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Morphotectonic Analysis of South Solok Area: Implication for Geothermal Manifestation and Relative Tectonic Activity

Rina Sahara[1], Muhammad Fadhli[1], Ugi Kurnia Gusti[1,2]
[1]Geological Engineering Study Program, Sriwijaya University, Indonesia
[2]School of Earth, Environment, and Society, McMaster University; Kanada
**Korespondensi e-mail*: ugikgusti@gmail.com

SARI
Distribusi energi panas bumi di Indonesia mencapai 40% dari seluruh cadangan panas bumi Indonesia. Sapan Maluluang, Solok Selatan merupakan salah satu daerah yang memiliki manifestasi panas bumi yang menjanjikan. Daerah ini memiliki perbukitan struktural yang mengelilingi daerah depresi yang menjadi ciri daerah yang memiliki beberapa manifestasi permukaan panas bumi. Kombinasi analisis morfotektonik dan observasi lapangan manifestasi permukaan digunakan untuk memahami distribusi distribusi panas bumi potensial di wilayah penelitian. morfometrik dilakukan untuk menganalisis bagaimana kontrol morfotektonik di daerah penelitian menggunakan input data dem. Smf dan Vf digunakan untuk memahami evolusi lanskap dan kontrol tektonik dengan kondisi morfologi saat ini. Selain itu, observasi lapangan dilakukan tentang bagaimana kondisi sumber manifestasi yang ditemukan di lokasi penelitian dan pengamatan litologi dan pengendalian struktur geologi. Pada analisis data DEM dihitung unsur-unsur analisis morphotectonic, seperti valley height-weight ratio (Vf) yang menghasilkan nilai sinuositas front gunung (SMF) 0,02 – 2,38 yang memiliki nilai 1,1-1,3. Area penelitian sangat dikendalikan oleh tektonik aktif. Berdasarkan hasil pengamatan lapangan, diketahui bahwa terdapat 5 sumber manifes panas bumi berupa mata air panas yang memiliki suhu 175 C -185 C dan dikendalikan oleh litologi batuan vulkanik Gunung Kerinci. Selain itu, dari analisis kelurusan di lokasi penelitian, ditemukan bahwa kelurusan NW-SE searah dengan zona sesar Sumatera.
Kata kunci : Geothermal Solok Selatan, Morfotektonik, Lineament, Manifestasi Geothermal

ABSTRACT
The distribution of geothermal energy in Indonesia reaches 40% of all Indonesia's geothermal reserves. Sapan Maluluang, South Solok is one of the areas that has a promising geothermal manifestation. This area has structural hills that surround the depression area which characterizes areas that have several geothermal surface manifestations. A combination of morphotectonic analysis and field observation of surface manifestation were used to understand the distribution of potential geothermal distribution in the study area. morphometric was carried out to analyze how the morphotectonic control in the research area used dem data input. Smf and Vf were used to understand the landscape evolution and tectonic control to the present morphological condition. In addition, field observation is carried out on how the condition of the source of manifestation found at the research site and observations of the lithology and geological structures control. In the dem data analysis, morphotectonic analysis elements were calculated, such as valley height-weight ratio (Vf) which resulted in 0.02 – 2.38 values of mountain front sinuosity (Smf) which had a value of 1.1-1.3. The research area is heavily controlled by active tectonics. Based on the results of field observation, it is known that there are 5 geothermal manifest sources in the form of hot springs which have a temperature of 175˚ C -185˚C and are controlled by the lithologies of the volcanic rocks of Mount Kerinci. In addition, from the lineament analysis at the research site, it was found that the NW-SE lineament was in the same direction as the Sumatran fault zone.
Keywords *: Geothermal South Solok, Morphotectonic, Lineaments, Geothermal Manifestation*

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Jl. Srijaya Negara, Palembang, Sumatera Selatan
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teknikgeologi@ft.unsri.ac.id

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INTRODUCTION

Indonesia is one of the greatest countries that have geothermal potential with a distribution of 25,875 MW or 40% of Indonesia's entire geothermal reserves (ESDM, 2010). Sapan Maluluang, South Solok is one of the areas that have geothermal manifestations. Regionally the research site is on the Bukit Barisan column which is characterized by the existence of a fault zone associated with a row of active volcanoes northwest-southeast. The Sumatra Fault Zone is composed of Pre-tertiary rocks to late-quarter volcanic rocks in the form of metamorphic rock complexes and volcanic rock units (Figure 1).

The collision zone of the Indo-Australian Plate and the Eurasian plate forms a cluster of rows of hills that extends from the north to the south of Sumatra Island (Barber, 2005). The active tectonics of the Indo-Australian plate move sharply against the Eurasian plate moving southward at a rate of movement of 7 cm/year (Sieh & Natawidjaja, 2000). The research area experienced several times uplifting, folding, and switching events in the Mesozoic era, resulting in the deposition of shallow seas to the deep in the eastern part and the Cretaceous in the west (Sieh & Natawidjaja, 2000). Cretaceous tectonic events were accompanied by regional uplift, alignment, and switching. The alignment that occurs controls the formation and development of basins between volcanoes. During Tertiary, volcanism activity produces eruptions and leads at the bottom are sea parts and at the top become sea stacking (Kusnama & Mangga, 2007).

Regional structural patterns consist of the fault and folding structures in the general northwest-southeast direction. While the direction of the anticlinal axis and sinking of Tertiary rocks is almost the same as the direction of the crease of pre-tertiary rocks that flow. Depression in the magmatic arc of Sumatra, occupying the eastern part of the Barisan Mountains and Bukit Barisan Anticline. This depression has straightness with the Ombilin Basin, Sinamar Basin, sub-Kiliran Basin along Bukit Barisan (Rosidi & Pendowo, 1996).

The main fault of part of the Sumatra fault is the shear fault and some normal faults are northwest-southeast (Sieh & Natawidjaja, 2000). The research site is in the Suliti Segment with tectonic basins located in the North Labuh Estuary. The Suliti segment has a length of 95 Km (Sieh & Natawidjaja, 2000).

In addition, the characteristics of the landscape can identify geological processes of plains, plateaus, hills, mountains, slopes and rivers represent the founding of research sites. The topography of the research site consists of hills to mountains from the southern end of Muaralabuh to the north of Muaralabuh. The area of active tectonics and quaternary volcanism is related to the shape of the manifestation of hot water and the appearance of ancient caldera seen from structural basins influenced by down warping tectonic regions which control the distribution of geothermal distribution in the study area.

METHOD

The research was done using, a combination of morphotectonic analysis and field observation of surface manifestation were used to understand the distribution of potential geothermal distribution in the study area (Figure 2). Morphometrics was carried out to analyze how the morphotectonic control in the research area used DEM data input (Noordwijk, et al., 2004). Vf and Smf were used to understand the landscape evolution and tectonic control of the present morphological condition based on watershed function (Noordwijk, et al., 2004). In addition, field observation is carried out on how the condition of the source of manifestation found at the research site and observations of the lithology and geological structures control, was carried out by observing the morphology formed by the geological structures that formed an area, that is what is called "Morphotectonic" (Hancock, 1994).

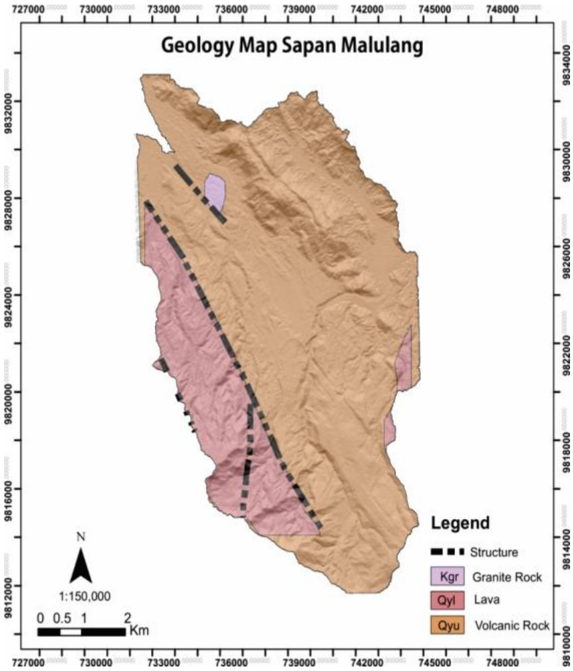

Figure 1. Geology Map of Sapan Malulang, South Solok (Modiefied From (Rosidi & Pendowo, 1996).

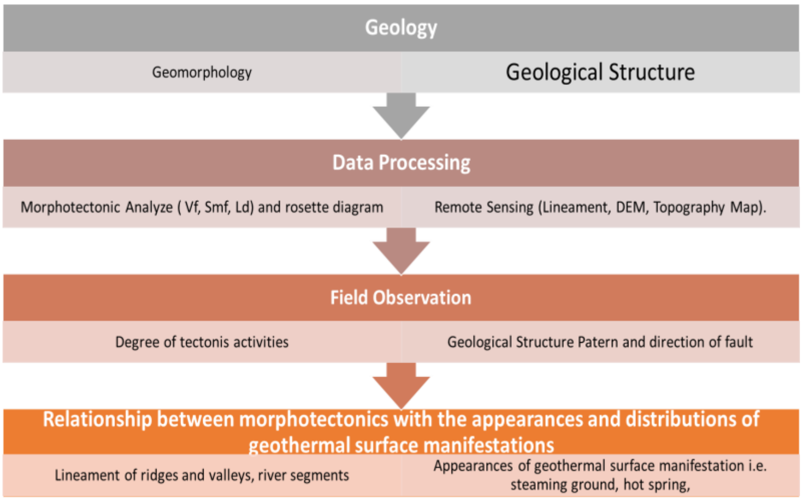

Figure 2. Research workflow

Vf (Valley Floor Widht to Height Ratio)

The calculation of the ratio of the width of the valley floor and between the two heights, which this method was first introduced by Bull & McFadden, 1977) (Figure 3) as a geomorphic index used to discriminate between the V-shaped valley floor and the U-shaped valley floor. With the calculation of the Vf index, it can be seen that there is a uplifting process in an area. in the study area.

$$Vf = \frac{2Vfw}{Eld+Erd-2Esc} \quad (1)$$

Smf (Mountain Front Sinuosity)

Smf is calculation of the ratio between the face of the mountain range and the straight-line projection (Bull & McFadden, 1977) (Figure 3). So that it can detect the level of erosion formed that can be used as a parameter whether the area is controlled by high tectonics or not. The SMF concept was first introduced by Bull & McFadden, 1977).

$$\text{Smf} = \frac{Lmf}{Ls} \ (2)$$

Ld (Lineameant Density)

Lineament density is used to determine the relationship (Bull & McFadden, 1977) between structure density areas formed by the interconnections of fractures or lineament and faults. Ld can be used to identify permeability rate of the rocks and can be used to identify damage zone.

$$\text{Ld} = \text{F/A} \ (3)$$

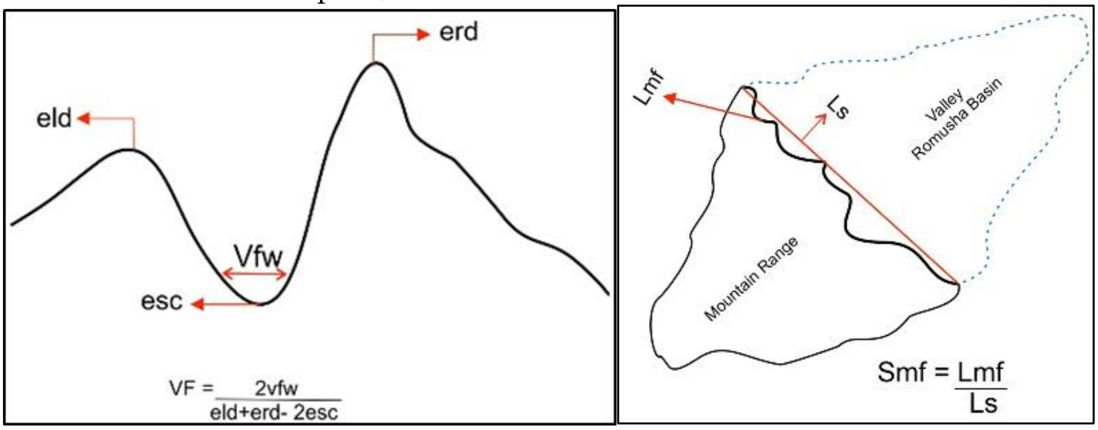

Figure 3. Valley floor width to valley height ratio calculation (Vf) calculation method and Mouintain Front Sinousity (Smf) calculation method.

RESULT

Geomorphology Unit

The research area geomorphology included plains, plateaus, hills, mountains, slopes, rivers, and other features. The creation of landscapes on Earth is influenced by tectonic forces. As a result, the landscape technique can detect geological activities at the research location. The study findings revealed that the study site was impacted by complicated tectonic factors, such as the construction of the morphology of the hills to the south of the Muaralabuh. Hot water manifestations are strongly tied to active tectonics and quaternary volcanism. This may be seen in structural basins influenced by the tectonic area of down warping, where the appearance of manifestations of Sapan Maluluang hot water is 850 m high (Figure 4).

RESULTS AND DISCUSION

Vf (Valley Floor Widht to Height Ratio)

The morphotectonic index is calculated by analysing the ratio of the valley floor to the height of a bordering morphology. The valley morphology created in the measurement might be V or U-shaped (Bull & McFadden, 1977). The analysis of the VF index is used to determine whether or not there is a level of uplifting activity in a watershed. If the value of Vf < 0.5, then it is included in the high uplift level (High), the medium uplift level (Medium) has a value > 0.5 to < 1, and the value > 1 is included in the low tectonic level (Low) (Sukiyah, et al., 2016; Keller & Pinter, 1996).

The calculation result of Vf Batang Ampalu Watershed on the location numbers 3, 5, 6, 7, 10, and 14 showed high uplift rates with Vf values ranging from 0.18 to 0.47 (Figure 5, 6). While locations numbers 1,4,8,9,11 and 12 have moderate uplift rates with the value of Vf in a range from 0.63 to 0.94 and have lower uplift rates in locations numbers 2 and 13 with the value of Vf in the field from 1.04 to 1.35 (Figure 5, 6). Next, a result of Vf Aia Manyuruak Watershed on location number 15 shows high uplift rates

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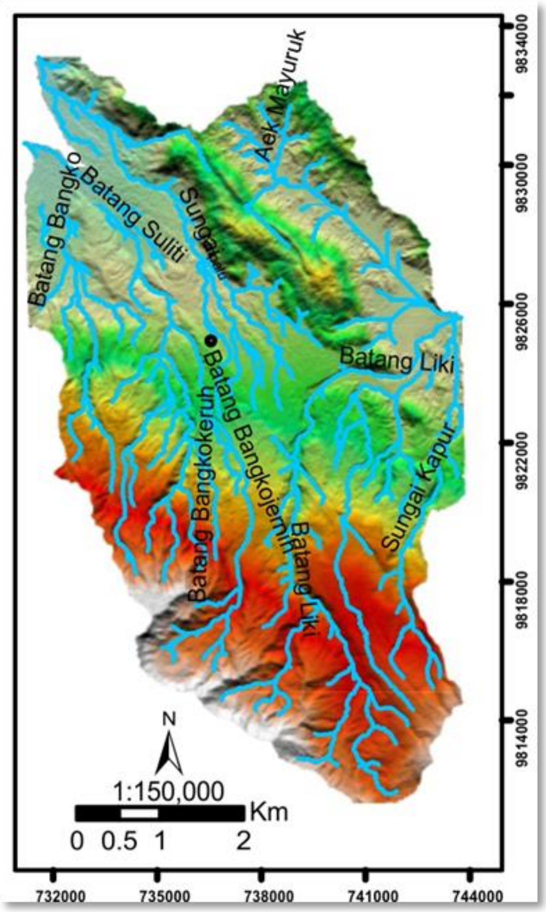

Figure 4. Morphology map and drainage pattern.

with Vf values in a range from 0.29 (Figure 5, 6). While location numbers 17,18,19 and 20 have moderate uplift rates with the value of Vf in the field from 0.52 to 0.59 and have lower uplift rates in location number 16 with the result, Vf values of 1.04 (Figure 5, 6). Furthermore, the calculation result of Vf Batang Bangko Jernih and Batang Bangko Keruh Sub Watershed locations number 22, 23, 24, 25, 35, 36, 37, 38 and 39 have Vf values of 0.10 to 0.41 that tend to show high uplift rates (Figure 5, 6). While the location of Batang Bangko Jernih and Batang Bangko Keruh Sub Watershed numbers 26, 27, and 40, a moderate uplift rate has occurred, shown by the Vf value in the range from 0.73 to 0.78 (Figure 5, 6). They are obtained on the downstream part of Way Batang Suliti watershed, in the Nothern part of the researched area. The calculation result Vf values 0.22 show high uplift rates in location number 56. While location numbers 54, 55, and 58 have moderate uplift rates with Vf values ranging from 0.53 to 0.56 and have lower uplift rates in locations number 57,59, and 60 with the value of Vf in a range from 1.25 to 2.38 (Figure 5, 6).

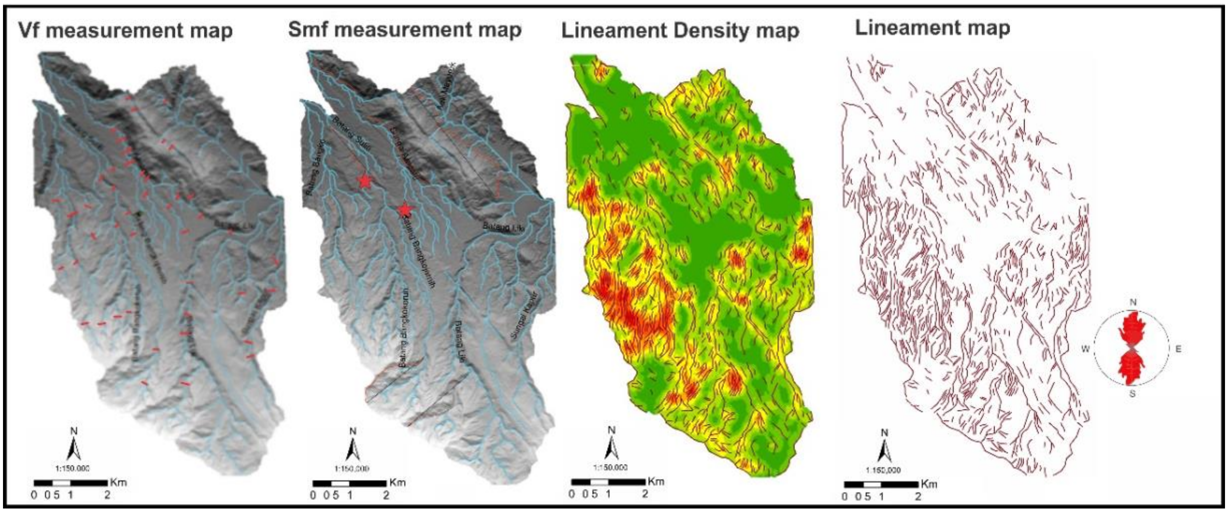

Figure 5. Map of lineament density (Ld) shows areas that have low to high density.

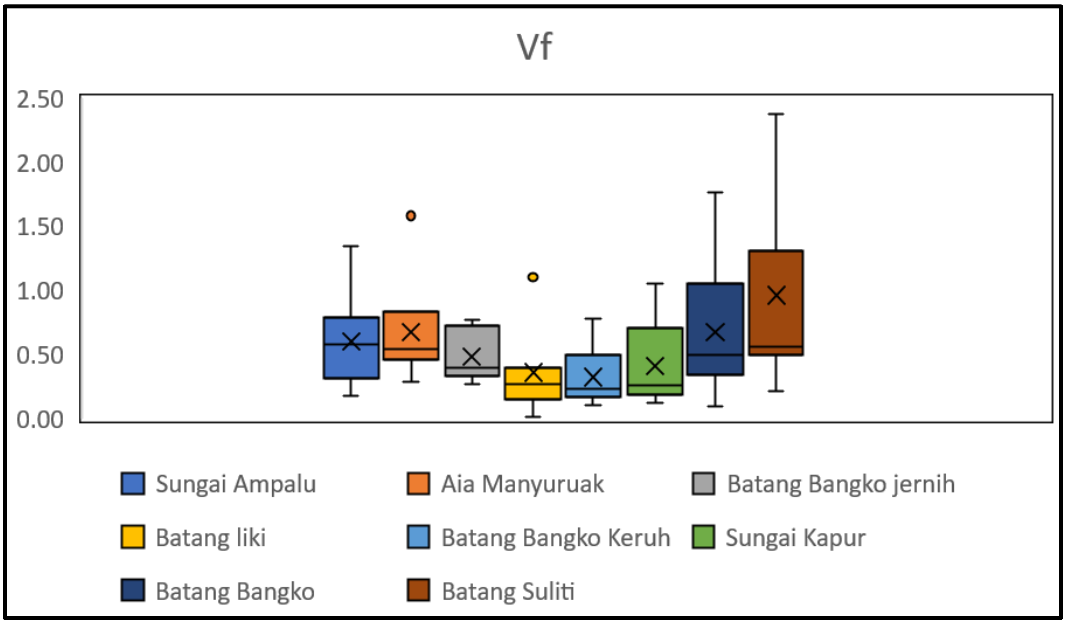

Figure 6. Box-whisker plot of Vf analysis.

Moreover, locations Batang Kapur Watershed, locations number 42,43,44, and 45, have a high uplift rate with the value ranging from 0.12 to 0.37, and location number 41 has a lower uplift rate with a value of value 1.05 (Figure 5, 6). At the same time, the result of Vf Batang Liki Watershed shows high uplift rates in locations number 29,30,31,32,33, and 34 with the value ranging from 0.02 to 0.40 and have lower uplift rate number in location number 28 (Figure 5, 6). At the end of Batang Bangko Watershed, locations number 45,46, 47, 51, and 52 45 have a high uplift rate with values ranging from 0.10 to 0.40. While the number of the locations 48,49,50 and 53 have moderate uplift rates (Figure 5, 6). While location numbers 50 and 53 have reasonable uplift rates with Vf values ranging from 0.59 to 0.62 and lower uplift rates with the value of Vf ranging from 1.20 to 1.76 in location numbers 48 and 49 (Figure 5, 6). The result expressed low to high uplift in the area as shown in Table 1 and Figure 5, 6.

Smf (Mountain Front Sinuosity)

The calculation of the morphotectonic index is in front of the mountain, and the back of the hill, which is seen from the tendency to erosion, so it can develop to find out how an area is controlled by high or low tectonic activity. This method was first introduced by (Bull & McFadden, 1977). Based on the calculation, the results can be categorized that an area has an active tectonic level if it has an Smf value < 1.5, while if it has a value > 3.0, it is classified as an area with a tectonic level that is no longer active (El Hamdouni, 2008).

The Calculation of Mountain Front Sinusity was done by determining the Smf by observing the topography and position of the mountain front of Batang Ampal Aia Manyurak, Batang Suliti, Batang Bangko keruh dan Batang Liki Watershed (Figure 5, 7) to know the level of tectonic activity on the research area. The Smf calculation indicates that all segment watershed in the researched area is dominated by active fault. The Overall Smf calculation result of six segments produces Smf values ranging from 1.1 to 1.3 (Figure 5, 7). Most of them are situated in an active tectonic activity level, and this can be described from Smf values of active tectonic such as Segment A (1.2), B (1.1), C (1.04), D (1.1), E (1.3) and F (1.1) (Figure 5, 7). According to SMF Index (El Hamdouni, 2008), this area is controlled by active tectonics (Table 2).

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Table 1. Vf (Valley Floor Widht to Height Ratio) calculation shows low-moderate-high uplifit rates.using the classification by Keller and Pinter (2002); Hamdouni (2008); Sukiyah, (2015).

No	Vfw	2Vfw	Eld	Erd	Esc	2Esc	Vf	Watershed	Uplift Rate
1	132	264	620	1066	600	1200	0.54	Sungai Ampalu	M
2	37	74	731	704	690	1380	1.35	Sungai Ampalu	L
3	13	26	1006	1050	970	1940	0.22	Sungai Ampalu	H
4	26	52	756	784	735	1470	0.74	Sungai Ampalu	M
5	7	14	999	976	969	1938	0.38	Sungai Ampalu	H
6	19	38	919	1024	906	1812	0.29	Sungai Ampalu	H
7	11	22	621	624	599	1198	0.47	Sungai Ampalu	H
8	8	16	868	873	862	1724	0.94	Sungai Ampalu	M
9	7	14	758	766	751	1502	0.64	Sungai Ampalu	M
10	10	20	956	991	917	1834	0.18	Sungai Ampalu	H
11	17	34	1241	1224	1208	2416	0.69	Sungai Ampalu	M
12	10	20	665	667	650	1300	0.63	Sungai Ampalu	M
13	25	50	835	833	810	1620	1.04	Sungai Ampalu	L
14	26	52	938	954	865	1730	0.32	Sungai Ampalu	H
15	3	6	1081	1078	1069	2138	0.29	Aia Manyuruak	H
16	49	98	711	761	705	1410	1.58	Aia Manyuruak	L
17	25	50	810	785	751	1502	0.54	Aia Manyuruak	M
18	13	26	755	753	729	1458	0.52	Aia Manyuruak	M
19	21	42	1182	1154	1130	2260	0.55	Aia Manyuruak	M
20	34	68	781	785	725	1450	0.59	Aia Manyuruak	M
21	60	120	954	754	743	1486	0.54	Batang Bangko jernih	M
22	15	30	871	920	856	1712	0.38	Batang Bangko jernih	H
23	27	54	964	981	904	1808	0.39	Batang Bangko jernih	H
24	25	50	1980	2073	1934	3868	0.27	Batang Bangko jernih	H
25	33	66	1660	1639	1551	3102	0.34	Batang Bangko jernih	H
26	39	78	832	843	784	1568	0.73	Batang Bangko jernih	M
27	27	54	641	625	598	1196	0.77	Batang Bangko jernih	M
28	64	128	1000	1040	962	1924	1.10	Batang liki	L
29	18	36	1221	1227	165	330	0.02	Batang liki	H
30	12	24	1804	1698	1673	3346	0.15	Batang liki	H
31	19	38	1303	1415	1269	2538	0.21	Batang liki	H
32	28	56	1095	1175	1065	2130	0.40	Batang liki	H
33	14	28	850	885	831	1662	0.38	Batang liki	H
34	23	46	1073	1088	995	1990	0.27	Batang liki	H
35	15	30	1660	1663	1625	3250	0.41	Batang Bangko Keruh	H
36	11	22	1885	1936	1805	3610	0.10	Batang Bangko Keruh	H
37	12	24	1822	1880	1795	3590	0.21	Batang Bangko Keruh	H
38	11	22	1656	1659	1614	3228	0.25	Batang Bangko keruh	H
39	9	18	1391	1388	1343	2686	0.19	Batang Bangko keruh	H
40	54	108	1123	1116	1050	2100	0.78	Batang Bangko keruh	M
41	31	62	945	942	914	1828	1.05	Sungai Kapur	L
42	22	44	1394	1421	1323	2646	0.26	Sungai Kapur	H
43	12	24	1503	1600	1454	2908	0.12	Sungai Kapur	H
44	13	26	852	838	810	1620	0.37	Sungai Kapur	H
45	19	38	1020	997	935	1870	0.26	Sungai Kapur	H
46	13	26	959	1023	864	1728	0.10	Batang Bangko	H
47	21	42	879	852	813	1626	0.40	Batang Bangko	H
48	60	120	736	752	710	1420	1.76	Batang Bangko	M
49	39	78	650	625	605	1210	1.20	Batang Bangko	M
50	13	26	895	915	883	1766	0.59	Batang Bangko	M
51	13	26	908	942	891	1782	0.38	Batang Bangko	H
52	18	36	1350	1379	1311	2622	0.34	Batang Bangko	H
53	26	52	812	770	749	1498	0.62	Batang Bangko	M
54	38	76	738	768	685	1370	0.56	Batang Suliti	M
55	18	36	705	733	683	1366	0.50	Batang Suliti	M
56	11	22	760	788	723	1446	0.22	Batang Suliti	H
57	19	38	618	633	611	1222	1.31	Batang Suliti	L
58	17	34	779	791	753	1506	0.53	Batang Suliti	M
59	15	30	571	577	562	1124	1.25	Batang Suliti	L
60	19	38	633	643	630	1260	2.38	Batang Suliti	L

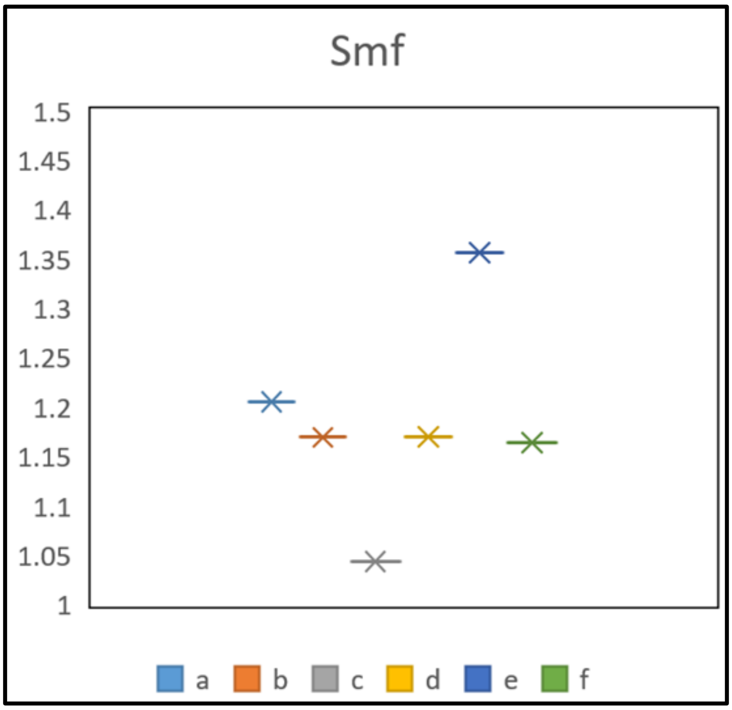

Figure 7. Box-whisker plot of Smf analysis.

Table 2. Smf (Mouintain Front Sinousity) calculation shows Tectonic Activity Level.

Segment of Mountaint Front	Lmf	Ls	Smf	Tectonic Active Level
A	8310	6896	1.205046	Active
B	4280	3662	1.16876	Active
C	7476	7169	1.042823	Active
D	3635	3109	1.169186	Active
E	4705	3470	1.355908	Active
F	4755	4086	1.16373	Active

Ld (Lineameant Density)

Lineament density is performed to sharpen the determination of zone high dominant lineament intensity describing the permeability rate of the rocks formed (Figure 5). The Calculation result of the Lineameant density will produce contour maps based on the absolute value of lineament with Extraction in Software PCI Geomatica.

The interconnections, fractures or lineament, and faults can be used as evidence that active tectonic activity passes the area. The result calculation shows that the highest lineament density values range from 0.25 Km - 5.92 Km (Figure 5). Tthe primary orientation that is northwest southeast and north-south was in the same direction as the Sumatran fault zone and then be related in the are found geothermal manifestations in the research area (Figure 5).

Geothermal Surface Manisfestasion

Geothermal surface manifestations such as hot springs, mud pools, changed rock, steaming ground, steam-heated water, solfatara, and fumaroles are being studied. Five geothermal manifest sources are identified in the research area in the form of hot springs with temperatures ranging from 175 C to 185 C and are governed by the lithologies of Mount Kerinci's volcanic rocks (Figure 8).

Figure 8. Ilustration of geothermal surface manifestations at the observation area.

CONCLUSIONS

The computation of Uplift Values in the valley floor and height ratio (Vf) yielded values ranging from 0.02-2.38. This demonstrated that the research region was experiencing quite significant levels of uplift in several areas. While the amount of tectonic activity that governs the research area has a value in the range of 1.1-1.3 in the analysis of mountain front sinuosity (Smf), it may be classified as places with reasonably high uplift rates.

Furthermore, lineament density study revealed that the hotspot regions range from 0.25 km2 to 5.92 km2, with the predominant orientation being northwest-southeast and north-south, which is the same way as the Sumatran fault zone.

Moreover, the field observation data revealed symptoms with temperatures ranging from 175 C to 185 C. Those places form the way for the appearance of prospective geothermal resources based on the computed Morphotectonic Indexes (Vf and SMF) and Surface manifestation.

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