Reduction of Landslide Risk in Sri Lanka

Part 2 - Landslide Hazard Zonation and Monitoring

Time Capsule project of ISSMGE
Sri Lankan Geotechnical Society

Landslide Disaster Risk Reduction

Risk Identification

1. Identification through susceptibility/ Hazard / Risk zoning
2. Site specific investigations (eg. Landslide investigation)

Risk Communication

1 Monitoring
2. Early warning
3. Education, Training and Awareness
4. Preparedness

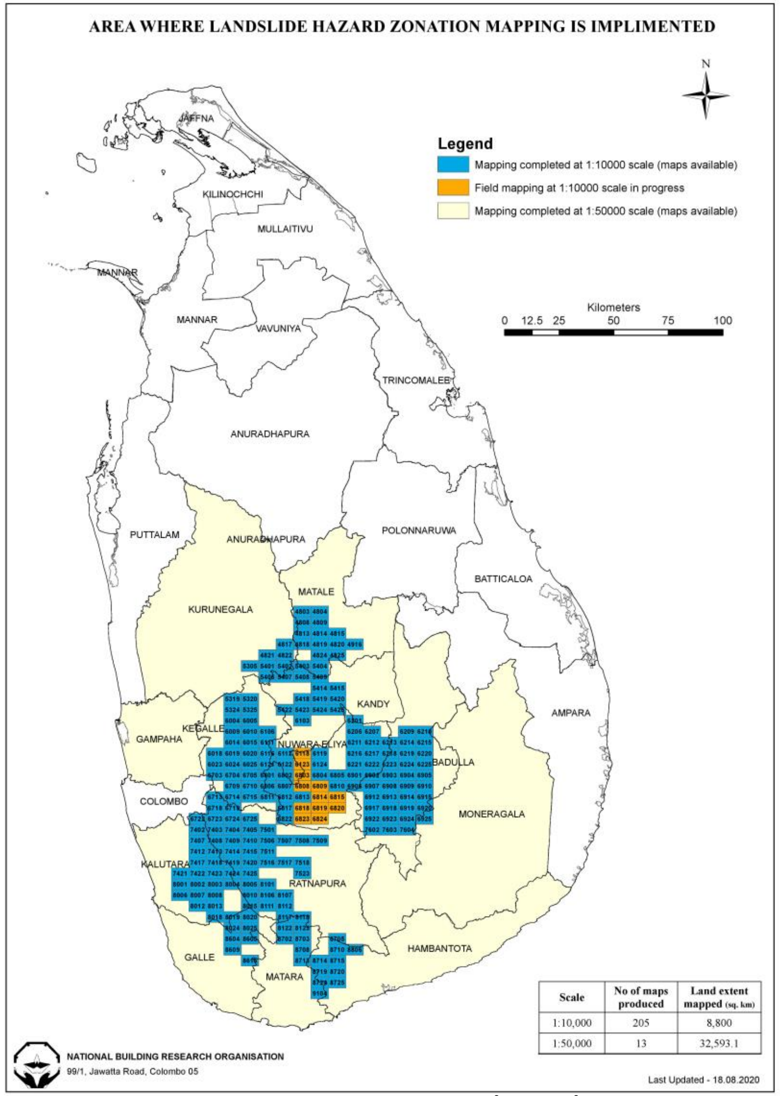
Risk Mitigation

1. Development control
2. Land use planning
3. Resilient construction
4. Special Investigation and design of countermeasures
5. Resettlement

National Building Research Organisation (NBRO) is the major government body designated to handle risks of landslides. NBRO designs and implement risk management measures.

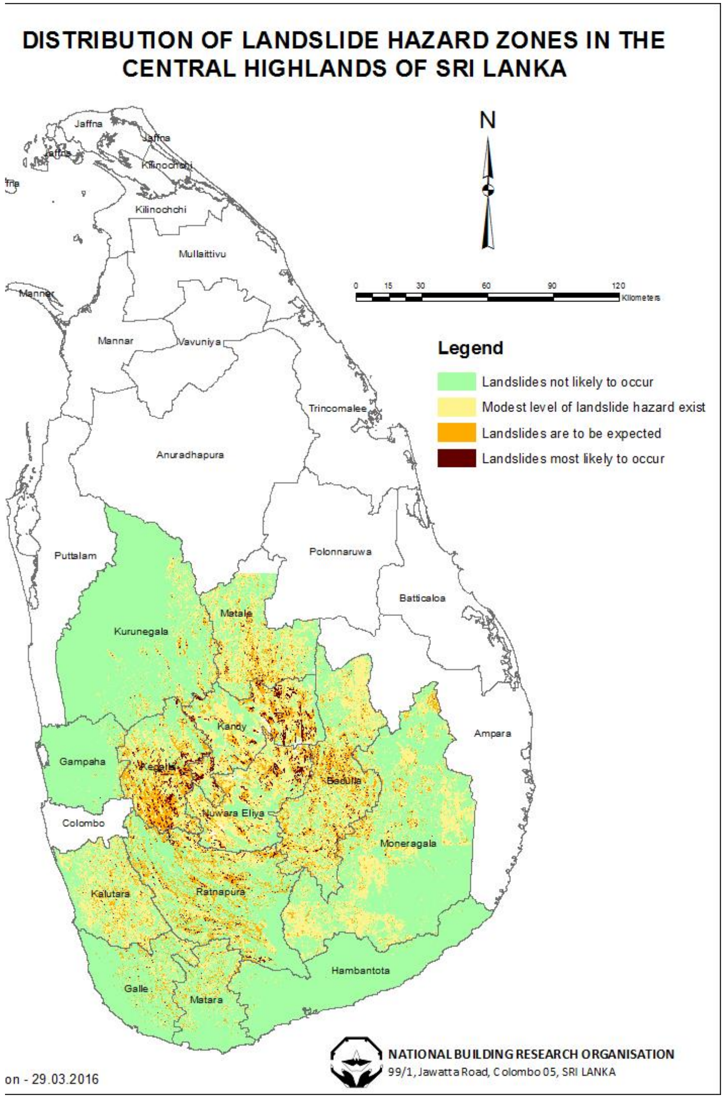
SRI LANKAN GEOTECHNICAL SOCIETY S L G S 1986

Landslide hazard zonation in Sri Lanka



Scale	No of maps produced	Land extent mapped (sq. km)
1:10,000	205	8,800
1:50,000	13	32,593.1

1:10000 map availability



1:50000 zonation map

Commenced with UNDP Assistance in 1990-95

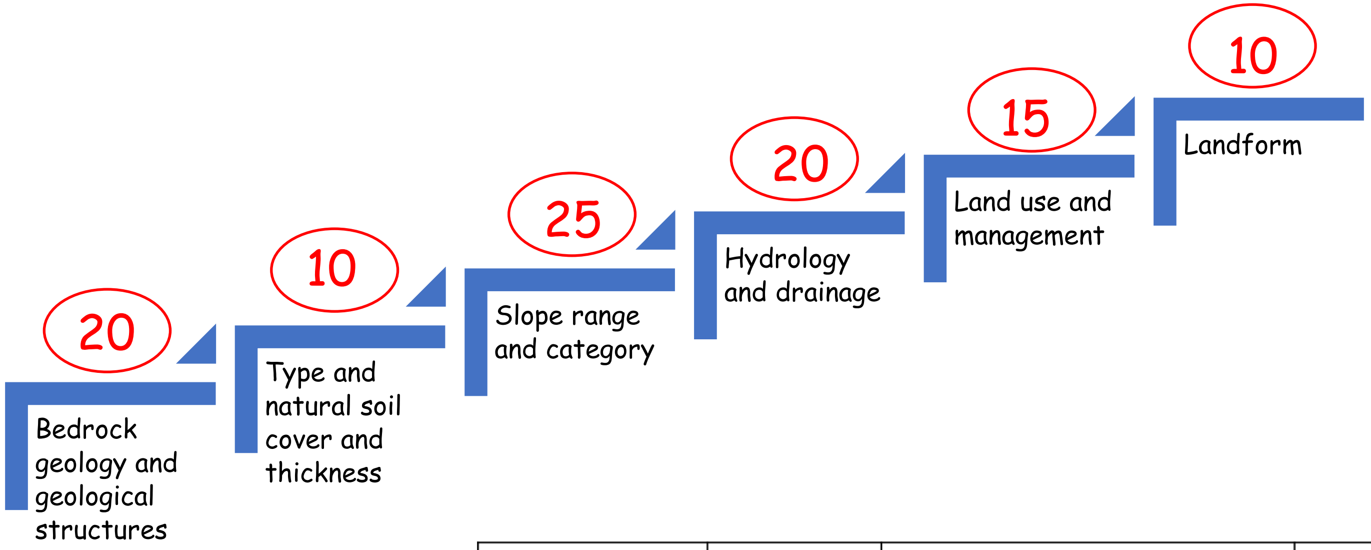
In Sri Lanka 1:50,000 and 1:10,000 hazard zonation maps are being used.

1:50,000 maps have already been prepared to cover 13 districts in Sri Lanka.

Preparation of 1:10,000 maps is still in progress.

Landslide hazard zonation in Sri Lanka

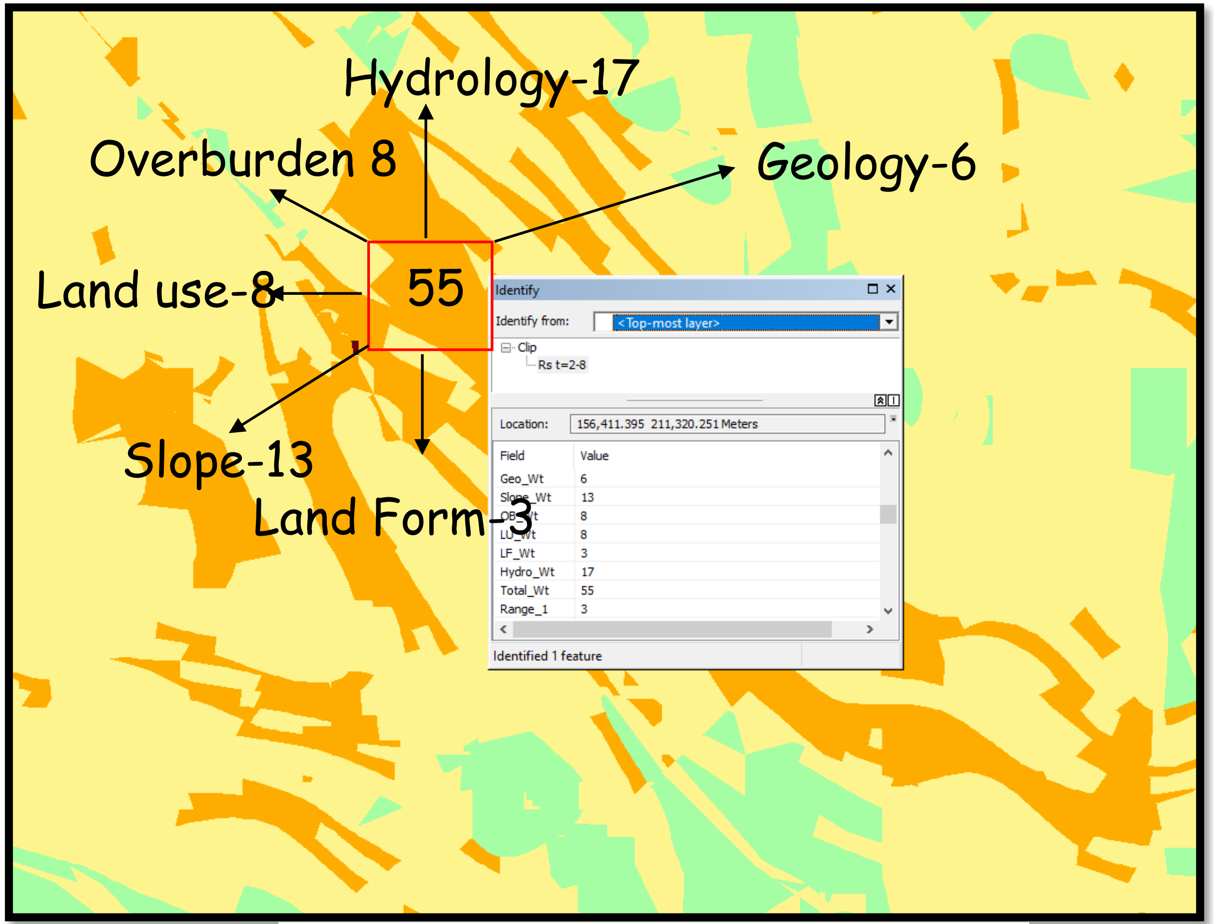
The prepared weight maps are combined using GIS to obtain an overall hazard rating for different zones



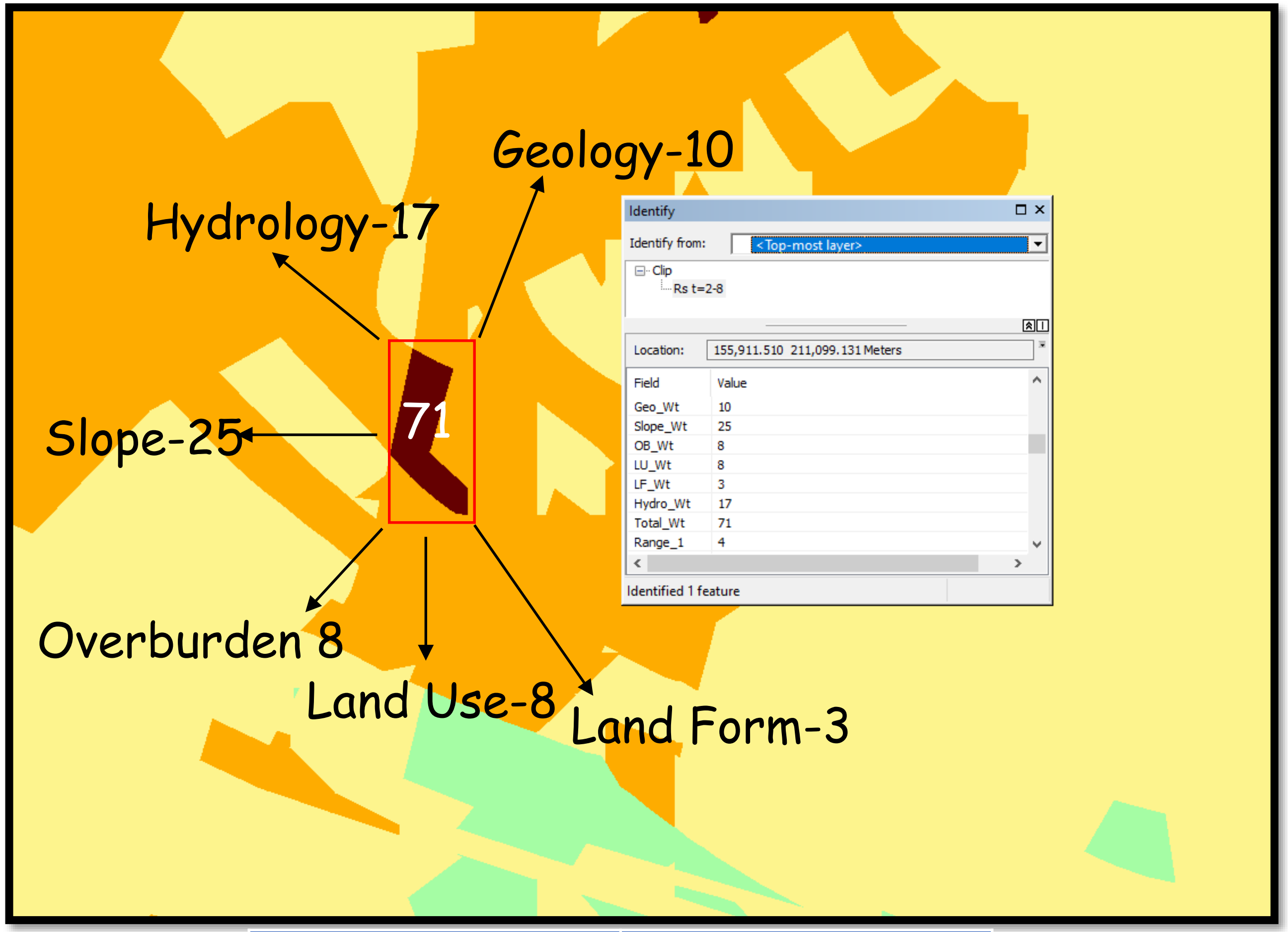
Overall Hazard Rating (R)	Hazard Zone	Description	Colour
R<=40	1	Safe slope	
40<R<=55	2	Landslide not likely to occur	
55<R<=70	3	Modest level of landslide hazard	
70<R	4	Landslides are to be expected	

Major factors & Max. weighting		Sub factors & Maximum weighting		Sub factor elements (factor classes)	Linguistic rating(x) & Scores(z) x	z
Bedrock Geology & Geological structures	20	Lithology	8	Marble	very low	0
				Weathered rock	low	1
				All others	medium	3
				Charnockite, Granulite or bedrock not exposed	high	5
				Quartzite	very high	8
		Amount of dip & type of slope	4	Dip & scarp 71-90	very low	0
				Dip & scarp 56-70	low	1
				Dip 11-30, scarp 46-55 & all intermediate slopes	medium	2
				Dip 0-10, scarp 31-45	high	3
				Dip 31-55, scarp 0-30	very high	4
		Deviation angle (degrees)	6	Angle 26-120	very low	0
				Angle 11-25 or 121-155	low	2
				Angle 156-180	high	4
				Angle 0-10	very high	6
		Other Discontinuities	2	To be decided on case to case basis	very low	0
					very high	2
Type of natural soil cover & thickness	10	Soil cover (m)	10	Bare bedrock	very low	0
				Colluvium <1, Residual <2	low	2
				Colluvium 1-3, Residual 2-8	medium	8
				Colluvium 3-8, Residual >8	high	9
				Colluvium >8, Residual >8	very high	10
Slope range & category	25	Slope range & category (degrees)	25	Slope category I (>40)	very high	25
				Slope category II (31-40)	high	16
				Slope category III (17-31)	medium	13
				Slope category IV (11-17)	low	7
				Slope category V (0-10)	very low	5
Hydrology & Drainage	20	Relief amplitude(m)	5	Relief >350	Very low	1
				Relief 0-170	medium	2
				Relief 170-350	very high	5
		Hydrological map unit area (sq. km)	4	Area 0-0.07 or > 0.5	very low	1
				Area 0.07-0.2	medium	2
				Area 0.2-0.5	very high	4
		Hydrological map Unit shape (form factor	4	0.6-1.0	very low	1
				0.3-0.6	medium	2
				< 0.3	very high	4
		Drainage density (km/sq. km) with or without soil cover	5	With >5 or without >10	very low	1
				With 3-5 or without 6-10	medium	2
				With 0-3 or without <6	very high	5
		Proximity to water bodies	2	To be decided on case to case basis	very low	0
					medium	1
					very high	2
Land use & Management	15	Land use & Management	15	JT1, JC, JQ, JWb, W1, S1	very low	3
				JT2,JR,JWp,HP,HK,HM,HW,W2,W3,W4, S2,S4	medium	8
				HA, G1, G2, S3, N1, N2, N3, N4	very high	15
Landform	10	Landform	10	F11,F12,F31-35,F43,F91-92, F94,A10-13, X1,X2	very low	1
				F41,F42,F44-48,F53	medium	3
				F51,F52,F54-58,X13,X14	high	5
				F61,F62,F71-74,F81-83, F92,X11,X15	very high	10

SRI LANKAN GEOTECHNICAL SOCIETY SLGS 1986



Factor	Score
Geology	6/20
Overburden	8/10
Slope	13/25
Hydrology	17/20
Land Use	8/15
Land Form	3/10
Total	55/100



Factor	Score
Geology	10/20
Overburden	8/10
Slope	25/25
Hydrology	17/20
Land Use	8/15
Land Form	3/10
Total	71/100

SRI LANKAN GEOTECHNICAL SOCIETY SLGS 1986

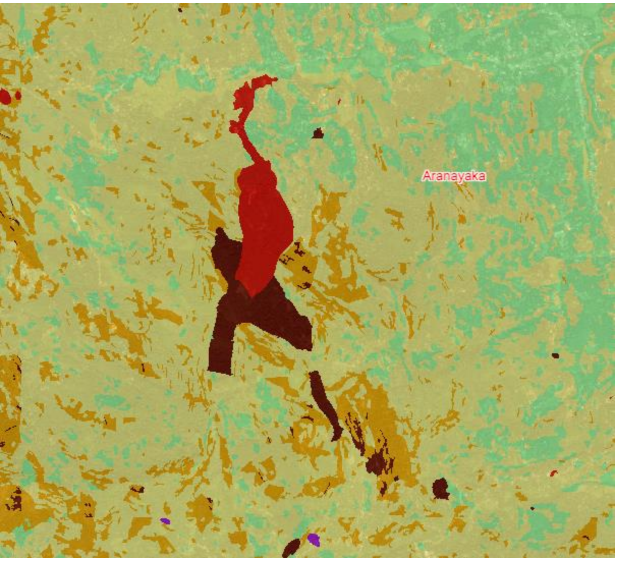
Utilization of Maps

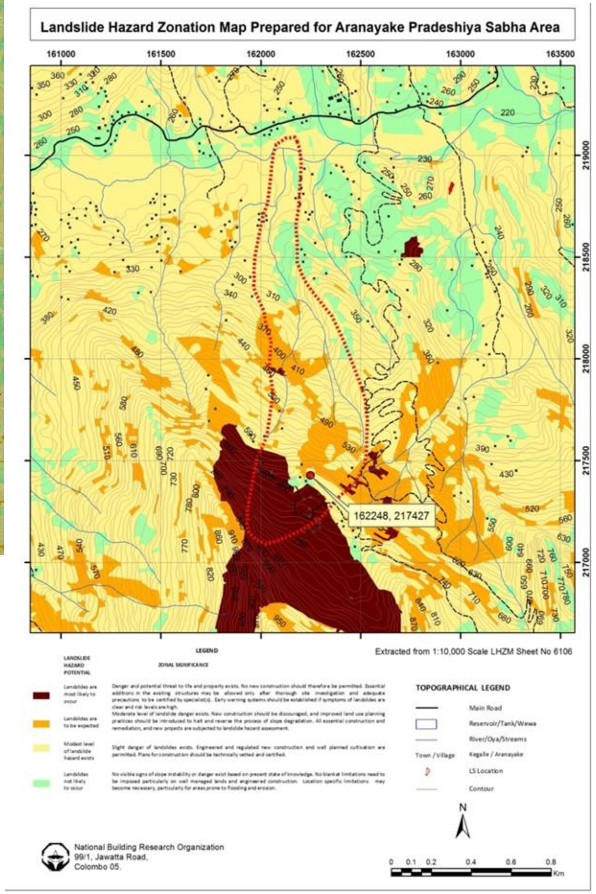
Landslide hazard zonation maps and associated construction guidelines are incorporated in development plans prepared by,

- National Physical Planning Department (NPPD)
- Urban Development Authority (UDA)
- Road Development Authority (RDA)
- Local Authorities in landslide prone districts
- Central Environmental Authority (CEA)

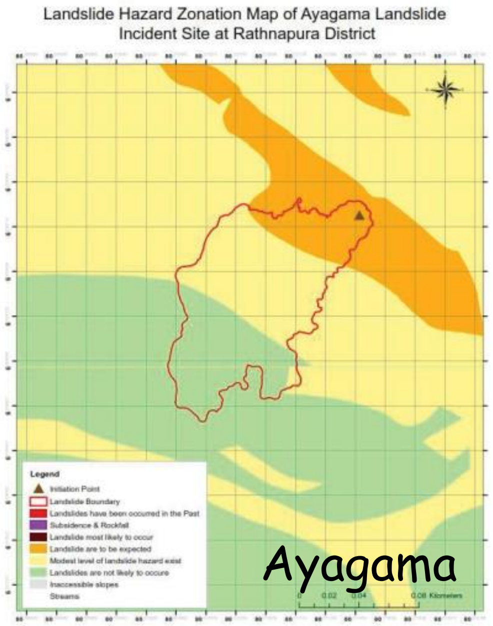
Banks and Insurance companies also can utilize these maps in considering for loans and insurance plans

Landslide hazard zonation in Sri Lanka

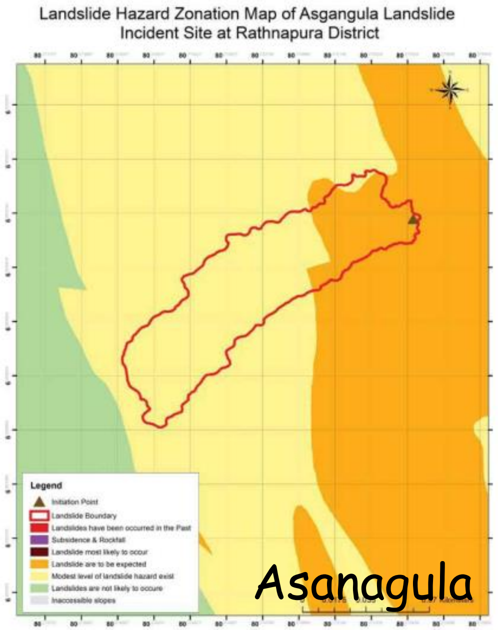




Aranayaka landslide



Ayagama



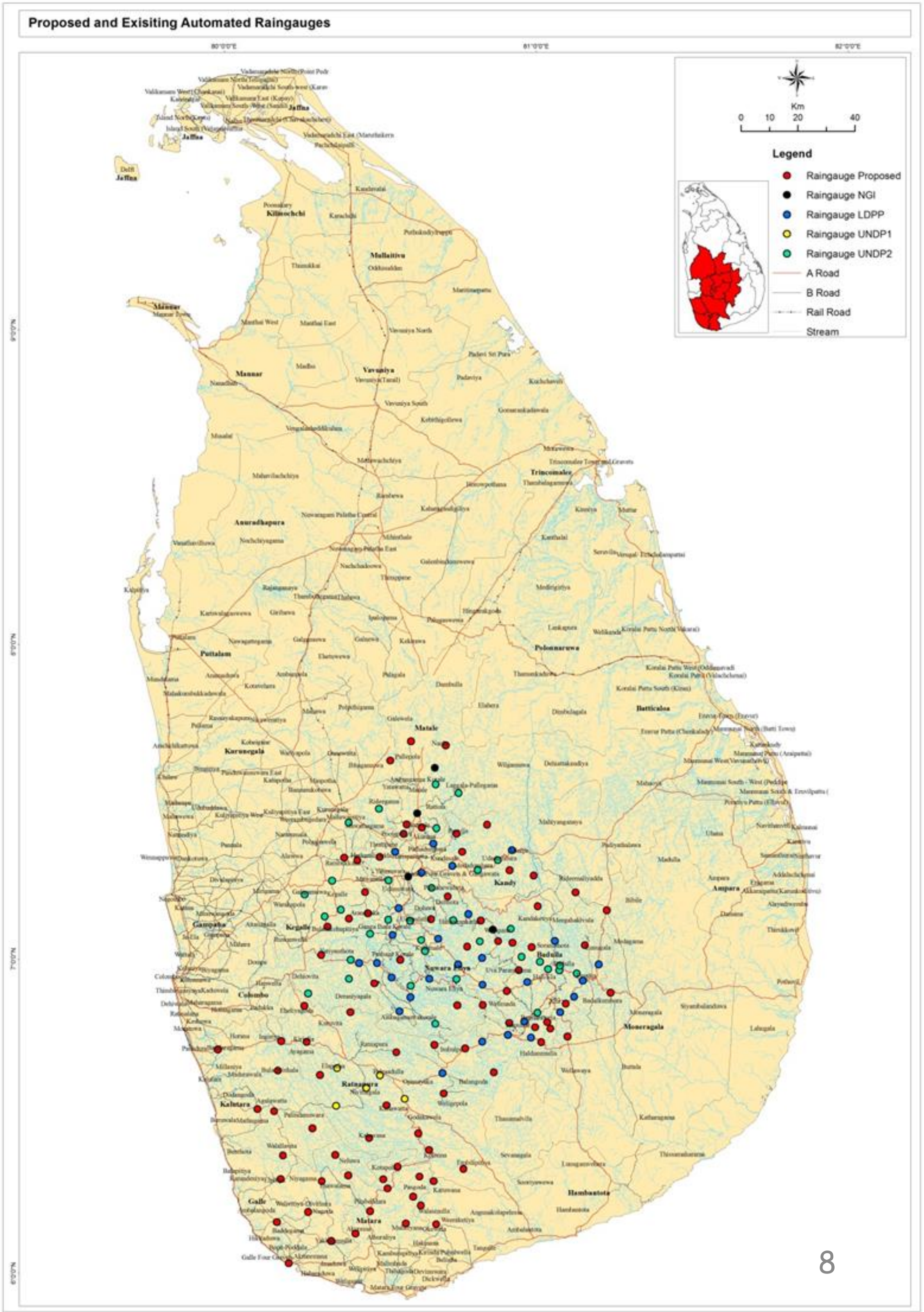
Asanagula

LHZM successfully used in predicting some major landslide events

Landslide Monitoring & Early Warning

Real time landslide forecasting and early warning capacity of NBRO

- NBRO has been assigned the task of issuance of Landslide Early Warning
- 325 automated rain gauge stations in pre-selected catchments in landslide prone districts
- These stations are now working in the automated rain gauge network of NBRO for landslide early warning



Landslide early warning in SL

- In Sri Lanka rainfall measurements from the telemetered rain gauge networks are being used to issue early warning.
- Rainfall thresholds have been developed empirically in a regional scale.
- Early warning is issued at 3 levels based on the daily and hourly rainfall intensity.

Watch

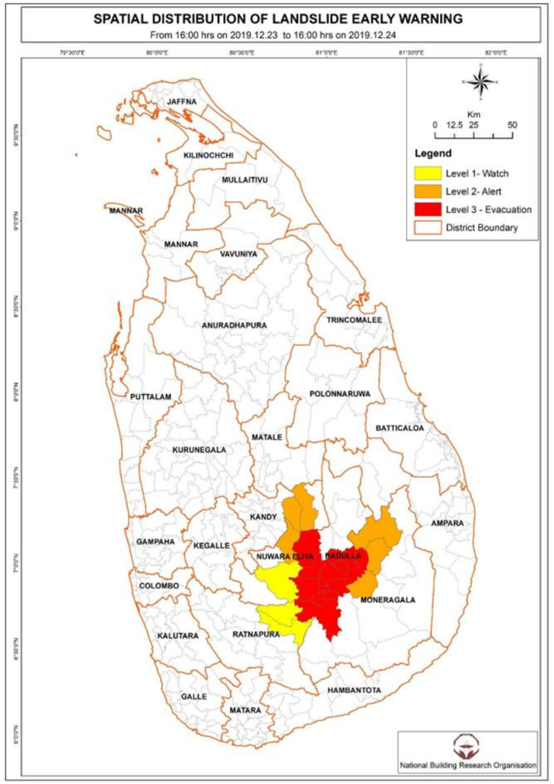
The rainfall within the past 24 h exceed 75 mm continuing

Alert

The rainfall within the past 24 h exceed 100 mm and continuing

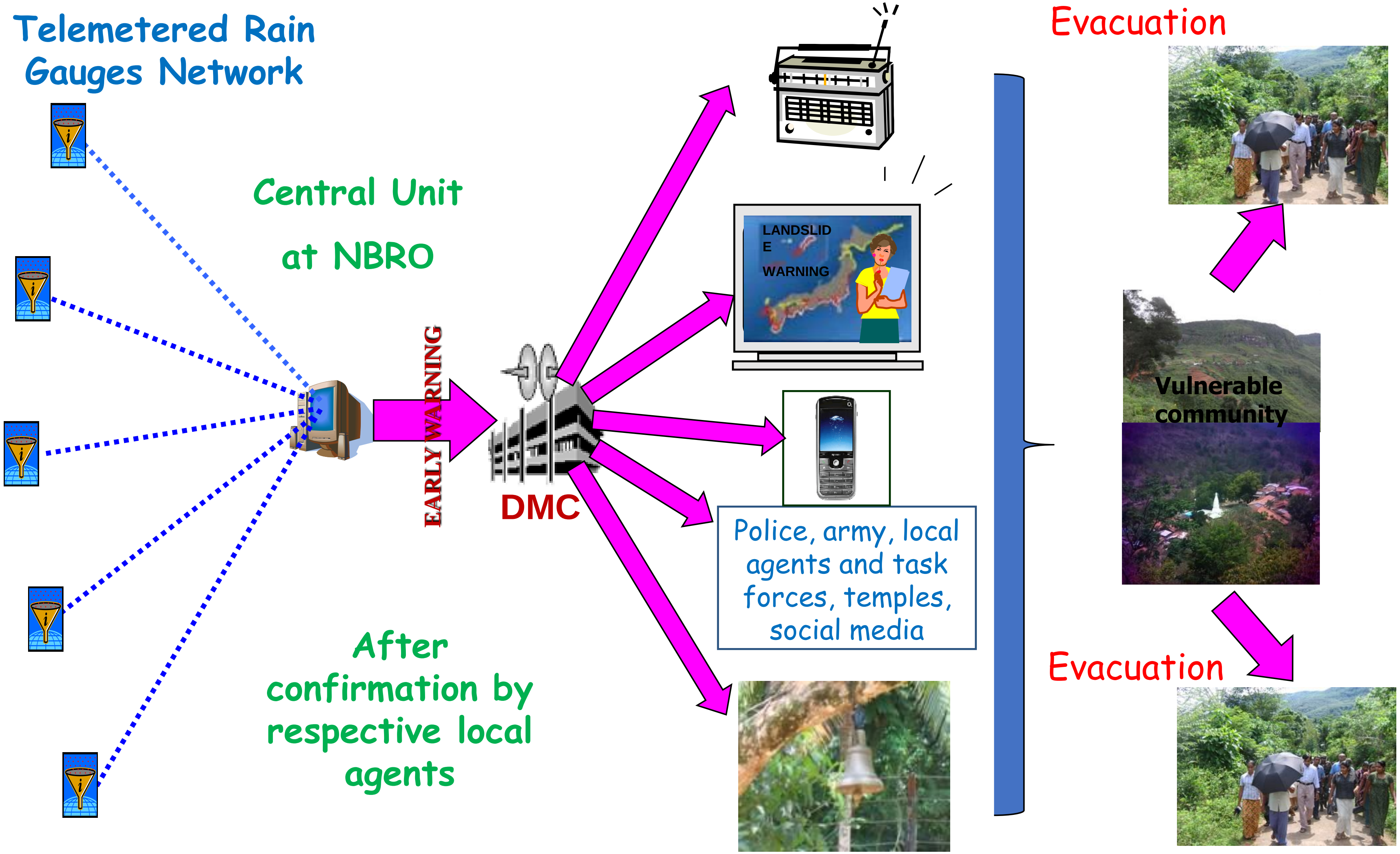
Evacuate

The rainfall within the past 24 h exceed 150 mm or 75 mm within 1 h and continuing



Example of landslide early warning issued on 2019/12/24

General Landslide Early Warning System –NBRO Based on Rainfall

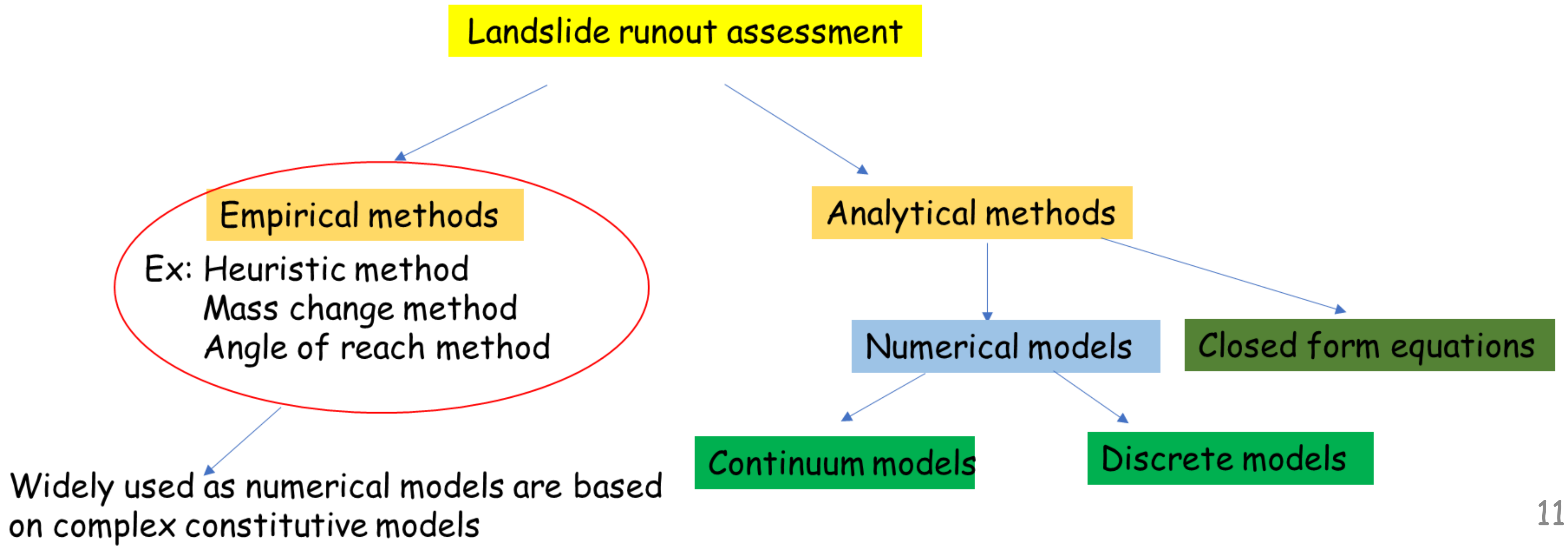


Landslide runout assessment

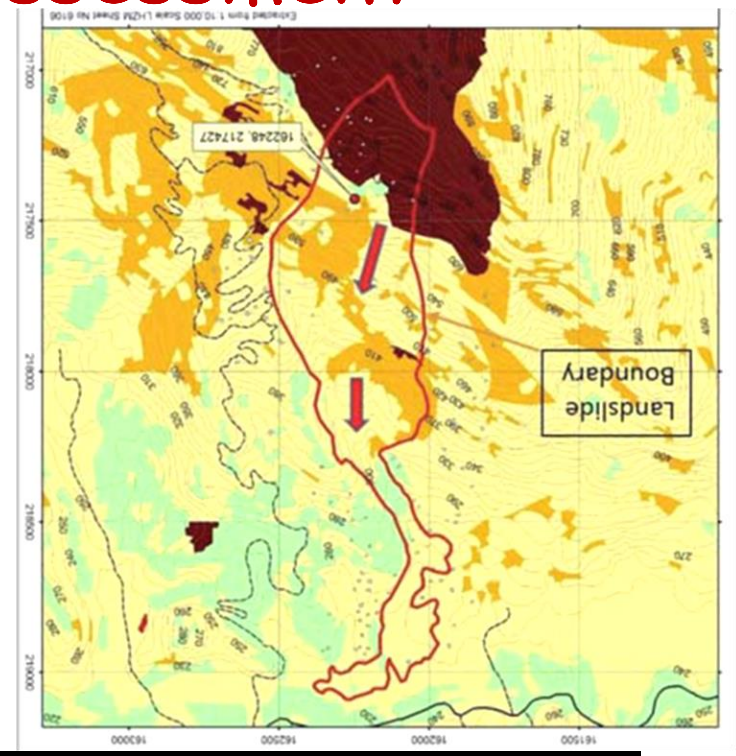
Landslide Hazard Zonation Identifies the Zones of susceptibility only , but
Most of the fatalities related to landslides are occurring in the flat areas due to;

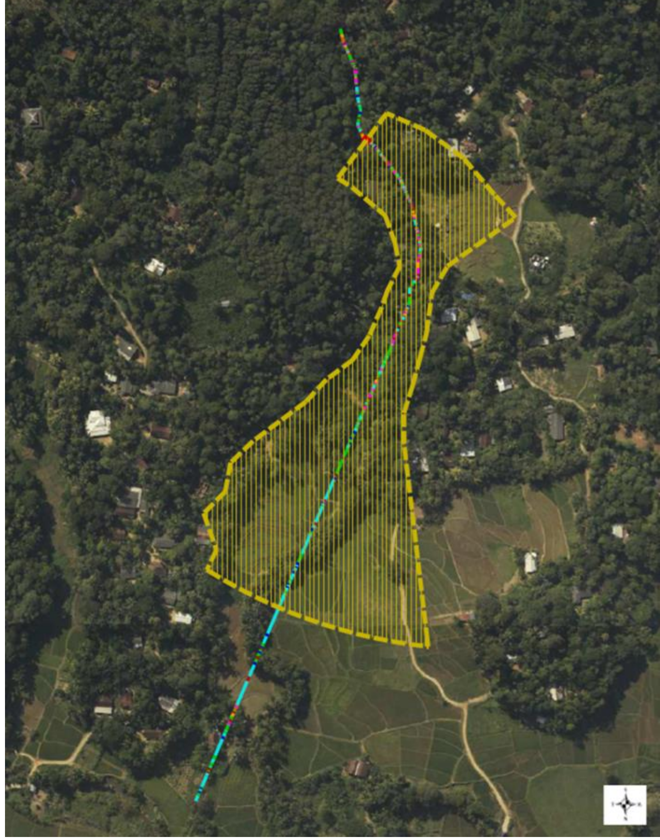
- High population density
- Deposition of the debris
- Rapid velocity

Hence landslide runout assessment is critically important, and studies are underway at present.

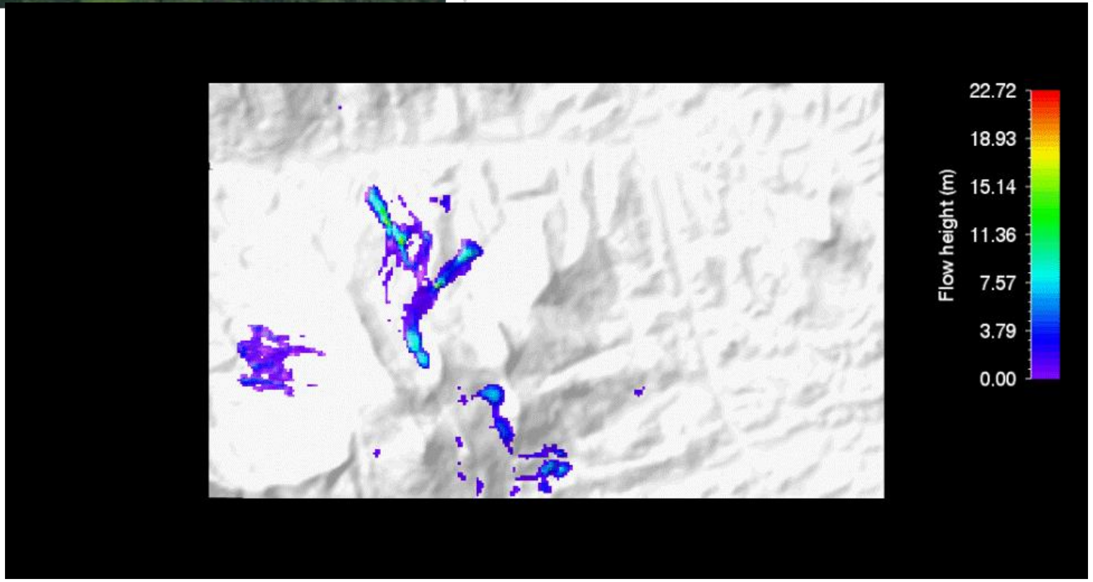


Landslide Runout Assessment





Day 16.5.2017 @17:00 h
28 dead, 99 missing

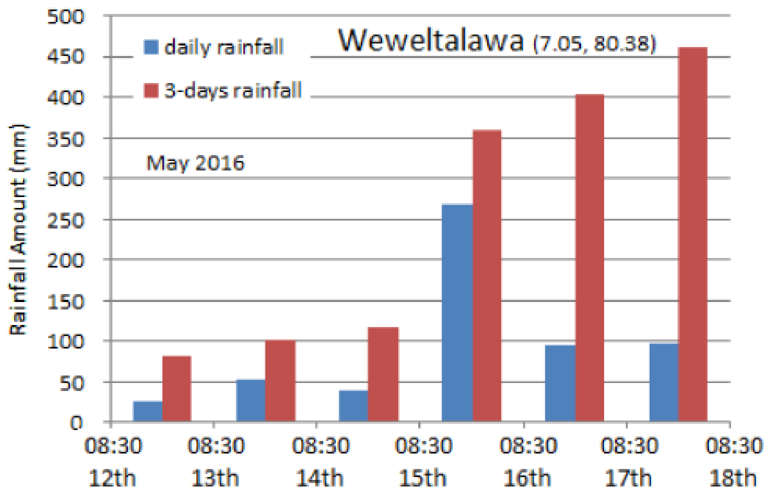


Software used

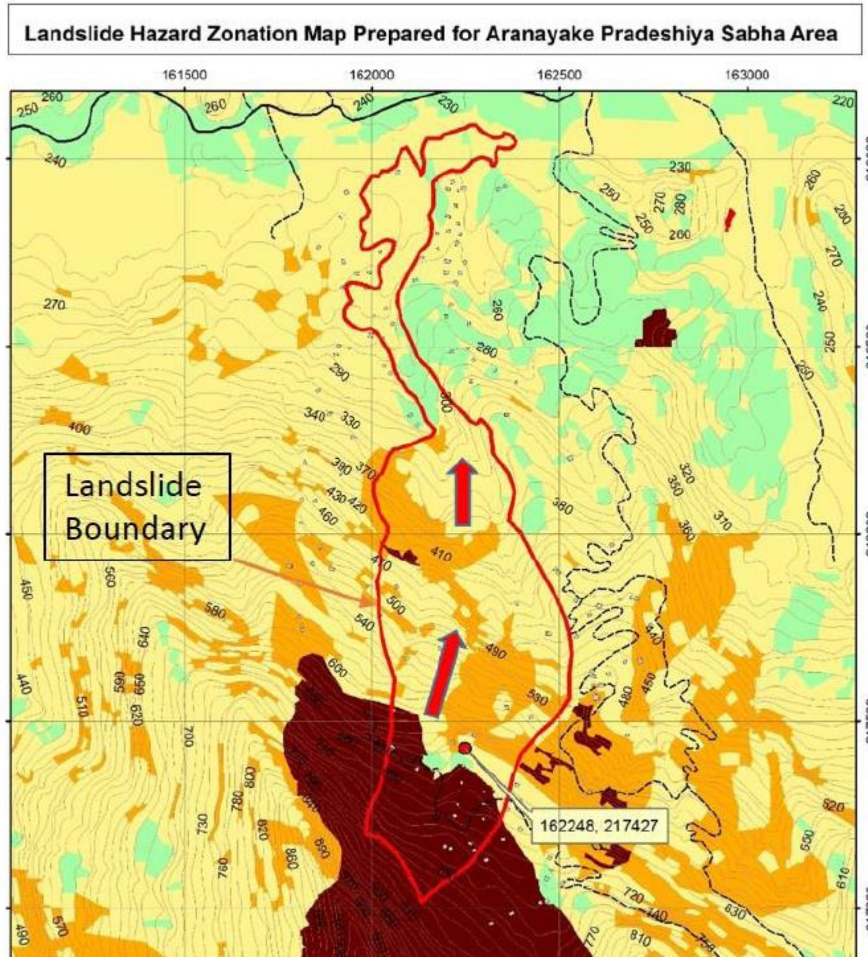
- ILLWIS & PC-Raster
- Flow –R
- RAMMS
- Kanako
- DAN 3D

Major Landslide at Aranayaka -2016

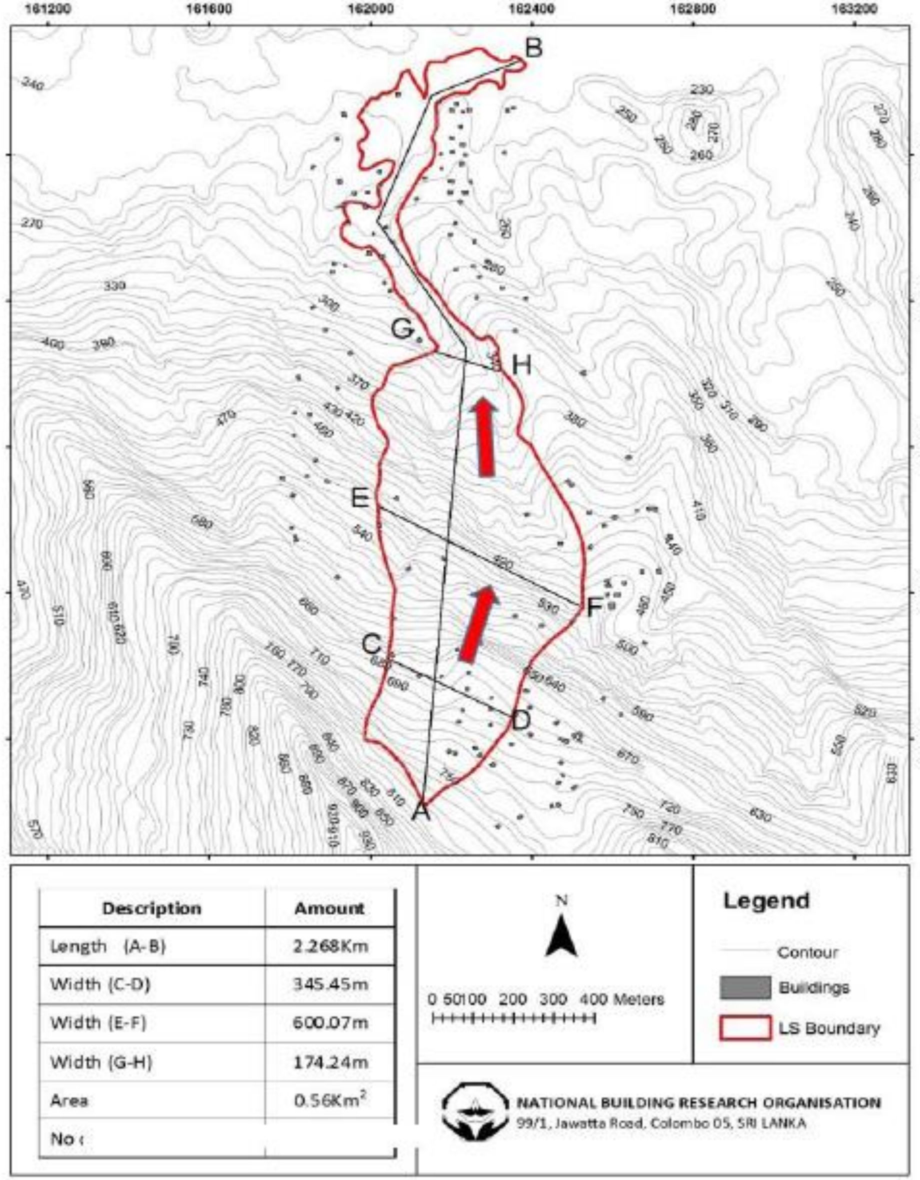
- Aranayaka – Kegalle District
- Date of occurrence - 17th May 2016 at 4.30-5.00 PM
- No of houses destroyed - 76
- No of deaths reported – 129
- Length of debris Flow – 2.3 km



The view of the whole landslide from north direction



Landslide Hazard Zonation Map corresponding to the Area



Description	Amount
Length (A-B)	2.268Km
Width (C-D)	345.45m
Width (E-F)	600.07m
Width (G-H)	174.24m
Area	0.56Km^2
No (	

Boundary of Aranayaka landslide

- The width of the crown of the landslide is about 345 -350 m and the scrap height is about 50-75 m. The bedrock of the area is a high grade metamorphic rock called Garnet Biotite Gneiss in which two major vertical joints could be observed. It has a thin soil cover.

- There was significant infiltration from the heavy prolonged rainfall that prevailed. This slide triggered by this ended up as a debris flow.

The crown of the landslide – An aerial view

This debris flow moved down to the flat terrain at the intermediate level where number of houses were located. The thick layer of colluvium in this terrain too, had got saturated and the debris flow originated from the top destabilized it further with the impact.

The slide has turned into a debris flow very quickly completely destroying the houses in the terrain. The debris flow had then moved down the second steep escarpment destroying the houses in the lower level. The speed of the debris flow would have increased several times more when it moved downwards along the escarp slope of about 70° angle .

SRI LANKAN GEOTECHNICAL SOCIETY
SLGS
1986

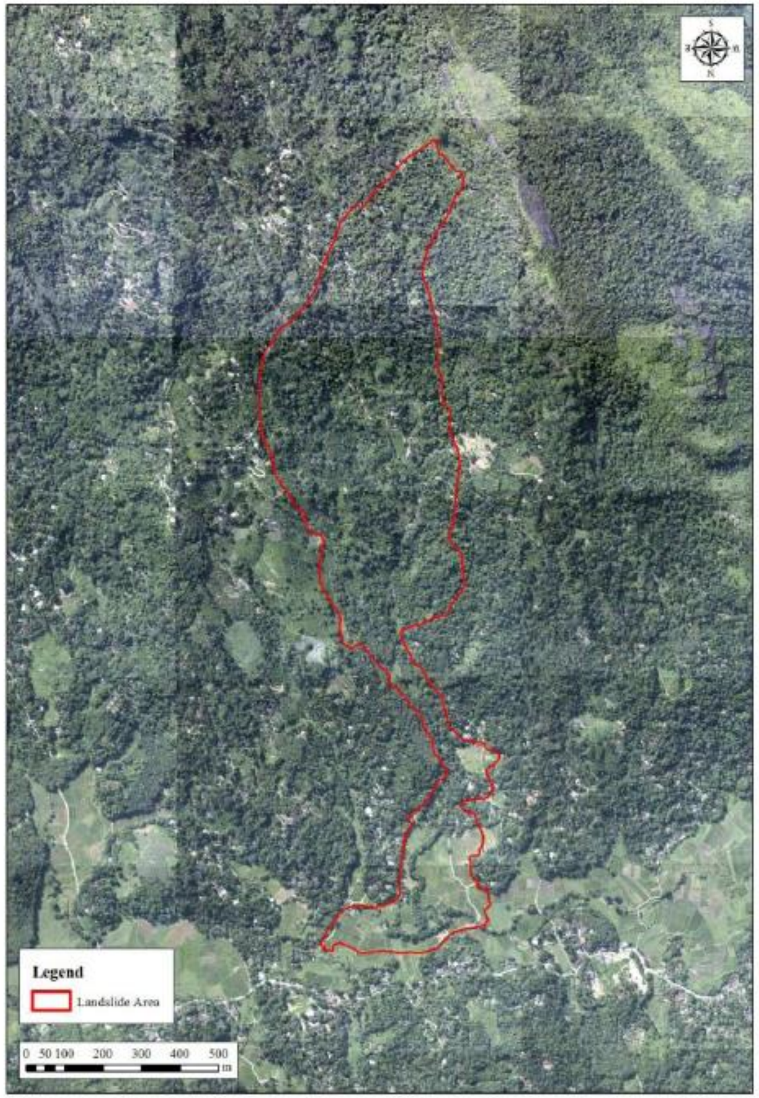
The whole view of the site from West direction

Completely unaffected houses and a natural forest cover could be observed at the intermediate area of the slide.

- The mass of collapse flew from two directions. : The left side is about 75-125 m wide while the right-side is about 350-450 m wide.
- It joined into one stream and ran down as a debris flow.
- The position that the main body of debris flow stopped shown by the circle.

Area where debris flow flooded. The soil and mud are flooding

Before (26th Dec 2015)



Ortho Image by LiDAR Survey
0.5 m Resolution
LiDAR : Light Detection and Ranging

Provided from the Survey Department of Sri Lanka, which is prepared by JICA's Development Study "Capacity Development Project for Creating Digital Elevation Model Enabling Disaster Resilience"

After (22nd May 2016)

Aerial Photo by Chopper
0.5m Resolution

Source – JICA – Sri Lanka

Comparison of the site – Before and After

Monitoring of Critical Sites of High Susceptibility

Rainfall is the triggering factor. In addition to rainfall, it is necessary to monitor the effects that it has caused in the soil.

Need to monitor;

- Moisture content changes
- Matric suction loss
- Pore water pressure development
- Ground movements at surface level
- Ground movements at deeper level

Monitoring is done by;

Different Types of instruments installed at identified locations - site specific

Monitoring Equipment

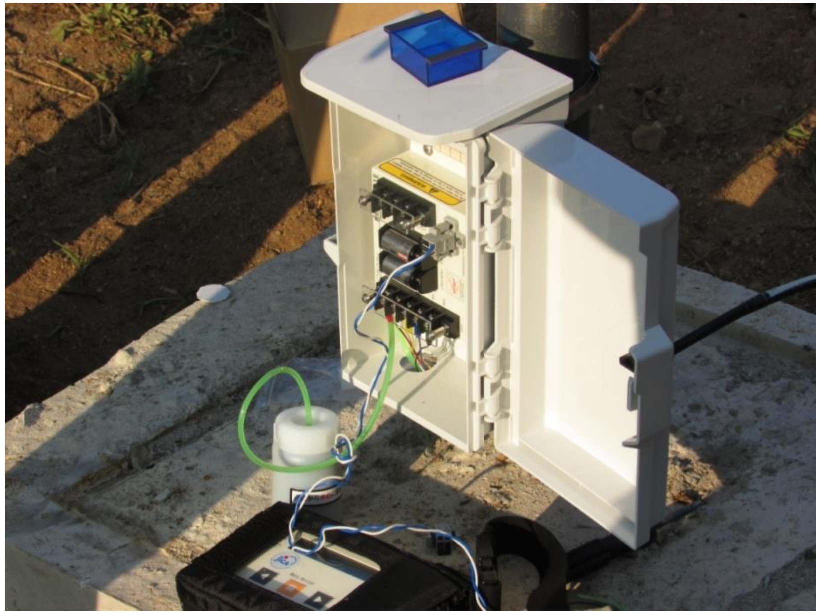
- Moisture Sensors
- Tensiometers, piezometers - Matric suction or pore water pressure, water level meters

- Extensometers, tilt sensor – surface level movement
- Strain gauges – movements at deeper levels

(data can be acquired periodically using electronic devices and transmitted to a control station)

- Inclinometers – identification of failure surface (data need to be acquired at site periodically)

Monitoring the pore pressure Regime



Water Level Gauge –
Installation and Monitoring

This would provide the groundwater level in the borehole. Useful only under simple ground conditions of uniform soil

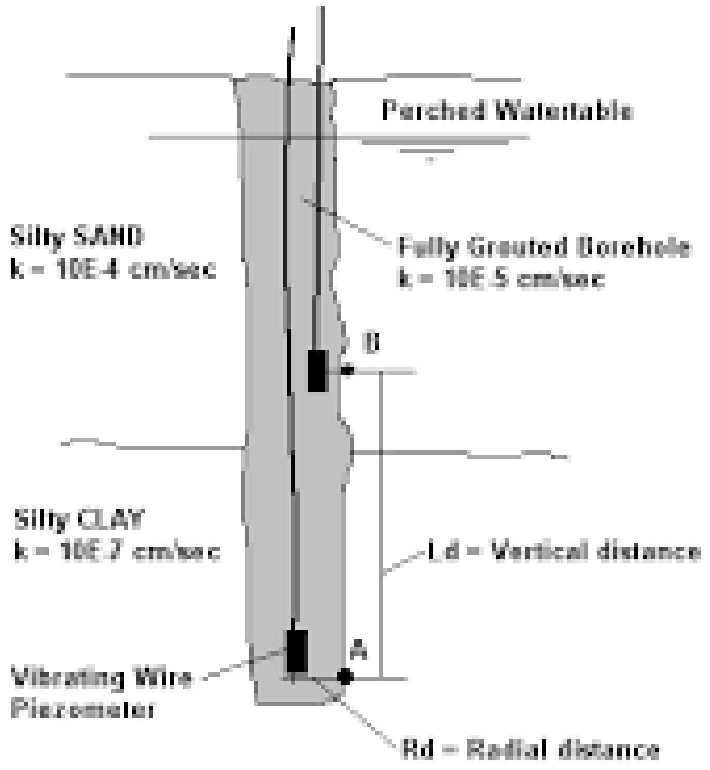
Monitoring pore water pressure in different layers

Soil layers of highly contrasting permeability - a character of residual soil formations.

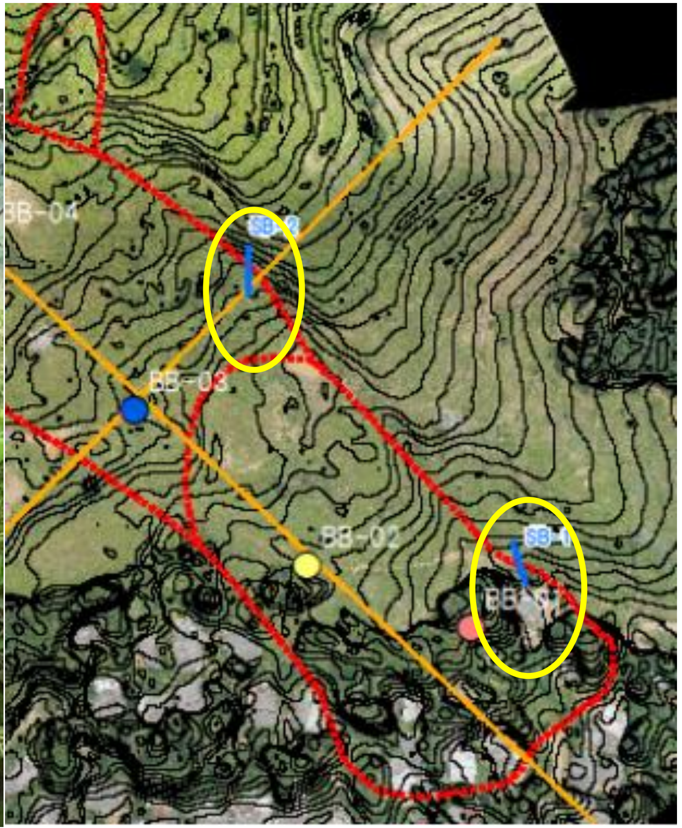
Pore pressure development and dissipation of layers would be different.

This would become the controlling factor.

Hence it is important to monitor pre water pressure separately in different layers.
In a borehole piezometers will have to be placed at multiple levels.



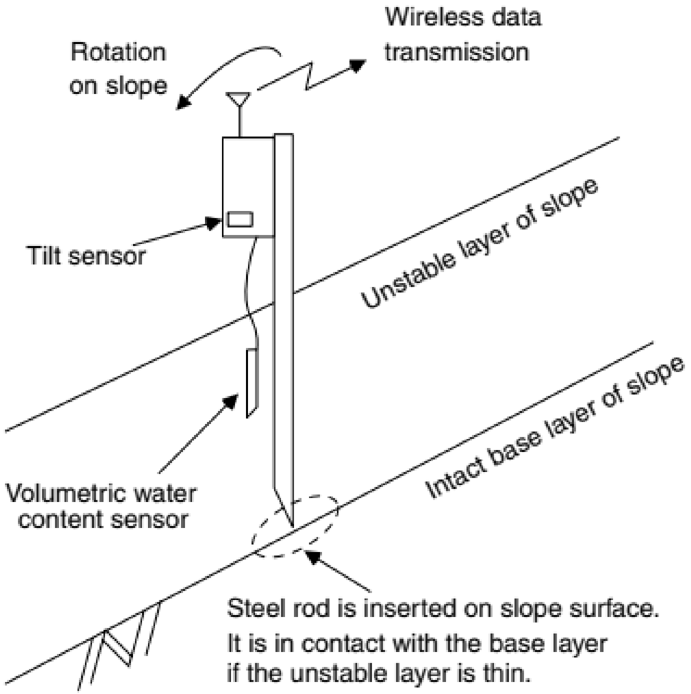
Extensometers are used to detect ground movements at surface level



One end is outside the potential slide are and the other within the slide area. Identify appropriate locations by a careful study

Extensometer –
Installation and monitoring

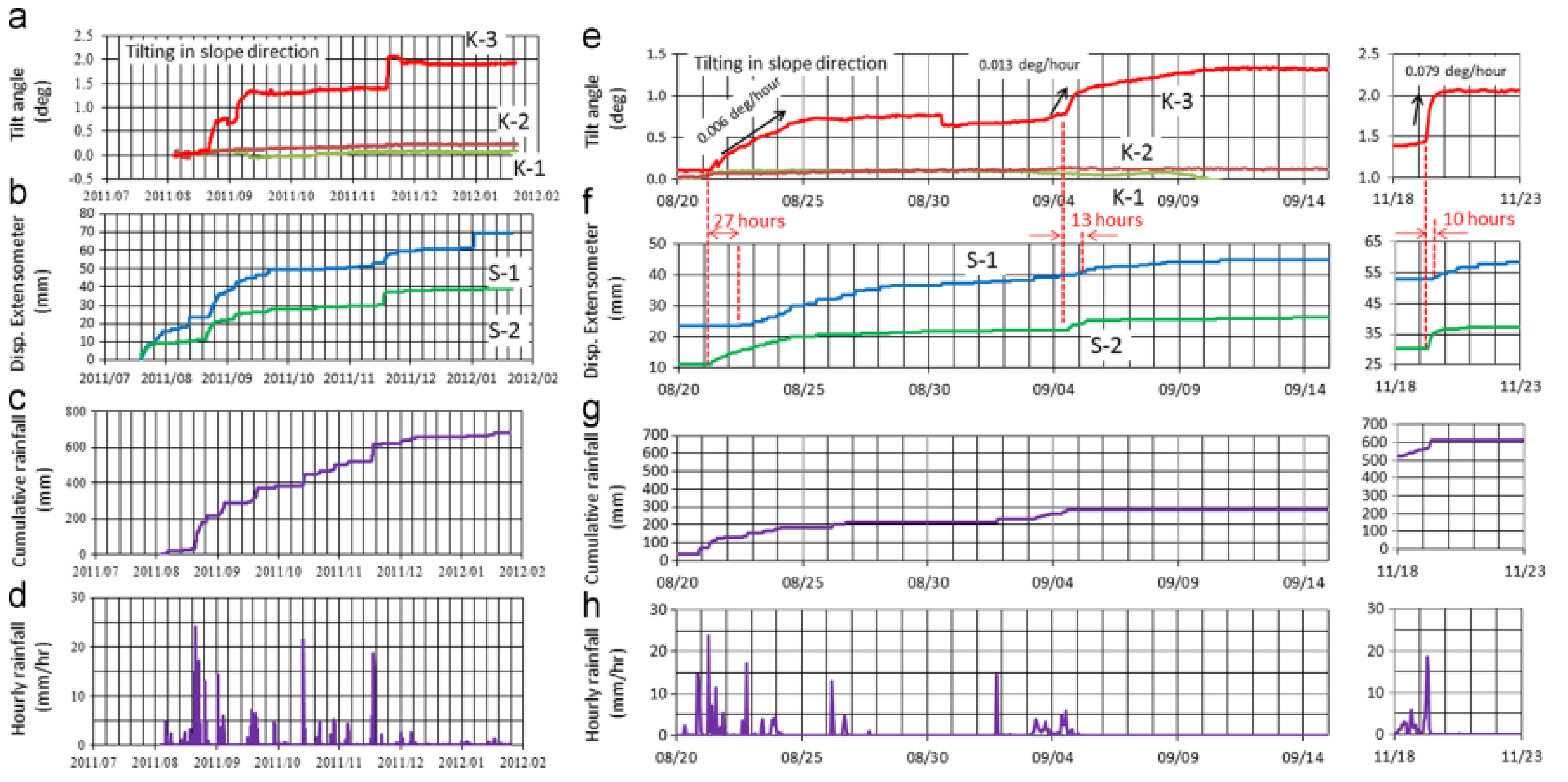
Tilt Sensors Uchimura, Towhata, Lin Wang (joint research with University of Tokyo)



Capable of measuring tilt angles (rotations) and progressive deformations.

The long wire of an extensometer is not required, and therefore, the installation and maintenance are simple and inexpensive.

system proposed herein watches the rotation and the volumetric water contents near the slope surface.



(d) rainfall

Time histories of monitored items

a) Tilt angles by surface tilt sensors
b) displacements by extensometers
c) accumulated amount of rain
d) rainfall intensity
e-h) Zoom up for heavy rainfall events

Inclinometers

Inclinometer tubes are used to identify deeper level surface movements along a potential sliding surface.

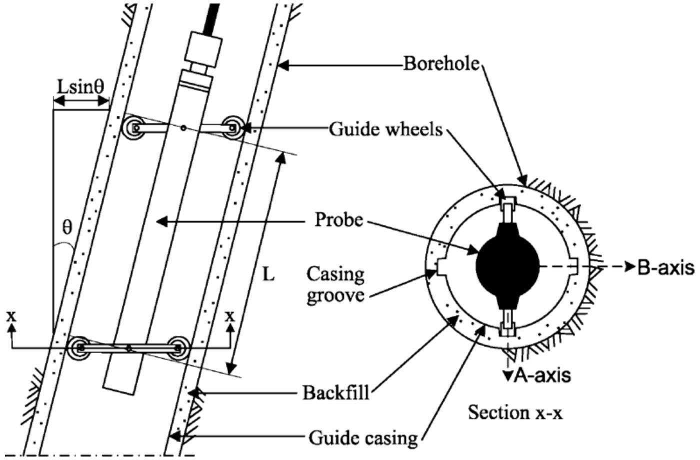
Should extend below the potential failure surface

Inclinometer
-Installation

SRI LANKAN GEOTECHNICAL SOCIETY SLGS 1986

The commonly used probe is a biaxial probe which contains two perpendicular accelerometers, so only two passes of the probe are required to measure movement in the four different directions.

One accelerometer measures the tilt in the plane of the inclinometer wheels which tracks the longitudinal grove of the casing, while the other accelerometer measures the tilt in the plane perpendicular to the wheels. Thus, in a biaxial probe, the A-sensor is oriented to the A direction which is parallel to the wheels of the probe, and the B-sensor is oriented transverse to the wheels in the probe.



Landslide Monitoring with Strain gauges

Are used to identify strains - movements at different depths

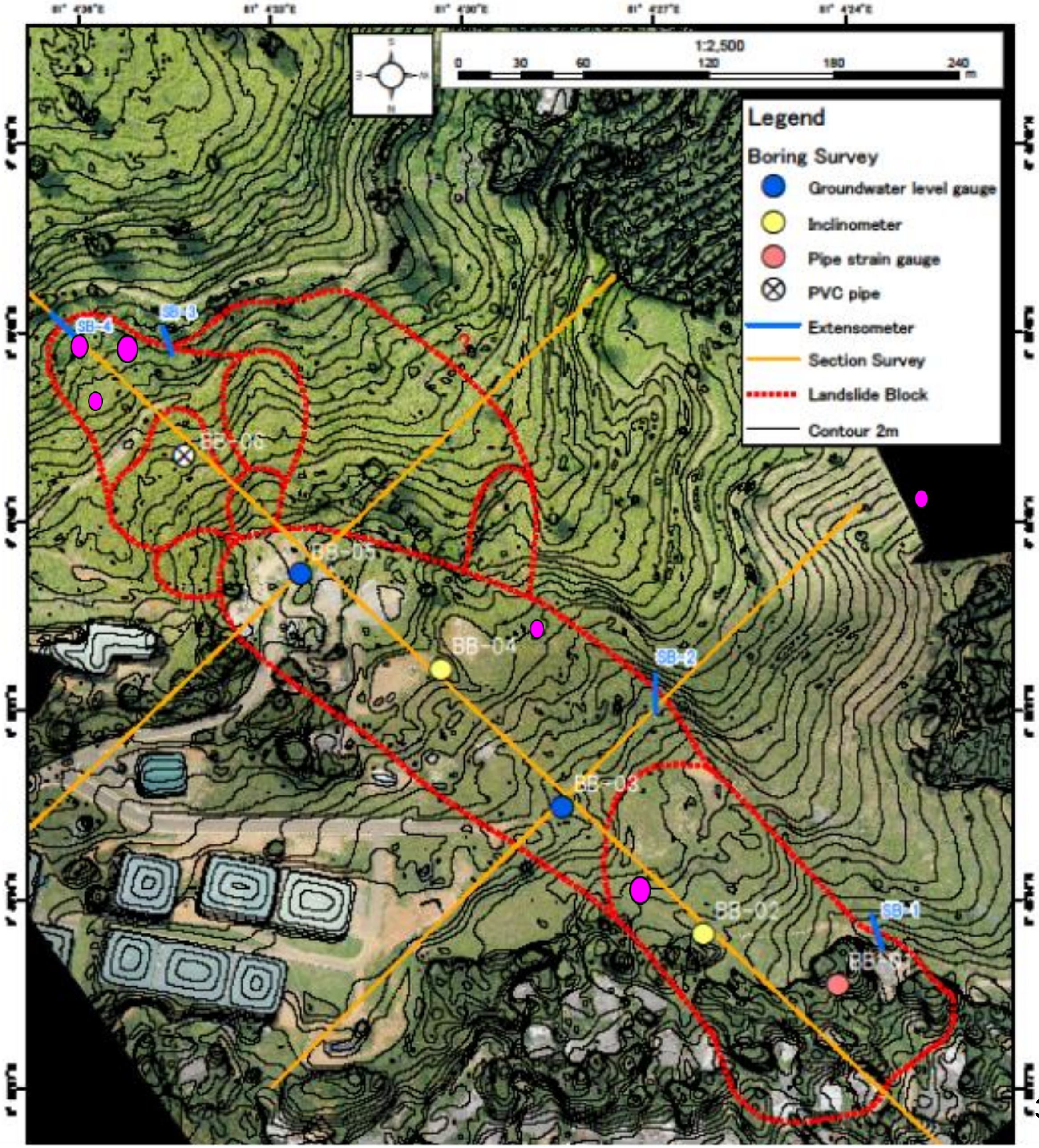
Strain gauges – Installation and Monitoring

SRI LANKAN GEOTECHNICAL SOCIETY
SLGS
1986

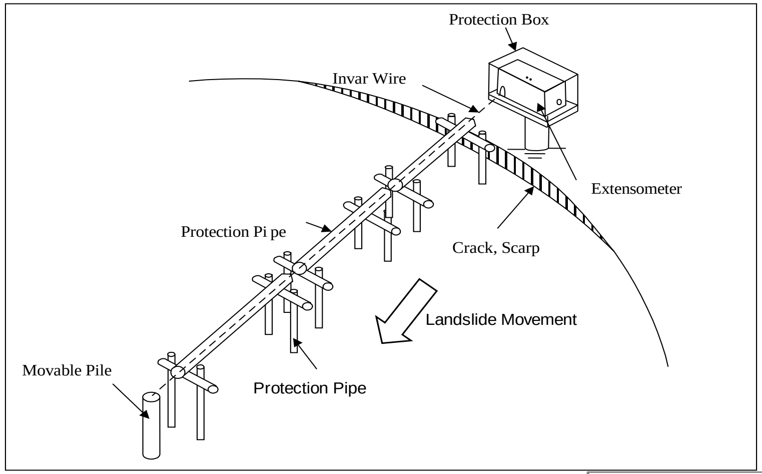
Instrumentation in Badulusirigama Landslide

Instrument	Locations
Inclinometer	BB-2 , BB -4
Water Level Gauge	BB -3 , BB -4
Pipe strain gauge	BB -1
Extensometer	SB -1, SB -2, SB-3, SB-4

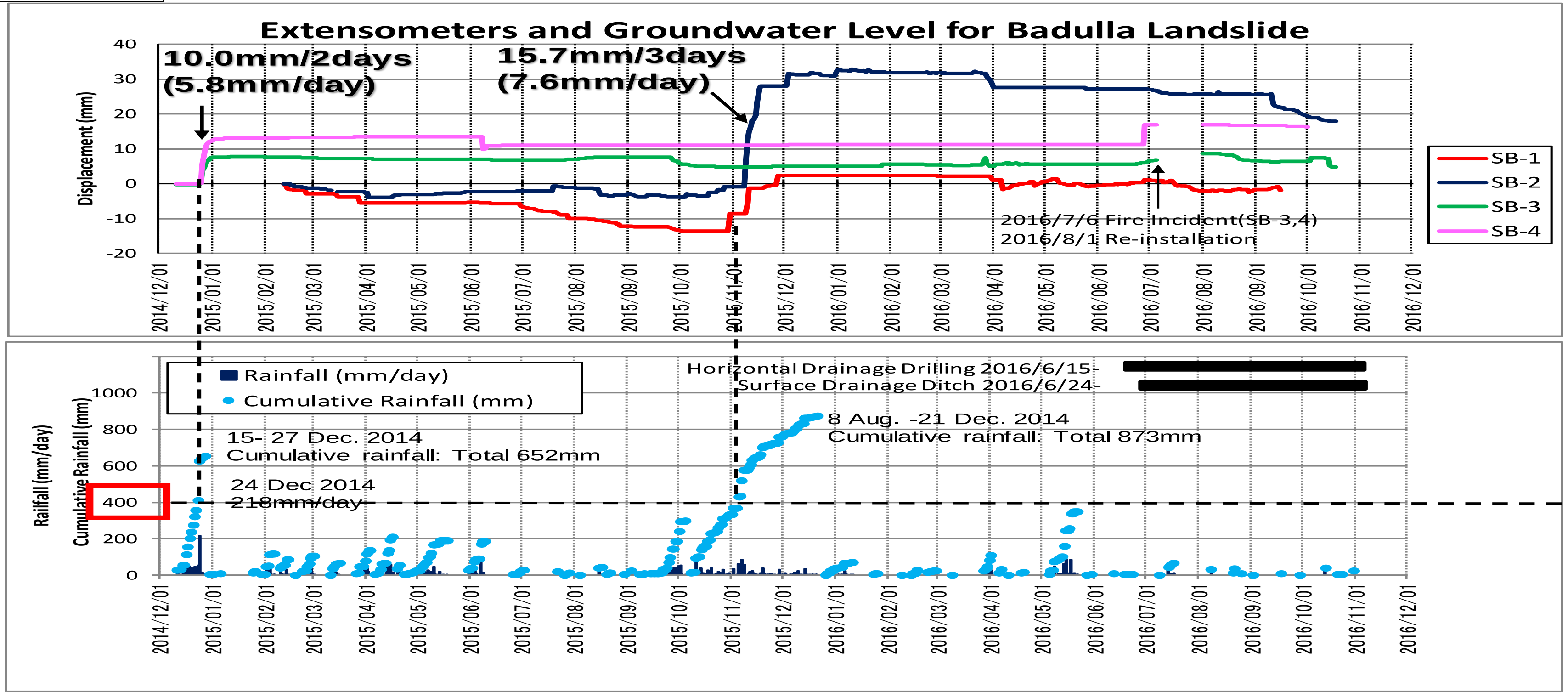
● Sensor unit (Tilt sensor, Volumetric water content sensor)



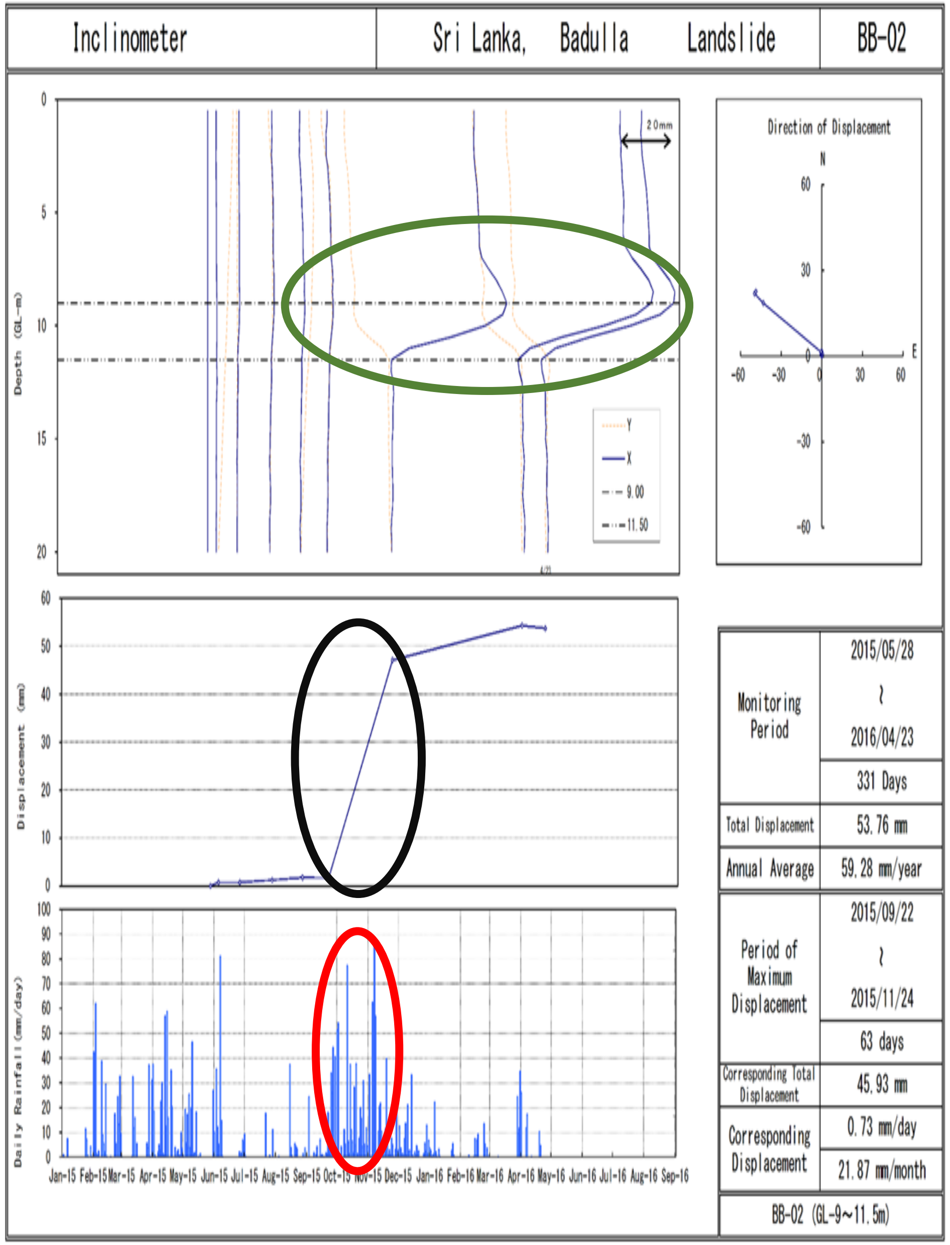
Instrumentation and Monitoring



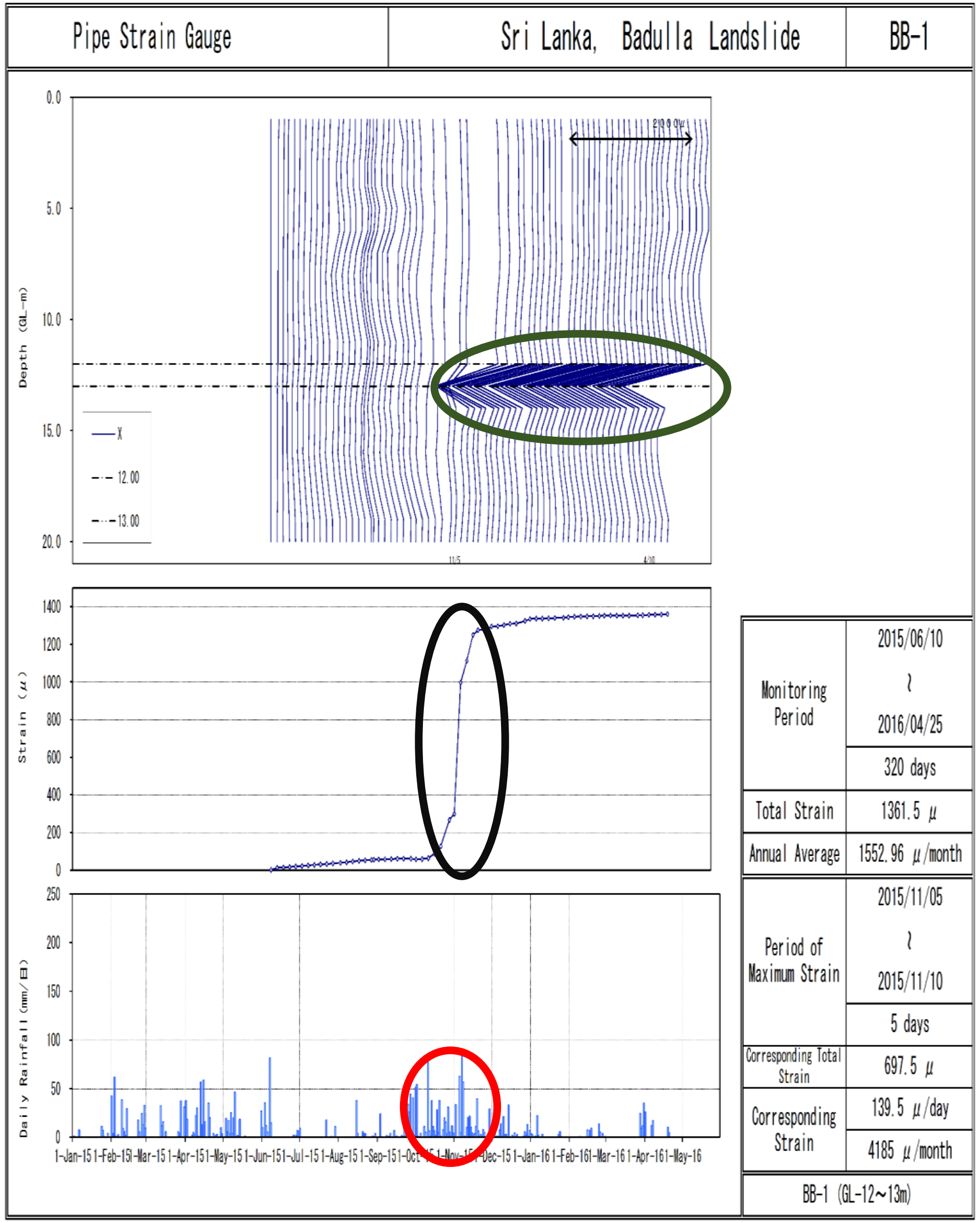
Monitoring Data- Before implementing rectification measures
- Response of Extensometer



Response of inclinometer to rainfall



- Considerable cumulative displacement were observed at the depth of GL- 9.5 m - 11.5 m of BB-2 inclinometer.
- From the end of September 2015 to the end of November, active movement occurred at that depth.
- The displacement was 45 mm during 2 months.



Response of Pipe Strain gauge to rainfall

- A considerable cumulative displacement were observed at the depth of G.L-12.0 m – 13.0 m of BB-1 inclinometer.
- The movement has increased from the end of October 2015 to the middle of November 2015.

Thank You