Assessment of Active Tectonic from Morphometric Properties in Krueng Raya Watershed, Aceh Besar, Indonesia

Muhammad R. P. Siahaan, Emi Sukiyah, Nana Sulaksana, Agus D. Haryanto.

***Abstract*— Geographical Information System (GIS), when applied to active tectonic settings, has been widely used in morphometric analysis as a powerful tool to quantitatively correlate the characteristics of a landform, such as geology, geomorphology, and hydrology characteristics. In this study, GIS is used to study the Krueng Raya watershed, which is comprised of neat-jagged, gentle-steep, and diverse geological features. This study area will be the subject to analyze the watershed and landform characteristics that utilize Digital Elevation Model (DEM) DEMNAS (8m-resolution). Hillshade data extraction from DEMNAS results in low relief mountain (56.11%) and sloping to moderately steep (63.1%), a total sub-basins area of 60.3 km^2, a stream length of 178.66 km and up-to-4th-order 294 stream segments of which flow patterns are dendritic, rectangular, and sub-parallel. The geomorphometric variables calculated are areal or basin parameters (drainage density, stream frequency, circularity ratio, and elongation ratio), linear parameters (bifurcation ratio and stream length ratio), and form factor. The outcomes from these parameter calculations are quantitative morphometric showing rough to very rough textures, generally deformed, long sub-basin shape, narrow and elongated basin, and short-moderate frequency segments of stream. These morphometric anomalies are the predominant factors indicating the active tectonics and show geospatial analysis and satellite imagery combined that apply to any kind of drainage basin morphometry.**

***Keywords* — GIS, morphometric, DEMNAS, Seulimeum-fault, Seulawah Agam Volcano (SAV).**

I. Introduction

Morphometric analysis has been widely carried out since several decades ago to perform drainage basins linear, areal, and relief characteristics [1]-[3]. This has become imperative for any kind of basin management for each characteristics holding both hydrological and morphological behaviors [3]; a) linear characteristics, including stream order, stream number, bifurcation ratio, strength length, and mean stream length; b) areal or basin characteristics, including circularity ratio, elongation ratio, drainage density, and drainage frequency; and c) relief characteristics that include dissection index, ruggedness index, and hypsometric characteristics [4]. The relationships amongst these morphometric characteristics should be able to be used to understand the underlain structure [3], geology [5], soil erosion, flood mitigation [2]-[5], military affairs [6], and even further to the evolutionary history of a basin, that is closely related to tectonic activities [6], [9].

A tectonic activity could form a structure that indicates a movement, e.g. a fault, a fold, an uplifting or more contrast epeirogeny and orogeny, and an overall tilt of terrain; these structures are often reflected by the characteristics of geomorphological features such as linear valleys, ridgelines, slope breaks, stream patterns and watersheds [5], [9]. Such terrain characteristics (shape and landform) are extractable from digital topographic data [9], [10], that the investigation of the endogenetic and exogenetic geomorphological process (stage of geomorphology age) can be connected with tectonics during the geological time [10]-[12].

Digital topographic data obtained from remote sensing are proven to be a viable tool to extract terrain characteristics. Some researchers study cases in drainage basins made use of GIS-based approach to analyze the morphometrics [10]-[12]. This form of geospatial analyses can quantify the terrain characteristics because it results in ratios, dimensionless numbers, that amplify the comparison but irrespective of the scale [10], [11].

The Krueng Raya watershed has a complex geological feature, both tectonically and lithologically [7], [13]. Composed of Lamteuba volcanic rocks and Alluvium formation, Krueng Raya watershed is situated across the Seulawah Agam Volcano (SAV) to the northern coast of Aceh Besar region. The watershed, having the fault name "Seulimeum" attached to it, is closely related to the tectonic activity associated with fault. The Seulimeum-fault is a strike-slip fault in the northern part of Sumatran Fault Zone. Some structure-related geothermal surface manifestations are found in the area, named Ie Su'um [7], [13]. Previous studies in Seulimeum-fault covered the morphology and tectonics of the Andaman forearc [7], as well as local studies about the fault identification by using gravity and seismic geophysics [7], [13].

However, a morphometry study is not yet to be found. However, the study about geothermal surface manifestations through geochemical and geophysical prospecting has been

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done. Because the fault-related tectonics is depicted by the geomorphological features from topographic/terrain data, geospatial analysis of morphometry will be conducted on Krueng Raya watershed. The objective of the study is to perform a GIS-based analysis attempting to highlight the key drainage basins characteristics, whether linear, areal, or relief that link to the active tectonic activity and structures.

II. Material and Method

Geological setting of the study area is dominated by Lamteuba volcanic rocks (QTvt), Its formed from basaltic, andesite to dacite, volcanic breccias, tuffs, and agglomerates. On the other hand, Alluvium formations (Qh) are only slightly found in sagpond and coastal areas, they formed from mostly gravel, sand, and mud [7]. Tectonic activity is identified by the presence of a Seulimeuem-fault (segment of the Great Sumatran Fault), which produces geothermal manifestations in the form of hot spring [7].

Geomorphologic maps (quantitative geomorphic) can represent natural conditions and resources besides the ecological and geographical environment. Morphometric indices are the basic data for researching global or regional climate change, environmental protection, and disaster monitoring. It is also widely used in agriculture, forestry, water resources planning, regional land resource mapping, engineering construction, public education and even military scientific research [5], [6]. To generate a geomorphological map, raster data of DEM images are needed, while multispectral satellite sensors are used for lithological and landform characterization. Generally, this satellite imaging is employed for a quicker deformation process identification, an automatic extraction, and more efficient valleys and slopes surface discontinuation recognition compared to a manual process [5]. This study area will be the subject to analyze the watershed and landform characteristics using DEMNAS (8m-resolution) with the Universal Transverse Mercator (UTM) Zone 46 North coordinate system projected by the 1984 World Geodetic System.

A. *Digital Elevation Model (DEM) By DEMNAS*

DEMNAS was released at the end of July 2018 by Badan Informasi Geospasial (BGI) Indonesia. This DEM is composed of several sources such as 5-meter-resolution IFSAR and TERRASAR-X, also ALOS PALSAR (11.25-meter-resolution) [8]. The resolution of DEMNAS follows up to 0.27 Arcsecond (8 meter). DEMNAS provide good and high resolution DEMs which may be used as a set of reference DEM for registration and error evaluation purpose for this study [8], [14]. Synthetic aperture radar (SAR) interferometry is used in detecting dynamic changes, elevation and slope information and in mentoring phenomenon's that affecting the Earth's surface [8], [14].

B. *Morphometric Parameters*

There are many morphometric parameters, but only a few are related to tectonic activity. In this study, the parameters used are only those that indicate the occurrence of tectonic activity. These formulas by using basic attributes computed from spatial data (Table 1). Determination of stream order was based on segmentation method (Strahler), while stream network is strongly influenced by the geological structure, especially in the active tectonic area [3], [5]. The drainage pattern consists of a variety of ranges such as dendritic, parallel to rectangular. The patterns indicate tectonic influence in its development and reflect the geological condition of an area [1], [3].

The hillshade analytical technique was used to simulate the artificial effect of morphology. Using different sun azimuth hill shading can identify anomalies in relief, lithology, and rock formation boundaries [5]. According to the basic morphologic types, combined elevation and relief are arranged from low to high altitude such as: low altitude plains, middle altitude plain, and high altitude plain. Slopes analysis are classified into flat, sloping, and steep group, while slope was also analyzed and mapped based on DEM topographic map [5], [6].

The sub-parameter of geomorphic that is used in this study is morphometry, of which indices have been widely used to understand development of geomorphic features in the watershed area and young mountain belt, which is established as a proven technique [2], [4], [5].

Morphometric analysis with particular regard to the quantitative measurement of various aspects, as well as extraction data from DEM to obtain the stream network and pattern, is essential for drainage systems including filling, density, drainage, flow direction, and distribution [4], [5], [12].

Drainage density (Dd) is the total length of stream channel per unit of the watershed area (km/km^2). The Dd classification is divided into 6 textures; very rough (0–1.37), rough (1.38–2.75), intermediate (2.76–4.13), rather smooth (4.14–5.51), smooth (5.52–6.89), and very smooth (more than 6.89) [1]-[3], [12].

Bifurcation ratio (Rb) indices calculated by the ratio of the number of stream branches at a given order (n) to the number of stream branches of the next higher order (n+1). The result of the bifurcation ratio shows how far a watershed or a basin is deformed. The deformed area will be shown by >5 and <3 indices, while the indices between them shows undeformed area [1], [3].

The Stream frequency (Fs) is defined as the total number of stream segments of order 'u' of all order per unit area; classified into very poor (0–2), poor (2.1–5), moderate (5.1–10), high (10–15), and very high (>15). Circularity ratio (Rc) is computed by the ratio of basin area to the area of circle having the same perimeter (P) as the basin [4], [10]. Indices of Rc <0.5 shows elongated form of watershed/basin – an indication that the waterflow is relatively fast coming into and going away from the basin. On the other hand, indices of Rc >0.5 shows a circular form that indicates a static or stagnant fluid. Elongation ratio (Re) is the ratio of diameter of a circle of the same area as the watershed to the maximum watershed length that shows the watershed/basin form. The elongation ratio classifications are: elongated (<0.7), less elongated (0.7–0.8), and oval (>0.8) [4], [10].

Form factor is defined as the ratio of basin area to the square of the basin length. This factor indicates the lower value represents an elongated shape [4], [9], [10]. Stream length ratio (Rl) is defined as the total length of the stream order 'u' and the total length of its next lower stream order

[10]-[12]. The linear, areal, and relief/shape characteristics that will be used in this study are those which have direct implication to geology and tectonic activity [10]-[12].

TABLE I
THE FORMULA OF MORPHOMETRIC VARIABLES [9]-[12]

Parameters	Formula	Reference
Drainage Density (Dd)	Dd = Σ Lu / A	Horton (1945)
Bifurcation Ratio (Rb)	Rb = Nu + Nu + 1	Schumm (1956)
Stream Frequency (Fs)	Fs = Σ Nu / A	Horton (1932)
Circularity Ratio (Rc)	$Rc = 4\pi A / P^2$	Miller (1953)
Elongation Ratio (Re)	$Re = 2 / Lb * \sqrt{(A / \pi)}$	Schumm (1956)
Form factor (Ff)	$Rf = A / Lb^2$	Horton (1932)
Stream Length Ratio (Rl)	RL = Lu / Lu-1	Strahler (1964)

III. RESULT AND DISCUSSION

A. GIS Data Analysis

Topographic format with 8m resolution is very good in identifying surface morphology and landform [14]. Several analysis parameters can be performed using topographic data, by making use of DEM topography and spatial analysis, quantitative indices such as elevation, shade/relief, slope, stream network, drainage basin, incising depth, and drainage pattern [5], [6]. GIS technology with geosciences has greatly influenced geomorphologic method, remote sensing data can be integrated, overlapped and calculated in a GIS environment [11], [16]. GIS data are not only important sources to assist ground surveying, but also important data from different sources such as digital elevation models (DEM), vegetation and geological maps [4], [14], [16].

The total area of Krueng Raya watershed is 60.3 km^2 with twenty-seven sub-basins of which the perimeter is 198.85 km. The total stream length is 178.66 km which can be divided into several streams order, from 1^{st} order to 4^{th} order (Fig. 1) with a total of 294 stream segments (Table 2).

The analysis towards stream pattern is a measure to identify geological structure and its morphological characteristics. The three main types of drainage patterns found in Krueng Raya watershed: dendritic, rectangular, and sub-parallel (Fig. 1). The dendritic pattern (twelve sub-basins) indicates a homogeneity of rocks and influenced by the general topography and rainfall condition around the mine river [12]. On another note, structures seems to be not affecting the topography in this pattern. Meanwhile, the rectangular pattern (six sub-basins) identified in the southwest part of the main river shows the resistance rocks towards erosion and the residence of structures, such as joint, fractures and faults [3], [5].

The sub-parallel pattern (nine sub-basins) dominant in the northeastern part of the main river indicates area bearing gentle and uniform slope. Having existed up in the upstream that sits on the debris flow of Seulawah Agam Volcano (SAV) with active volcanic activity, its bed rock is of less resistant type [9].

TABLE II
LINEAR ASPECTS OF KRUENG RAYA WATERSHED

Parameter	1^{st}	2^{nd}	3^{rd}	4^{th}	Total
Stream Length (km)	103.46	48.54	23.35	3.31	178.66
Stream Segments	209	62	21	2	294
Sub-Basin Area (km^2)					60.30
Sub-Basin Perimeter (km)					198.85

Van Zuidam classification for elevation and slope was adapted [6]. Slightly over half (56.11%) of the Krueng Raya watershed area is dominated by low relief mountain (200–500 m.a.s.l.), taking up about 42 km^2 (Table 3). Moreover, the moderately steep (15–30%) slopes are higher than the sloping ones (7–15%), making 34.4% of the total area a little over 26 km^2 (Table 4). Meanwhile, the steep, very steep, and extremely steep slopes are noticeable in the geological anomaly due to the tectonic activity, e.g. strike-slip fault. There is a distinct volcanic morphologic zone at the formation boundary–sag pond spotted in between Lamteuba volcanic rocks (QTvt) and Alluvium (Qh) revealing Ie Su'um manifestation (Figs. 2 a and b).

B. Result of Morphometric Indices

The morphometric indices completely calculated on twenty-seven sub-basins at the Krueng Raya watershed (Tables 5 and 6), where stream and shape watershed are the main geomorphological parameters in this study.

Drainage density (Dd) values in range from 0.44–9.7 km/km^2 and its mean value is 2.75 km/km^2. This value range can be classified into very rough until very smooth and the mean value is classified into rough. Thirteen sub-basins are classified into very rough and four into rough landforms are found in regions with sparse vegetation and high relief. It totals to 63% of the watershed area, indicating that this area is dominated by hard resistance rocks, and the rough landform explains that the flow of sedimentary material transported by streams will be smaller [2], [3], [10].

High Dd values are found in sub-basin connected to the Krueng Raya river, where erosion potential and runoff are higher [4], [10]. This condition is related to smooth texture with impermeable subsurface material, high relief, and indication of tectonic activity [2], [4], [10].

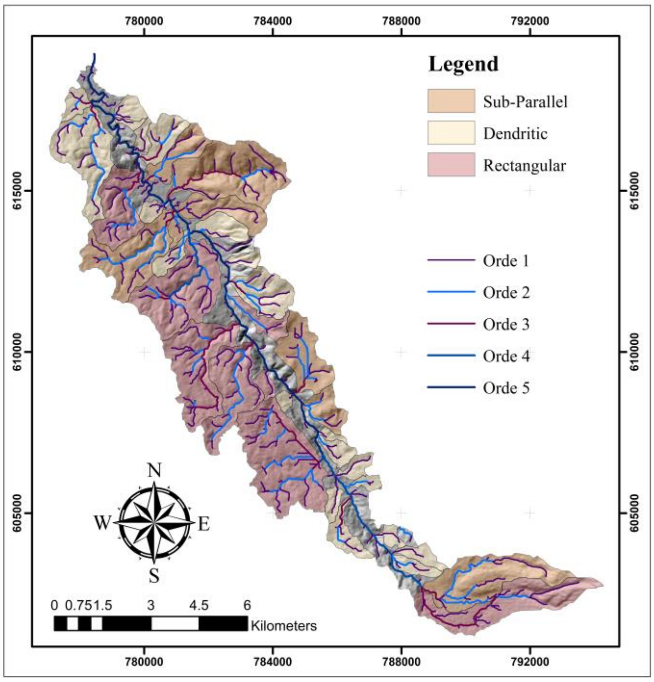

Fig. 1. Krueng Raya watershed show the identified stream order up-to-4^{th}-order of the drainage pattern is dendritic (44%), sub-parallel (33%) and rectangular (22%).

Bifurcation ratio (Rb) was calculated to three conditions: Rb of order 1st to order 2nd (Rb_{1-2}), order 2nd to order 3rd (Rb_{2-3}), and Rb average (Rb_a). Rb_{1-2} value in range 2–5.2 where seventeen sub-basins are classified as deformed (63%), Rb_{2-3} value in range 1–2 where twelve sub-basins are classified as deformed (63%), where eight sub-basins is unclassified. Rb_a value in range 1.5–4.5 where fifteen sub-basins are classified as deformed (56%) and twelve classified as not deformed.

The deformed value range indicates that drainage basin is deformed due to the tectonic activity and is in the fault system and manifestation (Ie Su'um hot spring) [2], [3], [10]. The Higher values of Rb indicate greater soil erosion, whereas, low values of Rb imply that it developed on almost homogenous topographic structure [4], [10].

In the stream parameters, Stream frequency (Fs) values range from 3–12 segment/km^2 (mean value is 5.74) and can be classified into poor until high frequency. Specifically, this area is dominated by moderate classified about fourteen sub-basins, eleven in poor class and two in the high class. Stream frequency mainly depends on the lithology and reflects the texture of the drainage network, moderate values indicate the presence of a permeable subsurface material and middle relief [4], [12]. Fs density indicates establishing the erosional processes, sequences of relief developments, and the degree of ruggedness in the area [4], [10], [12]. Moderate frequency in the fault area is an indication of the presence of tectonic activity.

Stream length ratio (Rl) is calculated to three conditions: Rl_{2-1} value in range 0.04–7.7 (mean value is 1.02), Rl_{3-2} value in range 0.1–3.2 (mean value is 0.98), and Rl_a value in range 0.07–3.8 (mean value is 0.83), there is no classification for Rl. Overall Rl shows this area is below the mean value, a decreasing trend in Rl from higher-order to lower order. It is indicating the youth stage of geomorphic and affected by the tectonic control [11], [12].

Basin shape parameters are calculated as Circularity ratio (Rc), Elongation ratio (Re), and Form factor (Ff). Rc value in range 0.25–0.8 (mean value is 0.47) and Re value in range 0.46–1 (mean value is 0.66) both have eighteen sub-basins that indicate elongated, long, narrow basin shape characteristics, with its 68% of the watershed area. Low values of Rc indicate the young life cycle of the tributary watershed [12]. Rc values in this study indicate high relief, steep slope, and high susceptibility to erosion resulting from

TABLE III
ELEVATION AND RELIEF CLASSIFICATION MODIFIED [6].

Elevation (masl)	Van Zuidam Classification, 1983 (modified)	DEMNAS	
		Km^2	% area
< 0	Under Sea	0.05	0.06
0 – 50	Plain	7.38	9.68
50 – 100	Platform	6.04	7.91
100 – 200	Hill	9.82	12.87
200 – 500	Low relief mountain	42.81	56.11
500 - 1000	Middle relief mountain	8.75	11.47
> 1000	High relief mountain	1.44	1.89

TABLE IV
SLOPE CLASSIFICATION MODIFIED [6],[8]

Slope (%)	Van Zuidam Classification, 1983 (modified)	DEMNAS	
		Km^2	% area
0 – 2	Flat	1.80	2.36
2 – 7	Gently sloping	11.70	15.33
7 – 15	Sloping	21.84	28.63
15 – 30	Moderately steep	26.28	34.44
30 - 45	Steep (medium)	10.56	13.84
45 - 70	Steep (high)	3.82	5.01
> 70	Very steep, extreme steep	0.30	0.40

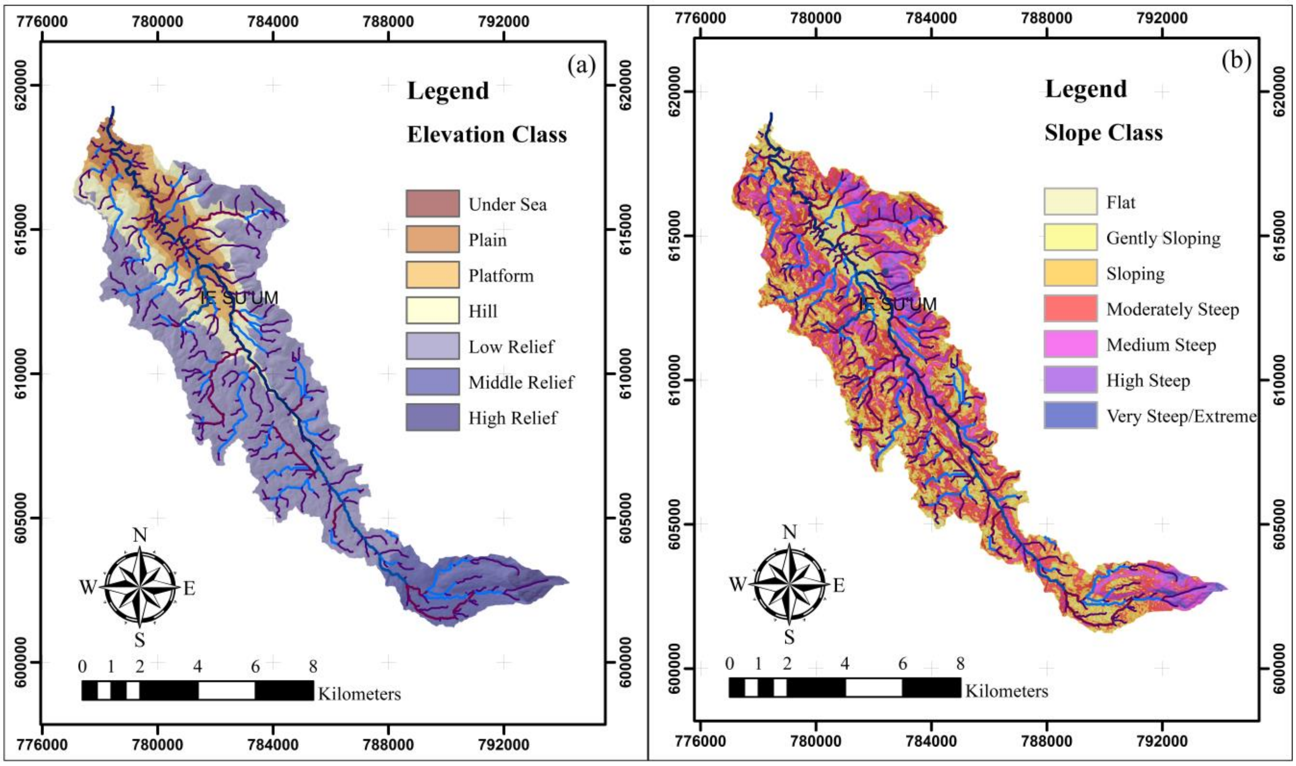

Fig. 2. (a). Hillshade and topography extraction for elevation classification, low relief is dominant with 56.11%. (b) Extraction for slope classification show moderately steep is dominant with 34.44% of study area.

transportation of sediment load [4], [10].

Ff values range from 0.17–0.8 (mean value is 0.36). This value range can be classified into very long until slightly elongated and the mean value indicate sub-basin are elongated in their shape have a low peak flow with a longer duration of time [4], [10].

C. Potential Classification of Active Tectonic

Determination of active tectonic zones based on morphometric indices indicates morphological changes due to tectonic activity. From field observation, the evidence of tectonic activities showed by faults outcrop and hot spring manifestation (Fig 3).

In this study, morphometric variables are grouped into two parameters. The first is a parameter related to stream and drainage activities, while the second is related to the shape of the watershed.

Stream and drainage parameters on the morphometric parameters describe the level of relief roughness, slope, and topography influence on the geomorphological system. Therefore, Dd, Rb, Fs, and Rl are variables used.

Fs and Rl values represent a positive correlation with the Dd, which indicates that the stream population is influenced by material properties and permeability rocks condition [9], [12]. The relationship between the variables Rb and Dd is that if the classification of Rb shows a deformed watershed, then the watershed is intermediate to smooth texture. It is an indication of the presence of tectonic activity [1], [4].

In this group parameters, six morphometric variables will be classified into active tectonic zones, it's Dd, Fs, Rl, and three conditions of Rb. Where, if the morphometric variables is more than three, it's classified as a tectonic active zone. Then, if it is indicated by three morphometric variables, it's classified as a moderately tectonic zone. At last, if it is indicated less than three morphometric variables, it's classified as a weak tectonic zone.

The classification results show that ten sub-basins (basin (W-01, W-03, W-06, W-09, W-12, W-13, W-19, W-25, W-31 and W-32) are classified as active tectonic zones, five sub-basins (W-08, W-15, W-18, W-27, W-28) as moderately tectonic zones, and twelve sub-basins (W-02, W-07, W-10, W-11, W-14, W-16, W-20, W-21, W-23, W-35, W-36 and W-37) as weak tectonic zones (Table 7). The dominant active tectonic zones (red color) are related to the Seulimeum-fault and minor faults. The moderate tectonic zones (pink color) are related to the Ie Su'um (hot spring) manifestation and the weak tectonic zones (yellow color) are related to several minor faults (Fig. 4).

In the second group parameters, morphometric basin shape variables assess active tectonic zones by morphological indices such as Rc, Re, and Ff. The three morphometric variables show the relationship between the shape of the watershed and the geomorphic age [4], [11]. The elongated, longer, and narrower watershed, it is indicated high relief, steep slope, and youth geomorphic stage with affected by tectonic activity [11], [12].

The classification of the shape parameters is carried out based on the influence of morphometric shape variables on the sub-basin tectonic activities. Such as, if the sub-basin is indicated by these three morphometric variables, then the

TABLE V
MORPHOMETRIC PARAMETERS I

Watershed (Sub-basin)	Dd	Bifurcation Ratio			Rc	Re	Ff
		$Rb_{(1-2)}$	$Rb_{(2-3)}$	Rb_a			
W-01	4.85	2	2	2	0.58	0.70	0.38
W-02	0.69	5	2	4	0.43	0.59	0.28
W-03	3.29	2	1	2	0.75	0.93	0.67
W-06	1.91	2	2	2	0.49	0.68	0.36
W-07	1.13	5	2	4	0.49	0.71	0.40
W-08	2.21	2	2	2	0.36	0.55	0.24
W-09	6.18	2		2	0.77	0.78	0.48
W-10	0.45	4.67	3	3.83	0.52	0.69	0.38
W-11	0.76	5	2	4	0.34	0.73	0.42
W-12	1.32	2	2	2	0.41	0.56	0.25
W-13	9.21	2		2	0.45	0.61	0.29
W-14	5.65	3		3	0.40	0.51	0.20
W-15	0.59	2.86	4	2.79	0.53	0.85	0.57
W-16	1.30	2		2	0.64	0.65	0.33
W-18	1.67	2	3	3	0.67	0.76	0.46
W-19	3.09	2		2	0.27	0.46	0.17
W-20	1.31	5	4	5	0.39	0.69	0.37
W-21	0.89	4.50	2	3.25	0.35	0.55	0.24
W-23	1.09	2.25	4	3.13	0.46	0.65	0.33
W-25	2.45	2	2	2	0.58	1.04	0.84
W-27	3.87	2		2	0.58	0.71	0.40
W-28	0.44	5	3	3	0.50	0.74	0.43
W-31	9.66	2		2	0.43	0.57	0.25
W-32	3.51	3	2	2	0.33	0.65	0.33
W-35	5.56	3		3	0.48	0.51	0.20
W-36	0.58	3.67	3	3.33	0.36	0.51	0.20
W-37	0.62	4.50	4	4.25	0.25	0.46	0.17
Mean	2.75	3.05	2.53	2.71	0.47	0.66	0.36

TABLE VI
MORPHOMETRIC PARAMETERS II

Watershed (Sub-basin)	Fs	Stream Lenght Ratio		
		$RL_{(2-1)}$	$RL_{(3-2)}$	RL_a
W-01	11.98	0.38	1.24	0.81
W-02	3.56	0.52	0.14	0.33
W-03	7.15	7.65		3.83
W-06	5.53	0.60	1.54	1.07
W-07	4.87	0.49	0.42	0.46
W-08	4.86	0.30	0.45	0.37
W-09	7.89	0.13		0.07
W-10	3.41	0.23	1.77	1.00
W-11	3.49	1.00	0.16	0.58
W-12	3.89	0.04	2.09	1.07
W-13	10.21	1.23		0.61
W-14	6.27	1.05		0.52
W-15	5.98	0.24	0.17	0.20
W-16	3.03	0.44		0.22
W-18	5.41	0.57	0.33	0.45
W-19	3.35	2.61		1.31
W-20	5.67	0.08	3.11	1.59
W-21	3.56	0.72	0.11	0.42
W-23	5.60	0.87	0.30	0.58
W-25	6.26	1.09	0.10	0.60
W-27	4.88	0.43		0.22
W-28	5.26	0.60	0.44	0.52
W-31	8.84	3.47		1.74
W-32	8.22	0.45	1.90	1.18
W-35	7.01	0.84		0.42
W-36	3.43	1.19	0.19	0.69
W-37	5.31	0.18	3.18	1.68
Mean	5.74	1.02	0.98	0.83

zone is classified as an active tectonic zone. Second, if the sub-basin is indicated by two morphometric variables, it's classified as a moderately tectonic zone. The last, if the sub-basin is indicated by one of these morphometric variables, it's classified as a weak tectonic zone (Fig.5).

The shape group parameter uses the characteristics of the sub-basins shape such as Rc, Re, and Ff, it can be affected by the tectonic or volcanic control. The result shows eleven sub-basins (W-02, W-08, W-12, W-13, W-14, W-19, W-21, W-31, W-35, W-36 and W-37) were classified as active tectonic zones, four sub-basins (W-06, W-20, W-23 and W-32) as moderate tectonic zones, and twelve sub-basins (W-01, W-03, W-07, W-09, W-10, W-11, W-15, W-16, W-18, W-25, W-27 and W-28) as weak tectonic zones (Table 7).

The active tectonic zones (red color) and moderately tectonic zones (green color) are related to several minor faults and volcanic morphology. Active tectonics related to the elongated watershed has high relief, it leads to more vulnerable to erosion [11]. This condition is proven by the presence of debris/lava flow morphology. On the other hand, the hot spring manifestation (Ie Su'um) is in the weak tectonic zones (yellow color). This manifestation is affected by Elongated ratio (Re) and proof that the Seulimeum-fault is active.

To ensure a sub-basins is affected by tectonic activity, it is better to combine all parameters. So that it will be obtained a watershed that has identified the presence of tectonic activity with a high level of confidence. The result shows twelve

Fig. 3. (a) Outcrop of minor fault is found in the northern part of Krueng Raya watershed. (b) The hot spring manifestation (Ie Su'um) related to tectonic activity of the Seulimeum-fault.

TABLE VII
MORPHOMETRIC ACTIVE TECTONIC CLASSIFIED BY PARAMETERS

Water-shed (Sub-basin)	Dd	Fs	Rl	$Rb_{(1-2)}$	$Rb_{(2-3)}$	Rb_a	Rc	Re	Ff
W-01	Rather Smooth	High	Mature	Deformed	Deformed	Deformed	Short, Wide	Elongated	Neither Elongated
W-02	Very Rough	Poor	Intermediate	Not-Deformed	Deformed	Not-Deformed	Long, Narrow	Elongated	Elongated
W-03	Intermediate	Moderate	Mature	Deformed	Deformed	Deformed	Short, Wide	Oval	Slightlt to Widened
W-06	Rough	Moderate	Mature	Deformed	Deformed	Deformed	Long, Narrow	Elongated	Slightly Elongated
W-07	Very Rough	Poor	Intermediate	Not-Deformed	Deformed	Not-Deformed	Long, Narrow	Less Elongated	Neither Elongated
W-08	Rough	Poor	Intermediate	Deformed	Deformed	Deformed	Long, Narrow	Elongated	Elongated
W-09	Smooth	Moderate	Intermediate	Deformed		Deformed	Fan-Shape	Less Elongated	Neither Elongated
W-10	Very Rough	Poor	Mature	Not-Deformed	Not-Deformed	Not-Deformed	Short, Wide	Elongated	Neither Elongated
W-11	Very Rough	Poor		Not-Deformed	Deformed	Not-Deformed	Long, Narrow	Less Elongated	Neither Elongated
W-12	Very Rough	Poor	Mature	Deformed	Deformed	Deformed	Long, Narrow	Elongated	Elongated
W-13	Very Smooth	High	Mature	Deformed		Deformed	Long, Narrow	Elongated	Elongated
W-14	Smooth	Moderate	Intermediate	Not-Deformed		Not-Deformed	Long, Narrow	Elongated	Very Long
W-15	Very Rough	Moderate	Intermediate	Deformed	Not-Deformed	Deformed	Short, Wide	Oval	Neither Elongated
W-16	Very Rough	Poor	Intermediate	Deformed		Deformed	Short, Wide	Elongated	Slightly Elongated
W-18	Rough	Moderate	Intermediate	Deformed	Not-Deformed	Deformed	Short, Wide	Less Elongated	Neither Elongated
W-19	Intermediate	Poor	Mature	Deformed		Deformed	Long, Narrow	Elongated	Very Long
W-20	Very Rough	Moderate	Mature	Not-Deformed	Not-Deformed	Not-Deformed	Long, Narrow	Elongated	Neither Elongated
W-21	Very Rough	Poor	Intermediate	Not-Deformed	Deformed	Not-Deformed	Long, Narrow	Elongated	Elongated
W-23	Very Rough	Moderate		Deformed	Not-Deformed	Not-Deformed	Long, Narrow	Elongated	Slightly Elongated
W-25	Rough	Moderate	Mature	Deformed	Deformed	Deformed	Short, Wide	Oval	Slightlt to Widened
W-27	Intermediate	Poor	Intermediate	Deformed		Deformed	Short, Wide	Less Elongated	Neither Elongated
W-28	Very Rough	Moderate	Intermediate	Deformed	Deformed	Not-Deformed	Long, Narrow	Less Elongated	Neither Elongated
W-31	Very Smooth	Moderate	Mature	Deformed		Deformed	Long, Narrow	Elongated	Elongated
W-32	Intermediate	Moderate	Mature	Deformed	Deformed	Deformed	Long, Narrow	Elongated	Slightly Elongated
W-35	Smooth	Moderate	Intermediate	Not-Deformed		Not-Deformed	Long, Narrow	Elongated	Very Long
W-36	Very Rough	Poor	Mature	Not-Deformed	Not-Deformed	Not-Deformed	Long, Narrow	Elongated	Very Long
W-37	Very Rough	Moderate	Mature	Not-Deformed	Not-Deformed	Not-Deformed	Long, Narrow	Elongated	Very Long

Note :
Classification of active tectonic zones related to result of Dd (by intermediate to very smooth), Fs (by moderate to high), Rl (by decressing trend/mature geomorphic age), Rb (by deformed), Rc (by long, narrow basin), Re (by Elongated shape) and Ff (by elongated to very long shape).

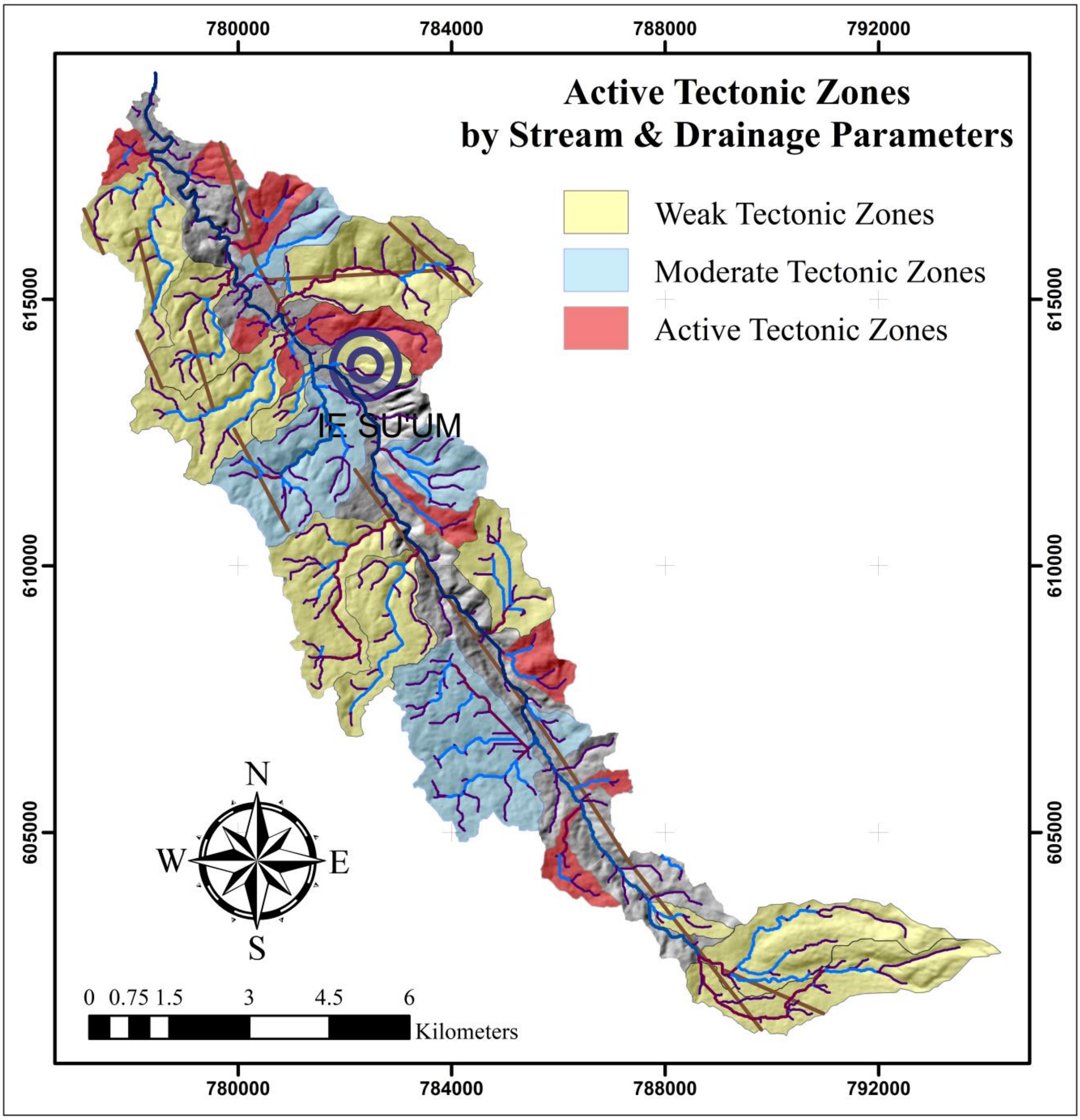

Fig. 4. Yellow color shows weak tectonic zones classified by < 3 variables, pink is moderate tectonic zones classified by three variables and red color shows active tectonic zones classified by > 3 variables.

sub-basin (W-01, W-03, W-06, W-08, W-12, W-13, W-14, W-19, W-25, W-31, W-32 and W-35) affected by tectonic activity based on morphometric parameters. (Fig. 6).

The Seulimeum-fault is the major fault identified in the study area, besides that there are several other minor faults [7], [13]. This fault plotting is related to the sub-basins tectonic activities, which means GIS and morphometric data is an excellent alternative technique used in monitoring, investigating, assessing, and mapping tectonic activities [16], [17].

In this study, GIS and morphometric data could be used to support decision-making in emergency risk management related to tectonic and volcanic activities. It can provide information and tools for the analysis of the spatial data, these services will provide the knowledge required in the process of representation and analysis of tectonic hazards [16], [17].

IV. Conclusion

Krueng Raya watershed is situated in the low relief mountain zone with sloping to moderately steep slope class. The quantitative morphometric indices assessment based on the DEM (satellite imagery) interpretations in this study indicate that the Krueng Raya watershed is tectonically active with rough to very rough textures, generally deformed, long sub-basin shape, narrow and elongated basin, and short-moderate frequency segments of stream.

In this paper, the identification of active tectonic zones is developed using morphometric indices based on two group parameters. Both groups show indications of moderate to high tectonic activity, it is proven by the presence of faults

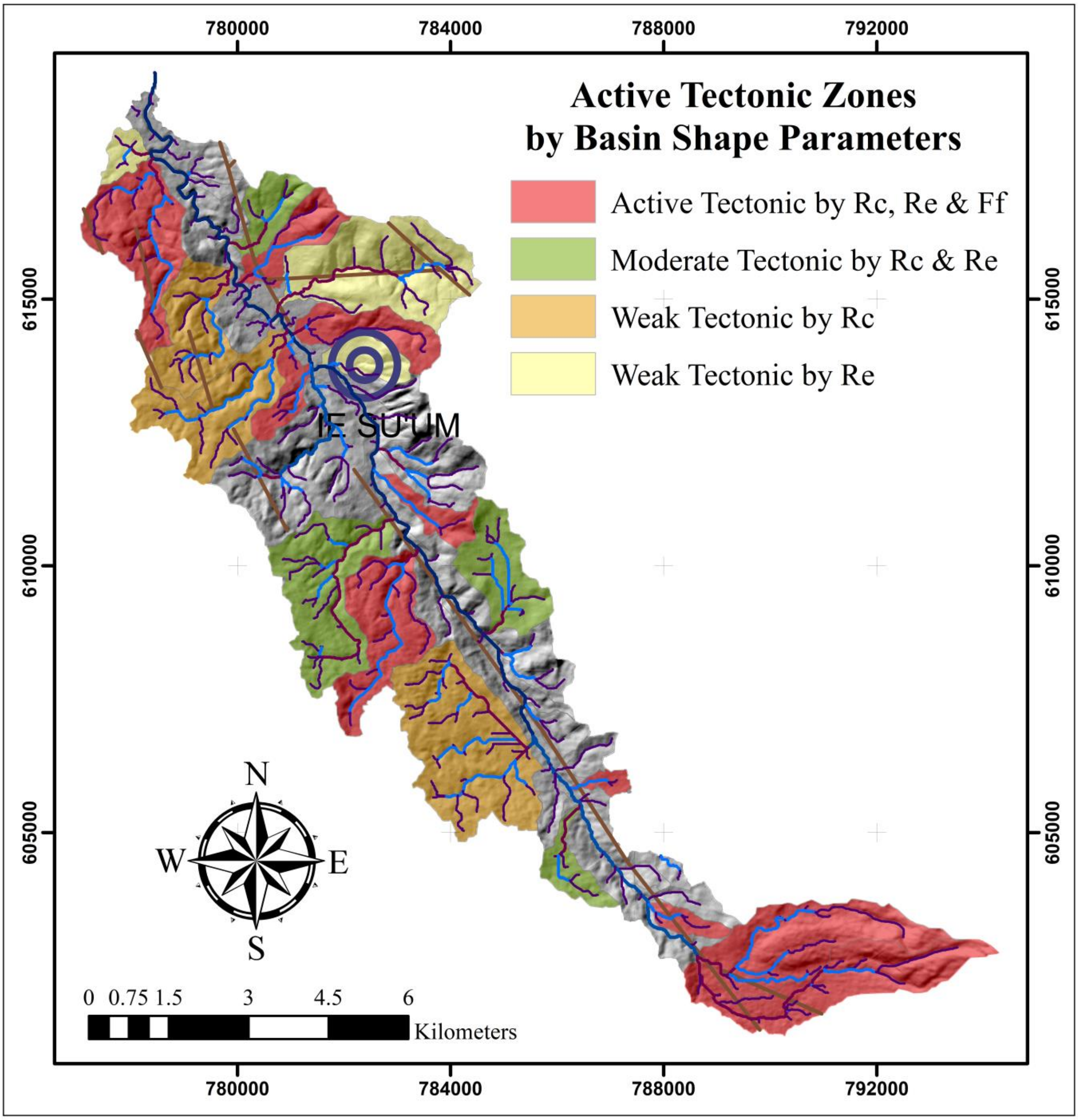

Fig. 5. Red color of basin shape parameter shows tectonic activity classified by Rc, Re and Rf. Green color is moderate tectonic classified by Rc and Re. Orange and yellow color is weak tectonic classified only Rc or Re.

around the study area.

With the result of all parameters, these morphometric anomalies are the predominant factors indicating the active tectonics. They show geospatial analysis and satellite imagery combined, which applies to any kind of drainage basin morphometry.

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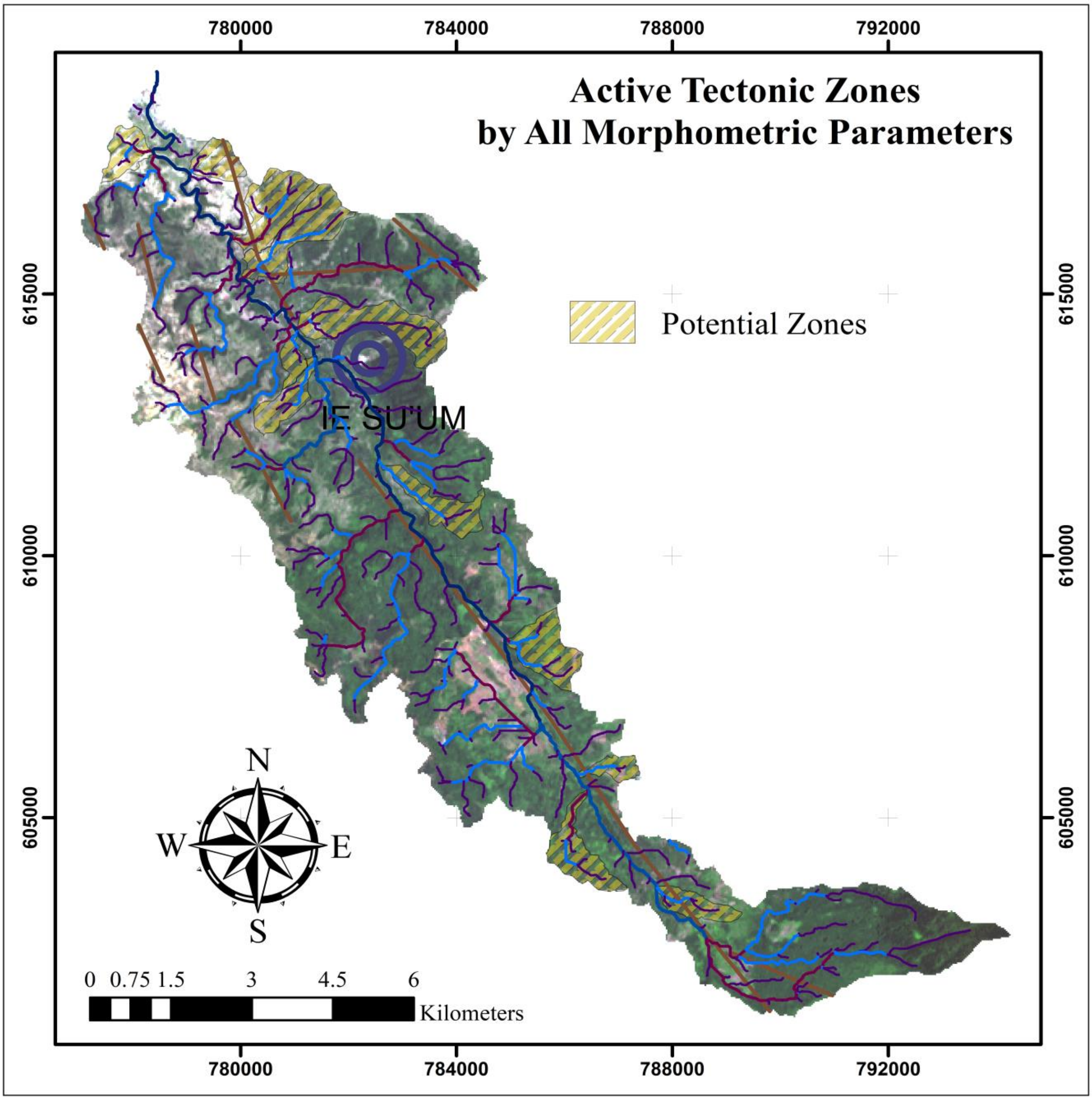

Fig. 6. The shaded area shows a potential zone of tectonic activity with a high level of confidence.

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