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Natural Slope Failure on Weathered Andesitic Breccia in Samigaluh Area, Indonesia

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ABSTRACT

Six events of landslides occurred simultaneously on weathered Andesitic Breccia in Samigaluh Area, following the heavy rainfall. Field investigation, laboratory works and slope stability analysis were carried out to assess the mechanism of the failures, their controlling factor and identify the triggering rainfall characteristics. It was found that the rainfall was the key factor inducing the failure. However, further investigation which incorporates slope hydrodynamic numerical modeling is still required, in order to find the triggering rainfall characteristics. In addition, the role of slope inclination was less significant than the soil and vegetation types covering the slopes. Finally, the landslide susceptibility map could be performed to support the prevention system.

KEYWORDS

Landslides, natural slope failures, weathered Breccia, triggering rainfall, soil types, vegetation types.

INTRODUCTION

Following the rainfall, six events of landslides occurred simultaneously on the 23rd of March 1996 in Samigaluh area. Such area is located in the Regent of Kulon Progo, at the Special Province of Yogyakarta, in Central Java, Indonesia (Figure 1).

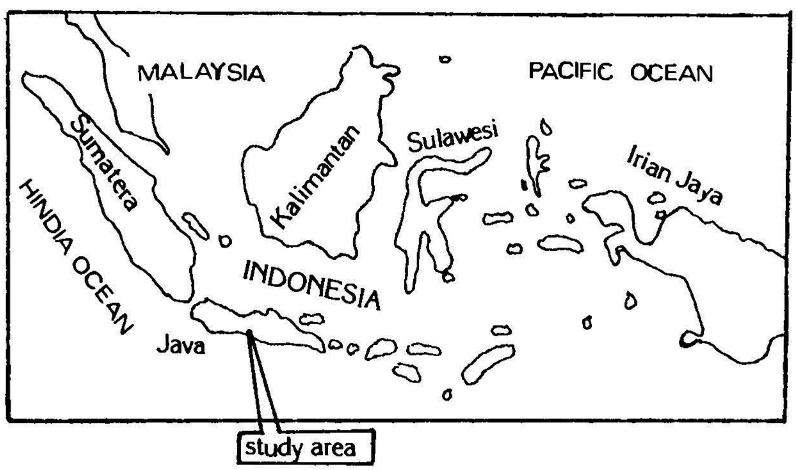

Figure 1. Location of the study area

A study to investigate factors controlling the landslides and to identify the triggering rainfall characteristics was carried out. This study consists of a field survey and mapping, some laboratory works and slope stability analysis. By doing so, the map of landslide susceptibility could be established. Thus, the occurrence of the next landslide can be predicted and prevented.

GEOMORPHOLOGY AND GEOLOGY

Geomorphology

The study area is characterized by hilly morphology with various slope inclinations, i.e. from 10° to 70°. The highest elevation is 1050 m above sea level, which is located in the west part of the study area. All of the landslides occurred surrounding this highest part. The lowest elevation is 375 m above sea level, which lies on the south.

According to their inclinations, slopes in the study area could be classified as follows (Figure 2a):
1. Slopes with inclination greater than 15°
2. Slopes with the inclination of 15° to 25°
3. Slopes with the inclination greater than 25°

All of the landslides (slope failures) occurred on the slopes with inclination of 25° to 35°.

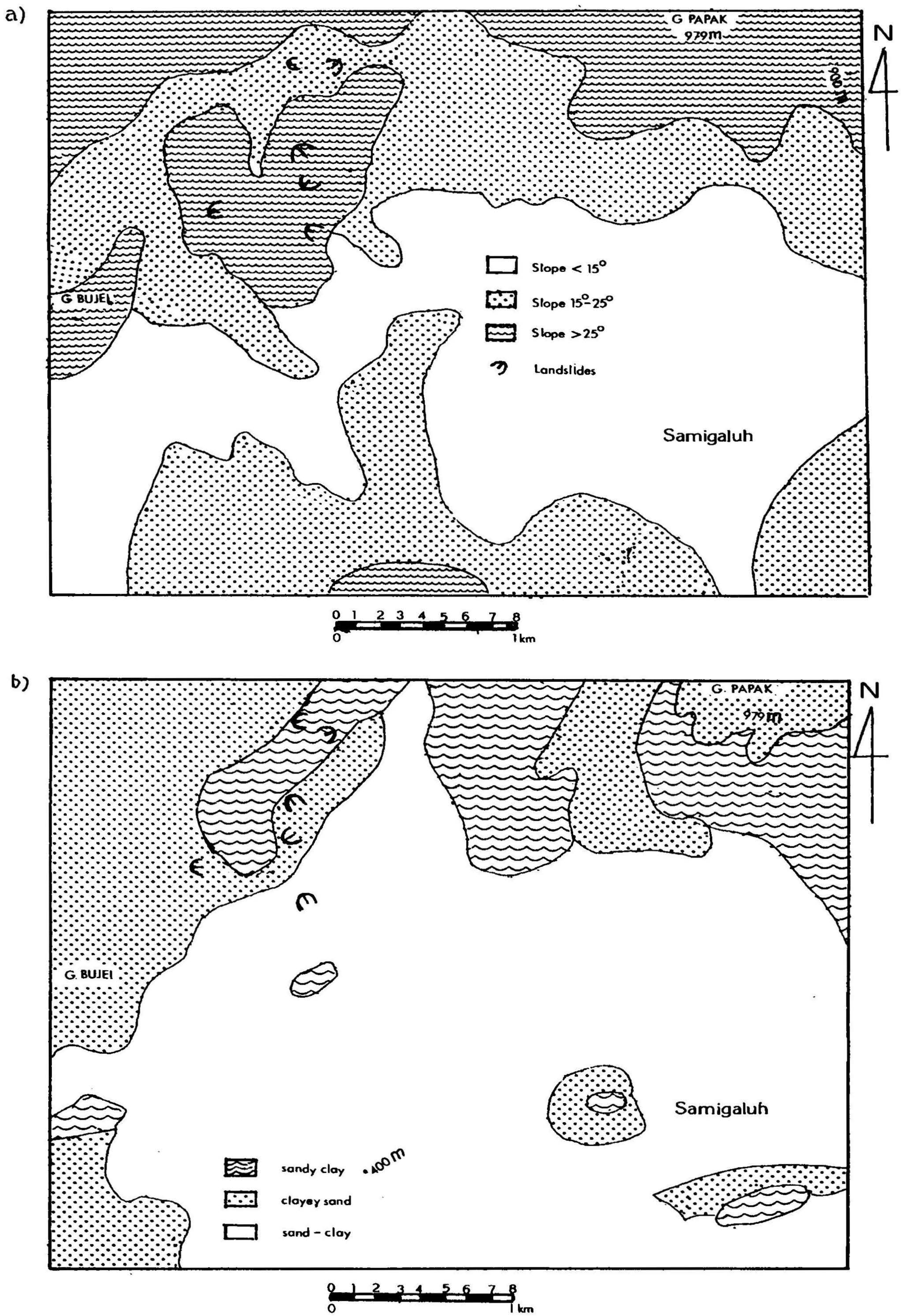

Figure 2. a) Slope Distribution Map and b) Soil Distribution Map in Samigaluh Area

Geology

Bedrock underlying the study area is Andesit Breccia. Such Breccia consists of rock fragments (Andesit and Tuff) with various diameter size, i.e. 3 mm to 2 m. The matrix of Breccia comprises of Sandy Tuff. Most of the Breccia exposed is intensively weathered which results in various soil conditions as listed in Table 1. This bedrock is predominantly covered by those soils. Distribution of the soils in the study area is illustrated by Figure 2b.

ROCK AND SOIL PROPERTIES

Due to the limitation of testing equipment, not the fragment but the matrix of Andesitic Breccia was deliberately considered in this investigation. Admittedly, this can result in the conservative value of shear strength, which tends to underestimate the rock mass strength. Yet, it will give the more safe result.

The soils in the study area could be classified into three different soil types according to their grain size, i.e. Sandy Clay, Clayey Sand and Sand-Clay. Three of the landslides occurred on reddish brown Clayey Sand, two of them on yellowish brown Sandy Clay and the other one on dark brown Sand-Clay.

It is illustrated in Table 1 that the matrix of bedrock (Andesitic Breccia) has substantially higher strength, i.e. cohesion (c') and frictional angle (ϕ'), but lower hydraulic conductivity (K) than the other soils covering the slope.

Table 1. Rock and soil properties

Properties	Matrix of Breccia	Sandy-Clay	Clayey-Sand	Sand-Clay
Color	brown	yellowish brown	reddish brown	dark brown
γ_s (kN/m^3)	17.00	15.30-16.40	12.60-15.20	16.80-17.00
γ_d (kN/m^3)	12.90	10.90-11.10	1.00-1.10	13.20
Water content (%)	31.30	37.50-60.00	32.20-44.60	26.70-28.80
w_L (%)	42.00	44.60-53.50	66.90-47.60	47.90-48.40
w_P (%)	35.40	35.90-39.60	34.70-44.80	32.20-32.70
I_P (%)	6.60	5.00-17.50	12.90-22.10	15.70
G_S	2.58	2.62-2.69	2.52-2.53	2.63-2.68
Void ratio	1.03	1.34-1.46	1.30-1.81	1.00-1.03
S (%)	80.00	71.50-93.00	55.66-80.88	71.08-75.13
% of clay fraction	26.00	42.60-67.60	22.60-50.90	49.80-55.30
K (m/sec)	5.20x10^{-8}	1.1x10^{-7} to 1.83x10^{-7}	1.27x10^{-7} to 2.12x10^{-7}	3.00x10^{-7}
c'(kPa)	35.00	7 to 12	1 to 8	13
ϕ' (o)	48.00	28 to 34	34 to 40	30 to 40

LANDSLIDE CONDITIONS

The geometry of the landslide is illustrated in Figure 3. From field inspection, it was recognized that only the soils, in particular Clayey Sand, were moved by the sliding. Meanwhile, the bedrock of Andesitic Breccia remained stable. Clearly, the contact between the soil and bedrock of Andesitic Breccia behaved as the failure (sliding) surface. Such surface was relatively parallel to the slope surface. In addition, the moving soils were very wet (muddy) and showed the flow pattern. This indicates that the landslide type was the earth flow as that was reported by the eyewitnesses.

It was also recognized that all of the failed slope were covered by corn and cassava crops (Figure 4). Meanwhile, other slopes which had similar inclination to the failed ones and were covered by cultivated plant or forest, remained stable.

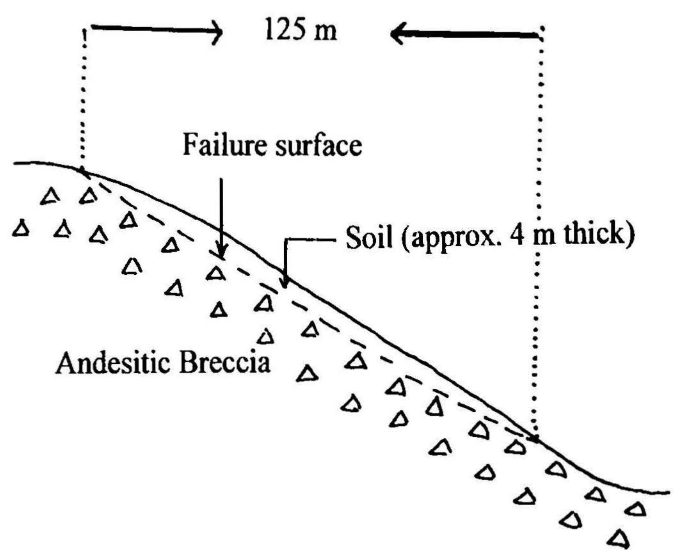

Figure 3. Landslide conditions

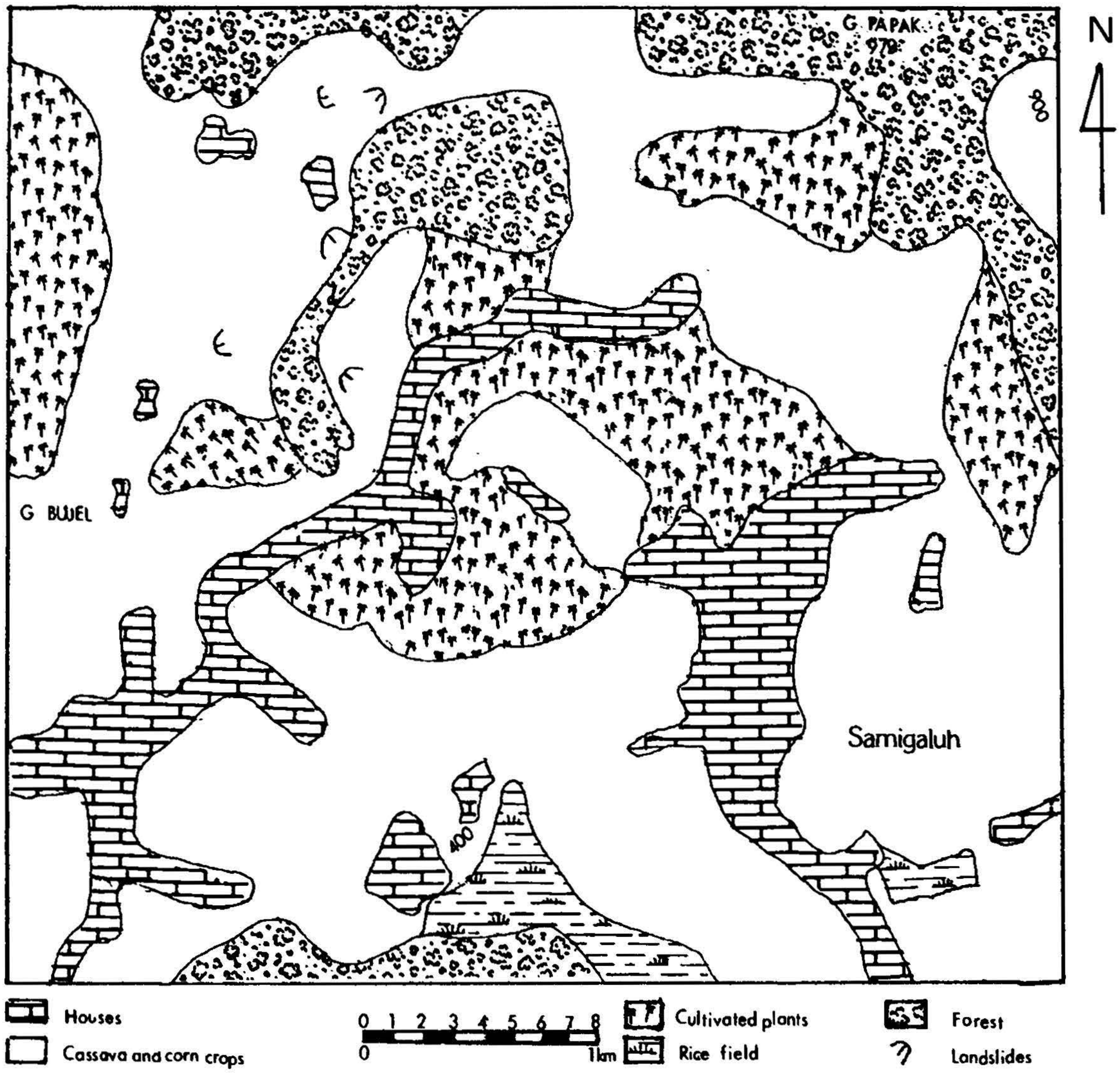

Figure 4. Landuse Map in Samigaluh Area

RAIN CHARACTERISTICS

The rainfall data was collected from the rain-gauge station located in Samigaluh at the elevation of 625 m above sea level. During 1986 to March 1995 the average annual and monthly precipitation were 2992 mm and 241 mm respectively. The highest annual precipitation was 3849 mm occurring in 1986, and the highest monthly precipitation in that year was 321 mm. However, there were no landslide events. On the other hand, landslide events occurred in March 1996 when the monthly rainfall was 340 mm (Figure 5). This is slightly higher than the average monthly precipitation since 1986.

Figure 6 illustrates the daily rainfall during March 1996. The landslide occurred on the 23[rd] when the daily rainfall was only 10 mm. It is interesting that these events did not coincide with the highest daily rainfall (i.e. 86 mm) which had occurred 2 days before.

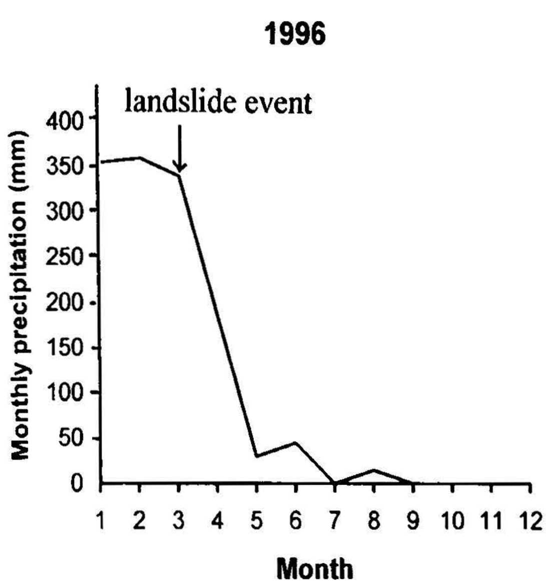

Figure 5. Monthly rainfall in 1996 (no data available in September to December)

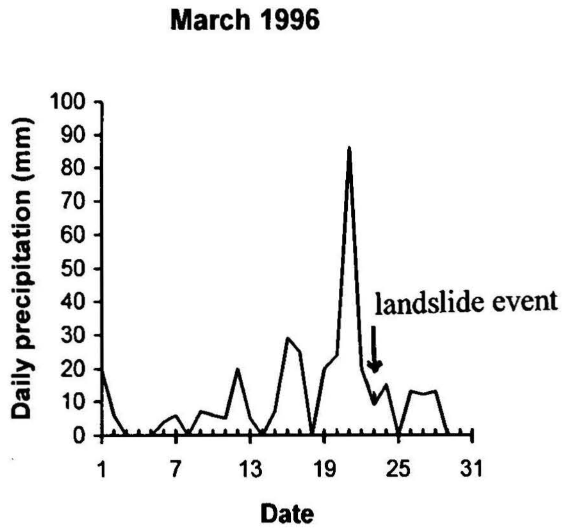

Figure 6. Daily rainfall in March 1996

DISCUSSIONS

Mechanism of Slope Failures

As indicated from the field inspection the slope failure was due to the soil movement, i.e. the earth flow. It is also clearly indicated by the rainfall record that landslide events occurred following the heavy rainfall, which occurred 2 days before. Therefore, those landslides were induced by this heavy rainfall. The rainwater must significantly increase the saturation of the soil overlying the bedrock. It is crucial that the infiltration of rainwater to the bedrock was prevented. This is because the hydraulic conductivity of the bedrock, i.e. 5.20×10^{-8} m/s, was substantially lower than that of the overlying soils, i.e. 1.10×10^{-7} to 3.00×10^{-7} m/s. Thus, the more the rainwater infiltrated, the more the water was accumulated in the pores of soil above the bedrock. This consequently resulted in the rise of pore water pressure at the contact surface between the bedrock and soil, which then reduced the soil shear strength in this contact surface. Finally, this led to the slope failure. This is also the reason why the failure plane passed through such surface.

This mechanism of failure also in conforms to the slope stability analysis result. When the slope was dry, the slope factor of safety was 1.34. This means the slope remained stable. Nevertheless, when the slope was gradually saturated by the water table rising above the bedrock surface, this factor of safety gradually decreased. Finally, when the water table rose until it reached the slope surface, the factor of safety dramatically drop to 0.60. In hence it is clear that the slope failure or landslide was due to the rise of water table induced by the rainfall.

Factors Controlling Failures

Slope inclination. All of the landslides occurred on the area which was steeper than 25°. However, it was evident that some other slopes, which were steeper than 35o but covered by dark brown Sand-Clay and cultivated plants or forest, remained stable in response to the rainfall. Thus, it seems that the slope inclination exhibits less significant control on landslides than the soil type and vegetation.

Soil Types. It was found that three of the six landslides occurred on the slope covered by reddish brown Clayey Sand. According to the laboratory test results as illustrated in Table 1 this sand had the lowest shear strength, i.e. 1 to 8 kPa. That is why the slope that is covered by this soil type is the most sensitive one to fail.

It was apparent that various soil types in the study area were weathered from the same bedrock. These variations may be due to the heterogeneity of Andesitic Breccia. However, further investigation on this phenomenon is still required.

Rainfall. Clearly, that the slope failures strongly related to the heavy rainfall. However, such failures did not immediately follow the heavy rainfall, but they were delayed for two days. This may be because the permeability of the soils which is relatively low. Thus, it took couple days for the rainwater to build up the pore pressure, so that the failure could be induced.

Vegetation. It is apparent that the root system of the corn and cassava crops tends to loose the interconnection of soil particle. This can increase the soil permeability at the root zone. Accordingly, the rate of rainwater infiltration was higher on the slope covered by these vegetation types. As a result, the rise of groundwater table proceeded in the higher rate as well, which then led to the more rapid shear strength reduction and thus the slope failure.

Key factor. It was evident that all of the steep slopes in the study area, which were covered by the most weak soil, (i.e. Clayey Sand) and cassava as well as corn crops, remained stable when there was no heavy rainfall. In hence, among those controlling factors discussed above the rainfall is the most significant one.

Unfortunately, it is still difficult to identify the triggering rainfall characteristics. It seems that the heavy rainfall, i.e. that exceeded 86 mm/day or 70mm/hour, was responsible for the failure. This is in conform to that was suggested by Brand (1984), Heath and Sarosa (1988), and Premchitt (1995). Nevertheless, in March 1994 there was no landslide events although the daily rainfall exceeded 140 mm. Therefore simple empirical correlation between the rainfall intensity and duration, and the landslide event are not always sufficient. Further investigation by analytical approach, which incorporates the slope hydrodynamic numerical modeling, is required (Anderso et al, 1990, Fredlund and Rahardjo, 1993; Karnawati, 1996). This will enable the insight assessment on all factor controlling the landslide to be performed.

LANDSLIDE SUSCEPTIBILITY MAP

By considering all factors controlling the landslides as well as overlying several maps illustrating the distributions of slope classes, soil types and landuses (Figure 2a, 2b and 4 respectively), a map of landslide susceptibility could be established. The sensitivity of the area to the landslides is illustrated in such map (Figure 7). This will be useful to support the landslide prevention system in this area.

CONCLUSION

Rainfall is the key factor controlling the slope hydrodynamic conditions leading to the slope failure. Simple empirical investigation is not always sufficient to identify the triggering rainfall characteristics. Analytical approach, which incorporates the slope hydrodynamic modeling, is essential to perform more accurate landslide prediction. Additionally, the slope inclination has less significant role than the soil types and vegetation cover in controlling slope failures in the study area.

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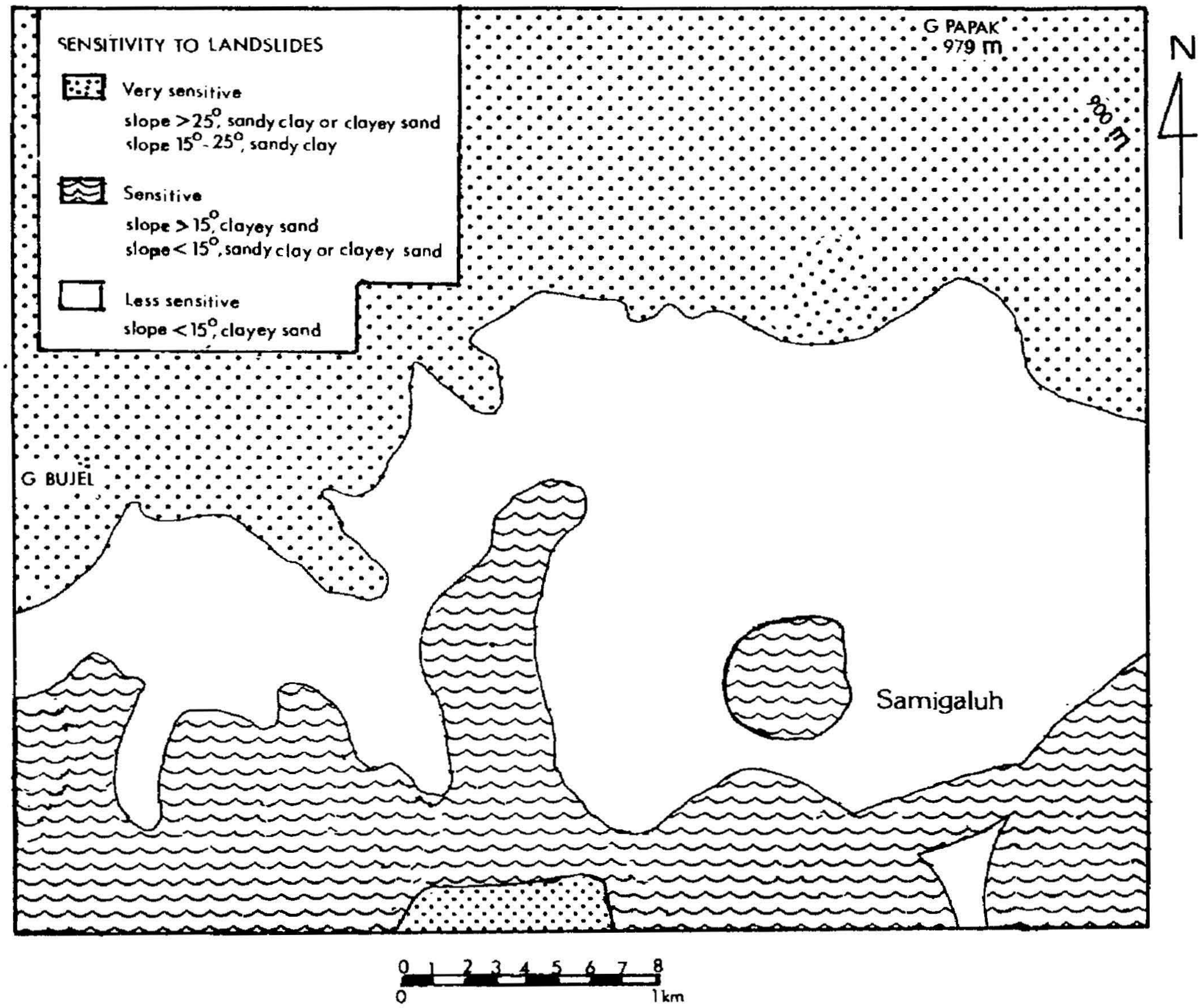

Figure 7. Landslide Susceptibility Map in Samigaluh Area