An Evaluation of Valuable Lands towards Landslide Susceptibility at Heritage Site, Sangiran, Central Java, Indonesia

S. Afifah\textsuperscript{1}\textsuperscript{*}, A. U. Putra\textsuperscript{1}, A. Christianawati\textsuperscript{1}, K. P. Prastika\textsuperscript{1}, M. I. Thoban\textsuperscript{1}, R. Lukafiardi\textsuperscript{1}, S. E. Siahaan\textsuperscript{1}, U. Widyanarko\textsuperscript{1}, and D. R. Hizbaron \textsuperscript{1}

\textsuperscript{1}Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Indonesia

\textsuperscript{*}sani.afifah@mail.ugm.ac.id

Abstract. Sangiran Early Man Site is a world heritage located in a peri-urban area in Sragen Regency, Central Java, Indonesia. Due to its significance, this 59.21 km\textsuperscript{2} area is recognized as a valuable land. However, landslides persistently threaten its existence. The research intended to evaluate 1) the landslide susceptibility and 2) the vulnerability of the valuable lands in Sangiran Site. It applied the weights-of-evidence method to produce a landslide susceptibility map, which was further validated with field survey. The analysis output included five classes of susceptibility, namely, very low, low, moderate, high, and very high. The classification aimed to generate matrices containing indications of valuable lands in each class. The field survey found no landslides in very-low susceptible areas and several small ones in low susceptible areas. Landslides were found in valuable lands endangered with a moderate degree of landslides. Large but non-risky landslides were detected in highly susceptible areas, while large and risky ones were in very highly susceptible areas. Sangiran consists of 19 valuable lands that help to narrate geological and human evolution through fossils, scarcity, stratigraphy, and other unique features. For each land, a number is assigned to it to mark priority based its importance clues. Priority 13 was included in the low susceptibility class. While priorities 1, 5, 6, 7, 8, 12, 17, and 18 belonged to moderate susceptibility class, priorities 2, 3, 4, 9, 10, 11, 14, 15, 16, and 19 were classified into high susceptibility class. Therefore, Sangiran Site comprises heterogeneous characteristics that make its valuable lands the subjects of protection against landslide occurrences.

1. Introduction

Civilization has been long evolving and leaving historical traces in what is known today as cultural sites. There are a total of 845 cultural sites worldwide [1]. Cultural sites must at least contain universal values and meet ten selection criteria. For instance, they have to be directly associated with traditions, ideas, and beliefs, contain outstanding natural phenomena, and be an example revealing the earth’s history from the perspectives of geomorphology, physiography, and the development of landforms.

Indonesia is among the 167 participating countries with a recognized wealth of civilization in the World Heritage Convention. There are eight properties inscribed on the World Heritage List. Four of which are cultural sites, including Borobudur Temple, Prambanan Temple, Bali Subak System, and Sangiran Early Man Site. In the context of development, the governments of the city, regency, or province where a cultural site is located jointly regulate its protection. The management not rarely involves two or more administrative units because the cultural sites occupy an extensive area.

Sangiran Early Man Site, or Sangiran Site, is one of the most acknowledged cultural sites in the world because it is a silent witness to human evolution. This cultural site is of great significance because after the excavation in 1936-1941, more than 60 fossils have been discovered underneath it [1]. Fossils can give benefits to the community, such as awards and financial compensation from the government to the local people who have submitted their fossil findings to the Center for Ancient Human Sites Preservation (BPSMP) Sangiran [2].

Sangiran Site covers an area of approximately 59.21 km\textsuperscript{2} and still contains a large number of undiscovered fossils. The presence of cultural heritage in the soil and soil outcrops needs to be immediately preserved to prevent losses and damages. Sangiran Site has several scientific, historical, and economic significance that are perceived as exceptional universal values; that is, the values that
direct the preservation of world heritage sites. The scientific importance includes the potential for this site to bring about further research into the evolutions of human, culture, and environment. Outcrops of soil layers, stratigraphy, and heterogeneity of social and physical ecosystems support this claim. The historical significance is strongly related to the origin of the human race in Indonesia and the process of human evolution in Sangiran Site, all of which are manifested in the local wisdom. Meanwhile, the economic importance is attributable to the development of the Sangiran Site as one of the leading tourist destinations in Central Java Province as an attempt to improve the economy of community.

Sangiran Site is notable for findings of fossils. As a world heritage, these valuable objects are naturally endangered by time and age. Apart from these internal factors, there are external threats to its preservation, e.g., natural disasters [3]. Lateral erosion and moderate to high rainfall create a precondition for landslides. As reported in a news website krjogja.com on February 9, 2019, landslides buried the road connecting Cengklik to Bukuran Hamlet, Bukuran Village, Kalijambe District. The dimension of the rupture was 15 m in length and 3 m in depth. The impact included disrupted access to Sangiran Museum [4].

Vulnerability and hazard analysis followed by risk analysis is part of the pre-disaster stage in disaster management praxis [5]. Located at a landslide-prone area, the Sangiran Site is in danger of unsustainability and extinction. Accordingly, this study was designed to identify the landslide susceptibility levels, the conditions of the valuable lands, and the threats of landslides to valuable lands at Sangiran Site.

2. Methods

2.1 Location and Time of Research

The Sangiran Archeological Site occupies four districts, comprising 23 subdistricts and 1,666 hamlets, in Sragen and Kranganyar Regencies, Central Java Province. Astronomically, it extends between 110°49’-110°53’ E and 07°24’-07°30’ S. The administrative borders of this site are as follows:
- Northern borders: Miri and Plupuh Districts
- Eastern borders: Plupuh and Gondangrejo Districts
- Southern borders: Gondangrejo District
- Western borders: Gondangrejo and Kalijambe Districts

Covering an area of 59.21 km², this site has several geographical units, including Krikilan Cluster, Bukuran Cluster, Ngebung Cluster, and Dayu Cluster [6]. Sangiran Site consists of several zones, namely Core Zone, Buffer Zone, and Development Zone [7], as presented in Figure 2.1 below.

![Zonation Map of Sangiran Site](image)

**Figure 2.1.** The Zonation Map of Sangiran Site

The geographical boundaries of Sangiran Site are the slopes of Mount Lawu in the east, the Kendeng Mountain range in the north, and the Southern Mountain range in the south. [8]. The research area, as shown in Figure 2.2, is located in a natural basin named the Solo Depression, and the highest peak of the hills on the Sangiran area is only ±180 m above sea level. In ancient times, Sangiran was a stretch of ocean. After several geological processes and natural disasters, i.e., the eruptions of Mounts Merapi, Lawu, and Merbabu, a mainland was formed [9]. The stratigraphic formations in Sangiran from
the oldest to the youngest are Kalibeng Fm, Pucangan Fm, Grenzbank Fm, Kabuh Fm, Notopuro Fm, and Terrasses Fm. Geologically, it is a suitable location for landslide susceptibility studies.

![Figure 2.2 The Map of the Study Area](image)

2.2 Methods
The research was carried out at Sangir an Archeological Site with an analysis unit of point of location, namely the locations of valuable lands and past and potential landslides. The secondary data, obtained from agencies and previous research, included elevation, slope, land use, geological formation, road buffer, river buffer, geomorphology, points of historical landslide events, and valuable lands. The primary data of the 19 valuable lands were collected by purposive sampling method. Meanwhile, the
landslide data was acquired by inventory mapping of landslide deposit identified in field survey, which is the oldest technique in inventory mapping [10]. The inventory of landslide points was processed by the heuristic-statistical method (to generate landslide susceptibility maps) and the bivariate statistical method based on the weights of evidence. In landslide analysis, the weights-of-evidence (WOE) method compares the landslide density in each influencing factor with the landslide density in the entire study area [11]. WOE was applied to analyze the research parameters in ILWIS 3.3 software using the following equation:

$$Wi = \ln \frac{\frac{N_{pix}(Si)}{\sum N_{pix}(Si)}}{\frac{N_{pix}(Ni)}{\sum N_{pix}(Ni)}}$$

Where:
- $Wi$ = The weight of each class of variable
- $D_{enclass}$ = Landslide density in each class of variable
- $N_{pix}(Si)$ = Number of pixels with landslides in each class of variable
- $N_{pix}(Ni)$ = Total number of pixels in each class of variable
- $\sum N_{pix}(Si)$ = Total number of pixels with landslides in the map
- $\sum N_{pix}(Ni)$ = Total number of pixels

In this research, valuable lands are elements at risk of landslides. At-risk elements are a set of elements resulting from a natural event of an absolute magnitude [12]. The measured characteristics of the valuable lands were importance values, land use, and morphology; all of which were used as the basis for photo map. The landslide susceptibility on valuable lands were also analyzed using photo mapping.

2.3 Research Flowchart

This research consisted of three stages namely pre-field survey, field survey, and post-field survey. The pre-field survey included collecting data, determining variables, and processing maps for the field survey. During the field survey, the products of the previous stage were validated. Meanwhile, the post-field survey involved processing data from the validation results, producing three crucial outcomes, as described in Figure 3.
Figure 2.3: The Research Flowchart
3. Results and Discussion
The landslide susceptibility map is composed of seven parameters that describe proneness to landslides, namely land use, morphology, slope, geological formation, elevation, river buffer, and road buffer. In ILWIS, this map was processed together with historical landslide data using the weights-of-evidence (WOE) method. This process utilized secondary data to generate a tentative landslide susceptibility map. Therefore, validation was required to increase its accuracy. For this purpose, each of the five susceptibility classes was represented by three validation points, creating a total of 15 validation points. During the field survey, the morphology, land use, and landslide typology at these points were recorded. The results were then added to the previously produced tentative map to generate a landslide susceptibility map by photo mapping, as seen in Figure 3.1

In general, the validation results indicate that the tentative map has reflected the actual condition because the magnitudes of the landslides identified in the field corresponded to the five classes of landslide susceptibility. Very low susceptibility class generally occupies flat to undulating terrain. This morphology has the most stable soil because the possibility of erosion is minimal. As a result, various types of intensive land utilization for settlements, rice fields, and plantations take place. Validation in the field did not find any landslide scars in this very low susceptibility class. The three validation points of this class were points 13, 14, and 15 (see Figure 3.1) with flat to undulating morphology and intensive land utilization for rice fields, settlements, and plantations.

Gently sloping morphology typifies low landslide susceptibility. In this terrain, landslides are rarely found because there is a small possibility of occurrences. The triggering factor includes slope cutting as a modification strategy to create small terraces for rice fields. Cut slopes are unstable, forming a precondition for small landslides on terraced rice fields. While the validation in the field found a small landslide scar in one validation point (point 10 in Figure 3.1), none were identified in the other two validation points (points 11 and 12 in Figure 3.1). The landslide scar showed a small mass of soil falling down the terraced slopes and presumably did not harm the surrounding farmlands. Nearly level to gently rolling terrain with vast rice fields and multi-species plantation characterized the validation points of this low susceptibility class.

![Figure 3.1 The Photo Map of the Landslide Susceptibility Levels in Sangiran Site](image)
The moderate susceptibility class covers areas with steeper morphology than the previous two classes, namely gently rolling. Steeper slopes increase the potential for landslides of greater magnitude [13]. The three validation points of this class (points 7, 8, and 9 in Figure 3.1) confirmed that past landslides had higher magnitudes than those identified in lower susceptibility classes. These landslides were translational slides of debris that did not cause damages to the surrounding environment. The sampled locations for morphological analysis were of strongly rolling terrain. The land use at the three validation points, namely mixed plantations and settlements, did not require intensive land management.

Relative to the previous classes, areas highly susceptible to landslides typically have steeper terrain, i.e., strongly rolling. Aside from morphology, another triggering factor in this class is proximity to rivers and roads. While distance to river determines the possibility of lateral erosion that triggers landslides, distance to roads indicates the presence of slope cutting i.e., unstable slope [11]. During the field survey, this research validated the presence of landslide scars in all three validation points (points 4, 5, and 6 in Figure 3.1). These scars were relatively large with a tremendous amount of displaced mass at the foot of the ruptures. Nevertheless, these landslides did not negatively impact the surrounding environment because they occurred in uninhabited lands. The two validation points did not have steep terrain. Although the morphology was undulating to gently rolling, close distance to the river and the road was presumed to be the cause of landslides in both points. The typology of landslides in this susceptibility class was mainly debris fall.

The very high susceptibility class has the steepest morphology among the others, namely strongly rolling, which creates a highly unstable soil. Moreover, the proximity to roads and rivers increases the potential for landslides of sizeable destructive magnitude. During the validation in the field, landslide scars were identified in all three validation points. In contrast to the highly susceptible areas, the landslides in this class had a significant impact, i.e., local roads were disconnected in all three validation points (points 1, 2, and 3 in Figure 3.1), leaving only half of the road segments.

The archeologists work at Sangiran Site explained that the valuable lands in this site had the same importance value because they experienced natural evolution. The 19 priority valuable lands are presented in the Map of Valuable Lands Distribution (Figure 3.2). The selection of these valuable lands is based on the findings of Homo erectus that provide information on human evolution, stratigraphy, and the uniqueness or rarity of the fossils.
Landslides with low, moderate, and high degrees of susceptibility threaten the nineteen valuable lands in the Sangiran area. The valuable land with low susceptibility class was priority 13. The valuable lands with moderate susceptibility class were priorities 1, 5, 6, 7, 8, 12, 17, and 18, while those threatened with high landslide susceptibility were priorities 2, 3, 4, 9, 10, 11, 14, 15, 16, and 19. Nine of the 19 valuable lands are presented in the photo map below (Figure 3.3).

Figure 3.3. The Photo Map Showing the Threats of Landslides in the Valuable Lands of Sangiran Site

Priority 13 is the only saltwater spring in Sangiran, which, according to the results of this study, is threatened by low landslide susceptibility. This condition is mainly because the surrounding areas of this spring are rice fields with low vegetation density. A few meters from it, minor landslides occurred due to lateral erosion by ephemeral river flow, i.e., the main river channel traversing the rice fields (Figure 3.4).

Figure 3.4 Minor Landslide Scars In the Rice Fields Nearby the Saltwater Spring
Priority 1 is located in a moderately susceptible area. The identified landslides on the cliffs of this valuable land endanger its importance value, including the finding of the *Homo erectus* S17 fossils. These fossils have complete skulls of extinct human species, for which they are the Sangiran’s masterpiece. The weights-of-evidence analysis revealed that land use was the major influencing factor of landslides. The vegetation covering the cliffs beside this valuable land consisted of multi-species stands. The hard tree roots that do not entirely extend into bedrocks increase the loads on the slope, especially during heavy rainfall when soils are saturated with water (Figure 3.5). Priority 1 is only 0-25 meters far from the Cemoro River; hence, the soils are often wet and susceptible to landslide events. Wet soils with loose materials are part of the factors that induce landslide occurrences [14].

![Figure 3.5 The Multi-Species Vegetation Stands on the Cliff Beside the Valuable Land in Priority 1](image)

Priority 10 is one of the valuable lands subjected to a high level of landslide susceptibility. Its importance value is the contact layer between clay stone (Pucangan Fm) and grenzbank and sandstone (Kabuh formation). Grenzbank is a very hard sub-formation marking the time of transition when Sangiran transformed into today’s land area. Strongly rolling terrain naturally causes landslides in these outcrops (Figure 3.6) whose sloping gradient reaches 100% or 45°. This slope is the slope angle that has the highest deviation value if the soil materials collapse [15]. There is a high probability that the widely spread teak trees in the area will be cut down for various commercial purposes and eventually lead to deforestation. One of the main influencing factors of landslides in Central Java is anthropogenic activities like deforestation that increases the exposure of soils and rocks to external factors [16].

![Figure 3.6 The Strongly Rolling Morphology in the Valuable Land in Priority 10](image)
4. Conclusions
Referring to the elaborate discussion on landslide susceptibility, valuable lands, and their relationship in Sangiran Site, this research has concluded that:

1. The very low susceptibility class has flat to undulating morphology with intensive land utilization for rice fields and settlements and no landslides. The low susceptibility class is composed of nearly level to undulating terrain mainly used for rice fields, and it has small landslides in several points. The moderate susceptibility class is gently rolling with land utilization for multi-species plantation and has moderate landslides. The high susceptibility class also has strongly rolling terrain and some landslides with no resulting damages and losses to the community. The very high susceptibility class has strongly rolling morphology with some large landslides believed to have caused damages and losses. Main parameter of landslide susceptibility is landuse. The more intense the landuse, the higher the landslide susceptibility is.

2. The nineteen valuable lands in Sangiran become valuable because of their contribution to science, especially for archaeology and geology. Sangiran’s nineteen valuable lands could reveal information from their soil contents to reconstruct the chronologies of the past. Most of them have Homo erectus and other animal fossils. The other have saltwater spring, mud volcano and some clear rock outcrops. Those scientific values of valuable lands could be damaged and endangered if there is no mitigation towards landslide occurrences.

3. Landslides with varying degrees of susceptibility endanger the nineteen valuable lands in the Sangiran area. Based on this research, the valuable land in priority number 13 is located in an area with low landslide susceptibility class. Priorities number 1, 5, 6, 7, 8, 12, 17, and 18 occupy moderate landslide susceptibility class, while priorities number 2, 3, 4, 9, 10, 11, 14, 15, 16, and 19 are located in high landslide susceptibility class.

5. Recommendation
Research related to the threat of hazard towards cultural heritage is still sparse, especially at the Sangiran Site. This research attempts to assess the potential threat of landslides at 19 important lands on the Sangiran Site. Based on the factors causing landslides as a result of WoE method, land use has the biggest contribution to trigger landslides. Therefore, recommendations to carry out land conservation are planting vegetation which is able to stabilize slopes such as sengon trees, sugar palm, angsana, pine, avocado, and others (Riyanto, 2016) [17]. Mechanical engineering can also be carried out to stabilize the slope by installing gabions or groynes.

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