Supporting Report N

Study on Sediment Disaster

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N.1 Classification of Sediment Disasters

Mass movement is the term generally used to describe the phenomena in mountain regions of downward movement of slope-forming materials from slopes and torrents streams primarily under the influence of gravity. There are various types of mass movement distinguished by the differences of where it occurs, the displaced material and the involvement of surface or ground water. Additionally, it is not uncommon for one type of mass movement to change into another during its course as determined by the external conditions. When a landslide occurs, loose earth and gravel will enter the stream transforming it into a debris flow, or furthermore, as is often the case, ultimately becoming a mud flow.

Sediment disasters caused by mass movement in turn cause human and property damage: directly if within range of, and indirect damage in the vicinity of, the downward movement of materials. The terms mass movement and sediment disaster have commonly come to be called by the same name.

The names for various types of sediment disaster are often used because the type of mass movement changes. In Sri Lanka, the following classifications are used or have been proposed.

Table N.1.1 The Classification of Mass Movements

Terms by Fernando (1951)	Terms by Cooray, 1958	Terms by Dahanayake, 1989
Slope failure	Debris avalanche	Topple
Earth slip	Earth flow	Slide
Slump	Slump	Lateral spread
Rock fall	Debris slide	Flow
Debris fall	Rock slide	
Flow	Rock fall	
	Subsidence	

Table N.1.2 Classification of Mass Movements by Cooray, 1994

Terms		Description
Rock slide		Rock slides occur mostly in quartz schists and quartzo-feldspthic schists where the dip of the rocks coincides with or is close to the slope of the ground. Slabs slide down the slope under the influence of gravity.
Rock fall		Rock falls generally occur where the dip of the rocks is horizontal or opposite to the slope of the ground. Large blocks of rock are loosened by weathering and action of roots of trees.
Other mass movement	Soil creep	Soil creep is the down hill movement of soil under the influence of gravity. It takes place slowly, but is recognized by the leaning over of trees, telephone poles and fence posts.
	Mud flow	Mud flow is a stream of fluid consistency which moves as a tongue of mixed mud, soil, rock, and water, often in gullies or stream courses.
	Earth flow	Earth flow is less fluid than mud flow, and moves shorter distance down slope.
	Debris avalanche	This type is common in Sri Lanka, as in all humid mountainous regions. In this type, water, saturated soil and overburden may move rapidly, carrying rocks and boulders and sweeping away trees, houses and roads in their way.
	Debris slide	This type is similar to debris avalanche, but is more restricted in extent. This is controlled by the material in the slides.
	Slump	This type is a movement in which mass of material moves as a unit, in most instances slipping along a surface that is concave upwards, and with a backward rotation on the curved slip area. Slumps may form either in weathered overburden or in colluvium.

Table N.1.3 Terms Used in Landslide Investigation of NBRO

Terms	Description
Fall : Rock fall Rock slide	Rock fall result from the free fall of material from a steep slope. In Sri Lanka, rock falls are very common. These usually involve the fall of rock from a cliff or boulder terrain. These rocks move by falling, rolling or bouncing, coming to rest on the slope below. If the mass movement of rocks involves mainly sliding (as for slip along a dip slope), then it is a rockslide, and not a rock fall.
Slide : Earth slide Rotational slide Transitional slide	Slides involve the down slope movement of material along well defined surfaces of movement. Slides are classified according to the material that is displaced, and by the geometry of the sliding surfaces. Most slides in Sri Lanka consist of soil materials, so that they are termed earth slides. However, as mentioned above, rock slides can also occur. In terms of slip surface geometry, a rotational slide has a curved or circular (in cross section) slip surface; and a translational slide has a planar slip surface. Rotational slides are characterized by back tilting at the top, and heaving at the toe of the displaced mass.
Flow : Earth flow Mud flow Debris flow	Flows are rapid down slope movements of masses of material, with no slip surfaces as such. If more than 50% of the involved material is soil, then these can be termed earth flows or mud flows. If the majority of the material is rock then the correct term is debris flow. In Sri Lanka, most flows follow the courses of gullies. They are extremely dangerous and destructive.
Movement : Slope movement Subsidence Creep	Slow, gradual downhill movement of surface material is termed slope movement in the LHMP mapping legend. Subsidence is a slow vertical lowering of the ground surface. Slope movement and subsidence often occur together. Creep is term referring to a very slow (millimeters per year) downhill movement.
Gully erosion :	Gully erosion is the erosion of soil by running water that forms clearly defined, narrow channels on a slope. This type of erosion is most intense during or after heavy precipitation, when the channels carry their heaviest loads of surface runoff. Gully erosion is commonly an indicator of improper land use.
Other : Cutting failures	In the hill country, cuttings on slopes are commonly made in order to construct roads, houses, other buildings or irrigation canals. These cuttings are likely to fail in times of rain. Although similar to small landslides, these should be referred to as cutting failures.

Source: NBRO, BY R.D. CRUICKSHANK, UN ASSOCIATE EXPERT (1995); MANUAL ON FIELD MAPPING FOR LANDSLIDE HAZARD ZONATION

In Japan, where various sediment disasters occur, disaster-related administrative organizations and research bodies that are studying their characteristics and differences have adopted a great deal of terms as well.

Consequently, it is desirable to define and unify the terms concerning sediment disaster, and, experts aside, aim to disperse knowledge among citizens at the national level.

N.2 Past Sediment Disasters and Rainfall

As for past sediment disasters, the NBRO has arranged the reports and data. The JICA Study Team analyzed the relationship between the occurrence of the sediment disaster and rainfall from the NBRO's reports describing rainfall.

Past sediment disasters distribution was summarized by the NBRO and published the information on their webpage (http: //www.nbro.gov.lk/lshistory.pdf).

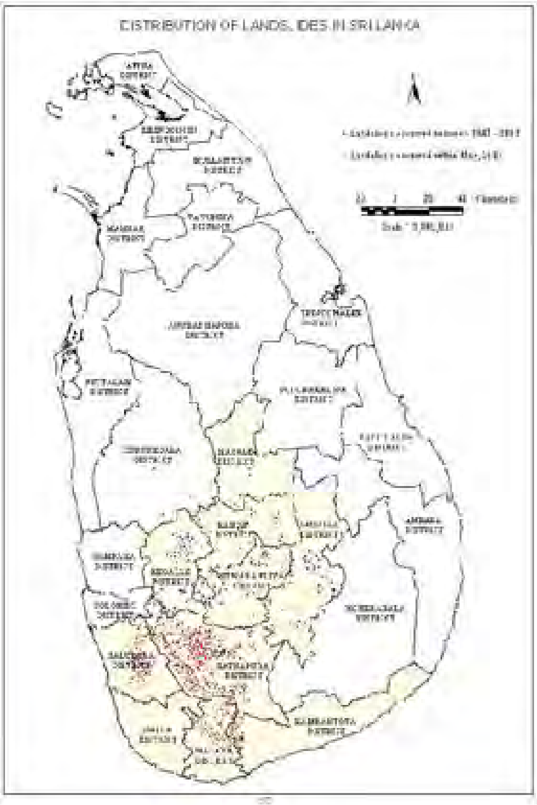


Figure N.2.1 Distribution of Sediment Disaster Locations Occurred during 1947 – 2002 and in 2003 (NBRO)

N.2.1 Some Examples of Major Sediment Disasters

(1) Watawala Sediment Disaster, Nuwara Eliya District (3 June, 1992 and 3 June, 1993)

The landslide occurred on the southern slope of the Watawala ridge in the Nuwara Eliya district, where the Colombo-Badulla railroad runs. The slope was creeping for about 50 years, and it finally failed on June 3, 1992. The total area of the moving mass was about 33,120m^2. The Colombo-Badulla railroad was heavily damaged, and thousands of passengers who use the train daily as well as tourists were in the train. The landslide caused a severe impact on the people and economy of the country.

Figure N.2.2 Watawala Landslide and the Damage of Train (photo by NBRO)

Bed rock geology of the landslide mainly consists of garnet granulitic gneiss with biotite gneiss, garnet sillimannite graphite gneiss etc, which are inter-layered. Overburden deposits of the landslide slope are composed of colluvial deposits with boulders less than 3m in diameter, residual soil and completely weathered rocks. The slope gradient of unstable land is 18 degrees to 35 degrees. The land has been used for tea cultivation under the Watawala Plantation Ltd.

The time of the landslide could not be confirmed by witnesses, but is clarified by the train schedule and the accident. The Colombo-Badulla night mail train with couple of thousand passengers passed the location at 4 AM on June 3, 1993. About one hour later, the Hatton-Colombo train passed and sunk into the landslide. That means that a large landslide was activated between 4 AM and 5 AM.

Annual mean rainfall in Watawala is approximately 5,200mm, which is a higher value than in other areas in Sri Lanka. Daily rainfall on 2 June 1993, the day before the landslide, was recorded at 196mm. Due to heavy rain on the previous day, the landslide occurred early the next morning.

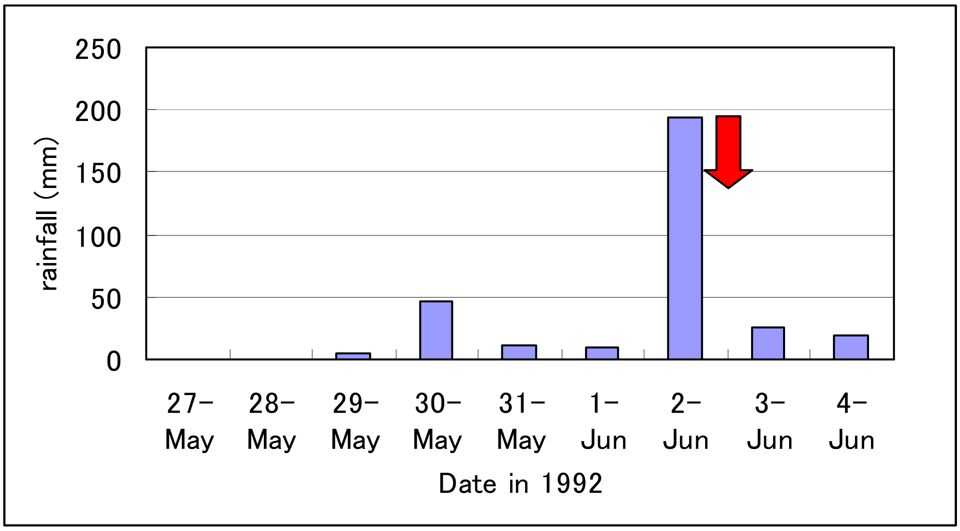


Figure N.2.3 Daily Rainfall at the time of the Watawala Sediment Disaster (3 June 1992)

The same landslide was reactivated exactly one year later on 3 June 1993. The preceding 6 days of rainfall exceeded 500mm, and rainfall of the day was 147mm.

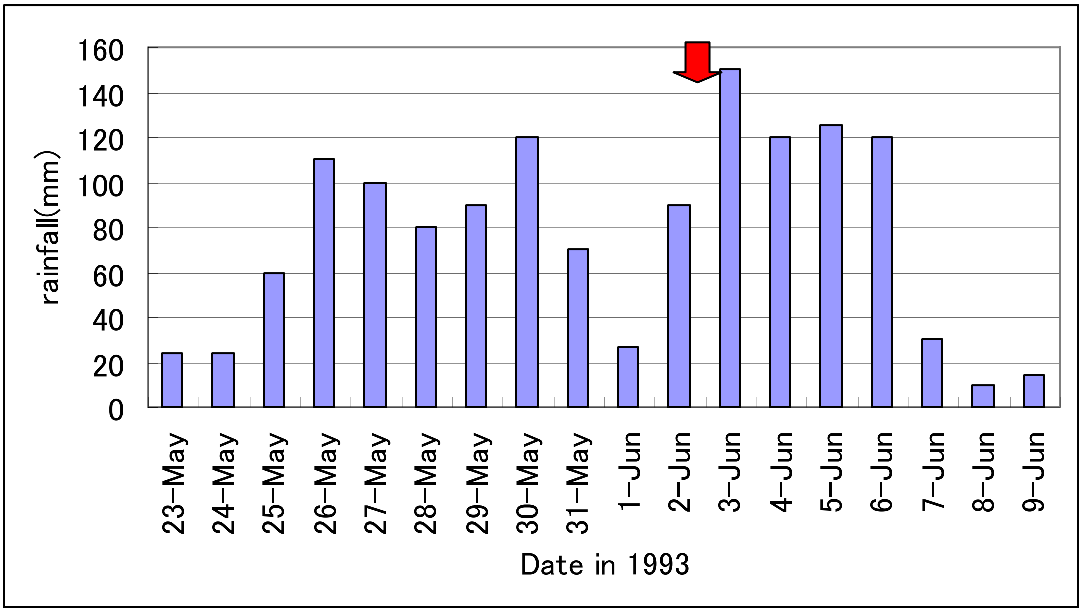


Figure N.2.4 Daily Rainfall at the time of the Watawala Sediment Disaster (3 June 1993)

(2) Helauda Sediment Disaster, Ratnapura District (8 October 1993)

On 8 October 1993, at around 7:30 AM, an earth flow occurred on a slope approximately 3km north of the heart of Ratnapura city. The road and houses below the slope, which ran parallel with the road, were instantly swallowed, resulting in the death of 31 inhabitants.

The collapsed part, on a steep incline with an angle of approximately 40 degrees, was a weathered layer of red clay which collapsed with a depth of 2 or 3 m. The collapsed earth and sand became saturated when it was mixed with water flowing in from the channel to the west of the collapsed part, transforming into an earth flow, which slid and fell from the top of the cliff catching up boulders of 2 to 3 meters in size. The channel of water, accumulated from a table mountain behind, carried the collapsed earth and sand. Because unstable earth and sand had previously accumulated in the middle of the hillside of the collapsed part, following that, torrential rains, as mentioned below (17 May, 2003), caused a small-scale earth flow in the same place on 24 August 2006.

Figure N.2.5 Earthflow at Helauda (left: photos by NBRO in 1994, right: in 2006)

The killer earthflow occurred around 7 AM on 8 October. One of the causative factors was heavy rain exceeding 177mm on the previous day. The three day cumulative rainfall was 280mm at Ratnapura city. Though the landslide occurred in the morning on the day of 41mm daily rainfall, the heavy rain of the previous day seemed to have influenced the earthflow.

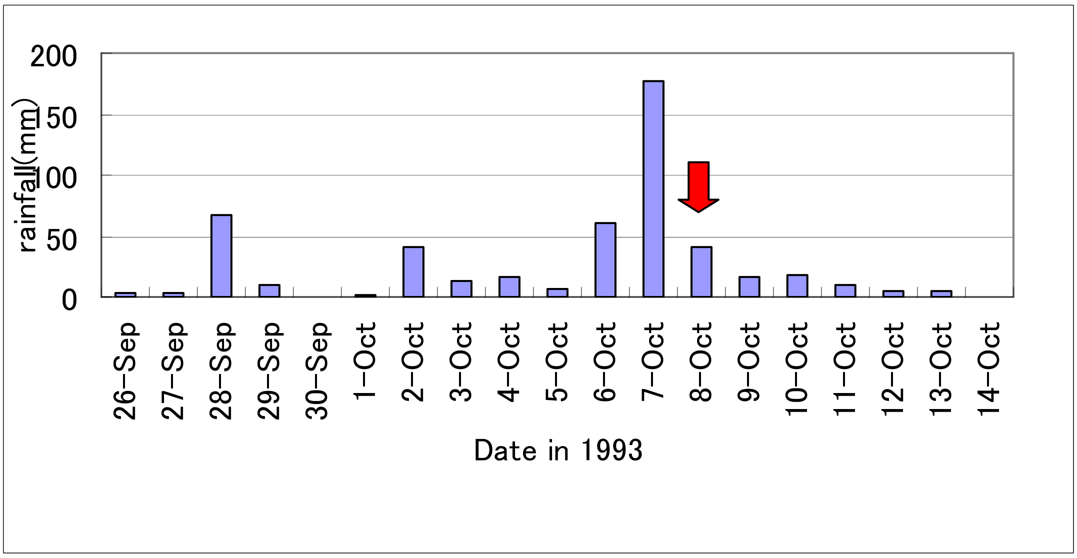


Figure N.2.6 Daily Rainfall at the time of the Helauda Sediment Disaster
(8 October, 1993)

(3) Palawala Sediment Disaster, Ratnapura District (17 May 2003)

The torrential rains this time continued to fall in the heart of the Sri Lankan southwestern districts, such as Ratnapura, Kalutara, Matara, and Hambantota.

Starting on 12 May, continual rainfall lasted until the 17 May, reaching 600 mm, and particularly, on the day of the 17th when 345mm of rainfall was recorded. According to the NBRO's investigation report, the sediment disasters occurred 9 AM to 12 Noon.

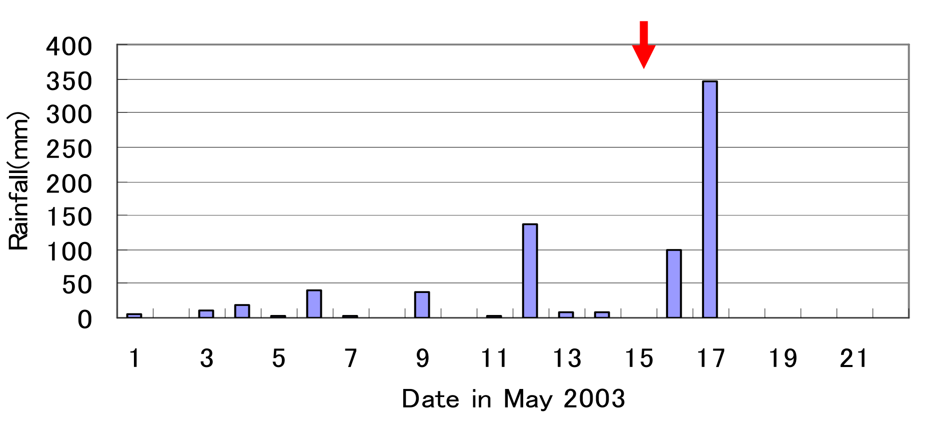


Figure N.2.7 Daily Rainfall at Ratnapura at the time of Palawela Sediment Disaster, (17 May 2003)

There were also large-scale earth flows, such as in Palawale, where the gentle slope of a mountain base slid down, crossing the valley floor and ran up against the slope on the opposite side. The tail end of the earth flow combined in the small rivers and became a debris flow. The overall length of the debris flow was nearly 1km from the collapsed section. In this way, the primary factor of the long distance flow is presumed to be the loose debris in the lower part of the collapsed slope, with the gentle angle of the colluvial slope, which made it difficult to stop. Furthermore, it is presumed that the participation of ground water and sub-surface water were also a large factor.

According to the NBRO, and also described in the investigation sketch after the disaster, there were streams recorded in the earth flow trail. Also, as the JICA Study Team were able to observe surface water in the collapsed slope during their field survey despite the fair weather, it was clear that there were water channels in the surface layer of the earth. It is presumed that at the time of the torrential rains, the abundant amount of water furthermore increased the current.

Figure N.2.8 Earthflow at Palawela (2003, photo by NBRO)

The feature of this earth flow is a steep slope consisting of a weathered layer of clay soil in the rear, beneath which the advancing slope of a relatively gentle slope consisting of residual soil, water from the rear slope water channel joined the weathered layer of residual soil and slid together. In other places where earth flows have occurred, it is often that the upper part where concentrated low-level weatherized bedrock is exposed. As for the slip surface, it is often the place where the bedrock and weathered layer interface.

In the hillsides, there are tea gardens and orchards, and the homes of people who work there. In mountain regions, these homes are often observed located on slopes with a high risk of earth flow - slopes with a thick, weathered layer or those on gentle slopes of residual soil.

(4) Walapane Sediment Disaster, Nuwara Eliya District, 12 January 2007

Last 12 January 2007, a spate of landslide disasters occurred within Nuwara Eliya District Walapane DS. Division and Hanguruketha DS. Division.

In this region, the mountain range has an altitude from 1000m to 1800m in height, with steep slopes widely distributed in the area. A gentle slope made up of colluvial deposits on which communities and farmland are distributed continues from halfway up the mountains to the base and the national highway B413 ties those communities together.

Quartzite is the main geological feature, and the fresh bedrock is exposed in the mountain streams and such. Even on the surface of fresh bedrock, foliation can be observed, where it can easily become a slip surface. The slope is heavily covered with red, weathered soil. The soil distribution of the slope mid-section is residual soil, and the lower part of the slope is colluvial soil which includes rolling stone.

This time, the landslide disaster occurred due to the heavy rains from 9 -12 January. Daily rainfall during this period at the Liddesdale Observatory, closest to this disaster location, is shown in Figure N.2.9. It is notable that the rainfall of the two days preceding the landslide disaster both exceeded 100 mm. During the peak of the storm, the conditions were such that nothing other than the sound of rain was audible. This landslide which caused the deaths of 10 people occurred 2 days after peak rainfall was recorded.

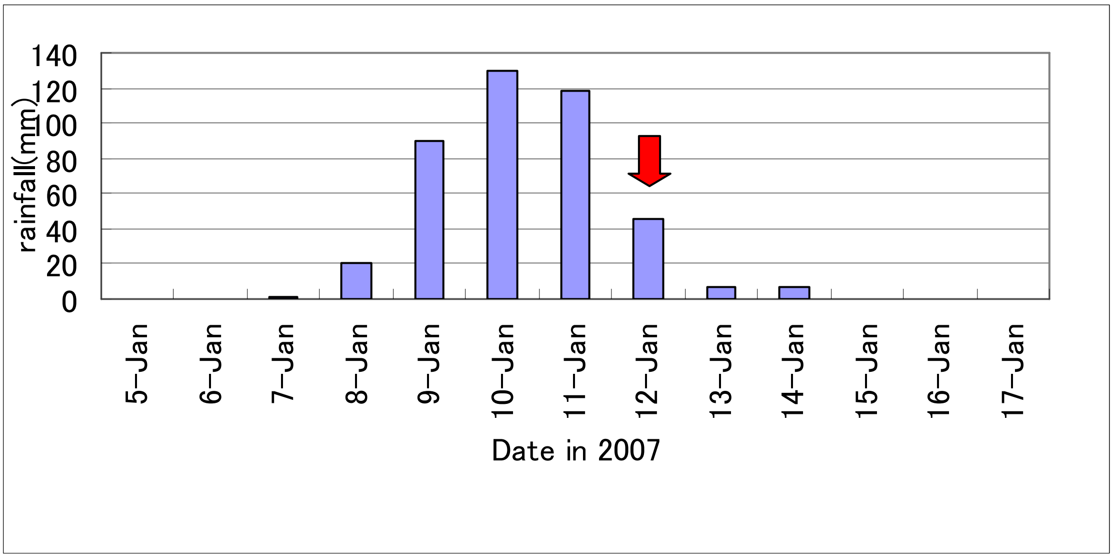


Figure N.2.9 Daily Rainfall at Liddesdale at the time of Walapane Landslide (12 January 2007)

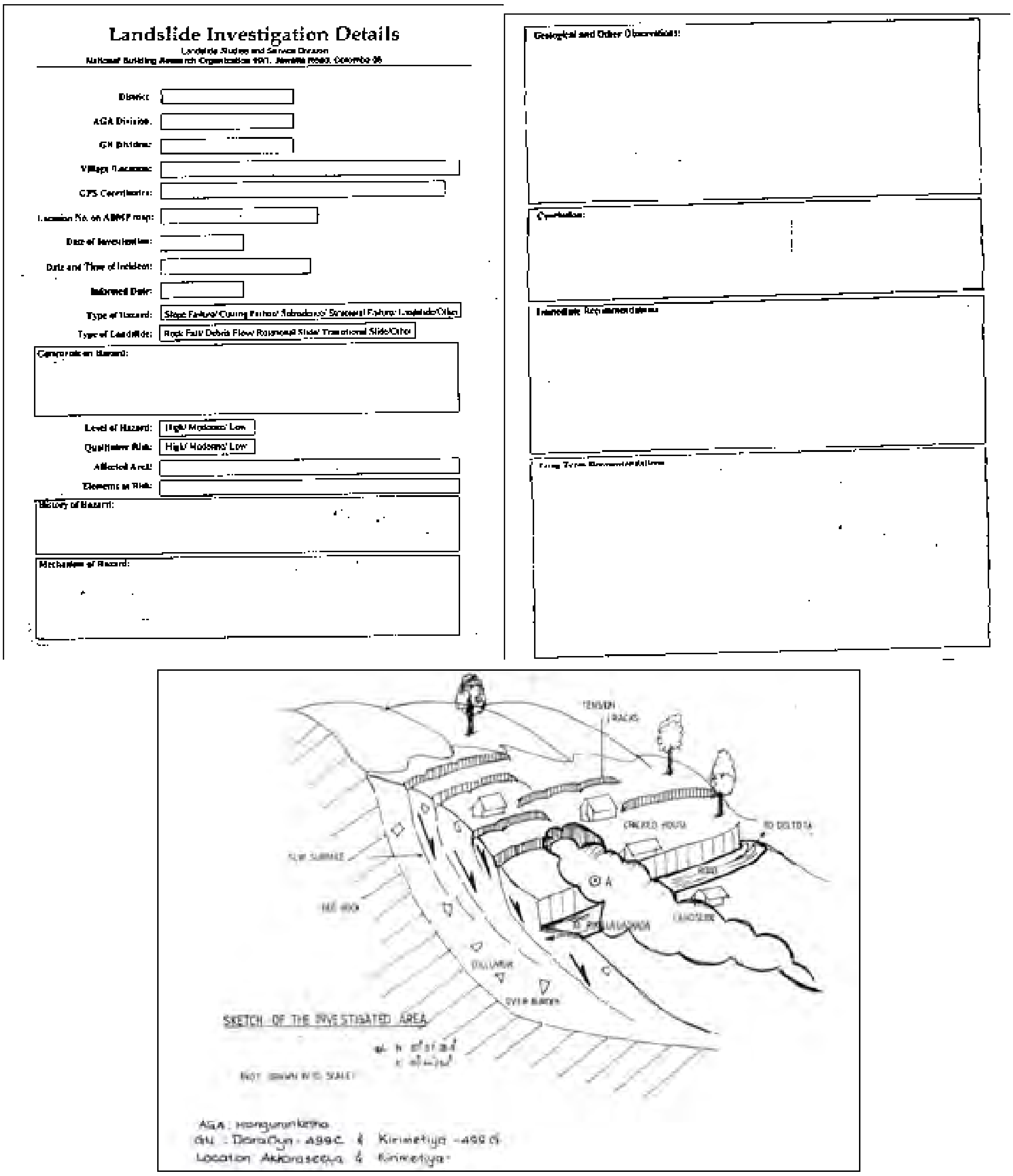
Figure N.2.10 Landslide at Walapane

Walapane National Highway B413 saw multiple episodes of cutting failure, landslide and debris flow. Among places along the national highway where landslide disasters occur frequently, one occurrence reached 100m. In the tracks left behind a landslide which resulted in the deaths of 10 people, traces of piping and the water channel were confirmed and it is thought that the permeation of groundwater caused the deep landslide.

The RDA performed the job of removing debris from along National Highway B413 and ensured temporary transit, but the large quantities of debris along the sides of the road were left in unstable condition, and the danger of a secondary collapse was high. Slow-moving landslides were also observed in two places. When the movement of the Marigold Watta landslide began on 18 December 2006, the inhabitants then evacuated. On 11 January 2007, when serious landslide activity took place, the homes, road and farmland were all completely destroyed. In addition, the landslide which occurred at the Estate in Diyan Hawatta (Figure N.2.11) continues at present to move slowly and destruction of the tea garden and the road is advancing.

Figure N.2.11 Landslide at the Estate in Diyan Hawatta

Regarding such landslide disasters, the NBRO mobilizes its landslide technicians immediately after the disaster and performs field work. Following reports by local municipalities concerning the locales, it visits the site, prepares a cost investigation and reports results to the District Office.



Landslide Investigation Details

Landslide Studies and Services Division

National Building Research Organization 99/1, Jawatta Road, Colombo 05

District:

AGA Division:

GN Division:

Village / Location:

GPS Coordinates:

Location No. on ARMP map:

Date of Investigation:

Date and Time of Incident:

Informed Date:

Type of Hazard: Slope Failure/ Cutting Failure/ Subsidence/ Structural Failure/ Landslide/Other

Type of Landslide: Rock Fall/ Debris Flow/ Rotational Slide/ Translational Slide/Other

Comments on Hazard:

Level of Hazard: High/ Moderate/ Low

Qualitative Risk: High/ Moderate/ Low

Affected Area:

Elements at Risk:

History of Hazard:

Mechanism of Hazard:

Geological and Other Observations:

Conclusion:

Immediate Recommendations:

Long Term Recommendations:

Figure N.2.12 Landslide Investigation Sheet of NBRO (Example)

N.2.2 Rainfall in the Case of Some Major Sediment Disasters

The relationship between rainfall and 12 major sediment disasters published by the NBRO was investigated based on their reports. Table N.2.1 shows daily rainfall, and Table N.2.2 shows 7 days cumulative rainfall, respectively, in the case of 12 major sediment disasters. Figure N.2.13 shows 7 days cumulative rainfall, and Figure N.2.14 shows 7 days cumulative rainfall going back from the days of the sediment disaster, respectively, in the case of 12 major sediment disasters.

Table N.2.1 Rainfall in the Case of 12 Major Sediment Disasters (Daily Rainfall)

Location and date of the sediment disaster	**6 days before**	**5 days before**	**4 days before**	**3 days before**	**2 days before**	**1 day before**	**The day of disaster**	**1day after**
Handurukanda, landslide 1982/12/20	50	18	71	41	100	34	22	-
Hetikande, 1989/5/30, earthslide	4	12	5	0	4	119	230	
Pattipola-Ohiya, landslide 1991/12/18	18.1	16.9	64.9	35.1	34.5	44.1	9.0	0.0
Watawala, earthslide 1992/6/3	0.0	5.6	47.1	11.3	9.4	194.2	26.4	18.9
Watawala, earthslide 1993/6/3	80.0	91.2	118.8	68.8	26.2	88.8	147.5	118.7
Helauda, debris flow 1993/10/8	40.8	12.8	17.0	7.0	61.2	177.6	41.6	16.1
Eheliyagoda, debris flow, 1994/5/28	11.4	20.3	55.2	46.0	102.0	112.0	87.0	
Navalapitiya, rockfall 1994/8/2	-	25.6	25.6	4.0	28.0	52.5	139.5	9.0
Holipitiya, landslide 1996/6/8	18.8	6.5	23.9	15.8	0.0	3.1	392.5	31.5
Neketiya, landslide 1997/11/19	22.9	87.4	120.0	0.0	48.5	28.6	28.6	17.7
Helauda, Palawela, earthslide etc 2003/5/17	2.8	135.8	8.6	8.0	0.9	99.6	345.2	0.8
Walapane, earthslide 2007/1/12	0.0	1.4	20.3	89.7	129.6	117.9	45.9	7.3

Table N.2.2 Rainfall in the Case of 12 Major Sediment Disasters
(7 Days Cumulative Rainfall)

Location and date of the sediment disaster	**6 days before**	**5 days before**	**4 days before**	**3 days before**	**2 days before**	**1 day before**	**The day of disaster**	**1day after**
Handurukanda, landslide 1982/12/20	140.5	158.3	229.4	270	370.8	404.3	427.2	-
Hetikande, 1989/5/30, earthslide	4	12	5	0	4	119	230	-
Pattipola-Ohiya, landslide 1991/12/18	18.1	35.0	99.9	135.0	169.5	213.6	222.6	222.6
Watawala, earthslide 1992/6/3	0.0	5.6	52.7	64.0	73.4	267.6	294.0	312.9
Watawala, earthslide 1993/6/3	80.0	171.2	290.0	358.8	385.0	473.8	621.3	740.0
Helauda, debris flow 1993/10/8	40.8	53.6	70.6	77.6	138.8	316.4	358.0	374.1
Eheliyagoda, debris flow, 1994/5/28	11.4	20.3	55.2	46.0	102.0	112.0	87.0	-
Navalapitiya, rockfall 1994/8/2	0.0	25.6	51.2	55.2	83.2	135.7	275.2	284.2
Holipitiya, landslide 1996/6/8	18.8	25.3	49.2	65.0	65.0	68.1	460.6	492.1
Neketiya, landslide 1997/11/19	22.9	110.3	230.3	230.3	278.8	307.4	336.0	353.7
Helauda, Palawela, earthslide etc 2003/5/17	2.8	138.6	147.2	155.2	156.1	255.7	600.9	601.7
Walapane, earthslide 2007/1/12	0.0	1.4	21.7	111.4	241.0	358.9	404.8	412.1

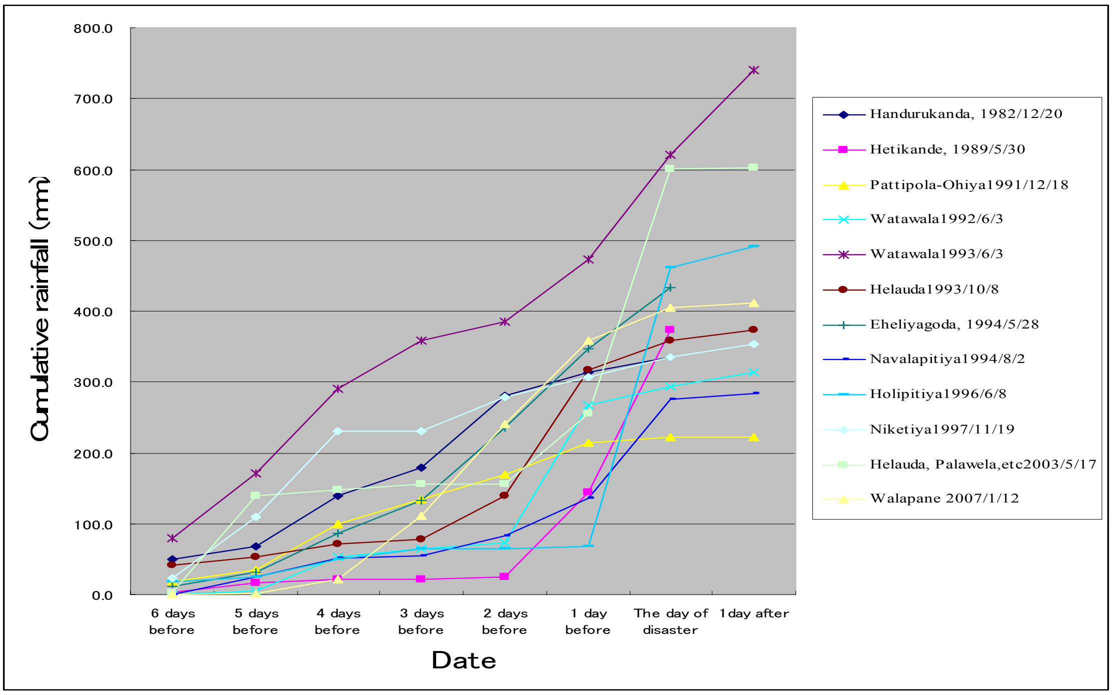


Figure N.2.13 Rainfall in the Case of 12 Major Sediment Disasters (7 Days Cumulative Rainfall)

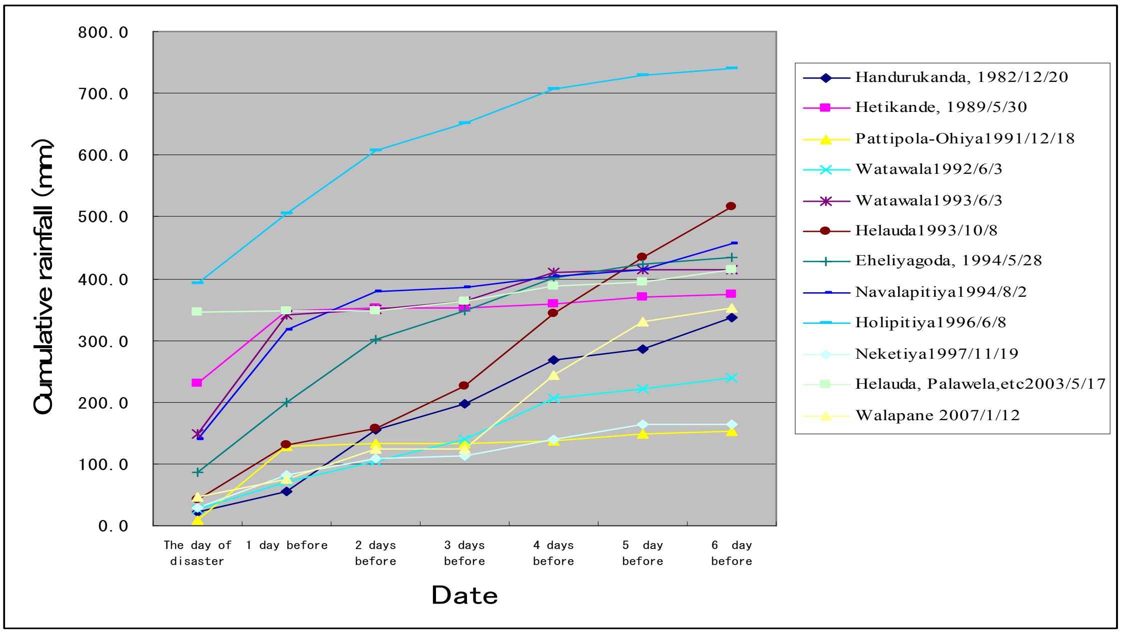


Figure N.2.14 Rainfall in the Case of 12 Major Sediment Disasters
(7 Days Cumulative Rainfall going back from the day of the Sediment Disaster)

There was a remarkably heavy rainfall on the day sediment disasters occurred at Holipitiya (8 June 1996) with 392mm, and Helauda, Palawela, etc (17 May 2003) with 345mm. Heavy rainfall on the same day was concluded to be the cause of these two disasters, and thus it is possible to categorize these as "same day heavy rainfall". Also, heavy rain fell the day prior to sediment disasters which occurred in Watawala (2 June 1992) with 194mm, and Helauda (7 October 1993) with 177mm. Nonetheless, these two disasters occurred in the early morning of the same day, and thus fundamentally fit into the above-mentioned "same day heavy rainfall" category. Another category, "continual rainfall", where heavy rains fall 1 week or 3 days prior, includes Pattipola-Ohiya (18 December 1991), Watawala (May to June 1993), Navalapitiya (July to August 1994), Neketiya (November 1997), and Walapane (January 2007). Among these, Pattipola-Ohiya (18 December 1991) and Neketiya (November 1997) were sediment disasters with comparatively little antecedent rainfall.

N.2.3 Rainfall Characteristics in Ratnapura

Presently, the JICA Study Team analyzes the relationship between rain and sediment disasters according to their analysis of daily amounts of rainfall. The Ratnapura Observatory - near Palawela, which experienced earthflow in 2003; Helauda, where earthflow occurred in 1993; and Hoilptiya, where landslide occurred in 1996 - is examining the relationship between amounts of rainfall and sediment disasters. In approximately 16 years, maximum daily rainfall amounts were 392.5 mm (8 June 1996), 345.2 mm (17 May 2003), 232.3 mm (19 April 1999), and 177.6 mm (7 October 1993), where landslide disasters occurred three times among these figures, on 8 June 1996, 17 May 2003 and 7 October 1993 .

In addition, frequent occurrence of rainfall for one day, 2 days and 3 days are expressed in Figure N.2.15 through Figure N.2.17. After that, Figure N.2.18 shows the daily rainfall at the Ratnapura Observatory in relationship to landslide disaster recorded as "occurred" or "not occurred". The day before the 1993 earthflow at Helauda, heavy rains amounted to 177.6 mm and because the earthflow occurred around 7:30 AM, it can be deduced that the torrential rains of the preceding day had an influence.

Due to the few "occurred" samples, it was not possible to separate the "occurred" and "not occurred" data according to amount of rainfall; however, when daily rainfall rises above 200 mm, it can be said that the danger of landslide disaster occurrence increases.

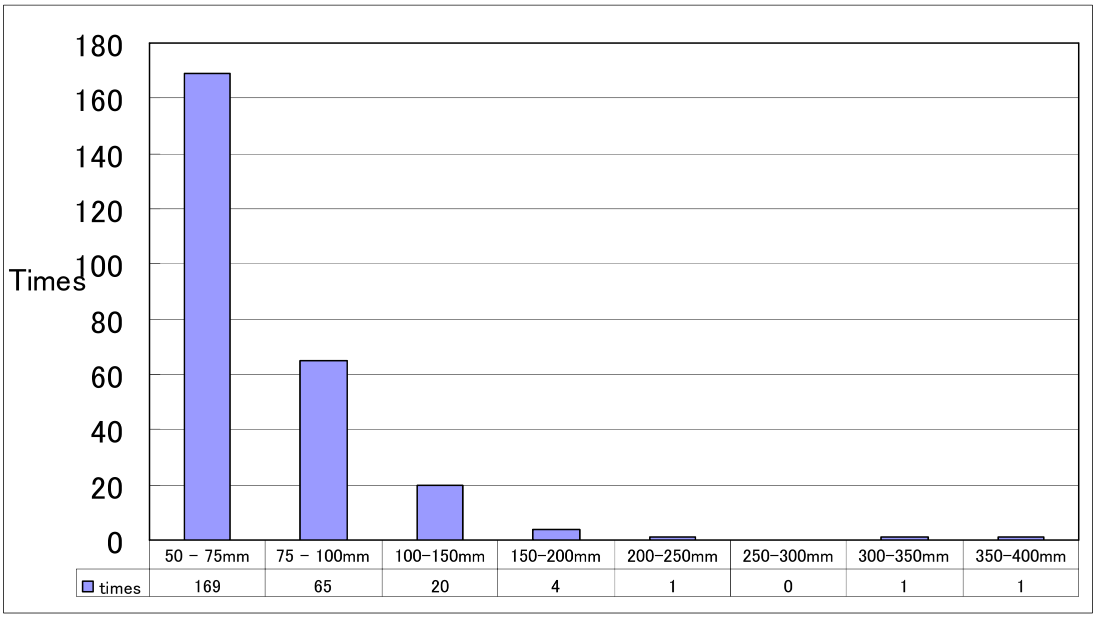


Figure N.2.15 Frequency of One Day Rainfall at Ratnapura (From 1991 to October 2006)

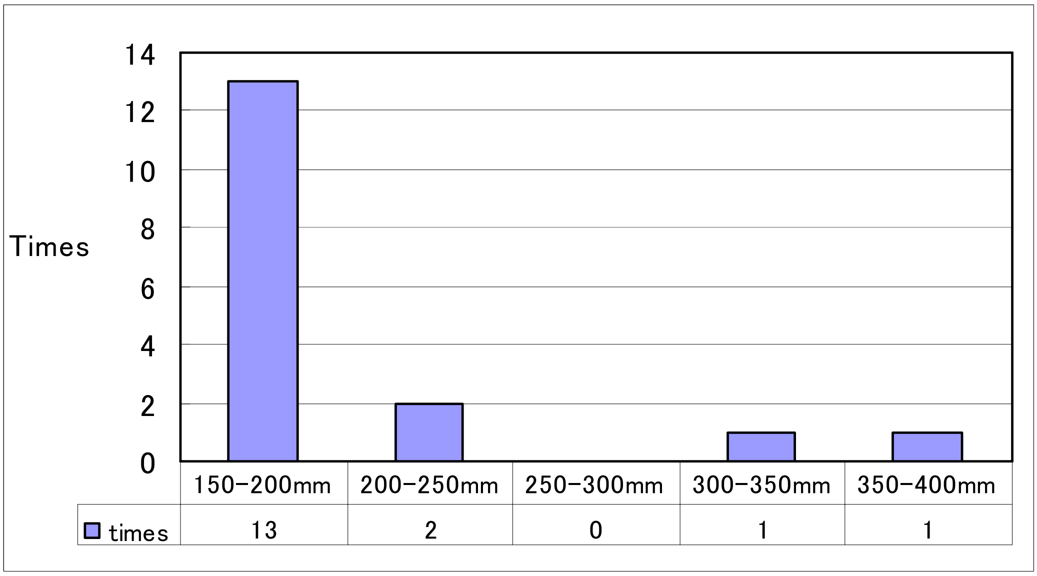


Figure N.2.16 Frequency of Two Days Rainfall at Ratnapura (From 1991 to October 2006)

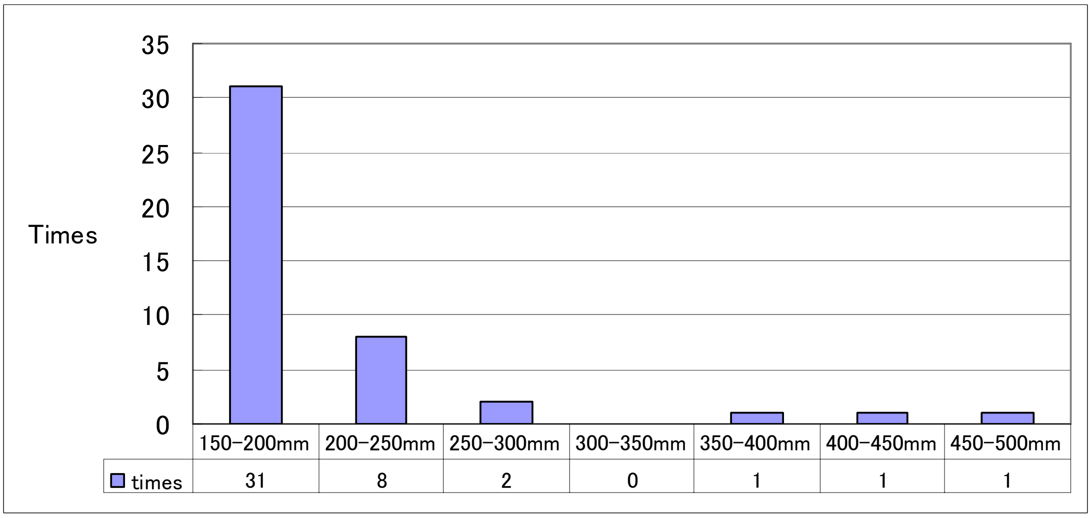


Figure N.2.17 Frequency of Three Days Rainfall at Ratnapura (From 1991 to October 2006)

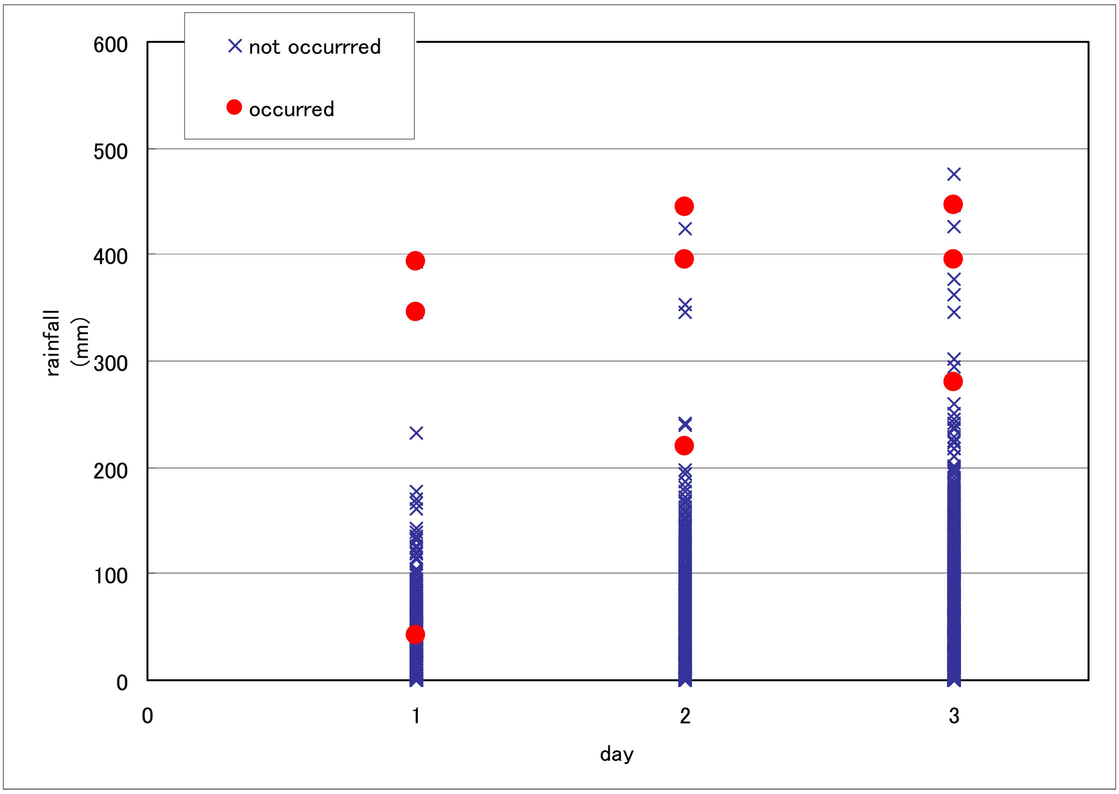


Figure N.2.18 Relationship between Plotted Rainfall Data of Sediment Disaster Occurrence at Ratnapura (From 1991 to October 2006)

N.3 Analysis between Sediment Disaster and Rainfall

The Landslide Studies and Service Division (LSSD) is involved in hazard mapping and, up to now has mainly been involved in predicting the location of sediment disaster occurrences. However, at present, due to structural changes within the Ministry of Disaster Management and Human Rights, greater importance will be placed on the task of predicting the time of sediment disaster occurrences. Therefore, it can be expected that it will be an organization/system which can clarify the relationship between sediment disaster and rain as well as for the release of alerts and early warnings. Rainfall observation has begun in the Ratnapura district by JICA (4 pilot communities for CBDM) and UNDP (5 stations). It is necessary to collect and aggregate those two data to set critical rainfall for warning and evacuation from sediment disasters, etc.

N.3.1 Significance of Rain Gauge for Villagers

JICA Study Team installed a rain gauge with sensors in 4 pilot communities for CBDM on sediment disaster and villagers started observing rainfall. An overview of the place where the gauges were installed and the status of observations are given in the table below.

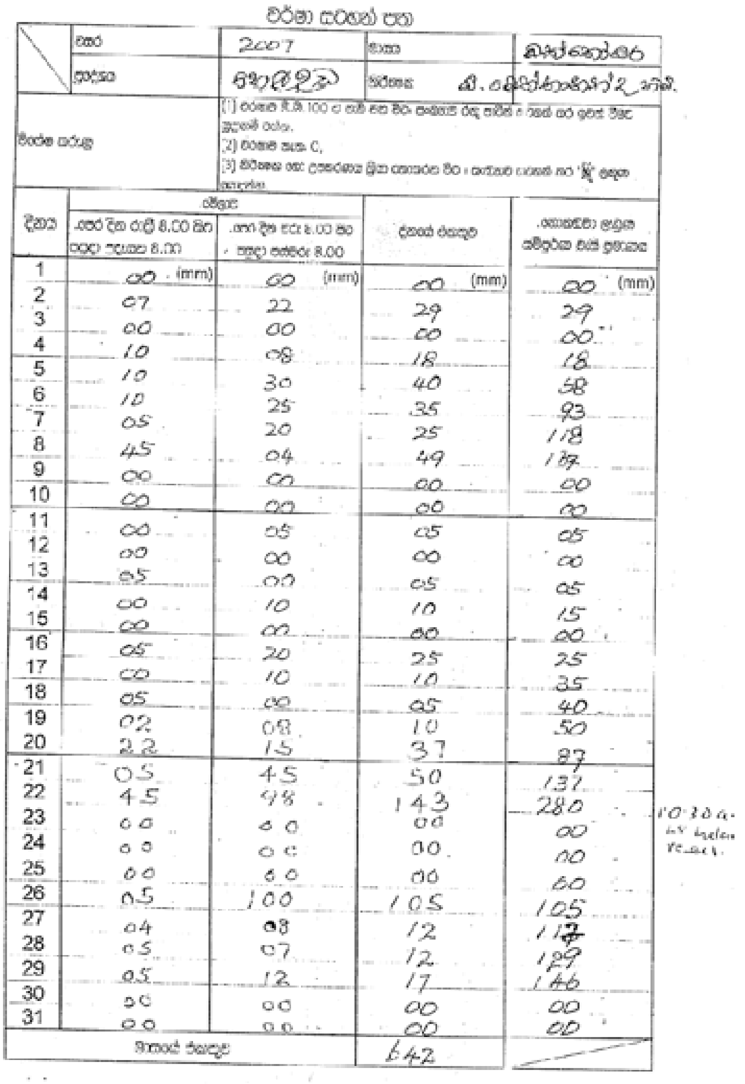
Table N.3.1 Rain Gauge Installation

4 pilot communities for CBDM on sediment disaster	Initiation date	State of installation
Halauda, Ratnapura District	1 July 2007	Rain collector was installed on the roof of the village temple. The monk is in charge of observation.
Kiribathigala, Ratnapura District	11 July 2007	Rain collector was installed on the roof of the villager's house. The villager is in charge of observation. There are trees nearby.
Niggaha, Kalutara District	1 June 2007	Rain collector was installed on the roof of the villager's house. The villager is in charge of observation.
Nagalakanda, Kalutara District	1 June 2007	Rain collector was installed on the roof of the villager's house. The villager is in charge of observation. There are trees nearby.

Figure N.3.1 Rain Gauge in the Helauda Temple(left) and Kiribathigala(right), Ratnapura District

The gauge records 12 hour rainfall on a daily basis at 8 AM and 8 PM. By adding together these 12 hour measurements, one arrives at the amount of rainfall over a 24-hour period. Futhermore, by adding together 24-hour measurements, cumulative rainfall for 24 hours is calculated. Should cumulative rainfall for 24 hours in one day be zero, the gauge is reset. The record sheets are sent to NBRO every month by the villagers at the beginning of the following month. An example of a record sheet is shown in Table N.3.2.

Table N.3.2 Example of Monthly Rainfall Record Sheet
（Helauda, Ratnapura District）



2007

1	00 (mm)	00 (mm)	00 (mm)	00 (mm)
2	07	22	29	29
3	00	00	00	00
4	10	08	18	18
5	10	30	40	58
6	10	25	35	93
7	05	20	25	118
8	45	04	49	187
9	00	00	00	00
10	00	00	00	00
11	00	05	05	05
12	00	00	00	00
13	05	00	05	05
14	00	10	10	15
15	00	00	00	00
16	05	20	25	25
17	00	10	10	35
18	05	00	05	40
19	02	08	10	50
20	22	15	37	87
21	05	45	50	137
22	45	98	143	280
23	00	00	00	00
24	00	00	00	00
25	00	00	00	00
26	05	100	105	105
27	04	08	12	117
28	05	07	12	129
29	05	12	17	146
30	00	00	00	00
31	00	00	00	00
			642	

Rain gauges are installed at villagers' homes and the families take responsibility to continue observations so that measurements are hardly ever missing. It is also apparent that an interest in the relationship between sediment disaster and rainfall has been developed by these villagers through the rain gauges. The observation period has been short at present (November 2007) so there have been no sediment disasters noted. At this point, 4 level (water level) sensors are not utilized.

N.3.2 Arrangement of Observation Data by Communities

NBRO places the unchanged data results they retrieve into a spreadsheet (i.e. Excel). Using the collected data, the JICA Study Team investigated model methods of arrangement and presented examples to NBRO.

Table N.3.3 shows villager observation of 12-hour rainfall in an input table and Figure N.3.2 shows the graphing of that data.

Table N.3.3 Data Input Table

Date and Time	12hours rain	24hours rain
2007/08/25 12:00	0	0.00
2007/08/26 00:00	85	85.00
2007/08/26 12:00	45	130.00
2007/08/27 00:00	0	45.00
2007/08/27 12:00	0	0.00
2007/08/28 00:00	5	5.00
2007/08/28 12:00	10	15.00
2007/08/29 00:00	35	45.00
2007/08/29 12:00	5	40.00
2007/08/30 00:00	5	10.00
2007/08/30 12:00	0	5.00
2007/08/31 00:00	0	0.00
2007/08/31 12:00	5	5.00
2007/09/01 00:00	5	10.00
2007/09/01 12:00	10	15.00
2007/09/02 00:00	0	10.00
2007/09/02 12:00	5	5.00
2007/09/03 00:00	10	15.00
2007/09/03 12:00	10	20.00
2007/09/04 00:00	10	20.00
2007/09/04 12:00	95	105.00
2007/09/05 00:00	70	165.00
2007/09/05 12:00	50	120.00

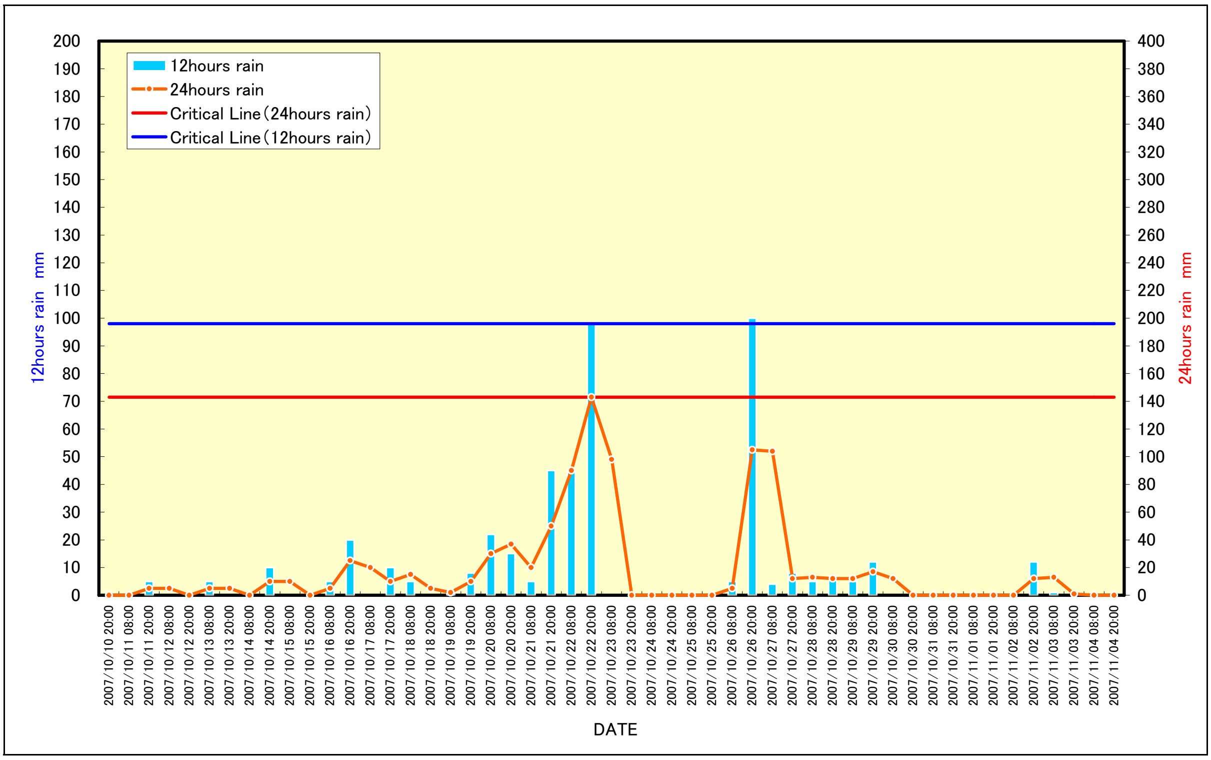


Figure N.3.2 Part of 12-hour and 24-hour Rainfall Graph

(The blue line indicates 12 hours and red line indicates 24 hours, respectively)

A provisional threshold is set for 12-hour rainfall and 24-hour rainfall, although it is necessary in the future, as observation data is added, to set rainfall indicators for warnings and evacuation. Mr. RMS. Bandara of NBRO has proposed the following indicators for 24-hour rainfall and 12-hour rainfall for alert, warning and evacuation admist observations.

Table N.3.4 Reference Rainfall for Sediment Disaster Presented by NBRO

Information	24 hour rainfall	12 hour rainfall
Alert	75mm within 24 hours	XX mm within 12 hours
Warning	100mm within 24 hours	XX mm within 12 hours
Evacuation	150mm within 24 hours 75mm within 1 hour	XX mm within 12 hours XX mm within 1 hour

N.3.3 Rainfall Observation of the UNDP Rain Gauge

Rainfall observation by UNDP is done with an automatic rain gauge in 5 locations in the Ratnapura District. This rain data is transmitted to NBRO in real time. In the future, dynamic models showing the relationship of rainfall and the occurance of sediment disasters will be clarified, and there are plans to implement a sediment disaster early warning system.

Table N.3.5 Rain Gauge Site and Initiation Date

Rain Gauge Site	Initiation Date
Elapatha	1 March 2007
Kalawana	22 May 2007
Kahawata	22 May 2007
Nivithigala	22 May 2007
Palumadulla	23 May 2007

Figure N.3.3 Rain Gauge Stations in Ratnapura District Installed by UNDP
(From NBRO's Presentation)

TIME	RF(mm)	DRF(mm)
11:30	001.00	0.50
12:30	001.00	0.00
13:30	001.00	0.00
14:30	004.75	3.75
15:30	004.75	0.00
16:30	004.75	0.00
17:30	004.75	0.00
18:30	006.00	1.25
19:30	006.00	0.00
20:30	006.00	0.00
21:30	006.00	0.00
22:30	006.00	0.00
23:30	006.00	0.00
00:30	006.00	0.00
01:30	008.25	2.25
02:30	008.50	0.25
03:30	008.50	0.00
04:30	008.50	0.00
05:30	012.50	4.00
06:30	020.25	7.75
07:30	027.25	7.00

Elapatha - 000.00mm Kahawaththa - 015.50mm Kalawana - 001.00mm Nivithigala - 006.25mm Palmadulla - 027.25mm

Figure N.3.4 Output of Cumulative Rainfall of 24 Hours

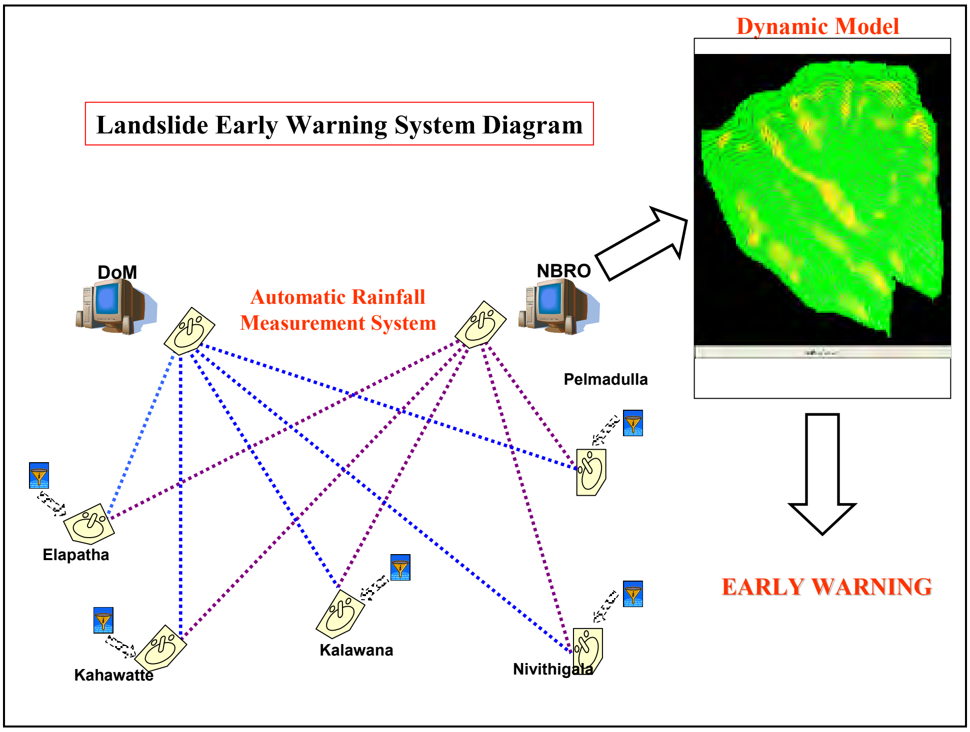


Figure N.3.5 Landslide Early Warning System Diagram
(From NBRO' Presentation)

N.4 Four (4) Pilot Communities for CBDM on Sediment Disaster

NBRO provided 20 recommendations for target sites which were then refined to 6 locations after conducting a field survey and looking at the sediment disaster hazard and condition of the communities. Afterwards, a community survey was done and finally the following 4 pilot communities were selected.

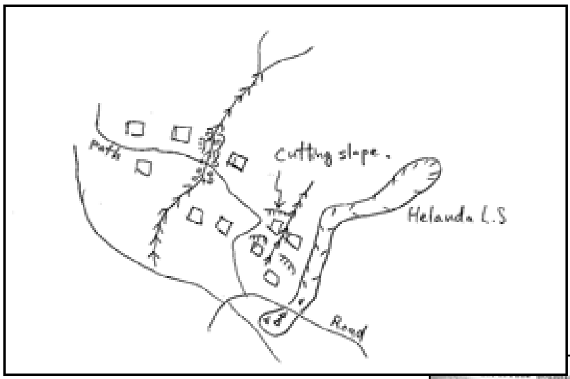
Table N.4.1 Four (4) pilot communities for CBDM on sediment disaster

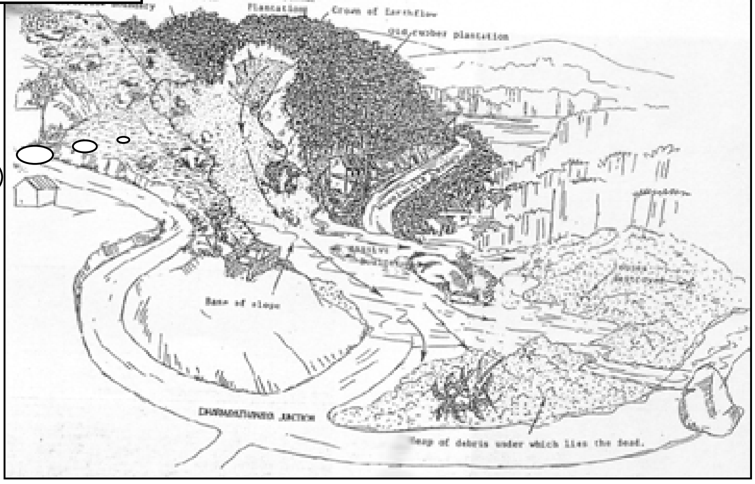
Site	Past disaster and hazard	Present status
Helauda, Ratnapura, District	Memorable disaster killing 31 people occurred in 3 October 1993. After the disaster, slope failure and debris flow sometimes occurred at the same slope.	20 families are dwelling on the dangerous slope. Villagers recognize the hazard of sediment disaster due to their experience of the disaster. JICA installed rain gauge and village people have started rain observation. UNDP has a plan of drainage construction.
Kiribathgala, Ratnapura, District	Tea plantation and scattering houses exist on the gentle slope under the huge cliff. 3 of the houses were damaged by landslide, cracks on the floor and wall appeared during the heavy rain of 2005. 3 clear landslide scarps can be observed.	23 families are dwelling on the slope. 4 families have evacuated due to the landslide. 4 more families are facing landslide hazard. JICA installed rain gauge and village people have started rain observation.
Niggaha, Kalutara, District	Steep slopes standing in the rear of the village, village located on the talus or alluvial fans. In 1986, earth slide with 90m width and 150m length occurred. Debris flow occurred in some small valleys. Furthermore, lowland along the river in front of the village is prone to floods.	About 23 families are dwelling on the slope. They need to pay attention to both sediment disaster from behind and flood from front. JICA installed rain gauge and village people have started rain observation.
Nagalakanda, Kalutara, District	Houses are scattered at the foot of isolated mountain. Lands are used by cutting the slope, some houses are facing cutting failures. Cracks appeared on the slope.	37 families are dwelling at the foot of the mountain. 12 families have evacuated due to the landslide. A part of the slope is artificially modified. JICA installed rain gauge and village people have started rain observation.

Table N.4.2 Pilot Site for Sediment Disaster Sheet (1/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Ratnapura	Mawala	Helauda
Site Information (Risk objects)	Number of families	Number of evacuated families	Number of warned families
	20	0	20
Landuse	rubber plantation		
Landform/Topography	slope with 25 to 35 degree, gullies developed		
Geology	fresh rock and talus deposit		
Type of disaster	Landslide [✓ Slope failure] [✓ Debris flow] Rockfall Flood Other ( )		
Hazard level by NBRO	high		
Comments on damage	At Helauda debris flow, 31 people killed by debris flow. Some people heard the big sound of landslide. That event occurred 3 times. Current damage is none, but people still scare about landslide.		

Illustration (plane and profile)



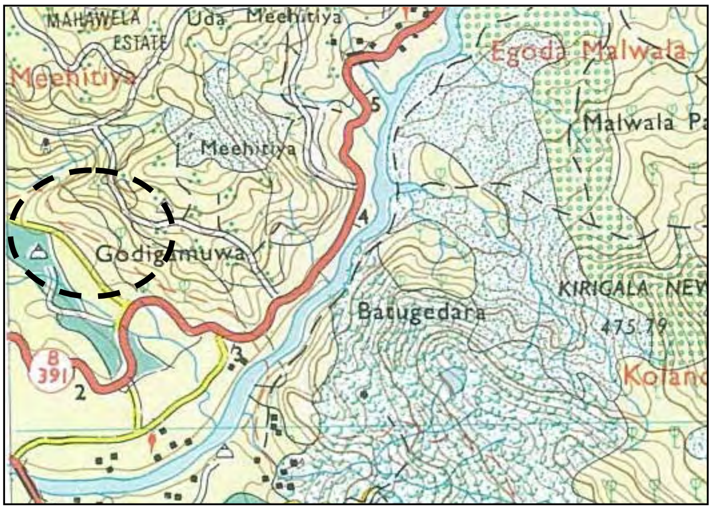


left of this sketch

Table N.4.2 Pilot Site for Sediment Disaster Sheet (2/3)

	D.S. Division	G.N.Division	Location
District:Ratnapura	Ratnapura	Mawala	Helauda

Map



Photographs


Slope beside Helauda landslide


House on the colluvial slope


House and cutting slope


Installed rain gauge

Table N.4.2 Pilot Site for Sediment Disaster Sheet (3/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Ratnapura	Mawala	Helauda

Hazard Map

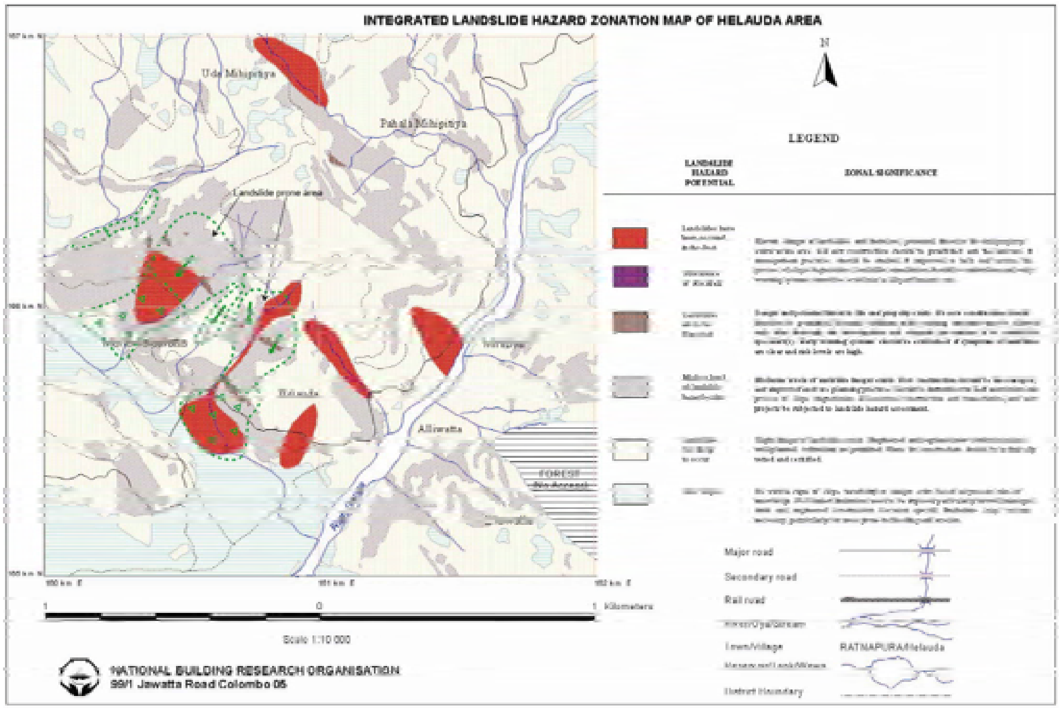


Table N.4.3 Pilot Site for Sediment Disaster Sheet (1/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Nivithigala	Kiribathgala	Kiribathgala

Site Information (Risk objects)	Number of families	Number of evacuated families	Number of warned families
	23	3	4
Landuse	tea plantation		
Landform/Topography	landslide slope with 10 to 15 degree, and steep cliff behind		
Geology	fresh rock, weatherd red soil and talus deposit		

Type of disaster	[✓ Landslide] Slope failure Debris flow Rockfall Flood Other ( )
Hazard level by NBRO	high
Comments on damage	Some tensional cracks were observed above the Kahawatta Road and some cracks in houses. Two small scale landslides with clear scarp is observed in the tea plantation. As there were 3 major zones in this area which have a risk of landslides. 3 houses were at high risk and recommended to be evacuated.

Illustration (plane and profile)

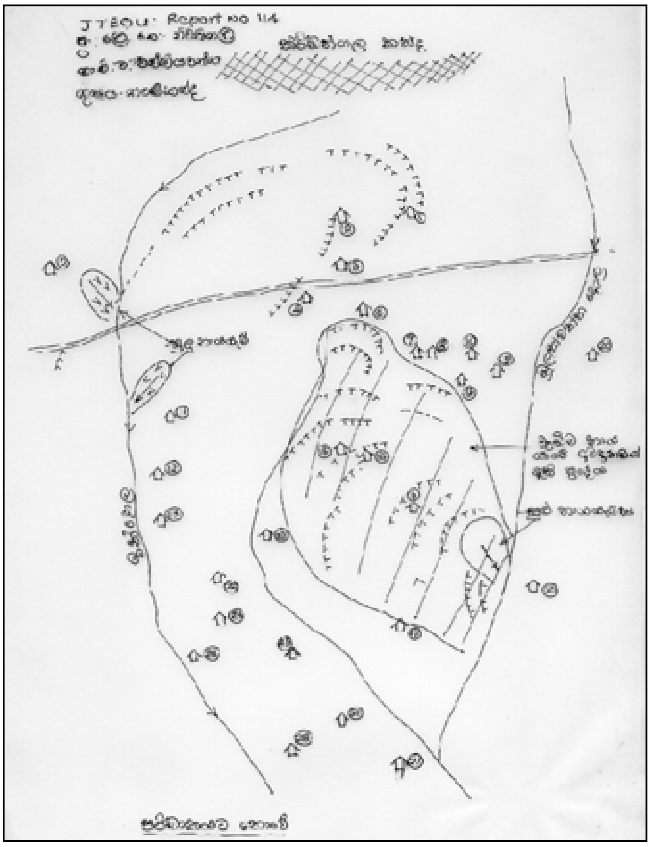


Table N.4.3 Pilot Site for Sediment Disaster Sheet (2/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Nivithigala	Kiribathgala	Kiribathgala

Map

Photographs

top of thelandslide and cliff

an overall view of landslide slope

crack on the wall

Installed rain gauge

Table N.4.3 Pilot Site for Sediment Disaster Sheet (3/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Nivithigala	Kiribathgala	Kiribathgala 4 km. along Nivithigala – Kahawatta road

Hazard Map

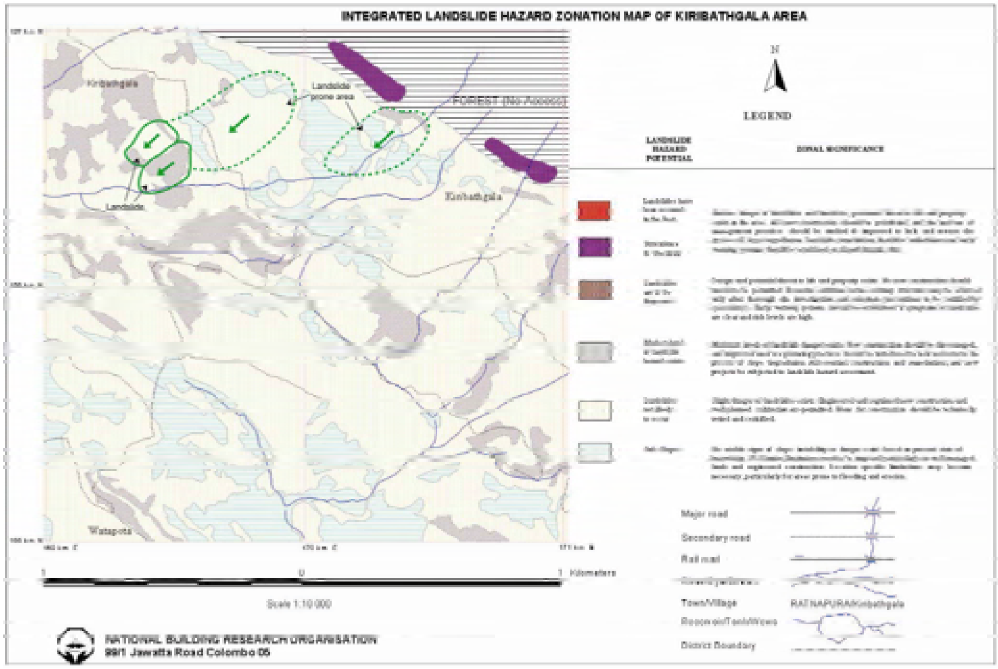


Table N.4.4 Pilot Site for Sediment Disaster Sheet (1/3)

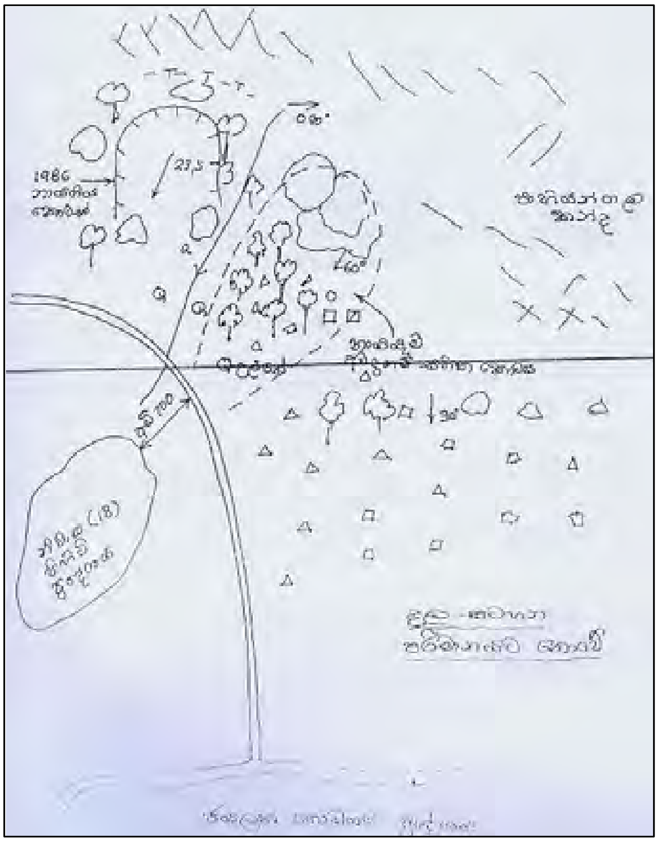
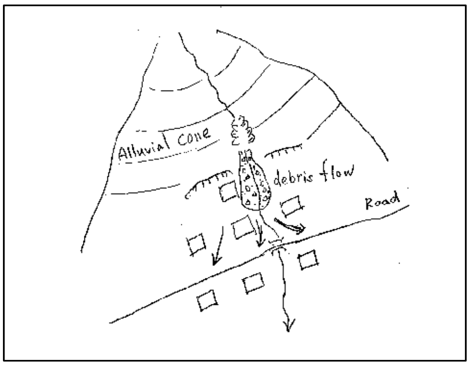
District:Kalutara	D.S. Division	G.N.Division	Location
	Bulathsinhala	Niggaha	Niggaha
Site Information (Risk objects)	Number of families	Number of evacuated families	Number of warned families
	15 to 20		
Landuse	tea and rubber plantation		
Landform/Topography	landslide slope with 30 to 40 degree, and torrent flow down and formed clear alluvial cone. Alluvial cone is dissected and formed gully, recently.		
Geology	weathered rock, weathered red soil and debris flow deposit		
Type of disaster	[✓ Landslide] Slope failure [✓ Debris flow] Rockfall Flood Other ( )		
Hazard level by NBRO	high		
Comments on damage	Early landslide occurred in 1986 of width 300 ft. and length 500 ft. There was a tension crack appeared beyond the slide. Few boulders are located at the east. The soil below the slope is unconsolidated and that may be due to the removal of rubber and tea plantation. Water springs can be observed during rainy days. There are two houses directly below the torrent. This community is high hazard for debris flow.		
Illustration (plane and profile)			
			

Table N.4.4 Pilot Site for Sediment Disaster Sheet (2/3)

District:Kalutara	D.S. Division	G.N.Division	Location
	Bulathsinhala	Niggaha	Niggaha

Map

Photographs

steep slope and torrent

debris flow deposits

alluvial cone deposit behind house

Installed rain gauge and record file

Table N.4.4 Pilot Site for Sediment Disaster Sheet (3/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Ratnapura	Mawala	Niggaha

Hazard Map

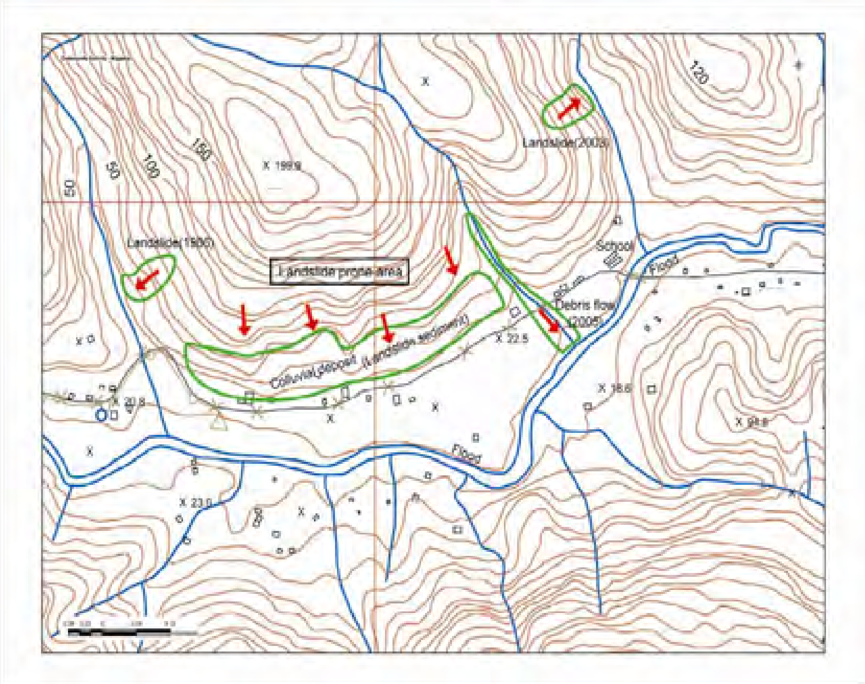


Table N.4.5 Pilot Site for Sediment Disaster Sheet (1/3)

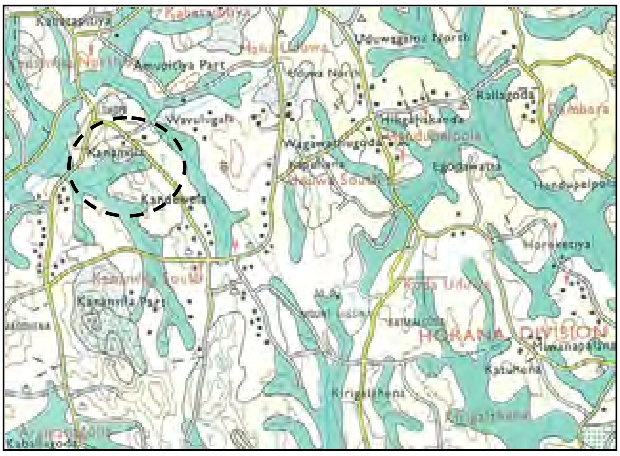
District:Kalutara	D.S. Division	G.N.Division	Location
	Horana	Kananvila-south	Nagalakanda
Site Information (Risk objects)	Number of families	Number of evacuated families	Number of warned families
	37	12, 5(seosonal)	
Landuse	rubber plantation		
Landform/Topography	slope angle is between 30 to 35 degree, colluvial slope is 20 degree		
Geology	weathered rock		
Type of disaster	[✓ Landslide] Slope failure Debris flow Rockfall Flood Other ( )		
Hazard level by NBRO	high		
Comments on damage	Large tension crack appeared. Rockfall occur sometime at the time of heavy rain. 17 families live on colluvial slope and 20 families live lowland apart from the slope. Within 17 families, 12 families moved completely, 5 families evacuate in rainy season.		

Illustration (plane and profile)

Table N.4.5 Pilot Site for Sediment Disaster Sheet (2/3)

	D.S. Division	G.N.Division	Location
District:Kalutara	Horana	Kananvila-south	Nagalakanda

Map



Photographs

landslide prone slope

ruin of evacuee's house

cutting slope behind the house

Installed rain gauge and family in charge

Table N.4.5 Pilot Site for Sediment Disaster Sheet (3/3)

District:Ratnapura	D.S. Division	G.N.Division	Location
	Ratnapura	Mawala	Nagalakanda

Hazard Map