BASIS OF SEDIMENT DISASTER

CHAPTER 1 PRINCIPLES OF OCCURRENCE OF SEDIMENT DISASTERS

1.1 Modes of Sediment Disaster Occurrence

1.1.1 Phenomena to cause sediment disasters

Sediment disasters are defined as the phenomena that cause direct or indirect damage to the lives and properties of people, inconveniences to the life of people, and/or the deterioration of the environment, through a large-scale movement of soil and rock. Damage due to these disasters occurs in several forms: 1) the ground on which buildings and farmland are situated are lost due to a landslide or an erosion; 2) houses are ruined by the destructive force of soil and rock during their movement; 3) houses and farmland are buried underground by a large-scale accumulation of discharged sediment; and 4) aggradation of a riverbed and burial of a reservoir are caused by sediment discharge along a river system, which may invoke flooding, disorder of water use functions, and deterioration of the environment.

Sediment disasters are roughly categorized into two types: 1) the direct type sediment disasters that cause direct damage as a result of sediment movement; 2) the indirect type sediment disasters that cause a flood or an inundation through the aggradation of a riverbed or blocking of a river course. Disasters of the latter type are not the subject of the present Guidelines. Phenomena that cause the direct type sediment disasters include debris flows, slope failures, and landslides. They are explained as follows:

Table 1.1 Phenomena that cause the direct type sediment disasters: debris flow, slope failure, and landslide [4)]

Debris flow	This is a phenomenon in which soil and rock on the hillside or in the riverbed are carried downward at a dash under the influence of a continuous rain or a torrential rain. Although the flow velocity differs by the scale of debris flow, it sometimes reaches 20-40 km/hr, thereby destroying houses and farmland in an instant.
Slope failure	In this phenomenon, a slope abruptly collapses when the soil that has already been weakened by moisture in the ground loses its self-retainability under the influence of a rain or an earthquake. Because of sudden collapse, many people fail to escape from it if it occurs near a residential area, thus leading to a higher rate of fatalities.
Landslide	This is a phenomenon in which part of or all of the soil on a slope moves downward slowly under the influence of groundwater and gravity. Since a large amount of soil mass usually moves, a serious damage can occur. If a slide has been started, it is extremely difficult to stop it.

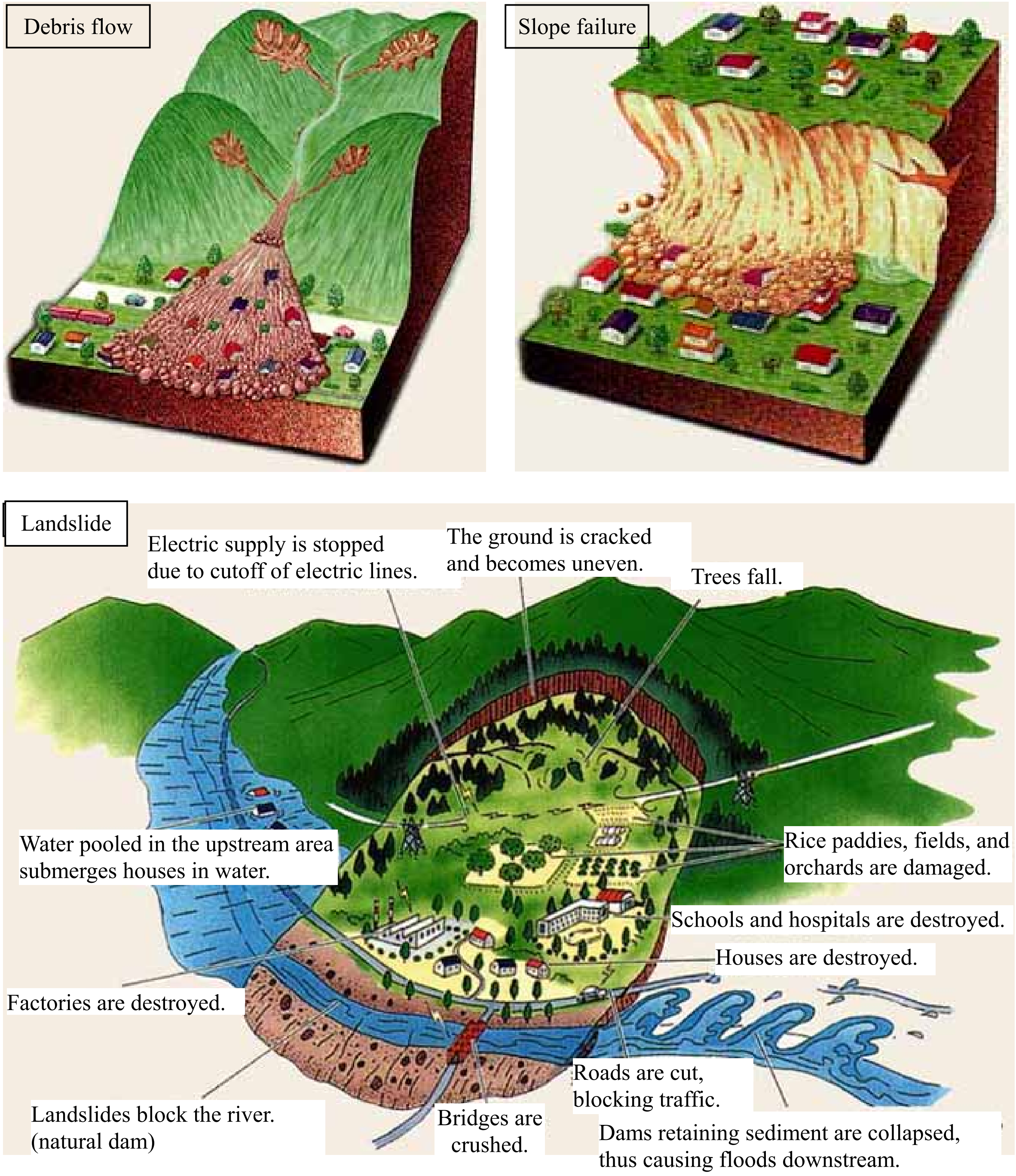


Fig. 1.1 Phenomena that cause the direct-type sediment disasters: debris flow, slope failure and landslide [2)]

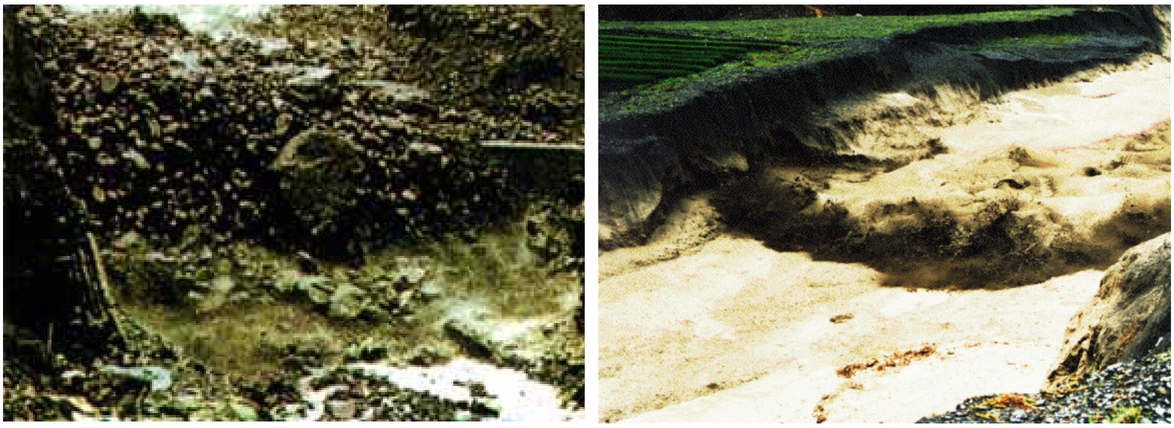
1.1.2 Types of debris flows

Debris flows occur in a variety of forms depending on the conditions of the site and the factors contributing to their occurrence. When classified by the contributing factors, debris flows are roughly divided into five types, as shown in Table 1.2. Except for the natural dam collapse type, all types of debris flows are primarily related to the short-term (less than one hour) rainfall intensity.

Table 1.2 Types of debris flows classified by contributing factors [4)]

Type	Features
Riverbed sediment movement type (sediment gradient type)	Mass discharge of sediment is triggered when the sediment accumulated on the riverbed exceeds the gradient made by the bed-load transport of sediment and the balance between them is lost.
Slope failure type	A slope failure directly changes into a debris flow.
Natural dam collapse type	A debris flow is caused due to the collapse of a natural dam which is formed by landslide or slope failure.
Landslide type	A debris flow occurs as the last stage phenomenon of a landslide. It occurs because the soil is almost liquefied due to extremely clayey alteration.
Volcanic activity type	In a narrow sense, this means debris flows caused by a volcanic eruption or an earthquake. But, in a broad sense, it means debris flows that occur in areas of an active volcano. A volcanic mudflow is also included in this type. Debris flows of this type are rich in fine grains, highly flowable, and readily occur even under a small rainfall.

The flow mode and flow characteristics of debris flows differ largely depending on the type, size, and concentration of stoney grains included in them. If a large amount of coarse gravel and a relatively small amount of fine grain finer than silt are contained, it is called the gravel type debris flow. In contrast, if a small amount of coarse gravel and a large amount of fine grain are contained, it is called the mudflow type debris flow. If the amount of clay and silt is especially large, it is called the viscous type debris flow.



Gravel type debris flow: a debris flow occurred at Kamikamihori Valley in Mt. Yakedake

Mudflow type debris flow (viscous type debris flow): a debris flow occurred at Jiangja Creek, Yunnan Province, China

Fig. 1.2 Examples of the gravel type debris flow and the mudflow type debris flow [2)]

1.1.3 Slope failures and landslides

The Working Committee on World Landslide Inventory, which was set up in cooperation of UNESCO and international academic societies related to foundation engineering, has defined the landslide as the "movement of a mass of rock, debris or earth down a slope". It classified landslide movements into not only slide but also fall, topple, spread, and flow in terms of kinematics.

Meanwhile, the Landslide Prevention Law of Japan defined the landslide as the "phenomenon in which part of land slides or moves downward under the influence of groundwater or other factors". This law is intended to cover a phenomenon that almost never moves at high speed in a large scale at a time (therefore, this is referred to as "J-landslide" to distinguish it from a landslide in a broad sense). In another Japanese law, namely, the Law Concerning Prevention of Disasters due to Collapse of Steep Slopes (Steep Slope Law), slopes with a gradient of 30°or over are defined as steep slopes and they are assumed as hazardous slopes at risk of collapse. This law is mainly intended to cover a phenomenon in which soil and rock move downward at high speed (slope failure). The differences between j-landslides and slope failures are outlined in Table 1.3. As seen, j-landslides are different from debris flows and slope failures in that the former is slow at moving speed and difficult to predict. Therefore, j-landslide is not included in the subjects of the current Guidelines.

Table 1.3 Features of slope failure and j-landslide [5)]

Item	J-landslide	Slope failure (landslip, earth fall)
Geology	Occurs in specific geology and geological structure.	Almost no relation to geology
Topography	Occurs at a gentle slope in a so-called landslide topography	Occurs at a steep slope.
Depth of movement	Several meter to over 10 meter	Within 1-2 m
Scale of movement	Large	Small
Speed of movement	Usually slow, sometimes abrupt	Abrupt
Incitant factors	Groundwater	Torrential rainfall
Signs of movement	Tilted trees, cracks on the ground surface	Almost none
Land use	Used as arable land	Not used
Possibility of recurrence	Possible	Not possible for several years to over a decade

1.2 Mechanical Factors and Incitant Factors of Sediment Disasters

Both mechanical factors and incitant factors should be considered as the factors contributing to the occurrence of sediment disasters. Mechanical factors are the conditions of the site where a sediment disaster occurs, and incitant factors are the forces applied to the occurrence site as the external forces. The mechanical factors and incitant factors of debris flows and slope failures are summarized in Table 1.4.

Table 1.4 Mechanical factors and incitant factors of debris flows and slope failures [5)]

	Debris flow	Slope failure
Mechanical factors	**Topography of river basin:** Existence of an unstable hillside in a steep slope, ease of convergence of surface water, presence of groundwater and spring water **Topography of river:** Longitudinal gradient of riverbed, plane and longitudinal configurations of river course **Unstable sediment**: Thickness of weathered soil layer in a hillside slope, thickness and amount of riverbed sediment, volumetric concentration and grain size distribution of accumulated sediment, accumulated sediment due to slope failure	**Geology:** In addition to the strength of rocks, dominant factors are the level of weathering, alteration, fissure and fracture, direction of layers, conditions of permeable layers, and distribution of loose layers such as a surface layer. **Topography:** Failures tend to occur at slopes of 40-50°, and at slopes or locations easy to collect rainwater, such as a concave type slope, the bottom of a long slope, and the bottom of a gentle slope. **Vegetation:** Forests have a collapse prevention effect with regard to surface failures caused by infiltration of torrential rainfall.
Incitant factors	**Rainfall, snowmelt:** Sudden increase of water discharge, a large amount of rainwater discharge **Earthquake, volcanic activity:** A large amount of unstable sediment produced by slope failure (mechanical factor), collapse of a crater lake and outflow of snowmelt due to a volcanic eruption	**Rainfall, snowmelt:** The number of slope failures increases if a rainfall of strong intensity occurs when the ground is already moist. **Earthquake, volcanic activity:** The ground becomes unstable when stress conditions in the slope are altered due to an earthquake or a volcanic eruption. **Groundwater:** An increase in pore water pressure caused by a subsurface flow due to rainfall leads to a slope failure. **Artificial activities:** Deforestation, artificial changes of a natural slope by cut and fills.

[Reference: Mechanical factors and incitant factors of j-landslide]

Mechanical factors	J-landslides occur most frequently in the layer called the Tertiary formation which was formed some two million to sixty million years ago. The reason is that, as this formation is relatively new, rocks are low in the degree of solidification and less resistant to weathering. Weathering of this formation is distinctive in that soil and rock are quickly granulated and become clayey by the repetition of drying and wetting called slaking. Of the two stones - sandstone and mudstone - in this formation, mudstone contains smectite (montmorillonite) that has a property of swelling, which is one of causes of a landslide.
Incitant factors	The incitant factor causing a landslide is water. Water from rainfall and snowmelt permeates into the ground. The permeated water generates a pore water pressure and then decreases the shear strength of the soil. Therefore, landslides tend to occur in the rainy season or at the time of typhoons. In the meantime, landslides due to artificial causes are grouped into two types: landslides that occur due to cut of slopes in landslide areas; landslides that occur due to cut or fill of slopes in non-landslide areas. The former type of landslides can be predicted by the reading of landslide survey maps and aerial photographs. The latter type of landslides is difficult to predict, but not so hard to prevent if structural works are installed.

1.3 Mechanism of Occurrence of Sediment Disasters

A slope failure occurs when the balance between the shear stress and the shear resistance of the soil in a slope is lost. The former is a force to cause a slide and the latter is a force to prevent it. Slope failures can occur in any steep slopes. The incitant factors of slope failure are mainly those that work to decrease the shear resistance of the soil in a slope, such as rainfall and the rise of groundwater level.

On the other hand, landslides of the riverbed sediment accumulation type (sediment gradient type) are triggered when a soil mass loses its stability due to saturation and the resulting decrease of friction resistance. The occurrence mechanism of this type of landslide is essentially the same with that employed in the stability analysis of large slopes.

In brief, slope failures and debris flows occur when the force to move a soil mass become greater than the shear resistance derived by the Mohr-Coulomb's Equation shown below.

$$\tau = c + (\delta - u)\tan\phi \cdots\cdots\cdots\cdots (1)$$

where τ: shear stress
δ: normal stress
ϕ: internal friction angle
c: cohesion of soil and gravel
u: pore water pressure

1.3.1 Mechanism of occurrence of slope failures

When a linear slip surface with a depth of h and parallel to a slope gradient θ is assumed, as shown in Fig. 1.3, the occurrence of a slope failure is determined by the relative magnitude of the force component of collapsing soil mass, τ, that works along the slope and the shear resistance of the soil, τ_L. The safety factor, F, which indicates the stability of a slope is given by $F = \tau_L / \tau$, and the slope stability is judged using the following criteria:

$F > 1$: failure is unlikely

$F < 1$: failure is likely

$F = 1$: critical state

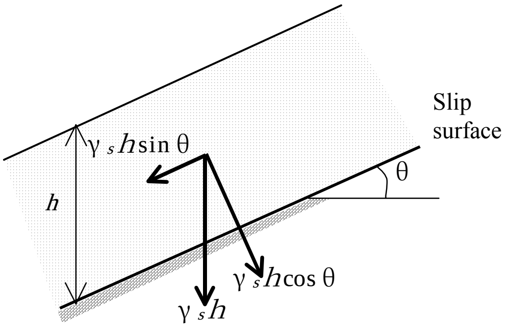


Fig. 1.3 A representation of stability analysis of a slope that has a linear slip surface parallel to the ground surface

When the density of soil is given by γ_s, F is derived by the following equation.

$$F = \frac{c + (\gamma_s g h \cos\theta - u)\tan\phi}{\gamma_s g h \sin\theta} \cdots\cdots\cdots\cdots (2)$$

where g : gravitational acceleration

1.3.2 Mechanism of occurrence of debris flows

In debris flows of the riverbed sediment accumulation type (sediment gradient type), a surface water flow is generated and its weight has a significant effect on the stability conditions of a slope. Also, as the soil mass is already saturated when a surface water flow is generated, the volumetric density of soil mass, γ_s, which was also used in Equation (2) is given as shown below, using the density of soil grain, σ, the density of water, ρ, and volumetric density of sediment, C_*.

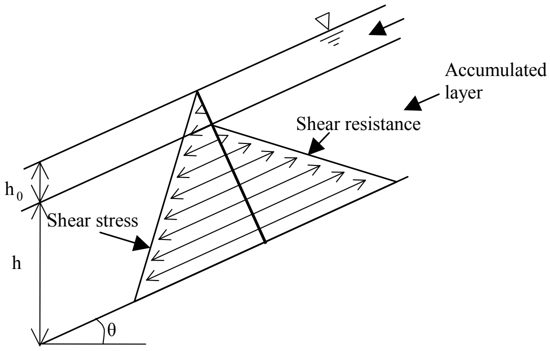


Fig. 1.4 A representation of stress distribution when a surface flow is present

$$\begin{aligned}\gamma_s &= C_*\sigma + (1-C_*)\rho \\ &= C_*(\sigma-\rho)+\rho\end{aligned} \quad \cdots\cdots (3)$$

Accordingly, when the thickness of accumulated layer, *h*, and the depth of surface water flow, h_0, are used, the shear stress acting on the bottom of a soil mass, τ, becomes as follows:

$$\tau = \left[\{C_*(\sigma-\rho)+\rho\}gh + \rho g h_0\right]\sin\theta \quad \cdots\cdots (4)$$

On the other hand, if it is assumed that the only normal stress acting on the bottom of the soil mass is the effective stress of the soil mass, the pore water pressure existing in the soil mass can be ignored. Further, if cohesion of the soil mass is ignored by assuming it to be too small, the shear resistance, τ_L, becomes as shown below.

$$\tau_L = C_*(\sigma-\rho)gh\cos\theta\tan\phi \quad \cdots\cdots (5)$$

Then, the equilibrium equation between them becomes as follows:

$$\left[\{C_*(\sigma-\rho)+\rho\}gh + \rho g h_0\right]\sin\theta = C_*(\sigma-\rho)gh\cos\theta\tan\phi \quad \cdots\cdots (6)$$

If the value on the left side (shear force) exceeds that of the right side (shear resistance), a debris flow is caused. Hence, a critical slope gradient, θ_p, which distinguishes the occurrence and non-occurrence of a debris flow, is obtained by the following equation.

$$\tan\theta_P \geqq \frac{C_*(\sigma-\rho)}{C_*(\sigma-\rho)+\rho(1+h_0/h)}\tan\phi \quad \cdots\cdots (7)$$

Takahashi considered that only the forces that work between the grains are effective as the shear resistance, and expressed the critical gradient for the occurrence/non-occurrence of debris flows as shown below, using the grain size, *d*, instead of the thickness of accumulated layer, *h*.

$$\tan\theta_P \geqq \frac{C_*(\sigma-\rho)}{C_*(\sigma-\rho)+\rho(1+h_0/d)}\tan\phi \quad \cdots\cdots (8)$$

With regard to the behavior of a debris flow and the riverbed gradient, it is known that there is a relationship as shown in Table 1.5.

Table 1.5 Relationship between the behavior of a debris flow and the riverbed gradient

Behavior of debris flow	Gradient of riverbed	
	Ordinary mountain streams	Volcanic area
Section where a debris flow occurs	20°≤ θ	15° ≤ θ
Section where a debris flow runs down and accumulates	10° ≤ θ < 20°	10° ≤ θ < 15°
Section where sediment accumulates	3° ≤ θ < 10°	2° ≤ θ < 10°

Note) Cases are reported in which a debris flow containing a large amount of fine sediment, much like a sediment flow, reached an area with a riverbed gradient less than 3° (less than 2° in case of a volcanic sabo area), when allowed by the properties of the debris flow and topographical conditions of the site. This table is usable as a reference for debris flows of riverbed sediment movement type (sediment gradient type: see Table 1.2).

1.4 Prediction of Sediment Disaster Occurrence by Rainfall

Slope failures and debris flows are most often caused by rainfall and the resulting river flow, except for the cases caused by an earthquake, volcanic activity, and snowmelt among the direct incitant factors shown in Table 1.4. It is a well-known fact that influential rainfall differs not only by the type of sediment movement such as slope failure or a debris flow but also by the kind of topography and geology in the area.

The prediction method of the occurrence of sediment disasters are roughly categorized into three types:

1) **Method utilizing the measurements of sediment movement**
A wire sensor for detection of debris flow, a vibrometer for detection of debris flow, a clinometer, observation and monitoring by humans

2) **Method used for the prediction of sediment movement in a wide area**
This is a method to predict sediment movement, like a debris flow and a slope failure, in a wide area that shares some common features, like an entire river basin.

3) **Method used for the prediction of sediment movement at a specific location**
This is a method to predict sediment movement at a specific location vulnerable to a debris flow or a slope failure, by conducting intensive surveys on topography, geology, and rainfall and constant monitoring on signs of movement.

In the case of floods, it is possible to take a warning and evacuation activity or a flood fighting operation with some preparation time, if changes in rainfall and water level have continuously been monitored. However, in the case of sediment disasters, prediction of an approaching danger is almost impossible unless the very site of soil movement has been identified and it is continuously monitored. Even though dangerous conditions are detected, safe evacuation of the local people is very difficult because a debris flow or collapsed sediment reaches their houses in such a short time. However, if the rainfall is utilized and the hourly rainfall data is obtainable, disaster occurrence can generally be predicted one or two hours before. This allows enough time for people to evacuate safely. In view of this, a disaster prediction method targeting a wide area utilizing the rainfall that is relatively easy to obtain is employed in the current Guidelines as the basic approach.

CHAPTER 2 ACTUAL STATE OF SEDIMENT DISASTERS

AND PREVENTIVE MEASURES

2.1 Actual Damage due to Sediment Disasters

A sediment disaster is not so large as an earthquake, flood, storm surge or tsunami, in terms of the size of occurrence, but its danger to human lives is very high because it occurs at multiple locations at a time. In Japan, 54% of the dead and missing by natural disasters during the 31-year period from 1967 to 1997 are accounted for by sediment disasters (excluding the victims in the Hanshin Awaji Earthquake in 1995).

In the case of sediment disasters, it is very difficult to install preventive works at every location in need of them because such locations are virtually countless. Therefore, it is important to mitigate damage by establishing an effective warning and evacuation system, which includes the grasp of hazard areas, prediction of dangerous phenomena leading to a disaster, and designation of sediment disaster hazard areas. Actually, many cases has been reported in which people were not involved in sediment disasters because they evacuated in time by detecting the disaster signs quickly. This clearly indicates that the local people have or do not have knowledge of potential disasters in their area spells the difference between their life and death.

Before modern times, few people lived in an area susceptible to sediment disasters. And if they lived in such an area, they handed down disaster experiences from generation to generation as the history of their area. However, with the rapid increase of population and the enlargement of arable land after entering the modern times, the population living in hazardous areas has increased enormously. People living in newly developed areas often do not have knowledge about sediment disasters. Such a change of the social environment is one of factors worsening the damage of disasters. Here, sediment disaster cases in Japan, Indonesia, and Nepal in recent years are introduced.

2.1.1 Examples of debris flow disasters

(1) Debris flow disaster in Kagoshima Prefecture (Japan) [2)]

In July 1997, a large-scale debris flow occurred in the Harihara area, Izumi City, Kagoshima Prefecture, killing 21 people.

[Date]
At 0:44 on July 10, 1997
[Location]
Harihara, Sakai-machi, Izumi City, Kagoshima Prefecture
River name: the Harihara River (basin area: 1.55 km^2; total length: 2.3 km)
[Damage]
Death - 21, injury - 13, building damage - 29, damage to farmland - 10.2 ha.
[Rainfall]
Continuous rainfall - 401 mm (midnight of July 6 - 24:00 of July 9), daily rainfall - 275 mm (July 9), maximum hourly rainfall - 62 mm (16:00-17:00, July 9)
[Scale of failure]
Slope length - approx. 200 m, width - approx. 80 m, maximum failure depth - 28 m, sediment volume collapsed - 166,000 m^3 (80,000 m^3 ran down to the downstream of the sabo dam), average gradient - 26°

A Sabo dam built on the upstream of the disaster-stricken area exhibited an effect by capturing over 50,000 m^3 of sediment, but the total sediment volume collapsed was far greater than the design sediment volume.

On the evening of July 9, the local people were advised to evacuate to a community center used as a refuge facility, but none evacuated to this facility.

(2) Torrential rainfall disaster in Hiroshima Prefecture (Japan) 2)

Hiroshima Prefecture is a region susceptible to sediment disasters because of its topographical and geological features. The number of places at risk of sediment disasters in this prefecture amounts to over 30,000. On June 29, 1999, a large-scale disaster was caused by localized torrential rainfall due to a stationary front. Damage occurred not only in this prefecture but in a huge area, extending from the Chugoku and Kansai regions to the Tokai region.

In the northwestern part of Hiroshima City and in Kure City where torrential rainfall was especially serious, slope failures and debris flows were triggered at multiple locations simultaneously, killing 31 persons and missing 1 person in total.

[Date]
On the evening of June 29, 1999
[Location]
North and northwestern parts of Hiroshima City, Kure City, and other places in Hiroshima Prefecture
(Slope failure -186 locations, debris flow - 139 locations)
[Damage]
Death - 31, missing - 1, houses of total collapse - 154
[Rainfall]
Continuous rainfall - 271 mm (June 28 - 29, obtained at Toyama), maximum hourly rainfall - 82 mm (14:00 - 15:00, June 29, at the Yawatagawa Bridge)

(3) Flood and sediment disasters on Nias Island in the Province of North Sumatra (Indonesia) 8)

Sediment disasters occur almost every year in Indonesia. Just like Japan, Indonesia is a country having both mechanical and incitant factors of disasters, such as topographical and geological features, a number of active volcanoes, earthquakes, and torrential rainfalls. More than 280 people were reported victimized in a sediment disaster that occurred in the southern part of Nias Island in the Province of North Sumatra in 2001.

[Date]
At midnight of July 31, 2001
[Location]
The southern part of Nias Island in the Province of North Sumatra
[Damage (estimated)]
Death - 77, missing - 95, houses - 325, school - 1, bridges - 5, public facilities - 2, farmland - several thousand ha.
[Rainfall]
Daily rainfall - 222 mm

(4) Debris flow disaster in Modjokerto Prefecture in the Province of East Java (Indonesia) 8)

A total of 32 people were killed in a debris flow disaster that occurred in Modjokerto Prefecture in the Province of East Java in 2002. The victims included many children who were playing in a hot water swimming pool built on a riverbank extracting water from a nearby hot spring.

[Date]
Around 14:30 of December 11, 2002
[Location]
Pacet in Modjokerto Prefecture in the Province of East Java
River name: the Dawahan River, a tributary of the Cumpleng River (basin area: 4.5 km^2)
[Damage]
Death – 32
[Rainfall]
Daily rainfall - 222 mm
[Scale of failure]
Discharged sediment - 7,000 m^3

The biggest cause of this disaster involving a number of human lives is considered to be an artificial one. The affected site is a mountain stream that experienced another sediment disaster in the past, which is clearly known from topography around the site as well as from the sediment accumulated in the stream. However, this kind of debris flow risk was not understood among those concerned with the resort development project.

(5) Slope failure and debris flow disasters in Matatirtha (Nepal) 9)

Natural disasters occur almost every year in Napal under the influence of monsoons as well as due to topographical and geological structures that are being formed by the still active orogenic movements. 55 sediment disasters occurred in this country in 2002, resulting in a loss of over 380 people in total.

[Date]
On the morning of July 23, 2002
[Location]
At a place about 4 km away from the western end of the loop road encircling the capital city of Kathmandu
[Damage]
Death - 16, damage to houses - 8, damage to roads - several locations, damage to farmland - approx. 1 ha
[Rainfall]
Daily rainfall - 207 mm (the largest in the past 30 years)
[Discharged sediment]
Collapsed sediment - approx. 7,000 m^3, discharged sediment - approx. 1,500 m^3

2.1.2 Examples of slope failure disasters

(1) Slope failure disaster in Kubmen Prefecture in the Province of Central Java (Indonesia) 8)

[Date]
Around 21:30 of October 4, 2001
[Location]
Lemah Abang Hill in Kubmen Prefecture in the Province of Central Java
[Damage]
Death - 9, injury - 4, damage to houses – 4
[Rainfall]
Continuous rainfall - 190 mm (rainfall continued for abut 6 hours)
[Scale of failure]
Slope length – 200-300 m, width – 30-70 m, estimated sediment volume - 25,000 m^3, slope gradient – 30-60°

According to the results of field survey, the disaster occurred in two stages: (i) relatively slow collapse at the lower area of slope; (ii) sudden collapse at the middle to upper area of slope.

(2) Slope failure disaster at 15+050 positions of the Kathmandu-Naubise road (Nepal) 9)

[Date]
Around 22:00-23:00 of July 22, 2002
[Location]
At a place 15 km to the west of Kathmandu, along the Tribhuvan Highway
[Damage]
Death - 9, injury - 1, damage to houses - 2, damage to roads - several locations
[Rainfall]
Daily rainfall - 93.5 mm, hourly rainfall just before the start of disaster - 13.0 mm
[Scale of failure]
Slope length - approx. 110 m, width – 30-40 m, estimated sediment volume - 1,500 m^3, slope gradient - 45°

The incitant factor of this slope failure was the rainfall, but the mechanical factor was that a gutter installed along the road was blocked with sediment from a small-scale roadside failure and the flowing water converged at the head area of this slope failure disaster.

(3) Sediment disaster at Butwal City (Nepal) 9)

A slope failure and the ensuing debris flow occurred in three consecutive stages on August, 27, August 29, and September 5, 1998 at the suburb of Butwal City located at some 180 km to the west of Kathmandu.

[Date]
August 27-September 5, 1998
[Location]
Churia Hill in the suburb of Butwal City (the Lumbini zone in western Nepal)
[Damage]
Death - 1, injury - 2, houses of total collapse - 35
Total damage value - approx. 58 million Nepal rupee
[Rainfall]
(No data are available. Local people said in the post-disaster hearing that a rainfall with high intensity continued for long hours after the first collapse had occurred.)

2.2 Present State of Structural Measures against Sediment Disasters

2.2.1 Structural measures against debris flows

As the method to control debris flows, three methods are considered: (i) to prevent the start of debris flow movement; (ii) to prevent the growth of debris flow movement that has already started; (iii) to dissipate the energy of debris flow movement and put it under control. Preventive measures against debris flows should be determined by considering topographical conditions, subjects of conservation, and the cause and flow mode of a debris flow in each of the occurrence area, the flowing area, and the sedimentation area. Primary preventive measures to be taken in each area are described below:

- Occurrence area: soil retaining works, groundsill works, etc.
- Flowing area: sabo dam with a sedimentation reservoir, sabo dam with slits, sand pocket, etc.
- Sedimentation area: revetment works, training dike works, channel works, dam works, etc.

A sabo dam is the most principal measure to be taken against debris flows. It can provide a variety of functions, ranging from the storage function like arrest and accumulation of debris flow, control function of sediment load, erosion control function, conversion function of transportation mode, and grading function of grains. Sabo dams can provide a certain level of effect even after they are filled up with sand.

No. 1 sabo dam on the Name River in the Kiso River system: A large-scale debris flow occurred in July, 1989 due to localized torrential rainfall, but this sabo dam prevented it from reaching the downstream.

Sabo dam in mid-area of the Aratani River: A debris flow and accompanying driftwood were restrained by this sabo dam in a torrential rainfall disaster that occurred in the coastal area in Hiroshima Prefecture in June, 1999.

Fig. 2.1 Sabo dams constructed in the flowing area of debris flow [2)]

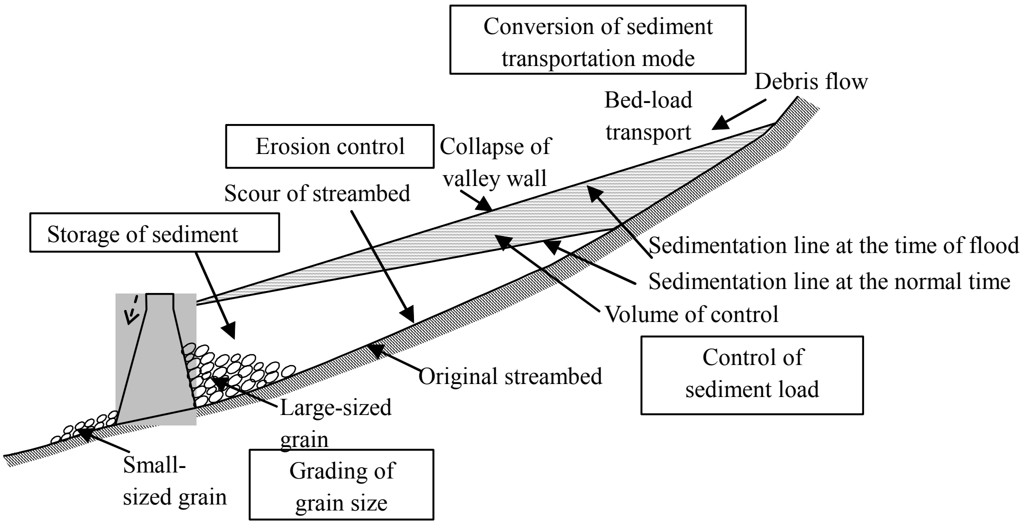


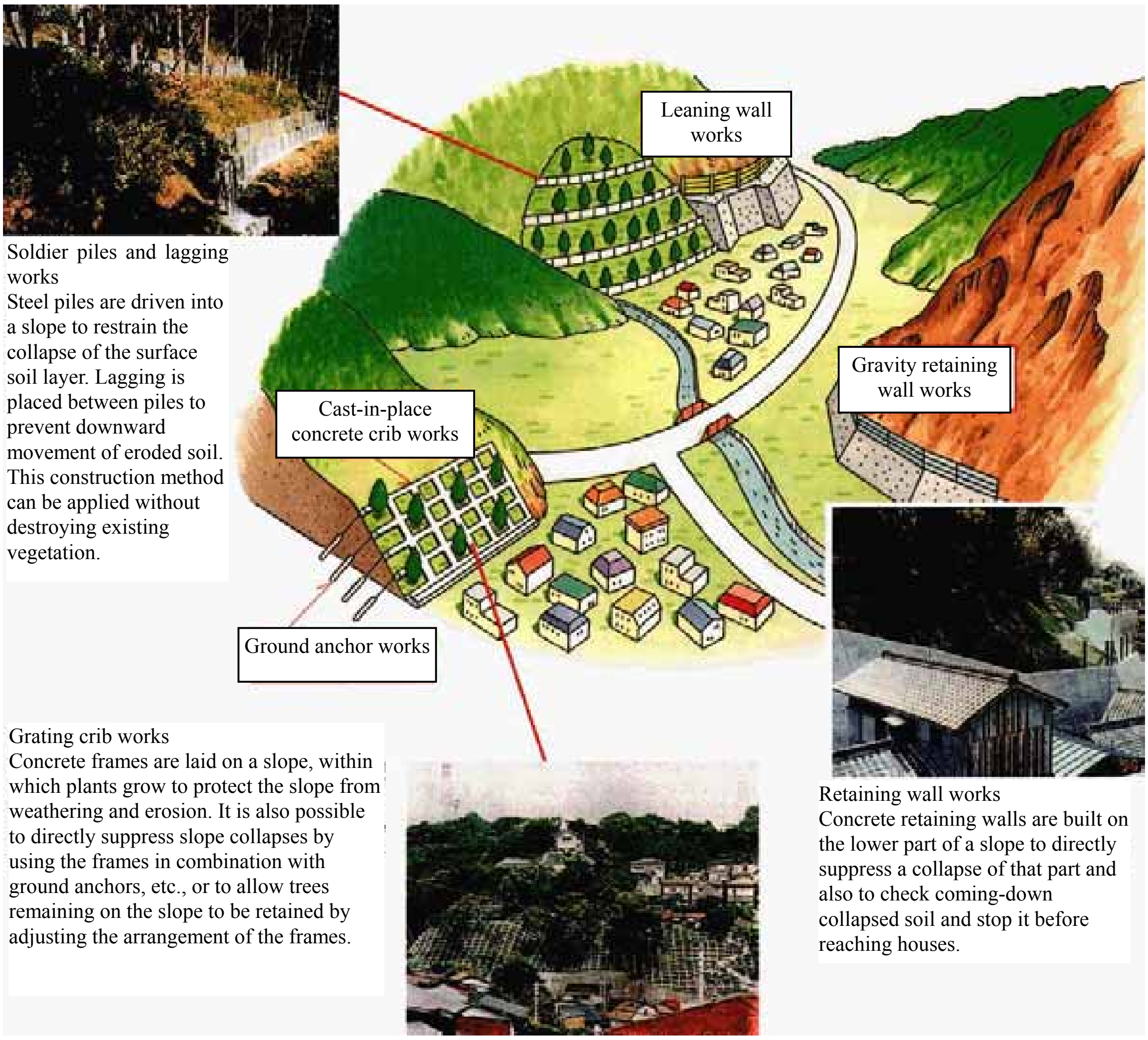
Fig. 2.2 Various functions of a sabo dam [4)]

2.2.2 Structural measures against slope failures

Broadly, structural measures against slope failures are classified into two types of works: control works and restraint works. The control works are employed to mitigate or remove the factors that may lead to slope failures, whereas the restraint works are intended to prevent failures by the installation of structures. They are summarized as shown in the table and the figure next page.

Table 2.1 Structural measures against slope failures

Type	Primary purpose	Type of works
Control works	To mitigate the effect of rainfall	Drainage works, vegetation works, slope protection works
	To remove a soil mass highly likely to collapse	Cutting of an unstable soil mass
Restraint works	To reinforce the surface soil layer in a slope	Cutting of slope to improve the form, retaining wall works, anchor works, pile works, loading embankment works



Soldier piles and lagging works
Steel piles are driven into a slope to restrain the collapse of the surface soil layer. Lagging is placed between piles to prevent downward movement of eroded soil. This construction method can be applied without destroying existing vegetation.

Grating crib works
Concrete frames are laid on a slope, within which plants grow to protect the slope from weathering and erosion. It is also possible to directly suppress slope collapses by using the frames in combination with ground anchors, etc., or to allow trees remaining on the slope to be retained by adjusting the arrangement of the frames.

Retaining wall works
Concrete retaining walls are built on the lower part of a slope to directly suppress a collapse of that part and also to check coming-down collapsed soil and stop it before reaching houses.

Fig. 2.3 Preventive measures against slope failures $^{2)}$

2.3 Need for the Development of Warning and Evacuation System

Preventing the occurrence of disasters by controlling the mechanical and incident factors with the installation of structural works is the most basic approach to disaster prevention, and all who are involved in disaster prevention efforts are arduously waiting it to be realized. However, the rage of the nature sometimes attacks us with a magnitude beyond our imagination. Because it is extremely difficult to identify the disaster site and the occurrence time in advance, complete prevention of sediment disasters is virtually impossible even today when the society is enjoying highly advanced technologies.

Accordingly, together with the continuous efforts to prevent the occurrence of sediment disasters, another important aspect has to be focused which is to prevent the enlargement of damage after a disaster has occurred. It is well known that an evacuation is extremely effective in preventing and mitigating damage to humans by natural disasters.

To carry out an evacuation swiftly and adequately, the disaster prevention organizations as well as the local people need to take the activities shown in Table 2.2. It is important to establish a warning and evacuation system in which the activities shown in the table are interlinked and coordinated systematically.

Table 2.2 Activities needed for evacuation from disasters

	Normal time	Warning time
Disaster prevention organizations	- Preparation of disaster prevention plan - Dissemination of disaster prevention plan - Implementation of disaster prevention training - Establishment of information transmission system	- Collection and transmission of disaster information - Recommendation and instruction to evacuate - Guide for evacuees and rescue operation
Local people	- Voluntary disaster prevention organizations - Improvement of disaster prevention awareness - Disaster prevention training	- Grasp of the state and judgment - Actual evacuation - Mutual cooperation in community

As non-structural measures against sediment disasters, three methods are considered: (i) to develop warning and evacuation system, (ii) to restrict the land use in the area that has the risk of sediment disasters, (iii) to prepare hazard map with public involvement and to publish its map. The development of warning and evacuation system is mainly explained in the current Guidelines.

CHAPTER 3 PREDICTION METHOD OF OCCURRENCE OF SEDIMENT DISASTERS

3.1 Outline of Various Prediction Methods

Setting methods of standard rainfall for warning and evacuation used for the prediction of sediment disasters are classified into several types by different researchers. In general, however, they are divided into two types in terms of practical application: 1) methods appropriate for a wide area that includes a number of locations at risk of sediment disasters; 2) methods appropriate for a localized area. Of the two methods, the former is the mainstream at present in view of the availability of data and the convenience for administrative operation. Four methods are considered as the setting method of standard rainfall for warning and evacuation appropriate for use in a wide area.

(i) Setting method using tank model
(ii) Setting method using working rainfall
(iii) Setting method using rainfall intensity within the traveling time of runoff water
(iv) Setting method using multiple factor analysis

These setting methods are further divided into subcategories by the differences of the treatment of the details. Outline of the four methods are summarized in Table 3.1.

As the methods other than the above, four methods are mainly available: (i) the setting method that additionally incorporates the forecast of short-term rainfall. This method is employed in several prefectures in Japan; (ii) the setting method that additionally incorporates geological factors as the experimental procedure; (iii) the method utilizing the neural network; and (iv) the method utilizing the data envelopment analysis (DEA).

3.2 Prediction Method Using Working Rainfall

Explained below are four methods that are commonly used by sabo-related divisions in Japan as the setting method of standard rainfall for warning and evacuation against sediment disasters. The technical development process and features of those four methods are shown in Fig. 3.1.

(i) Method A by the tentative guidelines in 1984 (Method A)
(ii) Method B by the tentative guidelines in 1984 (Method B)
(iii) Method by Yano (Yano Method)
(iv) Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures (Committee Method)

In general, sediment disasters occur under the influence of not only the rainfall at the time of disaster occurrence (causing rainfall) but also the rainfall during the period of one to two weeks before the occurrence of a disaster (antecedent rainfall). The degree of influence of the antecedent rainfall normally reduces as time becomes distant from the causing rainfall. Therefore, for the prediction of sediment disasters, use of the accumulative rainfall that takes the effect of the antecedent rainfall into account is effective. In view of this, the working rainfall defined as follows are used in the four setting methods shown above.

The working rainfall is defined as the sum of the antecedent working rainfall and the accumulative rainfall during a series of rain.

Here, one sequence of rain having more than 24 hours of non-rainfall duration before and after that rain is called “a series of rain”. The total amount of rainfall during that period is called the “continuous rainfall (R_C)”. The rain during the period of one to two weeks before the start of “a series of rain” is called the “antecedent rain”. And, the rainfall during that period is called the “antecedent rainfall (R_A)”. Also, the 24-hour rainfall one day before the causing rainfall is multiplied by the coefficient of “α_1 time”. The 24-hour rainfall two days before the causing rainfall is multiplied by the coefficient of “α_2 time”. In this way, the 24-hour rainfall up to “t” days before the causing rainfall, or “d_t”, is multiplied by the coefficient of “α_t time ($\alpha_t < 1$)”. And, the total of those rainfalls is called the “antecedent working rainfall (R_{WA})”. For details, refer to Item 2.4.2 in Part III - Planning.

$$R_{WA} = \alpha_1 \cdot d_1 + \alpha_2 \cdot d_2 + \cdots + \alpha_{14} \cdot d_{14} = \sum_{t=1}^{14} \alpha_t \cdot d_t$$

Table 3.1 Classification and outline of primary setting methods of standard rainfall [10)]

Method	Method (subcategory)	Index	Target phenomena	Outline	Features
Method using tank model	Method by Suzuki et al.	(i) Storage height in 1st tank (ii) Storage height in 2nd tank	Slope failure Debris flow	This method uses a tank model in which a tank with an outlet in the bottom and another outlet on the side is vertically placed in three layers. This method makes use of good relationship seen between the water height stored in tanks against the input rainfall value and the occurrence timing of a slope failure or a debris flow.	It is desirable to determine various constants of tanks which indicate permeability characteristics of the target area by evaluating conformity with the measurement results such as the flow rate. However, measurement data are usually insufficient, which makes the determination of those constants difficult. It is said that relatively effective disaster prediction is possible even in different geological conditions, if constants in the area of granite are used.
	Method by Michiue et al.	(i) Storage height in 1st tank (ii) Total of storage height in 1st and 2nd tanks	Slope failure Debris flow		
	Method by Makihara et al.	Total of storage height in three tanks	Slope failure		
Method using working rainfall	Method by the tentative guidelines in 1984 (Method A)	Working rainfall (antecedent rainfall, half-life: daily)	Debris flow	Setting of standard and judgment are made using a rainfall index derived by adding the antecedent working rainfall to the continuous rainfall from the start of rain.	During the examination process, the hourly rainfall at a given time and the working rainfall up to one hour before a given time are treated separately, but judgment is made using only the working rainfall up to a given time. Thus, the examination process is rather difficult to understand. This method is in a sense easy to disseminate because the rainfall index used is only one and it is similar to the continuous rainfall. It is pointed out, however, that this method shows some unconformity if used for a long rain or an intermittent rain.
	Method by the tentative guidelines in 1984 (Method B)	(i) Working rainfall intensity (ii) Working rainfall (antecedent rainfall, half-life: daily)	Debris flow	Evaluation is made using a rainfall index derived by combining of the working rainfall used in Method A and the effective rainfall intensity. Because the rainfall index is a combination type index, setting of the standard and judgment is made using a X-Y graph.	Because the antecedent working rainfall used in Method A is also used, this method (Method B) is pointed out to have some unconformity if employed for a long rain or an intermittent rain. This method is recognized as a reference to be used when setting of standard by Method A is difficult. Hence, actual application is not so many compared with Method A.
	Method by Yano (Yano Method)	(i) Working rainfall (one-tank model)	Debris flow	A rainfall index is derived by improving the operation method of the working rainfall in Method A, and by making it to be harmonizing with the transition of the moisture content in the soil.	Unconformity for a long rain or an intermittent torrential rain has been improved by the change of the operation method of working rainfall. This index is also effective for the cancellation of warning. No concrete method is specified about the setting of half-life.
	Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures (Committee Method)	(i) Working rainfall (half-life: 1.5 hours) (ii) Working rainfall (half-life: 72 hours)	Slope failure Debris flow *)	The operation method of working rainfall given in Yano Method and the disaster prediction method using a three-layered tank model are adopted. The rainfall index is derived using a combination of two half-lives, 1.5 hours and 72 hours.	As this method uses the working rainfall used in Yano Method, unconformity for a long rain or an intermittent torrential rain seen in Method A is improved. This index is also effective for the cancellation of warning. The general-purpose applicability of this method is confirmed through use at various locations.
Method using rainfall intensity within the traveling time of runoff water	Method by Hirano et al.	Rainfall intensity within the traveling time of runoff water	Slope failure Debris flow	The rainfall intensity within the traveling time of runoff water derived by using the occurrence model (physical model) of debris flow or slope failure, is used as the index.	Although the traveling time of runoff water differs by topographical and geological conditions, it can be obtained empirically by analyzing causing and non-causing rainfalls in the past. This empirical derivation method is showed.
Method using multiple factor analysis	Method by Araki et al.	A combination of topographical factors and rainfall factors	Debris flow Slope failure **)	Topographical factors deeply related to the occurrence of a debris flow are surveyed and measured at each mountain stream at risk of this disaster. Equations for analysis are derived incorporating these survey results and various rainfall indexes.	Laborious measurement of topographical features is required as the prior work. But, it can be done using topographical maps, and labor can be saved if the distinct element method (DEM) or other efficient method is employed. The standard value can be set for each mountain stream or for a group of similar streams.

*): This method is proposed exclusively for the precipice failure. But, as the tank model used by this method is useful for debris flows, this method is considered to be useful for debris flows.

**): In the literature concerning this method, mountain streams at risk of debris flow are mainly treated. Basically, however, the occurrence of a slope failure and the occurrence of a debris flow are assumed identical.

Method by the tentative guidelines in 1984 (Methods A and B)

♦ Outline

(i) Proposed for debris flows.

(ii) The working rainfall used for the derivation of rainfall index is calculated by adding the effect of antecedent rainfall to the continuous rainfall from the start of rain.

♦ Advantages

(i) In Method A, the standard value is expressed by a single index like “the working rainfall is ○ mm (the continuous rainfall is ○ mm when the effect of antecedent rainfall is excluded). This is easy to understand and simple to make known.

♦ Disadvantages

(i) When a long rain or an intermittent rain continues, the amount of rainfall may easily exceed the standard value or does not fall below it for a long time.

(ii) Decision for cancellation of warning cannot be made unless no precipitation for over 24 hours is confirmed.

Method by Yano (Yano Method)

♦ Outline

(i) Proposed for debris flows.

(ii) Problems contained in Methods A and B are improved.

(iii) The working rainfall used for the derivation of rainfall index is calculated using a method harmonious with the changes of the moisture content in the soil.

♦ Advantages

(i) The standard value is expressed by a single index like “the working rainfall is ○ mm”. This is easy to understand and simple to make known.

(ii) Problems contained in Methods A and B are improved.

♦ Disadvantages

(i) A problem remains with the setting of half-life.

Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures
(Committee Method)

♦ Outline

(i) Proposed for precipice failures which were not covered by any other methods. The precipice failures to be dealt by this method are restricted to those occurring locally.

(ii) Problems contained in Methods A and B are improved.

(iii) The working rainfall used for the derivation of rainfall index is calculated using a method harmonious with the changes of the moisture content in the soil, just like Yano Method.

(iv) For the operation of working rainfall, a half-life determined by a sediment-related disaster forecast method using a tank model is specified.

(v) The tank model used in this method is also usable for debris flows. Hence, this method is also considered applicable to debris flows.

♦ Advantages

(i) Problems contained in Methods A and B are improved.

(ii) The half-life is such that almost any regional differences are allowed.

♦ Disadvantages

(i) The standard value is shown by a linear line like “$y = ax + b$”, which is difficult to make known. It is better to use an easy-to-understand expression like a single index by using the intercept value on the standard line as the standard value.

Fig. 3.1 Overview of four methods for the setting of standard rainfall [10)]

CHAPTER 4 ACTUAL STATE OF WARNING AND EVACUATION SYSTEM AGAINST SEDIMENT DISASTERS

4.1 Development of Warning and Evacuation System against Sediment Disasters in Japan (A Case at Mt. Unzen-Fugen)

Since Mt. Unzen-Fugen first erupted in 1990, the occurrence of a large-scale debris flow became a real threat at rivers originating from this mountain (River Mizunashi, River Akamatsudani, River Nakao, River Yue, and River Hijikuro). Responding to this situation, the Ministry of Land, Infrastructure and Transport, Nagasaki Prefectural Government, and municipal governments around this mountain joined forces to establish a warning and evacuation system against debris flows. The monitoring system of debris flow movements is made up of a wire sensor for detection of debris flow, a vibrometer for detection of debris flow, and a rain gauge. The monitoring data are transmitted by radio to the master station placed in Nagasaki Prefecture's Shimabara Development Bureau by way of two relay stations. And then, information from this master station to relevant organizations is transmitted by telephone line.

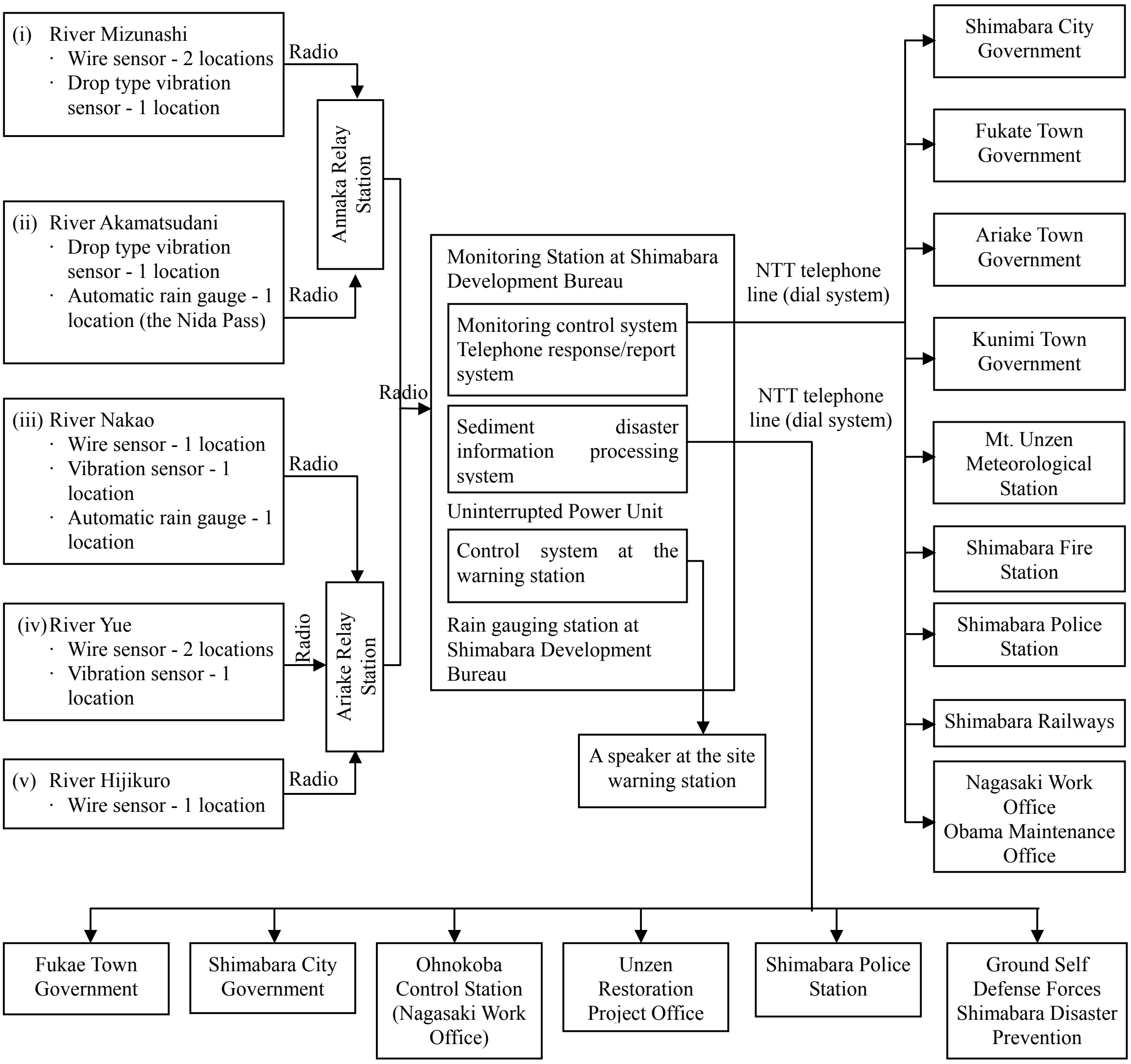


Fig. 4.1 Debris flow monitoring system at Mt. Unzen-Fugen volcano [11)]

During the three-year period from the first eruption in 1990 to June 1993, a total of 26 debris flows occurred at the five rivers mentioned above. Although the damaged buildings during those years amounted to over 1,200, the number of injured persons remained just one. This clearly indicates that a warning and evacuation system established at this volcanic mountain is highly effective.

Table 4.1 Evacuation activities taken against a debris flow on May 19, 1991

Date/time	Warnings and activities	Date/time	Warnings and activities
May 19 13:20	Evacuation was recommended to the Kami-ohnokoba area (Fukae Town).	May 20 7:31	A debris flow occurred (small scale).
13:39	A wire sensor at River Mizunashi was cut.	8:48	A debris flow occurred.
13:43	Evacuation was recommended to all households in the basin of River Mizunashi (Shimabara City).	9:51	The Ohnokoba Bridge was removed.
13:45	Evacuation was recommended to the areas in the basins of River Akamatsudani and River Mizunashi (Fukae Town)	14:32	The heavy rain and flood warning was cancelled.
14:57	The Tsutsuno Bridge was carried away.	14:46	Evacuation recommendation in Shimabara City was cancelled.
15:00	A heavy rain and flood warning was issued.	15:00	Evacuation recommendation in Fukae Town was cancelled.
15:09	A bridge for agricultural use was carried away.		
15:21	The Hirabara Bridge was demolished and removed (removal by self-decision).		
15:34	Evacuation of the North and South Kamikoba areas was completed.		

[Note] In Japan, a head of local government (a mayor or a village chief) who has close-relationship with local residence has authority and obligation to be responsible for recommendation and cancellation of evacuation.

4.2 Development of Warning and Evacuation System against Sediment Disasters in Developing Countries

4.2.1 Warning system against sediment disasters established at the Merapi volcano (Indonesia)

The area around the Merapi volcano is designated by the government of Indonesia as the most important disaster prevention area in the national disaster management program. A number of sabo projects, both structural and non-structural, have been implemented in this area as the nation's model project against disasters due to an active volcano. Fig. 4.2 and 4.3 show the warning system against sediment disasters in this area.

On the hillside of Mt. Merapi, 16 observation posts are installed, each equipped with a telemeter system. To collect data, 6 rain gauges that can measure the 10-minute rainfall, 9 water level gauges, and 6 vibrometers and wire sensors are installed. The radar rain gauge is installed at the Sabo Technical Center (STC)/Research Center for River and Sabo (RCRS) located in Yogyakarta City. The data are transmitted to the master station placed in the STC/RCRS.

In this area, warning information against sediment disasters is transmitted to the people in hazardous areas through an operation office established in the local government after it is sent from the STC/RCRS. The transmission of warning information down to the community level is done by radio or telephone, but the delivery of it from the community level to the local people is made either by a direct notification in which some responsible person runs around by motorcycle to tell the warning, or by banging a traditional bell called Kentongan (a wooden alarm bell hung in front of a house to tell an approaching danger). The operation office in the local government also uses a siren for delivering a warning. At present, a warning system utilizing the LAN network is being introduced to the STC/RCRS. When its introduction is completed, the real-time transmission of rainfall conditions and the results of disaster prediction will become possible at various divisions and organizations in and around the Sabo Technical Center.

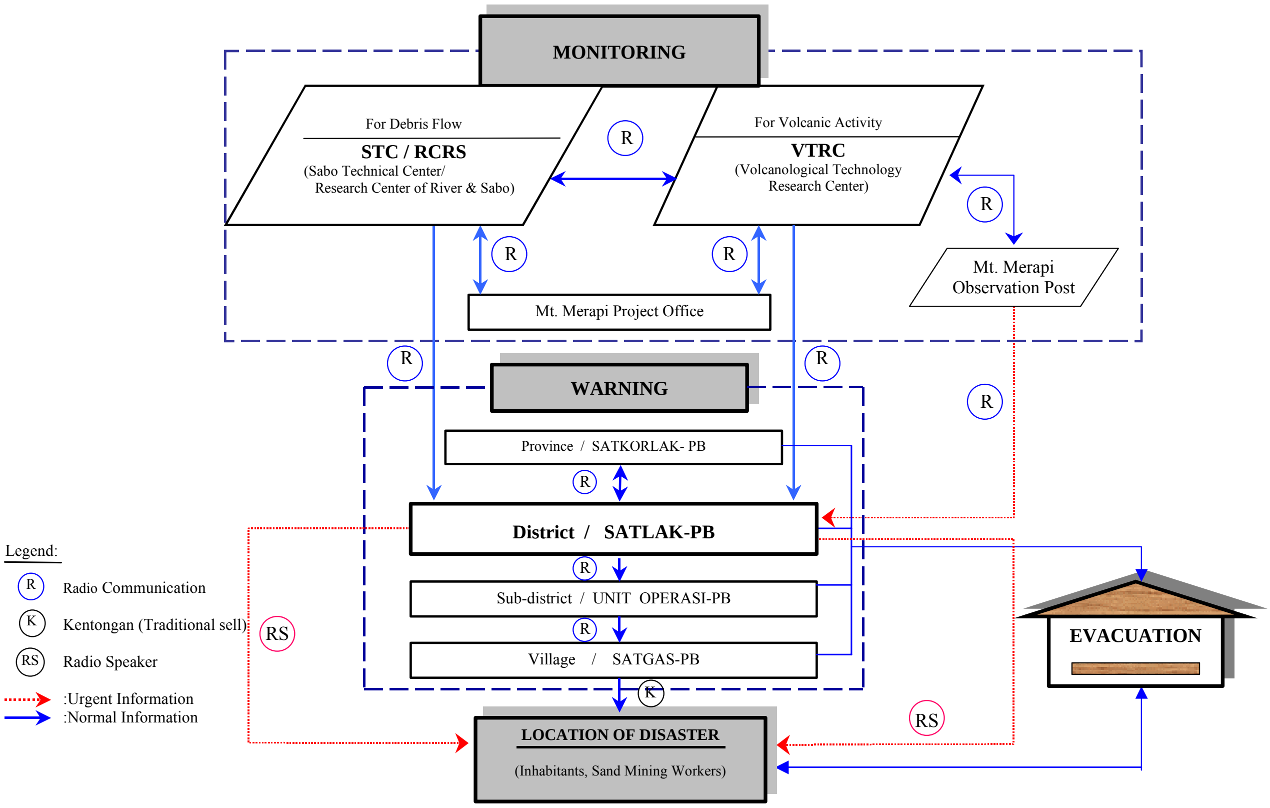
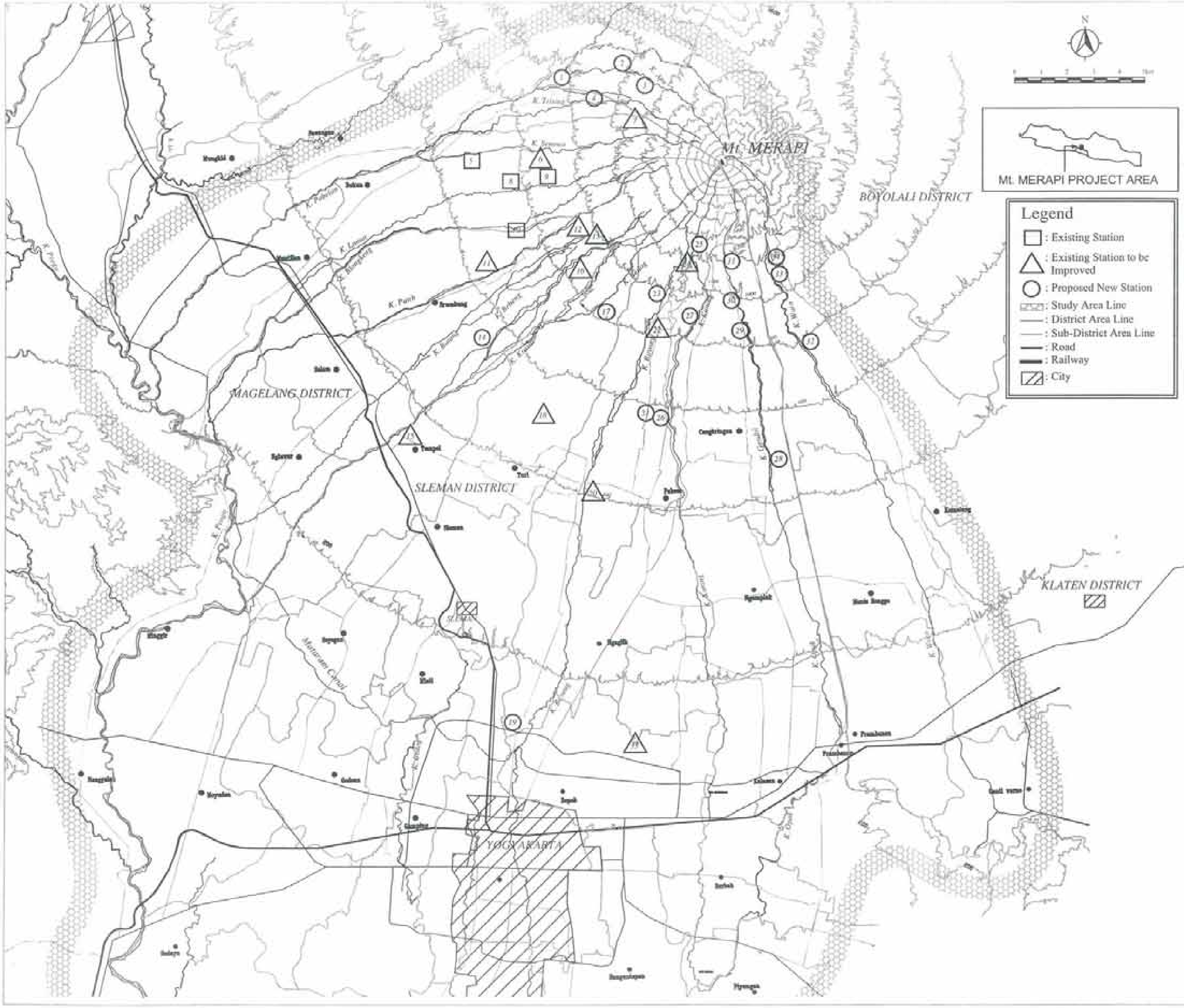


Fig. 4.2 Warning and evacuation system established in an area around the Merapi volcano [12)]



Monitoring Station

No.	Name of Station	Class	Monitoring System			
			Rainfall	Water Level	Wire Sensor	Vibration Sensor
1	Sengi 1	PN		◎		
2	Klakah	PN			◎	◎
3	Setabelan	PN	◎			
4	Sengi 2	PN		◎	◎	◎
5	Kajangkoso	E		○		
6	Trono	PI	◎		○	○
7	Babadan	PI	●			
8	Gemer 2	E		○		
9	Gemer 1	E	○		○	○
10	Salamsari	E		○		
11	Mranggen	PI	●	○		
12	Jurangjero	PI		○	●	●
13	Maron	PI	●			
14	Nganggrong	PN		◎		
15	Kopen	PI		●		
16	Gimbal	PI		●	○	○
17	Ngandong	PN	◎			
18	Girikerto	PI	●			
19	Pogung	PN		◎		
20	Pulowatu	PI		●	○	○
21	Wonorejo	PN	◎			
22	Kaliurang 2	PI		○		
23	Kaliurang 1	PI			●	●
24	Plawangan	PI	●			
25	Repeater station	PN				
26	Hargo Binangun	PN		◎		
27	Plunyon	PN	◎	◎	◎	◎
28	Nglancar	PN		◎		
29	Kopeng	PN		◎		
30	Jambu	PN			◎	◎
31	Kaliadem	PN	◎			
32	Balerante 2	PN		◎		
33	Balerante 1	PN		◎	◎	◎
34	Deles	PN	◎			
35	Master Station	PI				

E : Existing
PN : Proposed New
PI : Proposed Improve Existing Facilities

○ : Existing
◎ : New
● Renewal, Replace

Fig. 4.3 The Rainfall and Debris Flow Monitoring System in the Mt. MERAPI Volcano Areas

4.2.2 Warning system against sediment disasters established in the upstream of the Chang Jiang River (China)

The upstream area of China's largest Chang Jiang River (the Yangtze River) is an area frequented with sediment disasters, because this area contains approximately 10,000 mountain streams at risk of a debris flow and about 150,000 locations at risk of a slope failure or a landslide. These persistent threats have a serious effect on the economical development and the social stability of the area.

Since 1990, the "Water and Land Retention Committee in the Upstream Chang Jiang River" has been working to establish a warning and evacuation system against landslides and debris flows, in cooperation with other organizations. According to the "Management Policy of Warning and Evacuation System against Landslides and Debris Flows in the Special Area for Water and Land Retention in the Upstream Chang Jiang River" which was stipulated in January 2002, the warning and evacuation system in this area is made up of five aspects: (i) development of a warning and evacuation system and responsibilities of each organization (division); (ii) preparation and inspection before the rainy season; (iii) warning and evacuation activity by local people; (iv) analysis of monitoring data and reporting; and (v) survey and research.

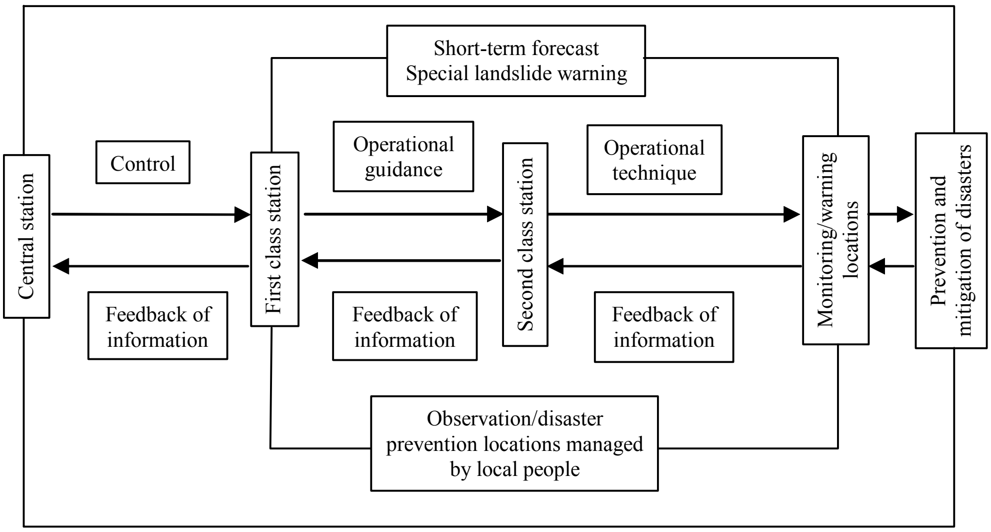


Fig. 4.4 Warning system against sediment disasters established in the upstream of the Chang Jiang River [13)]

After the establishment of the warning system in 1990, 58 monitoring locations are installed and 5 prefectures are designated as the model prefectures for warning and evacuation activity conducted by local people. They are attaining significant results.

4.2.3 Disaster prevention activities in the Provinces of Central Java and Jogjakarta (Indonesia)

In November 2000, a slope failure occurred at Menorah Hill lying across Purworejo Prefecture in the Province of Central Java and Kulonprego Prefecture in the Province of Jogjakarta, claiming the lives of about 70 people. To prevent the recurrence of such a disastrous damage, a small-scale housing relocation and a disaster prevention education were carried out in these prefectures in cooperation of the Sabo Technical Center (STC), the Research Center for River and Sabo (RCRS), and the University of Gadjah Mada (UGM), and the International Cooperation Agency (JICA) of Japan, with a grass-roots financial assistance from Japan.

The disaster prevention education was held for three days in each prefecture, inviting representatives of counties, villages, and communities, school teachers, people related to the Red Cross, and NGO groups. A lecture and a field workshop were held on such subjects as the causes of sediment disaster, locations at risk of sediment disaster, installation of a simple rain gauge and measurement, and evacuation and relief activities.

Fig. 4.5 Disaster prevention education held in local communities [8)]

4.2.4 Disaster prevention meeting and evacuation training in the Dahachowk area (Nepal)

Disaster prevention education and evacuation training were extended to the local people in the Dahachowk area in Nepal which is frequented with debris flow disasters, with the intention of enlightenment toward disaster prevention and the establishment of a warning and evacuation system as a part of non-structural measures against sediment disasters. Although the disaster prevention meeting and evacuation training were held during the daytime, about 70 local people participated, which clearly indicates the high awareness of the people toward disaster prevention. Because a deep understanding of debris flows is indispensable for proper warning and evacuation activities, the actual state of debris flows, their causes, and preventive measures, as well as the importance of warning and evacuation were explained to the people through video screening and panel discussion. After that, an evacuation training was conducted to reconfirm the evacuation route, the location of refuge facilities, and the cautions to be observed during evacuation.

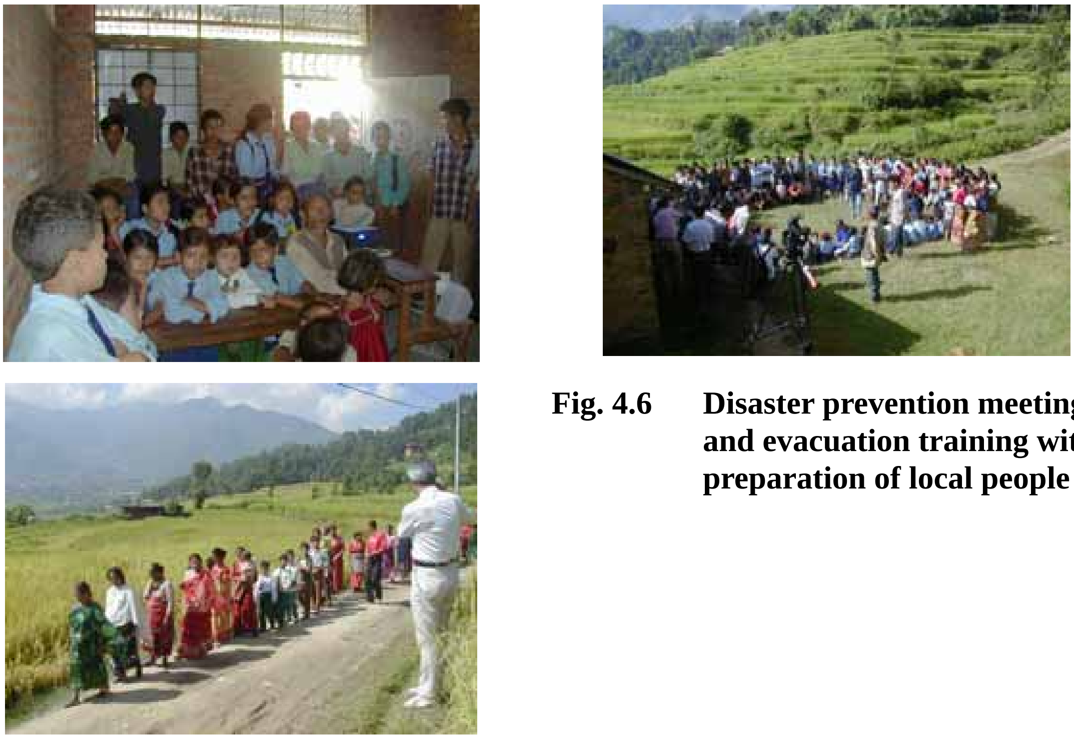


Fig. 4.6 Disaster prevention meeting and evacuation training with preparation of local people [9)]

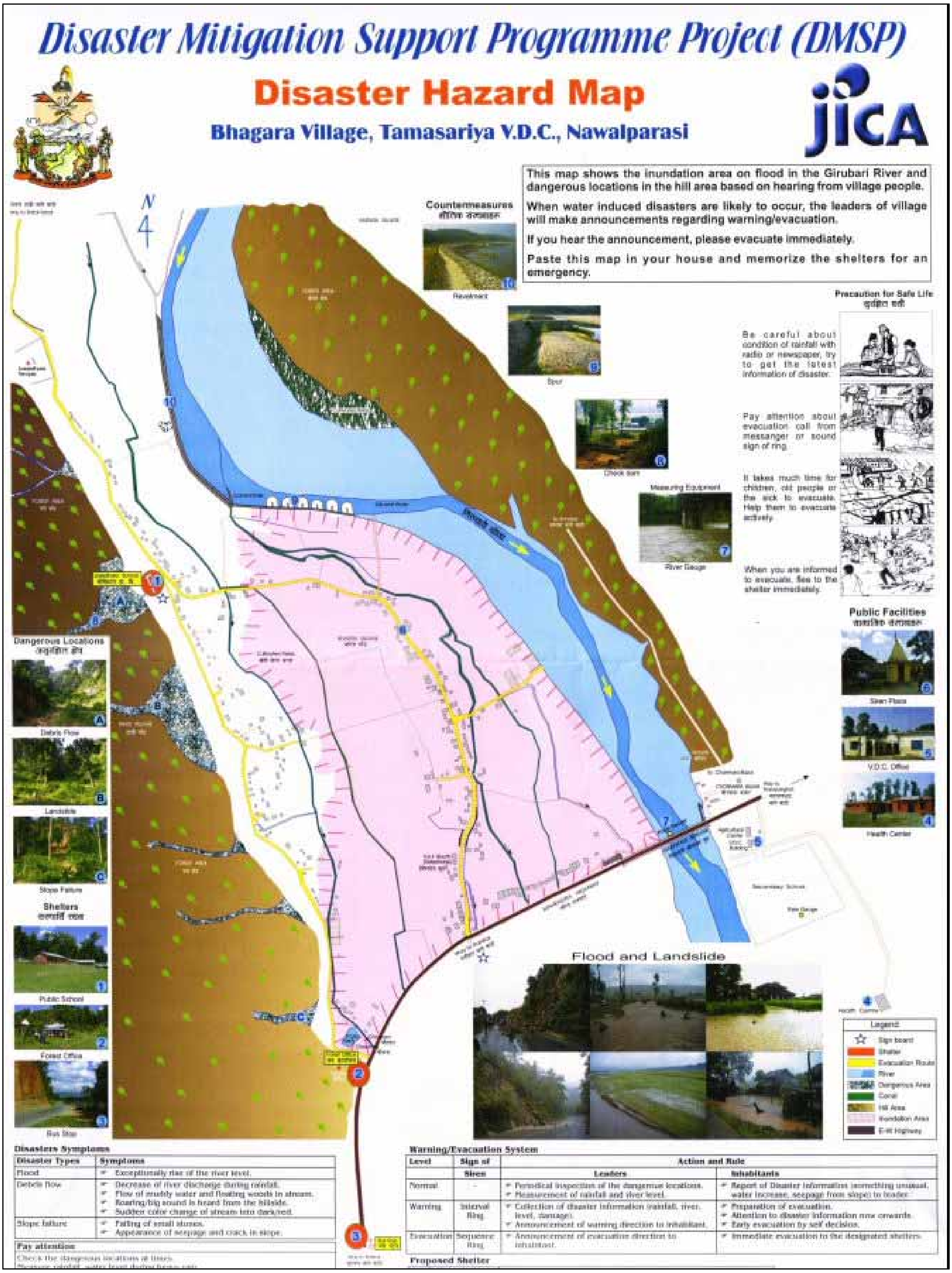
4.2.5 Preparation of hazard map in the Bhagra area with public involvement (Nepal)

A hazard map showing potential flooding areas and areas at risk of sediment disasters was prepared in the Bhagra area along the Girubari River which is designated as the model site for the establishment of a warning and evacuation system. See Fig.-4.7.

Employing the PRA's social map preparation method which is one of the methods of the public involvement type, the hazard map was prepared based on the surveys of refuge facilities, evacuation routes, places at risk of disasters that were completed with the cooperation of local people. The information included in this hazard map is limited to that useful to the local people. Discussion was also made with the local people on what method is suited to them to transmit the information on warning and evacuation.

Traditionally, in this area where only one house owns a telephone, a messenger person was appointed to deliver the information from the representative of a community to each household. However, in an emergency situation like a flood or a debris flow, this type of information transmission is unable to save people from an approaching danger. To respond to this need, a communication system, or the use of an alarm bell, that can deliver a warning information instantly to the entire area was proposed.

As the refuge facilities, school buildings and public facilities often used by local people were selected in consideration of their accommodation capacity, location, and structure. However, a problem remained that refuge facilities themselves are situated in a disaster hazard area. To cover this weakness, it was determined to install simple structural works. Using the gabions provided by the current project, the groundsill works were installed with the hands of local people. Besides these structural works, staffs for measuring the water level in rivers and simple rain gauges for measuring rainfall were provided to this area to be utilized for warning and evacuation-related judgment.



This map shows the inundation area on flood in the Girubari River and dangerous locations in the hill area based on hearing from village people.

When water induced disasters are likely to occur, the leaders of village will make announcements regarding warning/evacuation.

If you hear the announcement, please evacuate immediately.

Paste this map in your house and memorize the shelters for an emergency.

Be careful about condition of rainfall with radio or newspaper, try to get the latest information of disaster.

Pay attention about evacuation call from messanger or sound sign of ring.

It takes much time for children, old people or the sick to evacuate. Help them to evacuate actively.

When you are informed to evacuate, flee to the shelter immediately.

Disasters Symptoms

Disaster Types	Symptoms
Flood	Exceptionally rise of the river level.
Debris flow	Decrease of river discharge during rainfall. Flow of muddy water and floating woods in stream. Roaring/big sound is heard from the hillside. Sudden color change of stream into dark/red.
Slope failure	Falling of small stones. Appearance of seepage and crack in slope.

Pay attention

Check the dangerous locations at times.

Warning/Evacuation System

Level	Sign of Siren	Action and Rule	
		Leaders	Inhabitants
Normal	-	Periodical inspection of the dangerous locations. Measurement of rainfall and river level.	Report of Disaster information (something unusual, water increase, seepage from slope) to leader.
Warning	Interval Ring	Collection of disaster information (rainfall, river, level, damage). Announcement of warning direction to inhabitant.	Preparation of evacuation. Attention to disaster information now onwards. Early evacuation by self decision.
Evacuation	Sequence Ring	Announcement of evacuation direction to inhabitant.	Immediate evacuation to the designated shelters.

Proposed Shelter

Fig. 4.7 Hazard map of the Bhagra area [9)]