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Regional and Local Scale Lineament Analysis Using ALOS PALSAR DEM for Geological Structure Identification in the Sentul Area, West Java, Indonesia

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Geological structure; lineament analysis; lineament density; rose diagram; ALOS PALSAR DEM

Abstract

Geological structures play an important role in controlling geomorphological development and tectonic deformation within the Sentul area, West Java, Indonesia. However, detailed structural mapping is often constrained by limited field accessibility and spatial coverage. This study, Regional and Local Scale Lineament Analysis Using ALOS PALSAR DEM for Geological Structure Identification in the Sentul Area, West Java, Indonesia, aims to identify geological structures using ALOS PALSAR Digital Elevation Model (DEM) data integrated with multi-directional hillshade analysis, lineament extraction, rose diagram analysis, and lineament density mapping within a Geographic Information System (GIS) environment. The multi-directional hillshade effectively enhances topographic discontinuities, including aligned valleys, ridge alignments, and slope breaks, enabling the extraction of structural lineaments at both regional and local scales. A total of 347 regional lineaments and 53 local lineaments were identified, indicating a well-developed structural network throughout the study area. Rose diagram analysis reveals a dominant structural orientation trending NNE–SSW to NE–SW, suggesting consistent structural control across multiple spatial scales. Lineament density mapping indicates that the highest concentration of structural features is located within the Hambalang–Tangkil sector, while local-scale analysis highlights several NE–SW-oriented structural corridors within the Sentul area. The consistency observed among DEM-derived, hillshade, lineament, density, and orientation analyses suggests that the identified lineaments represent potential structural discontinuities associated with the regional tectonic framework of the Bogor Zone. These findings demonstrate that ALOS PALSAR DEM, combined with GIS-based terrain analysis, provides an effective and cost-efficient approach for geological structure identification and can support future geological investigations, geohazard assessment, and regional land-use planning in West Java.

INTRODUCTION

Indonesia is situated within one of the most tectonically active regions in the world due to the convergence of the Indo-Australian, Eurasian, and Pacific plates. The interaction among these major tectonic plates has generated a complex geological framework characterized by active volcanism, faulting, folding, and crustal deformation that continuously shapes the Indonesian archipelago (Rosalia et al., 2021). These tectonic processes have significantly influenced the development of geological structures that control topographic evolution, drainage patterns, groundwater occurrence, and various geological hazards (Gnann et al., 2025; Rajaveni et al., 2017; Wali et al., 2024). Therefore, understanding the spatial distribution and characteristics of geological structures is fundamental for both geological investigations and sustainable land-use planning in tectonically active regions (Alanazi & Bashir, 2025; Rodríguez et al., 2021).

West Java represents one of the most structurally complex regions in Indonesia due to its location within the Sunda Arc tectonic system (Supendi et al., 2025). Long-term subduction processes along the southern margin of Java have resulted in the formation of numerous regional-scale geological structures, including faults, folds, and fracture systems that strongly influence regional geomorphology (Rosalia et al., 2021). These structural features contribute to the development of fault-controlled valleys, aligned ridges, and drainage networks that dominate the landscape of West Java. Furthermore, geological structures play an important role in controlling slope stability, groundwater circulation, and the spatial distribution of geological hazards, making their characterization essential for regional geological assessment and hazard mitigation.

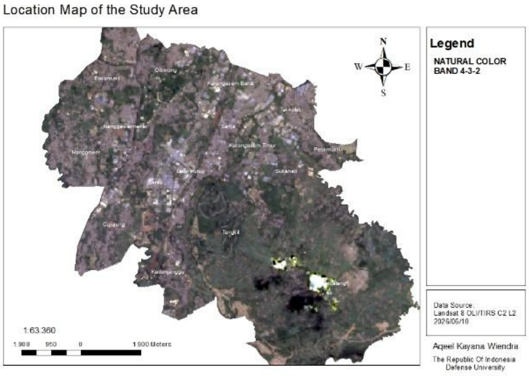
Among the various approaches available, lineament analysis has become one of the most widely used techniques for indirect structural mapping because surface lineaments commonly represent the geomorphological expression of faults, fractures, joints, and lithological boundaries (Ahmadi & Pekkan, 2021). The orientation, length, density, and spatial distribution of lineaments can provide valuable information regarding tectonic deformation patterns and structural controls within a region (Farahbakhsh et al., 2018). Consequently, lineament mapping has been widely applied in geological mapping, mineral exploration, groundwater studies, geothermal investigations, and geohazard assessments.

Digital Elevation Models (DEMs) are particularly effective for lineament extraction because geological structures frequently control topographic expressions such as linear valleys, aligned ridges, escarpments, and drainage anomalies (Fan & Ni, 2023). Terrain visualization techniques derived from DEMs, especially hillshade analysis, can significantly enhance subtle topographic discontinuities associated with geological structures. Furthermore, multi-directional hillshade visualization has been shown to improve the recognition of structural features by minimizing illumination bias and highlighting terrain features from multiple viewing directions (Abduh et al., 2021).

METHOD

Study Area

The study was conducted in the Sentul area, Bogor Regency, West Java Province, Indonesia. The study area was located between 106°50′–107°05′ E and 6°30′–6°45′ S, covering Babakan Madang, Sukamakmur, and parts of Citeureup and Jonggol. The area was selected due to its strategic position within a rapidly developing region characterized by complex geological and geomorphological conditions. In recent decades, Sentul has experienced significant urban expansion and infrastructure development, accompanied by increasing land-use intensity, which has heightened the need for comprehensive geological information to support sustainable regional planning and hazard mitigation.



Picture 1. Location Map of The Study Area

Geomorphologically, the Sentul area is dominated by hilly to mountainous terrain with elevations ranging from approximately 150 m to over 1,000 m above sea level. The landscape is characterized by steep slopes, deeply incised valleys, structurally controlled drainage networks, and volcanic landforms associated with the geological evolution of West Java. These geomorphological features reflect the combined influence of tectonic deformation, volcanic activity, and erosional processes that have shaped the region over geological time. The complex topography of the area provides favorable conditions for the identification of topographic expressions associated with geological structures, including fault-controlled valleys, aligned ridges, escarpments, and linear drainage systems.

Geologically, the study area is situated within the Bogor Zone, one of the major tectonostratigraphic zones of West Java. The Bogor Zone is characterized by folded and faulted sedimentary sequences overlain and intruded by volcanic products generated during the Neogene to Quaternary periods (Van Bemmelen, 1949). The geological framework of the region has been strongly influenced by the ongoing subduction of the Indo-Australian Plate beneath the Eurasian Plate along the Sunda Trench, resulting in intensive deformation and the development of numerous structural features such as faults, fractures, folds, and joint systems (Hall, 2012; Rosalia et al., 2021). These structures have played an important role in controlling landscape evolution, drainage patterns, groundwater occurrence, and slope stability throughout the region.

Data Acquisition

Table 1. Datasets used in this study

Data	**Source**	**Spatial Resolution**	**Format**	**Purpose**
ALOS PALSAR DEM	ASF DAAC/ JAXA	12.5 m	GeoTIFF	Topographic analysis and lineament extraction

Data	Source	Spatial Resolution	Format	Purpose
Geological Map of Bogor Sheet	Geological Agency of Indonesia	1:100,000	PDF / SHP	Geological interpretation and structural validation
Administrative Boundary Map	Geospatial Information Agency (BIG)	Variable	SHP	Study area delineation and map preparation
Regional and Local AOI Boundary	Author-generated	-	SHP	DEM clipping and spatial analysis

DEM Processing

The ALOS PALSAR DEM utilized in this study has a spatial resolution of 12.5 m, allowing detailed representation of topographic variations within the Sentul area. Prior to analysis, the DEM data were clipped according to the predefined regional and local study boundaries to reduce computational requirements and ensure consistency in subsequent analyses. The regional-scale DEM was used to investigate large-scale structural trends and tectonic controls, whereas the local-scale DEM was employed to examine detailed geomorphological expressions associated with geological structures.

Following clipping, the DEM datasets were visually inspected to ensure data quality and completeness. Elevation values were examined to identify potential anomalies, missing data, or artifacts that could affect terrain visualization and lineament interpretation. The processed DEMs were subsequently displayed using elevation-based color gradients to enhance topographic representation and facilitate the recognition of geomorphological characteristics throughout the study area.

Multi-Directional Hillshade Generation

To minimize illumination bias and improve the visibility of structural features from multiple orientations, this study employed a multidirectional hillshade approach. Four individual hillshade images were generated using illumination azimuth angles of 45°, 135°, 225°, and 315°, while maintaining a constant solar altitude angle of 45°. These azimuth directions were selected to illuminate the terrain from the northeast, southeast, southwest, and northwest directions, respectively, thereby enhancing topographic features regardless of their orientation.

The multidirectional hillshade was subsequently generated by averaging the four individual hillshade images according to the following equation:

where MDHS represents the multidirectional hillshade, while HS45, HS135, HS225, and HS315 correspond to hillshade images generated using azimuth angles of 45°, 135°, 225°, and 315°, respectively.

Multi-Directional Hillshade Generation

Multi-directional hillshade was generated from the ALOS PALSAR DEM to enhance terrain features associated with geological structures within the Sentul area. Geological structures such as faults, fractures, fold axes, and lithological boundaries commonly influence surface morphology, producing geomorphological expressions including linear valleys, aligned ridges, escarpments, and structurally controlled drainage systems. These features often represent the surface manifestation of subsurface geological discontinuities and therefore serve as important indicators for structural interpretation (Ahmadi & Pekkan, 2021).

In this study, four hillshade images were generated using illumination azimuth angles of 45°, 135°, 225°, and 315° with a constant solar altitude angle of 45°. These illumination directions were selected to enhance topographic features trending in different orientations and to reduce directional bias commonly associated with single-direction hillshade visualization.

Table 2. Parameters used for multi-directional hillshade generation

Parameter	Value
Elevation Data	ALOS PALSAR DEM
Spatial Resolution	12.5 m
Solar Altitude Angle	45°
Azimuth 1	45°
Azimuth 2	135°
Azimuth 3	225°
Azimuth 4	315°

The four hillshade layers were subsequently combined to generate a single multi-directional hillshade image according to the following equation:

where *MDHS* represents the multi-directional hillshade image, while *HS45*, *HS135*, *HS225*, and *HS315* correspond to hillshade layers generated using azimuth angles of 45°, 135°, 225°, and 315°, respectively.

The resulting multi-directional hillshade provided a comprehensive visualization of terrain morphology across both regional and local scales. At the regional scale, the hillshade image facilitated the identification of major structural trends expressed through elongated valleys, aligned ridges, and regional geomorphological discontinuities. At the local scale, the enhanced terrain representation enabled the recognition of smaller structural features, including fault-controlled valleys, fracture-related lineaments, escarpments, and drainage alignments. These geomorphological indicators were subsequently used as the primary basis for geological lineament interpretation.

Lineament Geometry Analysis

Lineament geometry analysis was conducted to quantitatively characterize the spatial properties of interpreted lineaments and to evaluate their relationship with the structural framework of the Sentul area. The geometry of geological lineaments provides important information regarding the intensity, scale, and distribution of tectonic deformation because surface lineaments commonly represent the geomorphological expression of faults, fractures, joints, and other structural discontinuities (Ahmadi & Pekkan, 2021).

Table 3. Geometric parameters used in lineament analysis

Parameter	Description	Geological Significance
Number of Lineaments	Total number of interpreted lineaments	Indicates structural complexity
Lineament Length	Length of individual lineaments	Reflects structural continuity
Total Lineament Length	Sum of all lineament lengths	Represents overall structural development
Mean Lineament Length	Average lineament length	Indicates dominant structural scale
Maximum Lineament Length	Longest lineament observed	May represent major fault zones

The longest interpreted lineament was also identified because major lineaments often correspond to significant geological structures that exert strong controls on topography, drainage development, and geomorphological evolution. Such features may represent regional fault systems or major fracture zones that have influenced landscape development within the Sentul area.

Orientation Analysis

Lineament orientation analysis was conducted to determine the dominant directional patterns of geological lineaments identified within the Sentul area. The orientation of lineaments is an important parameter in structural geology because it provides information regarding the direction of tectonic deformation, fault development, fracture propagation, and regional stress regimes that have influenced the geological evolution of a region (Ahmadi & Pekkan, 2021).

In this study, the orientation of each interpreted lineament was determined based on its azimuth direction. Azimuth values were calculated from the start and end coordinates of individual lineaments and expressed within a range of 0°–180° to avoid directional duplication. The resulting azimuth data were subsequently grouped into equal angular intervals to facilitate statistical analysis and graphical visualization.

Table 4. Azimuth classification used in lineament orientation analysis

Azimuth Range (°)	Structural Trend
0-2.5	N-S
22.5-67.5	NE-SW
67.5-112.5	E-W
112.5-157.5	NW-SE
157.5-180	N-S

Lineament Density

Lineament density analysis was performed to evaluate the spatial concentration of geological lineaments and to identify areas characterized by varying degrees of structural complexity within the Sentul region. While lineament geometry analysis provides information regarding the size and abundance of lineaments, density analysis focuses on their spatial distribution and clustering patterns. This approach is widely applied in structural geology because areas exhibiting high lineament density commonly correspond to zones of intensive deformation, faulting, fracturing, and tectonic activity (Ahmadi & Pekkan, 2021).

The density calculation was performed using the Line Density tool available in ArcMap 10.8 under the Spatial Analyst extension. The tool calculates the total length of lineaments within a predefined search radius and converts the result into a continuous raster surface representing the spatial variation of lineament concentration throughout the study area.

The lineament density value was calculated according to the following relationship:

$$LD = \frac{\sum L}{A}$$

Where:

LD : Lineament Density

$\sum L$: Total lineament length within the search area

A : Area of the search neighborhood

The resulting density raster was subsequently classified into several density categories to facilitate interpretation of structural intensity across the study area.

Table 5. Classification of lineament density

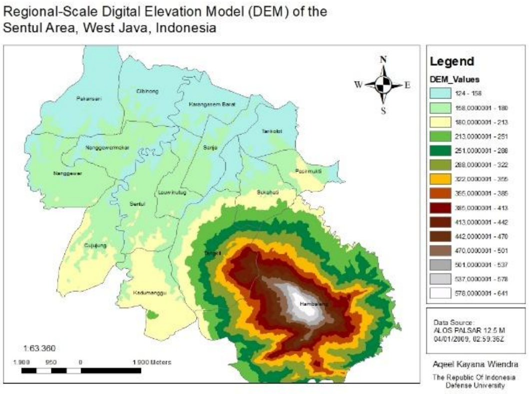
Density Class	Interpretation
Low Density	Weak structural influence
Moderate Density	Moderate structural development
High Density	Intensive structural deformation
Very High Density	Potential major fault or fracture concentration zone

In contrast, the local density map was intended to investigate the spatial distribution of smaller-scale fractures and secondary structures. Localized zones exhibiting elevated lineament density may represent areas of intense rock fracturing, fault intersections, structural reactivation, or zones where tectonic stress has been concentrated. Such areas are often associated with enhanced permeability, preferential groundwater flow paths, and increased susceptibility to geomorphological processes such as erosion and slope instability.

RESULT AND DISCUSSION

Digital Elevation Model (DEM) Characteristics

The regional-scale Digital Elevation Model (DEM) derived from ALOS PALSAR data reveals considerable topographic variation across the Sentul area, with elevation values ranging from approximately 124 m to 641 m above sea level (Figure 2). The elevation distribution exhibits a clear spatial pattern, characterized by low-relief terrain in the northern and central portions of the study area and progressively higher elevations toward the southern and southeastern sectors.

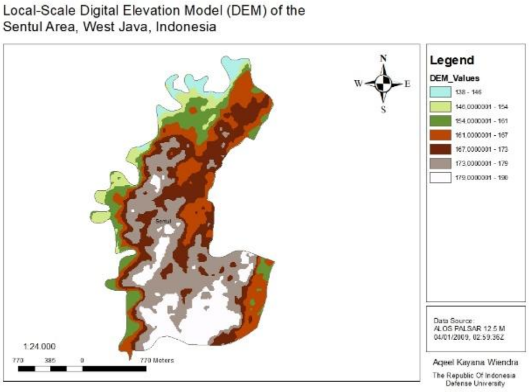


Picture 2. Regional-Scale Digital Elevation Model (DEM) of the Sentul Area, West Java, Indonesia.

The lowest elevations, generally below 158 m, are concentrated in the northern part of the study area, particularly within Pakansari, Cibinong, Karangasem Barat, and Tarikolot. These areas are characterized by relatively flat to gently undulating terrain and represent the lowest topographic domain within the study area. The dominance of low elevations suggests extensive erosional modification and relatively subdued geomorphological relief compared to the surrounding regions.

The highest elevations occur in the Tangkil and Hambalang areas, where elevation values increase significantly from approximately 250 m to more than 641 m above sea level. These areas constitute the principal topographic high of the study area and are represented by concentric elevation patterns that indicate a prominent elevated landform. The steep elevation gradients surrounding Tangkil and Hambalang suggest strong relief development and significant geomorphological differentiation from adjacent lower-elevation regions.

While the regional-scale DEM provides an overview of the broader topographic framework of the Sentul area, a more detailed understanding of local geomorphological characteristics can be obtained through local-scale DEM analysis. The local study area was selected within the Sentul region to investigate terrain variations at a finer spatial scale and to identify topographic features that may be associated with localized geological structures.



Picture 3. Local-Scale Digital Elevation Model (DEM) of the Sentul Area, West Java, Indonesia.

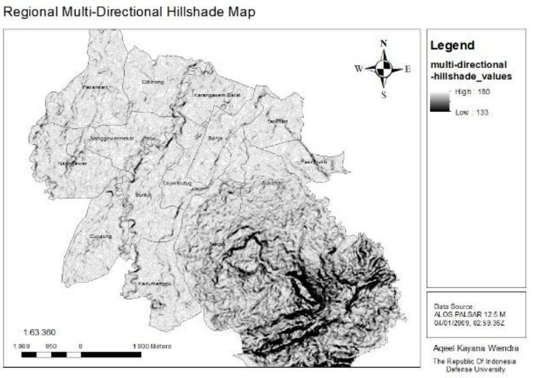
The local-scale DEM indicates that elevation values range from approximately 138 m to 190 m above sea level. Compared with the regional DEM, the local study area exhibits a narrower elevation range, reflecting a more homogeneous topographic setting. Nevertheless, significant spatial variations in elevation are still evident and provide important information regarding local geomorphological development.

The lowest elevations, ranging from approximately 138 m to 154 m, are predominantly distributed along the northern, northwestern, and western margins of the study area. These zones are characterized by relatively gentle terrain and likely represent areas subjected to prolonged erosional processes (Vijith & Dodge-Wan, 2019). The occurrence of lower elevations along the study area boundaries suggests the presence of local drainage pathways that facilitate sediment transport and landscape denudation.

The highest elevations, ranging from approximately 173 m to 190 m, are concentrated mainly within the central and southern sectors of the study area. These elevated zones form prominent topographic highs that stand out from the surrounding terrain. The concentration of higher elevations in these areas suggests localized uplift, differential erosion, or lithological resistance that has enabled the preservation of elevated landforms (Emmerton et al., 2018). In addition, the irregular distribution of these high-elevation patches indicates that local geomorphology may be influenced by structural discontinuities and fracture-controlled landscape development.

Multi-Directional Hillshade

To enhance the visualization of geomorphological features associated with geological structures, a multi-directional hillshade image was generated from the regional-scale ALOS PALSAR DEM using four illumination azimuths (45°, 135°, 225°, and 315°). The resulting image exhibits hillshade values ranging from **133 to 180**, where lower values correspond to relatively shaded terrain and higher values represent more illuminated topographic surfaces (Figure 5). The integration of multiple illumination directions effectively enhances terrain discontinuities and minimizes directional bias, allowing structural features of various orientations to be more clearly identified.



Picture 4. Regional Multi-Directional Hillshade Map of the Sentul Area, West Java, Indonesia.

The regional multi-directional hillshade reveals significant differences in terrain texture and geomorphological complexity across the study area. The northern sector, encompassing Pakansari, Cibinong, Karangasem Barat, Tarikolot, Nanggewer, Nanggewermekar, Sanja, and Pasirmukti, is characterized by relatively smooth hillshade patterns with limited shadow contrast. This observation is consistent with the regional DEM analysis, which indicates predominantly low-relief terrain within these areas. The subdued topographic texture suggests that geomorphological expressions of geological structures are less pronounced compared to the southern part of the study area.

In contrast, the southern and southeastern sectors, particularly around Tangkil and Hambalang, display markedly higher terrain roughness and stronger hillshade contrasts. Numerous elongated ridges, incised valleys, and abrupt topographic transitions are visible in these areas. The concentration of dark and bright linear features indicates significant variations in slope orientation and relief, reflecting a more complex geomorphological framework. Such characteristics commonly develop in areas affected by structural deformation, differential erosion, or lithological contrasts (Ali et al., 2024).

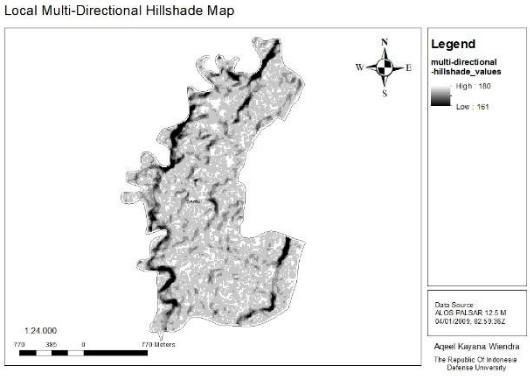
A notable observation from the hillshade image is the occurrence of several linear and sub-linear geomorphological features extending across the central and southeastern portions of the study area. These features appear as aligned valleys, ridge segments, and topographic breaks that exhibit relatively consistent orientations over considerable distances. The persistence and continuity of these features suggest potential structural controls rather than purely erosional landform development. Similar geomorphological expressions have frequently been associated with faults, fracture systems, and fold-related structures in tectonically active regions (Ahmadi & Pekkan, 2021).

Table 6. Geomorphological Characteristics Interpreted from the Regional Multi-Directional Hillshade

Area	**Hillshade Characteristic**	**Geomorphological Interpretation**	**Structural Significance**
Pakansari-Cibinong	Smooth texture, low contrast	Low-relief terrain	Limited structural expression
Karangasem Barat - Tarikolot	Weakly dissected morphology	Gentle hills and valleys	Minor structural influence
Nanggewer – Sentul - Leuwinutug	Moderate terrain roughness	Transitional geomorphological zone	Potential local structures
Sukahati - Pasirmukti	Moderate to High toughness	Dissected hills	Possible fracture-controlled morphology
Tangkil - Hambalang	Strong contrast, rugged terrain	Highly dissected elevated terrain	High structural complexity and potential fault/fracture concentration

The regional multi-directional hillshade indicates that structural influence becomes progressively stronger toward the southeastern part of the study area. The concentration of topographic discontinuities, aligned valleys, ridge alignments, and drainage anomalies within the Tangkil–Hambalang sector suggests that this region likely represents the most structurally deformed area within the regional study area. Therefore, subsequent lineament extraction is expected to yield a greater abundance and continuity of lineaments in this sector compared to the northern low-relief regions. This observation is consistent with the regional topographic framework identified from the DEM analysis and provides an important foundation for evaluating the structural architecture of the Sentul area.

To investigate geomorphological features at a finer spatial scale, a local-scale multi-directional hillshade image was generated from the ALOS PALSAR DEM using four illumination azimuths of 45°, 135°, 225°, and 315°. The resulting hillshade image exhibits values ranging from 161 to 180, representing variations in terrain illumination and shadowing that enhance the visibility of subtle topographic features (Figure 6). Compared to the regional-scale hillshade, the local-scale image provides a more detailed representation of micro-topographic variations and geomorphological discontinuities that may reflect underlying geological structures.



Picture 5. Local Multi-Directional Hillshade Map of the Sentul Area, West Java, Indonesia.

The local multi-directional hillshade reveals a complex pattern of linear and curvilinear geomorphological features distributed throughout the study area. Although the local DEM exhibits a relatively narrow elevation range (138–190 m), the hillshade image successfully enhances subtle terrain variations that are not readily recognizable from elevation data alone. This demonstrates the effectiveness of multi-directional illumination in highlighting structural and geomorphological elements within low-relief landscapes.

One of the most notable characteristics observed in the hillshade image is the presence of several elongated shadowed zones and linear topographic breaks occurring predominantly along the western, northern, northeastern, and southeastern portions of the study area. These features appear as continuous dark-toned alignments that contrast sharply with adjacent illuminated surfaces. The persistence and continuity of these features suggest that they may represent structurally controlled landforms rather than purely erosional features.

The northern sector of the study area exhibits several prominent linear escarpments and aligned slope breaks extending generally along a northeast–southwest trend. These features are characterized by strong hillshade contrast and relatively continuous geometry, indicating significant variations in local slope orientation. Such topographic expressions are commonly associated with fault-controlled scarps, fracture zones, or structurally guided erosion. Their occurrence within the northern part of the study area suggests that tectonic structures may have influenced local geomorphological development.

In the western portion of the study area, several linear valleys and elongated depressions can be identified through the alignment of shaded terrain segments. These features display relatively consistent orientations and appear to influence local drainage organization. Structurally controlled valleys are frequently formed when surface runoff preferentially exploits zones of weakness such as fractures and faults. Consequently, the observed valley alignments may indicate the presence of subsurface discontinuities that have guided erosional processes over time.

The southeastern portion of the study area displays some of the strongest hillshade contrasts observed within the local dataset. Several prominent linear features occur in this sector, characterized by abrupt transitions between illuminated and shadowed surfaces. These geomorphological expressions may indicate localized deformation zones where structural discontinuities exert significant control on terrain morphology. The concentration of such features suggests that this area may contain a higher density of fractures or fault-related structures compared to other parts of the study area.

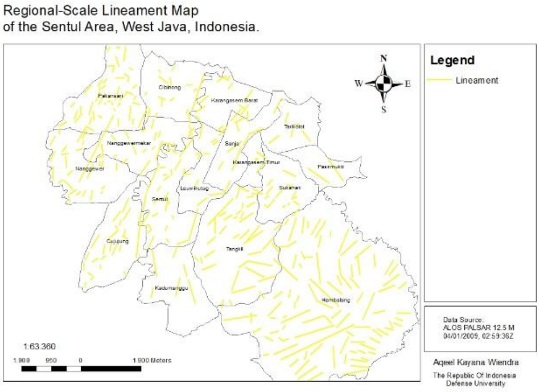
Table 7. Geomorphological Characteristics Interpreted from the Local Multi-Directional Hillshade

Geomorphological Feature	**Hillshade Expression**	**Structural Interpretation**
Linear Valleys	Continuous shadowed depressions	Potential fracture or fault zones
Topographic Breaks	Abrupt contrast between illuminated and shaded areas	Structural discontinuities
Escarpments	Sharp linear slope transitions	Fault-related landforms
Ridge Alignment	Elongated elevated terrain	Structural ridges or fold-related features
Drainage Alignments	Linear stream segments	Structurally controlled drainage

The local multi-directional hillshade analysis indicates that the study area contains numerous geomorphological features exhibiting linearity, continuity, and directional consistency. These characteristics are commonly recognized as surface expressions of geological structures in tectonically active regions. The concentration of topographic discontinuities along the northern, western, and southeastern sectors suggests that these areas may represent structurally significant zones within the Sentul region. Consequently, the local hillshade image serves as a critical intermediate product linking topographic analysis to geological lineament extraction and provides strong evidence that structural deformation has played an important role in shaping the present-day landscape of Sentul.

Regional Lineament

The regional-scale lineament map derived from the multi-directional hillshade image reveals the presence of numerous linear geomorphological features distributed throughout the Sentul area (Figure 6). These lineaments were interpreted from aligned valleys, ridge crests, topographic breaks, escarpments, and drainage alignments that potentially represent the surface manifestation of underlying geological structures. As lineaments commonly reflect zones of weakness within the Earth's crust, their distribution and orientation provide valuable information regarding the structural framework controlling the geomorphological evolution of the study area.



Picture 6. Regional-Scale Lineament Map of the Sentul Area, West Java, Indonesia.

The extracted lineaments are not uniformly distributed across the study area. Instead, their abundance and spatial density vary considerably between the northern, central, and southeastern sectors. The northern areas, including Pakansari, Cibinong, Karangasem Barat, Nanggewer, and Nanggewermekar, contain a moderate number of lineaments that are generally shorter and less clustered. These regions are characterized by relatively low-relief topography, which limits the geomorphological expression of structural discontinuities. Although structural features are still present, their manifestation is less pronounced compared to areas with higher topographic variation.

A markedly different pattern is observed in the southeastern portion of the study area, particularly within Tangkil and Hambalang. These areas exhibit the highest concentration of extracted lineaments and contain numerous long and continuous linear features. The abundance of lineaments corresponds closely with the rugged topography and strong geomorphological contrasts identified in the DEM and multi-directional hillshade analyses. The coincidence of high relief and dense lineament distribution suggests that tectonic deformation has significantly influenced the landscape evolution of these regions.

The extracted lineaments were subsequently classified according to four principal orientations, namely North–South (N–S), West–East (W–E), Northwest–Southeast (NW–SE), and Northeast–Southwest (NE–SW). The frequency of each orientation was calculated for every administrative unit within the study area to evaluate regional structural trends.

Table 8. Frequency Distribution of Regional Lineament Orientations

Area	**N-S**	**W-E**	**NW-SE**	**NE-SW**	**Total**
Pakansari	9	3	11	20	43
Cibinong	5	1	4	6	16
Karangasem Barat	1	1	2	10	14
Nanggewer	3	1	2	21	27
Nanggewermekar	4	1	4	9	18
Cijujung	5	0	4	14	23
Sentul	3	4	5	18	30
Leuwinutug	1	1	0	5	7
Sanja	0	0	1	8	9
Karangasem Timur	0	1	1	2	4
Tarikolot	2	1	1	1	5
Pasirmukti	0	0	2	0	2
Sukahati	0	0	4	9	13
Kadumanggu	1	0	3	2	6
Tangkil	3	2	8	25	38
Hambalang	17	10	27	38	92
Total	54	26	79	188	347

The orientation analysis reveals that the NE–SW direction is the dominant structural trend, accounting for 188 lineaments, or approximately 54.2% of the total extracted lineaments. This dominant trend is consistently observed throughout nearly all areas of the study region and reaches particularly high frequencies in Hambalang, Tangkil, Nanggewer, Pakansari, Sentul, and Cijujung. The widespread occurrence of NE–SW-oriented lineaments suggests the presence of a regional structural control that has influenced geomorphological development across the Sentul area.

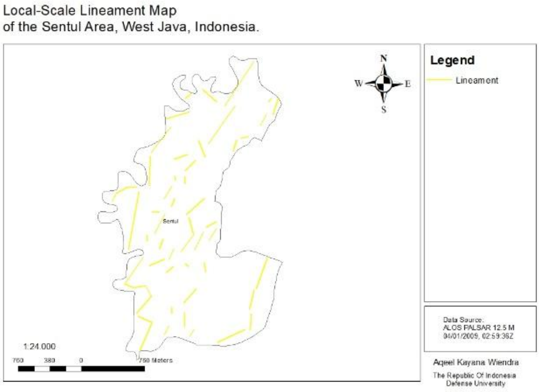
The spatial distribution of lineaments further highlights the importance of the Hambalang–Tangkil sector as the principal structural domain within the study area. Together, these two areas contain 130 lineaments, representing approximately 37.5% of all mapped lineaments. This concentration indicates a significantly higher degree of structural deformation compared to the northern and central sectors. The presence of numerous intersecting lineaments, combined with rugged topography and strong hillshade contrasts, suggests the existence of fracture corridors and fault-controlled geomorphological features that have influenced landscape development over geological timescales.

From a regional tectonic perspective, the dominance of NE–SW and NW–SE lineament orientations is consistent with the structural characteristics of the Bogor Zone, which has undergone significant deformation associated with the convergence of the Indo-Australian and Eurasian plates. The observed lineament network likely represents the geomorphological expression of fault systems, fracture zones, and fold-related structures that developed during the tectonic evolution of western Java (Hall, 2012).

Overall, the regional lineament analysis demonstrates that the Sentul area possesses a well-developed structural framework characterized by dominant NE–SW and NW–SE orientations. The highest structural complexity occurs within the Hambalang–Tangkil sector, where lineament abundance, topographic relief, and geomorphological discontinuities collectively indicate strong tectonic influence. These findings provide a robust basis for subsequent lineament density analysis, which is used to identify zones of concentrated structural deformation and evaluate their significance within the regional geological setting.

Local Lineament

The local-scale lineament extraction was conducted using the multi-directional hillshade image to identify structural features within the Sentul area (Figure 7). The resulting map shows several linear geomorphological features distributed throughout the study area, which are interpreted as surface expressions of geological structures such as faults, fractures, and structural discontinuities.



Picture 7. Local-Scale Lineament Map of the Sentul Area, West Java, Indonesia.

The extracted lineaments are primarily concentrated along the northern, western, and southeastern parts of the study area, whereas the central area exhibits relatively fewer lineaments. This distribution is consistent with the local hillshade interpretation, where several linear valleys, slope breaks, and topographic alignments were observed. The occurrence of these features suggests that structural controls have influenced the development of local geomorphology.

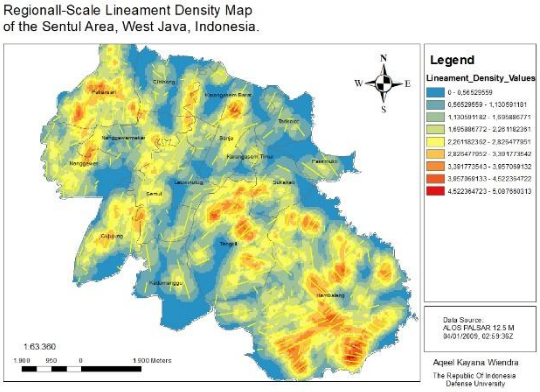
To evaluate the dominant structural trends, the extracted lineaments were classified into four principal orientations: North–South (N–S), West–East (W–E), Northwest–Southeast (NW–SE), and Northeast–Southwest (NE–SW).

Table 9. Frequency Distribution of Local Lineament Orientations

Orientation	**Number of Lineaments**
N-S	8
W-E	5
NW-SE	6
NE-SW	34

The analysis identified a total of 53 lineaments, with the NE–SW orientation being the dominant trend, accounting for 34 lineaments (64.2%). This orientation significantly exceeds the other structural directions, indicating that the local structural framework of Sentul is predominantly controlled by NE–SW-oriented discontinuities. Meanwhile, N–S, NW–SE, and W–E orientations occur in smaller proportions, representing secondary structural trends within the study area.

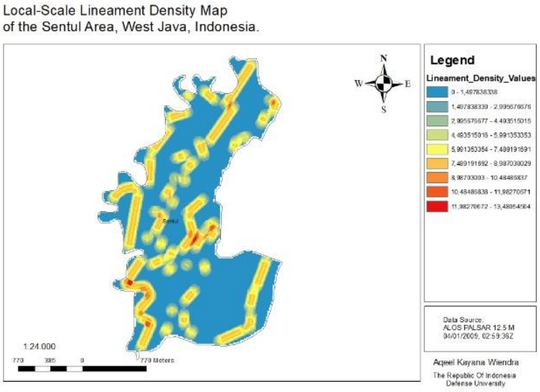
Lineament Density



Picture 8. Regional-Scale Lineament Density Map of the Sentul Area, West Java, Indonesia.

The regional-scale lineament density map (Figure 8) exhibits density values ranging from 0 to 5.09, with a clear spatial variation across the study area. The highest density values, represented by orange to red colors, are predominantly concentrated in the southeastern part of the study area, particularly within the Hambalang and Tangkil regions. Several moderate-density zones are also observed around Sukahati, Sentul, Nanggewer, and Pakansari, while low-density areas are mainly distributed in Leuwinutug, Karangasem Timur, Tarikolot, and Pasirmukti.

The concentration of high-density zones in Hambalang and Tangkil is consistent with the regional DEM, hillshade, and lineament analyses, which identified these areas as having the highest topographic relief and the greatest abundance of extracted lineaments. This relationship suggests that structural deformation is most intense within the southeastern sector of the study area. The clustering of numerous lineaments within relatively small areas indicates the presence of fracture corridors or fault-controlled zones that have strongly influenced terrain development.



Picture 9. Local-Scale Lineament Density Map of the Sentul Area, West Java, Indonesia.

The local-scale lineament density map (Figure 9) shows density values ranging from 0 to 13.48, which are significantly higher than those observed at the regional scale.

This increase is expected because the local analysis focuses on a smaller area, resulting in a higher concentration of lineaments per unit area.

The density map reveals several elongated high-density zones following the orientation of the extracted lineaments. The highest density values are represented by orange to red colors and occur mainly along the western, central, northeastern, and southeastern portions of the study area. These zones correspond directly to clusters of closely spaced lineaments identified in the local lineament map.

A notable characteristic of the local density distribution is the presence of several linear high-density corridors trending predominantly NE–SW, which corresponds to the dominant lineament orientation identified in the previous analysis. These corridors likely represent areas where multiple fractures or structural discontinuities overlap, resulting in higher structural complexity compared to surrounding areas.

The local density pattern demonstrates that structural deformation within Sentul is not evenly distributed but concentrated along several distinct lineament corridors. These corridors likely represent the most structurally significant zones within the study area and may correspond to fracture networks that control local geomorphology, drainage development, and rock weathering processes.

The dominance of high-density zones associated with NE–SW lineaments supports the interpretation that this orientation constitutes the principal structural trend controlling the geomorphological development of Sentul. Consequently, the lineament density analysis confirms that the structural architecture of the Sentul area is governed by a network of interconnected fractures and faults, with the highest degree of deformation occurring within concentrated structural corridors. These findings strengthen the interpretation that tectonic processes have played a major role in shaping the present-day landscape of the Sentul region.

CONCLUSION

This study identified the geological structural framework of the Sentul area, West Java, through the integration of ALOS PALSAR DEM, multi-directional hillshade analysis, lineament extraction, rose diagram analysis, and lineament density mapping. The DEM analysis revealed notable topographic variations, with the highest elevations concentrated in the Hambalang–Tangkil sector, while lower elevations dominated the northern and central regions. Multi-directional hillshade improved the visualization of linear geomorphological features, including aligned valleys, ridge segments, and slope discontinuities, which formed the basis for lineament extraction. A total of 347 regional lineaments and 53 local lineaments were identified, indicating a well-developed structural network across the study area. Both regional and local analyses consistently indicated a dominant structural orientation trending NNE–SSW to NE–SW, suggesting strong tectonic control on the geomorphological evolution of the Sentul area.

Lineament density and rose diagram analyses further confirmed that structural deformation was concentrated within specific zones rather than being uniformly distributed across the landscape. High-density anomalies were predominantly located in the Hambalang–Tangkil sector at the regional scale and along several structural corridors within the local Sentul area, indicating zones of enhanced fracturing and structural complexity. The consistency of the dominant NNE–SSW to NE–SW trend across all analyses suggests that the extracted lineaments represent the surface expression of regional fault and fracture systems associated with the tectonic evolution of the Bogor Zone. Therefore, the integration of remote sensing–based terrain analysis techniques proved effective for geological structure identification and demonstrated that the structural architecture of the Sentul area is primarily controlled by NNE–SSW to NE–SW-oriented tectonic structures, with the southeastern sector representing the most intensely deformed region within the study area.

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