http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 7 No 2 2022

RESEARCH ARTICLE

Morphotectonic Control of Land Movements at Wundulako Region, Kolaka Regency, Southeast Sulawesi Province, Indonesia

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Received: Apr 1, 2022; Accepted: Jun 30, 2022.
DOI: 10.25299/jgeet.2022.7.2.9235

Abstract

This research is located at Wundulako District, Kolaka Regency, Southeast Sulawesi Province. The purpose of this study are to determine the level of tectonic activity and the effect of tectonic activity on the land movement of the study area. Based on the DEM (Digital Elevation Model) analysis, geomorphology of the study area is dominated by mountains unit that indicate the influence of tectonic activity. Geomorphological aspects were analyzed to determine the tectonic classes in the study area such as watershed and non-watershed analysis. The results showed that, tectonic class of the study area is classified as very high and moderate tectonic class. The effect of tectonic class level on land movement in the study area shows a least correlation. This interprets that the cause of land movement at study area is not only influenced by tectonic factors but is also influenced by other factors such as rainfall, lithological conditions, geomorphology, earthquakes, and human activities. This shows that morphotectonic control has little effect on the land movements at Wundulako District, Kolaka Regency, Southeast Sulawesi Province, but is also influenced by other factors such as rainfall, lithological conditions, geomorphology, earthquakes, and human activities.

Keywords: Morphotectonic, land movement, tectonic classes.

1. Introduction

1.1 Morphotectonic

Morphotectonic is the study of the landscape produced by tectonic activities or interactions between tectonic processes and geomorphology ((Poedjopradjitno, 2012). Morphotectonics is influenced by morphological conditions and tectonic processes that occurred in the past, because morphology has a spatial dimension and tectonic has a time dimension. Tectonic land formation will express topographic formations that can be used as indicators of tectonic movement. Topographic forms that have undergone displacement can be seen and observed through aerial photographs and imagery that provide morphotectonic features in the form of river flow patterns, hilly displacement, river deflection, alignment, fault escarpment, and river terrace appearance. While the form of topography that experiences movement at an older age will be difficult to observe by aerial photography because it has been covered by sedimentation and erosion (Anfasha; et al., 2016).

Morphotectonic consists of several elements such as fault escarpment, wedge steps structure, fault pool, fault line valley and river flow shift. Morphotectonic elements that are identified together with other physical data and seismic data can be used as a zoning classification parameter of natural disaster vulnerability in the area concerned (Poedjopradjitno, 2012).

To find out the tectonic activity in certain regions, morphotectonic studies are needed. Morphotectonic studies themselves learn about everything related to the relationship between geological structures and landforms (Wahyudi et al., 2015).

1.2 Morphometry

In morphotectonic studies a morphometric analysis is needed which is used to identify the character of the shape of an area and its relation to the level of tectonic activity. Morphometric analysis combined with a comparison of the straightness of the flow pattern and the direction of the land movement crown can strengthen the interpretation of the tectonic state that develops in an area. Tectonic processes can cause a stocky or fracture in a rock body. If the fracture is formed on a large scale then filled with water it will form into a drainage pattern, while the direction of the land movement crown can reflect a weak zone of the fault in the area (Wahyudi et al., 2015).

Determining the level of tectonic activity in an area can be done by morphometric analysis. Morphometry is defined as a quantitative measurement of landscape / morphological form. Quantitative measurements follow the rules of geomorphology as objects of comparison of landforms and calculation of parameters directly geomorphic indications which are very useful for identifying the characteristics of an area and the level of tectonic activity (Hidayat, 2010).

Wahyudi et al. (2015) stated that to identify the level of tectonic activity based on morphometric analysis on a watershed can be done by calculating the ratio of the width of the valley floor to the height of the valley (Vfw), river gradient index (SL), asymmetry of the basin (AF), sinusity of the ridge surface (Smf), density river (dd).

Comparison of valley width and height (ratio of valley floor width to valley height / Vf) is the value of the ratio between width and height of valleys in an area. Asymmetry factor is one of the quantitative analysis of basin drainage to detect tectonic tilting at both large and large basin drainage scales. Mountain front bend (mountain front sinuosity / Smf) is a series of mountains found on the front / face. Mountain face bends are an index that reflects the balance between erosion forces / forces that have a cutting tendency along the face mountain ridges and tectonic forces that directly produce mountainous faces and coincide with active fault zones that reflect active tectonics (Supriyadi et al., 2018).

Watershed morphometry calculations can be done based on the following parameters:

1. Asymmetry of drainage basins (AF)

   $AF = 100\ (Ar / At)$ (1)

   where,

   AF : Asymmetry factor
   Ar : Right hand basin area
   At : Total area of the basin area

2. River gradient index (SL)

   $SL = (\Delta H / \Delta L) \times L$ (2)

   where,

   ΔH : Difference in elevation from the point to be calculated
   ΔL : Length of river to be calculated
   L : Total length of the river from the count point to the headwaters of the river

3. Sinusity of the Ridge Surface (Smf)

   $Smf = Lmf / Ls$ (3)

   where,

   Smf : Sinusity of the ridge surface
   Lmf : The length of the surface of the mountain face
   Ls : Long straight face of the mountain

4. The ratio of valley floor to valley height (vf)

   $Vf = 2Vw / [(Eld - Esc) + (Erd - Esc)]$ (4)

   where,

   Vf : Index
   Vw : Width of the riverbed valley
   Erd/Eld : The height of the right / left of the valley is measured from the bottom of the river
   Esc : Elevation of the valley floor

5. River Density (DD)

   $Dd = L / A$ (5)

   where,

   Dd : River density
   L : Total length of river drainage
   A : The total area of the watershed

River flow density illustrates the storage capacity of surface water in basins such as lakes, swamps and river bodies flowing in a watershed (Rafighian et al., 2016).

Classification of river density (Dd), tectonic activity and geomorphological index can be seen in Tables 1, Table 2 and Table 3, resepectively.

Table 1. Value of river density according to (Utama et al., 2016).

No.	Dd (km/km^2)	Density class	Information
1	< 0,25	Low	The flow of the river passes through rocks with hard resistance, so the transport of sediment transported by river streams is smaller when compared to river channels that pass through rocks with softer resistance, if the other conditions that affect it are the same.
2	0,25 – 10	Medium	River flow passes through rocks with softer resistance, so the transport of sediment transported by the flow will be greater.
3	10 – 25	High	The river channel passes through rocks with soft resistance, so the estimated transport of sediment will be greater.
4	> 25	Very high	The river flows through watertight rocks. This situation will indicate that the rain that becomes the flow will be greater when compared to an area with low Dd through large permeability rocks.

Table 2. Classification of the relative tectonic activity levels of the morphometric parameters referred (Mulyasari et al., 2017).

No	Morphometric parameters	Tectonic grade level		
		Class 1 (High)	Class 2 (Medium)	Class 3 (Low)
1	SL	SL ≥ 500	(300 ≤ SL < 500)	SL <300
2	AF	(AF ≥ 65 or AF < 35)	(35 ≤ AF <43 or 57≤AF<65)	(43 ≤ AF < 57)
3	Smf	Smf <1,1	(1,1 ≤ Smf < 1,5)	Smf ≥ 1,5
4	Vf	< 0,5	0,5 < Vf < 1,0	> 1,0

Table 3. Classification of geomorphological index grade levels (Sumaryono et al., 2014)

Class indeks	Class 1 (Very high)	Class 2 (High)	Class 3 (Medium)	Class 4 (Low)
	1,0 ≤ – < 1,5	1,5 ≤ – < 2,0	2,0 ≤ - < 2,5	2,5 ≤

1.3 Land movement

Earthquakes originating from the movement of active faults in addition to destroying and destroying buildings, can also cause the formation of land cracks. If the ground cracks occur on a steep slope, then the land is prone to slide (Wahyudi et al., 2015). Land movement movement is a process of mass transfer of rocks or soil due to gravity

(gravity). This may cause many casualties or loss of property. The movement may occurs due to the natural and non-natural controlling and triggering factors. Natural disasters such as land movement or land movements often occur where such disasters are very detrimental, because they can damage various infrastructure facilities (Marani et al., 2018).

Putra et al. (2015) defined the movement of soil / rock as movement down or out of a slope by the mass of the land or rocks making up the slope, as well as the mixing of both as a material for shredding, due to the disruption of the stability of the soil or rocks making up the slope. If the pressure force to lower the material down is greater than the pressure force to resist the movement there will be land movement, and vice versa. The cause of the ground movement can be influenced by 2 (two) factors, namely controlling factors and triggering factors. Controlling factors are factors that make the condition of a slope or cliff vulnerable and ready to move, including:

1. Geomorphological conditions,
2. Stratigraphic conditions (rock / soil type),
3. Geological structure conditions,
4. Hydrological conditions and
5. Land use conditions.

Factors are processes that change a slope from a vulnerable or ready to move condition to a critical condition and finally move, including:

1. Rainfall,
2. Earthquake vibrations, and
3. Human activities that can result in changes in burden.

2. Geological setting

Based on the map of the geomorphological unit of the Southeast Sulawesi arm, the Kolaka area has a gemorphological unit, namely mountain units (Mekongga mountains) and plain units.

The Mekongga Mountains have the highest peaks with an altitude of 2790 masl. This mountain morphological unit has a rugged topography and has a northwest-southeast direction, this direction indicates that this mountain range is in the same direction as the regional fault structure pattern, namely the NW-SE trending Kolaka Faul (Fig. 1) (Surono, 2013).

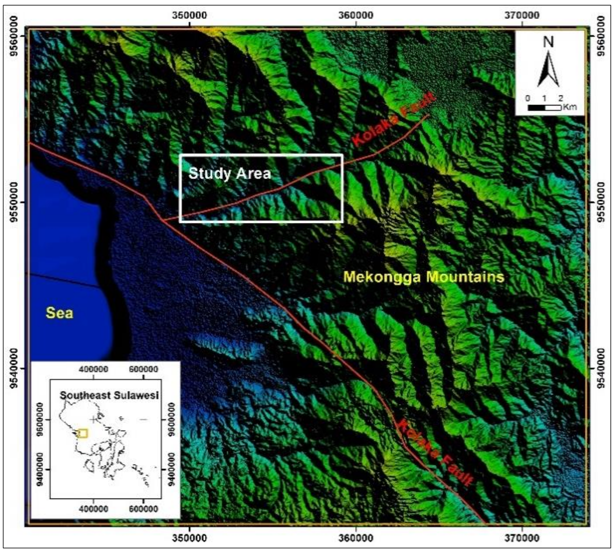

Fig 1. Geomorphological map of the Kolaka area (modified from Surono, 2013). DEM was extracted from https://tanahair.indonesia.go.id/demnas/#/demnas

The plain geomorphological unit of the Kolaka area occupies the west of the Mekongga mountains, the formation of this plain is influenced by the shear fault structure, namely the Kolaka fault. After experiencing the collision, the southeastern arm of Sulawesi has left shear faults such as the Lawanopo fault system, the Matarombeo fault, the Konaweha fault system and the Kolaka fault and lineages (Surono, 2013and Simandjuntak et al., 1993) (Fig. 2)

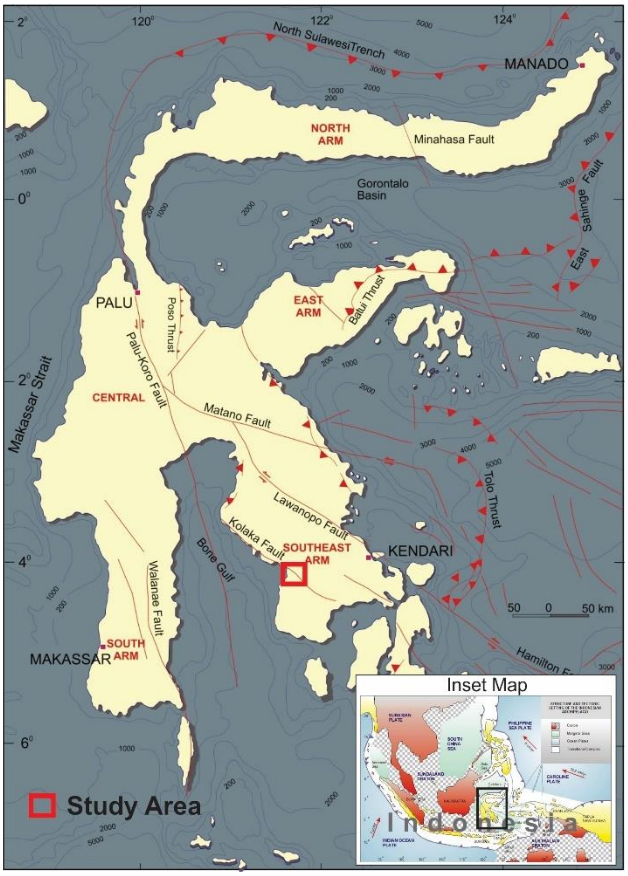

Fig 2. Map of the geological structure of the island of Sulawesi (modified Surono, 2013 and Simandjuntak et al., 1993).

The fault and lineage show a pair of main directions, namely the Southeast - Northwest direction (332o) and the Northeast Southwest (42o). Southeast - Northwest direction is the general direction of the left shear fault in the southeastern arm of Sulawesi (Surono, 2013).

3. Research methods

After the required data is collected, the next step is the data processing stage by means of primary data taken from geomorphological observations to observe the geomorphological conditions of the study area, megascopic outcrop data and lithological data to see the types of lithology in the study area. Then the data is further processed using analysis, namely:

3.1 Structural analyses

The structural data that is here are the solid direction data, the direction data Land movement crown and river segment alignment direction and ridge straightness data. The muscular direction data obtained from the field were analyzed in the Dips program to see the dominance of the direction and then compared with the direction of the river segment and the straightness of the ridge, while the land movement crown direction data were obtained through direct measurements carried out in the field. River segment straightness data obtained from river flow patterns processed from the RBI map at a scale of 1: 25,000, river segment straightness and ridge straightness then input into the dips program to see the azimuth dominance of the straightness. The straightness of the river segment measured is the straightness of the river segment of the watershed in the study area. Furthermore, the data on the land movement crown direction and river segment alignment were tested through different tests to see the relationship between the land movement crown direction and the river segment straightness. Difference test is used to determine between two populations. In this study, the survey used a different test function to test the comparative hypothesis of two independent samples with an alpha of 0.05. Different tests were carried out using SPSS software (Wahyudi et al., 2015).

3.2 Morphometric analyses

Analysis of morphometric data involve the valley floor - valley height ratio (Vfw), river gradient index (SL), mountain face sinusity (Smf), drainage basin asymmetry (AF), and river density (Dd) calculated in DAS (Watershed) contained in the research area. This analysis was carried out to determine the tectonic class in the study area. Furthermore, the results of the calculation of morphometric analysis are determined based on the tectonic class classification, so that based on this classification, the tectonic class can be deterined in the study area.

4. Results and Discussion

4.1 Analysis of Structure

The structure found in the study area can describe the tectonic process that occurs in the study area. Structure in the study area in the form of solid data found at the station and the waterfall found at the station. Solid data direction of the study area that has been analyzed shows the dominant direction of northwest - southeast (Fig. 3), the dominant direction of land movement of the study area which is spread over several research location points shows the north-northwest - south-southeast direction (Fig. 4), the dominant direction of the river segment straightness is analyzed based on the river segment straightness of the study area which is known to be directed to the Northeast - Southwest (Fig. 5) and the dominant direction of the ridge line alignment that is to the Northeast - Southwest direction (Fig. 6).

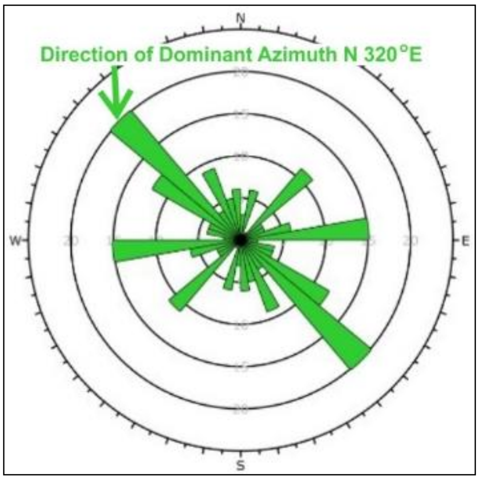

Fig 3. Rosette diagram Stump direction

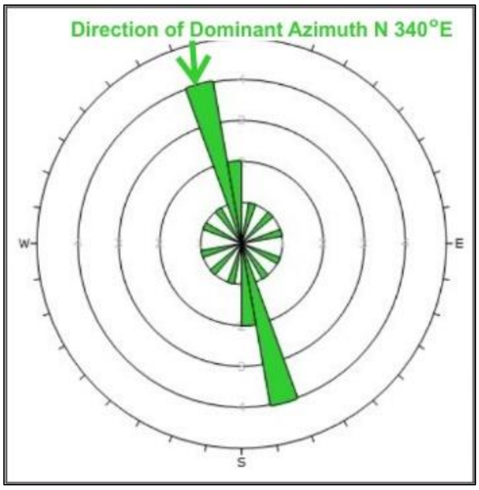

Fig 4. Rosette diagram towards the land movement crown

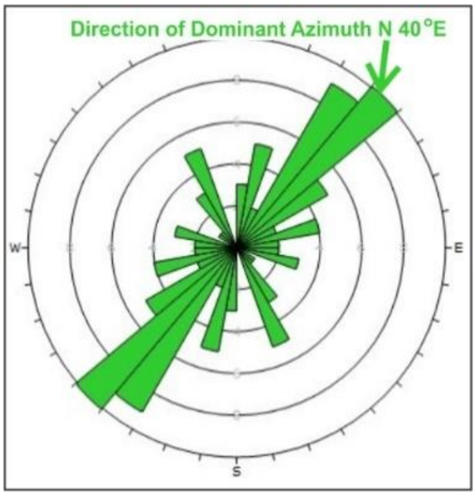

Fig 5. Rosette diagram of ridge straightness

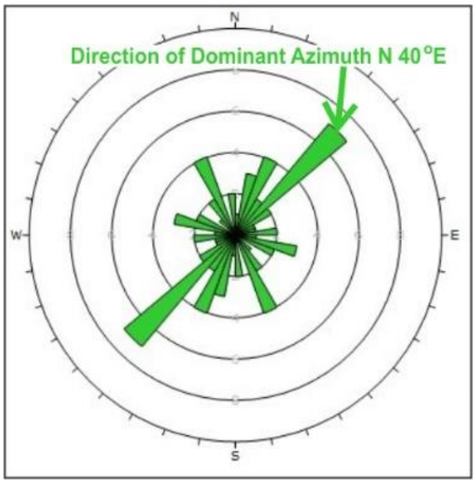

Fig 6. Rosette diagram of lineament alignment

4.2 Morphometric analyses

a. Watershed morphometric analysis
   - Basin asymmetry factor

   Basin asymmetry factor is a quantitative analysis of basin drainage which aims to determine the tectonic tilt (tectonic tilting) both on the scale of small and wide drainage basins. Based on the results of the analysis of the DEM data processed in argis 10.3 the study area is divided into 2 main basins. From these 2 basins then an asymmetric factor analysis for each basin with area Ar in basin 1 is 2102.13 KM^2 and At area is 5614.5 KM^2. The calculated value of the At / Ar area is 37.44 KM^2. While in basin 2, Ar area is 12649.06 KM^2 and At area is 45249.4 KM^2, from the calculation of At / Ar area is 27.95 KM^2 (Table 4).

Table 4. The value of the basin asymmetry (AF) factor

No	Name	Ar (KM^2)	At (KM^2)	AF (KM^2)	Class
1	Basin 1	2102.13	5614.51	37.44	Medium
2	Basin 2	12649.06	45249.40	27.95	Active

- River gradient index (SL)

Table 5. The result of river gradient index (SL)

Name	Length (M)		Different Elevation (M)	Value of Sl (Gm)	Class
	Length River	Total Length River			
Basin 1	4666.78	15456.55	100	331.2	Medium
Basin 2	10511.34	30651.21	175	510.3	Active

To determine the river gradient index can be done by calculating the difference in river height you want to know the level of slope, distance and total length of the river from upstream to downstream. The results of the river gradient index analysis can be seen in Table 5.

- River Density (Dd)

River density is an index that shows the number of tributaries in a watershed that can provide an overview of water storage capacity in a basin or region. Determination of river flow density is an important factor in identifying runaway water velocity, the higher the density of a river an area, the greater the runaway water velocity (Table 6)

Table 6. The value of river density (Dd)

Name	Total Area DAS (Km2)	Total Length River (Km)	Value of Dd	Class
DAS 1	56.15	42.04	0.75	Medium
DAS 2	37.12	110.91	0.33	Medium

- Valley bottom width versus valley height (Vf)

The value of Vf is presented is Table 7.

Table 7. The value of valley botton width versus valley height (Vf)

No.	Name	Esc (M)	Erd (M)	Erd - Esc	Eld	Eld – Esc	2vw (M)	Vf value (M)	Class
1	Basin 1	55	200	145	187.5	132.5	200	0.72	Medium
2	Basin 2	40	137.5	97.5	125	85	90	0.49	Active

b. Non-watershed morphometric analysis

- Mountain front sinusity (Smf)

The value of Smf reflects the balance between erosion forces that have a tendency to cut along ridges of mountain faces and tectonic forces that directly produce mountainous faces and coincide with active fault zones that reflect active tectonics (Table 8)

Table 8. Value of mountain face sinusity (Smf)

No.	Line Lmf	Line Ls	Smf Value	Class
1	2.22	1.79	1.24	Medium
2	2.86	2.32	1.24	Medium
3	2.94	2.91	1.01	Active
4	3.98	3.35	1.19	Medium
5	2.47	1.98	1.24	Medium
6	1.96	1.86	1.05	Active
7	2.07	1.69	1.22	Medium
8	1.45	1.26	1.15	Medium
9	1.65	1.37	1.20	Medium
10	1.45	1.30	1.12	Medium
Average value			1.17	Medium

Table 9. Geomorphological index and tectonic class

No	Name	Af	Sl	Vf	Smf	Index	Tectonic Class
1	Basin 1	2	2	2	2	2	Medium
2	Basin 2	1	1	1	2	1.25	Very High

Based on the classification of geomorphological index and tectonic class it can be concluded that the tectonic activity class in the study area has two tectonic activity classes, namely class 1 (very high) and class 3 (moderate). This indicates that in basin 1 tectonic and deformation forces are at work while in basin 2 there is a very high tectonic and deformation force (Table 9).

4.2 Morphometric analyses

4.2.1 Effect of Tectonic Class on the Ground Movement

Land movement is a process of mass transfer of rocks or soil due to gravity (gravity), this can cause many casualties or loss of property, movements that occur due to natural and non-natural controlling and triggering factors.

Sumaryono et al. (2014) inferred that the direction of the crown of a land movement that correlates with the direction of the river segment shows that local tectonic conditions affect the ground movement that occurs in the area.

Fig 7. Typical land movement crown in study area

Based on the results of the field survey found 11 land movement points in the study area, Then measuring the direction of the land movement crown from each land movement (Fig. 7 and Fig. 8), then the direction of the river segment and the direction of the land movement crown are tested with SPPS analysis to determine the correlation between the two data. SPPS test results between the direction of the river segment and the direction of the land movement crown showed a value> 0.05 (uncorrelated) and the percent correlation value showed 0.282 with a positive value considered to show weak correlation (Table 10). From the results of the analysis that between the direction of the river segment and the direction of the land movement crown has a weak correlation level, so it can be concluded that the land movement that occurs in the study area is not only influenced by tectonic factors but also influenced by other factors such as rainfall, lithological conditions and human activities.

Fig 8. Small land movement crown in study area

Table 10. The correlation value between the direction of river straightness and the land movement crown

		River Segment	Land movement Crown
River Segment	Persent Corelation	1	,282
	Sig. (2-Tailed)		,086
	N	38	38
Land movement Crown	Persent Corelation	,282	1
	Sig. (2-Tailed)	,086	
	N	38	38

5. Conclusions

Based on the results of research that has been done, the authors conclude several points, including:

1. The results of morphometric analysis of watershed and non-watershed areas show that the research area has a level of "moderate and very high" tectonics.
2. The structure that developed in the study area is not the main factor causing the land movements occurred in the Wundulako area, Kolaka Regency, Southeast Sulawesi Province.

Acknowledgements

Thanks to the Regent of Kolaka who has given permission to do research in Wundulako District, Kolaka Regency, Southeast Sulawesi Province.

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