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GEOMORPHIC UNITS, HAZARDS, AND LAND-USE PLANNING IN MUARO KALABAN, WEST SUMATRA, INDONESIA

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ABSTRACT

Understanding geomorphic units and expressions is essential for development planning in areas undergoing tectonic deformation and active surface processes. Several factors such as variations in slope, landform type, and fluvial dynamics strongly influence the occurrence of possible geomorphic hazards such as landslides, erosion, and flooding. Muaro Kalaban area that is located in Sawahlunto City, West Sumatra, Indonesia, exhibits diverse geomorphic conditions that require detailed analysis to support sustainable development area planning. This study integrates field-based geomorphological observations with remote sensing analysis. Then followed with geomorphological mapping that was conducted through morphological and geomorphic process observation, focusing on erosion, weathering, geological structures, fluvial activity, and slope measurement and calculation. DEM derived parameters, including elevation and slope gradient, were used to delineate and validate geomorphic units and their spatial distribution. The results indicate that the study area consists of four main geomorphic units: denudational hills with moderate to steep slopes, denudational hills with gentle slopes, the Kepalakoto floodplain, and a meandering river channel. This study found that each geomorphic unit exhibits distinct surface processes and hazard potentials. The results revealed that denudational hills that are mostly associated with surface erosion and slope instability, while the floodplain and meandering river channel geomorphic units are characterized by fluvial processes and are prone to flooding and channel migration. This study inferred that geographical distribution and features of these geomorphic units emphasize significant limitations and challenges for development planning in Muaro Kalaban. By integrating geomorphological data into landuse planning perhaps can assist in identifying hazard prone areas, and also beneficial to promote sustainable development solutions which can reduce geomorphic risk.

Keywords: Geomorphic Units, geomorphic hazards, land-use planning, Muaro Kalaban, Ombilin Basin, DEM, Sawahlunto

ABSTRAK

Pemahaman terhadap satuan dan ekspresi geomorfik sangat penting untuk perencanaan pembangunan di wilayah yang mengalami deformasi tektonik dan proses permukaan yang aktif. Beberapa faktor seperti variasi kemiringan lereng, tipe bentanglahan, dan dinamika fluvial sangat memengaruhi terjadinya potensi bahaya geomorfik seperti longsor, erosi, dan banjir. Daerah Muaro Kalaban yang terletak di Kota Sawahlunto, Sumatera Barat, Indonesia, menunjukkan kondisi geomorfik yang beragam sehingga memerlukan analisis terperinci untuk mendukung perencanaan pembangunan wilayah yang berkelanjutan. Penelitian ini mengintegrasikan observasi geomorfologi berbasis lapangan dengan analisis penginderaan jauh menggunakan. Selanjutnya dilakukan pemetaan geomorfologi melalui pengamatan morfologi dan proses geomorfik, dengan fokus pada erosi, pelapukan, struktur geologi, aktivitas fluvial, serta pengukuran dan perhitungan kemiringan lereng. Parameter yang diturunkan dari DEM, termasuk elevasi dan gradien lereng, digunakan untuk mendelineasi dan memvalidasi satuan geomorfik serta distribusi spasialnya. Hasil penelitian menunjukkan bahwa daerah kajian terdiri atas empat satuan geomorfik utama, yaitu perbukitan denudasional dengan lereng sedang hingga curam, perbukitan denudasional dengan lereng landai, dataran banjir Kepalakoto, dan saluran sungai berkelok (meandering). Penelitian ini menemukan bahwa setiap satuan geomorfik menunjukkan proses permukaan dan potensi bahaya yang berbeda. Hasil penelitian mengungkapkan bahwa satuan geomorfik perbukitan

denudasional sebagian besar berkaitan dengan erosi permukaan dan ketidakstabilan lereng, sedangkan satuan geomorfik dataran banjir dan saluran sungai berkelok dicirikan oleh proses fluvial dan rentan terhadap banjir serta migrasi saluran sungai. Penelitian ini menyimpulkan bahwa sebaran geografis dan karakteristik satuan geomorfik tersebut menegaskan adanya keterbatasan dan tantangan yang signifikan bagi perencanaan pembangunan di Muaro Kalaban. Integrasi data geomorfologi ke dalam perencanaan tata guna lahan dapat membantu mengidentifikasi daerah rawan bahaya, serta bermanfaat dalam mendorong solusi pembangunan berkelanjutan yang dapat mengurangi risiko geomorfik.
Kata Kunci : Geomorphic Units, geomorphic hazards, land-use planning, Muaro Kalaban, Ombilin Basin, DEM, Sawahlunto

INTRODUCTION

Geomorphological characteristics play a significant role in landscape stability factors and environmental processes, particularly in regions with complex interactions between topography and active surface dynamics (Burbank and Anderson, 2011a, 2011b; Chorley, n.d.; Hugget, 2007; Strahler, 1957). As for example, variations in landform morphology, slope gradient, and fluvial systems could possibly influence the occurrence of potential geomorphic hazards in the area such as landslides, massive surface erosion, and flooding, which in fact can affect land suitability for future development planning (Burbank and Anderson, 2011b; Fairbridge, 2006; Gerasimov and Mescherikov, 2006; Hugget, 2007; Wilson, 2006), and geotourism (Adrianda et. al., 2025). It can be seen in rapidly developing areas, inadequate analysis of geomorphological conditions could leads to an increased in environmental risk and infrastructure vulnerability (Burbank and Anderson, 2011b; Forti et al., 2021). As one of the areas that pose diverse geomorphic settings, including denudational hills and fluvial landforms, the Muaro Kalaban area in Sawahlunto City, West Sumatra, Indonesia, is a critical area for assessing how geomorphological processes constrain and inform sustainable development planning (Gusti and Susilo, 2019).

Preliminary studies have showed that geomorphological mapping and landform analysis is important in evaluating development suitability and hazard potential, particularly in actively deformed mountainous and fluvial environments (Burbank and Anderson, 2011a, 2011c; Gusti et al., 2023; Rockwell and Keller, 1985; Sahara et al., 2022). In Ombilin Basin, existing research mainly focused on slope mapping based remote sensing in denudational landscapes, and landslide mapping, or morphotectonics (Sahara et al., 2022; Santoso and Lumbanbatu, 2007). However, many previous studies address these elements partially, without combining multiple geomorphic units into an integrated geomorphic framework for development planning. In the context of West Sumatra, where tectonic activity, high rainfall, and undulating relief, site specific geomorphological studies that focus on linking geomorphic units to city development constraints remain limited, particularly at the local scale areas such as Muaro Kalaban.

This study aims to analyse the geomorphological characteristics of the Muaro Kalaban area and its surrounding and explore their implications for future city development planning. Primarily, the research focuses to 1) identify and classify geomorphic units, 2) assess their main controlling surface processes and associated geomorphic hazards, and then 3) interpret how these factors influence land suitability for future city development. By integrating geomorphological mapping with an analysis of geomorphic processes, this study intends to provide a scientific basis for risk-informed and sustainable development planning in the Muaro Kalaban area and comparable geomorphological settings.

DATA AND METHODS

This study combined conventional field based geomorphological observation with remote sensing analysis using satellite data. Geological mapping included geomorphological observation that was conducted by focusing on identifying present day surface process in the study area, including erosional features, weathering intensity on the rock and landform, geological structures, fluvial processes, and other indicators such as slope instability of outcrops or landforms. These observations provide important data and information for further interpreting and characterizing geomorphic units, dominant geomorphic processes, and potential geomorphic hazards relevant to development planning and disaster mitigation.

For the secondary data, it consisted of Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data with a spatial resolution of 30 m (NASA Shuttle Radar Topography Mission (SRTM), 2013). The SRTM dataset was used for remote sensing analysis and to calculate topographic parameters such as elevation, slope gradient, and landform morphology using ArcGIS

ArcMap 10.8. The integration of field observations with DEM analysis supports a comprehensive characterization of geomorphic units and their spatial distribution across the Muaro Kalaban area.

Geomorphological Analysis

In this study, for the geomorphological analysis follows the established concepts in geomorphology, which focus on landforms, their material composition, and the geomorphic processes (Burbank and Anderson, 2011a; Hugget, 2007). Geomorphology is a branch of geological science that is focussed on the evolution of the Earth's surface and the formation of geomorphic units through endogenic and exogenic processes (Burbank and Anderson, 2011b; Fairbridge, 2006; Hugget, 2007; Wilson, 2006). In this research, geomorphological analysis is used to identify and classify geomorphic units and to interpret their implications for land stability and development suitability.

This study analyses the geomorphic aspects and geomorphic units. The physical characteristics of the landscape characterized from lithological properties, rock resistance, and morphological relief are referred to geomorphic aspects. Geomorphic aspect is evaluated through two main components: morphological analysis and geomorphic process analysis (Burbank and Anderson, 2011d; Fairbridge, 2006; Gerasimov and Mescherikov, 2006; Hugget, 2007; Wilson, 2006). On the other hand, morphological analysis focuses on landform shape, slope configuration, elevation differences, and surface roughness, while geomorphic process analysis examines active processes such as erosion, weathering, mass movement, and other fluvial processes that influence landform evolution (Hugget, 2007; Strahler, 1957).

Remote Sensing and Mapping Methods

For the remote sensing analysis, this study was using SRTM 30 m DEM data to support the mapping and delineation of geomorphic units. DEM analysis results were included slope maps and elevation profiles using ArcGIS ArcMap 10.8, those maps were generated to assist in delineating landform boundaries and assessing geomorphic characteristics (Baharvand et al., 2020; Hugget, 2007; Widyatmanti et al., 2016).

Slope values were calculated using the Slope tool in *Spatial Analyst Tools → Surface → Slope*. The algorithm computes the maximum rate of change in elevation between each cell and its surrounding neighbors based on a 3 × 3 moving window. The slope is derived using a finite difference method that estimates the partial derivatives in the x and y directions (Horn, 1981).

These two maps were integrated with field observations to improve the accuracy of geomorphic unit classification and to validate interpretations of geomorphic surface processes. The final output was geomorphological map of the Muaro Kalaban area by synthesizing field-based geomorphic observations with topographic information from DEM analysis. This integrated approach allows for interpretation of geomorphic units and associated hazards, providing a fundamental step for evaluating development constraints and supporting future land use planning.

RESULTS AND DISCUSSIONS

Morphological Analysis

Morphological analysis discusses the state of morphology and morphometry. Morphographic analysis is a result of differences in elevation height or also often referred to as relief. Meanwhile, morphometric analysis presents a quantitative classification of values which can be in the form of a slope value and shows the difference in the density level of the elevation difference.

Morphographic Analysis

The study area was found to have elevations ranging from 192 - 575 meters above sea level (masl), can be seen on the Morphological Elevation Map (Figure 1). The highest elevation is in the south, northwest and southwest of the study area. The southwest part is Bukit Silungkang which has an elevation of 350 meters above sea level -> 575 meters above sea level into the classification of hills and at the top is High Hills (PT). Furthermore, the northwestern part of the Bukit Air Dingin and Bukit Kaampat are included in the classification of the Hills and the top part is the High Hills with Elevation> 550 meters above sea level. In addition, the hills extending from Bukit Padang Lawas, Bukit Iban and Bukit Parhatianbaras are also hills (200-500 meters above sea level). The Baturatdorong hills have an elevation of 450 - 475 meters above sea level. Meanwhile, the eastern part of the study area is included in the classification of hills - Low hills (PR) with an elevation of 192 - 275 masl.

In addition to using 2-dimensional maps, morphographic analysis is also performed using 3-dimensional projections in the form of block diagrams from the study area. The 3-dimensional block diagram can be seen in (Figure 2) from the 3-dimensional map, there is a contrasting relief between high hills, low hills and low hills. Meanwhile, high hills have a distribution in the northwest and south of the study area. Meanwhile, in the middle of the study area, there are hills with elevations> 500 meters above sea level. Furthermore, the 3-dimensional block diagram validates the existence of hills with elevations of ± 200 mph in the western part of the study area extending from north to south.

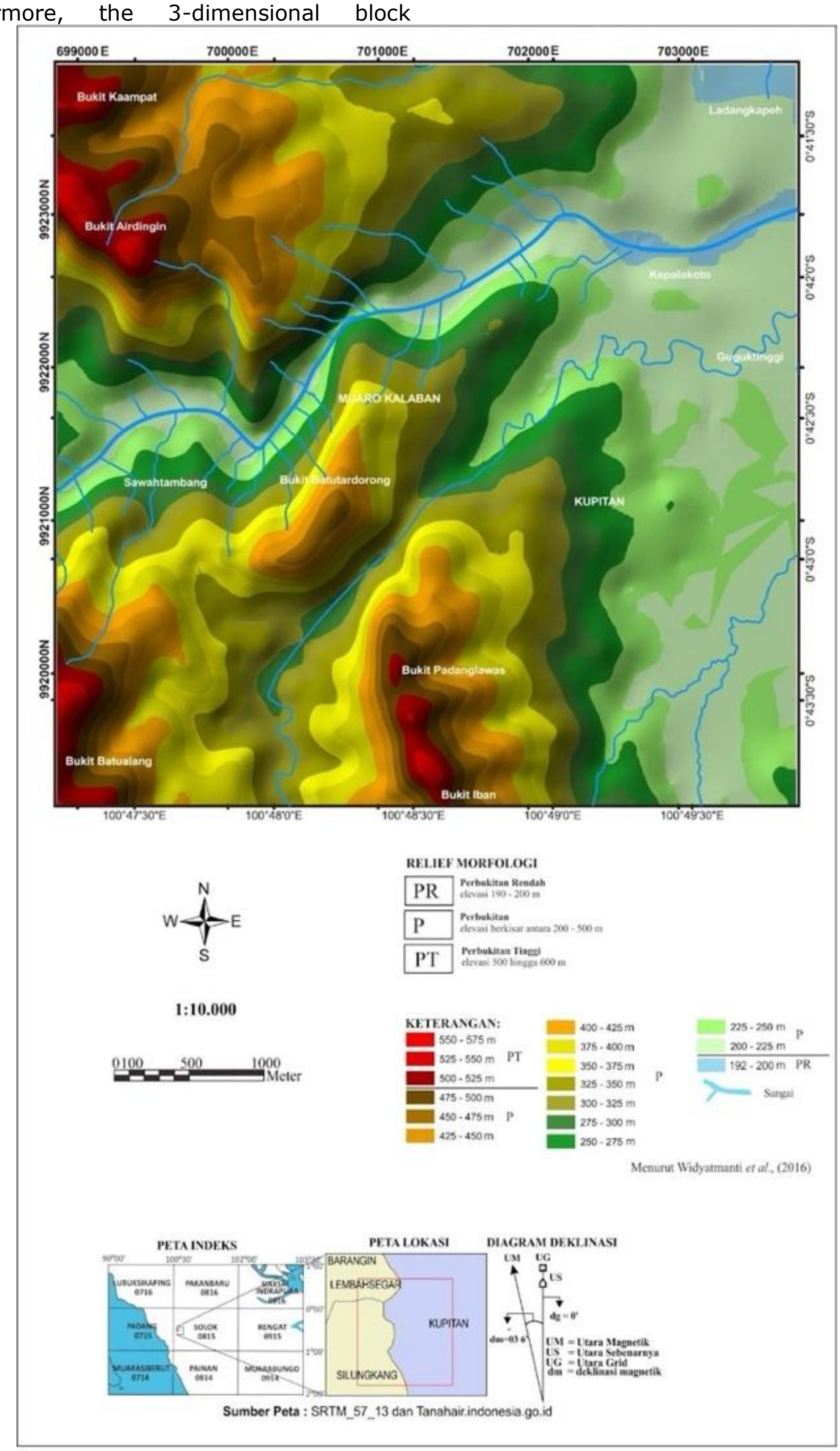

Figure 1. Elevation Morphology Map of Muaro Kalaban and its surroundings.

Morphometric Analysis

Morphometric analysis is performed by analyzing slope slope maps that are built based on SRTM data. Morphometry itself according to Huggett (2011) is a quantitative or mathematical parameter in determining geomorphic units. One part of the morphometric analysis is a slope map. The slope is obtained from the comparison between the intensity of the contour line density and a unit area (Widyatmanti et al., 2016). The results of these calculations are in the form of data which is then used in classifying the slope. In classifying the slope in the study area, the classification of Widyatmanti et al. (2016) was used. Based on the slope classification according to Widyatmanti et al. (2016), the slope of the study area can be grouped into 7 classes of slope, namely flat (0-2%), sloping (3-7%), sloping (8-13%), moderate sloping (14-20%), steep (21 - 55%), very steep (56 - 140%) and upright (> 140%) (Fig. 4.3).

In the eastern part of the study area which consists of the Village Head of Koto in the middle and the Village of Guguk Tinggi in the northern part has a slope value from flat to an almost flat slope with a percentage of 0 - 2%. Meanwhile, in the Bukit Air Dingin and Bukit Kaampat areas located in the northwestern part of the study area, the slope classes ranged from medium to steep - 14 - 55% and meanwhile on the cliffs the percentage of slope values ranged between 56 -> 140% which means very steep to upright. Furthermore, on the Baturardorong Hill which is located in the middle of the study area, this hill has a slope which is dominated by medium to very steep slopes with values ranging from 14 - 140% and on the cliffs on the western side of the hill has very steeply slopes to upright (> 140%).

Furthermore, the study area in the southern part consists of hills and high hills. The high hills are the peak of Parhatianbaras Hill, the summit of Bukit Padanglawas Hill, and also the peak of Mount Iban which is in the south-central part. The west side of these hills has a very steep slope (56-140%) to erect (> 140%). Meanwhile in the western part of this hilly region has a very steep slope (56-140%) to erect (> 140%) which is marked by the dominance of the orange to red. But although the west and east sides are dominated by very steep to steep slopes, at the top of these hills the slopes are medium.

Meanwhile, in the southwest part of the study area which is the northeastern part of the Silungkang Hills and High Hills, the slope starts from the medium slope (14-20%) to steep (21-55%). Whereas in the eastern part of Silungkang Hill there are valleys that have slope ranges from flat (0 - 2%) to sloping (8-13%). Besides that, on the side of the Ombilin River which is in the northeastern part of the study area, the slope is flat to almost flat (0 - 2%). Another case with the side of the Ombilin River in the middle of the study area which has a steep slope (21 - 55%) to very steep (56-140).

Geomorphic Process

Geomorphic process is a variety of configurations of chemical and physical activities that modify the features of the face of the earth (Burbank and Anderson, 2011a; Hugget, 2007). Many things control the geomorphic processes that occur to produce geomorphic conditions as they are today. Geomorphic processes can originate from within the earth (geological processes) as a result of the tectonic forces at work and can also originate from the surface of the earth and in the atmosphere (surface processes).

Geological Process Geological

process is a process that occurs by involving the activities of tectonism and volcanism (Burbank and Anderson, 2011b, 2011a; Hugget, 2007). Tectonism is a geological process related to the activity of plate movements in both continents and oceans. Meanwhile volcanism is a geological process that includes the assimilation, generation, and diffusion of magma in the bowels of the earth. The process that works in the study area is initially controlled by tectonic activity which lifts the rock above the surface into a stretch of hills. This geological process can be seen from the presence of geological structures in the form of 2 flat horizontal flares, 1 down fault and 1 *conical fold* as accompanying folds. In addition, the study area consists of 4 rock formations, namely: Silungkang Formation Limestone Unit, slate Unit Member of the Tuhur Formation, Limestone Unit Member of the Tuhur Formation and Sawahtambang Formation Sandstone Unit. Stratigraphically the southwest part of the study area consists of massive limestone with a high level of resistance forming a hill while the valley in the northeast consists of slate and limestone has weak resistance. Meanwhile, in the central part of the north and north the area is made up of coarse sandstone with high resistance forming hills. Meanwhile in the eastern part of the study area even though it is composed of sandstone it has a lower morphology due to its relatively fine grain size.

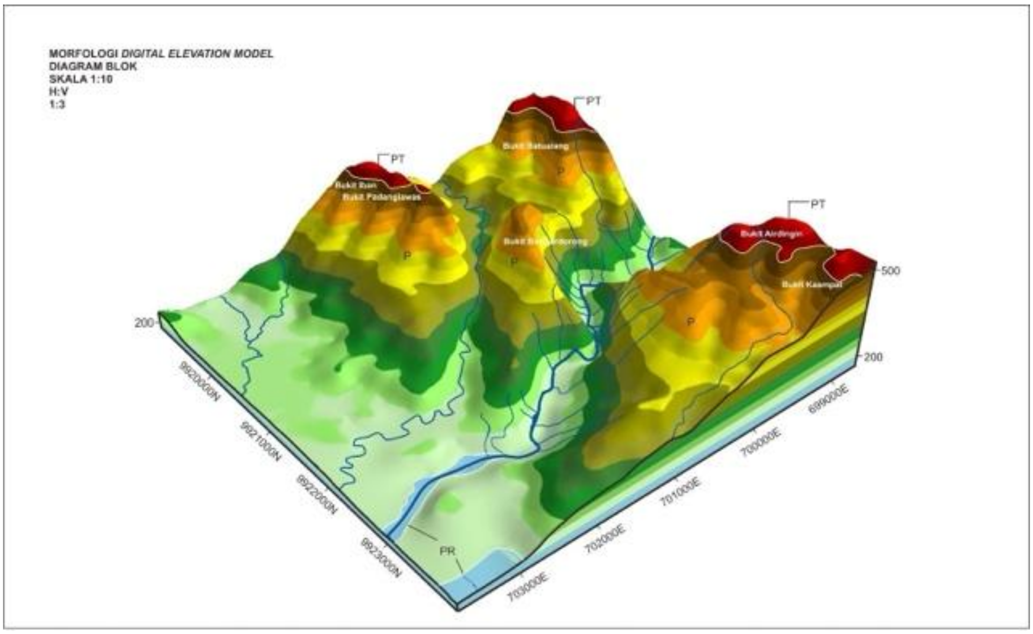

Figure 2. 3D morphography block diagram showing relief difference between high hills (PT) (northeast and southeast), hills (P) (middle), and low hills (PR) (west side).

Surface Processes

Surface processes play a very important role in the formation of the most recent shades of the earth in the study area. According to (Hugget, 2007; Ramkumar et al., 2016; Rockwell and Keller, 1985) the surface process consists of at least three main components namely atmospheric activity, biosphere activity and hydrosphere activity. Atmospheric activity results from changes in weather and climate. Meanwhile, the activity of the biosphere is closely related to the presence of living things as well as plantation activities by humans. While the hydrosphere component is related to the river process, the flow of which can deform the landform.

The weathering process in the research area is developing intensively. Weathering process in the study area can be seen from the density of vegetation that is thick enough to cover the exposed rock surface. The roots of the vegetation cause a weak zone that allows rainwater to enter the body of rocks. The erosion process in the study area was identified as being present side by side with the river flow (Kirby and Whipple, 2012; Strahler, 1952; Tucker, 2004). This is known based on the analysis of the catchment area (*recharge* area). Based on the analysis of the recharge *area*, the Muaro Kalaban and surrounding areas consist of at least 4 Watersheds, namely the Mutogading Sub-watershed, Ombilin Sub-watershed, Piruko Sub-watershed and Gosan Sub-watershed.

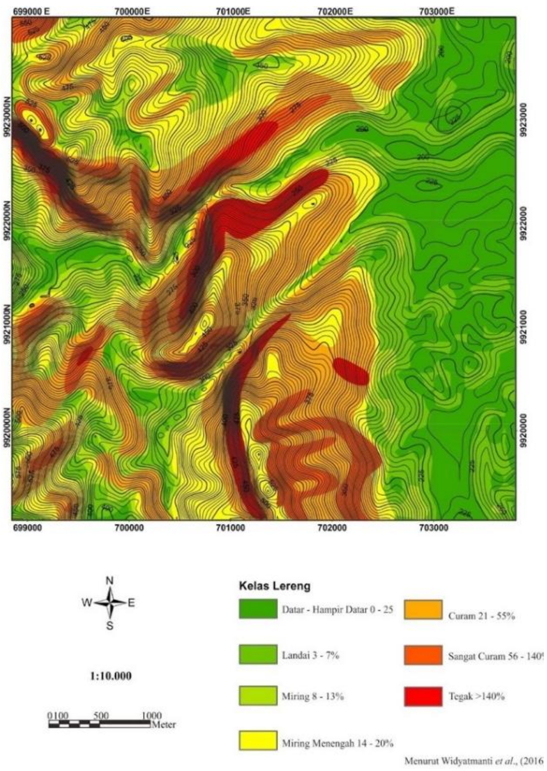

Figure 3. Slope Map of Muaro Kalaban and its surrounding area.

In the study area, the Ombilin River is the main river. Ombilin River becomes the estuary of tributaries in the blood of Muaro Kalaban and its surroundings. In the hydrosphere aspect, river flow from upstream to downstream allows the erosion process that can also carry sediment material in its flow. The river flow has a direction which is then used to determine the direction of erosion that works in the study area (Figure 4 and Figure 5). Each sub-watershed in the study area has a different direction that is controlled by the slope. First is the Ombilin Sub-watershed which eroded the central part of the study area with the direction of flow N30ºE-N40ºE (Northeast). Furthermore, the Mutogading Sub-watershed is responsible for the erosion process that occurred in the Cold Water Hills in the direction of the flow N80ºE-N90ºE (East). Then the Humidity Sub-Basin in the western part is responsible for the erosion process with the flow direction of N90ºE-N100ºE (East). After that, the Gosan Sub-Basin in the southeast of the study area is responsible for the erosion process in the southern area of Guguktinggi Village with the flow direction N355ºE-N05ºE (North). And finally Piruko Sub-watershed which eroded Bukit Batutardorong and Bukit Padanglawas has erosion direction N30ºE-N40ºE (East-Northeast). In addition, of the five sub-watersheds (DAS), all have a uniform flow pattern (Figure 6). The river drainage pattern can be used to identify the intensity of denudation, geological structure and geomorphic stages that take place in the study area. (Twidale, 2004) said that based on the analysis of river flow patterns, it can be seen variations in lithology and slopes or geological activities that work in an area. River drainage patterns in the study area consist of one type of drainage patterns, namely Sub-Parallel. This is controlled by the formation of an elongated slope causing the river flow to approach parallel to one another. This can be seen from the Ombilin River, which has an erosion direction relative to the west, has a Sub Parallel (SP) drainage pattern that lies between two valleys in the north and south. The slope of the morphology in the study area also affects the flow patterns of the Mutogading River, Piruko River, Gosan River.

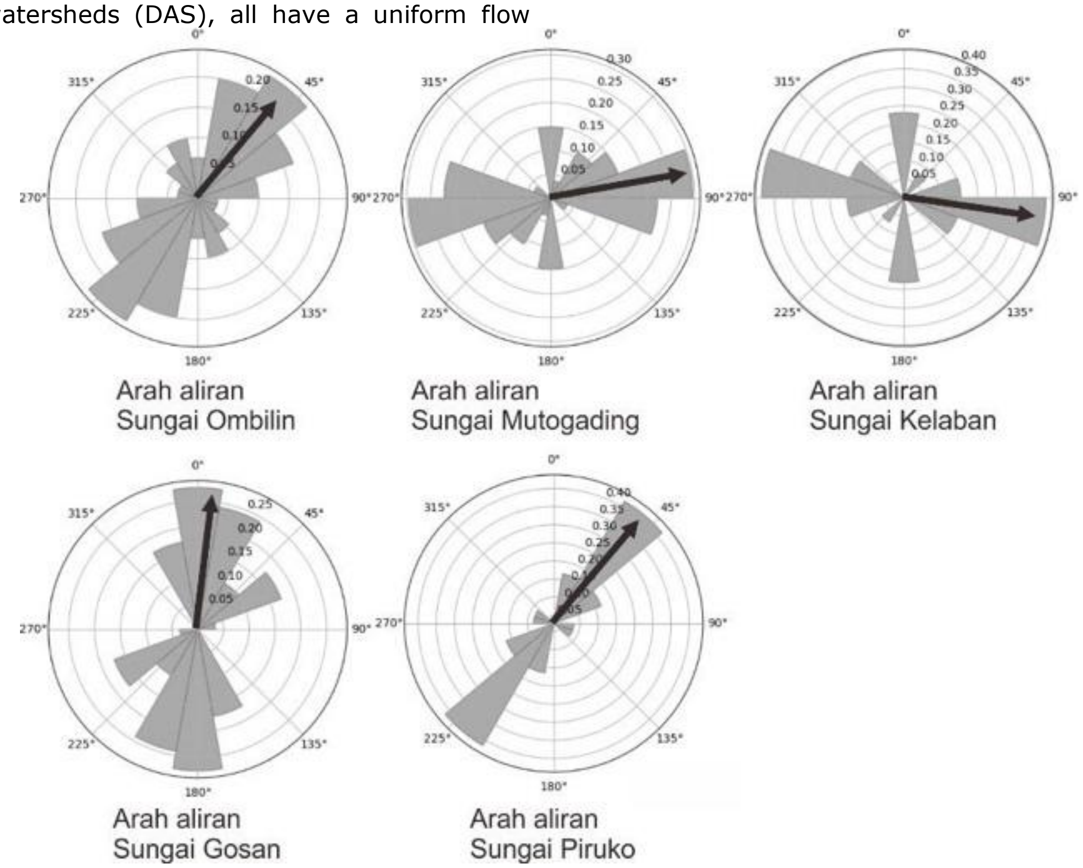

Figure 4. Rose's diagram shows the direction of erosion of the flow from the five Sub-Watersheds.

In addition there are landslide data in several study sites (Figure 7). Denudational activity can be seen from the presence of rock material that has experienced a movement or landslide (Korup, 2008). The density of evidence of the movement of rock material in several observations indicates the weathering process that is active in the research area (Iverson, 2000). Rocks in the research area exposed on the surface of the earth are in contact with tropical weather in the study area so that it experiences weathering. After the rock material has been weathered, it forms a pore space which when filled with water fluid results in an incidental increase in the rock mass. When the rock mass elevates, the adhesive strength of the rock will decrease so that there will be movement of the rock material (Iverson, 2000). Avalanches in the study area are in claystone lithology which has *swelling* properties when saturated with water (Iverson, 2000). Meanwhile, sandstone lithology has weathered chunks which are then separated from the main rock body due to gravity. Based on (Hugget, 2007; Iverson, 2000) the process of landslides in the study area is controlled by hydrosphere activity. This is caused by the study area which has a high rainfall intensity.

Geomorphic Unit

The geomorphic unit of the study area has several morphological variations. The study area consists of at least four geomorphic units. Geomorphic units that developed in the study area are Denudation Hills with Medium-Upright Slope, Denudation Hills with Flat-Slope Slopes, Kepalakoto Flood Plains and the Winding River Canal. The distribution of geomorphic units in the study area can be seen on the Geomorphological Map of the Muaro Kalaban and Surrounding Areas (Table 1).

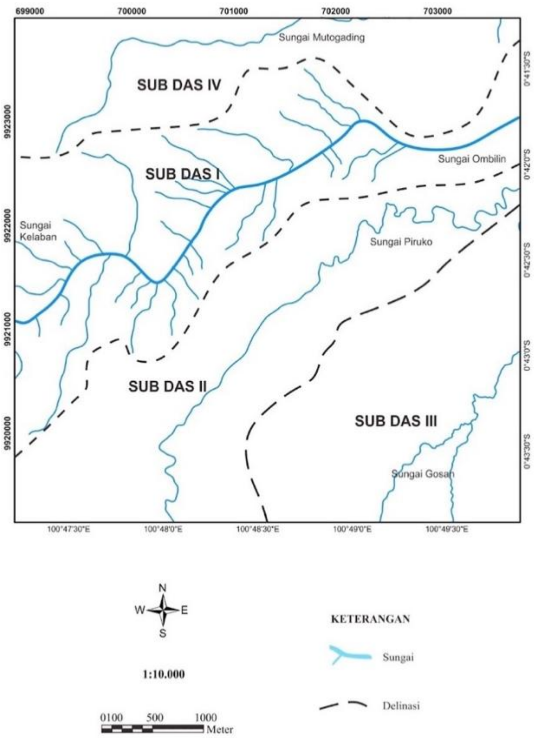

Figure 5. Map of Muaro Kalaban Watershed and Surrounding Areas

Denudational Hills Unit with Medium - Upright Sloping Slope

Denudational Hills Unit with Medium - Upright Sloping Slope (P) has a distribution covering 66% of the area of the study and is dominated by altitudes ranging from 200 - 500 m above sea level. However, the peaks of the hills have elevation> 500 meters above sea level which is not so significant and only at the peak. This unit is located in the central and western parts of the research area, which is characterized by the presence of hills separated by valleys and also in Taratakbanca Village in the southwest and Bukit Air Dingin in the northwest. This unit has a slope ranging from medium to vertical slope (14 -> 140%).

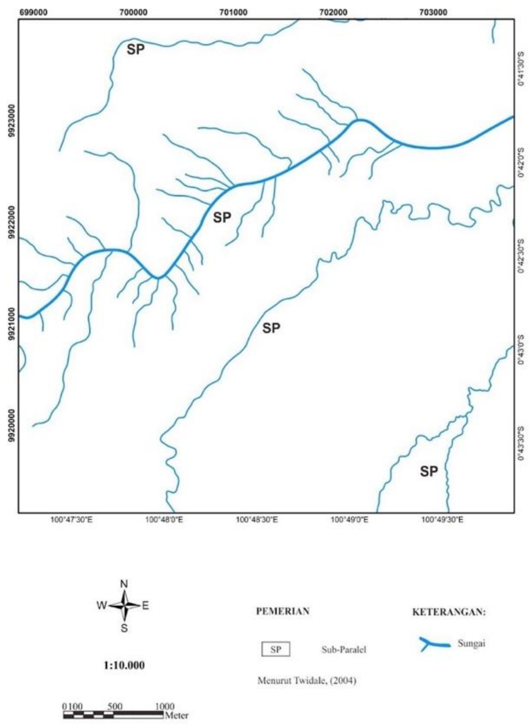

Figure 6. Map of Drainage Patterns of Muaro Kalaban and Surrounding Areas.

Furthermore, in the northwestern part of the study area, this geomorphic unit was compiled by coarse sandstone lithology at the bottom and intermittently fine sandstone with claystone at the top. At the top of this unit, the weathering and erosion process is very intensive which is supported by the existence of forest clearing to become an area of citrus and oil palm plantations by humans. It also found the presence of loose material avalanches in this morphology. In (Figure 8.) We can see the appearance of hilly morphology that has a northwest-southeast trending slope. In addition, denudation hills in the northwestern part of the study area were found to have steep slopes and experienced intensive denudation (Figure 9). Meanwhile, the Hilly Unit in the southern part of the study area was composed by coarse sandstone lithology at the bottom which was quite resistant to erosion. The formation of morphology is controlled by the denudation process that forms this unit so that it has the appearance of the present condition. The appearance of this geomorphic unit can be seen in (Figure 10). This image is the result of morphological photographs taken facing east-southeast.

In addition, in this Denudation Hills can be seen very clearly the layers of rock that have a relatively northeast-directed tilt direction. The rock layers are well exposed as a result of the denudation process which works to peel the rock from its cover (Figure 11). The formation of this geomorphic unit is highly controlled by denudation activity which makes the constituent rocks of this form of morphology well exposed. On the eastern slope of this geomorphic unit, the general land use is used as an area of rice farming and rubber plantations by the surrounding community. These agricultural lands support the erosion process by the erosion activity of the irrigation flow and the denudation is very dominant in controlling the unit's geomorphic formation.

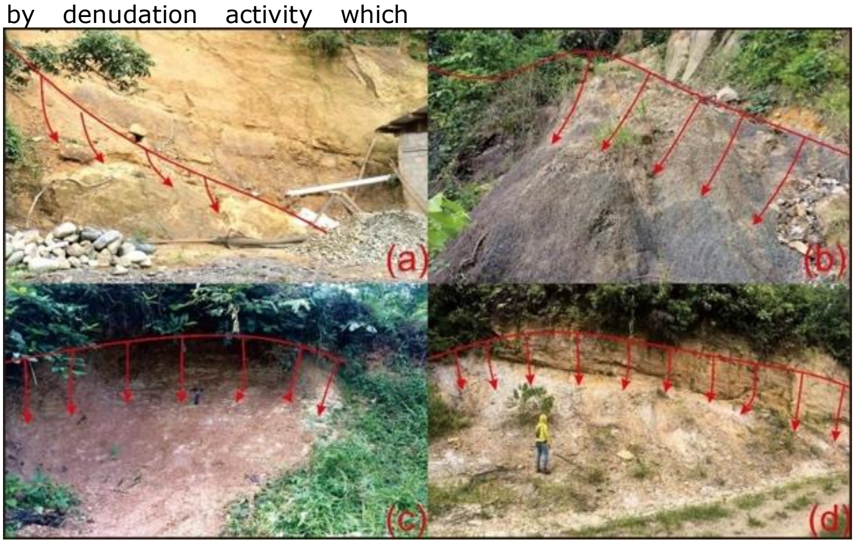

Figure 7. a and b) Landslide appearance on LP 14 with photo directed N10ºE. c) Landslide appearance on LP 58 with photo azimuth N310ºE. d) Avalanche at LP 84 with photo azimuth N300ºE.

Denudational Hilly Unit with Flat - Ramps Slope

The Denudational Hilly Unit with Flat - Ramp Slope (PD) occupies 30% of the study area. This unit is located in the eastern part which extends from the north to the south of the study area. This unit is located at an altitude of 200 or <200 m above sea level. This unit has a flat to sloping slope (0 - 7%). This unit has a morphological form in the form of hills with characteristics in the field of terrain with elevations above 200 masl. On the Geomorphological Map of the Muaro Kalaban area and its surroundings, this unit is given a light gray-brown color. The Hilly Unit is mostly used as agricultural land by local residents (Figure 12). The other part of the Denudation Hills unit with flat slopes is used by the surrounding community as settlements.

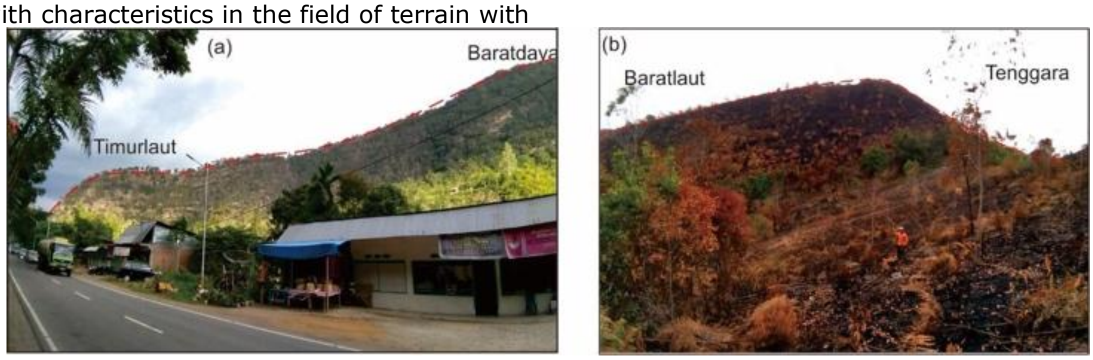

Figure 8. (a) The morphological appearance of the Sloping Medium-Steep Sloping Hills extending from northeast to southwest in the centre of the study area was taken from LP 26 with azimuth (N 89º E), (b) showing the peak of Bukit Batutardorong taken from LP 119 with azimuth (N 70º E).

The geomorphic unit of Denudational Hills with flat to sloping slopes is composed by fine sandstone lithology by intermittent layers of claystone and shale which are not sufficiently resistant to erosion. The process that works intensively on this unit is the erosion seen from river flows and weathering. This makes the western part of the study area a denudational geomorphic unit.

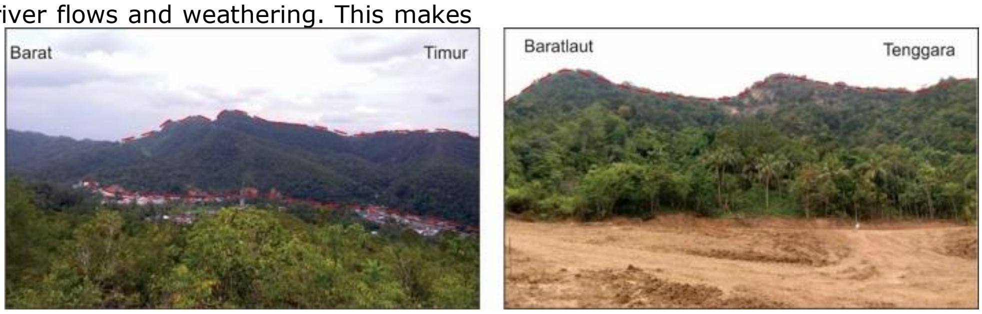

Figure 9. (Left) Morphological appearance of the geomorphic unit Denudation Hills with medium to vertical sloping views seen from the south to north, (right) shows the appearance of the Medium Sloping Angled Slope from west to east.

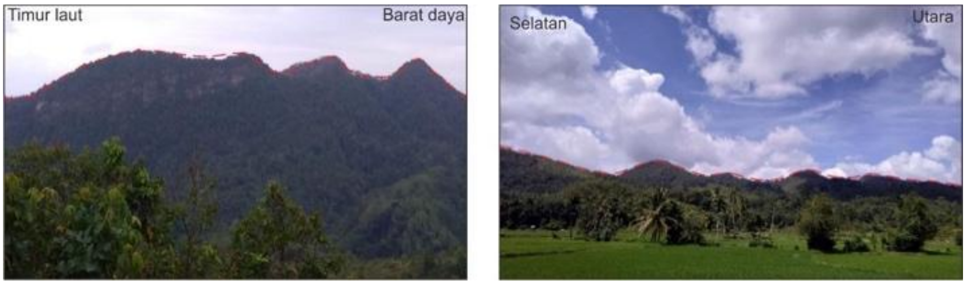

Figure 10. (Left) The appearance of a denuded hill geomorphic unit with an upright slope and shows the slope of the rock layer taken from the west side, (Right) and the appearance of a denuded high hill geomorphic unit taken from the east.

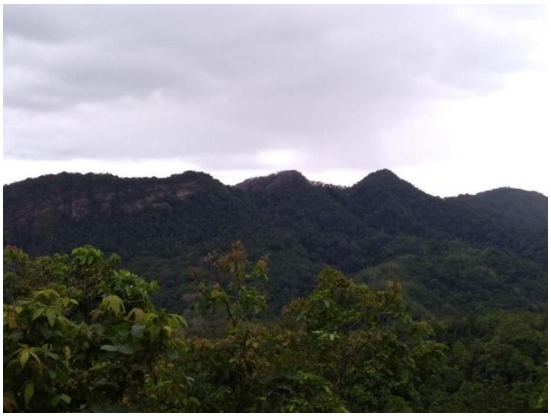

Figure 11. The morphological appearance of the geomorphic unit of the Denudational Hills undergoing an intensive denudation process so that it shows the slope of the rock layer in a direction relative to the northeast and taken from the western side with azimuth (N 153º E).

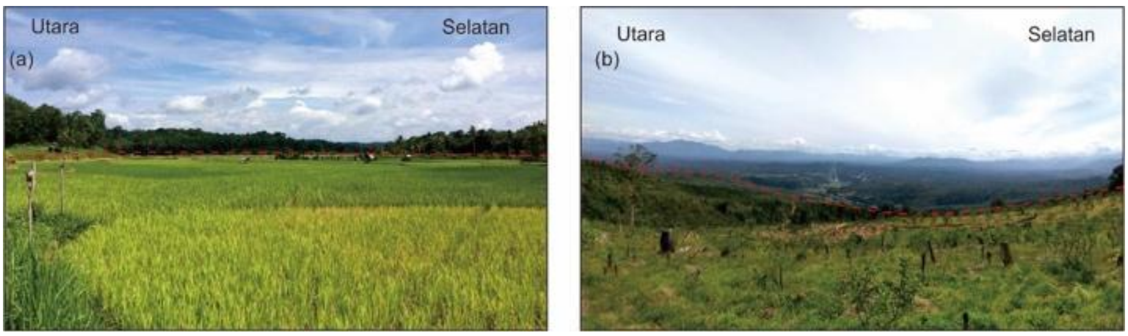

Figure 12. (a) The appearance of low hills morphology consisting of paddy fields is taken from LP 61, (b) low hills units seen from LP 19 with azimuth (N 103º E).

Flood Plain Unit
Floodplain or abbreviated to DB on the Geomorphological Map of the Muaro Kalaban area and its surroundings is marked in light green. The Flood Plain Geomorphic Unit is only around 2% of the area of the study. The geomorphic unit density of the Flood Plain is associated with the flow from the Ombilin River that flows from west to east in the study area. This geomorphic unit is located on the side of the Ombilin River in the eastern part of the study area.
This geomorphic unit of the Flood Plain has the characteristic of being at an elevation <200 meters above sea level. This floodplain is spread insignificantly because the type of river is the bedrock river which indicates that the riverbed is eroded rock and floodplains are formed when the river body cannot accommodate the elevated volume of water. Based on the grade value of the slope, it is found to be on a flat to the gentle slope (0 - 7%). The appearance of the Geomorphic Unit of the Flood Plain in the Muaro Kalaban and surrounding areas can be seen in (Figure 13).

Table 1. Summary of Geomorphic Units, Dominant Processes, Hazard Potential, and Development Implications in Muaro Kalaban

Geomorphic Unit	Dominant Processes	Hazard Potential	Development Implications
Denudational Hills (Moderate–Steep Slopes)	Surface erosion, weathering, slope instability, mass movement	High susceptibility to landslides and severe erosion, especially during intense rainfall	Not recommended for dense settlement; requires slope stabilization, proper drainage systems, and strict land-use control
Denudational Hills (Gentle Slopes)	Sheet erosion, soil creep, moderate weathering	Moderate erosion risk; localized slope instability	Conditionally suitable for limited development; requires soil conservation measures and controlled land clearing
Kepalakoto Floodplain	Fluvial deposition, overbank flooding, sediment accumulation	High flood susceptibility; seasonal inundation	Suitable for agriculture or low-intensity land use; permanent infrastructure should consider flood mitigation and river buffer zones
Meandering River Channel	Lateral channel migration, bank erosion, sediment transport	Flooding and channel migration; riverbank erosion	Development should maintain river setbacks; avoid permanent structures near active channel zones

The Meandering River Channel (*Sinus*)
The Sinuous/Meandering River Channel (*Sinus*) is named based on classification of *River Sinuosity Index* (Horacio, 2014; Twidale, 2004) a value of 1.24, occupying 2% of the area of the study. This unit is in the middle and is spread extending from west to east of the study area by occupying elevation 190-225 m above sea level. This unit is on a slope ranging from flat to gentle slope (0 - 7%). On the Geomorphological Map of the Muaro Kalaban area and its surroundings, this unit is given in blue. This unit has a morphological form in the form of a valley that runs southwest - northeast, with different characteristics in the west and east. This river erodes sedimentary rocks in the east to the middle while in the west erodes the metamorphic rocks. Ombilin River Flow In the middle of the study area and in the eastern part eroded the sandstone of the Sawahtambang Formation to form a valley located at LP 6 (Figure 14a and Figure 14b).

Figure 13. The geomorphic unit appearance of floodplains on winding rivers located at Observation Site 45.

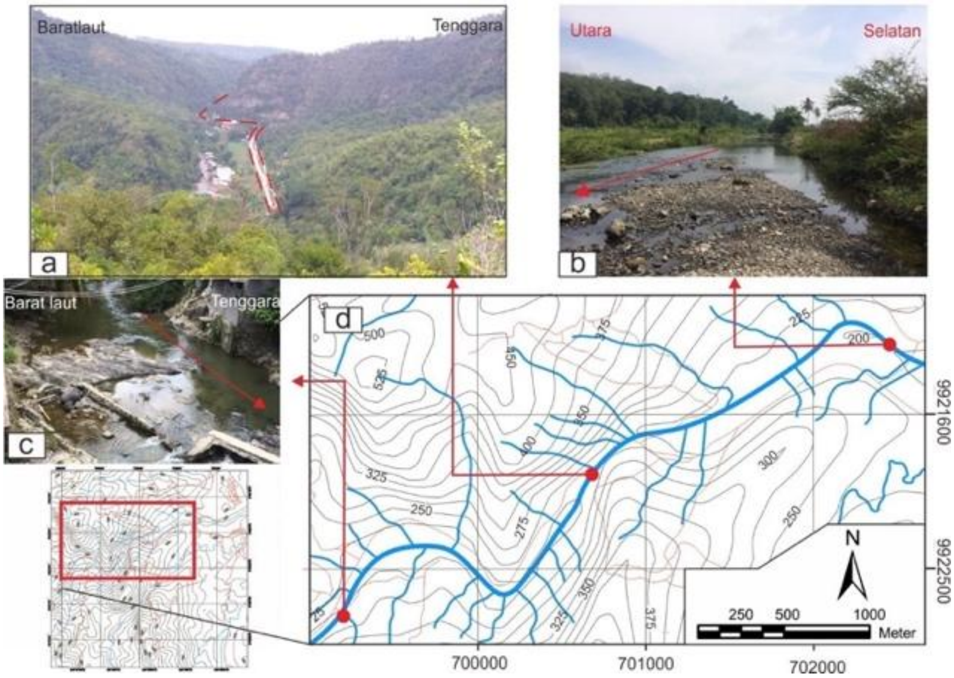

Figure 14. (a) Ombilin River flow in the middle section, (b) appearance of the Ombilin River flow in the east, (C) Ombilin River in the western part of the study area, (d) Topographic Map of the Muaro Kalaban Region and its surroundings.

This geomorphic unit is also characterized by the appearance of a meandering river cutting morphology so that it shows the appearance of a winding river canal from the Ombilin River which erodes Pre-Tertiary rocks such as slate and limestone in the west with type bedrock river at LP 132 (Figure 14c) (Gusti, 2026). This winding river channel unit erodes the pre-tertiary age of metamorphic and meta-sedimentary rocks in the west and sandstones in the middle and east of the study area. The processes that develop in this unit are erosion and weathering. The development of the weathering process can be seen from the quite thick vegetation control.

DISCUSSION

The geomorphological characteristics of the Muaro Kalaban area are closely related to the regional geological evolution of the Ombilin Basin, which has been widely discussed in previous studies (Koesoemadinata & Matasak, 1981; Barber et al., 2005; Gusti and Susilo; 2019; Sahara et al., 2022). Regional study has emphasized the structural control of folding and faulting on basin morphology, sediment distribution, and landscape development (Koesoemadinata & Matasak, 1981; Barber et al., 2005). These studies show that tectonic deformation played an important role in shaping the present-day relief of the basin, including the development of denudational hills and structurally controlled valleys.

The results of this study are consistent with those regional findings. The denudational hills identified in Muaro Kalaban reflect long-term erosion processes acting on sedimentary rock formations that were previously deformed by tectonic activity. The orientation of ridges and slope patterns also indicates structural influence, which has been recognized as a key factor in the geomorphic evolution of the Ombilin Basin (Barber et al., 2005). However, unlike previous regional studies that mainly focused on basin evolution and stratigraphy, this research provides a more detailed geomorphological mapping at the local scale of Muaro Kalaban area and directly links geomorphic units to land use planning considerations.

Each geomorphic unit shows different surface processes and levels of hazard potential. The denudational hills with moderate to steep slopes are mainly affected by surface erosion, weathering, and slope instability (Figure 3). These areas are relatively prone to landslides, particularly during periods of high rainfall. Therefore, they should be considered as high-constraint zones for development unless proper slope stabilization and drainage systems are applied. In contrast, denudational hills with gentle slopes have lower slope gradients and relatively better stability, making them more suitable for limited development with appropriate soil conservation measures (Figure 3).

The Kepalakoto floodplain and the meandering river channel are dominated by fluvial processes (Figure 4 and 14). Previous studies in the Ombilin Basin have highlighted the dynamic nature of river systems within structurally influenced basins, including lateral channel migration and overbank flooding (Koesoemadinata & Matasak, 1981). In Muaro Kalaban, the floodplain is relatively flat and composed of alluvial deposits, which makes it attractive for housing plan and infrastructure development. However, these areas are more exposed to flooding and potential channel migration. As a result, they should be classified as flood prone zones, and development planning should including river setbacks and flood mitigation strategies.

Overall, integrating geomorphological mapping with DEM based parameters provides a clear spatial basis for identifying relatively safe zones and hazard prone zones in Muaro Kalaban. This approach supports land-use planning that considers geomorphic constraints and helps reduce the risk of landslides, erosion, and flooding in tectonically influenced basin environments.

This study has several limitations that should be acknowledged. The geomorphological analysis relied mostly on DEM based parameters and field observations, where the spatial resolution of the DEM may influence the accuracy and precision of slope classification and geomorphic boundary delineation. Next, the hazard assessment done in this study remains qualitative, based on geomorphic interpretation and surface process indicators rather than quantitative calculation. Therefore, future research should utilize higher-resolution topographic data and integrate quantitative geomorphic hazard analysis, such as landslide susceptibility modeling and flood frequency assessment. Further field geotechnical investigations are also recommended to validate slope stability conditions and geophysical survey for subsurface characteristics, particularly in areas identified as potentially unstable. These approaches would improve the reliability of hazard zonation and provide stronger technical support for sustainable land-use planning in Muaro Kalaban area and elsewhere.

CONCLUSIONS

This study demonstrates that geomorphological analysis provides an imperative foundation for development planning in the Muaro Kalaban area, Sawahlunto City, West Sumatra, Indonesia. Through the integration of field based geomorphic observations with SRTM derived topographic data allowed this study for a detailed characterization of landforms, surface processes, and associated geomorphic hazards. The identification of four main geomorphic units highlights the spatial variability of landscape conditions and their influence on land stability as for denudational hills with moderate to steep slopes, denudational hills with gentle slopes, the Kepalakoto floodplain, and a meandering river channel.

This study explored each geomorphic unit that exhibits distinct process regimes and geomorphic related hazard potentials that impose specific challenges on land use. For example, denudational hills are primarily affected by erosion and slope instability, increasing susceptibility to generate landslides, particularly in areas with steep slope gradients. Contrary, the floodplain and meandering river channel are dominated by fluvial processes and while located in relatively low slope area are vulnerable to periodic flooding, lateral channel migration, and sediment deposition. These conditions appear as significant challenges for future infrastructure development and emphasize the need for more detailed study and consideration of geomorphic dynamics in spatial planning of Muaro Kalaban area.

The findings of this study emphasize the necessity of integrating geomorphological knowledge into future city development plans in order to decrease environmental risk and improve city sustainability. Geomorphological mapping and earth surface process based interpretation can help identify hazard prone areas and suggestions to land use decisions that are appropriate for the landscapes inherent capacity. This study presents a methodological framework that may be used to other locations with similar geomorphic setting, as well as a more robust approach to regional development planning in West Sumatra and similar situations.

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