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Unmanned Aerial Vehicle Technology for Quantitative Morphometry and Geomorphic Processes – Study Case in Rotational Landslide Deposited Areas

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ABSTRACT

The increasing use of drone technology to produce high-resolution digital imagery and elevation models has been associated with a growing interest in developing quantitative morphometric analysis (QMA). QMA analysis is an invaluable part of creating detailed topographic models in landslide scars that are still highly unstable and prone to erosion. This paper presents the results of a research that aims to create a topographic model in a landslide scarred area where the slope configuration is still varied. The study area was located in the landscape of the Cretaceous-Tertiary volcanic transition where many landslides have occurred. Three landslides were selected on the basis of different soil material characteristics that affect the topographic condition of the landslide scar. Aerial photography was recorded using a UAV with a flying height of 80 m, with an orthomosaic resolution of 1 cm. In detail, three morphometric variables (slope, plan curvature, topographic position index) were selected and calculated with the output evaluated based on visual-spatial interpretation. The results showed that morphometric variables performed well in modeling land surface topography. Steep slopes and surfaces with convex curvature are abundant at the ledges and landslide heads that allow water runoff to disperse as the initiation of gully erosion. The multidimensional gully erosion network is concentrated at relatively low elevations and surfaces with concave curvature. The undulating micro-relief of the land surface as a result of the process of material disposition builds up on each other to a gentle slope. Finally, the topographic model of the landslide surface can be used as a base material in implementation of both physical and vegetative land conservation strategies.

Keywords: morphometric, quantitative, landslide, UAV, modeling.

INTRODUCTION

Landslides are the most frequent geohazard in Indonesia. Landslides are concentrated on relatively steep and rugged hilly topography with different geological characteristics. Topographic conditions were clearly illustrated by using digital elevation model (DEM) data that is available in open source. DEM data can be extracted into quantitative analysis to improve qualitative and quantitative interpretation of earth surface and landscape processes (Sofia, 2020). One of the quantitative analyses of land configuration with morphometry is valuable for describing land surface topography and predicting signs of erosion events (Amatulli et al., 2020). Recently, advances in UAV technology have accelerated, allowing them to be used as large-scale and detailed mapping tools. UAVs are able to produce high-resolution mosaic DEM data and enable the identification of past and future geomorphic events on the land surface. The configuration of the landslide scar area will look different depending on the type of landslide, where rotational landslides are more high risk and characterized by wide, extensive landslide scar areas and abundant soil material (Noviyanto et al., 2020). The former rotational landslide area becomes a critical area that may still result in subsequent landslides and intense erosion (Samodra et al., 2020; Sestras et al., 2021). Monitoring of landslide scars is still relatively rare with UAVs, because it is considered to have no significant land value and impact.

There is increasing interest in the use of UAVs for landslide studies (Giordan et al., 2018), as UAVs offer several advantages over traditional monitoring methods, including the ability to collect high-resolution imagery, to access hard-to-reach areas, and to collect data frequently and at lower cost (Kotsi et al., 2023). UAVs are easily used to monitor landslides the location and position of which are relatively difficult to reach, such as in hilly and mountainous areas. Previous studies have used UAVs to measure the dynamics of soil material movement in landslide scars. Thus, the utilization of UAV is relatively proven to photograph landslide scars. Efforts to use UAVs to model and analyze land morphometry still need to be developed further. With more accurate and precise modeling from UAVs, it will be the basis for reducing the risk of erosion and landslide reactivation.

In this work, a research approach based on QMA was presented and aimed to investigate the spatial distribution of erosion events in landslide scar areas. The methodological approach was complemented by field surveys and qualitative visual interpretation of DEM-UAV-derived hillshade. The implication of this study may contribute ideas on the use of DEM-UAV for quantitative analysis of land surface topography as one of the geomorphological applications that can help the identification of erosion occurring in landslide scar areas.

MATERIAL AND METHOD

The research area was located on the south side of the Sumbing Volcano, Central Java Province, Indonesia (Fig. 1). The three selected locations were Tegalsari Village, Bruno District, Purworejo Regency (L1), Wonogiri Village, Kajoran District, Magelang Regency (L2), and Manglong Village Salaman District, Magelang Regency (L3). The specific cause of landslides that happen in the study area is also due to the controlling factor, namely geological factors. The lithology distribution in the study area is in two different rock formations, namely the Halang Formation (Tmph) and the Kebobutak Formation (Tomk). Rock formations can be very complex as a cause of landslides. Even so, the reasons can vary due to the very location-specific nature of landslides. Several observed landslide events may have occurred due to the nature of soil material from the weathered source rock below. Landslides in the Halang Formation are above the weathered sandy tuff rock and form a layer of clay-rich soil material. Landslides in the Kebobutak formation (Wonogiri and Manglong landslides) are above the altered andesite breccia. The appearance of altered andesite rocks in the Wonogiri landslide is in the scraps section, while in the Manglong landslide, it is seen at the toe of the landslide. Layers of volcanic ash deposits have occupied geological formations with different thickness variations, some of which have undergone further weathering to contain more clay than others. Figure 1 present the research area.

Unmanned aerial vehicles (UAVs) were used to obtain multiple aerial photographs of the landslide area. The results of several recorded aerial photographs were then processed using Agisoft 1.1 to obtain geo-corrected orthophoto and DEM. The resulting orthophoto was used to determine the appearance of the landslide area. The resulting DEM with an accuracy of <3 m was used to analyze several indicators of morphometric characteristics in the landslide area, such as the degree of slope, plan curvature, and topographic position index (TPI). The three morphometric indicators are related to determining the distribution pattern of surface water runoff and the characteristics of soil materials that affect landslides. Morphometric analysis was performed using ArcGIS 10.5 and Systems for Automated Geoscientific Analysis (SAGA) GIS 2.3.1.

RESULTS AND DISCUSSION

Morphometric characteristics in the former sliding area can affect variations in material movement events, such as erosion, creeping, and re-sliding. The three processes are controlled by topography and surface water runoff. Variations in the soil material characteristics before and after sliding also control the ease of movement of the soil material (Van Eynde et al., 2017). Morphometric factors that can describe surface water runoff movement include the degree of slope, plan curvature, and topographic position index (Kavzoglu et al., 2015). The degree of slope >45° in the Tegalsari and Manglong landslides only found in the scraps part, while in the Wonogiri landslide, it is found in the transitional part between the body and the toe of the landslide (Figures 2b, 2f, and 2j). The histogram of the Wonogiri landslide

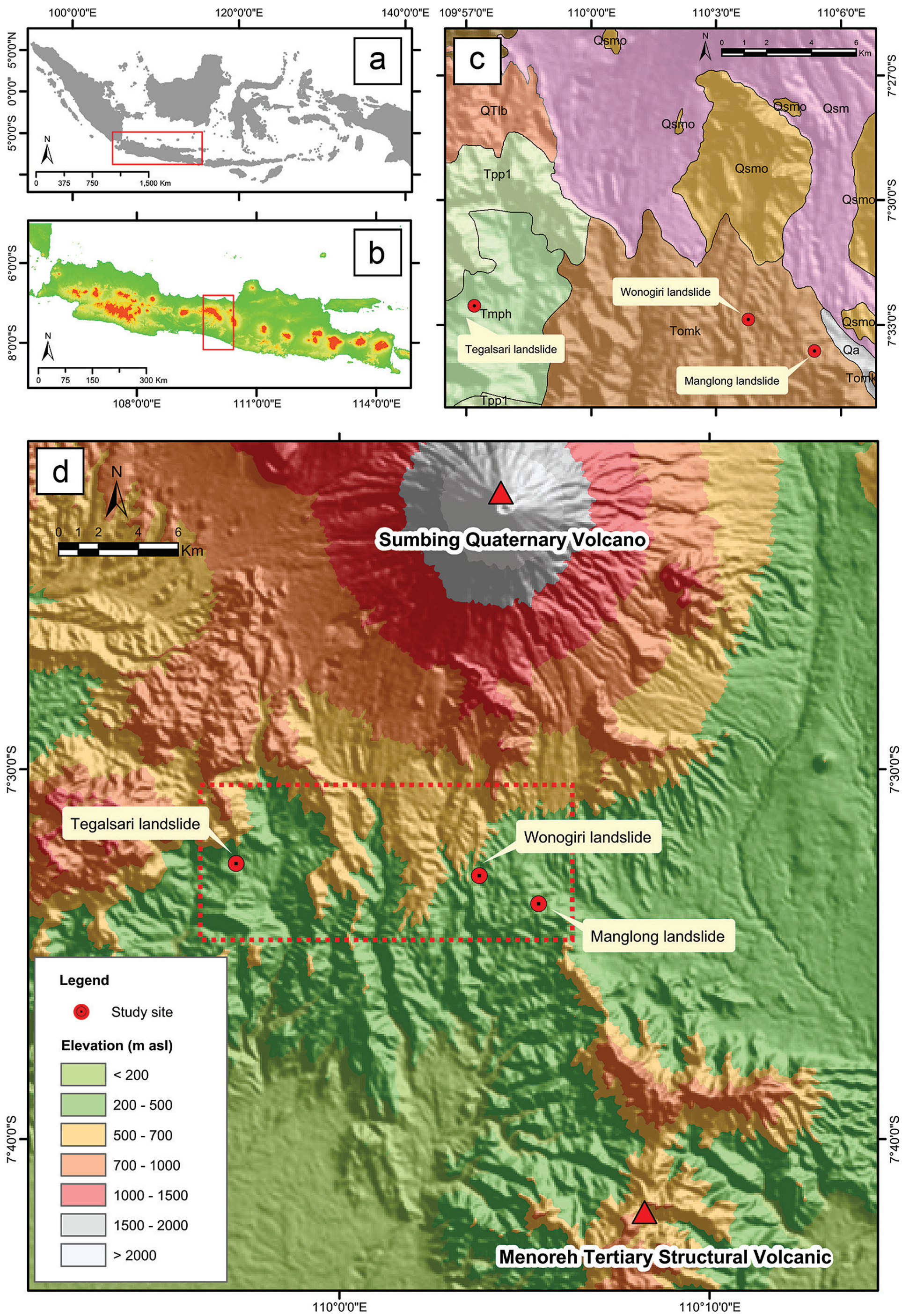

Figure 1. The research area: (a) Indonesia (b) Java Island (c) the geological condition; and (d) the elevation condition of the research area

slope angle value shows an increase in the pixel value with a slope angle of >45°, in contrast to the Tegalsari and Manglong landslide histograms where the number of pixels with a low slope angle was >45° (Figures 3a, 3d, and 3g). Figure 2 presents an orthophoto of landslides and some topographic indicator analyses. Figure 3 presents a histogram of the topographic indicator analysis. The erosion appearance in the underside of the Tegalsari and Manglong landslides is dominated by splash erosion, while in the transitional sections of the body and toe in all landslide locations, erosion of grooves and ditches. The characteristics of the soil in the area of landslides indicate the exposure of layers of soil material (Noviyanto et al., 2020), making it possible for re-sliding if the fluctuation of water content increases in the sensitive clay layer due to high rainfall intensity

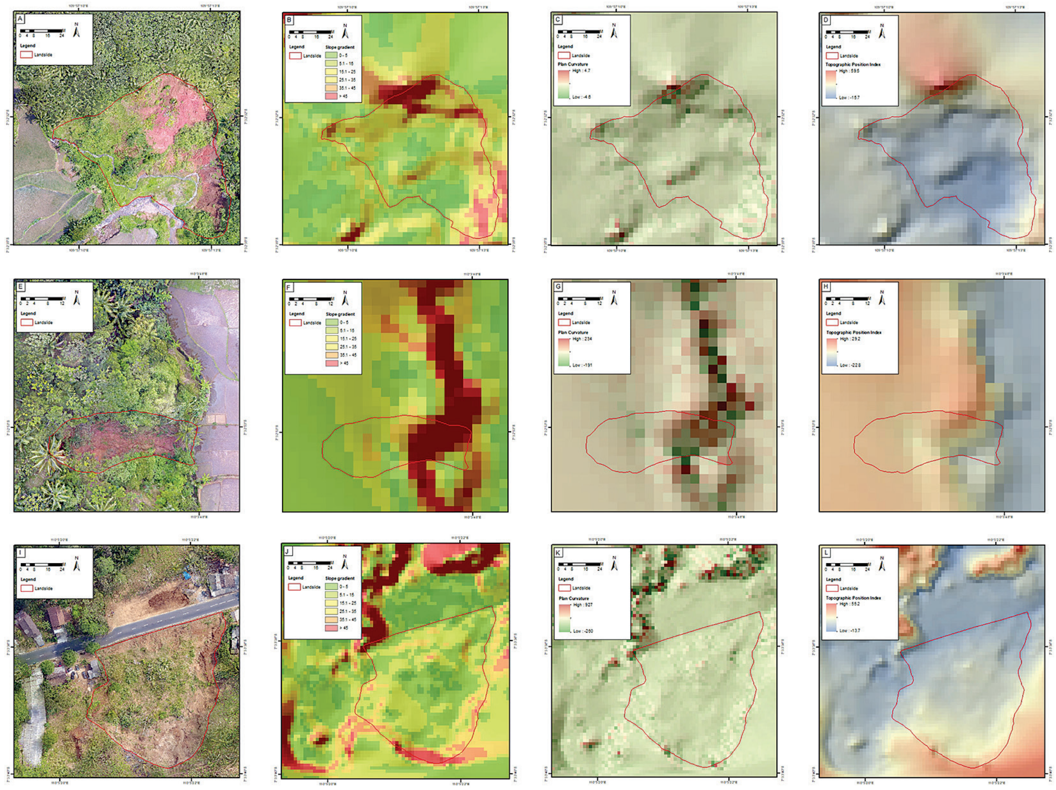

Figure 2. Orthophoto landslide Tegalsari (a) Tegalsari (b) landslide slope; Tegalsari (c) landslide plan curvature; TPI Tegalsari (d) landslide; Orthophoto landslide Wonogiri (e) Wonogiri (f) landslide slope; Wonogiri (g) landslide plan curvature; TPI landslide Wonogiri (h) Orthophoto landslide Manglong (i) Manglong (j) landslide slope; Manglong (k) landslide plan curvature; TPI Manglong landslide (l)

(Castro et al., 2020). Meanwhile, the soil characteristics in the transitional section between the body and the feet at all landslide locations tend to be dominated by the mixing of soil material with its saturated water conditions, so that it is possible for creepage or erosion of the grooves to the trenches to occur (Kuradusenge et al., 2020).

The slope sections tend to convex (plan curvature tend to high) cause the surface water flow to split in various slope directions. Conversely, the parts of the slope tend to be concave (plan curvature tends to low), causing surface water flow to be concentrated in specific spots on the slope (Figures 2c, 2g, and 2k). The three landslide locations have a plan curvature that tends to vary because the magnitude and morphology of the landslide surfaces are different. Still, the distribution of the most pixel values for the three landslides is at a value close to 0 (zero), which means it tends to be straight (Figures 3b, 3e, and 3h). The plan curvature value on the body to the feet at each landslide location tends to low, which means it is concave in shape. The concave slope shape causes the surface water flow to be concentrated (Gu and Wylie, 2016). Therefore, gully erosion formation becomes intensive (Garosi et al., 2019).

The plan curvature value that tends to be high is shown on the landslide head, causing surface water runoff to spread out and some parts to form grooves of relatively small size (Figure 4a). Convex slopes indicate thick soil and become the first part of becoming saturated with water when there is a rain event so that it becomes the location for the initial cracks (Figure 4b) (Ohlmacher, 2007). The Wonogiri landslide also shows a convex slope at the downstream side and the transitional part of the landslide body to the landslide toe (Figure 2g). High water saturation also makes the soil material in the basin unstable, resulting in soil sedimentation, and it may even be a trigger for reloading (Gao and Maro, 2010).

TPI describes the relative position to several points around it, where the slope also affects slope stability (Nseka et al., 2019). The crown and scraps sections at the three landslide locations had high TPI values, and the pattern of TPI values was becoming smaller towards the landslide feet (Figures 2d, 2h, and 2l). The difference in the shift

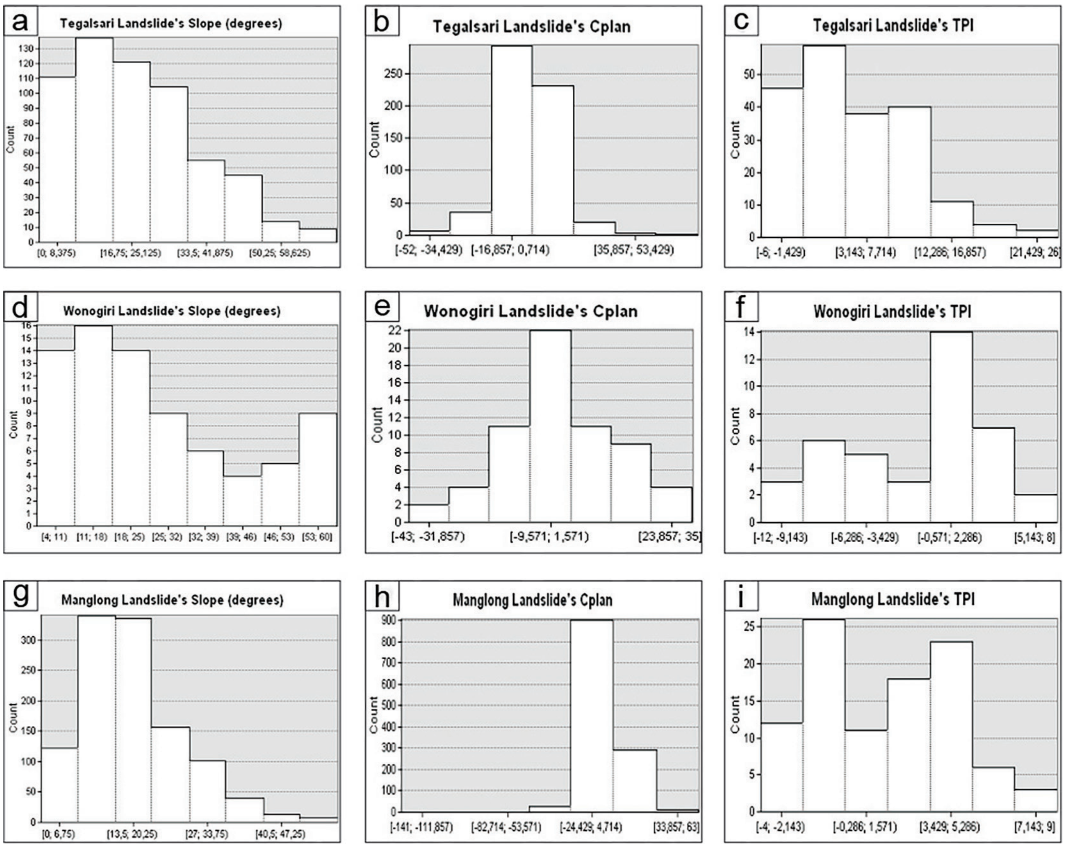

Figure 3. Histogram slope of Tegalsari (a) Landslide; Tegalsari (b) Landslide histogram curvature plan; TPI Tegalsari (c) Landslide histogram; Wonogiri (d) Landslide histogram slope; Wonogiri (e) Landslide histogram curvature plan; TPI landslide histogram Wonogiri (f) Manglong (g) Landslide slope histogram; Manglong (h) Landslide curvature histogram plan; TPI histogram Manglong landslide (i)

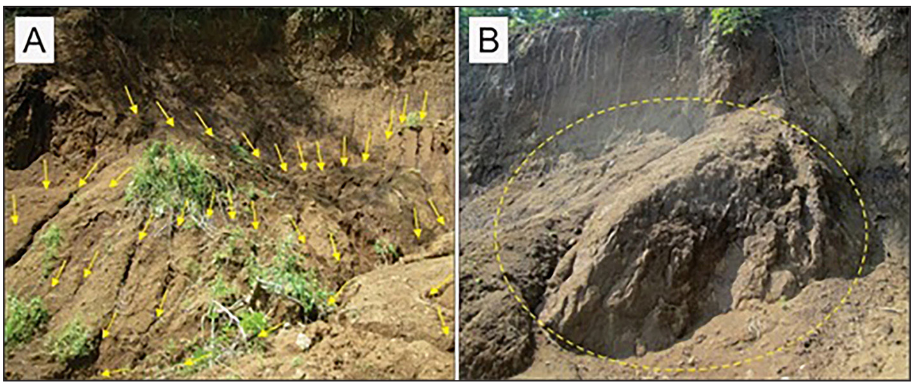

Figure 4. The appearance of groove erosion on the convex slope form (a) and the appearance of soil cracks on the convex slope form (b)

in TPI values from positive to negative values was observed in the Tegalsari and Manglong landslides to the Wonogiri landslides. The TPI value changed to negative at the border between the head and the landslide body in the Tegalsari and Manglong landslides. On the other hand, the TPI value in the Wonogiri landslide occurred at the border of the body with the landslide's toe (Figures 3c, 3f, and 3i). A high TPI value allows debris of soil material. As a result, the landslide crown will experience a setback (Choubin et al., 2020). The area with a low TPI value, namely at the toe of the slope, is accumulated surface water flow. As a result, there is a lot of erosion of grooves and gullies. Figure 5 shows the appearance of gully erosion on the body to the toe of the Manglong landslide.

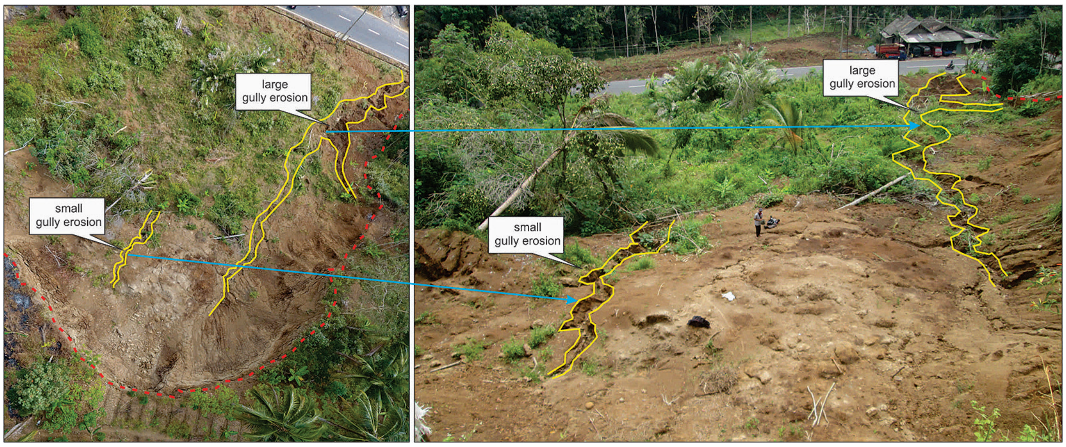

Figure 5. The appearance of small- and large-scale gully erosion on concave slopes

CONCLUSIONS

UAV is a low-cost, easy-to-use and transportable technology for recording aerial photographs and observing geomorphic processes in landslide deposition areas. DEM-UAVs are capable of producing quantitative morphometric extractions that are suitable in describing the actual conditions on the ground. The convex plan curvature is able to give the configuration of run off that is dispersed and creates erosion furrows, and the concave one will form the appearance of very large erosion gullies. Slope and topographic position index are supporting instruments in visual interpretation.

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