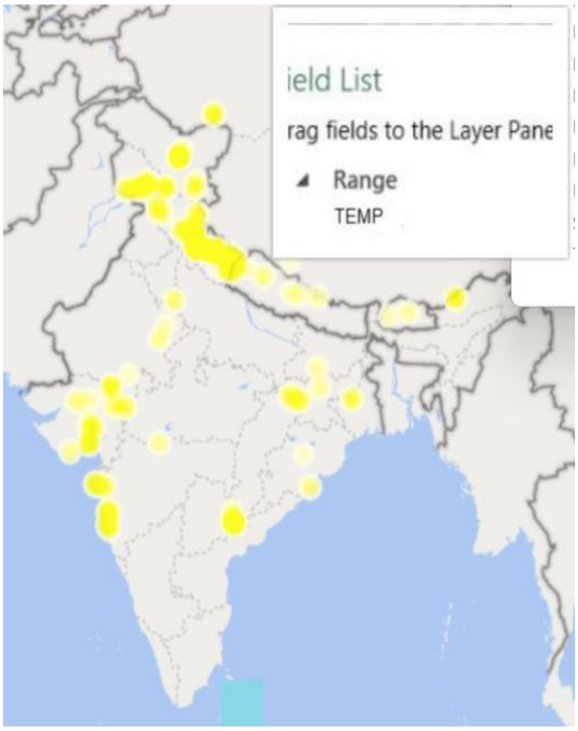
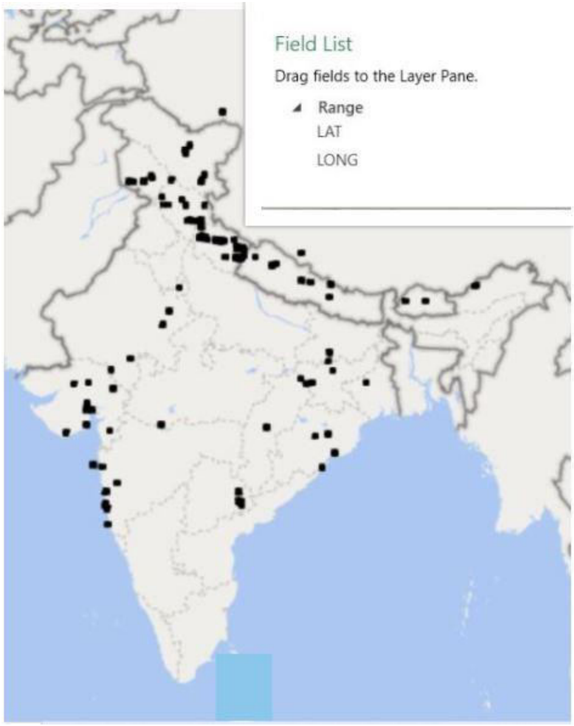
Range
F mg/L




## III. Data selection

The first step in creating a heat map is selecting the data to visualise and examine. Two types of data are required for multivariate geospatial heat map analysis: geographical location, such as data point coordinates (latitude and longitude), and continuous multivariate numeric variables, which define each data point's value and variable measures. Furthermore, the volume, resolution, and quality of data must be assessed to verify that it is consistent, accurate, and relevant to the study topic. The dataset, or observations/variables table, or Workbook = GTHREV.xlsx, used in this work comprises 182 rows and 11 columns, two for LAT_LONG and nine for geothermal geochemical variables.

## IV. Interpretation of results

The fourth stage is to assess the created heat map and derive conclusions based on geospatial analysis. Pattern recognition, trends, and linkages in the data, such as hotspots, clusters, outliers, gradients, or correlations, need special studies. It should also be compared with the previous findings from other sources of information, such as literature, theory, or context, to assess their validity, reliability, and significance. Heat map's limitations and assumptions, such as the impact of data selection, program choice, and parameter setting on output, as well as any flaws, biases, or uncertainties, have been taken care of in data analysis. Heat maps are effective tools for visualising data and highlighting regions of relevance. Colour gradients show changing levels of activity or intensity, allowing one to quickly discover patterns, trends, and anomalies within complicated statistics.

There are around 340 hot springs located throughout India, including the Peninsular and Extra-Peninsular regions. Schlagintweit compiled the first list of hot springs in India in 1852. In 1991, the Geological Survey of India produced a 'Geothermal Atlas of India', and the Indian government established a 'Hot Spring Committee' to investigate the development of geothermal power plants. Projects in the Puga Valley and Parvati aim to harvest 5000 MWh of geothermal energy, which is enough to run a 20 MWe power plant (Jonathan Craig, 2013). GTHERMIS is a computerised geothermal database system developed by the GSI (A. Roy, 1994).

This study expands on previous research that examined spatially dependent multivariate geothermal hot spring data from two geotectonic regions: a 2,400 km-long arc in the tectonically active Extra-Peninsular Himalayan region and the relatively stable Late-Precambrian or Proterozoic mobile belts in Peninsular India's Central Highlands. A comprehensive study was conducted employing a variety of robust multivariate statistical techniques to spatially dependent multivariate geothermal geochemistry data from hot springs in two regions with diverse geologic-tectonic settings. The purpose was to discover hidden patterns in hot springs' geothermal geochemistry (Amitabha Roy, 2024). This research was integrated to include geotectonic settings, hot spring disposition, and fluid geochemistry to determine the geomorphotectonic development of the Kutchch-Kathiawar and Karbi-Shillong outliers (Amitabha Roy, 2024; 2025).

The current study is notably different from the author's previous more complex statistical studies. Heat maps employ colour gradients to display data, making complex information more simple and visible at a glance. By presenting all of the values in a single heatmap, users may instantly grasp patterns, trends, and anomalies without having to go through the complex many steps involved in the typical complex statistical data analysis and interpretation procedure. The disadvantage is that heat map analysis cannot do data reductions in multivariate data, distinguishing significant components from minor ones.

The heat maps more or less confirm previous findings of the predominance of the acidic assemblage HCO3-CL-SO4-F and the high-temperature gradient in the Extra-Peninsular (Himalayan) region, whereas the alkaline group CA-MG-NA-K with low temperature is prevalent in Peninsular hotsprings. The geospatial heatmaps thus generated represent areas of high and low intensity of a certain parameters (for instance, multivariate variables in the present study) by displaying data points on a map in a visually interactive manner.

## V. Conclusions

In conclusion, this comprehensive multivariate geospatial heat map analysis effectively illustrates India's Peninsular and Extra-Peninsular hot springs through the lens of geothermal geochemistry. By leveraging a dataset of 182 observations across 11 variables, including geographic coordinates and various geochemical parameters, the study showcases the utility of heat maps in visualizing complex data, aiding in the identification of significant patterns, trends, and anomalies. The revealed insights into the distinct acidic and alkaline geochemical assemblages in the Himalayan and Peninsular regions, respectively, corroborate previous research while enhancing data accessibility for diverse audiences. This analysis underscores the role of heat maps as powerful tools for geospatial studies, streamlining the interpretation of geothermal resources, and emphasizing their potential in energy development. Additionally, it highlights the evolution of heat maps from their origins in manual data visualization to their modern application using tools like Excel. The findings not only validate previous studies but also simplify complex information, facilitating a clearer understanding of geothermal geochemistry across different geotectonic settings. Ultimately, this research contributes valuable knowledge to the ongoing exploration of India's geothermal resources and their implications for sustainable energy solutions.

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