Lineament analysis of digital elevation model to identification of geological structure in Northern Manna Sub-Basin, Bengkulu

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Abstract. Digital Elevation Model (DEM) is a representation of the actual landform based on elevation. DEM is part of the technological sophistication that is very helpful in planning, mapping, and surveying. This study applies DEM, which is constructed from DEMNAS, focusing on DEM optimization for geological structures identification. The applied method is ellipsoid stress model analysis approach to determine the type of structure. The scope of this study is located in North Manna Sub-Basin, tectonically is a basin that formed on Paleogen by an extensional force that forms half-graben along the Bengkulu Shelf. Interpretation of DEM in the study area showed the existence of 10 lineament patterns of NE-SW and five NNE-SSW patterns, controlled by normal fault, nine lineament patterns of NW-SE and six WNW-ESE patterns, controlled by a thrust fault and fold. Field observation using direct measurement method obtained by four faults with NE-SW and NNE-SSW pattern, one fault and four folds with NW-SE pattern, three faults and two folds with WNW-ESE trending pattern. This indicates that the accuracy level of DEM in the study area reaches 90%. The geological structure that is still active, certainly requires special attention in building construction.

1. Introduction

Technological advances and sophistication, provide many conveniences in a variety of areas, one of which is geological surveying and mapping. DEM is one of the sophistications that is very useful in that field. According to Burrough in [7], DEM is a representation of the actual surface of the earth with a certain degree of accuracy. The level of DEM’s precision to the actual situation depends on the resolution and the source of the DEM itself [3], [7]. DEM can be used in making maps of slopes, gradients, other aspects, and various interests such as geological analysis [2].

Identifying the geological structure using DEM has become something quite actual, because data that can be analyzed is a lineament illustrated by its three dimensional representation. DEM data provides vertical image reflection of the presence of faults and folds below the surface [4]. This study uses DEM from SRTM to test its accuracy in the identification of geological structures. Lineament analysis using DEM is the best way to get an initial illustration of the geological conditions of a place [16]. The use of DEM from SRTM for similar analysis is also done by [20], and yields data that is
good enough to be applied to other geological aspects, such as geodynamics, mineral exploration, and hydrogeology. The SRTM level accuracy test has also been done by [8], [14], and [6].

The study area has an area of 81 km$^2$, administratively located in South Bengkulu District, Bengkulu Province, Indonesia (Fig 1). Geologically, it is the northern part of the Manna Sub-Basin which in [23], it is referred to as Kedurang Graben. According to [5], the geological structure in this area is highly developed with strong influence from Sumatran Fault System (SFS).

![Fig. 1 The SRTM image illustrates that the northern morphology of the study area is a ridge with NW-SE direction (modification from [23]).](image)

2. An overview of geology

The subduction system of Sumatra has undergone three times of change of direction, namely the NW-SE direction of the Late Jura-Late Cretaceous with the compression phase, N-S direction in Late Cretaceous-Early Tertiary with the tensional phase, and the NE-SW direction at Middle Miocene-Recent by compression phase [19]. At Tertiary-Recent, subduction forms an angle of N25°E in the southern part of Sumatra and forms an angle N31°E on the northern part of Sumatra, this forming a major fault on the island of Sumatra with the movement of strike-slip fault namely Semangko Fault [18], [22], and [9]. The Bengkulu Basin itself began to develop in the Early Tertiary [9], [11]. This sedimentary basin then decreased slowly in the Early Miocene [12], [15]. At the Middle Miocene the removal of the Barisan Mountains lane triggers magmatic activity around it [13]. The process of descending the basin ends at the Late Miocene-Pliocene [23].

Tectonically, study area is dominated by the movement of the Sumatran Fault System (SFS). According to [21], the SFS along the Bengkulu Basin is divided into several segments, from the south, namely Kumering Segment, Manna, Musi, and Ketaun Segment. Study area, based on [21], is in the
southern part of the Manna Segment (Fig. 2). The Manna Segment has a length of 85 km, with morphological dominance of mountain ranges in the eastern fault zone [17]. According to [17], this segment is still active with evidence of an earthquake in 1893.

The stratigraphic sequence of study areas, from oldest to youngest, are Seblat Formation, Lemau Formation, and Simpangaur Formation [1]. Seblat Formations in the form of claystone, carbonaceous claystone, and sandstone with limestone insertions are deposited in conformity over the Hulusimpang Formation in the Early-Middle Miocene [1]. Then the Lemau Formation, which is composed of claystone, carbonaceous claystone, coal, sandstones, conglomerates, and breccias from the precipitated alignment above the Seblat Formation on Middle-End Miocene [23]. After that, it is precipitously aligned with the Simpangaur Formation with a conglomeratic sandstone, sandstones, claystone, and molluscs sandstone, and tufsandstone at the Late Miocene-Pliocene [1].

The geological structure of the study area, according to [23], is divided into two general directions, namely the NW-SE and NE-SW directions. Fault with dextral movement (Tanjung Sakti Fault, Ketaun Fault, and Manna Fault) is the controller of Pagarjati Sub-basin (Pagarjati Graben) in NW and Manna or Kedurang Sub-basin (Kedurang Graben) as study area in SE part of Bengkulu Basin [23]. The geological structure of the study area is regionally controlled by the Tanjung Sakti Fault, which is part of the Semangko Fault lane [23].

![Fig. 2 Tectonic of Bengkulu Basin [9].](image)

3. Methodology

Process of DEM maps making is using a global mapper and arcGIS software. The data used for this study is an elevation model with accuracy of 0.27-arcsecond (8.25 meters) from the web of DEMNAS, the Indonesian Geographic Information Agency. The procedure begins with opening elevation data in global mapper, then creating contour of the study area by using contour generate menu. The contours created must be in the projected UTM coordinates. Once the contour is finished, it is saved into a shapefile, next, opens the contour file with the arcgis program. To be a DEM, contour
data goes through two processes, namely the conversion of a file into a raster form, and then into a TIN. If the process succeeds, it will form the desired DEM.

The lineament pattern is done by delineating the form of lineament reflected from the appearance of three dimensional reliefs of DEM. After delineation, azimuth measurements, length of alignment, and number of lineaments are found in each zone of coordinate grid. The calculation of the number of lineaments is based on azimuth orientation. It is intended to know the intensity of the lineament in each zone. Comparison of lineament intensity is visualized into several forms like contours, graphs, and rose diagrams. Contours are created using the help of surfer programs, graphics using StatPlus, and rose diagrams using the dips program.

An analysis of the geological structure of the lineament was performed using an ellipsoid stress model [10]. The major axial direction used is NE-SW or Miocene-Recent decryption determined from previous studies [19], [9], [18], [22]. It is also assessed from the rock formations that make up the study area which is the Miocene Formation, so it is concluded that the structure of this region certainly has the same age or is younger than the age of formation.

The accuracy of alignment analysis derived from the percentage comparison of DEM’s geological structure analysis results with the availability of geological structures in the field. Parameters are assessed in the form of azimuth similarity, number of straightness, and structure type accuracy.

4. Result and discussion

The DEM maps created in this study visualize a three-dimensional relief form with a shadow derived from a solar lighting scenario with a 30° angle at azimuth N315°E (Fig. 3). Then after the delineation, obtained 36 directions of lineament (Fig. 4). In the previous study, the lineament was divided into several groups, namely N-S, E-W, NE-SW, NW-SE, NNE-SSW, ENE-WSW, WNW-ESE, and NNW-SSE [21]. In this study, the alignment encountered has N-S, E-W, NE-SW, NW-SE, NNE-SSW, and WNW-ESE orientations (Table 1). The lineament dominance occurs at the NE-SW orientation with ten straightnesses as results indicate, and the NW-SE orientation with nine straightnesses, while the least orientation is N-S and E-W orientations with the amount of three straightnesses in each. The most dominant percentage of lineament is 28% and the minimum is 8%.

Table 1 Length and percentage of lineament

| Length (km) | N-S | E-W | NE-SW | NW-SE | NNE-SSW | WNW-ESE |
|------------|-----|-----|-------|-------|---------|---------|
| 0-0.8      | -   | -   | 2     | -     | -       | 1       |
| 0.8-1.6    | 3   | 3   | 7     | 7     | 5       | 3       |
| >1.6       | -   | -   | 1     | 2     | -       | 2       |
| Sum        | 3   | 3   | 10    | 9     | 5       | 6       |
| %          | 8   | 8   | 28    | 25    | 14      | 17      |

As observed from the rose diagram, lineament in the study area also shows the NE-SW and NW-SE patterns (Fig. 5a). The alignment with the N-S and NE-SW directions is dominant in the Northeast study location. In the North, the lineaments with dominancy are the NW-SE and NNE-SSW patterns, while the Southern part is dominated by the E-W. The northwestern of the study area is dominated by the WNW-ESE lineament (Fig. 6a).

A fairly long range of alignment (> 1.6 km), is predominantly stretched from the NE-SW and SW-SE of study area (Fig. 6b). The pattern has NE-SW, NW-SE, and WNW-ESE orientations. Comparison between the length of straightness and azimuth orientation indicates that the study area is dominated by lineament in the direction of 0-90° and 270-360°, and has a length between 0.5-2.7 km (Fig. 5b).
Fig. 3  Appearance of DEM relief in the study area.

Fig. 4  Lineament pattern in the study area.
Results from the analysis with ellipsoid stress model [10], lineament with NE-SW and NNE-SSW directions, 100% are normal faults. This is directly proportional to the structure found in the field, where the orientation is entirely a normal fault. Lineament with orientations of NW-SE and WNW-ESE, has 50% of thrust fault and 50% in the form of folds, but the reality in the field shows 40% of the alignment is thrust fault and 60% are folds. In this analysis, there is no structure with orientations of N-S and E-W. Likewise, with the reality in the field, it is possible that the lineament N-S is part of the normal fault, while the E-W is a thrust fault or fold. From the comparison above, the accuracy of the DEM geological structure analysis’s lineament pattern reaches 90% (Fig. 7). This way, it is not burdensome to interpret the structure of the initial stage before doing geological mapping field.
Fig. 7 (a) DEM shows with geological structure plotted, (b) Digital Terrain Model (DTM) shows from 60° bird view direction.

5. Conclusion

The accuracy of geological structures analysis through DEM of DEMNAS reaches 90%. This indicates that the DEM data is sufficiently accurate and beneficial for assisting the interpretation of geological structures prior to mapping on the ground. Those results illustrate the sophistication of technology and the development of science, will facilitate various aspects of human life, including the field of earth science.

The results of this study are expected to be of guidance in interpreting early geological structures and can be applied in relatively similar locations with complex structural zones, with a reflection of topographic control. This study is very important to do in spatial planning and construction of a place, because the geological structure is related to tectonic processes. The geological structure that is still active, certainly requires special attention in building construction. Other than that, this study can be applied to the industries that have a close relationship with geological structures, such as geothermal or gold mining. Furthermore, this study will be able to be developed again on more specific themes, such as the discussion of validation and accuracy of DEM data.

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