SELECTION SAFE PLACES FOR TEMPORARY SHELTER FROM DEBRIS FLOW AND LANDSLIDE DISASTERS IN MOUNTAINOUS AREA

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***ABSTRACT*:** In mountainous area many people have suffered from landslide and debris flow disasters during typhoon and monsoon seasons. Landslides triggered by an earthquake after long rainfall isolate villages and paralyze the infrastructures, such as Niigata Chuetsu earthquake in 2004. In order to mitigate the damages, people need to evacuate to the safe places if houses are located at susceptible areas. However, in fact, many people cannot find any available places for evacuation because designated evacuation places are too far to arrive safely. In this study, we propose a method to select available buildings as temporary shelters by considering slope susceptibility to landslide triggered by rainfall and earthquake in a community. By comparing the availability with the resident's opinions, some advices are provided to improve their risk communication.

KEYWORDS: temporal evacuating place, landslide, mountainous area, risk communication

1. INTRODUCTION

Natural hazards cause substantial damages to the lives, infrastructure, economy etc. throughout the world. Although there are some engineering methods to prevent natural disasters, there is no perfect method because natural phenomena often exceed the assumption.

In Japan, we have kept rules that people evacuate the designated evacuation places by following the warnings distributed by local government. But many people have been suffered from disasters. In order to mitigate damages under catastrophic disasters, it is quite necessary to analyze factors of interfering safety. Causes of giving up or delaying evacuation have been investigated. Katada et al (2007) pointed out that most people tend to ignore distributed warning of disasters and advice to evacuation because they are accustomed to daily normal situation, and psychologically they hardly accept and take the emergence situation. Therefore the way to motivate people to evacuate has been one of the key issues.

On the other hand, recently it has been reported that some people are killed while they move to evacuation places by following the warning or recommendation distributed by local government during heavy rainfall. One of the main reasons is the rainfall pattern. Those damages tend to be caused by pointed heavy rainfall events, which affect very narrow areas with enormously strong rainfall. Because of the pointed rainfall event, local government hardly identifies the situation if affected area is far from the office. Even under the same meteorological condition, the susceptibility depends on the micro topographical conditions. In some area, evacuation is necessary for their safety because the house is located at hazardous zones, however, in some area, people should not evacuate because the routes are cross the hazardous zones. Actually, it was reported that people were flushed in a small ditch on the way to the public evacuation place under extremely serious rainfall (80mm per hour) on 9th August 2009 in Sayo-cho, Hyogo prefecture. At that time, local government officially announced necessity of evacuation to all over the village. However, in front of the evacuation place, there is a ditch and the route is across it. Even it is very narrow, people were sacrificed in this ditch because the flood spill out the road and the boundary between road and ditch could not be identified at all.

In our study, we proposed a method to extract buildings located at stable and available slopes for temporary shelter during heavy rainfall and earthquake. Moreover, we also proposed a method to estimate potential risk in local community, especially by comparing the susceptibility to landslide around a house and risk communication of the residents.

2. Methodology

2.1 Research flow

In order to effectively find a solution for mitigating damage due to landslide triggered rainfall or earthquake, our proposed algorithm is composed of geomorphological and social characteristics investigation. The flow of this analysis is systematically illustrated in Figure 1.

In order to mitigate the damages, people need to manage their safety by themselves especially under the small scale disaster events. In this study, we suppose both heavy rainfall and huge earthquake. Disaster management should be properly composed of knowledge, decision making, and action.

Previously, in the study area, we surveyed people's opinion about risk communication in heavy rainfall with questionnaire: whether evacuate or not during heavy rainfall, and the reasons of preventing people from evacuation(Hayashi 2010). About 15% people do not intend to evacuate during heavy rainfall. Main reasons are that they don't know how to evaluate the safety of the evacuation places, and that the evacuation place is too far to safely arrive.

However, in this region, many houses are located at slopes susceptible to rainfall triggered landslide, such as mouth of valley and foot of steep slope. Many people need to evacuate to avoid damage due to landslide or debris flow. If the method for estimating susceptibility is clearly indicated and if people can find safe evacuation place neighboring their houses, they will be more motivated to evacuate.

Since landslides triggered by earthquake after heavy rainfall, for example, Chuetsu earthquake in 2004, put many villages in isolated situation in mountainous areas, evacuation places need to be selected by considering both rainfall and earthquake as triggering factors.

Our proposed method is composed of four steps.

1) To estimate slope stability and susceptibility of rainfall induced landslide and earthquake induced landslide by using topographical factors
2) To inquire residents' risk communication plans and their opinion about evacuation
3) To analyze the relationship or gap between topological susceptibility of landslide and risk communication
4) To provide required efforts and improvement toward proper a risk communication.

By applying the method to the study area, we evaluated their current risk communication and provided some suggestions.

2.2 Study area

Shionoe town is located at the south part of Takamatsu city and composed of three districts; Yasuhara, Shionoe, Kaminishi, (Figure 2).

In this study, our proposed method was applied to Kaminishi district because the designated evacuation places are far from residential area and safe evacuation is the most difficult in the three districts. Kaminishi district is in mountainous area with steep slopes. Most village and hamlet are located on river terraces and gentle slopes formed by ancient large-scale landslides. Kaminishi district beds consists of the Izumi Group. Izumi Group is mainly composed of alternation beds of sandstone and the shale. The beds strike east-north-east to west-south-west and dlp about 30° to the south.

The sedimentation is composed of sandstone and gravel, and it includes the various sizes of particles. It implies that previously debris flow had occurred in this area. Actually, there is a monument about one previous landslide triggered by heavy rainfall during the typhoon in 1912.

3. Geomorphological approach

3.1 Selection of stable slope

Most villages and hamlets are located on gentle slopes formed by large-scale landslide. These large-scale landslides have been stable since construction the present houses.

Inagaki et al. (2005) derived quantitative relationship between the age of landslide and slope stability. It reported that stability index of old landslides (it is formed about more than 10,000 years ago) is larger than 1.1(Figure 3). Old stable landslides have remained on the halfway of the slope and resemble river terrace.

Traditionally landform interpretation is based on aerial photo interpretation by operators using stereoscope. The results of interpretation can not be shared with many people, so it is very difficult to explain the topographical characteristics to local people. Therefore we use digital elevation data visualized by red relief image map technology (Chiba et al., 2007). It makes possible to share the topographical interpretation with many people and clearly illustrate the reason of the hazard assessment.

Figures 4 (i) show the slope in Monoigawa district. Figure 4 (ii) shows broadly selecting stable slope by interpreting landform, uphill gentle slope. Each area within a red circle are selected as stable slopes.

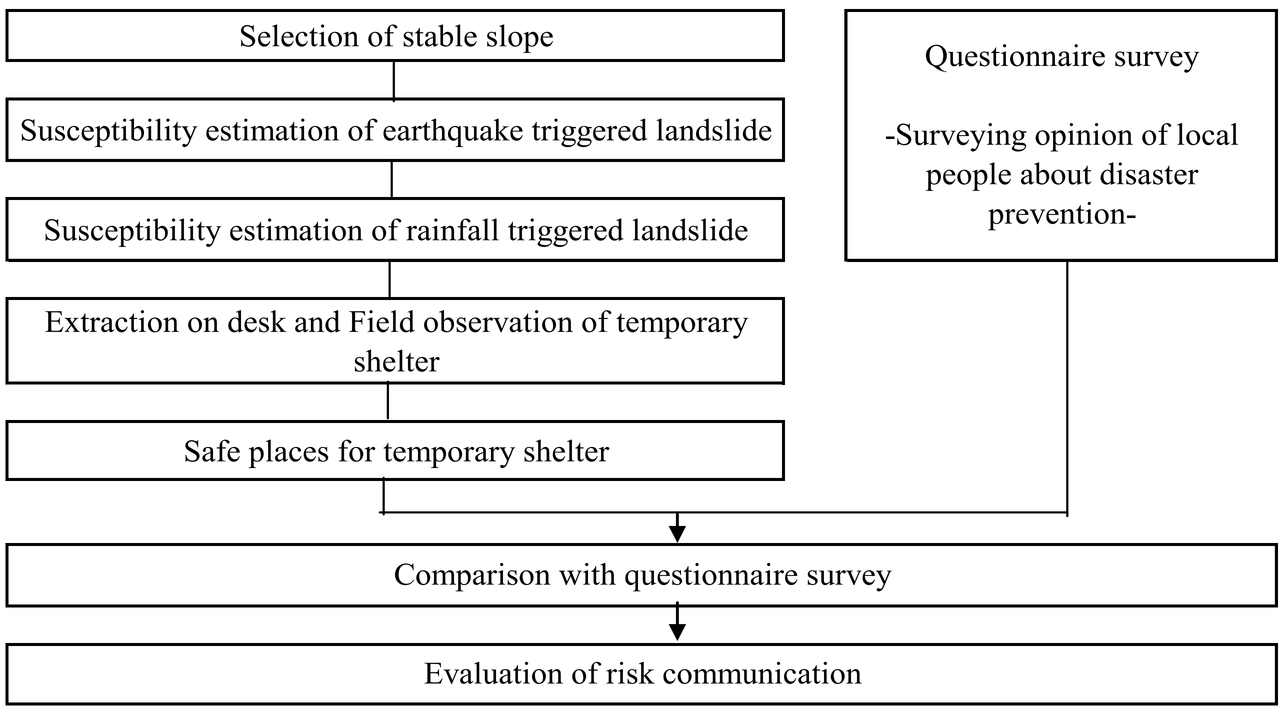


Figure 1 Research flow

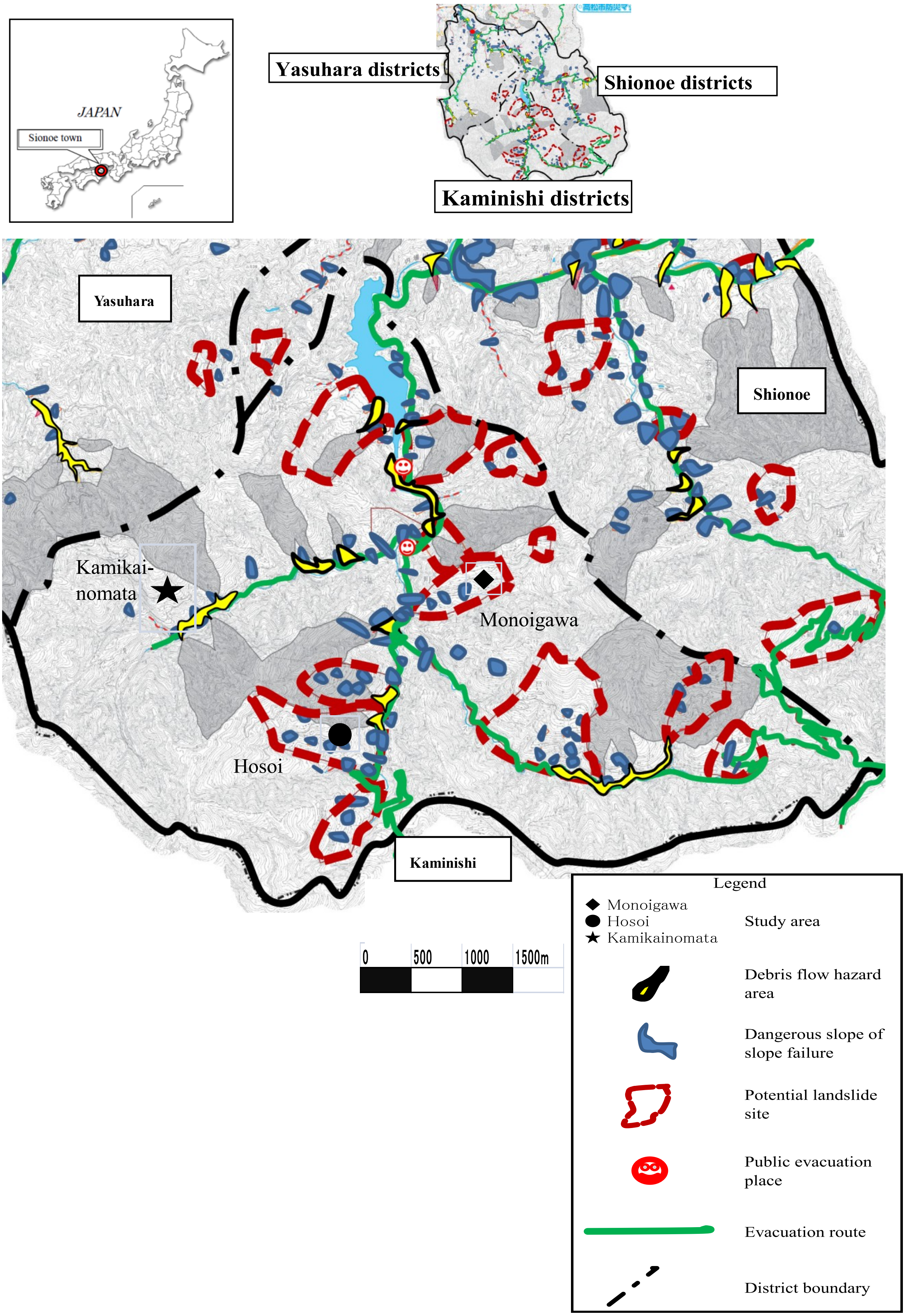


Figure 2 Study area (Three districts, Kaminishi, Yasuhara and Shionoe).
(modified from Takamatsu City Crisis Management Section(2008))

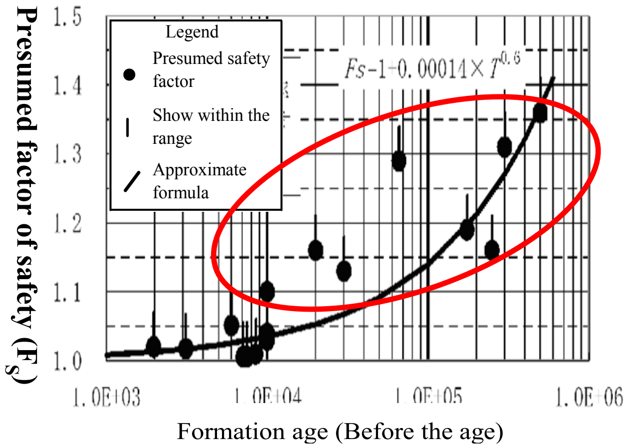
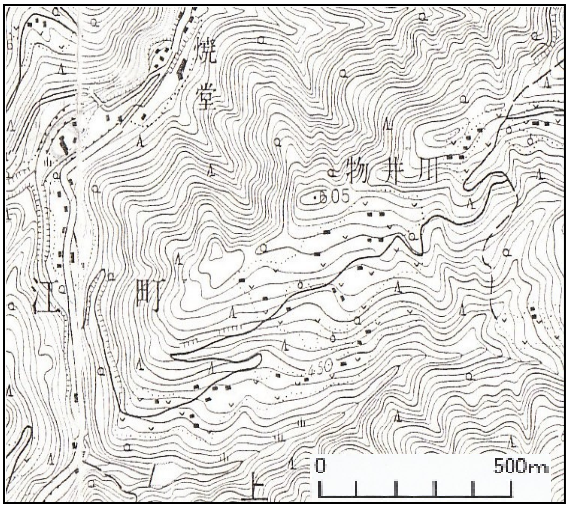
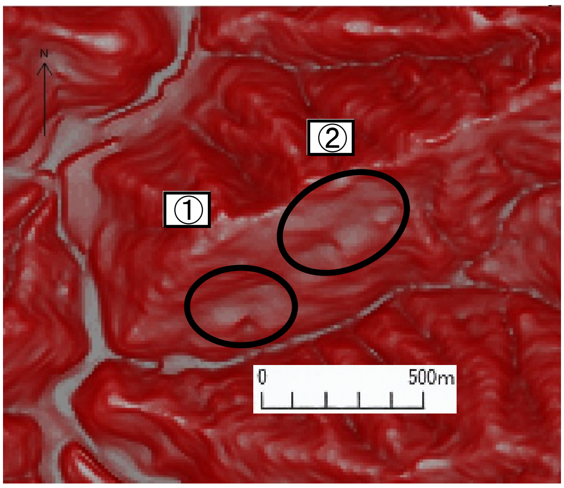


Figure 3 Formation age of ancient landslide and presumed Safety rate (Modified from Inagaki (2005))



(i)



(ii)

Figure 4 Maps of Monoigawa. (i) Topographical map, (ii) Broadly selected stable slopes (①② : The hill-sized gentle slope)

Slope stability was estimated by slice method (Japan Road Association, 2007) and selected area is regarded as a safe slope.

Figure 5 shows the linear relationship between depth of the slide surface and slope length of the landslide (Ueno, 2004). The depth of the slide surface is estimated by applying this relationship to length of the slope (Table 1).

$$L = 6.8D \quad \text{Eq. (1)}$$

L: Slope length of landslide(m) D: Landslide depth (m)

Slope stability is estimated by using cohesion (C:10kN/m^2), angle of internal friction (φ:25.55°), unit weight of soil, besides the depth of the slidesurface along profiles, which are located at the center of block. Figure 6 indicates the profiles in Monoigawa disatict. Along the all profiles, the safety value is estimated over 1.1 and it can be said that this slope is stable during earthquake.

3.2 Susceptibility estimation of earthquake triggered landslide

In order to estimate the susceptibility of earthquake triggered landslide, we followed the statistically derived relationship between landslide probability and morphological factors over Rokko area in Hyogoken nanbu earthquake (Uchida et al., 2004).

$$F = 0.075\times[\text{Slope gradient}(°)] - 8.9\times[\text{Average curvature}] + 0.0056\times[\text{Maximal acceleration}(cm/s^2)] - 3.2 \quad \text{Eq. (2)}$$

Eq. (2) was derived as discriminant function and F-value is discriminant value; F > 0 means there is any landslide probability, F ≦ 0 means there is no landslide probability, and the value of the F-value is corresponding with high possibility of slope failures.

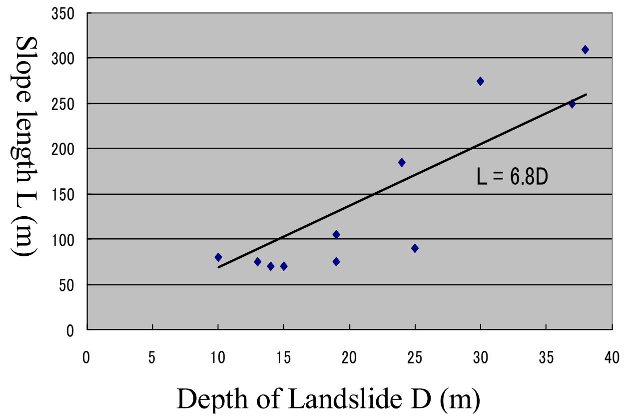


Figure 5 Relation between slope length and depth of landslide (after Ueno (2004))

Table 1 Estimated depth of slide surface by using Eq1

Slope number	The top		The bottom		Slope length	Presumed slide surface depth
	Distance (m)	Altitude (m)	Distance (m)	Altitude (m)	L(m)	D(m)
Monoigawa1	364.0	430.0	524.0	368.8	171.3	25.2
Monoigawa2	278.0	513.5	398.0	488.3	122.6	18.0
Monoigawa3	164.0	576.3	362.0	514.6	207.4	30.5

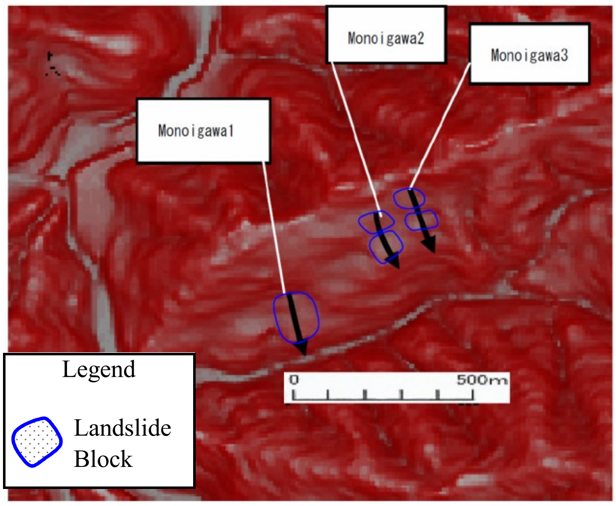


Figure 6 Representative profiles of the slope separated with blocks

Table 2 Result of slope stability calculation

Slope number	Sliding power(τ)	Sliding resistance power(S)			Safety
	(kN)	C(kN)	φ(kN)	Sum(C+φ)	factor
Monoigawa1	15456.243	1730.807	21688.225	23419.032	1.515
Monoigawa2	4286.709	1278.514	11611.947	12890.461	3.007
Monoigawa3	25527.106	2404.465	39886.547	42291.012	1.657

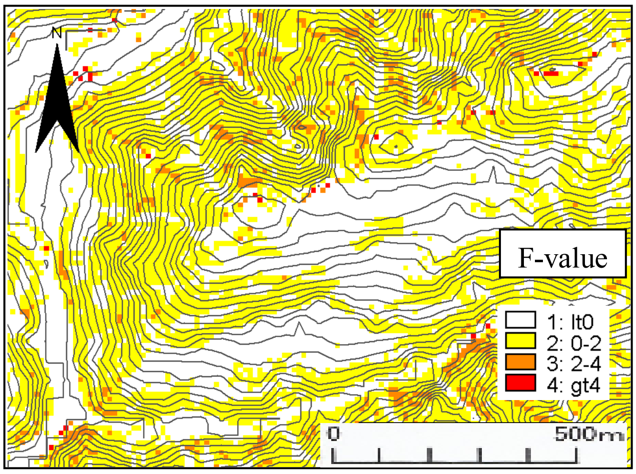


Figure 7 Estimated susceptibility of earthquake triggered landslide in Monoigawa

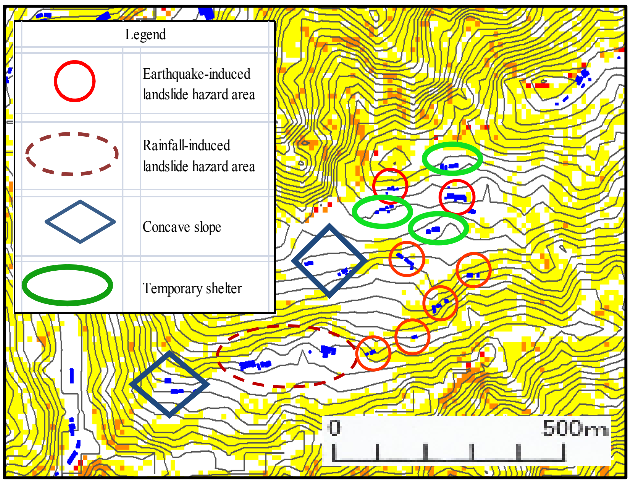


Figure 8 Classified buildings with availability as temporary shelters

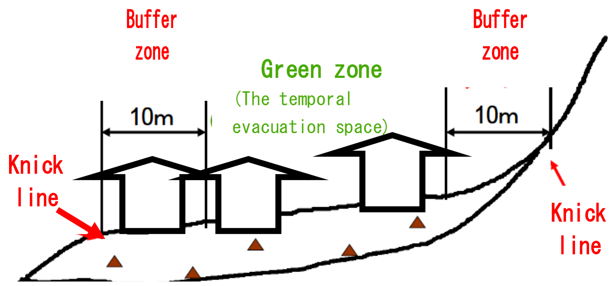


Figure 9 Susceptibility defined by considering micro topography of the slope (distance from knick lines)

F-value shows high value at steep and convex slope. The versatility of this relationship is identified in Chuetsu-oki earthquake (Hasegawa et al., 2009) even the geological condition is different from Rokko. Therefore, we estimate the susceptibility to earthquake triggered landslide by using Equation 2. Figure 7 shows the calculated F-value by using 10-m resolution DEM. The value is sliced into four classes. In this study, white area (F≦0) is regarded as safe space.

3.3 Susceptibility estimation of rainfall triggered landslide

In order to extract stable slope under heavy rainfall, we have omitted the sediment-related disaster warning area designated by Engineering Works part River Sediment Control Division of Kagawa Prefecture. The area within short dashed brown circle in Figure 8 shows debris flow hazard area and dangerous slope, extracted by analyzing a past disaster based on scientific knowledge.

3.4 Extraction on desk and Field observation of temporary shelter

Buildings located over the stable slopes were regarded as available buildings for temporary shelter during heavy rainfall and earthquake by extraction on desk.

After selecting stable slopes by using several kinds of data, we finally evaluate availability of each building located over the stable slopes with micro topographies; if it is located on a concave slope on near knick lines.

Figure 8 shows the classified buildings located over broadly selected stable slopes. Red circle shows buildings susceptible to rainfall induced landslide. Yellow rectangle shows buildings susceptible to earthquake induced landslide. Blue diamond shows building located on a concave slope, which is susceptible to debris flow after heavy rainfall.

Moreover, we made an assumption that stable slopes are also damaged if bounded slopes are failed (Figure 9). Knick lines are regarded as boundary between susceptible slopes. High slopes (higher than 5m) are already excluded by using the sediment-related disaster warning area. However, steep and susceptible slopes still might be included if their height are lower than 5m. In order to avoid damage obtained by landslide, buffer zone is defined to be 10m from the knick lines. It is twice of the maximum slope height, which might be affected if the slope is failed.

It also might be affected by landslide and it is called red zone in this study. Therefore available buildings for temporary shelter are selected from over the stable slopes (called blue zone), which are selected by considering slope stability, susceptibility to earthquake and rainfall triggered landslide, and the micro topographies.

3.5 Safe places for temporary shelter

In the study area, available buildings are extracted in three districts: nine out of ten houses in Monoigawa district, one of five houses in Kaminomata districs, and six of fourteen houses in Hosoi district. These temporary shelters are confirmed to safe by field observation of microtopography.

4. Comparison with questionnaire survey

4.1 Result of questionnaire survey

To understand the disaster prevention characteristic of each village, the hearing form that filled in the name and the address was collected.

In the three districts, people's opinions and their risk communications are surveyed by hearing research. Effective answers were obtained 60 %, 6 out of 10 in Monoigawa, 71 %, 10 out of 14 in Hosoi, 80 %, 4 out of 5 in Kamikainomata. Several kinds of hazard information are compared with their opinion (Table 3, Table 4 and Table 5).

The susceptibility of route from their houses to designated evacuation space is evaluated if it is included in "dangerous slopes of slope failure" and "debris-flow torrent" released by government. the susceptibility of their houses is evaluated by our proposed method.

If a house is located at out of blue zone but the inhabitant regards their house is unsusceptible to landslide, the risk can be considered “very high” and some improvements are necessary for their risk communication (B and E in Table 3, B, C and I in Table 5). If a house is located at blue zone but the inhabitant regards their house is unsusceptible to landslide, the risk can be considered “even” and some improvements are necessary for their risk communication(C in Table 3, A in Table 4, A, E, G and J in Table 5).

4.2 Evaluation of risk communication

Evacuation places will not be used, even it is safely available if people don’t have any motivation. In order to practically apply our proposed method to a community, we should also analyze their risk communication and their opinion, especially about evacuation.

In this study, we investigate the relationship between topographically estimated susceptibility and their opinion about safety of their own houses and availability of designated public evacuation building and temporal evacuation place within community.

If there is no gaps between topographically estimated susceptibility and opinion about susceptibility of their own houses, risk communication is already properly done. On the other hand, if there is any gap between topographically estimated susceptibility and opinions about susceptibility of their own houses, there is any possibility that risk communications are not properly done.

5. Conclusion

As one of the risk communication, various types of hazard map have been released from various institutes, such as local government, community. Those are useful to know the hazard. However, in some areas, whole community is included in hazard area and designated evacuation places are not available because of the safety of the route. It is often found in mountainous areas.

However, in fact, susceptibility depends on the local topography and susceptibility is relatively different. Therefore, for practical and reliable risk communication, available zone should be investigated.

In this study, we proposed the method to evaluate the susceptibility to landslide by considering topographies and to select temporal evacuation buildings.

Moreover we also proposed a method to evaluate resident’s risk communication and improve it by considering the relationship between residents’ opinion and topographical susceptibility. As a next step, the availability of the selected buildings will be practically discussed with the local people and the temporary shelter will be designated in the community.

Table 3 Necessity of early evacuation (Monoigawa)

Building	Danger of route to temporal evacuating place		Landslide susceptibility (Figure 8) (A)	Resident's evaluation about susceptibility to landslide (B)	Evacuate or not during heavy rainfall or earthquake (C)	Potential risk (A/B)	Necessity of early evacuation	Safe place for temporarily evacuation
	Dangerous slope	Debris flow						
A	〇	〇	safe	safe	no	even	No	O
B	▲	〇	unsafe	safe	no	high	Yes	
C	▲	〇	unsafe	unsafe	no	even	Yes	
D	〇	〇	safe	safe	Yes	even	No	O
E	〇	〇	unsafe	safe	no	high	Yes	
F	〇	〇	safe	unsafe	no	even	No	O

Table 4 Necessity of early evacuation (Kamikainomata)

Building	Danger of route to temporal evacuating place		Landslide susceptibility (Figure 8) (A)	Resident's evaluation about susceptibility to landslide (B)	Evacuate or not during heavy rainfall or earthquake (C)	Potential risk (A/B)	Necessity of early evacuation	Safe place for temporarily evacuation
	Dangerous slope	Debris flow						
A	▲	〇	unsafe	unsafe	no	even	Yes	
B	〇	〇	safe	unsafe	no	low	No	O
C	〇	〇	safe	safe	no	even	No	O
D	〇	〇	safe	safe	no	even	No	O

Table 5 Necessity of early evacuation (Hosoi)

Building	Danger of route to temporal evacuating place		Landslide susceptibility (Figure 8) (A)	Resident's evaluation about susceptibility to landslide (B)	Evacuate or not during heavy rainfall or earthquake (C)	Potential risk (A/B)	Necessity of early evacuation	Safe place for temporarily evacuation
	Dangerous slope	Debris flow						
A	▲	〇	unsafe	unsafe	no	even	Yes	
B	▲	〇	unsafe	safe	no	high	Yes	
C	〇	〇	unsafe	safe	no	high	Yes	
D	〇	〇	safe	unsafe	no	low	No	O
E	▲	〇	unsafe	unsafe	no	even	Yes	
F	〇	〇	safe	unsafe	no	low	No	O
G	▲	〇	unsafe	unsafe	no	even	Yes	
H	〇	〇	safe	safe	no	even	No	O
I	▲	〇	unsafe	safe	no	high	Yes	
J	▲	〇	unsafe	unsafe	no	even	Yes	

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