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Geostatistics As Applied To The Fluid Geochemistry Of Indian Hot Springs

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ABSTRACT
Spatially dependent multivariate geothermal data representing two spatially distinct regions of diverse geologic-tectonic settings were subjected to robust statistical techniques of Exploratory Factor Analysis, one from the 2400 km long arcuate belt of the tectonically active Extra-Peninsular Himalayan region and the other from Late-Precambrian or Proterozoic mobile belts in the Central Highland in an otherwise stable landmass or shield of Peninsular India. The goal of exploratory factor analysis is to compress a large number of variables into a smaller number of factors, or to isolate the significant few from the insignificant many. The multiple linear regression analysis of multivariate data is aimed at explaining variability in a dependent variable by means of one or more independent or control variables. It is critical to monitor how each of the independent variables moves in their environment and how their changes impact the output or target variable when forecasting the result variable. The first and most reliable approach used in this study is factor analysis, which generates a limited number of factors that account for the majority of the original variables' information but are unrelated to one another. Both the exploratory factor and multiple regression analyses support each other in determining the genesis of these two fluid geochemistry suites. The model study distinguishes two statistically significant suites of fluid geochemistry: 1. the overall salt assemblage and concentration of Cl-HCO3-SO4-Na-F or chloride-rich water suggestive of the existence of a deep-seated hydrothermal magmatic system operating in the geotherms of extra-peninsular India; and 2. shallower peninsular springs of K-Na-HCO3 bicarbonate-rich waters with low SO4-content and relatively higher contents of HCO3. Trend surface mapping of raw data of Chloride (Cl) and Bicarbonate (HCO3) was done using a GIS tool available at the Geography department of University of Calcutta. The research demonstrates the real distribution of fluid geochemical variables in the research region. The trend surface maps reveals a graben in Gujarat's Sabarmati plain. It is now necessary to justify the societal impact of the research outputs. The quantities of chloride and bicarbonate in geothermal fluids have an inverse reciprocal acid-base connection, which has a bio-medical influence. The influence of bicarbonate levels in irrigation water appears to be responsible for crop growth reductions in nutrient content, productivity, and crop quality. Knowledge of fluid geochemical properties is essential for the construction and operation of reliable geothermal power facilities.

Keywords:*Fluid geochemistry; geostatistics; exploratory factor analysis; multiple linear regression; trend surface mapping; Geologic-tectonic units; Himalayan Mountains; Proterozoic Mobile Belt*

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I. INTRODUCTION

In vew of the ever increasing demand as also the dwindling resources of conventional energy resources like Coal, Oil, gas etc, an urgent necessity was felt in all over the world for all forms of alternative renewable energy resources. This enthused a high interest for the exploration and exploitation of geothermal resources and gained momentum around the world. India was also not far behind in harnessing the geothermal energy. Surface manifestations of the presence of subsurface geothermal energy include evidence of volcanism, geysers, fumeroles, and hot springs. There are about 340 hot springs spread over different parts of India covering the Peninsular and Extra-Peninsular regions. The first attempt to list the hot springs in India was carried out by Schlagintweit in 1852 when he prepared an Inventory of 99 thermal springs. Later Govt. of India constituted a 'Hot Spring Committee' to examine the possibility of development of geothermal plants for power generation

Fig. 1.1. Geothermal Map of India showing location of Hot Springs

Table 1. Locations of Geothermal Springs of Peninsular and Extra-Peninsular India

45	Ungiya	Tapoban	30.0527,80.5313
46	Devkuna	Tapoban	29.5800,80.0856
47	Balati	Tapoban	30.0853,80.2023
48	Dobat	Tapoban	29.5150,80.3384
49	Panamik	Puga_valley	34.4650,77.3240
50	Pulthang	Puga_valley	34.4525,77.3330
51	Changlung	Puga_valley	34.5640,77.2825
52	Gul	Puga_valley	33.1620,75.0345
53	Yurdu	Puga_valley	33.4310,75.4430
54	Tatwain	Puga_valley	33.3030,75.5230
55	Galhar	Puga_valley	33.2040,76.5620
56	Puga	Puga_Valley	33.1300,78.1950
57	Chhumathang	Puga_valley	33.2200,78.2100
58	Sunsani	Beas_valley	32.4210,76.0425
59	Gajkhad	Beas_valley	32.0755,76.1050
60	Baijnath	Beas_valley	32.0710,76.4310
61	Sohnadh	Sohna	28.1500,77.0400
62	Sohna	Sohna	28.1500,77.0400
63	Didwaka	Toda	26.3530,76.1930
64	Rindli	Toda	27.0000,76.5300
65	Parai	Toda	24.1100,73.4110
66	Parsad	Toda	24.1300,73.4240
67	Gogbasp	Camby	21.4053,72.1544
68	Gogbatw	Camby	21.4053,72.1544
69	Dholera	Camby	22.1500,72.1200
70	Cambaywell	Camby	22.1400,72.4100
71	Barsan	Camby	23.2200,73.0500
72	Keedapad	Camby	23.2000,73.5600
73	Koknere	W.coast	19.4230,72.5100
74	Paduspada	W.coast	19.4105,72.5430
75	Akloli	W.coast	19.2930,73.0500
76	Vadavil	W.coast	18.0400,73.2700
77	Keed	W.coast	17.4300,73.2400
78	Toral	W.coast	17.1500,73.3500
79	Tapibasin	Satpura_Tapi	21.4196,76.1666
80	Tattapani	Tattapani	33.1435,74.2500
81	Bugga	Godavari_Valley	17.5500,80.4315
82	Gundala	Godavari_Valley	17.3830,80.5630
83	Manuguru	Godavari_Valley	17.5545,80.4425
	Pagdaru	Godavari_valley	17.5600,80.4300
84			
85	Janampeta_spring	Godavari_Valley	18.0600,80.4000
86	Tatapani	Chhatisgarh	23.6993, 83.6842
87	Anhoni	Narmada_HotSpring	22.5960,78.6052
88	chhota anhoni	Narmada_HotSprings	22.6492,78.3546
89	Chavalpani	Narmada_HotSpring	22.8101,78.6426
90	Dhuni Pani	Narmada_HotSpring	22.6512,81.7519
91	Babeha	Narmada_HotSpring	22.7638,80.2760
92	Babeha	Narmada_HotSpring	22.7638,80.2760
	Bendru Theertha	Karnataka	12.6805,75.1965

	Location	Geotherm_Field	Lat_Long
1	Agni kund	Bakreshwar	23.8833,87.3666
2	Suryakund	Bakreshwar	24.0900,85.4100
3	BakreshwarRiver	Bakreshwar	23.5200,87.2500
4	BakreshwarIB	Bakreshwar	23.5200,87.2500
5	Attri	Mahanadi_Graben	20.1230,85.3045
6	Tarabalo	Mahanadi_Graben	20.1505,85.1810
7	Athmalik	Mahanadi_Graben	20.4430,84.3010
8	Gopalpur	Mahanadi_Graben	19.2647,84.8620
9	Taptapani	Eastern_Ghat	19.2905,84.2350
10	Tatta	Damodar_Valley	23.4515,84.0212
11	Matang	Damodar_Valley	23.4920,84.2940
12	Sitakund	Damodar_Valley	25.2200,86.3600
13	Lachmikund	Damodar_Valley	25.0300,86.2900
14	Rajgir	Damodar_Valley	25.0100,85.2500
15	Tapoban	Damodar_Valley	24.5500,85.1900
16	Surajkund	Damodar_Valley	24.0900,85.4100
17	Takshing	Subansiri_Valley	28.2000,93.1500
18	Chetu	Subansiri_Valley	28.2500,93.2600
19	Naza	Subansiri_Valley	28.2730,93.2500
20	Jakrem	Meghalaya	25.5706,91.8708
21	Umjaraiñ	Meghalaya	25.4063,91.5355
22	Lingdem	Meghalaya	27.5332,88.4696

	Location	Geotherm_Field	Lat_Long
23	Yumthang	Meghalaya	27.7932, 88.7084
24	Ralong	Meghalaya	27.3502, 88.3228
25	Borong	NE_Himalaya	27.3657, 88.3277
26	Tatwani	Beas_Valley	32.0710,76.4310
27	Beas Kund	Beas_Valley	32.3821, 77.0838
28	Manikaran	Parbati_Vallet	32.0278, 77.3473
29	Chuza	Sutlez_Spiti	32.0345,78.3700
30	Jeori	Sutlez_Spiti	31.3140,77.4700
31	Napta	Sutlez_Spiti	31.3420,77.5820
32	Karchham	Sutlez_Spiti	31.3000,78.1050
33	Skiba	Sutlez_Spiti	31.3500,78.2230
34	Jamnotri	Tapoban	31.0000,78.2300
35	Banas	Tapoban	30.5720,78.2500
36	Chaudaduni	Tapoban	30.5502,78.3336
37	Jhaya	Tapoban	30.5325,78.4012
38	Tunja	Tapoban	30.5325,78.4330
39	Gaurikund	Tapoban	30.3905,79.0135
40	Badrinath	Tapoban	30.4445,79.2930
41	Ghorshila	Tapoban	30.4158,79.3520
42	Kanakar	Tapoban	36.3250,79.3130
43	Juna	Tapoban	30.3600,79.4810
44	Tapoban	Tapoban	30.2930,79.373
45	Ungiya	Tapoban	30.0527,80.5313
46	Devkuna	Tapoban	29.5800,80.0856
47	Balati	Tapoban	30.0853,80.2023
48	Dobat	Tapoban	29.5150,80.3384
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63	Didwaka	Toda	26.3530,76.1930
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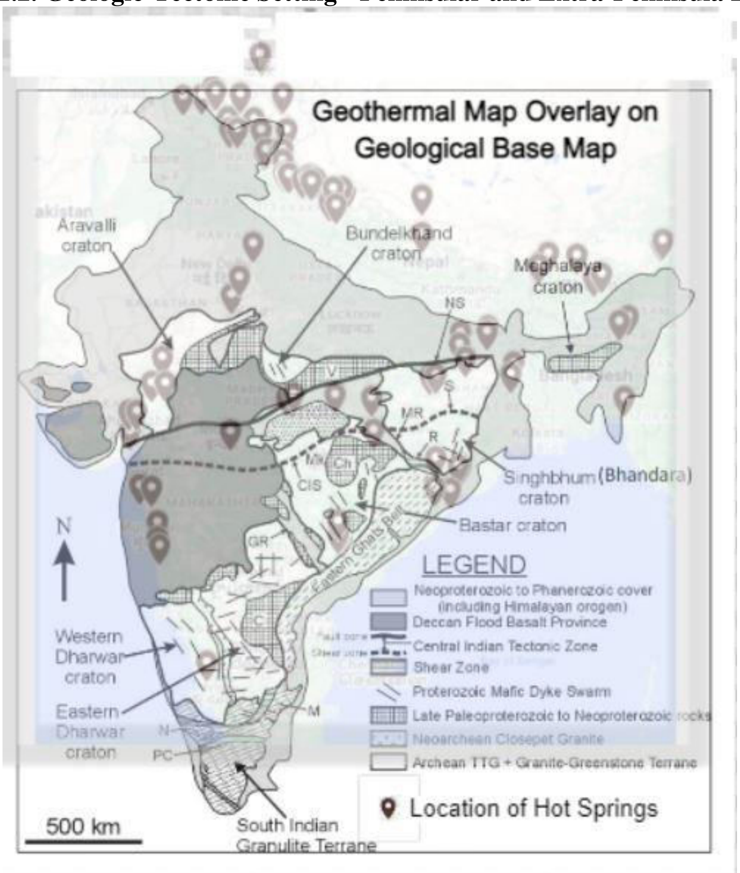
and other uses. The committee in its report in 1968 recommended for a systematic geothermal study and exploration in India in 1972. The GSI initiated geothermal exploration with the launching of 'PUGA PROJECT' in Jammu and Kashmir. The ONGC, in search for hydrocarbons, also collected significant geothermal data in sedimentary basins, both in 'off shore' and 'on land' areas in the Peninsular region. The NGRI formed a 'Geothermic Group' for carrying out studies on 'heat flow values' in some parts of the country. The Central Electricity authority (CEA) associated themselves with the UNDP geothermal project with India in the Puga valley and Parvati projects for utilisation of available geothermal resources for power generation. It is estimated to be possible to harness 5000 MWh of geothermal energy from Puga valley which is sufficient to sustain a 20 MWe power plant (Jonathan Craig et al., 2013).

Mainly due to this ever increasing interest shown by various National agencies in geothermal energy, the growth rate of geothermal data has been constantly accumulated during the last few decades. The Geological Survey of India has brought out a special Publication titled 'Geothermal Atlas of India' (Ravi Shankar et. al.,1991) based on the data compiled from all sources of information both published and unpublished on geothermal activities in India. However, the lack of uniformity in data acquisition practices and data recording formats followed by different Agencies and also manual handling of such huge quantities of data made the whole system of data storage, searching, retrieval and their analysis laborious, cumbersome and less efficient. This obviously necessitated computerized system that offer both speed, storage and user friendly capabilities of handling of the data.The GSI being the repository of most of the information concerning geological and other related data in the country, included in its field season 1993-94 program an R&D item No. 7/WB-5 for development of a computerised system of geothermal database system referred to as GTHERMIS (A.Roy, 1994).

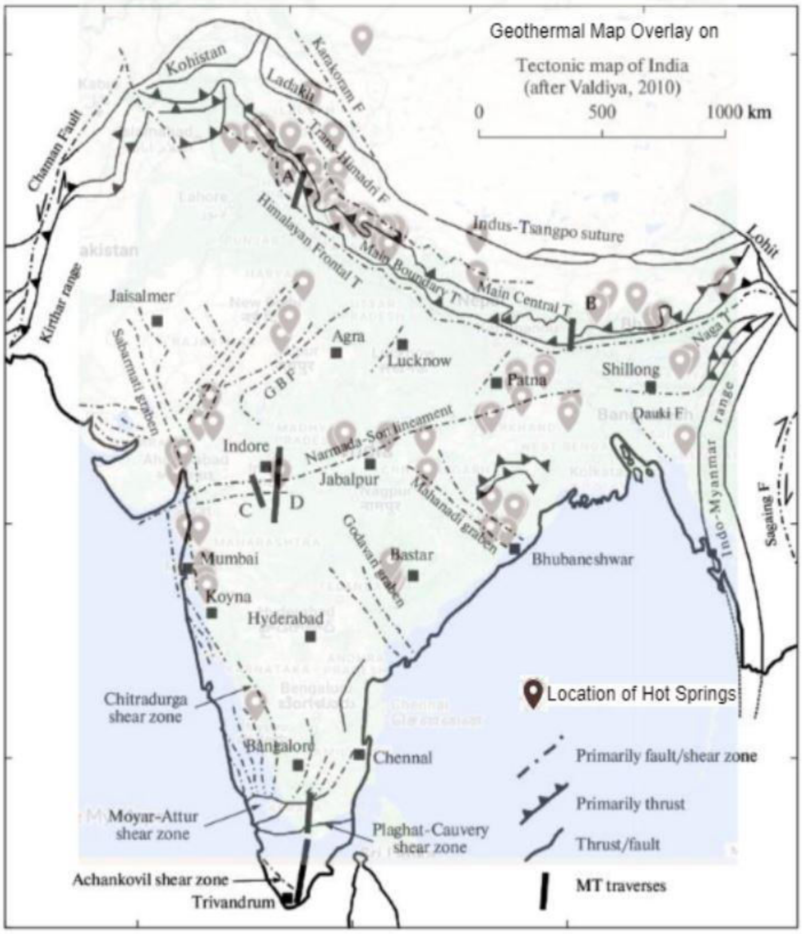
Fig. 1.2. Geologic-Tectonic Setting - Peninsular and Extra-Peninsula India



The geological regions of India broadly follow three distinct physical features - 1) **The Peninsular Plateau region** including the Shillong Plateau and the Kutchch Kathiawar region Outliers), 2) Indo-Gangetic Alluvium Plain and 3) **The Extra-peninsular region** – the mountainous region of Himalayas. The Peninsula is in shape 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. **The Peninsular Shield** is a mosaic of early to middle Precambrian stable landmasses known as cratons, late Precambrian Proterozoic mobile belts or suture zones, and late Mesozoic to Tertiary Deccan flood basalts. Cratons are composed of ancient igneous and metamorphic rocks (Archaean gneisses and schists/Dharwar system). The tectonically mobile belts are long, narrow bands inside the continental crust composed of older, higher-grade metamorphic rocks (quartzite-carbonate-phyllite suite). Bundelkhand, Aravalli, Singhbhum, Bastar (Bhandara), and Dharwar are the five primary cratons, and there are three major mobile belts: Satpura, Eastern Ghat, and Aravalli-Delhi belts. There were various sedimentary basins formed up of sedimentary rocks in Proterozoic epoch, related to cratons: Vindhyan, Chhattisgarh, Cuddapah, and Bhima-Kalagi.The major prominent rifts that separate the southern and northern blocks of the Peninsular shield is the Central India Tectonic Zone (CITZ) or Narmada - Son–Tapi (SONATA) or Saihadri Satpura Lineamrnt. Cuddapah, Vindhyan, Tattapani in Chhattisgarh, Rajgir-Monghyar in Bihar, Tatta and Jarom in Jharkhand, and the Eastern Ghat tracts of Orissa are also rift basins, as are the Damodar, Godavari, and Mahanadi Valleys, as well as the Kutch and Cambay basins. Peninsular India lacks early Palaeozoic marine successions. The late Palaeozoic Gondwana of Permo-carboniferous age forms a distinct fluviatile sequence of coal-bearing sedimentary strata that occur mostly along three river valley basins: the Damodar Valley, the Son-Mahanadi Valley, and the Pranhita-Godavari Valley. Marine incursions along its shores have laid down sedimentary strata of upper Gondwana, Cretaceous, and Tertiary periods.The Sabarmati plains, Saurashtra, and Kutch terranes are radically different in many ways, including the litho-tectonic pattern (mini-arcuate Nagar Parker fault in the north and north Kathiawar-Saurastra fault in the south), which bears resemblances to the western extension of smaller arcs of the Himalayas in central and south Asia (Hindukush and Karakorams). The northern Kutch region is extremely active and earthquake-prone, but the middle region is moderately active in terms of present deformation and manifestation by periodic earthquakes, which may be associated to the Himalayan orogen The Sabarmati plain in Gujarat conceals a 50-kilometer-wide N-S trending graben (K.S. Valdiya et al., 2017). The Cenozoic strata of this graben include petroleum and gas resources. The underlying Archaean litho-tectonics influenced the region's subsequent geometry.

The Extra-Peninsular or the Himalayan region, a 2400 long arcuate belt between the Namcha Barwa syntaxis at the eastern end and the Nanga Parbat syntaxis at the western end is divided into four tectonic units– 1) The SubHimalayas between Himalayan ecosystem and Indo-Gangetic plains in northwestern India forming the foothills called Siwaliks comprising a complete Palaeozoic sequence of marine fossiliferous sediments above the Precambrian crystalline basement and Lower Triassic, 2) The Lesser Himalayas (LH) thrust over the SubHimalaya along the Main Boundary Thrust (MBT) comprising metasedimentary sequence of quartzite,

Fig. 1.3 Geothermal Map overlay on Tectonic Map



metasandstone phyllite, and psammatic phyllite, at places Schist and gneiss, 3) The Central Himalayan Domai (CHD) or Greater or Higher Himalaya made up of 10-20 km-thick metamorphic rocks (schists and gneisses) and granites of Proterozoic-Cambrian age belonging to continental crust of the Indian plate and 4) The Indus-Tsangpo Suture Zone (I-TS) comprising heterogeneous blocks of ophiolitic serpentinite, gabbro, basalt) and sedimentary rocks (chert, limestone) set in a matrix of deep-sea clastic sedimens.

Association of Geothermal Fields and Tectonic Settings

There are about 340 hot springs spread over two litho-tectonically distinctive regions of India covering the Peninsular and Extra-Peninsular India. There is a striking similarity between the Peninsular and Extra-Peninsular regions in the distribution of the geothermal fields. There observed a conspicuous association of Geothermal fields with the tectonic settings be it recent very active Extra-Peninsular region or late Precambrian Proterozoic mobile belts in the Central Highland of the Peninsular shield. A remarkable relationship exists between geothermal fields and tectonic settings. In the current study, the GPS coordinates of all geothermal springs were plotted onto a Google map. The geothermal overlay map was then superimposed on the India tectonic map, which served as the base map.

Peninsular India's hot springs are restricted to the Proterozoic mobile belts of the Central Highlands, leaving the more stable southern Deccan plateau nearly devoid of any hot springs. The geochemical data in the Extra-Peninsular region were derived from hot springs representing the Puga geothermal field in NW Himalaya, Ladakh district, Jammu & Kashmir, and the Tuting-Tidding Suture Zone (TTSZ) in NE Himalaya, Arunachal, India, which are located near the junction of the Indian and Asian plates and are characterised by volcanic sedimentary assemblages of rocks, and Uttarakhand-Himachal Pradesh geothermal fields The geochemical data for the Peninsular region are derived from the Central Highland regions.

II. LITERATURE REVIEW

Anirbid Sircar et.al. (2015) in their paper "Geothermal exploration in Gujarat: case study from Dholera", mainly from the point of view of exploration of geothermal energy for power generation, tried to unearth subsurface picture using geoscientific data, for example, Gravity survey, Landsat imagery, magnetotelluric (MT) survey and water chemistry. According to them Hot springs exist over gravity high, which is the surface manifestation of deep and shallow water sources.

D Rouwet (2017), in his paper "Fluid Geochemistry and Volcanic Unrest: Dissolving the Haze ..." subscribes the origin of hot springs to degassing of magma.

F. Tassi et al (2010) in his paper titled "Fluid geochemistry of hydrothermal systems…. (northern Chile)" based on chemical and isotopic composition, came out with four chemical facies of thermal discharges varying from Na–Cl - SO4 rich waters to Na-Ca–Cl−SO4, Ca–SO4−HCO3 and Ca–SO4, all suggestive of interactions of deep-originated magmatic fluids intermixing with meteoric water at shallow depth**.**

H. Baioumy (2015) in his paper titled "Geochemistry and geothermometry of non-volcanic hot …" subscribes to the view of degassing of magma.

Mohammad Noor et.al. (2021) in their paper "A geochemical comparison between volcanic and non-volcanic hot springs from East Malaysia: Implications for their origin and geothermometry" infer that t**he** geochemical characteristic distinguishes non-volcanic thermal sources as K-Na-HCO_3, while volcanic thermal sources present the Cl-HCO_3-SO_4-Na type.

In light of the cited literature, I can state that, while the goal is the same, the gaps in knowledge and unresolved problems that are lacking in their studies have been addressed in my research by using a definitive approach of statistical/mathematical model study, providing insight into arriving at distinguishing two suites of distinct geothermal systems. The techniques used here, such as exploratory factor, multiple regression, and trend surface analyses, simplified and made it easier to follow comparisons between the fluid geochemistry inherent in two distinct geologic-tectonic environs: one very tectonically active Alpine-Himalayan Extra-Peninsular and the other ancient Proterozoic mobile belts of an otherwise very stable landmass or Peninsular Shield of India. A fascinating relationship exists between geothermal fields and tectonic units in both Peninsular and Extra-Peninsular regions of India

III. FLUI D GEOCHEMISTRY

Hot springs have a high mineral content, ranging from acid chloride-sulfate springs with a pH as low as 0.8 to alkaline carbonate springs saturated with silica and bicarbonate. Sulfur is an element that is frequently found in hot springs, and the most important microbial process is the oxidation of sulfur producing sulfuric acid. Water chemistry analysis was done by ion chromatography and mass spectrometry methods at the GSI Chemical Laboratory.

Table 3.1. Data Set - 1 : Extra-Peninsular Geothermal Data

NUM	TEMPC	pH	SPCMHO/cm	HCO3 mg/L	Cl mg/L	SO4 mg/L	TotHard	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	B mg/L	SiO2 mg/L	TDS mg/L
1	59	8.1	1271	300	163	62	0	14	5	210	13	12	5	80	800
2	96	7.7	827	170	133	36	131	44	15	88	19	0.8	33	60	514
3	59	7.1	5260	490	855	1244	1214	342	87	600	109	3.6	138	30	4072
4	24	8.2	795	210	102	83	136	30	15	110	19	1.2	25	25	488
5	56	7.6	1280	342	232	26	72	26	1	260	16	10	10	107	870
6	44	7.6	2015	303	200	340	302	103	11	260	45	6	13	87	1280
7	50	8.3	525	173	45	28	40	13	2	103	5	10	3	23	363
8	90	7.9	1045	276	170	33	0	52	12	135	27	3	10	83	874
9	73	7.5	410	145	30	55	0	38	13	30	7	1	3	50	378
10	52	7.8	25	15	2	0	12	3	1	1	0	0.2	0	2	20
11	50	8.2	700	248	72	48	40	13	2	140	6	5	3	65	480
12	55	7.7	400	272	10	14	0	56	24	8	5	0.4	0	68	366
13	54	7.6	845	445	35	0	0	50	52	50	10	1.2	0	41	536
14	55	6.8	2630	112	1485	22	230	70	13	490	37	1.6	19	115	1630
15	25	7.7	139	103	8	29	0	45	44	24	10	0.7	2	30	442
16	81	8.1	315	117	15	30	0	34	3	30	5	1.6	0	22	245
17	62	8	1460	861	48	14	72	14	99	290	43	3	5	91	1015
18	59	7.8	465	278	12	27	214	42	26	15	8	0.5	1	69	360
19	32	6.7	95	38	5	0	0	6	7	2	1	0.4	0	11	42
20	32	8.3	2000	953	86	0	0	0	47	80	83	0	0	18	0
21	68	6.4	1239	734	12	5	200	64	10	180	38	2	1	130	860
22	56	6.9	770	439	41	21	215	40	23	163	15	4	2	34	510
23	76	7.7	720	254	13	99	32	13	0	135	6	12.5	2.8	101	570
24	28	7.1	770	363	17	66	132	40	8	120	7	10	2	53	575
25	66	7.7	2030	1610	85	57	34	10	2	580	48	10	8	130	840
26	40	7.2	3641	259	11	1484	1352	504	22	200	6	2.5	1	35	2557
27	12	7	1060	233	58	383	536	169	28	10	2	0.2	0	18	834
28	12	7.1	63	32	3	0	24	9	0	2	0	0.4	0	6	42
29	68	6.9	386	112	30	72	40	14	1	56	4	6	1	35	235
30	9	8	178	0	6	12	52	15	3	9	3	1	0.9	9	114
31	18	8.3	205	0	7	2	88	27	5	6	2	0.2	0.9	9	123
32	34	7.4	2668	415	596	16	190	41	21	370	30	3	8	20	1399
33	40	7.6	469	264	13	10	186	44	18	19	10	0.3	0	28	279
34	35	6.6	446	49	104	6	20	7	1	75	3	7	1	28	260
35	52	7.2	8160	435	10	28	113	27	11	133	10	2.1	0	80	565
36	38	7.4	16630	362	154	370	396	127	19	150	17	1	0	60	1017
37	38	7.7	9800	353	35	36	158	54	5	86	9	0	0	40	638

Table 3.2. Data Set- 2 : Peninsular Geothermal Data

NUM	Temp_C	pH	SPCMHO/	HCO3 mg/	Cl mg/L	SO4 mg/L	TotHard	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	Bmg/L	SiO2 mg/l	TDS mg/L
1	32	7.5	5090	154	1375	210	872	204	88	660	18	0.7	0	18	2981
2	44	7.3	1115	339	165	24	270	82	16	110	6	0.4	0.9	46	500
3	40	7.7	1010	315	130	33	0	110	12	70	25	0	0	58	630
4	0	7.3	1410	390	195	75	0	65	40	210	5	0	0.1	40	830
5	26	7.8	1050	500	140	5	340	70	40	130	2	1	1.2	30	650
6	35.5	7.1	550	290	50	5	230	60	20	30	1	0.3	1.2	30	320
7	40	7.1	28980	190	1347	5	0	390	250	6810	55	0	0	16	0
8	0	7.2	960	410	110	25	0	45	15	95	2	0	0	4.5	0
9	43.5	7.4	8350	150	2725	10	0	105	40	1900	30	0.2	3	31	4790
10	99	0	0	1534	2428	672	0	9	8	1167	145	0	0	0	5744
11	40	7.4	4190	195	1485	0	0	90	40	875	14	0	0	25	0
12	39	7.6	550	183	71	33	160	40	21	40	2	0	0	22	328
13	54	7.5	13620	13	4800	185	4680	186	10	955	13	0	0.4	87	1614
14	43	9	2950	11	850	130	432	170	0.1	368	7	2	0.4	50	1868
15	64	8.6	4950	14	1210	144	890	348	0.2	391	8.5	7.2	0	65	2704
16	35	8.3	883	18	78	242	109	40	15	155	2	2.5	0	60	563
17	35	8	1917	71	426	107	100	32	6	292	4	1.5	1	5	965
18	61	7.6	1457	30	375	100	147	56	1.8	231	7.8	4	0.4	122	955
19	0	8	0	63	265	108	210	80	44	148	6	0.1	0	60	188
20	91	0	0	177	67	70	0	3	1	133	0	3	0.5	96	511
21	0	7.5	0	364	30	8	100	35	3	110	16	0.3	0	57	0
22	0	7.4	0	99	457	128	100	42	2	360	19	0.5	0	70	0
23	0	8	0	366	257	55	530	96	70	98	15	0.2	0	45	855
24	33	7.8	765	171	50	120.6	0	50	7.9	95	7.4	4	0	35	484.5
25	29	7.6	1077	128.6	166	182	0	20	13.4	208	4	5	0	28	756

IV. STATISTICAL ANALYSIS OF MULTI-VARIATE GEOTHERMAL GEOCHEMISTRY

The current study attempted to statistically analyse two data sets drawn from Peninsular and Extra-Peninsular regimes with two distinct geological and tectonic settings in order to determine similarity or dissimilarity, if any, in their thermochemistry. This chapter is divided into four sections: descriptive basic statistical analysis, exploratory factor analysis, multiple regression analysis, and trend line and trend surface analysis.

PART A: DESCRIPTIVE BASICSTATISTICS
Presenting the results and Visualizing the results in a graph

Table 4A.1. Descriptive Basic Statistics (Upper: Extra-Peninsula, Lower:Peninsula)

	TEMPC	pH	SPCMHO/cm	HCO3 mg/L	Ca mg/L	TotHard	SO4 mg/L	Cl mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	TDS mg/L	SiO2 mg/L	B mg/L
Mean	48.59	7.54	1,938.84	317.97	59.46	168.41	128.59	132.51	17.73	141.08	18.32	3.36	707.92	51.16	8.07
Std. Deviation	21.26	0.51	3,258.28	309.16	96.54	296.42	315.61	283.27	22.52	155.34	23.27	3.77	761.64	36.04	23.16
Minimum	9	6.4	25	0	0	0	0	2	0	1	0	0	0	2	0
Maximum	96	8.3	16,630	1,610	504	1,352	1,484	1,485	99	600	109	12.5	4,072	130	138

	Temp_C	pH	SPCMHO/cm	HCO3 mg/L	Ca mg/L	TotHard	SO4 mg/L	Cl mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	TDS mg/L	SiO2 mg/L	Bmg/L
Mean	35.36	7.07	3,234.96	247.02	97.12	366.8	107.06	770.08	30.58	625.64	16.59	1.32	1,129.46	44.02	0.36
Std. Deviation	26.53	2.17	6,209.25	303.73	96.64	933.93	137.52	1,126.61	50.93	1,361.05	29.3	1.93	1,476.2	29.52	0.68
Minimum	0	0	0	11	3	0	0	30	0.1	30	0	0	0	0	0
Maximum	99	9	28,980	1,534	390	4,680	672	4,800	250	6,810	145	7.2	5,744	122	3

Fig. 4A.1. Bar chart

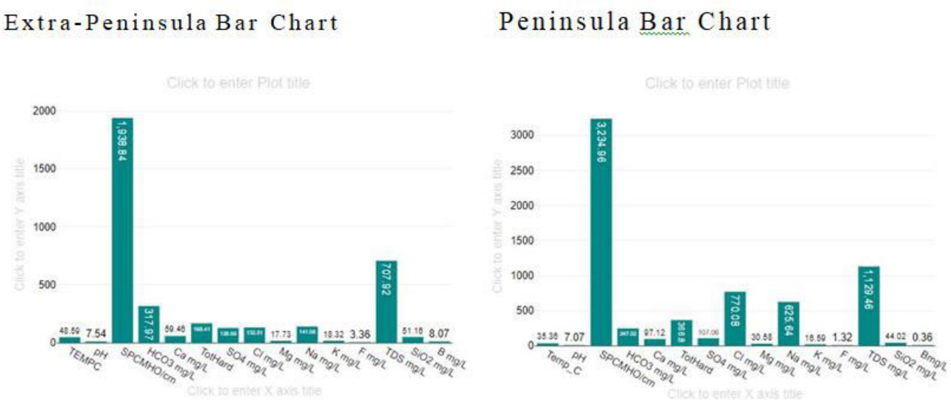


Fig.4A.2. Quatile-Quantile Plot

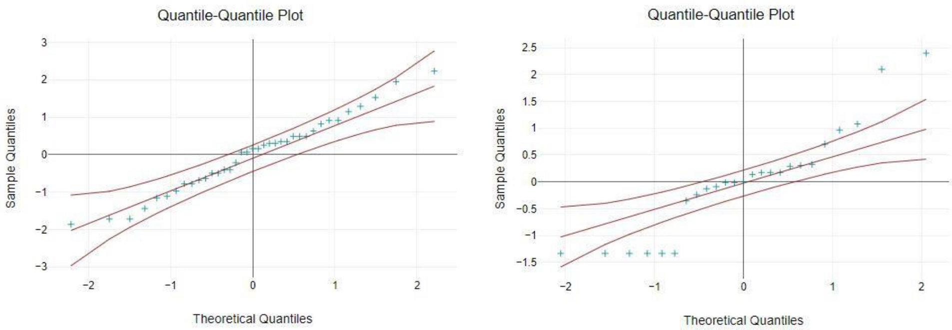
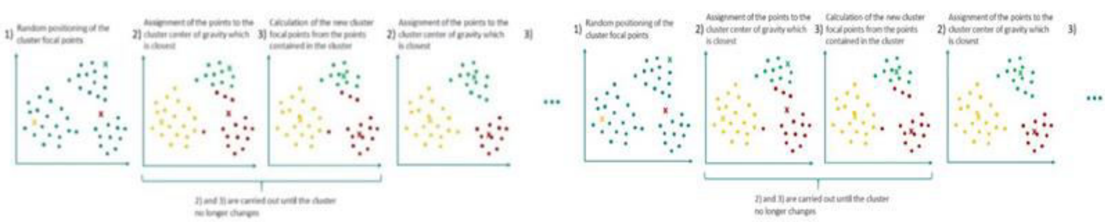


Fig.4A.3. K-Mean Cluster



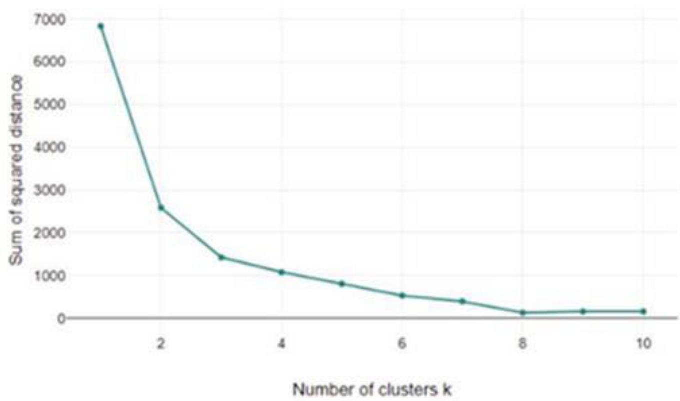
Interpreting the Results

Quantile-Quantile Plot : Purpose:Check If Two Data Sets Can Be Fit With the Same Distribution. The Data sets are compared to the normal distribution which forms the base distribution. Their quantiles are plotted along the X-axis as the Theoretical Quantile-Quantile while the sample Quantiles are plotted along the Y-axis as sample quantiles. Now in the case of Data Set-1 (Extra-Peninsula), the points fall on the 45 degree reference line which signifies that the data population is normally distributed. In case of Data Set-2 (Peninsula) the data though distributed normally in the middle portion, some points deviate on either ends of the reference line signifying hetreogenity of data due to number of causes like heterogeneous character of Peninsula both in lithological and tectonic settings. Moreover some of springs located in the Gangetic part also may contribute to this squed pattern. Contrarily the extra-Peninsular Himalyan region is a homogenious entity both in rock types and its arcuate tectonic settings which is beautifully exhibited in the Q-Q plots.

K-Means Clustering

Scaling data for k-means clustering : Since the variables under consideration do not have the same unit, the data has been first scaled before cluster analysis

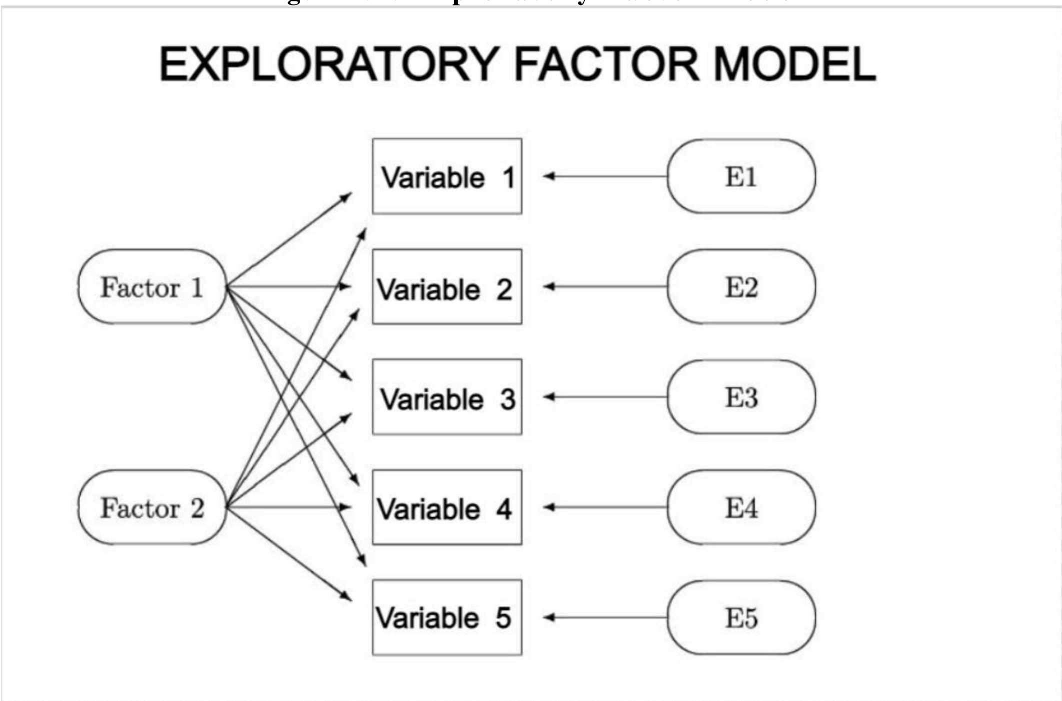
Fig.4A.4. Elbow Method



The k-Means method, developed by MacQueen (1967), is one of the most widely used non-hierarchical methods. K-means clustering is a method of vector quantization, originally from signal processing, that aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean, serving as a prototype of the cluster. First, an initial partition with k clusters (given number of clusters) is created. Then, starting with the first object in the first cluster, Euclidean distances of all objects to all cluster foci are calculated. These steps are repeated until each object is located in a cluster with the smallest distance to its centroid (center of the cluster). When you want to calculate a cluster analysis, often the big question is how many clusters should I take. The optimal cluster number is determined by elbow Curve method.In the present study 3 clusters are taken based on Elbow curve.

PART B:EXPLORATORY FACTOR MODEL STUDY

Fig. 4B.1. Exploratory Factor Model



The explorative factor analysis is a procedure that aims to uncover structures in large sets of variables. If you have a data set with many variables, it is possible to separate significant few, that is some of them correlatable with each other from insignificant many that. The prime aim therefore is to reduce a large number of correlating variables to a few independent latent variables, the so-called factors. In other words the aim of the latent variables is to clarify as much of the variance of the original variables as possible.

Basic Concept of Factor Analysis and its significance in interpretation

$$\mathbf{X_j} = \sum_{r=1}^{p} \mathbf{C_{jr}\, f_r}$$

where $\mathbf{f_r}$ (r=1,2,3……..p)represents commonunderlying factors and C_{jr} indicates the factor loadingsof variable X_j on factor f_r. Theoretical unkmown factors can then be expressed in terms of distinct groups of variables (in the present case fluid geochemical elements, which when correlated with the observed features of geothermal geochemistry of the area of investigation , provide significant insight into the causal factors (Roy. A., 1984).

To carry out this dimensional reduction with the data, the following computational steps are necessary:

Exploratory Factor Analysis Output

- Correlation Coefficient Matrix, the basis for factor analysis
- Unrotated Principal component Analysis
- Factor loading showing Varince explained by the variable on that particular factor matrix, Eigenvalues, Communality
- Detrmination of number of factors to retain
- Rotated (Varimax) Factor Analysis - Rotation method makes it more reliable to understand the output. There are a number of rotation methods available of which Varimax rotation method is used in the present study. Eigenvalues do not affect the rotation method, but the rotation method affects the Eigenvalues or percentage of variance extracted

In the Exploratory Factor Analysis the most baffling issue is to determine the number of factors to retain significant few from many insignificant ones. There are different criteria suggested by different researchers namely,

- Factors which have high eigenvalues
- The Eigenvalue > 1
- From the inflection point of scree or Elbow curve plot i.e. a graph of the eigenvalues (Y-axix) aginst the factors (X-axis) listed in the descending order.
- Communalities for each of the variables (somewhat like R^2 from Regresion analysis) at least 0.5
- The factor loadings for each variable should be ≥0.6 (Awang, 2014).

Factor analysis is a way to condense the data in many variables into a just a few variables. For this reason, it is also sometimes called "dimension reduction In the present studies trial runs of PCA analysis taking into consideration of all the above criteria for determination of number of factors have been tried and came to a compromised conclusion that in the present study four factors which accounts for 75±2% of the total variance of the original varables "load"on a factor of Principal component is retained for rotation to avoid b**oth** overextraction and underextraction of factors that may have deleterious effects on the results.This also corroborates the criteria for communalities for each of the variable closer to one (0.9) and eigenvalues.>1

Table 4B.1. Correlation Matrix – Extra-Peninsula

Correlation matrix - Extra-Peninsula

	TEMPC	pH	SPCMHO/cm	HCO3 mg/L	Cl mg/L	SO4 mg/L	TotHard	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	B mg/L	SiO2 mg/L	TDS mg/L
TEMPC	1	0.05	-0.06	0.22	0.09	-0.05	-0.1	-0.06	0.03	0.25	0.17	0.26	0.18	0.55	0.14
pH	0.05	1	-0.11	0.05	-0.25	-0.2	-0.3	-0.26	0.04	-0.16	-0	0.04	-0.1	-0.12	-0.25
SPCMHO/cm	-0.06	-0.11	1	0.19	0.17	0.31	0.34	0.3	0.11	0.25	0.19	-0.13	0.13	0.13	0.34
HCO3 mg/L	0.22	0.05	0.19	1	0	0.03	0.05	0.01	0.35	0.57	0.6	0.23	0.09	0.51	0.21
Cl mg/L	0.09	-0.25	0.17	0	1	0.22	0.31	0.23	0.21	0.7	0.51	0.01	0.54	0.24	0.6
SO4 mg/L	-0.05	-0.2	0.31	0.03	0.22	1	0.96	0.97	0.34	0.37	0.35	-0	0.55	-0.09	0.83
TotHard	-0.1	-0.3	0.34	0.05	0.31	0.96	1	0.97	0.37	0.41	0.37	-0.1	0.56	-0.08	0.85
Ca mg/L	-0.06	-0.26	0.3	0.01	0.23	0.97	0.97	1	0.34	0.32	0.28	-0.12	0.46	-0.07	0.81
Mg mg/L	0.03	0.04	0.11	0.35	0.21	0.34	0.37	0.34	1	0.3	0.6	-0.26	0.48	-0.02	0.49
Na mg/L	0.25	-0.16	0.25	0.57	0.7	0.37	0.41	0.32	0.3	1	0.71	0.38	0.58	0.53	0.75
K mg/L	0.17	-0	0.19	0.6	0.51	0.35	0.37	0.28	0.6	0.71	1	0.03	0.7	0.25	0.62
F mg/L	0.26	0.04	-0.13	0.23	0.01	-0	-0.1	-0.12	-0.26	0.38	0.03	1	0.03	0.44	0.11
B mg/L	0.18	-0.1	0.13	0.09	0.54	0.55	0.56	0.46	0.48	0.58	0.7	0.03	1	-0	0.76
SiO2 mg/L	0.55	-0.12	0.13	0.51	0.24	-0.09	-0.08	-0.07	-0.02	0.53	0.25	0.44	-0	1	0.21
TDS mg/L	0.14	-0.25	0.34	0.21	0.6	0.83	0.85	0.81	0.49	0.75	0.62	0.11	0.76	0.21	1

Table 4B.2. Correlation Matrix – Extra-Peninsula

Correlation matrix - Peninsula

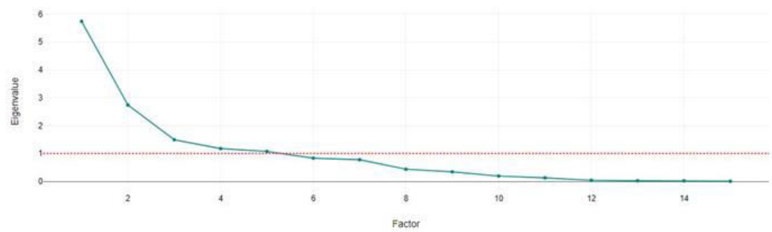
	Temp_C	pH	SPCMHO/cm	HCO3 mg/L	Cl mg/L	SO4 mg/L	TotHard	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	F mg/L	Bmg/L	SiO2 mg/L	TDS mg/L
Temp_C	1	-0.63	0.15	0.26	0.39	0.48	0.14	0.11	-0.13	0.15	0.45	0.33	0.15	0.17	0.53
pH	-0.63	1	0.1	-0.64	-0.14	-0.52	0.12	0.31	0.08	-0.07	-0.59	0.08	0.02	0	-0.36
SPCMHO/cm	0.15	0.1	1	-0.19	0.53	-0.13	0.33	0.78	0.8	0.93	0.22	-0.13	0.08	-0.1	0.06
HCO3 mg/L	0.26	-0.64	-0.19	1	0.1	0.59	-0.21	-0.28	-0.02	0.03	0.8	-0.34	-0.07	-0.44	0.46
Cl mg/L	0.39	-0.14	0.53	0.1	1	0.36	0.73	0.39	0.12	0.36	0.43	-0.18	0.24	0.02	0.59
SO4 mg/L	0.48	-0.52	-0.13	0.59	0.36	1	0.12	-0.12	-0.19	-0.04	0.73	0.13	-0.26	-0.13	0.65
TotHard	0.14	0.12	0.33	-0.21	0.73	0.12	1	0.32	-0.07	0	-0.07	-0.06	-0.01	0.31	0.13
Ca mg/L	0.11	0.31	0.78	-0.28	0.39	-0.12	0.32	1	0.62	0.65	0.08	0.15	-0.09	-0.01	0.14
Mg mg/L	-0.13	0.08	0.8	-0.02	0.12	-0.19	-0.07	0.62	1	0.87	0.22	-0.3	-0.07	-0.32	-0.09
Na mg/L	0.15	-0.07	0.93	0.03	0.36	-0.04	0	0.65	0.87	1	0.42	-0.19	0.06	-0.24	0.1
K mg/L	0.45	-0.59	0.22	0.8	0.43	0.73	-0.07	0.08	0.22	0.42	1	-0.25	-0.08	-0.33	0.65
F mg/L	0.33	0.08	-0.13	-0.34	-0.18	0.13	-0.06	0.15	-0.3	-0.19	-0.25	1	-0.13	0.35	0.06
Bmg/L	0.15	0.02	0.08	-0.07	0.24	-0.26	-0.01	-0.09	-0.07	0.06	-0.08	-0.13	1	-0.07	0.36
SiO2 mg/L	0.17	0	-0.1	-0.44	0.02	-0.13	0.31	-0.01	-0.32	-0.24	-0.33	0.35	-0.07	1	-0.2
TDS mg/L	0.53	-0.36	0.06	0.46	0.59	0.65	0.13	0.14	-0.09	0.1	0.65	0.06	0.36	-0.2	1

Presenting the results and Visualizing the results in a graph

Table 4B.3. Total Variance, Eigenvalues and Communality

Extra-Peninsula						Peninsula					
Explained Total Variance				Communality		Explained Total Variance				Communality	
Component	Total	% of variance	Accumulated %		Extraction	Component	Total	% of variance	Accumulated %		Extraction
1	5.74	38.26	38.26	TEMPC	0.39	1	4.29	28.6	28.6	Temp_C	0.7
2	2.74	18.24	56.5	pH	0.38	2	3.61	24.09	52.7	pH	0.64
3	1.49	9.94	66.45	SPCMHO/cm	0.31	3	2.29	15.27	67.97	SPCMHO/cm	0.96
4	1.18	7.84	74.29	HCO3 mg/L	0.83	4	1.44	9.63	77.6	HCO3 mg/L	0.87
5	1.07	7.15	81.44	Cl mg/L	0.82	5	1.21	8.08	85.68	Cl mg/L	0.92
6	0.83	5.55	86.99	SO4 mg/L	0.94	6	0.93	6.2	91.88	SO4 mg/L	0.78
7	0.78	5.17	92.16	TotHard	0.97	7	0.39	2.61	94.49	TotHard	0.67
8	0.43	2.9	95.06	Ca mg/L	0.94	8	0.27	1.82	96.3	Ca mg/L	0.81
9	0.34	2.28	97.34	Mg mg/L	0.74	9	0.17	1.16	97.47	Mg mg/L	0.92
10	0.19	1.27	98.61	Na mg/L	0.88	10	0.17	1.14	98.61	Na mg/L	0.92
11	0.13	0.84	99.45	K mg/L	0.88	11	0.12	0.78	99.38	K mg/L	0.92
12	0.04	0.25	99.7	F mg/L	0.56	12	0.05	0.36	99.75	F mg/L	0.7
13	0.02	0.15	99.85	B mg/L	0.77	13	0.02	0.14	99.89	Bmg/L	0.49
14	0.02	0.13	99.98	SiO2 mg/L	0.79	14	0.02	0.1	99.99	SiO2 mg/L	0.6
15	0	0.02	100	TDS mg/L	0.97	15	0	0.01	100	TDS mg/L	0.74

Fig. 4B.2.Eigenvalues plotted against Factors



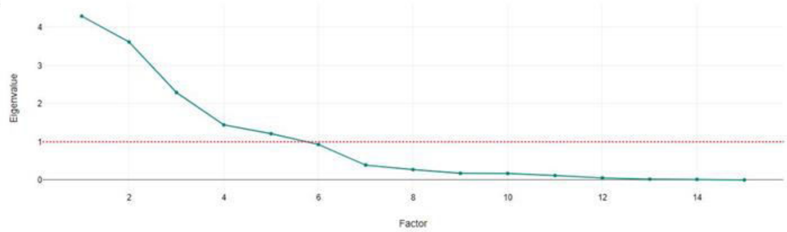


Table 4B.4. Unrotated Component Matrix

Extra-Peninsula

	Component 1	2	3	4
TEMPC	-0.14	0.58	0.16	0.02
pH	0.26	0.14	-0.49	0.23
SPCMHO/cm	-0.38	-0.09	0.08	0.38
HCO3 mg/L	-0.35	0.62*	-0.28	0.49
Cl mg/L	-0.6*	0.19	0.05	-0.65*
SO4 mg/L	-0.8*	-0.45	0.19	0.23
TotHard	-0.83*	-0.46	0.18	0.16
Ca mg/L	-0.77*	-0.49	0.22	0.23
Mg mg/L	-0.56	-0.04	-0.65*	0.08
Na mg/L	-0.78*	0.51	0.07	-0.12
K mg/L	-0.74*	0.34	-0.45	-0.07
F mg/L	-0.06	0.56	0.48	0.08
B mg/L	-0.78*	-0.01	-0.19	-0.35
SiO2 mg/L	-0.24	0.78*	0.32	0.17
TDS mg/L	-0.97*	-0.06	0.11	-0.05

Peninsula

	Component 1	2	3	4
Temp_C	0.59	-0.29	0.45	-0.26
pH	-0.54	0.55	0.07	0.2
SPCMHO/cm	0.52	0.83*	0.04	-0.07
HCO3 mg/L	0.6*	-0.56	-0.44	0.04
Cl mg/L	0.69*	0.21	0.49	0.38
SO4 mg/L	0.64*	-0.55	0.14	-0.21
TotHard	0.21	0.26	0.68*	0.31
Ca mg/L	0.35	0.77*	0.21	-0.24
Mg mg/L	0.38	0.75*	-0.43	-0.17
Na mg/L	0.6*	0.69*	-0.24	-0.17
K mg/L	0.89*	-0.27	-0.24	-0.09
F mg/L	-0.2	-0.11	0.53	-0.6*
Bmg/L	0.09	0.04	0.13	0.68*
SiO2 mg/L	-0.31	-0.01	0.67*	-0.22
TDS mg/L	0.73*	-0.32	0.25	0.22

Table 4B.5. Rotated Component Matrix (Varimax)

Extra-Peninsula

	Component 1	2	3	4
TEMPC	0.15	0.57	-0.07	-0.18
pH	0.33	-0.11	-0.42	0.29
SPCMHO/cm	-0.46	0.2	-0.16	0.17
HCO3 mg/L	0.01	0.61*	-0.67*	0.12
Cl mg/L	-0.19	0.11	-0.05	-0.87*
SO4 mg/L	-0.96*	0.03	-0.09	-0.08
TotHard	-0.97*	-0	-0.09	-0.15
Ca mg/L	-0.97*	0	-0.04	-0.05
Mg mg/L	-0.29	-0.16	-0.77*	-0.19
Na mg/L	-0.3	0.59	-0.33	-0.58
K mg/L	-0.24	0.22	-0.73*	-0.48
F mg/L	0.1	0.7*	0.22	-0.08
B mg/L	-0.45	-0.01	-0.36	-0.66*
SiO2 mg/L	0.11	0.87*	-0.07	-0.14
TDS mg/L	-0.78*	0.24	-0.24	-0.48

Peninsula

	Component 1	2	3	4
Temp_C	0.61	0.09	0.36	-0.43
pH	-0.78*	0.15	0.01	0.08
SPCMHO/cm	-0.02	0.97*	0.12	0.03
HCO3 mg/L	0.84*	-0.16	-0.14	0.34
Cl mg/L	0.3	0.45	0.79*	0.07
SO4 mg/L	0.83*	-0.11	0.16	-0.21
TotHard	-0.14	0.25	0.75*	-0.15
Ca mg/L	-0.12	0.86*	0.11	-0.24
Mg mg/L	0	0.87*	-0.34	0.22
Na mg/L	0.18	0.93*	-0.13	0.12
K mg/L	0.91*	0.25	0.01	0.16
F mg/L	-0.06	-0.12	0	-0.83*
Bmg/L	-0.1	-0.04	0.52	0.46
SiO2 mg/L	-0.3	-0.16	0.3	-0.63*
TDS mg/L	0.68*	0.06	0.52	0.08

Interpretation of the results

Table 4B.6. Results of Factor Analysis

Extra-Peninsula **Peninsula**

EXTRA-PENINSULA		PENINSULA	
Unrotated PCA	Rotated VARIMAX	Unrotated PCA	Rotated VARIMAX
F1 Cl-,SO4-, Ca-, Na-, K-,B-TDS-	F1 SO4, Ca, TDS	**F1** HCO3, Cl, SO4, Na, K, TDS	**F1** pH- , HCO3, SO4. K, TDS
F2 HCO3, SiO2	**F2** HCO3, F, SiO2	**F2** SPCMHO *, Ca, Mg, Na	**F2** SPCMHO*, Ca, Mg, Na
F3 Mg-	**F3** HCO3-, Mg-, K-	**F3** SiO2	**F3** Cl
F4 Cl -	**F4** Cl-, F-	**F4** B, F-	**F4** F-, SiO2-

SPCMHO/Cm* - is correctly defined as the electrical conductance of 1 cubic centimeter of a solution at 25 °C used to estimate the salinity , ionic strength and concentrations of major TDS solutes itrix n natural waters.

Graphical Signature Recognition of Cl and HCO3 Elemental Variables in Peninsular and Extra-Peninsular Hot Springs

In continuation of a comprehensive guide to the characterization of the fluid geochemistry of Peninsular and extra-Peninsular hot springs, in the present study, the author illustrates multiple graph lines or weighted variables in a Google Excel sheet using the same data weighted by a weighting factor (the principal component loadings in this instance), which are nothing but the correlations between variables and factors. A weighting **factor** provides a weighted variable value for each observation in a data set.

With the characteristic inverse phenomenon exhibited by multiple graph lines or factor weighted variables, the research affords a fascinating new insight into the origins of the two distinctive suites of fluid geochemistry of tectonically two diverse regions so close by yet so conspicuously distinctive.

Methodology Adopted

In the present study, factor F1 (Table 4B.6) of unrotated PCA was considered for both extra-Peninsula and Peninsula. The question may arise as to why PCA as well as F1 were preferred. The reason behind the choice is 1) that F1 of PCA bears a large number of variable assemblages and 2) that Factor 1 contains a common item TDS in both Peninsula and Extra-Peninsula. These preferential choices made interpretation more explicable in the light of earlier findings as regards the characterization of fluid geochemistry inherent in the two regions. Moreover, A. Fog (2014) expressed reservations about the recommendation of factor rotation. It, he claims, obscures general factors.

The same original raw data (Amitabha Roy, 2023) is weighted by a weighting factor (the principal component loadings in this instance), which are nothing but the correlations between variables and factors. A **weighting factor** provides a weighted variable value for each observation in a data set using FSCOR = X * B, where X are the analysed variables and B is the corresponding factor or component loading (or weight) on the variables. In the present study, Y (lat) and X (long) are redundant and left for future research with the aid of trend surface analysis.

Table 4B.7. Data Set -1. Weighted Data by a weighting factor (Component loading): Extra-Peninsula

Y	X	CL_FSCOR	SO4_FSCOR	Ca_FSCOR	Na_FSCOR	K_FSCOR	B_FSCOR	TDS_FSCOR
28.15	77.04	-97.8	-49.6	-10.78	-163.8	-9.62	-3.9	-776
28.15	77.04	-79.8	-28.8	-33.88	-68.64	-14.06	-25.74	-498.58
32.0345	78.37	-513	-995.2	-263.34	-468	-80.66	-107.64	-3949.84
31.314	77.47	-61.2	-66.4	-23.1	-85.8	-14.06	-19.5	-473.36
31.342	77.582	-139.2	-20.8	-20.02	-202.8	-11.84	-7.8	-843.9
31.3	78.105	-120	-272	-79.31	-202.8	-33.3	-10.14	-1241.6
31.35	78.223	-27	-22.4	-10.01	-80.34	-3.7	-2.34	-352.11
31	78.28	-102	-26.4	-40.04	-105.3	-19.98	-7.8	-847.78
30.572	78.25	-18	-44	-29.26	-23.4	-5.18	-2.34	-366.66
30.5502	78.3336	-1.2	0	-2.31	-0.78	0	0	-19.4
30.5325	78.4012	-43.2	-38.4	-10.01	-109.2	-4.44	-2.34	-465.6
30.5325	78.433	-6	-11.2	-43.12	-6.24	-3.7	0	-355.02
30.3905	79.0135	-21	0	-38.5	-39	-7.4	0	-519.92
30.4445	79.293	-891	-17.6	-53.9	-382.2	-27.38	-14.82	-1581.1
30.4158	79.352	-4.8	-23.2	-34.65	-18.72	-7.4	-1.56	-428.74
36.325	79.313	-9	-24	-26.18	-23.4	-3.7	0	-237.65
30.36	79.481	-28.8	-11.2	-10.78	-226.2	-31.82	-3.9	-984.55
30.293	79.373	-7.2	-21.6	-32.34	-11.7	-5.92	-0.78	-349.2
30.0527	80.5313	-3	0	-4.62	-1.56	-0.74	0	-40.74
29.58	80.0856	-51.6	0	0	-62.4	-61.42	0	0
30.0853	80.2023	-7.2	-4	-49.28	-140.4	-28.12	-0.78	-834.2
29.515	80.3384	-24.6	-16.8	-30.8	-127.14	-11.1	-1.56	-494.7
34.465	77.324	-7.8	-79.2	-10.01	-105.3	-4.44	-2.184	-552.9
34.4525	77.333	-10.2	-52.8	-30.8	-93.6	-5.18	-1.56	-557.75
34.564	77.2825	-51	-45.6	-7.7	-452.4	-35.52	-6.24	-814.8
33.162	75.0345	-6.6	-1187.2	-388.08	-156	-4.44	-0.78	-2480.29
33.431	75.443	-34.8	-306.4	-130.13	-7.8	-1.48	0	-808.98
22.303	75.523	-1.8	0	-6.93	-1.56	0	0	-40.74
33.204	76.562	-18	-57.6	-10.78	-43.68	-2.96	-0.78	-227.95
33.13	78.195	-3.6	-9.6	-11.55	-7.02	-2.22	-0.702	-110.58
33.22	78.21	-4.2	-1.6	-20.79	-4.68	-1.48	-0.702	-119.31
32.421	76.0425	-357.6	-12.8	-31.57	-288.6	-22.2	-6.24	-1357.03
32.0755	76.105	-7.8	-8	-33.88	-14.82	-7.4	0	-270.63
32.071	76.431	-62.4	-4.8	-5.39	-58.5	-2.22	-0.78	-252.2
28.2	93.15	-6	-22.4	-20.79	-103.74	-7.4	0	-548.05
28.25	93.26	-92.4	-296	-97.79	-117	-12.58	0	-986.49
28.273	73.25	-21	-28.8	-41.58	-67.08	-6.66	0	-618.86

Table 4B.8. Data Set -2. Weighted Data by a weighting factor (Component loading): Peninsula

Y	X	HCO3_FSCOR	Cl_FSCOR	SO4_FSCOR	Na_FSCOR	K_FSCOR	TDS-FCOR
28.15	77.04	92.4	948.75	134.4	396	16.02	1588.5749
28.15	77.04	203.4	113.85	15.36	66	5.34	266.45
26.353	76.193	189	89.7	21.12	42	22.25	335.727
27	76.52	234	134.55	48	126	4.45	442.307
24.11	73.4118	300	96.6	3.2	78	1.78	346.385
24.13	73.424	174	34.5	3.2	18	0.89	170.528
21.4053	72.544	114	929.43	3.2	4086	48.95	0
21.4053	72.1544	246	75.9	16	57	1.78	0
22.15	72.12	90	1880.25	6.4	1140	26.7	2552.591
22.14	72.41	920.4	1675.32	430.08	700.2	129.05	3060.9776
23.4329	71.4331	117	1024.65	0	525	12.46	0
23.2	73.56	109.8	48.99	21.12	24	1.78	174.7912
19.423	72.51	7.8	3312	118.4	573	11.57	860.1006
19.4105	72.543	6.6	586.5	83.2	220.8	6.23	995.4572
19.293	73.05	8.4	834.9	92.16	234.6	7.565	1440.9616
18.04	73.27	10.8	53.82	154.88	93	1.78	300.0227
17.43	73.24	42.6	293.94	68.48	175.2	3.56	514.2485
17.15	73.33	18	258.75	64	138.6	6.942	508.9195
22.6505	81.7518	37.8	182.85	69.12	88.8	5.34	100.1852
33.1435	74.25	106.2	46.23	44.8	79.8	0	272.3119
17.55	80.4315	218.4	20.7	5.12	66	14.24	0
17.383	80.563	59.4	315.33	81.92	216	16.91	0
17.5545	80.4425	219.6	177.33	35.2	58.8	13.35	455.6295
17.56	80.43	102.6	34.5	77.184	57	6.586	258.19005
18.06	80.4	77.16	114.54	116.48	124.8	3.56	402.8724
24.09	85.41	26.4	62.1	15.36	75	2.225	293.46
23.52	87.25	180	11.04	7.68	34.2	2.67	240.17
23.4515	84.0212	72	72.45	62.72	97.2	4.45	343.1

Presenting the results and Visualizing the results in a graph

Fig. 4B.3. Multiple Graph lines of Extra-Peninsular hot springs

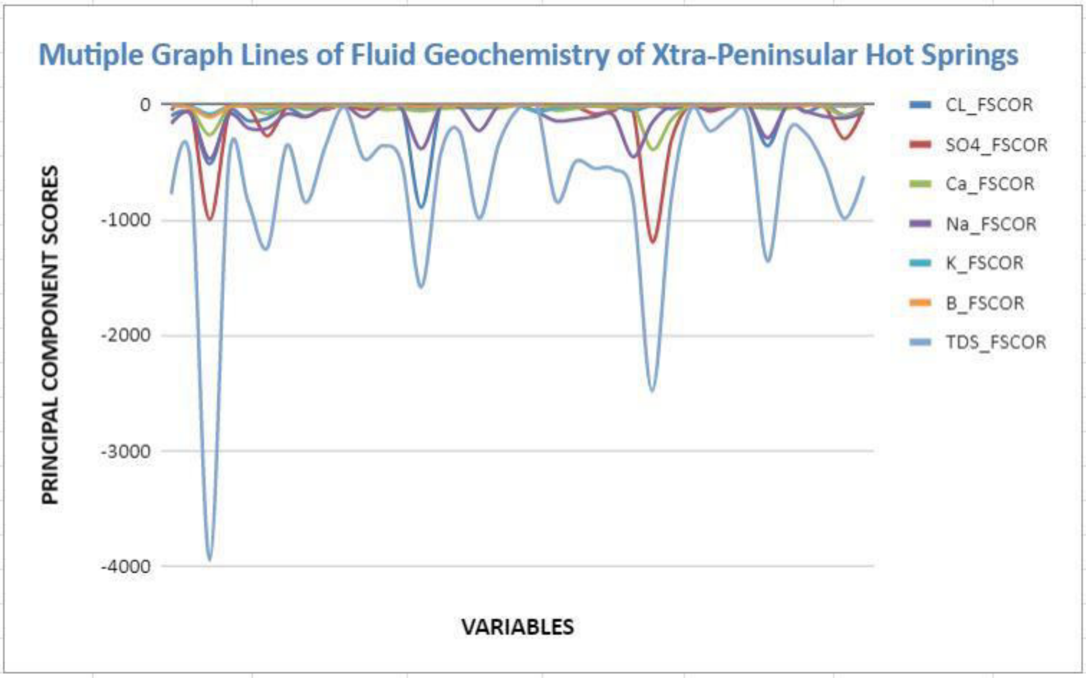
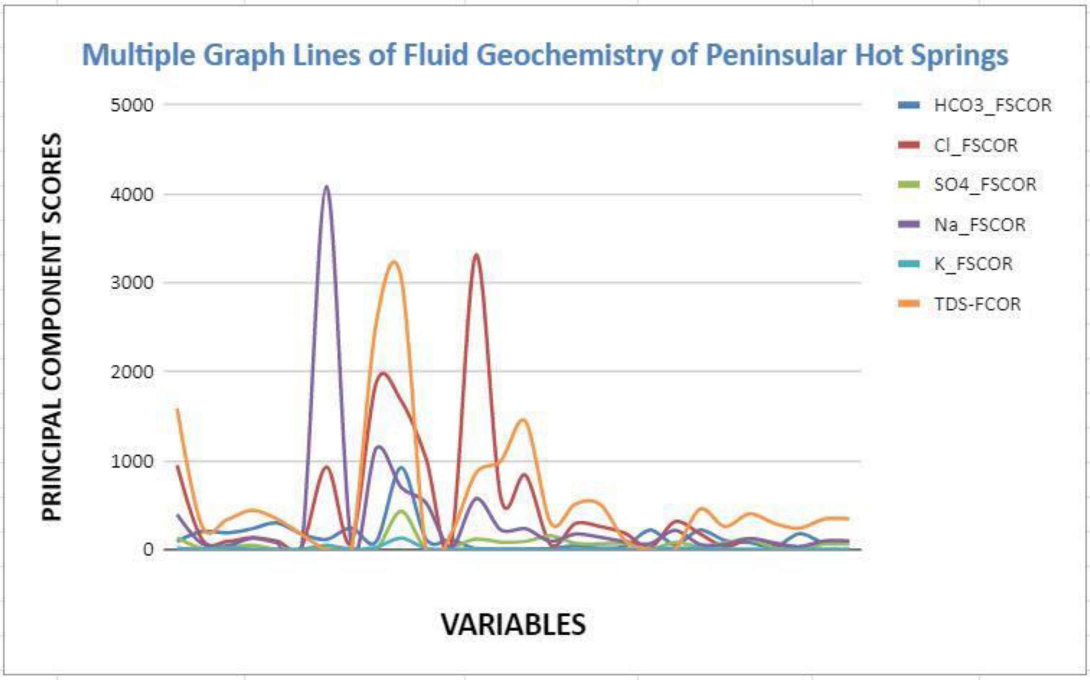


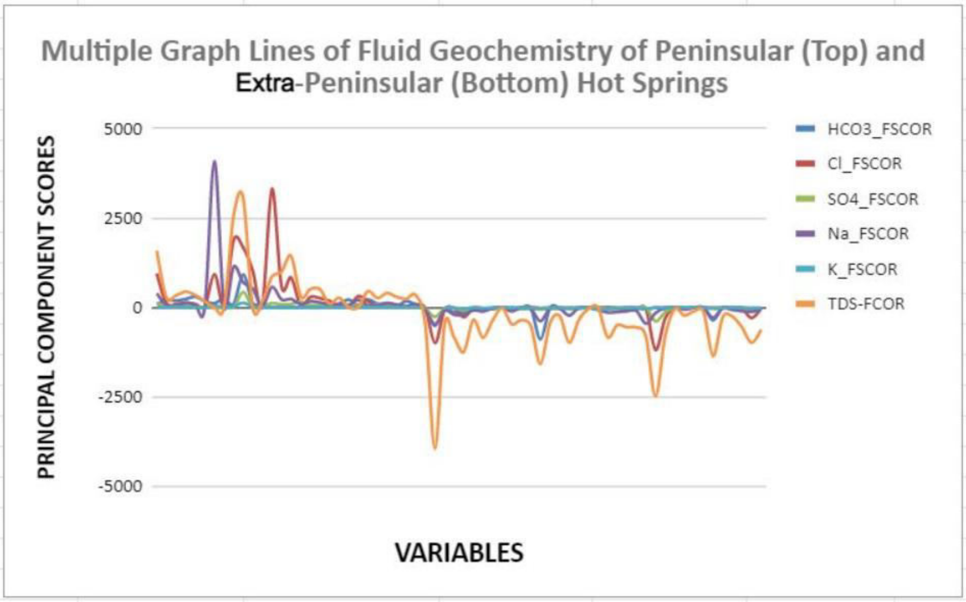
Fig. 4B.4. Multiple Graph lines of Peninsular hot springs



Interpretation of the results

The two data sets, 1 and 2, have been combined to get a composite bird's-eye view of the characterization of fluid geochemistry in two tectonically diverse regions of Peninsular and Extra-Peninsular India.

Fig. 4B.5. Multiple Graph lines of combined data of Extra-Peninsular and Peninsulsr hot springs



TDS vs. pH

"Dissolved solids" refer to any minerals, salts, metals, cations, or anions dissolved in water. TDS stands for total dissolved solids and represents the total concentration of dissolved substances in water. The total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions, inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates, and some small amounts of organic matter that are dissolved in water.

pH

A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acidic, and higher values are more alkaline. The pH is equal to log10 *c*, where *c* is the hydrogen ion concentration in moles per litre.

Though there is no direct relation between pH and TDS, carbonate, bicarbonate, and CO2 concentrations as part of TDS can affect the values of pH towards alkalinity.

An interesting feature needs be noted here.that HCO3 ions can behave either as an acid (a proton donor) or a base (a proton acceptor). Hence NaHCO3 is both an acid and a base.

OH^{-} + HCO3 $\longrightarrow$ H_2O + $CO3^{2-}$
Bronsted base Bronsted acid

This would explain the presence of HCO3 in the fluid geochemistry of both the Extra-Peninsular and Peninsular hot springs.

In the Factor Table, Factor F1 shows negative factor loadings for all items (Cl, SO4, Ca, Na, K, B, and TDS) in the case of Extra-Penindular hot springs, whereas for Peninsular hot springs, Factor F1 shows positive factor loadings for all items (HCO3, Cl, SO4, Na, K, and TDS), which is amply reflected in the Multiple Graph Lines of Fluid Geochemistry.

With this characteristic inverse phenomenon, the research affords a fascinating new insight into the origins of the two distinctive suites of fluid geochemistry of tectonically two diverse regions so close by yet so conspicuously distinctive.

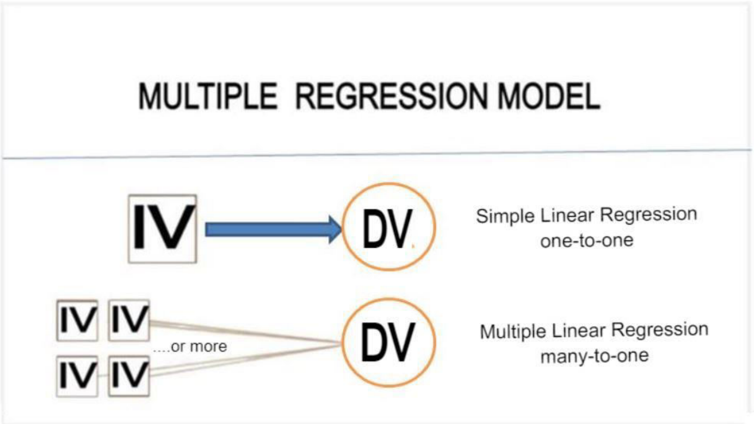
Discussions

Based on his experience in factor analysis A. Fog (2014), however expressed reservations about the recommendation of factor rotation. It, he claims, obscures general factors. As seen by my research and the comparison table above, there is some reality to this. In the current investigation, however, a compromise option was explored.

The present study found that the thermal springs of Extra-Peninsular region are deep-seated hot acidic in contrast to shallower relatively cold waters with high pH alkalinity. The overall salt assemblage and concentration of F, Cl, SO4, Na, K, Mg, and Ca suggest the existence of hydrothermal system operating in geotherms of Extra-Pensulaa. The geochemical characteristic as established by the exploratory Factor Analysis distinguishes non-magmatic thermal sources as K-Na-HCO3 of Peninsular springs as against the magmatic thermal sources as Cl-HCO3-SO4-Na type of Extra-Peninsular springs. There is a heterogeneity both in lithological and multi-directional tectonic settings that have a bearing on their fluid geochemistry.

PART C:MULTIPLE REGRESSION MODEL STUDY

Fig. 4C. 1. Multiple Regression Model



Multiple regression model

A regression model determines a relationship between an independent variable or variables (IV) and a dependent variable (DV), by providing a function. Formulating a regression analysis helps you predict the effects of the independent variable on the dependent one. Independent variables are also known as predictors, factors, treatment variables, explanatory variables, input variables, x-variables, and right-hand variables (appearing on the right side of the equals sign) and on graphs placed on the horizontal, or X, axis. The dependent variable (DV) also known as outcome or response variables or left-hand variables and on a graph placed on the vertical, or Y, axis.

Objective of Regression analysis is to explain variability in dependent variable by means of one or more of independent or control variables. A multiple regression model is used when there is more than one independent variable affecting a dependent variable. While predicting the outcome variable, it is important to measure how each of the independent variables moves in their environment and how their changes will affect the output or target variable.

The linear regression model describes the dependent variable with a straight line that is defined by the equation

$Y = a + b \times X$, where a is the y-intersect of the line, and b is its slope.

Regression line for a multivariable regression

$Y= a + b_1 \times X_1 + b_2 \times X_2+ \ldots + b_n \times X_n$,
where
Y = dependent variable
X_i = independent variables
a = constant (y-intersect)
b_i= regression coefficient of the variable X_i

everal data requirements have to be considered before we undertake a regression
analysis. These include the following:
– Sample size,
– Variables need to vary,
– Scale type of the dependent variable, and
– Collinearity.

Several data requirements have to be considered before we undertake a regression analysis. These include the following:
– Sample size,
– Variables need to vary,
– Scale type of the dependent variable, and
– Collinearity

Going back to the Factor analysis, the objective was to reduce a large number of variables into fewer numbers of factors or in other words to separate significant few from insignificant many. In factor analysis choice of number of factors out of as many as variables was a baffling issue. Here in multiple regression analysis too choice of relevant variable (IV) out of many is an issue**.** One should **n***ever* enter all the available variables at the same time. Carefully consider which independendent variable is distinct or whether relevant to the problem. The first and the most reliable option is to use factor analysis which creates a small number of factors that account for most of the original variables' information in them but which are mutually uncorrelated.

Assumptions

1) Is the sample size sufficient or the chosen samples are representative of the population
2) Do the DV and IV show variation
3) Is the DV interval or ratio scaled
4) Is linearity or linear relationship between IV and DV exist
5) Mutivariate normality i.e. approximately normally distributed (with a mean of zero)
6) No or little multicollinearity (occurs when the IVs are too highly correlated with each other)
6) No auto-correlation
7) Homoskedasticity vs Heteroskedasticity: The scatter plot is a good way to check whether the data are homoscedasticity meaning the residuals are equal around the regression line.

Multiple Regression Analysis Output.

- R (the multiple correlation coefficient),
- R squared (the coefficient of determination),
- adjusted R-squared,
- The standard error of the estimate.

These statistics help one to figure out how well a regression model fits the data. The ANOVA table in the output would give you the p-value and f-statistic.

Presenting the results and visualizing the graph

Extra-Peninsular India

Table 4C.1. Dependant Variable : Cl , Independent variables : HCO3, SO4, Na F

R	R^2	Adjusted R^2	Standard error of the estimate
0.92	0.84	0.82	120.07

ANOVA

Model	df	F	p
Regression	4	42.1	<.001

Coefficients

	Unstandardized Coefficients	Standardized Coefficients				95% confidence interval for B	
Model	B	Beta	Standard error	t	p	lower bound	upper bound
(Constant)	103.2		32.45	3.18	.003	37.08	169.32
HCO3 mg/L	-0.6	-0.66	0.08	-7.38	<.001	-0.77	-0.44
SO4 mg/L	-0.22	-0.25	0.07	-3.09	.004	-0.37	-0.08
Na mg/L	2.36	1.29	0.19	12.61	<.001	1.97	2.74
F mg/L	-24.81	-0.33	5.83	-4.25	<.001	-36.7	-12.92

(*B*)= This value represents the slope of the line between the predictor variable and the dependent variable; (*SE B*)= standard error for the unstandardized beta, similar to the standard deviation for a mean. The larger the number, the more spread out the; (β)= the standardized beta similar to a correlation coefficient, ranging between 0 and ±1; (*t*)= the *t* test statistic calculated for the individual predictor variable and used to calculate the *p* value; (*p*)= the probability level to tell whether or not an individual variable significantly predicts the dependent variable points

Fig. 4C.2 Scatter diagram

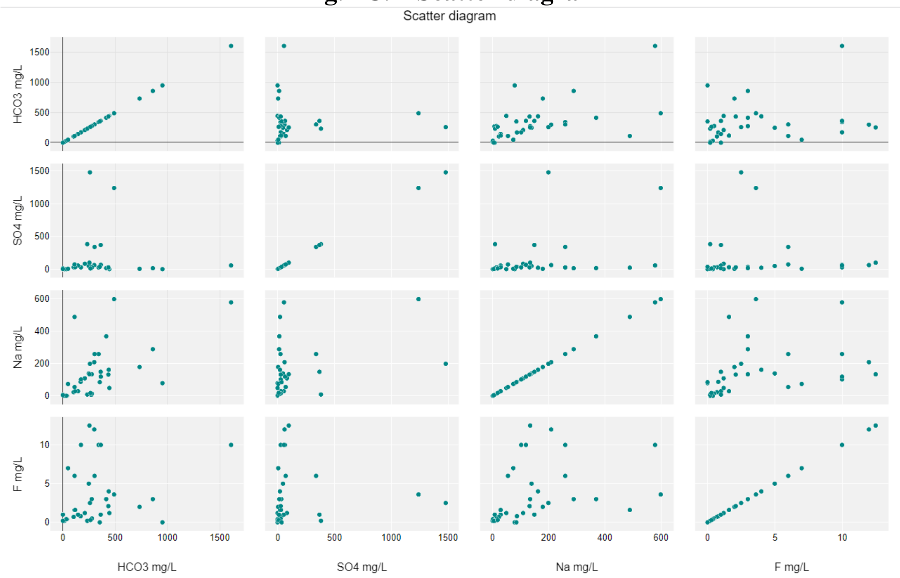
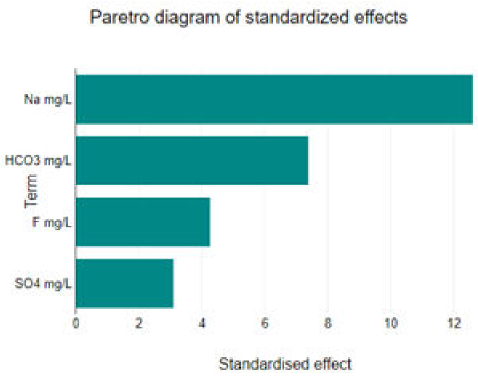


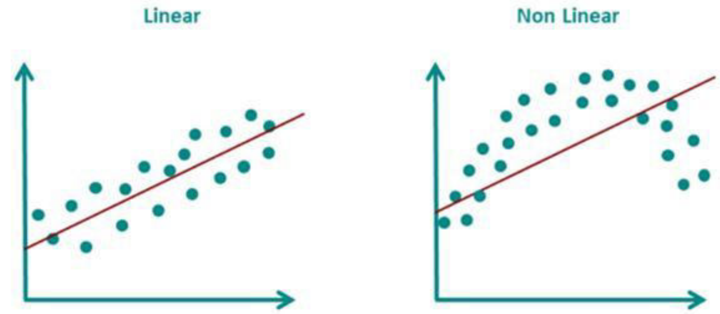
Fig. 4C.3 Paretro diagram of standardized effects



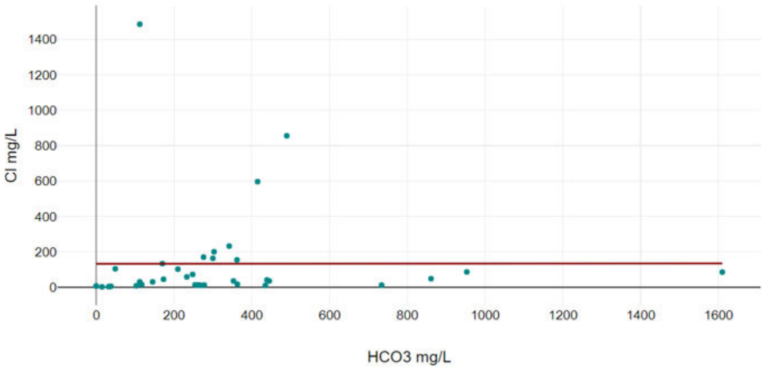
Assumptions

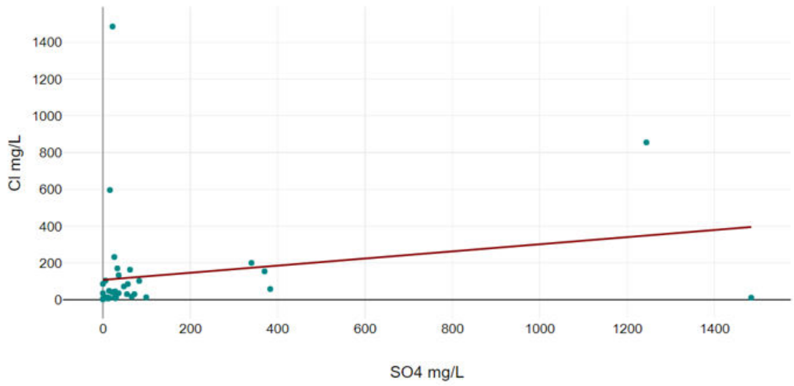
Linearity

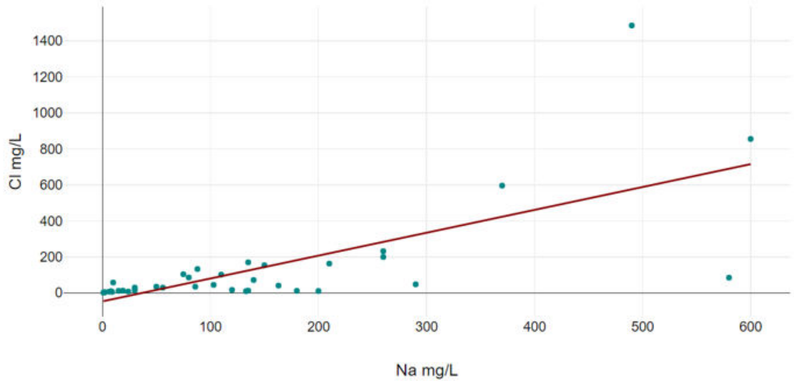
To calculate a linear regression, there must be a linear relationship between the dependent and independent variables. In linear regression, a straight line is laid through the data; this only makes sense if there is linearity.

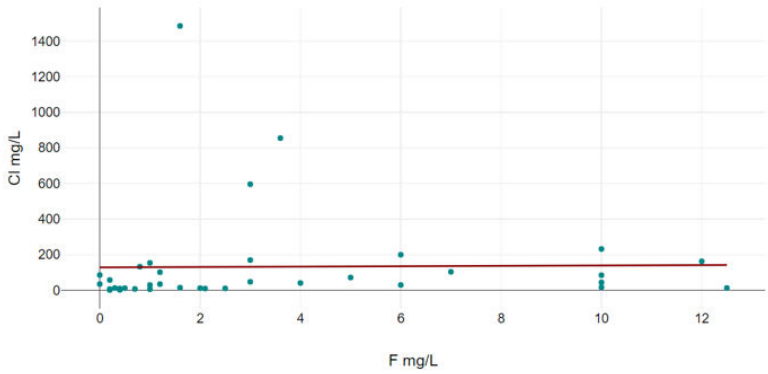


The following graphs result from your model:









Normality of errors

Tests for normal distribution of Residuum

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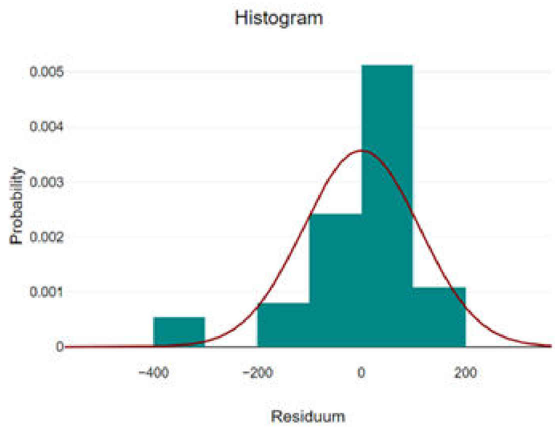
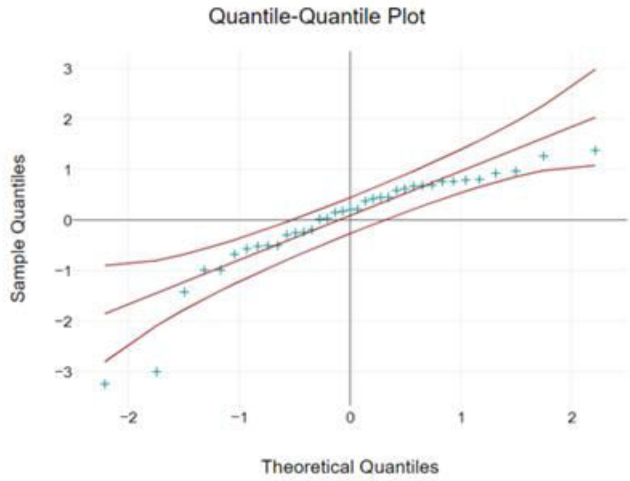
	Statistics	p
Kolmogorov-Smirnov	0.13	.52
Kolmogorov-Smirnov (Lilliefors Corr.)	0.13	.115
Shapiro-Wilk	0.86	<.001
Anderson-Darling	1.43	.001





Multicollinearity

Problematic if Tolerance < 0.10 or VIF > 10

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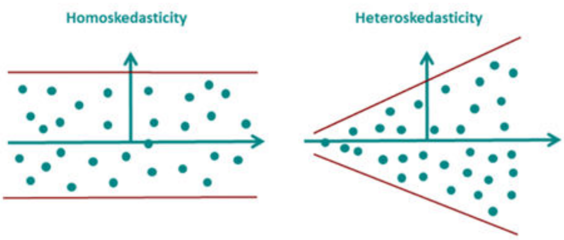
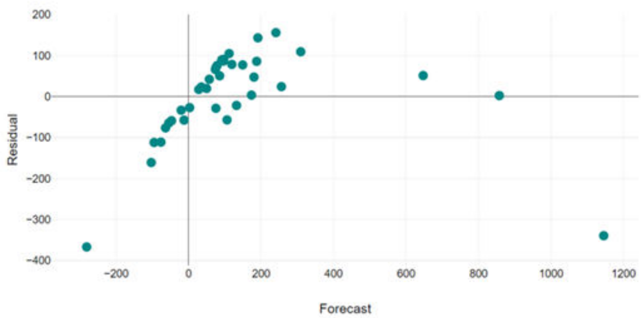
Modell	Toleranz	VIF
HCO3 mg/L	0.63	1.58
SO4 mg/L	0.79	1.27
Na mg/L	0.48	2.1
F mg/L	0.83	1.21

Heteroskedasticity

The variance of the residuals must be constant over the predicted values. Your data must therefore not exhibit heteroskedasticity.



Your model results in the following graph



Effect Size

Cohens f^2

	f^2
HCO3 mg/L	5
SO4 mg/L	5.03
Na mg/L	5.02
F mg/L	4.74

Peninsular India

Table 4C.2. Dependant variable = HCO3, Indipendent variable - Na , K

R	R^2	Adjusted R^2	Standard error of the estimate
0.87	0.76	0.74	156.16

ANOVA

Model	df	F	p
Regression	2	34.39	<.001

Coefficients

	Unstandardized Coefficients	Standardized Coefficients				95% confidence interval for B	
Model	B	Beta	Standard error	t	p	lower bound	upper bound
(Constant)	134.62		36.9	3.65	.001	58.1	211.15
Na mg/L	-0.08	-0.38	0.03	-3.25	.004	-0.14	-0.03
K mg/L	9.94	0.96	1.2				

Fig. 4C. 4 Scatter diagram

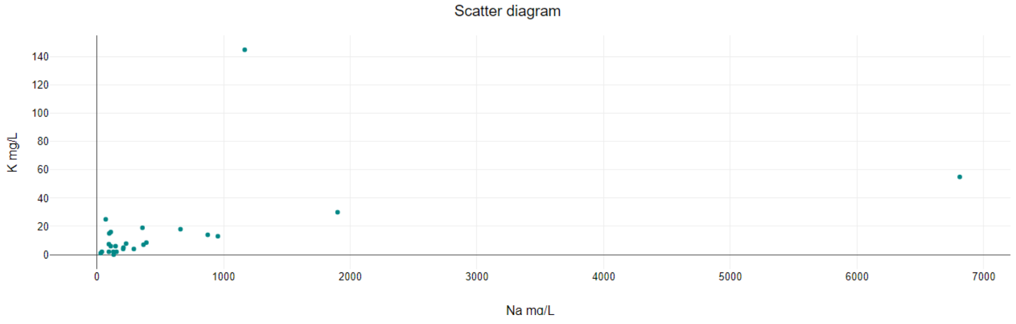
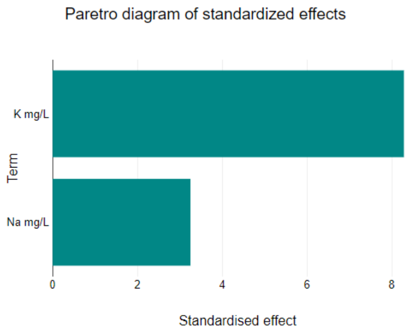


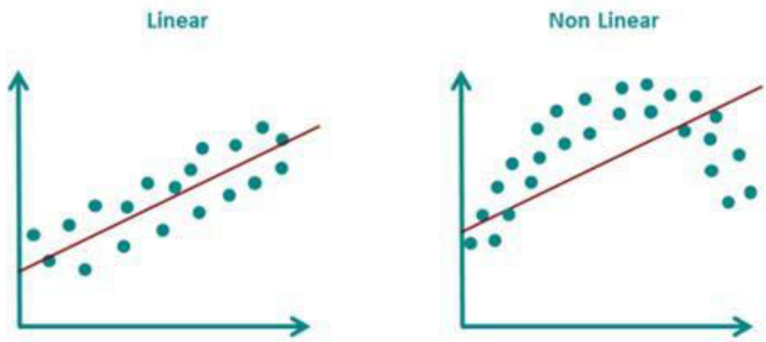
Fig. 4C.5. Paretro diagram of standardized effects



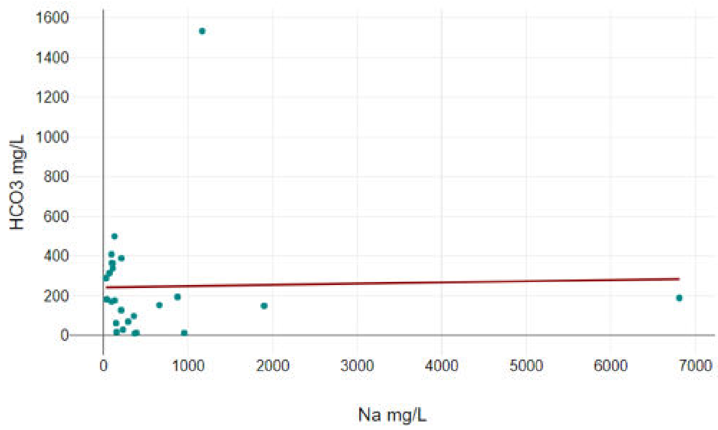
Assumptions

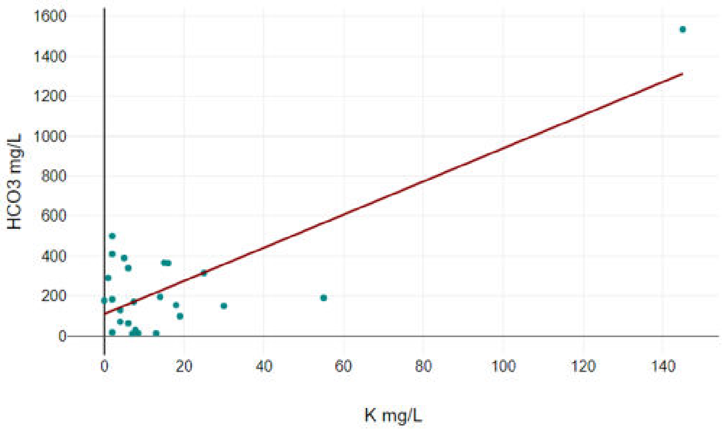
Linearity

To calculate a linear regression, there must be a linear relationship between the dependent and independent variables. In linear regression, a straight line is laid through the data; this only makes sense if there is linearity.



The following graphs result from your model:





Normality of errors

Tests for normal distribution of Residuum

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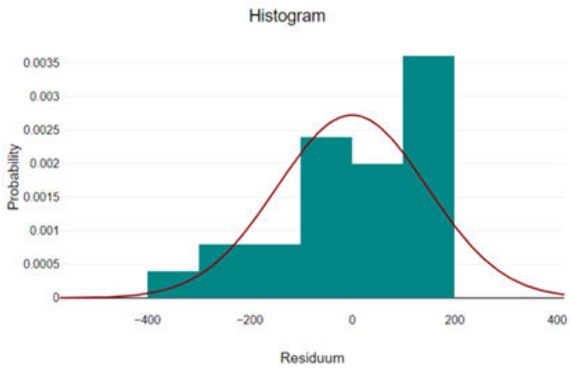
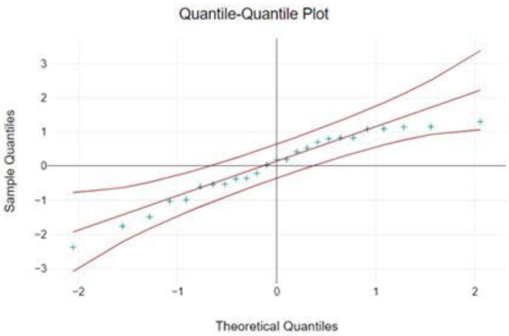
	Statistics	p
Kolmogorov-Smirnov	0.12	.844
Kolmogorov-Smirnov (Lilliefors Corr.)	0.12	.506
Shapiro-Wilk	0.94	.132
Anderson-Darling	0.49	.226





Multicollinearity

Problematic if Tolerance < 0.10 or VIF > 10

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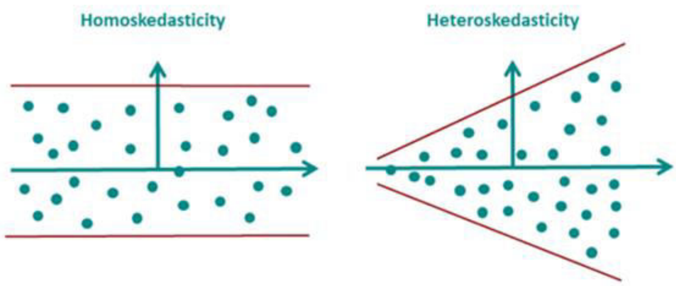
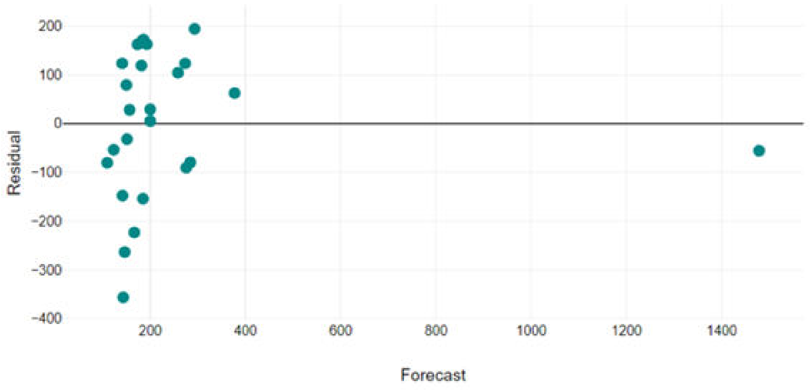
Modell	Toleranz	VIF
Na mg/L	0.82	1.22
K mg/L	0.82	1.22

Heteroskedasticity

The variance of the residuals must be constant over the predicted values. Your data must therefore not exhibit heteroskedasticity.



Your model results in the following graph



Effect Size

Cohens f^2

	f^2
Na mg/L	3.06
K mg/L	3.07

Interpretation of the results
Multiple Regression Analysis
Extra-Peninsular India

A multiple linear regression analysis was performed to examine the influence of the variables HCO3 mg/L, SO4 mg/L, Na mg/L and F mg/L on the variable Cl mg/L.

The regression model showed that the variables HCO3 mg/L, SO4 mg/L, Na mg/L and F mg/L explained 84.03% of the variance from the variable CL mg/L. An ANOVA was used to test whether this value was significantly different from zero. Using the present example, it was found that the effect was significantly different from zero (meaning statistically significant), F= 42.1, p= <.001, R^2=0.84.

Regression Coefficients

The following regression model is obtained:

Cl mg/L = 103.2-0.6 - HCO3 mg/L -0.22 - SO4 mg/L +2.36 - Na mg/L -24.81 - F mg/L

When all independent variables are zero, the value of the variable Cl mg/L is 103.2

The standardized coefficients beta are independent of the measured variable and are between -1 and +1, with the larger the amount of beta, the greater the contribution of the respective independent variable to explain the dependent variable Cl mg/L. In this model, the variable Na mg/L has the greatest influence on the variable Cl mg/L. The calculated regression coefficients refer to the sample used for the calculation of the regression analysis, and the null hypothesis is made for each coefficient that it is equal to zero in the population. The test statistic t is then calculated from the standard error and the coefficient. The P-value is used to test whether individual coefficients deviate from zero in the population. It is calculated from the standard error and the coefficient. The coefficients of HCO3 mg/L, SO4 mg/L, Na mg/L, and F mg/L all have p values of.001.Thus, the p-value is smaller than the significance level of 0.05, and the null hypothesis of zero is rejected, so it is assured that the coefficient for the variable age in the population is different from zero.

Interpretation of the results
Multiple Regression Analysis`
Peninsular India

A multiple linear regression analysis was performed to examine the influence of the variables Na mg/L and K mg/L on the variable HCO3 mg/L.

The regression model showed that the variables Na mg/L and K mg/ explained 75.77% of the variance from the variable HCO3 mg/L. An ANOVA was used to test whether this value was significantly different from zero. Using the present example, it was found that the effect was significantly different from zero (meaning statistically significant), F= 34.39, p= <.001, R^2=0.76.

Regression Coefficients

The following regression model is obtained:

HCO3 mg/L = 134.62 -0.08 - Na mg/L +9.94 - K mg/L

When all independent variables are zero, the value of the variable HCO3 mg/L is 134.62

The standardized coefficients beta are independent of the measured variable and are between -1 and +1, with the larger the amount of beta, the greater the contribution of the respective independent variable to explain the dependent variable HCO3 mg/L In this model, the variable K mg/L has the greatest influence on the variable HCO3 mg/L. The calculated regression coefficients refer to the sample used for the calculation of the regression analysis, and the null hypothesis is made for each coefficient that it is equal to zero in the population. The test statistic t is then calculated from the standard error and the coefficient. The P-value is used to test whether individual coefficients deviate from zero in the population. It is calculated from the standard error and the coefficient. The p value for the coefficient of Na mg/L is.004, which is smaller than the significance level of 0.05, and the null hypothesis that it is zero is rejected. For the coefficient of K mg/L, the p-value is .001, which is also smaller than the significance level of 0.05, and the null hypothesis that it is zero in the population is rejected. This indicates that the coefficient for the variable age in the population is different from zero.

PART D: TREND LINE AND TREND SURFACE MODEL STUDY

Fluid geochemical trend lines and trend surface analysis in Peninsular and Extra-Peninsular Hot Springs for HCO3 and Cl concentrations

The objective of performing a trend analysis is to identify a trend in the data by fitting polynomial functions to the dataset, selecting the best polynomial to use to simplify and analyse the data so obvious yet not revealed by the lines and surfaces using a statistical curve fitting technique that accomplishes "best-fitting' a series of polynomials by the least-squares criterion of multiple regression, and then using this trend surface for performing spatial interpolation, given the geographic coordinates of the location.

The systematic variations of a variable or set of variables in time and space can be solved by using a least-squares technique that finds the line of best fit through a scatter graph of a set of data points visualising the relationship between the variables. Deterministic functions such as polynomials or a curved line can be employed to describe a trend in fluctuating data. The polynomial degree can be determined by the number of fluctuations in the data or by the number of hills or valleys that appear in the curve. The second order-order trend, for example, has only one hill, while the third order has one or two hills or valleys. The trend function in Excel is a statistical function that computes the predictive value of Y for a given array of values of X using the least squares method based on the given data series. The aim of the present study is to interpret the fluid geochemical data with reference to variables HCO3 and Cl.

In the present study, the two sets of data representing Peninsular and Extra-Peninsular India were thoroughly blended, which was then subjected to trend analysis using Excel's statistical trend function. From the previous knowledge of the geochemical characteristics of the hot springs in regions with diverse tectonic settings, two types of spring water—bicarbonate, or HCO3, and chloride—were identified. Looking at the trend and between-group and within-group differences, the HCO3 and Cl contents of fluid geochemistry were considered for the present study.

Table 4D.1. The values of Y- and X- coordinates, HCO3 and Cl contents (in mg/L) at different localities along with other computed values

1	Location	Y	X	HCO3 mg/l	Cl mg/L	New HCO3	TREND (HCO3)	New Cl	TREND (Cl)
2	Agni kund	23.8833	87.3666	39	88	39	26.30802808	88	27.02928622
3	Suryakund	24.09	85.41	44	90	44	26.312141	90	27.02535254
4	BakreshwarR	23.52	87.25	150	8	150	26.39933495	8	27.18663363
5	Attri	20.123	85.3045	65	257	65	26.32941528	257	26.69688983
6	Tarabalo	20.1505	85.181	95	143	95	26.35409281	143	26.92110988
7	Athmalik	20.443	84.301	105	250	105	26.36231865	250	26.71065773
8	Gopalpur	19.2647	84.862	610	100	610	26.77772378	100	27.00568411
9	Taptapani	19.2905	84.235	205	0	205	26.4445771	0	27.20236837
10	Tatta	23.4515	84.0212	120	105	120	26.37465742	105	26.9958499
11	Matang	23.492	84.294	240	20	240	26.47336755	20	27.16303152
12	Sitakund	25.22	86.36	0	0	0	26.27594729	0	27.20236837
13	Lachmikund	25.03	86.29	0	0	0	26.27594729	0	27.20236837
14	Rajgir	25.01	85.25	22	1	22	26.29404415	1	27.20040153
15	Tapoban	24.55	85.19	26.4	2	26.4	26.29766352	2	27.19843468
16	Surajkund	24.09	85.41	60	94	60	26.32530236	94	27.01748517
17	Takshing	28.2	93.15	435	18	435	26.63377151	18	27.1669652
18	Chetu	28.25	93.26	362	154	362	26.57372285	154	26.89947462
19	Naza	28.273	93.25	353	35	353	26.56631959	35	27.13352888
20	Tatwani	32.071	76.431	15	2	15	26.28828606	2	27.19843468
21	Manikaran	32.0278	77.3473	9170	133	9170	33.81904638	133	26.94077831
22	Chuza	32.0345	78.37	490	855	490	26.67901365	855	25.52071799
23	Jeori	31.314	77.47	218	102	218	26.45527069	102	27.00175043
24	Napta	31.342	77.582	342	232	342	26.55727116	232	26.7460609
25	Karchham	31.3	78.105	303	200	303	26.52519037	200	26.80899986
26	Skiba	31.35	78.223	173	45	173	26.41825439	45	27.11386045
27	Jamnotri	31	78.23	276	170	276	26.50298059	170	26.86800513
28	Banas	30.572	78.25	145	30	145	26.39522203	30	27.14336309
29	Chaudaduni	30.5502	78.3336	15	2	15	26.28828606	2	27.19843468
30	Jhaya	30.5325	78.4012	248	72	248	26.47994823	72	27.0607557
31	Tunja	30.5325	78.433	272	10	272	26.49969025	10	27.18269994
32	Gaurikund	30.3905	79.0135	445	35	445	26.64199736	35	27.13352888
33	Badrinath	30.4445	79.293	112	1485	112	26.36807674	1485	24.28160718
34	Ghorshila	30.4158	79.352	103	0	103	26.36067349	0	27.20236837
35	Kanakar	36.325	79.313	117	15	117	26.37218967	15	27.17286573
36	Juma	30.36	79.481	861	48	861	26.98419247	48	27.10795993
37	Tapoban	30.293	79.373	278	12	278	26.50462576	12	27.17876626
38	Ungiya	30.0527	80.5313	38	5	38	26.3072055	5	27.19253415
39	Devkuna	29.58	80.0856	953	86	953	27.05987024	86	27.03321991
40	Balati	30.0853	80.2023	734	12	734	26.87972425	12	27.17876626
41	Dobat	29.515	80.3384	439	41	439	26.63706185	41	27.12172782
42	Panamik	34.465	77.324	254	13	254	26.48488373	13	27.17679941
43	Pulthang	34.4525	77.333	363	17	363	26.57454543	17	27.16893204
44	Changlung	34.564	77.2825	1610	85	1610	27.6003082	85	27.03518675
45	Gul	33.162	75.0345	259	11	259	26.48899665	11	27.1807331
46	Yurdu	33.431	75.443	233	58	233	26.46760946	58	27.0882915
47	Tatwain	33.303	75.523	32	3	32	26.30226999	3	27.19646784
48	Galhar	33.204	76.562	112	30	112	26.36807674	30	27.14336309
49	Puga	33.13	78.195	0	410	0	26.27594729	410	26.39596292
50	Chhumathang	33.22	78.21	0	7	0	26.27594729	7	27.18860047
51	Sunsani	32.421	76.0425	415	596	415	26.61731982	596	26.03013021
52	Gajkhad	32.0755	76.105	264	13	264	26.49310958	13	27.17679941
53	Baijnath	32.071	76.431	49	104	49	26.31625393	104	26.99781674
54	Sohnadh	28.15	77.04	154	1375	154	26.40262529	1375	24.49795986
55	Sohna	28.15	77.04	188	140	188	26.43059316	140	26.92701041
56	Didwaka	26.353	76.193	315	130	315	26.53506138	130	26.94667884
57	Rindli	27	76.53	390	195	390	26.59675521	195	26.81883407
58	Parai	24.11	73.411	500	140	500	26.6872395	140	26.92701041
59	Parsad	24.13	73.424	290	50	290	26.51449677	50	27.10402624
60	Gogbasp	21.4053	72.1544	190	1347	190	26.43223833	1347	24.55303145
61	Gogbatw	21.4053	72.1544	410	110	410	26.6132069	110	26.98601569
62	Dholera	22.15	72.12	150	2725	150	26.39933495	2725	21.84272242
63	Cambaywell	22.14	72.41	1534	2428	1534	27.53779178	2428	22.42687466
64	Keedapad	23.2	73.56	183	71	183	26.42648024	71	27.06272255
65	Koknere	19.423	72.51	13	4800	13	26.28664089	4800	17.76152413
66	Paduspada	19.4105	72.543	11	850	11	26.28499572	850	25.5305522
67	Akloli	19.293	73.05	14	1210	14	26.28746347	1210	24.82248888
68	Vadavil	18.04	73.27	18	78	18	26.29075381	78	27.04895465
69	Keed	17.43	73.24	71	426	71	26.33435078	426	26.36449344
70	Toral	17.15	73.35	30	375	30	26.30062482	375	26.46480241
71	Tapibasin	21.4196	76.1666	63	265	63	26.32777011	265	26.68115509
72	Bugga	17.55	80.4315	364	30	364	26.57536802	30	27.14336309
73	Gundala	17.383	80.563	99	457	99	26.35738315	457	26.30352132
74	Manuguru	17.5545	80.4425	366	257	366	26.57701319	257	26.69688983
75	Pagdaru	17.56	80.43	171	50	171	26.41660923	50	27.10402624
76	Janampeta_s	18.06	80.4	128	166	128	26.3812381	166	26.8758725
77	Tatapani	23.6993	83.6842	177	67	177	26.42154473	67	27.07058992

Methodology of calculating Trendline

Equation for Trend Line

The Trend Function finds the line that best fits data by using the least squares method. A trend line signifies a polynomial relationship. The equation for this relationship is as follows:

$$y = mx^n + b$$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \text{ (the average of } x)$$

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} y_i \text{ (the average of } y)$$

$$m = \frac{\sum_{i=1}^{n}(x_i - \bar{X})(y_i - \bar{Y})}{\sum_{i=1}^{n}(x_i - \bar{X})^2}$$

Where:

- *y is* the dependent variable to be calculated.
- *x is* the independent variable used to calculate *y*.
- b: the intercept (which indicates where the line intersects the y-axis and is equal to the value of y when x is 0).
- m: the slope (which indicates the steepness of the line).
- n- is the degree or power of polynomials.

This equation for the line of best fit is also used in the linear regression analysis.

TREND function

The TREND function returns values along a linear trend. It fits a straight line (using the method of least squares) to the array's known_y's and known_x's. TREND returns the y-values along that line for the array of new_x's that we specify.

The syntax of the TREND function is as follows:

TREND (known_y's, [known_x's], [new_x's], [const])

Where:

Known_y's (required): a set of the dependent y-values that is already known.

Known_x's (HCO3/Cl)): one or more sets of the independent x-values.

- If only one x variable is used, known_y's and known_x's can be ranges of any shape but equal dimension.
- If several x variables are used, known_y must be a vector (one column or one row).
- If omitted, known_x's is assumed to be the array of serial numbers 1, 2, 3,...

New_x's (New HCO3/New CL): one or more sets of new x-values for which we want to calculate the trend.

- It must have the same number of columns or rows as known_x.
- If omitted, it is assumed to be equal to known_x's.

Presenting the results and visualizing the results in a graph

Fig. 4D.1.Locations of hot springs

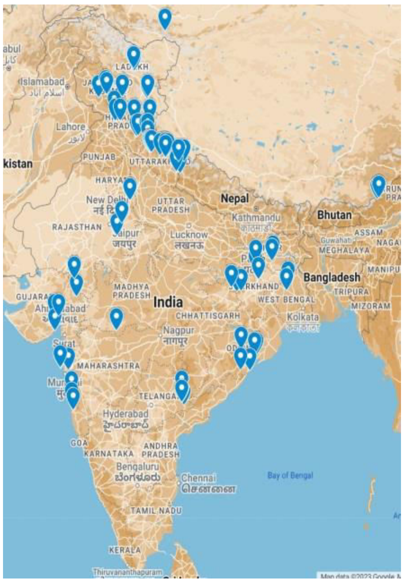
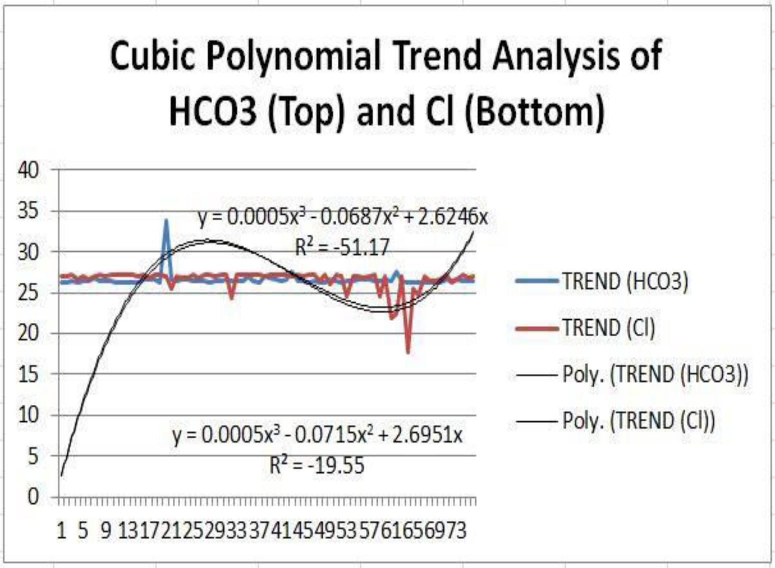


Fig.4D.2. Bivariate Trend analysis based on computed valued of variables



Interpreting the results

One of the significant benefits of trend analysis is that one can compare the performance of varying variables on trend-based charts. The visualisation designs mentioned above are amazingly easy to interpret. Besides, one can use these charts to create compelling data stories. In the present study, multivariate polynomial regression is used to model complex relationships with multiple variables. Deterministic functions such as polynomials or a curved line can be employed to describe a trend in fluctuating data. The polynomial degree can be determined by the number of fluctuations in the data or by the number of hills or valleys that appear in the curve. In the present study, cubic or third-degree polynomials are chosen, which give a better recognisable pattern than the original raw data. Looking at the trend and between-group and within-group differences, the HCO3 and Cl contents of fluid geochemistry show an inverse relationship between the bivariates of two distinct groups of geothermal springs.

Trend Surface Analysis

More recent studies furnish a geostatistical explanation of spatially dependent multivariate geothermal data representing two spatially distinctive regions of diverse geologic-tectonic settings: one from a 2400 km long arcuate belt of the tectonically active Extra-Peninsular Himalayan region and the other from Late-Precambrian or Proterozoic mobile belts in the Central Highland in an otherwise stable landmass or shield of Penininsular India. Geothermal hot springs spread over these areas, conspicuously coinciding with the respective tectonic zones of different degrees of severity. In the present study, the two sets of data representing Peninsular and Extra-Peninsular India in entirety were considered for trend surface analysis or trend surface mapping. From the previous knowledge of the geochemical characteristics of the hot springs in the two regions with diverse tectonic settings, two types of spring water—bicarbonate, or HCO3, and chloride, or Cl—were identified. While mapping, polynomial power was set at 3 or cubic, which gives a better recognisable pattern than the original raw data.

Mathematical consideration

A trend surface model is a particular case of a bivariate regression model with two independent variables, the coordinates X and Y, and a dependent variable, the thematic variable Z, to be modelled. In other words, the principle of a trend surface model is a regression function that estimates the variable value Z_i at any location based on the Xi and Yi coordinates of this location. The general function is:

$$Z_i = f\,(Y_i, X_i)$$

Where:

z_i = variable value at location i

Y_i, X_i = geographic coordinate values at location i

f = regression function

One can select a linear regression function (first order) or, if the spatial distribution is more complex, a polynomial function (2nd, 3rd,..., or nth order). The modelled surface will correspond to a flat, oriented plane or a curved surface with an increasing number of polynomial order.

The trend surface analysis technique is applied to separate the raw data into two components: the regional or background trend (regression) and the local anomalous values or residuals (deviations). It is in reality a mathematical curve fitting technique that accomplishes "best-fitting' a series of polynomial surfaces by the least squares criterion of multiple regression and determines a value about which the variance is a minimum. The goodness-of-fit of the appropriateness of trend surface curves to the data can be tested by the analysis of variance. A progressive higher-order trend surface fit to the data can be represented by the polynomial equation of arbitrary degree n:

$$Y_i = \sum_{r=0}^{n} a^r X_i^r$$

Where Y_i represents the calculated value in the i-th observation, a^r (r = 0,1,2,...n) indicates arbitrary complex coefficients, and X_i indicates the independent variable in the i-th observation. The 'best' is obtained when the sums of squares of differences between the observed values (y_i) for a particular application (in the present study, Cl and HCO3 elemental values) and the corresponding calculated values (Y_i) are as small as possible. That is

$$\sum_{i=1}^{n} d_i^2 = \sum_{i=1}^{n} (Y_i - y_i)^2 = \text{minimum}$$

The differences (d_i) are called residuals. Moreover, in the case of two-dimensional trend surface mapping, (X_i) is defined as a function of the independent variables, such as mutually perpendicular geographic coordinates X_i (the easting) and Y_i (the northing). The trend is therefore a linear function of the geographic coordinates of a set of observations, minimising squared deviations from the trend.

GIS MAPPING PROCEDURES

The principle of trend surface modelling is illustrated with a very obvious and observable spatial distribution: fluid geochemical variables, chloride (Cl), and bicarbonate (HCO3). The trend surface mapping of raw data was performed with the help of a GIS tool at the Geography Division of the University of Calcutta at Ballygunge Science College. While mapping, polynomial power was set at 3 or cubic, which gives a better recognisable 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. Outside of the sampled region, estimated values from trend surfaces become unreal. This is known as edge effects. These are the areas to avoid. Trend surfaces tend to fit better and better the interpolated distribution up to the fourth order. The value distribution then tends to deviate from the interpolated distribution. In the current study, the polynomial of power 3, i.e., cube, trend surfaces reasonably gives a better recognisable pattern than the original raw data.

Fig.4D.3. Trend Surface mapping of chloride

Fig.4D.4. Trend Surface mapping of Bicarbonate

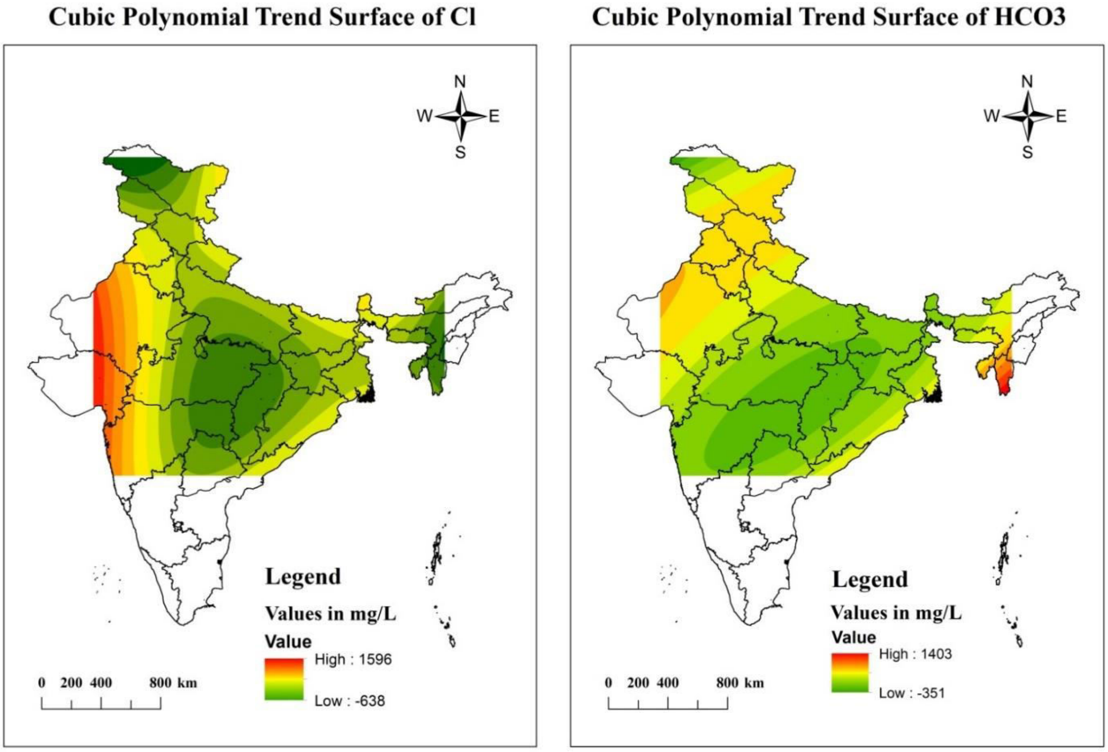
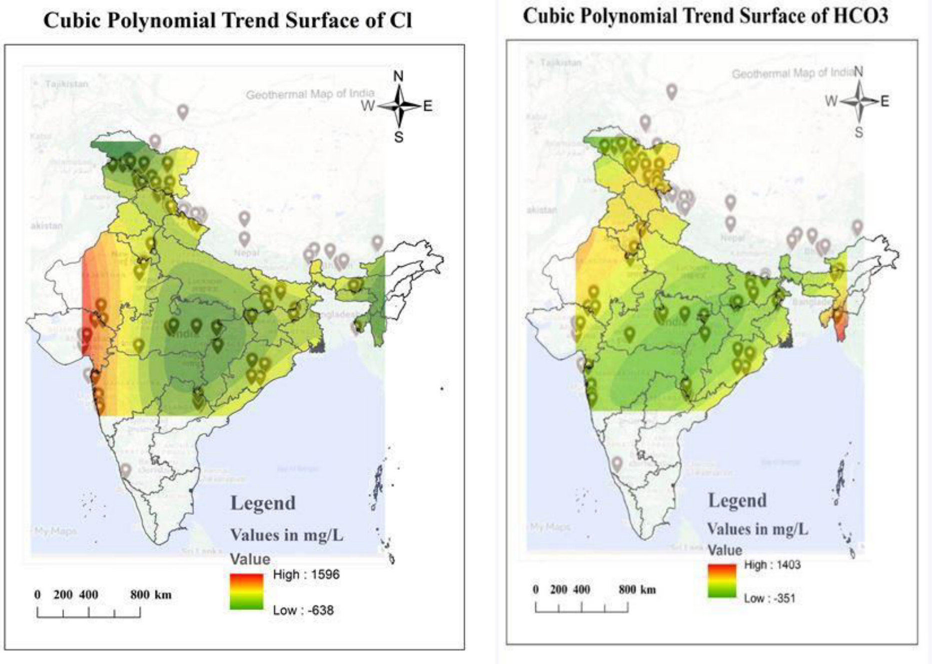


Fig. 4D. 5. Geothermal Map overlays on Trend Surface maps



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. The 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 above confirm the litho-tectonic structure in both the Peninsula and Extra-Peninsula regions.

V. SOCIETAL IMPACT OF CURRENT RESEARCH OUTPUT

Following a thorough investigation into differentiating the geochemical characterization of fluid geochemistry in two distinct geotherms in diverse geologic-tectonic settings, it is now necessary to justify the societal impact of my research output outside of their scholarly circle or academia. When it comes to research, societal impact is important. The social impact of research is and should be an important consideration. It expresses and quantifies the actual societal benefit of research output, which is critical in the development of holistically functional solutions. The ultimate beneficiaries of research should be society, decision-making, and the economy. As a result, producing research output that is not only technically effective but also socially beneficial is critical.

1. Bio-medical Impact: The bio-medical impact lies in the fact that the chloride and bicarbonate concentrations in geothermal waters share an inverse reciprocal acid-base relationship during either acidosis or alkalosis. These relationships are, in fact, due to the red cell chloride shift. Chloride-rich mineral waters are used as curative agents for digestive disorders like dyspepsia, irritable bowel syndrome, and constipation by breaking down food as a component of hydrochloric acid. Bi-carbonate neutralizes stomach acid, which makes it an effective antacid.

2. **Effect of Bi-carbonate waters on irrigation:**The effect of bicarbonate levels in irrigation water on nutrition content, production and quality of crop growth. Bi-carbonate raise the pH of the water and cause havoc in soil and plants. The specific effect of CO_3= and/or HCO_3^- ions seems to inhibit the metabolic processes in the plant and appears responsible for reduction of crop growth, absorption of nutrients and synthesis of proteins and carbohydrates.

3. Implications of Geothermal Fluid Composition on Power Plants: Geothermal energy is a sustainable and renewable energy source that uses steam to generate electricity. The steam comes from reservoirs of hot water located a few miles or more below the earth's surface, and the steam rotates a turbine that activates a generator, which produces electricity. Geothermal fluids with medium temperatures (125°–225°C) and high temperatures (>225°C) with a pH of 6.1-6.9 (neutral) can be used as geothermal power plants. Coping with complex geothermal fluid mixtures is a main challenge for designing and operating reliable and efficient geothermal power plants. Knowledge of the characteristics of fluid geochemistry is therefore important for the design and operation of reliable geothermal power plants.

VI. SUMMARY

The surface manifestations of geothermal fields are the volcanoes, fumaroles, geysers, steaming grounds, and hot springs. There are about 340 hot springs spread over different parts of India, covering the peninsular and extra-peninsular regions. The first attempt to list the hot springs in India was carried out by Schlagintweit in 1852, when he prepared an inventory of 99 thermal springs. India constituted a 'Hot Spring Committee' to examine the possibility of developing geothermal plants for power generation and other uses.

The committee in its report in 1968 recommended for a systematic geothermal study and exploration in India in 1972. The GSI initiated its geothermal exploration with the launch of the "Puga Project" in Jammu and Kashmir. In its search for hydrocarbons, the ONGC also collected significant geothermal data in sedimentary basins, both in 'off shore' and 'on-shore" areas in the Peninsular region. Mainly due to the ever increasing interest shown by various national agencies in geothermal energy, the growth rate of geothermal data has been constantly accumulated during the last few decades.

Based on the data compiled from all sources of information, both published and unpublished, on geothermal activities in India, the Geological Survey of India has compiled all data in a special publication titled 'Geothermal Atlas of India' (Ravi Shankar et. al., 1991). The GSI being the repository of most of the information concerning geological and other related data in the country, it was included in its field season 1993-94 program as a R&D item no. 7/WB-5 for the development of a computerized geothermal database system referred to as GTHERMIS (A. Roy, 1994).

The Peninsular Plateau is in the shape 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 Vindhyan and Satpura ranges. The Peninsular Shield is a mosaic of Early to Middle Precambrian stable landmasses called cratons, Late Precambrian Proterozoic mobile belts or suture zones, and Deccan flood basalts of Late Mesozoic to Tertiary age. The Extra-Peninsula is a 2400 km long arcuate belt of tectonically very active Himalayan mountain chains. The Indo Gangetic Plains in the middle separate the Himalayan Extra-Peninsular mountain region to the north from the Peninsular Shield to the south.

In both of these regions, there is a conspicuous association between the tectonic zones and the disposition of geothermal hot springs. The hot springs of Peninsular India are restricted to the Proterozoic mobile belts in the Central Highlands, leaving the more stable southern Deccan plateau completely devoid of any hot springs.

The hot springs of the Himalaya are located in the zones of deep faults that define tectonic boundaries between the north margin of the Himalaya and South Tibet , between the Great Himalaya and Lesser Himalaya, and between the Siwalik domain and the Lesser Himalaya. The geothermal activity is highest in the Ladakh region, where heat flow is of the order of 300 mW/m2 (Jonathan, 2013). In the Extra-Peninsular region, the geochemical data were drawn from hot springs representing Puga geothermal field in NW Himalaya, Ladakh district, Jammu & Kashmir, and the Tuting-Tidding Suture Zone (TTSZ) in NE Himalaya, Arunachal, India, situated near the junction of the Indian and Asian plates and characterized by volcanic sedimentary assemblages of rocks, and from Uttarakhand-Himachal Pradesh geothermal fields, which are located within the Middle or Lesser Himalayan Crystalline (LHC) Zone.

From the literature reviews of earlier researchers (D. Rouwet, 2022; F. Tassi et al., 2010; **Mohammad Noor et al., 2021),** which have relevance to my research topic, no clear inference of the origin of deep seated chloride rich hot spring waters as opposed to the shallower bicarbonate rich hot spring waters could be drawn. While the goal may be the same, the gaps in knowledge and unresolved problems that are lacking in their studies have been addressed in my research by adopting a definitive approach of statistical/mathematical modeling that gives an insight into arriving at the distinction of two suites of distinct geothermal systems. The combined robust techniques of exploratory factor analysis and multiple regression analysis to which the geothermal data were subjected made comparison simpler and easier to follow between the fluid geochemistry inherent in the two distinctive geologic-tectonic environs with two very contrasting tectonic histories with differing degrees of severity - recent Himalayan thrust zones in Extra-Peninsula in the north as against the late Precambrian Proterozoic mobile belts in the Central Highland of Peninsular India..

Both these exploratory factor and multiple regression analyses corroborate each other in deciphering the origin of these two suites of fluid geochemistry. The main types of primary fluids are Na-Cl waters, acid-sulphate waters, and high-salinity brines. When primary fluids rise towards the surface, they can undergo fluid mixing to form secondary geothermal fluids to produce carbon dioxide or sodium bicarbonate waters. The geochemical characteristics as established by multivariate exploratory factor analysis followed by multiple regression analysis revealed two statistically significant suites of fluid geochemistry: The thermal springs of the extra-Peninsular region are deep-seated and acidic, in contrast to the shallower, relatively cold waters with high pH alkalinity of the Peninsular springs. The overall salt assemblage and concentration of acidic Cl-HCO3-SO4-Na-F or chloride rich water suggestive of the existence of a deep-seated hydrothermal magmatic system operating in the geotherms of extra-peninsular India, and Peninsular springs of alkaline K-Na-HCO3 or bicarbonate rich waters with low SO4-content and relatively higher contents of HCO_3 compared to other anions SO_4, Cl, and F suggestive of a non-magmatic origin.

The statistical trend function in Excel was used to analyse two sets of data representing peninsular and extra-peninsular India in this study. The trend function determined the best fitting line for the data and returned values along a linear trend. The raw data was separated into two components using the trend surface analysis technique: the regional or background trend (regression) and the local anomalous values (deviations). The trend surface model is a bivariate regression model with two independent variables (X and Y) and one dependent variable (Z = HCO3 / Cl). Geothermal map overlays on the trend surface maps amply confirm the litho-tectonic structure in both the Peninsula and Extra-Peninsula regions.

Following a comprehensive inquiry into separating the geochemical characterisation of fluid geochemistry in two separate geotherms in varied geologic-tectonic contexts, I must now defend the societal influence of my research output outside of their academic circle or academia.

1. **Bio-medical Impact:** The bio-medical impact stems from the fact that chloride and bicarbonate concentrations in geothermal fluids exhibit an inverse reciprocal acid-base connection during acidosis or alkalosis.

2. **Effect of Bi-carbonate waters on irrigation:** Irrigation effects of bicarbonate waters: The influence of bicarbonate levels in irrigation water on crop nutrition, yield, and quality The particular action of CO3 and/or HCO3 ions appears to hinder metabolic activities in the plant and appears to be responsible for reduced crop growth, nutrient uptake, and synthesis. Following a thorough investigation into differentiating the geochemical characterization of fluid geochemistry in two distinct geotherms in diverse geologic-tectonic settings, it is now necessary to justify the societal impact of my research output outside of their scholarly circle or academia.

3. **Implications of Geothermal Fluid Composition on Power Plants:** The Effects of Geothermal Fluid Composition on Power Plants: Geothermal energy is a sustainable and renewable energy source that generates electricity by using steam. Dealing with complicated geothermal fluid geochemistry is a major problem when it comes to building and managing dependable and efficient geothermal power facilities. Knowledge of fluid geochemical properties is thus essential for the construction and operation of reliable geothermal power facilities.

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REFERENCES

[1]. Amitabha Roy, 2023. Multivariate Geostatistical Modeling Of Fluid Geochemistry In Peninsular And Extra-Peninsular India. J. Appl. Geol. & Geophys (ISOR-JAGG), V.11, Issue 2, Ser. I, Pp. 11-22

[2]. Amitabha Roy, 2023. Regression Analysis Of Multivariate Fluid Geochemical Data Representing Two Distinct Systems Operative At The Geothermal Fields Of Extra-Peninsular And Peninsular India J. Appl. Geol. & Geophys (ISOR-JAGG), V.11, Issue 2,Ser. I, Pp. 01-10

[3]. Amitabha Roy, 2023. Trend Analysis Of Fluid Geochemistry With Reference To HCO3 And Cl Contens Of Peninsular And Extra-Peninsular Hot Springs. J. Appl. Geol. & Geophys (ISOR-JAGG), V.11, Issue 3, Ser. I, Pp. 21-24

[4]. Amitabha Roy, 2023. Trend Surface Modeling Of Fluid Geochemistry Of Peninsular And Extra-Peninsular Hot Springs Of India. J. Appl. Geol. & Geophys (ISOR-JAGG), V.11, Issue 3, Ser. III, Pp. 07-11

[5]. Amitabha Roy, 2023. A Comparative Statistical Study Of Geochemistry Of Geothermalffields Of Peninsular And Extra Peninsular India. J. Appl. Geol. & Geophys (ISOR-JAGG), V. 11, Issue I, Ser. II, Pp. 32-44

[6]. .Amitabha Roy, 2023. Graphical Signature Recognition Of Fluid Geochemistry Of Hot Springs In Peninsular And Extra-Peninsular India. J. Appl. Geol. & Geophys (ISOR-JAGG), V.11, Issue 2, Ser. II Pp. 01-05

[7]. A.Roy, 1983. A.Roy, 1983. Computer-Assisted Trend Surface Mapping-An Aid To Geochemical Exploration In The Sargipalli Lead-Zinc Mine Area, Sundergarh District, Orissa (India). J. Geol.Soc.Ind. Vol 24, Issue 8

[8]. A.Roy,,1984. Computer Based Factor Model To Elucidate Secondary Trace Element Distribution Patterns Around The Sargipalli Lead-Zinc Sulphide Deposit , Sundergarh District, Orissa (India)

[9]. A.Roy, 1994. GTHERMIS – An Information Management And Analysis System For Geothermal Data Of India, A Field Season Report (1993-94)

[10]. A.Fog, 2014. Why Is Factor Rotation Always Recommended, Though It Obscures General Factors?, J. Ross-Cultural Research Awang, Z, Research Methodology And Data Analysis ...

[11]. Baioumy, 2015. Geochemistry And Geothermometry Of Non-Volcanic Hot …, J. Volcanol. Geotherm. Res.

[12]. D Rouwet, 2022. Fluid Geochemistry And Volcanic Unrest: Dissolving The Haze ...Springer (2017)

[13]. F. Tassi Et Al, 2010. Fluid Geochemistry Of Hydrothermal Systems In The Arica-Parinacota, Tarapacá And Antofagasta Regions (Northern Chile). J. Volcanol. Geotherm. Res.

[14]. Jonathan Craig, 2013. Hot Springs And The Geothermal Energy Potential Of Jammu & Kashmir State, N.W. Himalaya, India.

[15]. K.S. Vadiya Et Al., 2017. Sabarmati Plain And Saurastra –Kachchh Terrane. J. Developments In Earth Surfaces Process, V. 22, Pp. 207–221.

[16]. Miroslaw Grzesik, 2022. Table Containing The Values Measured And Calculated From The Regression Equation As Well As The Statistical Tests On The Regression Equation And Its Coefficients. Institute Of Chemical Engineering, Polish Academi Of Sciences.

[17]. Mohammad Noor Et Al., 2021. A Geochemical Comparison Between Volcanic And Non-Volcanic Hot Springs From East Malaysia: Implications For Their Origin And Geothermometry. Journal Of Asian Earth Sciences.