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Morphological Characteristics of Scoria Cones on the Eastern Part of Slamet Volcano, Karangreja, Purbalingga, Indonesia

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ABSTRACT

Scoria cones are the most common volcanic landforms that are formed by Strombolian eruptions. The Scoria Cones consist of pyroclasts with bomb- and lapilli-sized. In the Karangreja, Purbalingga Regency, these cones are exposed and used for agricultural activities, which has altered their original geomorphology. Despite this extensive modification, the geomorphology of scoria cones in Karangreja, Purbalingga Regency, Central Java, remains poorly studied. This research aims to characterize their external morphology and volcanic landforms through field-based geomorphological analysis, including diameter, height, and degradation processes. This research investigates six scoria cones located in the Karangreja District and surrounding area, on the eastern flanks of Slamet Volcano. Field observations, supported by Digital Elevation Model (DEM) analysis of Shuttle Radar Topography Mission (SRTM) data, were used to characterize their morphology, preservation state, and spatial distribution, and to classify them for geomorphological maps using the van Zuidam classification. The research location is divided into nine geomorphology units: V1, V2, V3, V4, V5, V6, V7, V9, and V12. The studied cones are grouped into V2 and V3. Mt. Asuringkuk, Mt. Kondang, Mt. Lompong, Mt. Tampingan, Mt. Dipajaya, and Mt. Malang feature a variety of morphologies, from very deteriorated forms altered by erosion and agricultural activity to well-preserved, steep-sided cones with distinct craters. The preservation classification reveals a range of states: Asuringkuk and Tampingan occupy intermediate stages, while Dipajaya and Lompong show extensive degradation, while Malang and Kondang represent comparatively newer and well-preserved cones. These variances reflect changes in anthropogenic modification, erosion, and eruptive age. The findings provide information on Slamet's volcanic past and on the establishment of monogenetic volcanic fields in subduction-related environments by demonstrating that the Karangreja scoria cones retain traces of multiple eruptive episodes and subsequent landscape change.

Keywords: Central Java, Slamet Volcano, scoria cones, volcanic geomorphology, cone degradation

INTRODUCTION

Scoria cones are volcanic landforms formed by the accumulation of pyroclastic materials such as bombs, blocks, and lapilli, around a central vent [1]. Scoria cones are usually less than 300 meters tall and are known for their simple structure and short-lived eruptive activity (Figure 1). These cones are often found in volcanic fields and tend to align along faults, revealing underlying tectonic features [1]. Despite their small size, they provide valuable insights into magma development, eruption history, and regional volcanic patterns.

In Karangreja and the surrounding areas of Purbalingga Regency, Central Java, 35 scoria cones are identified and distributed in the eastern part of Mount Slamet Volcano [2]

(Figure 2). These cones, although relatively understudied, include crater morphology, vesicular basaltic lava flows, and surrounding pyroclastic deposits [3]. Field evidence shows that they formed from past monogenetic eruptions, possibly connected to the history of Slamet Volcano. Previous researchers on scoria cones in the eastern sector of Slamet Volcano have highlighted their importance in understanding magma evolution and magmatic processes, especially through detailed studies of Mt. Loyang [4], [5].

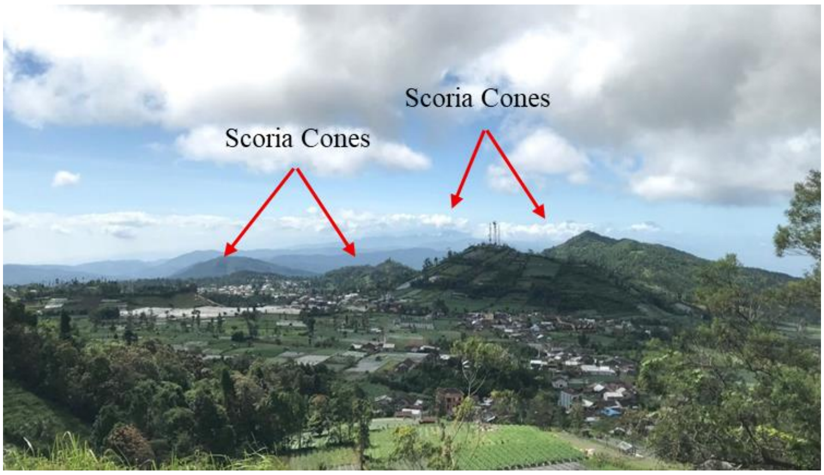

Figure 1. Scoria Cone Hill scenery in the research location

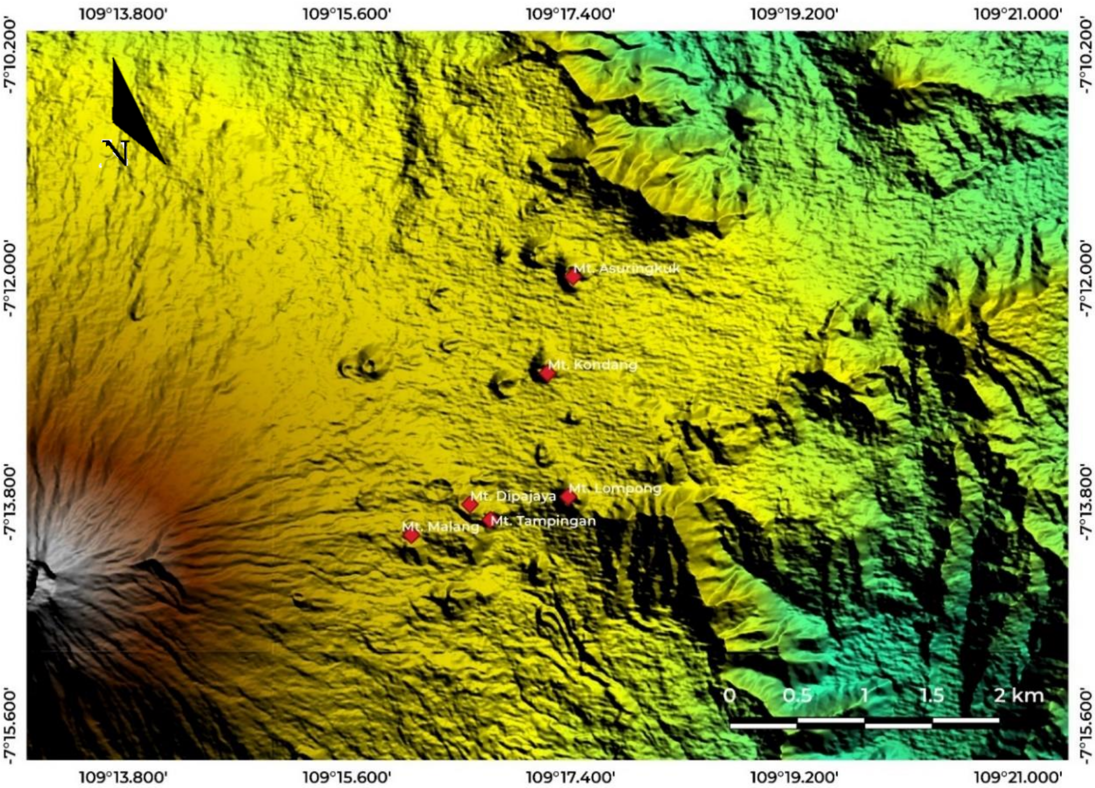

Figure 2. A high-resolution satellite image (Shuttle Radar Topography Mission) shows the study scoria location.

The study of scoria cones is important not only for understanding eruptive behavior but also for assessing volcanic hazards and interpreting the petrological features of primitive magmas [6], [7]. These cones often retain unaltered volcanic structures and pristine basaltic materials, making them valuable natural laboratories for petrological and volcanological studies. Additionally, their formation processes and spatial distribution offer important insights into subsurface magma plumbing systems and tectonic influences in volcanic regions [8].

Although several studies have examined scoria cones around the eastern part of Slamet Volcano, including Mt. Loyang, research on the scoria cones in the Karangreja area remains relatively limited. The study of exterior morphology, degradation patterns, and denudational processes has not been performed; most previous research has concentrated on eruptive behavior or petrological features. The lack of geomorphological research is significant, as agricultural activities and erosion have transformed the scoria cones in Karangreja, altering their original volcanic features. A detailed study of their morphological development and degradation stages is necessary.

The aims of the study are to provide a comprehensive understanding of the scoria cones located in the eastern part of the Slamet Volcano, Central Java. The main objectives are to characterize their external morphology and volcanic landforms, including cone diameter and height. The outcomes of this research are expected to contribute to the broader understanding of scoria cone development in subduction-related volcanic settings in Central Java and serve as a reference for future studies in volcanic geomorphology.

REGIONAL GEOLOGY

Quaternary volcanoes are distributed across Java Island, Indonesia, due to the subduction of the plate between the Eurasian and Australian Plates [9] (Figure 3A). These volcanoes are situated above sediment deposits dating from the Late Miocene to the Pliocene [10]. Java Island is part of the Sunda Arc, a volcanic arc system formed by the subduction of the Indo-Australian Plate beneath the Eurasian Plate. This distribution includes major stratovolcanoes such as Slamet, Sindoro, Sumbing, Merapi, Muria, and Semeru, each with different eruption histories and magma evolution [11].

Slamet Volcano, an active volcano located in Central Java, sits on older sedimentary rocks [12], [13] (Figure 3B). At 3432 meters, Slamet is the second-highest volcano. The volcano is divided into two parts: the Old Slamet (OS), in the western section, composed of andesitic to felsic rocks; and the Young Slamet (YS), in the eastern section, made up of basaltic rocks. The scoria cones studied here are part of YS [14]. Stratigraphic studies indicate that Slamet Volcano has undergone several growth phases, involving both effusive and explosive eruptions from the Late Pleistocene to the Holocene [15], [16]. Its most recent eruption occurred in 2014 and was characterized by ash emissions and phreatomagmatic activity. Recent hazard assessments have expanded the exclusion zone from 2 km to 3 km around the summit due to renewed seismic activity and gas emissions [17].

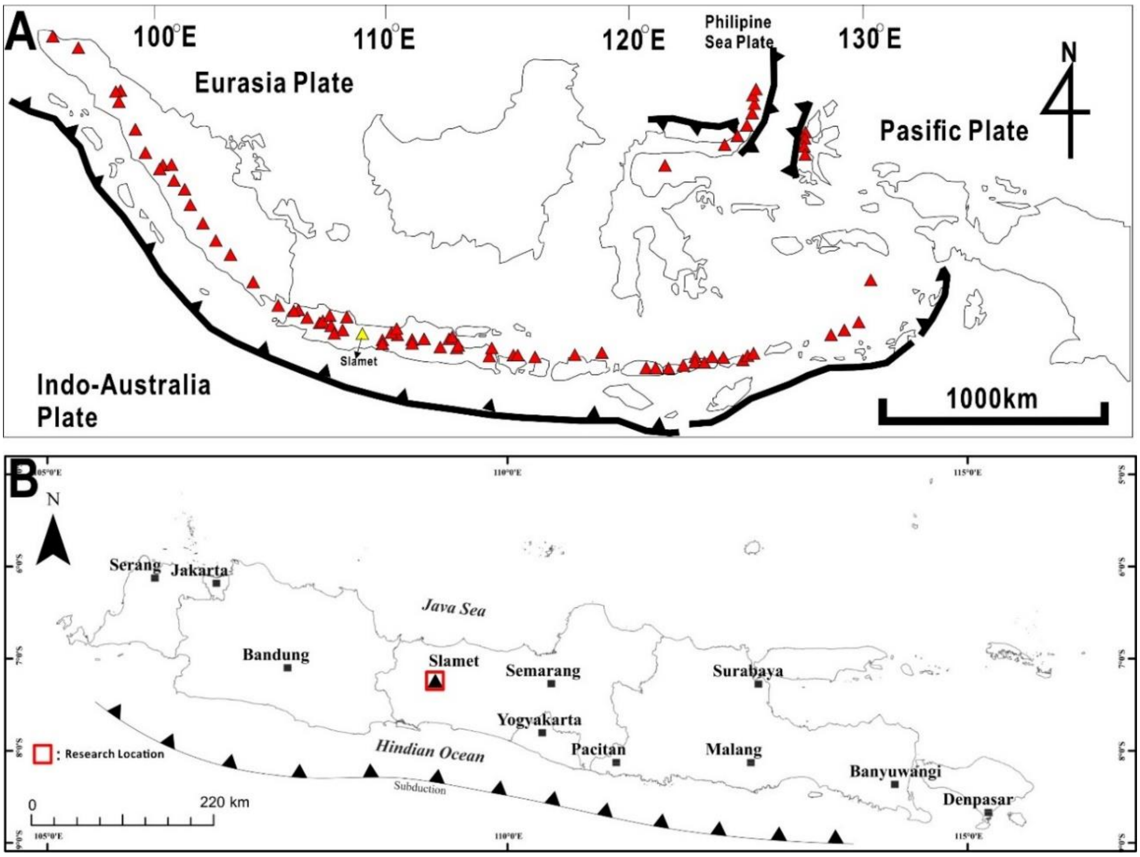

Figure 3. (A) Distribution of volcanoes in Indonesia; (B) The study area (Slamet Volcano) is located in Central Java, Java Island

Scoria cones are located on the eastern and northeastern flanks of Mount Slamet, forming a monogenetic volcanic field. These cones range from 130 to 750 meters in basal diameter and reach up to 250 meters in height. Geomorphological mapping and K–Ar dating have confirmed that many of these cones date to the Late Pleistocene, with eruptive centers aligned along radial and NW–SE trending faults [2]. According to geological maps of Slamet Volcano, the volcanic deposits are divided into 22 units, including 4 lava flows from central eruptions, 1 pyroclastic deposit, and 1 lahar deposit from Old Slamet [18]. The Young Slamet contains 4 lava flows from central eruptions, 2 from flank eruptions, 5 pyroclastic deposits from central eruptions, 2 from flank eruptions, and 3 lahar deposits. The research site is part of KSL, Kerucut Skoria Lompong (Figure 4). Petrological studies show that these cones consist of vesicular basaltic scoria, lava bombs, and minor lava flows, indicating a strombolian-to-Hawaiian eruptive style [19]. One notable example is Mount Loyang, a well-preserved scoria cone whose internal stratigraphy has been studied in detail to understand its eruptive history and magma evolution [5].

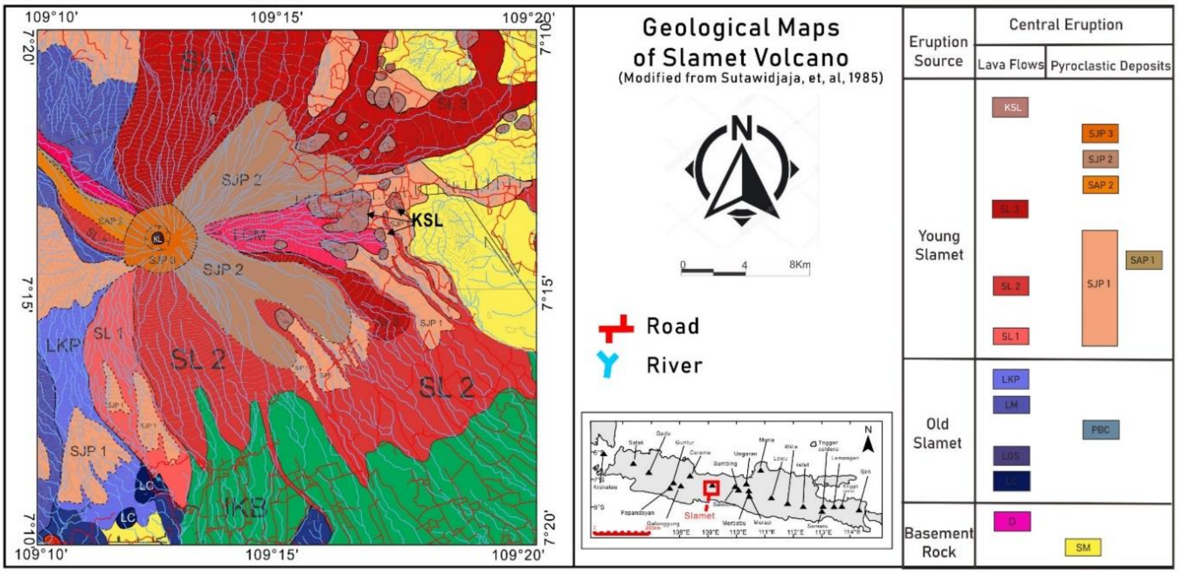

Figure 4. The geological map of Slamet Volcano (modified from [9]) shows the distribution of the Kerucut Skoria Lompong (KSL) in the eastern part

METHODOLOGY

Fieldwork was conducted to observe the morphology in Karangreja District, Purbalingga, Central Java. Six scoria cones were surveyed: Mt. Asuringkuk, Mt. Kondang, Mt. Lompong, Mt. Tampingan, Mt. Dipajaya, and Mt. Malang. These names follow the nomenclature used in the previous publication by Sutawidjaja and Sukhyar (2009) [2]. The six selected scoria cones represent the most complete range of morphological variations in the Karangreja volcanic field, from well-preserved to heavily degraded forms. Their clear topographic expression and accessibility enable reliable field- and DEM-based analyses. Observations focused on the structural characteristics and relationship of each cone to the surrounding landscape. The diameters and heights of Scoria Cones were measured using Google Earth and SRTM data.

Scoria cone diameter was calculated following the approach of Bailey et. al. (2025) [20], in which cone width (Wco) is defined as the arithmetic mean of the maximum (Wmax) and minimum (Wmin) basal diameters. This method provides a more representative estimate of cone size, particularly for cones with irregular or elliptical basal shapes resulting from erosion or post-eruptive modification.

Basal cone boundaries were delineated from Digital Elevation Model (DEM) data, and Wmax and Wmin were measured as perpendicular diameters, commonly approximated using a best-fit ellipse. Cone width was calculated using equation (1):

$$Wco = \frac{Wmax+Wmin}{2} \quad (1)$$

A similar approach was applied to crater height measurements. Cone height (Hco) was calculated following the classical approach of Bailey et. al. (2025) [20], which defines cone height as the vertical elevation difference between the cone summit and its basal surface. The basal elevation was estimated as the mean of the maximum and minimum basal elevations to account for basal topographic irregularities. The cone height was calculated using equation (2):

$$Hco = \frac{1}{2}((Aco - ABM) + (Aco - ABm)) \quad (2)$$

The geomorphological map of the study area is represented at a semi-detailed scale (1:25,000–1:250,000), where general field observations, extrapolation, and generalization are permitted [21]. Geomorphological analysis was conducted through detailed field investigations and supplemented by digital elevation data derived from the Shuttle Radar Topography Mission (SRTM), provided by Badan Informasi Spasial [22]. The data was processed using Global Mapper software to generate a Digital Elevation Model (DEM.

The morphological characteristics of scoria cones are subject to erosion, which can alter their dimensions and overall appearance. Older cones typically exhibit more advanced degradation than younger ones. Qualitative morphological assessment followed the classification by [23], which identifies cone degradation based on:

1. Reduction in cone relief – highly eroded cones exhibit rough relief, rills, and significant slope buckling, whereas well-preserved cones show smoother relief or narrow, deeply incised gullies.
2. Decrease in cone slope – erosion reduces the steepness of cone flanks.
3. Loss of crater definition – well-preserved cones retain a distinct, deep crater, while degraded cones exhibit a poorly defined or absent crater.

Based on these criteria, a qualitative cone morphology rating was proposed [23]:

- Rating 1: Excellent – clearly defined cone and vent morphology.
- Rating 2: Good – distinct cone shape with moderately defined vent morphology.
- Rating 3: Moderate to Good – visible cone but poorly defined vent.
- Rating 4: Moderate – visible cone shape, no vent definition.
- Rating 5: Moderate to Poor – poorly defined cone shape.
- Rating 6: Poor – cone shape indistinct.
- Rating 7: Very Poor – cone morphology absent or extremely poorly defined.

RESULTS

Geomorphology Classification

The geomorphological analysis indicates that the observed volcanic area exhibits a relatively complex array of volcanic landforms [21]. These landforms were formed by both primary volcanic processes and parasitic activities and are further influenced by exogenous processes such as erosion and sedimentation. The main landform developed is a stratovolcano in the western part of the area, which is classified as volcanic craters (V1) and volcanic cone slopes (V4–V5). Volcanic craters are characterized by steep slopes and by their active status. The upper slopes (V4) display a low to moderate degree of dissection, whereas the middle to lower slopes (V5) show strong dissection (Figure 5). This indicates that the stratovolcano body has undergone extensive erosion and is relatively older than the surrounding volcanic landforms [24]. Several small scoria cones were identified in the eastern–southeastern part of the main stratovolcano, classified as V2–V3. Cones that remain intact with a low degree of dissection fall into the V2 category [25] while cones showing stronger erosion are categorized as V3 (Figure 5). The presence of these landforms indicates that younger parasitic eruptions developed on the flanks of the stratovolcano.

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Other landforms include volcanic footslopes (V6–V7) located in the eastern and northern sectors (Figure 5). This unit exhibits gentle to moderate morphology with a low to moderate degree of dissection. Morphologically, it functions as a transitional zone between the stratovolcano body and the surrounding plains and serves as an area of accumulation for eruptive materials.

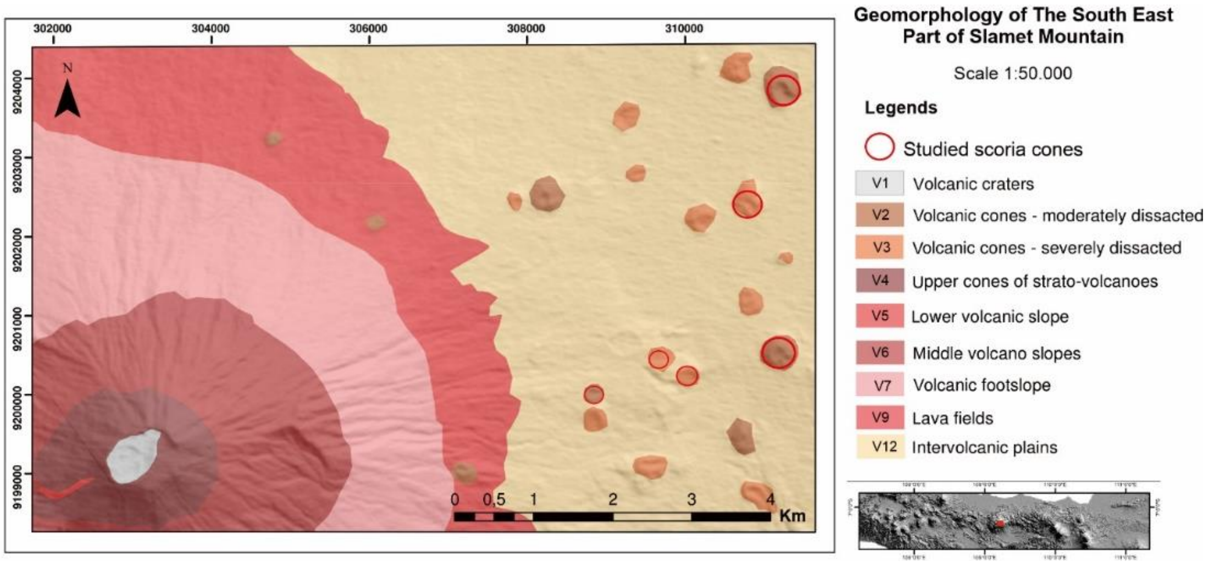

Figure 5. Geomorphological units in the northeastern part of Mount Slamet based on Van Zuidam's (1983) classification

The lava field (V9) was identified in the southern–southwestern part, characterized by relatively flat to gently inclined morphology. The surface of this lava field displays a distinctive undulating topography formed by the solidification of lava formation. The existence of this landform indicates an effusive eruptive phase that produced lava flows around the volcanic area.

An intervolcanic plain (V12) was identified in the northeastern part of the study area, characterized by relatively flat to gently sloping topography. This unit was formed from a mixture of volcanic and fluvial deposits, reflecting interactions between volcanic activity and the fluvial system that developed in the region.

Overall, the classification results indicate that the morphology of the study area comprises stratovolcano bodies, parasitic cones, volcanic footslopes, lava fields, and intervolcanic plains. The variation of these landforms illustrates the geomorphological evolution of the volcanic system, ranging from explosive and effusive eruptions, the development of parasitic cones, to erosion and sedimentation processes that shape the present-day landscape.

Scoria Cones Geomorphology

Scoria cone geomorphological characterization provides important information about the eruptive dynamics and structural development of these structures. Six scoria cones were found in the research region; they were all somewhat small but varied in height and basal diameter. Multiple craters are present across several cones, which may indicate changes in vent position and contribute to the morphological diversity observed throughout the area. (Figure 6 and Table 1).

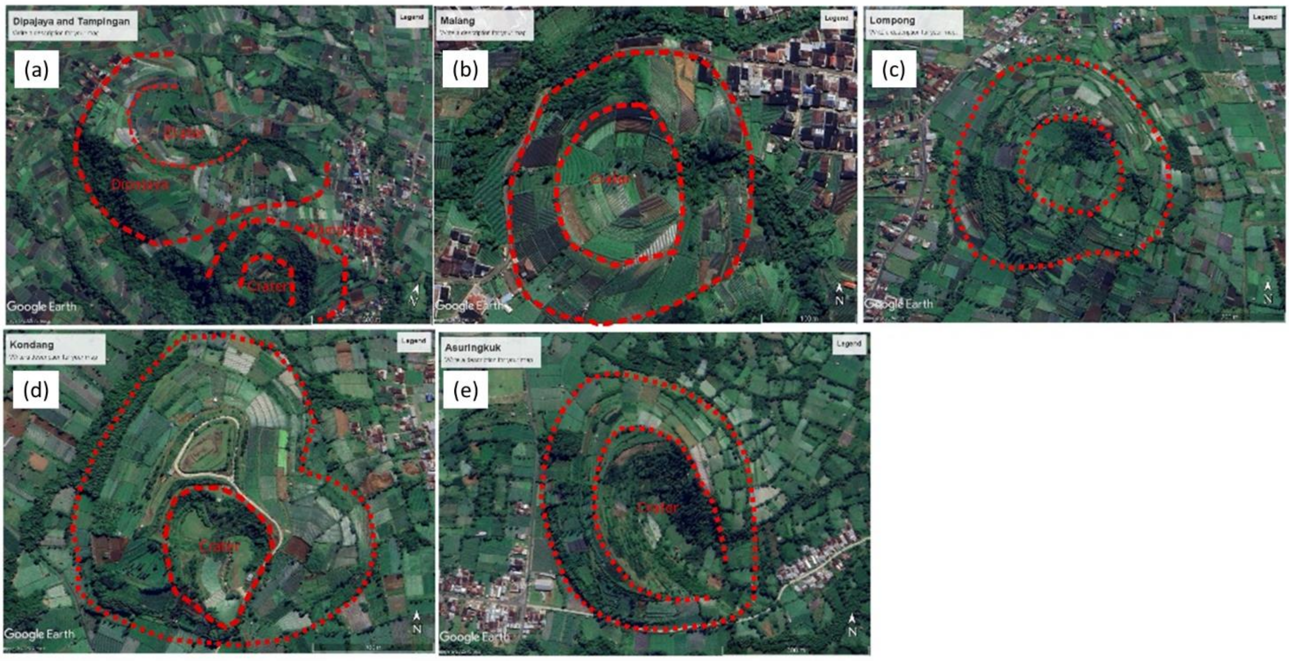

Figure 6. Satellite imagery (Google Earth) showing the six identified scoria cones in the Karangreja volcanic field: (a) Mt. Dipajaya and Mt. Tampingan; (b) Mt. Malang; (c) Mt. Lompong; (d) Mt. Kondang; and (e) Mt. Asuringkuk; the red dashed lines indicate cone boundaries and crater outlines used for morphological interpretation

Table 1. Morphometric characteristics and preservation ratings of scoria cones in the Karangreja volcanic field, Central Java, based on DEM interpretation and classification criteria [23]

No.	Scoria Cone	Diameter (m)	Height (m)	Preservation Rating [23]
1	Mt. Asuringkuk	571.54	156	4–5 (Moderate to Poor)
2	Mt. Kondang	508.3	136	3–4 (Moderate to Good)
3	Mt. Lompong	586.92	142	2–3 (Good to Very Good)
4	Mt. Malang	285.04	135	4–5 (Moderate to Poor)
5	Mt. Dipajaya	515.02	125	2–3 (Good)
6	Mt. Tampingan	443.40	159	3–4 (Moderate)

Mt. Dipajaya

Mt. Dipajaya scoria cone has a broad, uneven shape with a basal diameter of 512.02 meters and a height of 125 meters. Although the crater is visible, erosional processes have greatly altered it, leaving only a limited rim definition. An advanced stage of degradation is indicated by uneven slopes, rill erosion, and slope buckling on the sides of Dipajaya. Dipajaya is classified as moderate to poor preservation (rating 4–5) (Figure 7a) [23]. The cone's significant agricultural modification of its slopes and crater floor suggests that it is relatively old and has undergone prolonged erosion and human land use.

Mt. Tampingan

Mt. Tampingan cone is smaller than Mt. Dipajaya, with a basal diameter of 443.40 m and a height of 159 m. The cone's original steep slopes have been eroded, but it still features a distinct crater and a visible circular shape. Tampingan is classified as having moderate to good preservation (rating 3–4) based on overall morphology, indicating better preservation than Dipajaya (Figure 7a) [23]. This suggests that Tampingan has either experienced less severe erosion or is relatively younger. The spatial connection between the two cones indicates they were most likely formed during separate Strombolian eruptive

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events, with the younger Tampingan following an older phase represented by Dipajaya.

Mt. Lompong

Mt. Lompong scoria cone has a basal diameter of 586.92 meters and stands 142 meters tall. Although the crater has been significantly enlarged and partially filled, it remains recognizable, likely due to long-term erosion and agricultural modifications. The cone's slopes show clear signs of deterioration, including rill erosion, slope irregularities, and gentle, uneven slopes. The cone's original features are further obscured by agricultural terracing. Lompong is classified as having moderate to poor preservation (rating 4–5) (Figure 7b) [23]. This suggests that Lompong is an older scoria cone in the volcanic area that has undergone extensive human land use and prolonged erosion, both of which have greatly changed its original geomorphic features.

Mt. Kondang

The Kondang scoria cone maintains a well-preserved, nearly circular shape, with a basal diameter of 508.3 meters and a height of 236 meters, according to DEM analysis. There are a few signs of erosion, such as shallow rill formations, and the cone's slopes are moderately steep, retaining their original shape. Its volcanic landforms remain visible because they are not heavily covered by agricultural terracing. Kondang is classified as well-preserved (rating 2–3) (Figure 7c) [23]. Unlike older, more eroded cones such as Lompong, Kondang appears to be a relatively young scoria cone, exhibiting minimal erosion and clear geomorphic features.

Mt. Malang

According to DEM interpretation, Mt. Malang scoria cone is circular and symmetrical, measuring 135 meters in height and 285.04 meters in basal diameter. The crater has a distinct circular rim and shows little sign of collapse. It is well-preserved. The steepness and uniformity of the flank slopes indicate minimal erosional change. The early stages of surface deterioration are indicated by slight rill erosion and terracing resulting from agricultural activities. Malang falls into the good to very good preservation category (rating 2–3) based on the preservation index (Figure 7d) [23]. Malang seems to be one of the newer scoria cones in the Karangreja volcanic area, with most of its original constructional form still intact.

Mt. Asuringkuk

The Asuringkuk scoria cone is large and elliptical, standing 156 meters tall and with a basal diameter of 571.54 meters. Although the crater's broad, uneven outline remains recognizable, erosion and human activity, especially the growth of agriculture and settlements along its edges, have significantly altered it. Showing clear signs of degradation, such as rill erosion, uneven slopes, and partial infilling of the crater floor, the cone's flanks are relatively gentle. Some of the original construction features are hidden by vegetation and agricultural terracing, but the overall cone shape remains identifiable. Asuringkuk is classified as moderately preserved (grade 3–4) (Figure 7e) [23]. This suggests that Asuringkuk is an intermediate-aged scoria cone within the volcanic field, reflecting significant erosional processes and land-use modification, yet still maintaining a recognizable volcanic feature morphology.

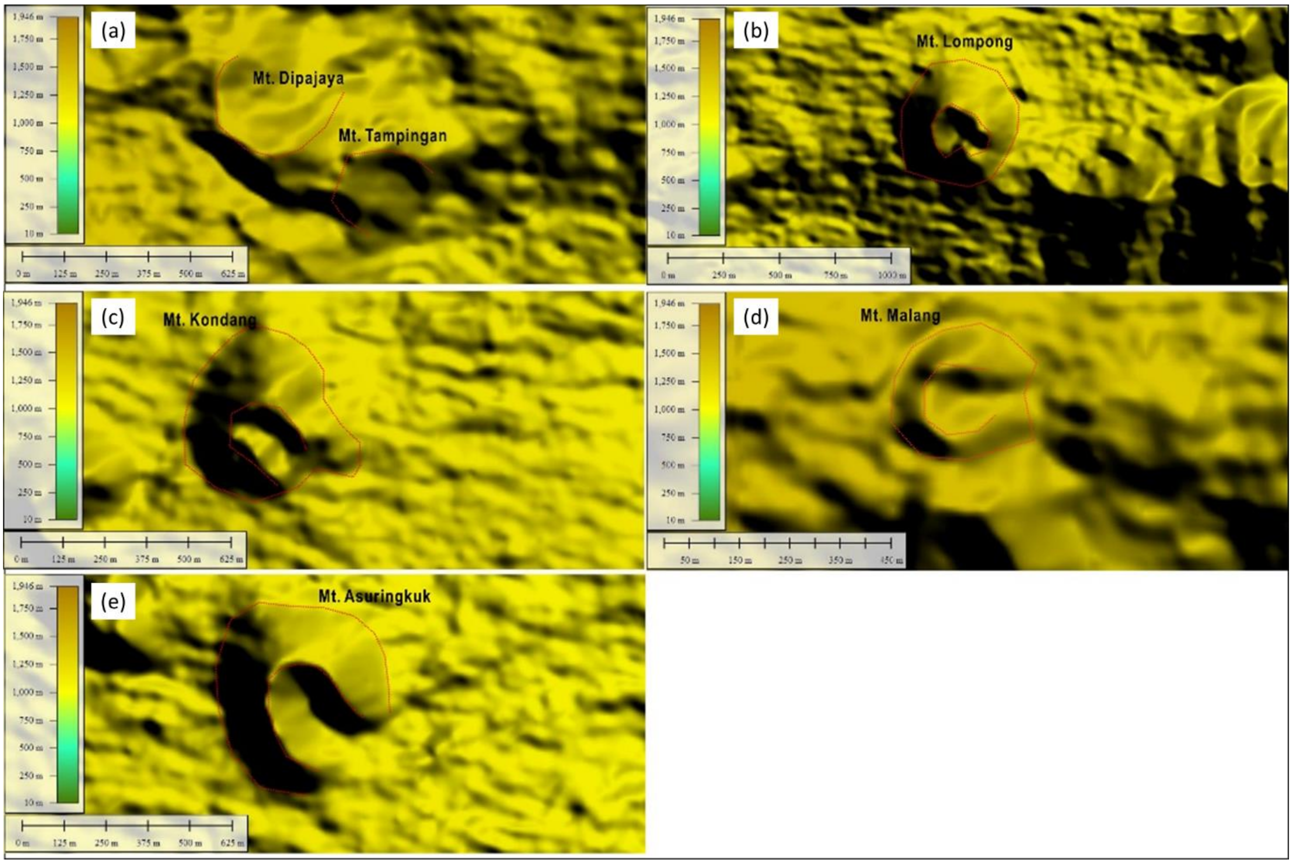

Figure 7. Digital Elevation Model (DEM) visualization of six scoria cones in the Karangreja volcanic field: (a) Mt. Dipajaya and Mt. Tampingan; (b) Mt. Lompong; (c) Mt. Kondang; (d) Mt. Malang; and (e) Mt. Asuringkuk; the red outlines mark the cone boundaries and crater rims

DISCUSSION

Due to differences in eruption age, erosional change, and human land use, the six scoria cones in the Karangreja volcanic area exhibit a wide range of shapes and degrees of preservation. Older cones, such as Dipajaya and Lompong, are classified as moderate to poorly preserved (rating 4–5) due to their broad, irregular shapes, poorly maintained craters, and severe slope erosion. Conversely, younger cones such as Malang and Kondang feature steep sides, circular outlines, and well-defined craters, indicating limited erosion and good preservation (rating 2–3). Tampingan and Asuringkuk fall in between, with partially intact craters and moderate slope changes, suggesting they are in transitional stages of cone deterioration.

These differences reveal how the volcanic field has evolved over time. Smaller, well-preserved cones are associated with more recent eruptions, whereas larger, more worn cones likely represent older eruptive phases. The variety of landforms supports a history of multiple Strombolian eruptions in the area, consistent with processes seen in other monogenetic volcanic regions. Human activities such as farming and settlement have further affected cone preservation, accelerating surface changes without completely erasing their volcanic features.

Morphological analysis based on DEM interpretation indicates that cones such as Malang and Kondang retain steep flanks and clearly defined craters, placing them in the good to very good preservation category [23]. Their relatively pristine morphologies suggest they are younger volcanic features with limited surface alteration. Dipajaya and Lompong, on the other hand, seem to be older volcanic formations that have undergone significant modification, as indicated by their heavily damaged features, including partially infilled craters, uneven slopes, and extensive erosion worsened by agricultural terracing. The intermediate states of Asuringkuk and Tampingan show transitional stages of deterioration, in which original volcanic features are obscured but not entirely erased by human land use and slow erosional reshaping. These differences highlight how scoria cone landscapes are shaped by a combination of initial volcanic construction, geomorphic evolution, and human activity.

These interpretations are supported by comparisons with other volcanic fields, which show that systematic declines in slope angles and crater sharpness correlate with increasing cone age across monogenetic volcanic fields worldwide, reflecting the morphological differences seen in Karangreja [26], [27]. At Mount Pengki, West Java, cone deterioration is linked to the interaction of stratigraphic structure and geomorphic processes, while subsurface stratigraphy in older cones records long-term erosion histories [28]. Regionally, cones around Slamet and Loyang confirm that morphometric parameters are reliable tools for estimating relative cone ages and degradation paths, while also emphasizing the growing impact of human activity in shaping volcanic landforms in Central Java [5].

CONCLUSION

The Scoria Cones in the research area exhibit significant morphological variation, reflecting both the original volcanic processes and subsequent post-eruption modifications. Differences in vent activity, eruptive style, and depositional methods are indicated by variations in basal diameter, relative height, and crater condition. From well-preserved cones with clear craters to heavily eroded forms where erosion and human activity have hidden the original volcanic features, the degradation study demonstrates a spectrum of preservation states.

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