Integration of rainfall thresholds and field monitoring data : Case studies from Japan and India

Italy-Japan joint workshop
on landslide monitoring systems and related topics

4th -5th November 2021
(online)

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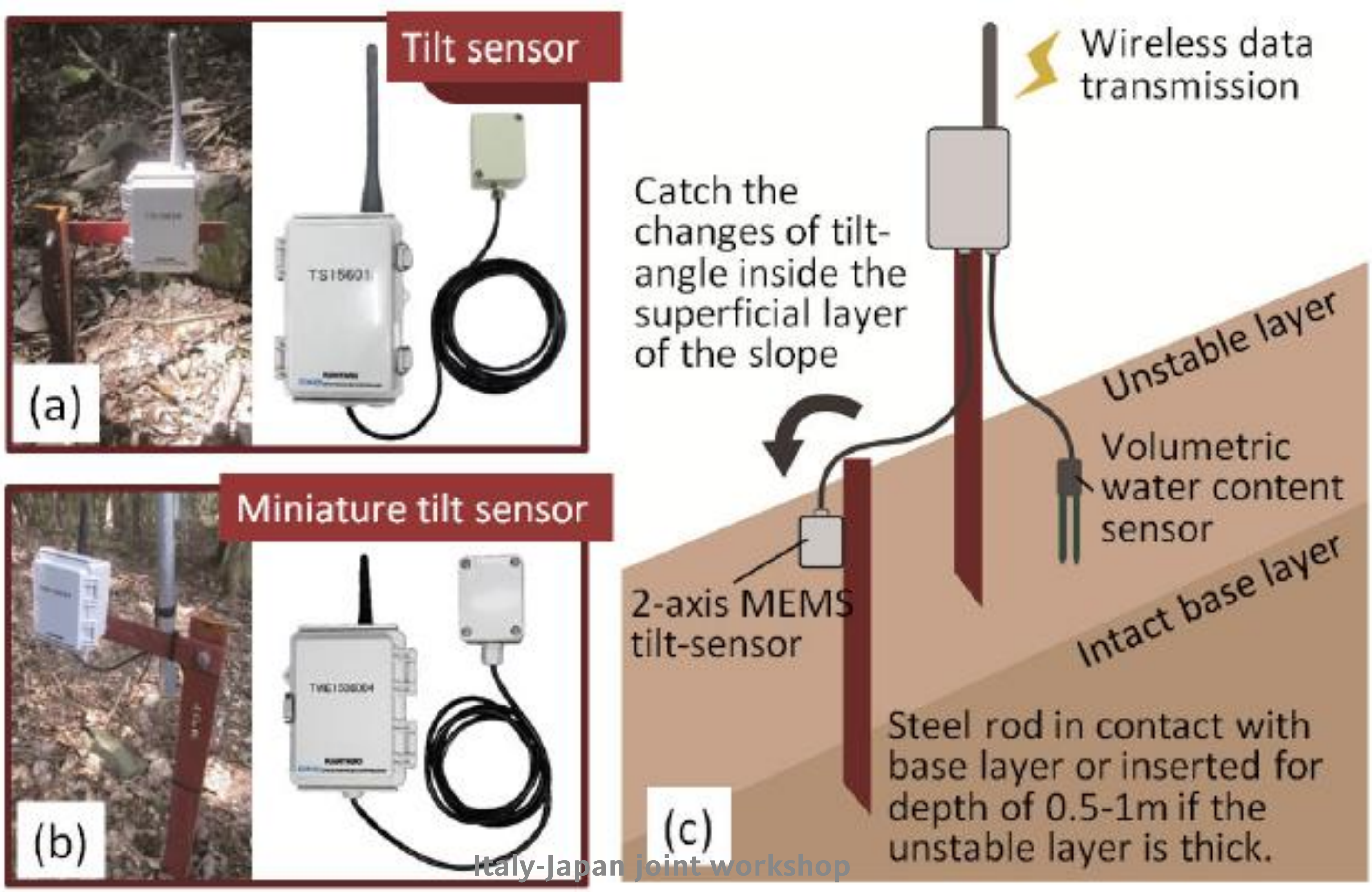
Overview

- Introduction
- Details of monitoring system
- Case studies from Japan
- Case study from India
- Integration of field monitoring data and rainfall thresholds

Introduction

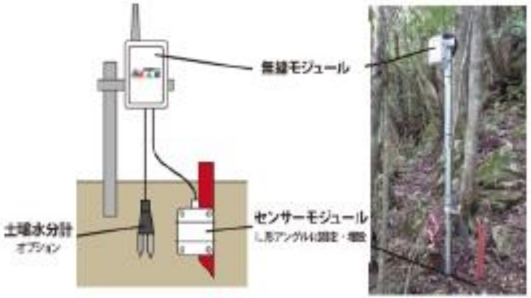
- The damages instigated by landslides in the recent past call for attention from authorities for disaster risk reduction measures.
- Real time field monitoring of unstable slopes – to understand the insitu conditions and provide landslide early warning.
- IoT based system- data transfer and alarms in real time.
- Micro-electro-mechanical systems (MEMS)-based tilt sensors and volumetric water content sensors
- Case studies from: Fukuoka prefecture, (Japan) and Chibo, (Darjeeling Himalayas, India).

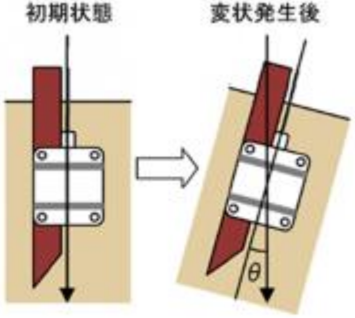
WIRELESS SENSOR SYSTEM
Developed at University of Tokyo, Japan

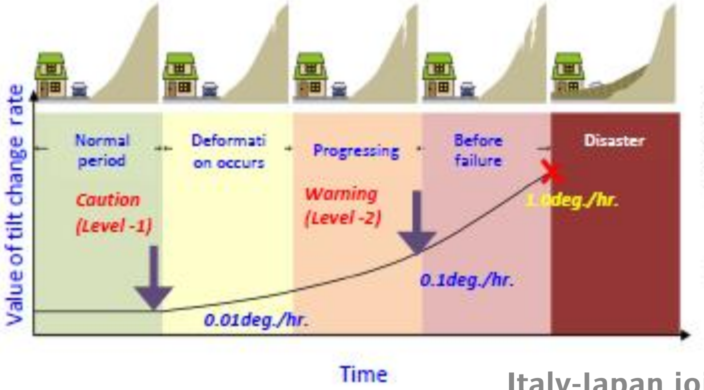


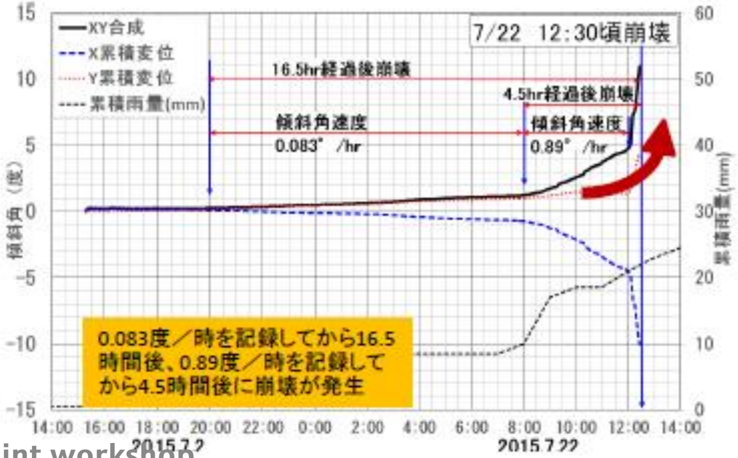
The Principle of Early Warning

➡ **Capture the rate of change of tilt / rotation angle**
→Evaluating the risk of slope deformation

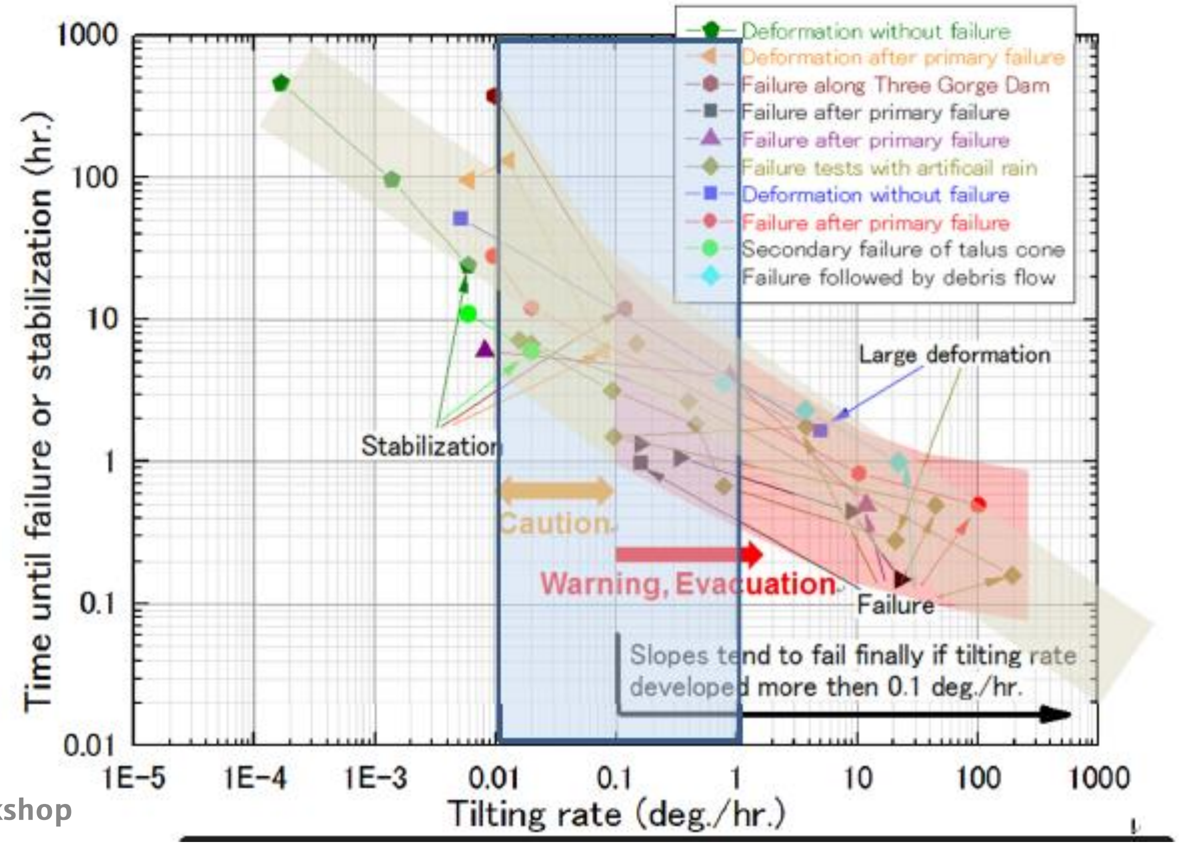




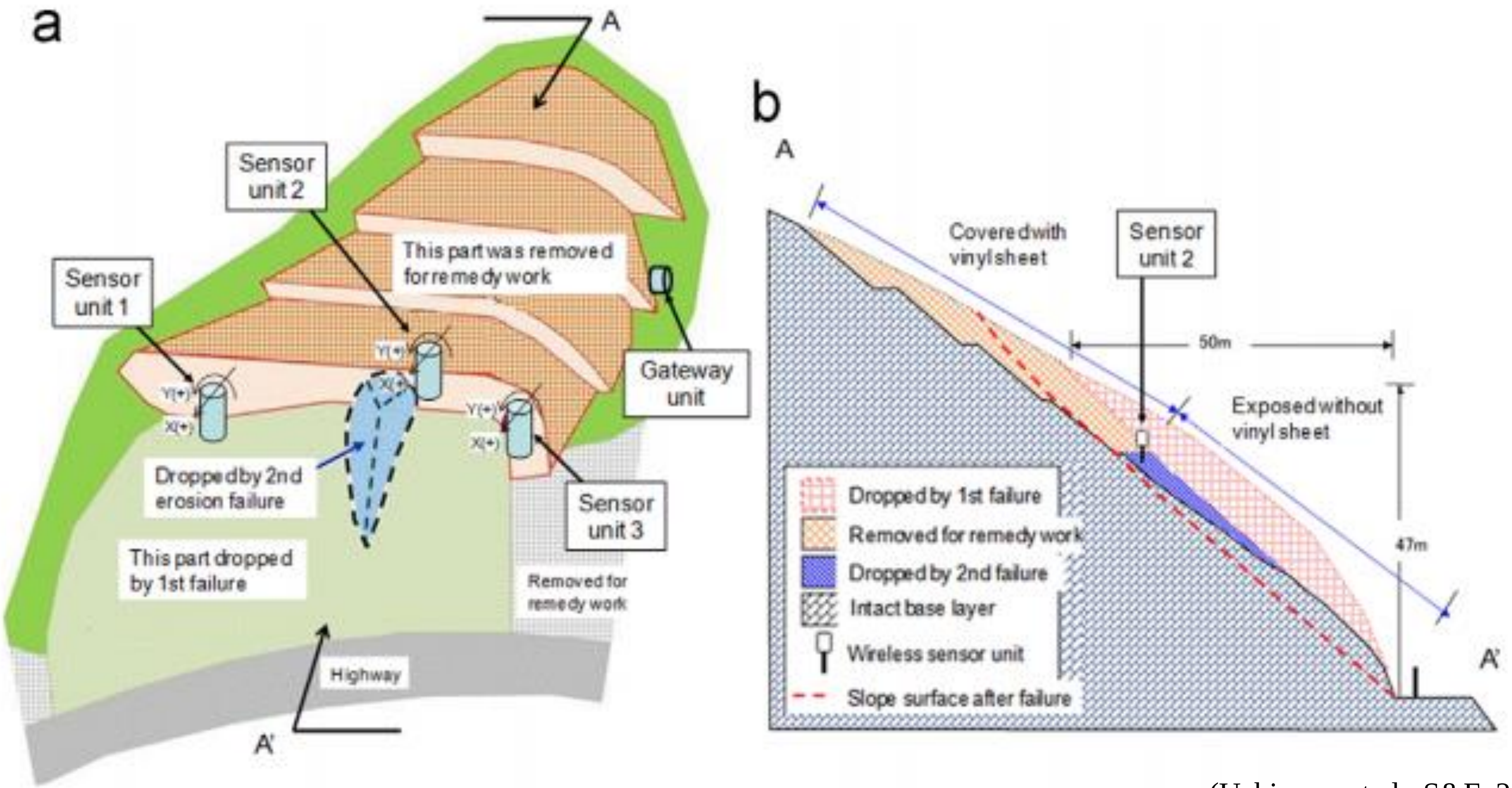




The tilting rate as a function of time before slope failure (or stabilization) for several case studies

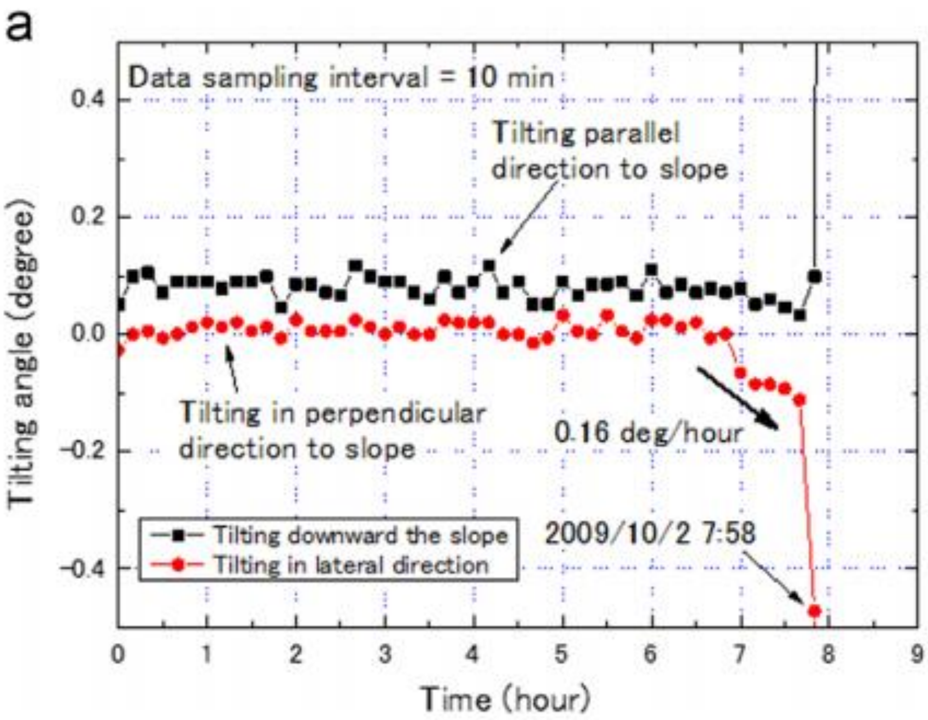


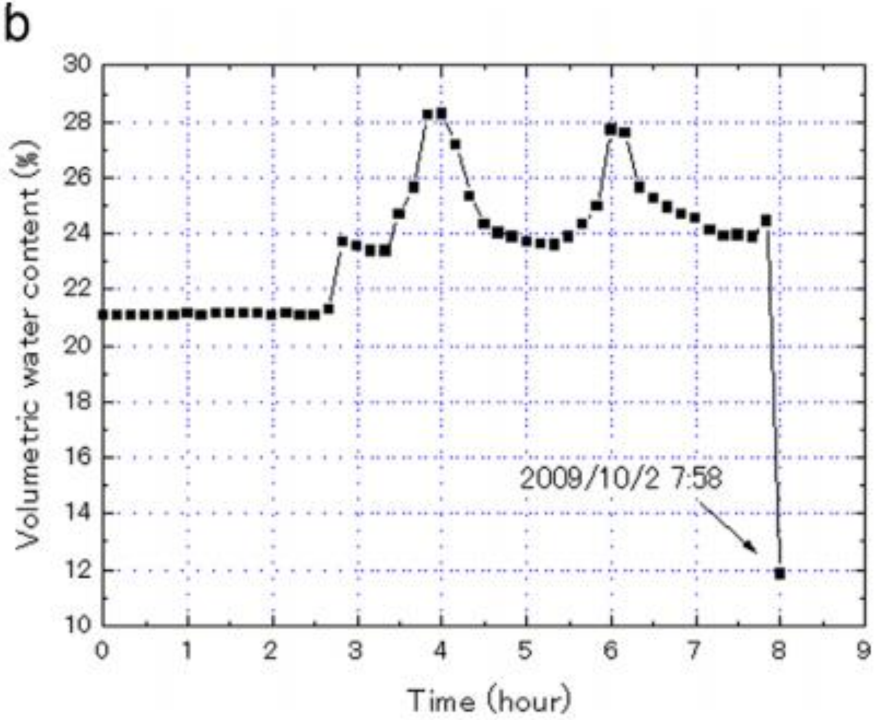
Case studies from Japan
Slope failure 1: along a highway in Fukuoka Prefecture, Japan



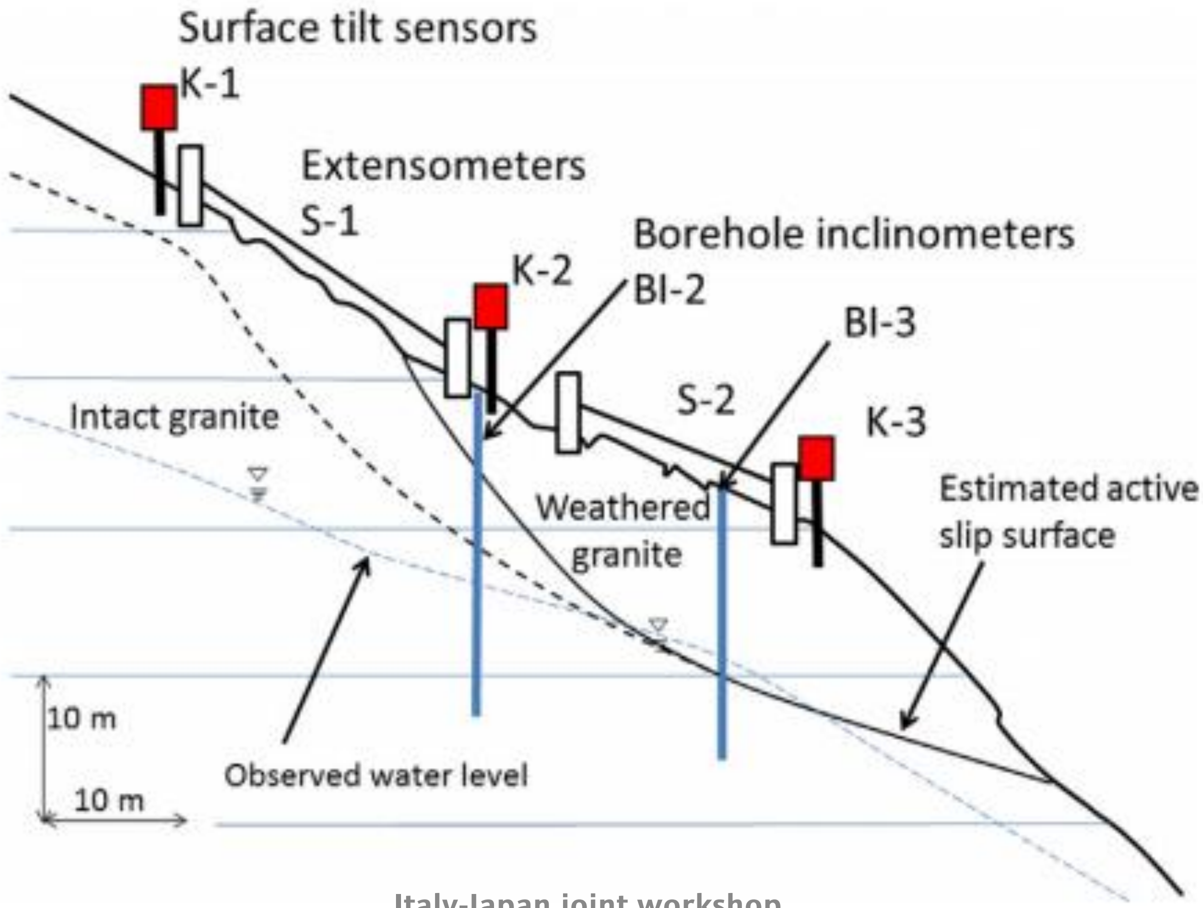
(Uchimura et al , S&F, 2019)

Tilting angle and volumetric water content obtained by sensor unit 2 on the slope site along highway just before the second failure

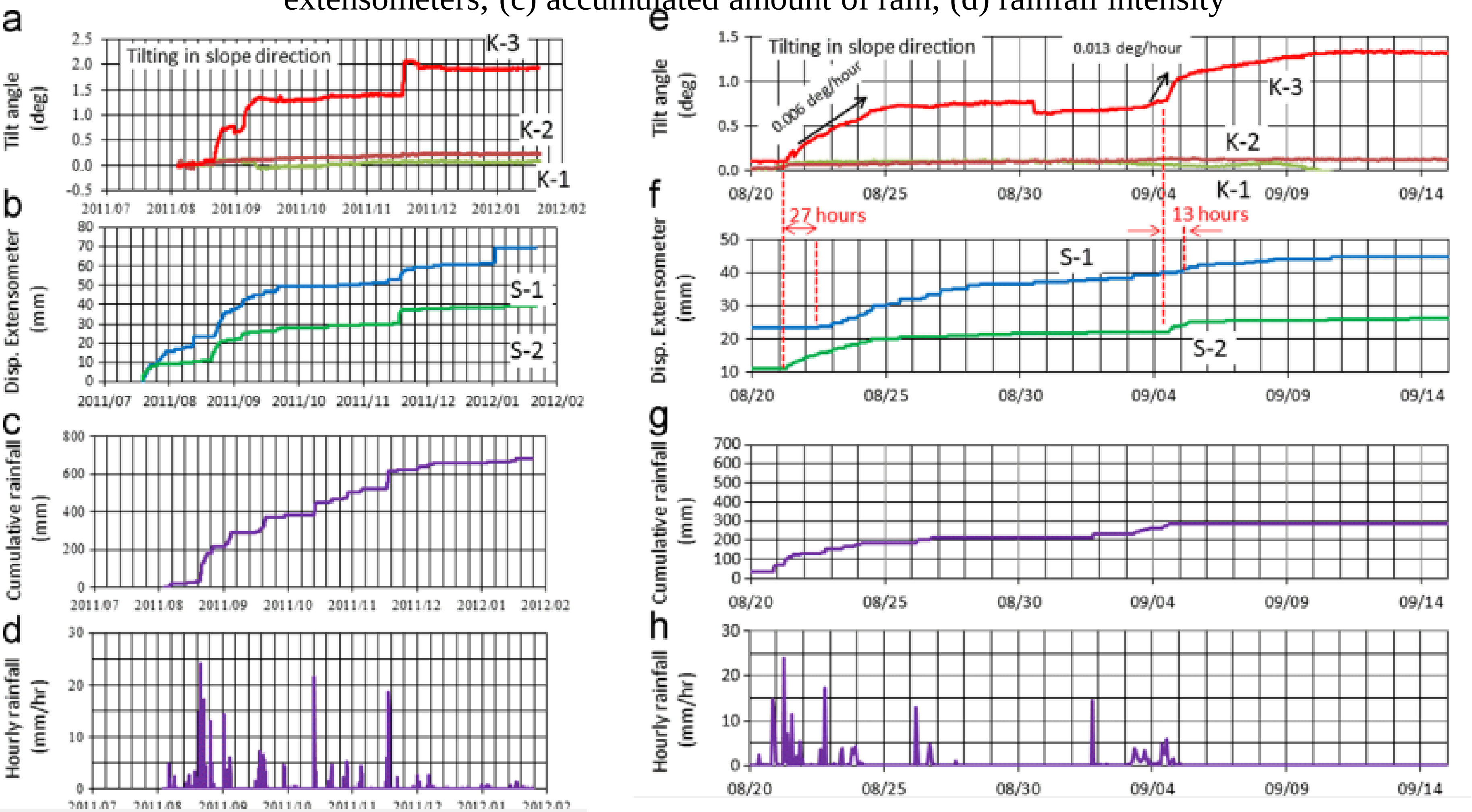




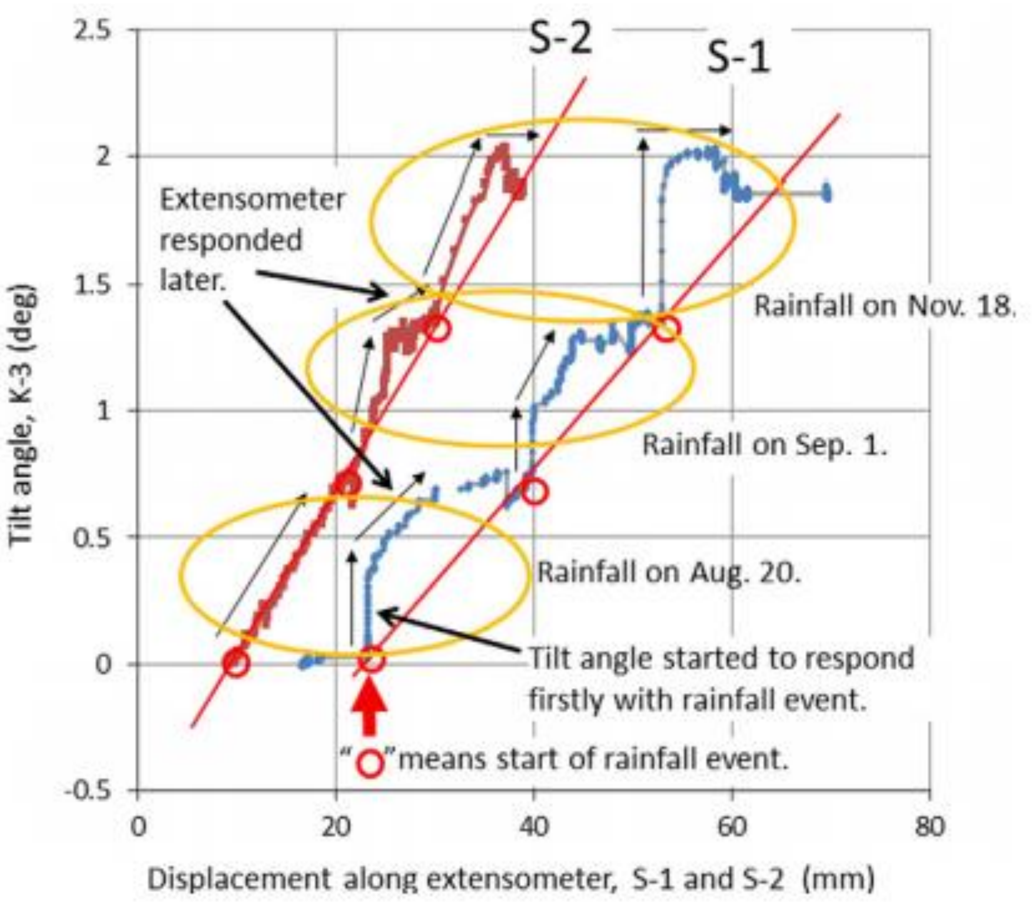
Slope failure 2: along a highway in Fukuoka Prefecture, Japan



Time histories of monitored items: (a) tilt angles by surface tilt sensors; (b) displacements by extensometers; (c) accumulated amount of rain; (d) rainfall intensity



Comparison between data from extensometer (S-1 and S-2) and surface tilt sensor (K-3).



Case study from India: LANDSLIDE FORECASTING APROACHES/MODELS

Empirical
- Intensity-Duration (ID) Thresholds
- Thresholds based on antecedent rainfall

Probabilistic
- Bayesian method
- 1 dimensional and 2 dimensional

Hydrological
- FLaiR Model

Physical
- TRIGRS Model

Algorithm based
- CTRL- T
- SIGMA Model

LANDSLIDE MONITORING

2D MEMS Tilt sensors,

Water content sensors,

Digital rainguage

Data logger

Analysis of data (2017-2019)

Validation of Thresholds

VALIDATION WITH MONITORING DATA

Empirical

ID Thresholds
- 84% efficiency
- LR 4.04

ED Thresholds
- 82 % efficiency
- LR 3.81

Probabilistic
- Found to be in good agreement with monitoring results.

Hydrological
- 61% of landslides predicted
- 13% false alarm rate

Physical
- ROC curves plotted

Algorithm based

CTRL-T
- 86 % efficiency
- LR 4.58

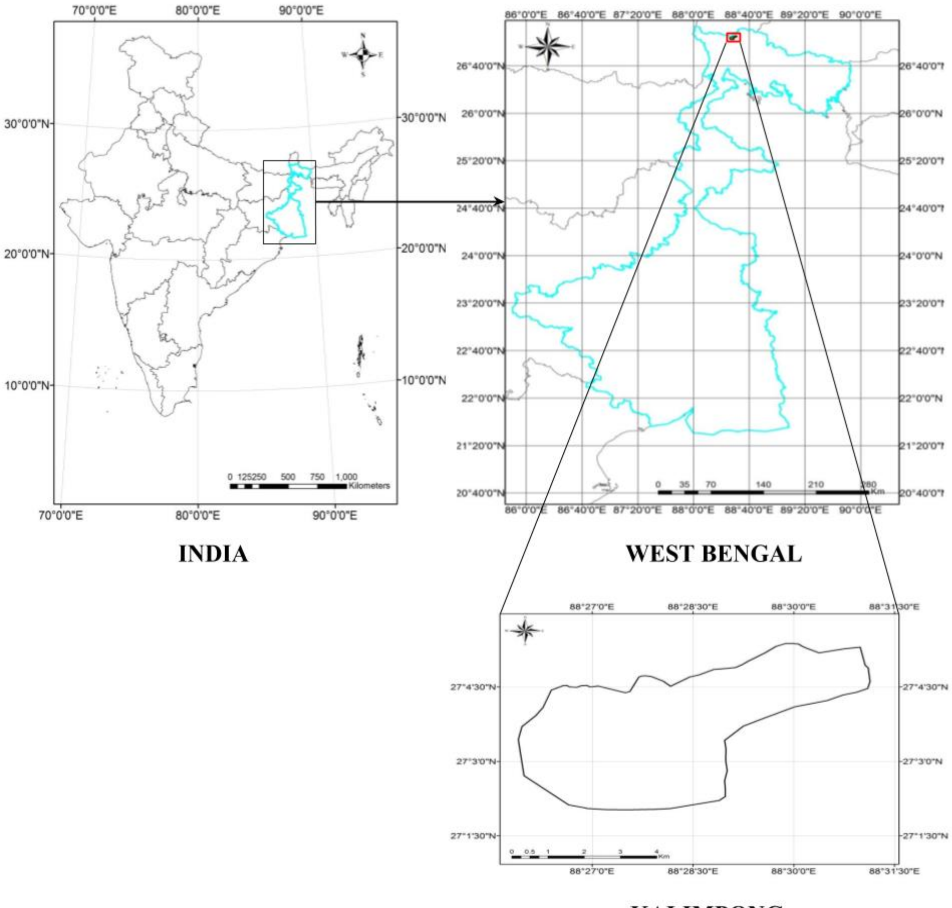
SIGMA
- 94% efficiency
- LR 11.28

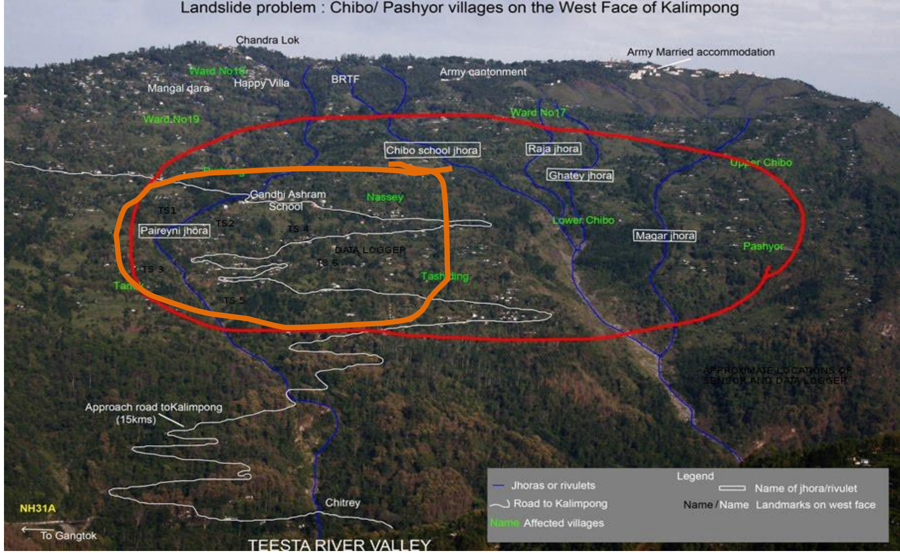
Improvements of empirical thresholds

Using SHETRAN
- 89% efficiency
- LR 7.48

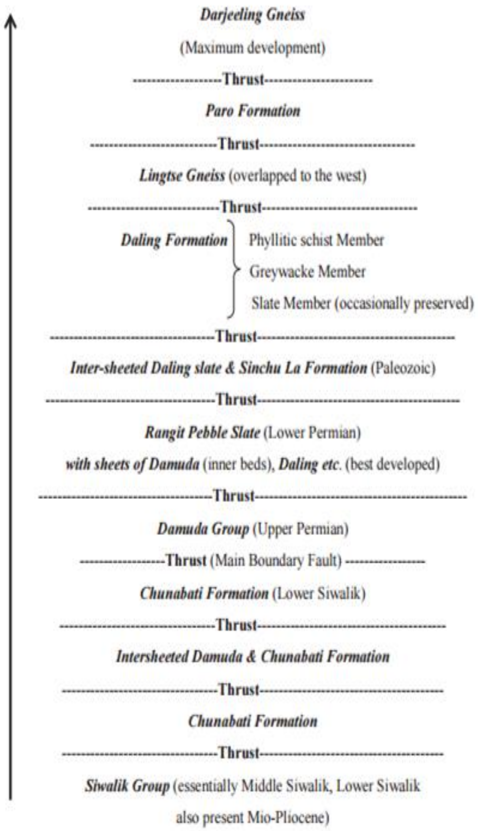
Using tilt rate
- 92% efficiency
- LR 11.33

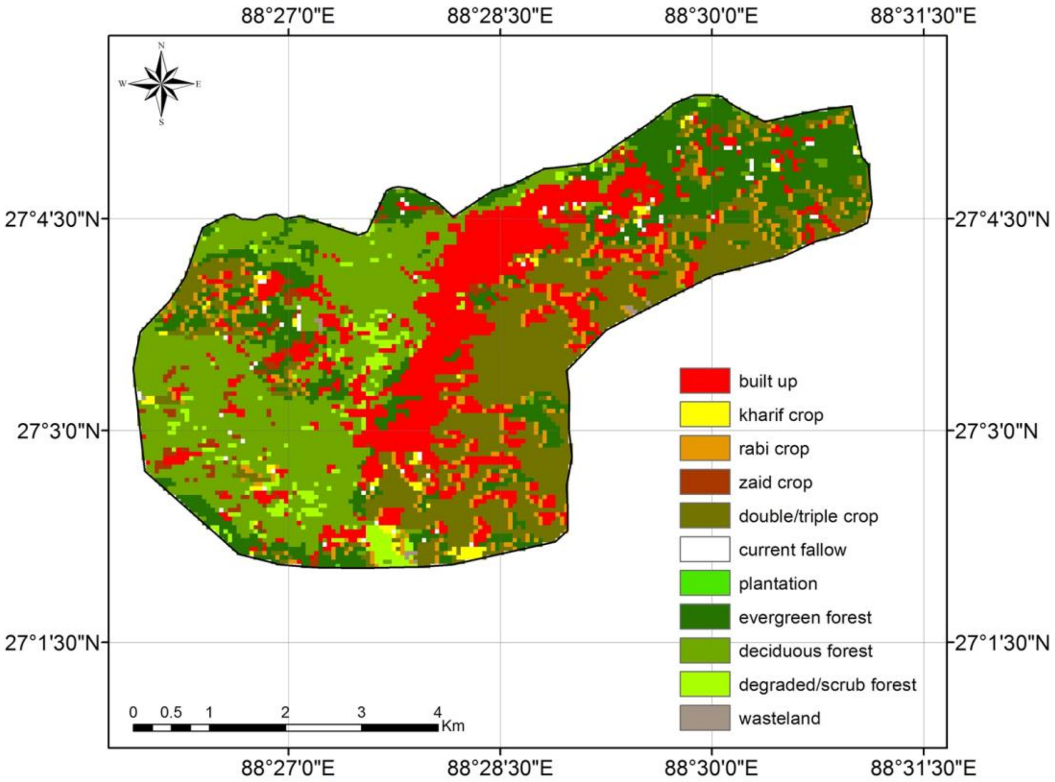
LOCATION OF CHIBO PASHYAR





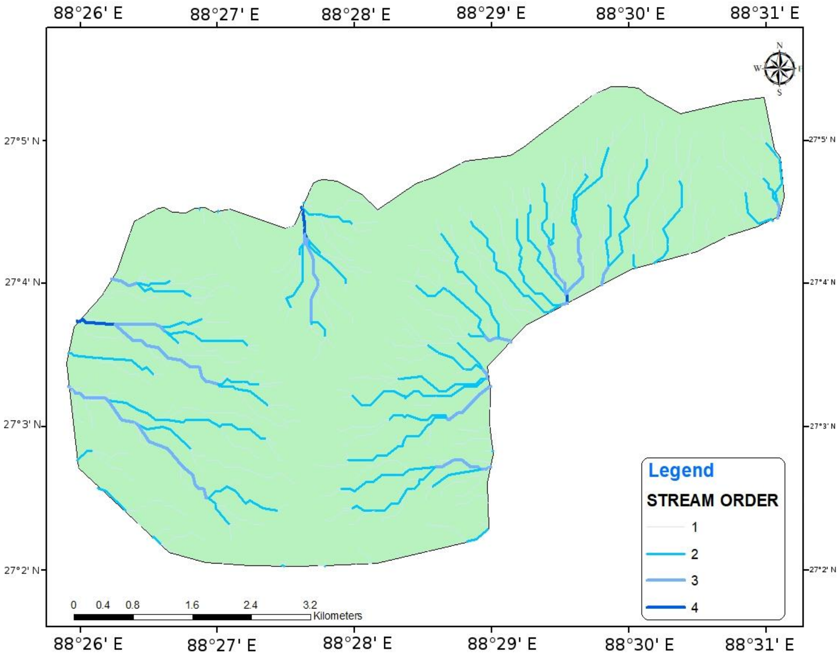
Jhoras affecting Chibo-Pashyar



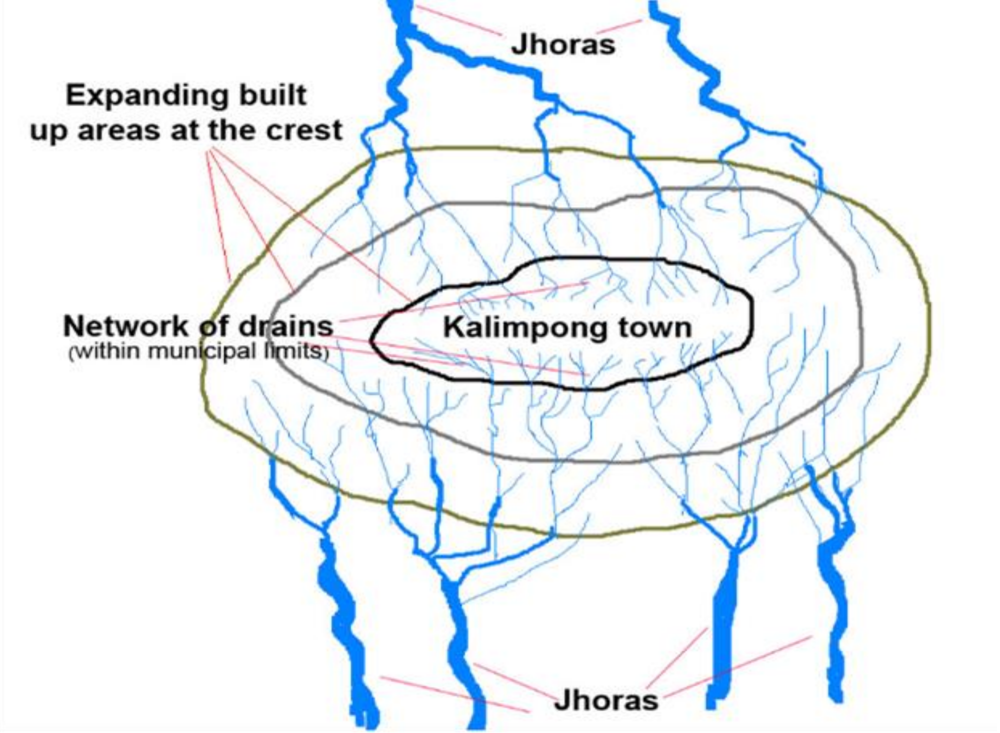


Land Use/LandCover Map of Kalimpong (Sourse: NRSC Hyd)

Typical stratigraphy of the study area (Acharyya, 1968)



Drainage map of the Kalimpong town



(Not to Scale)

The water during the monsoon is augmented by huge amounts of surface runoff because of reduction in ground seepage

(a) Damage to culvert

(b) Damaged road along NH 31A

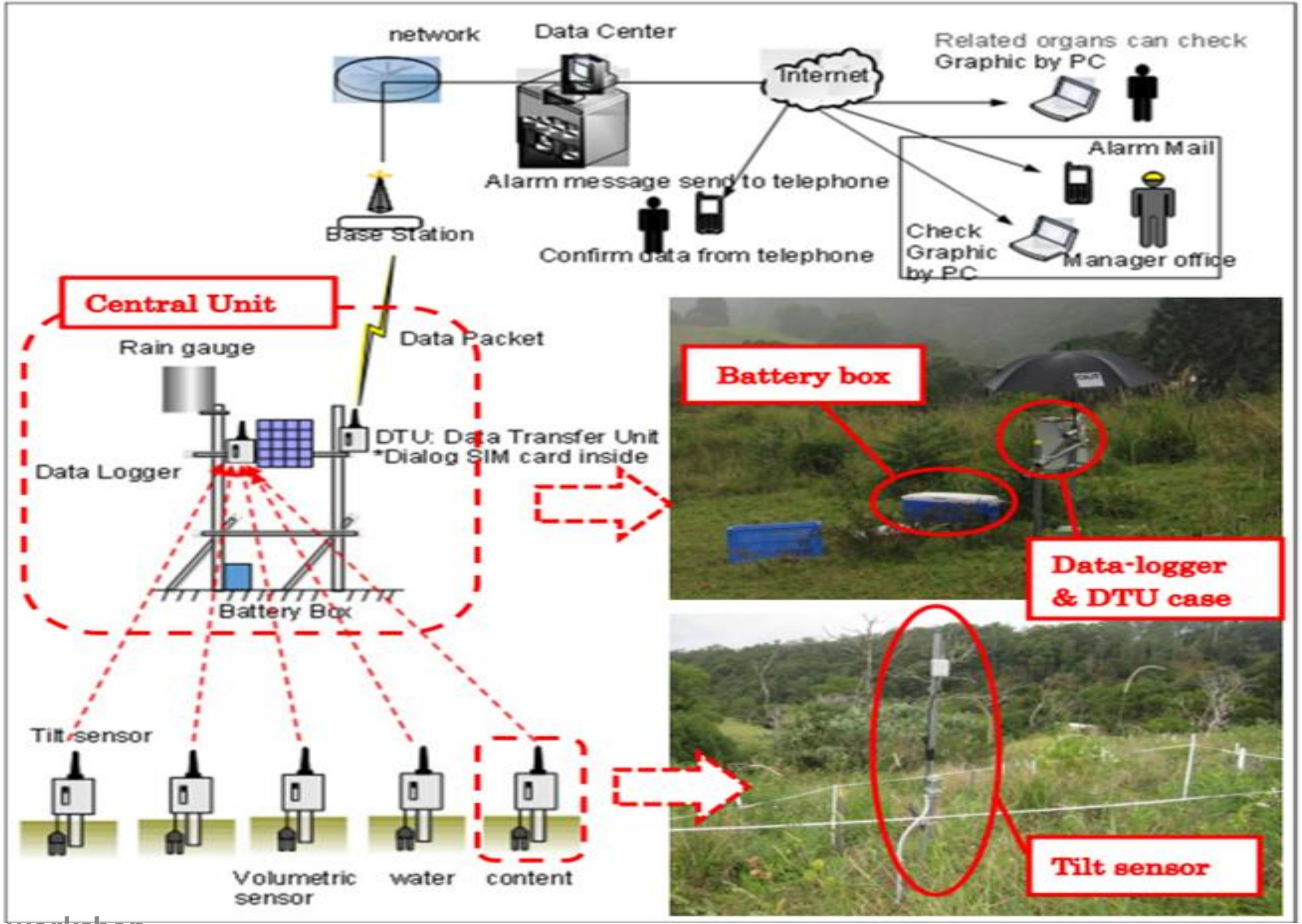
(c) Damage to house

(d) Mudflows and Debris

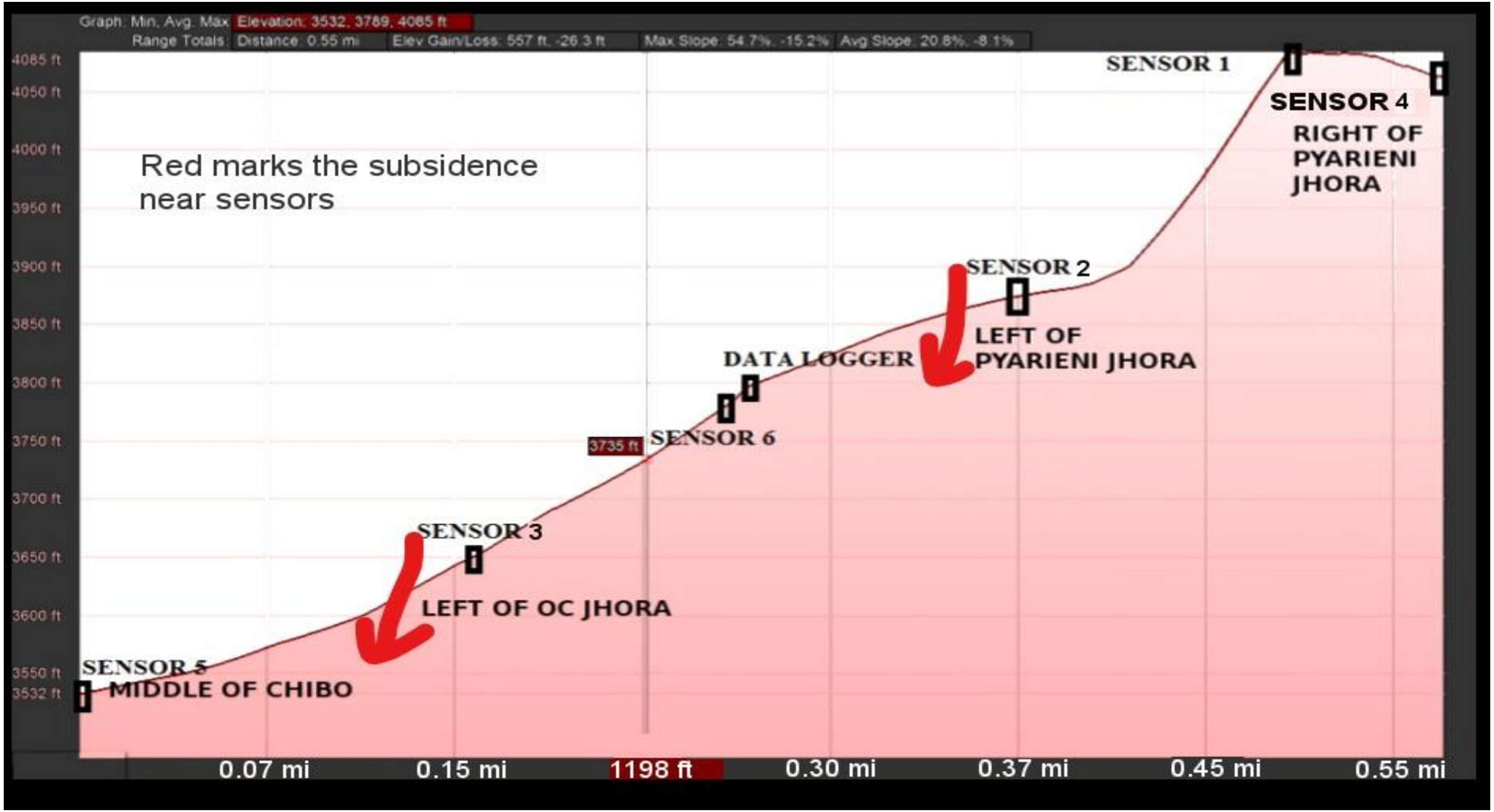
Observed damages during field visit (Dikshit and Satyam, IIS, 2018)

Landslide damages at Chibo Pashyar

NETWORK OF WIRELESS SENSOR SYSTEM INSTALLED AT CHIBO PASHYAR



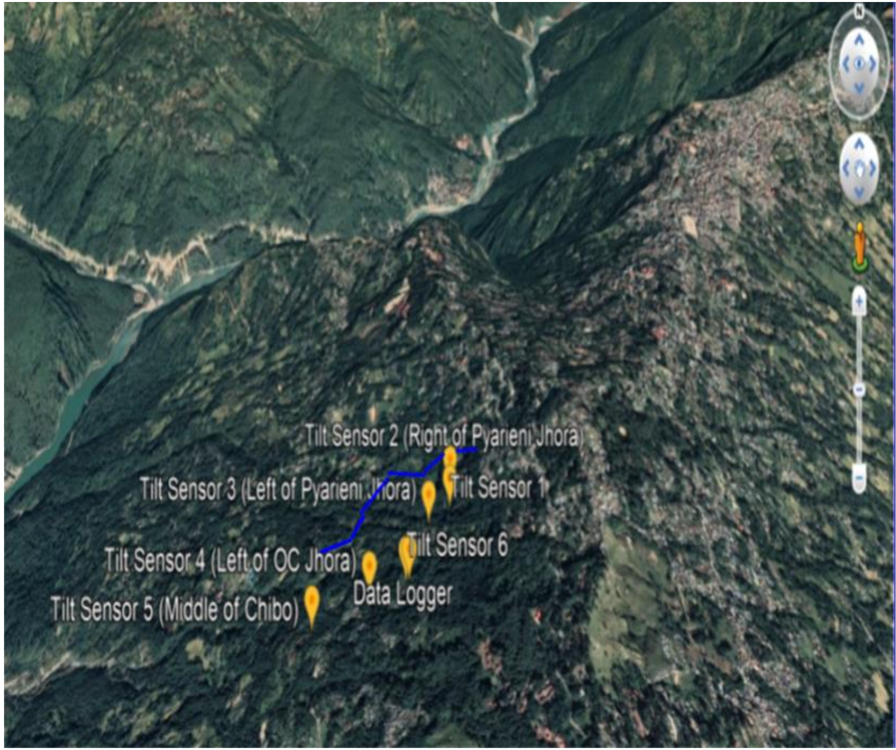
Elevation Profile of installed sensors



Instrumentation at Chibo Pashyar

- 6 Tilt Sensors and 1 Data Logger were installed at in the study area.

- The sensor locations were decided based on GSI inputs (across OC & Pyraeni jhora), local people and slope stability analysis



Data Logger : 27.0504, 88.4542
Sensor 1: 27.0527, 88.4559
Sensor 2: 27.0524,88.4550
Sensor 3: 27.0535, 88.4560
Sensor 4: 27.0502, 88.4525
Sensor 5: 27.0495, 88.4501
Sensor 6: 27.0504, 88.4540

Data Logger (27.0504, 88.4542)

Tilt Sensor 1 TS1704011 (27.0502, 88.4525)

Tilt Sensor 2 TS1704015 (27.0495, 88.4501)

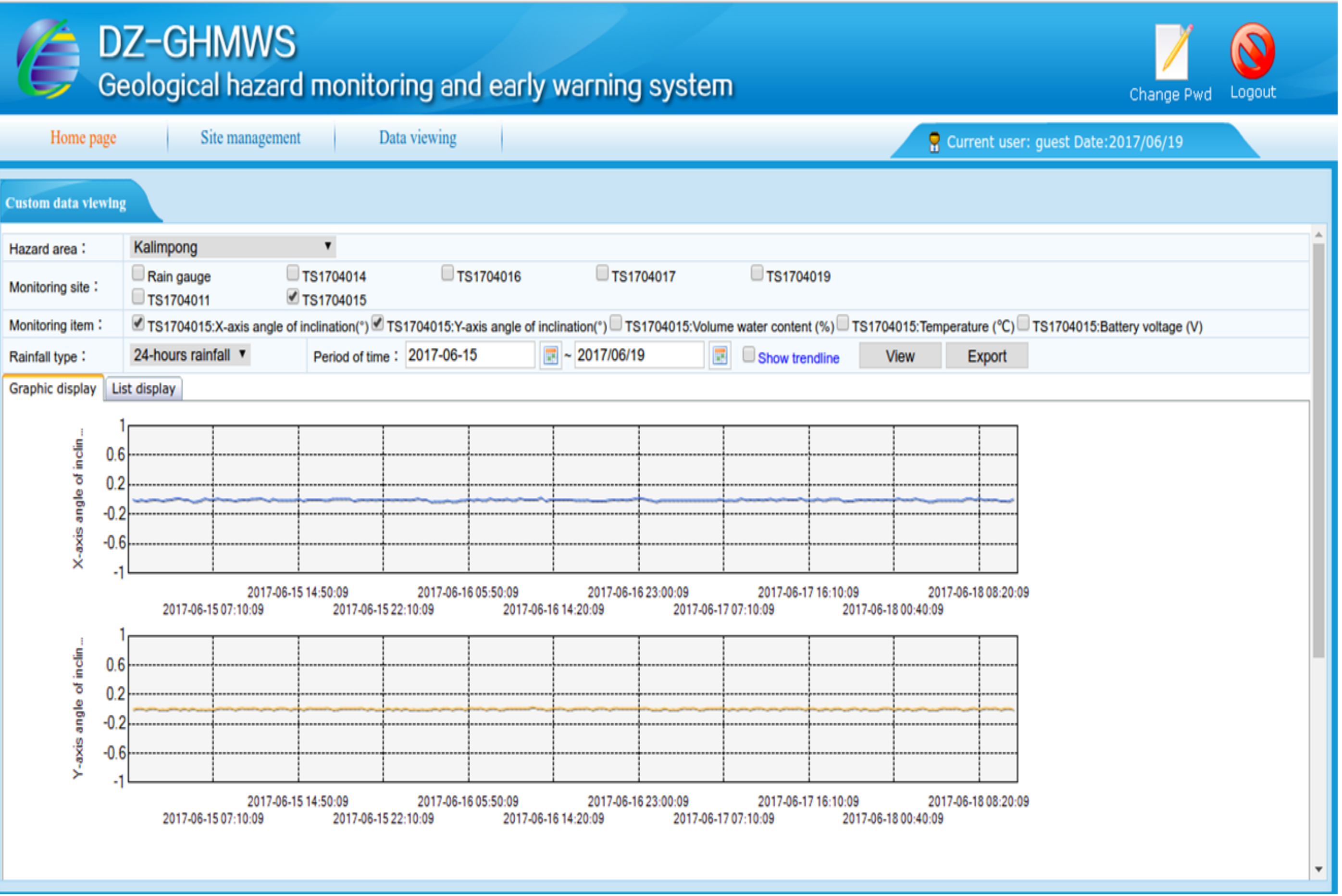
Tilt Sensor 3 TS1704016
(27.0527, 88.4559)

Tilt Sensor 4 TS1704019
(27.0504, 88.4540)

Tilt Sensor 5 TS1704017
(27.0535, 88.4560)

Tilt Sensor 6 TS1704014
(27.0524,88.4550)

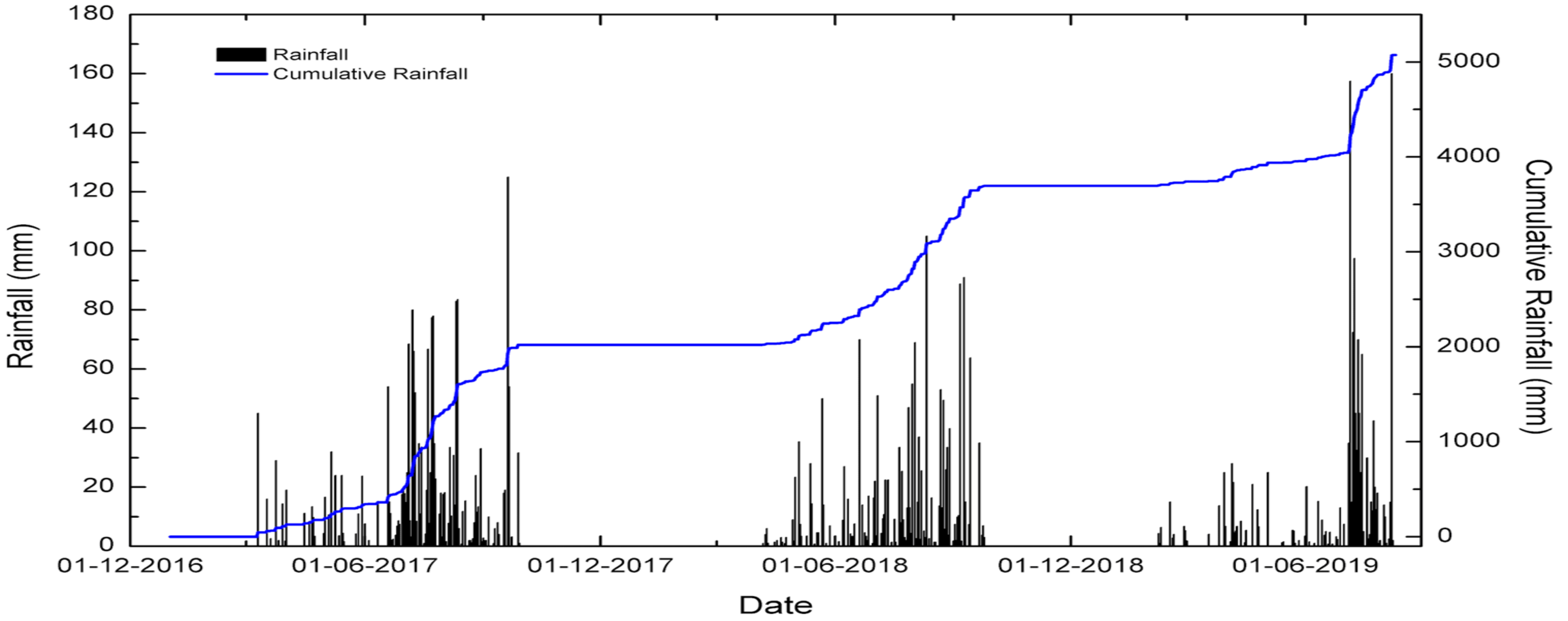
The data is available at : http://114.179.7.237/in001_kalimpong/index.aspx



<u>The data contains parameters as:</u>

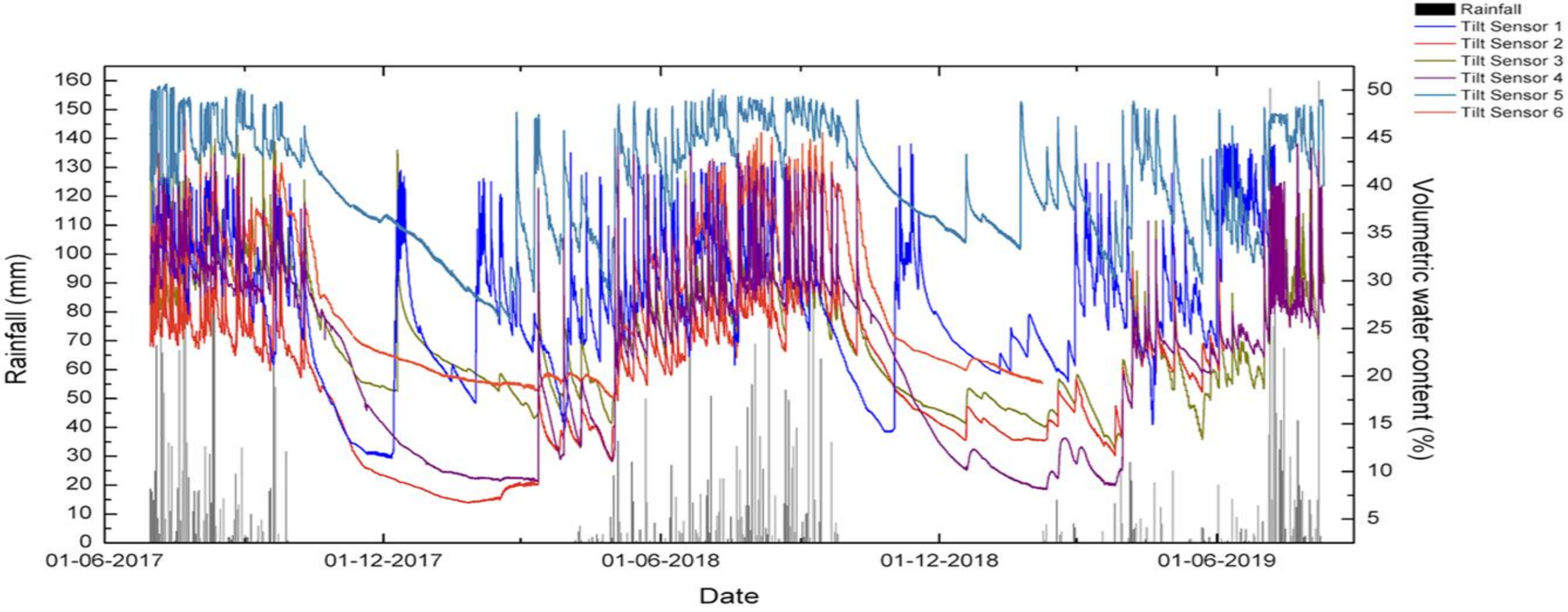
X-axis angle of inclination(°)
Y-axis angle of inclination(°)
Volume water content (%)
Temperature (℃)
Battery voltage (V)

Time History of monitored items



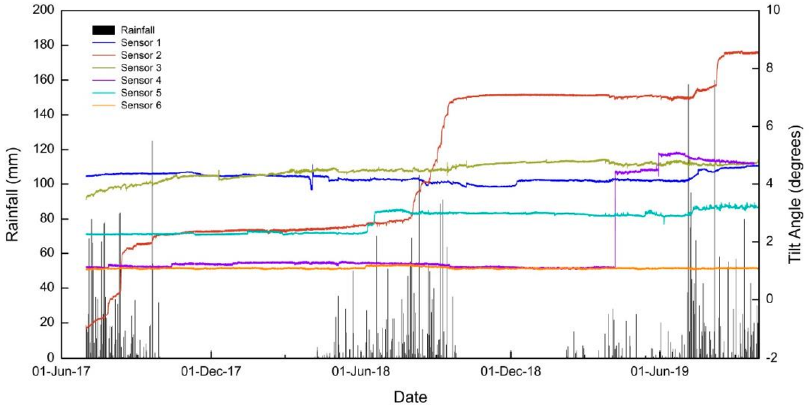
Time history of daily and cumulative rainfall for the study period (Abraham et al , Sensors, 2020)

Time history of volumetric water content

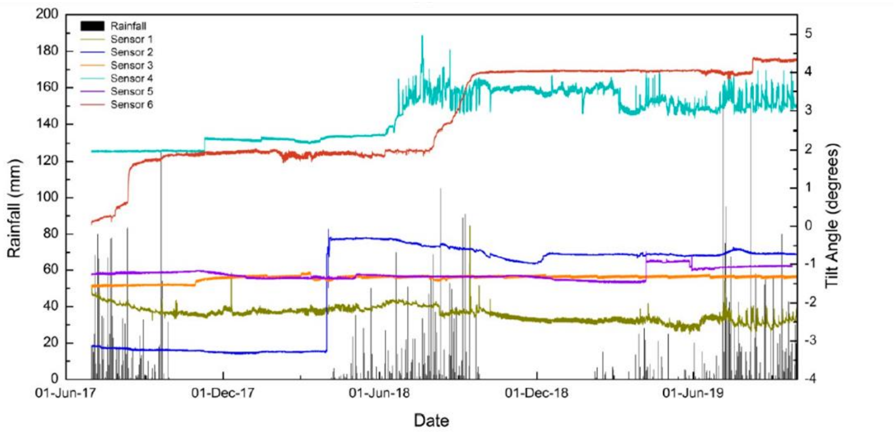


(Abraham et al , Sensors, 2020)

Time history of tilt angles by surface tilt sensors



Tilting in slope direction

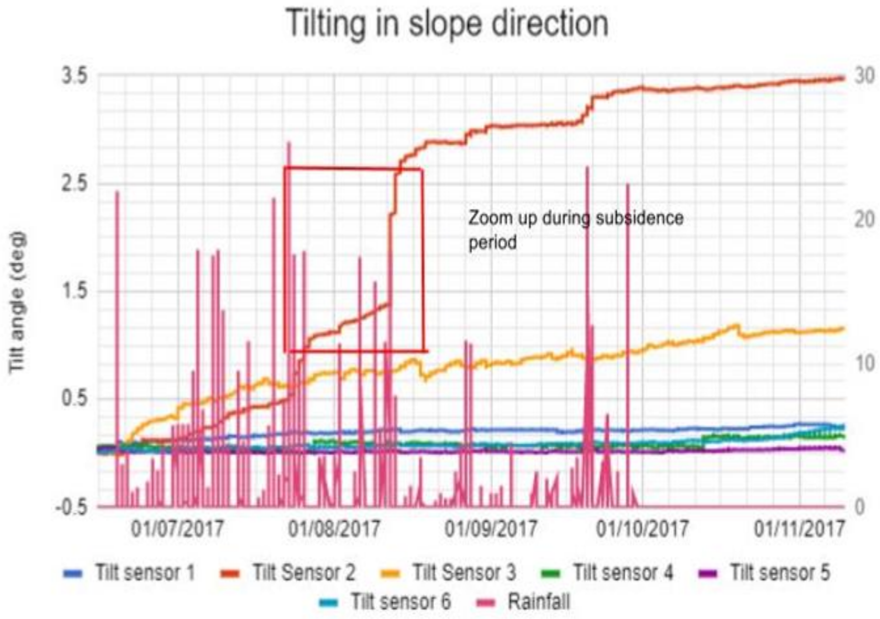


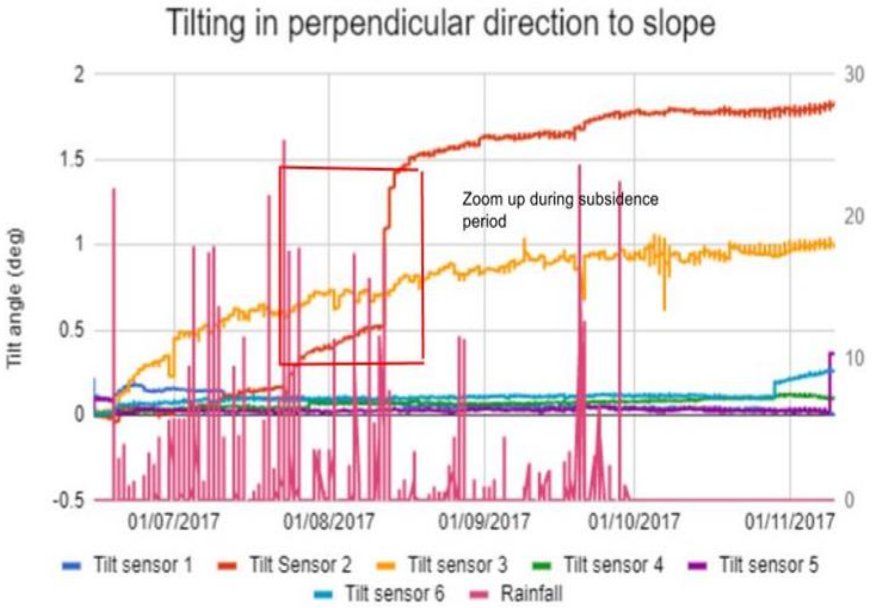
Tilting in horizontal direction

(Abraham et al , Sensors, 2020)

Time history of tilt angles by surface tilt sensors

Detailed description of displacement in 2017



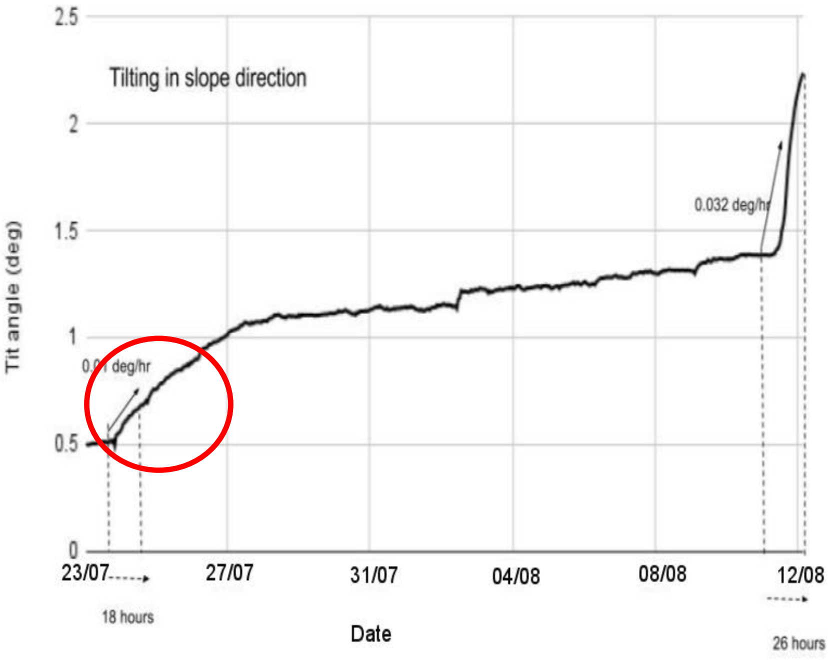


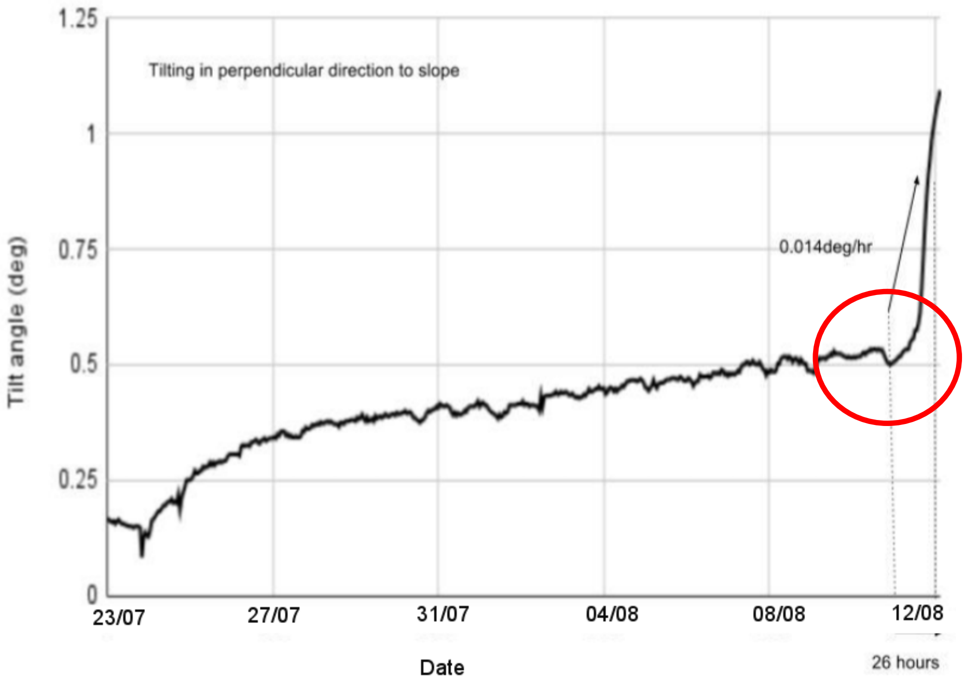
Tilting in slope direction

Tilting in horizontal direction

(Dikshit et al , NH, 2018)

2017: Variations in angle of inclination Tilt Sensor 2 from the start of subsidence (23/07/17-12/08/17)

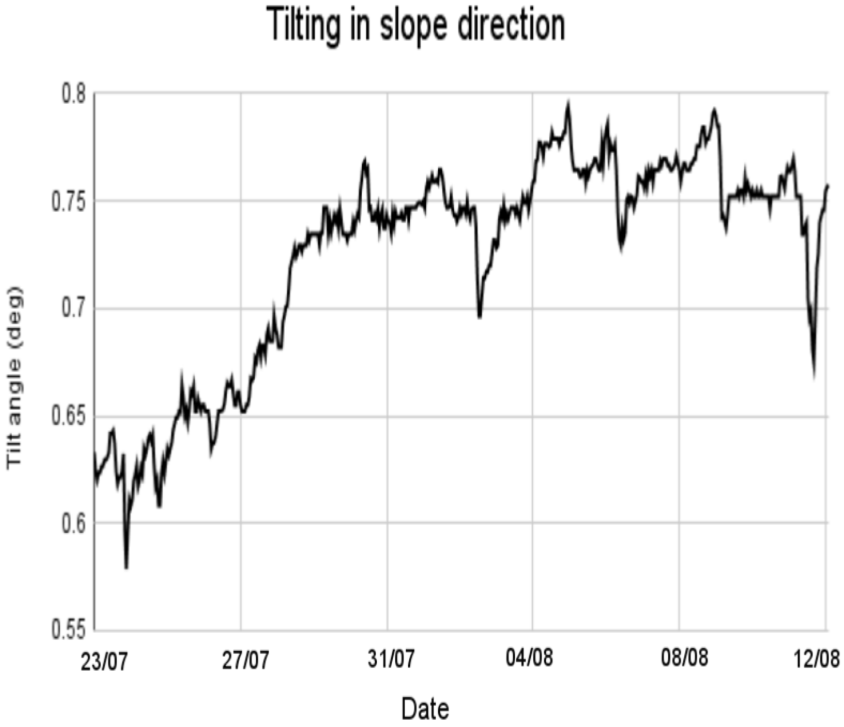


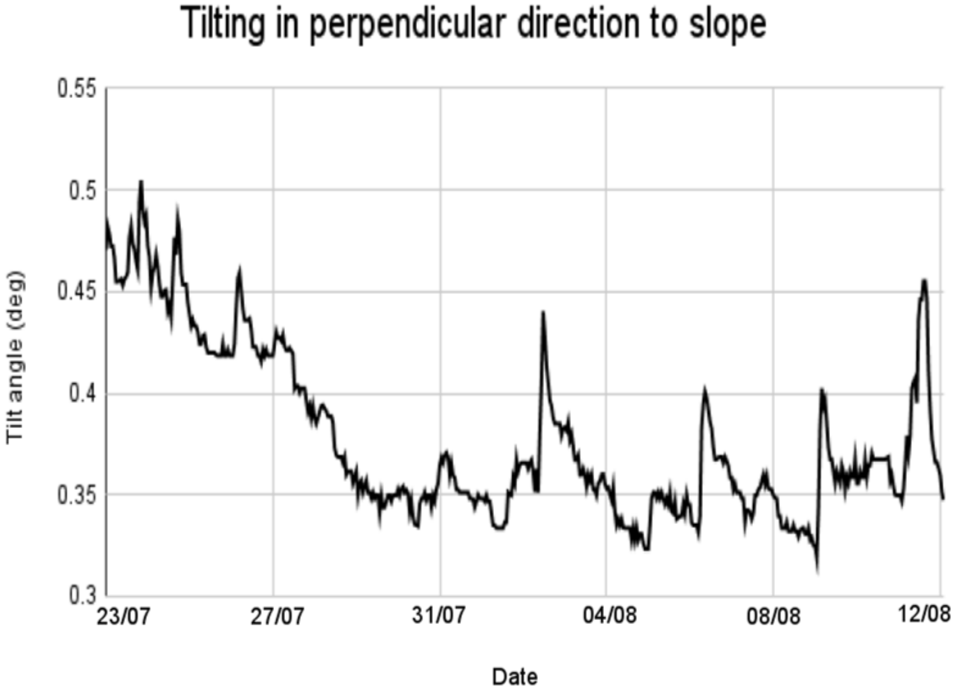


Needs a precaution if Tilt rate of 0.01 deg/hr

(Dikshit et al , NH, 2018)

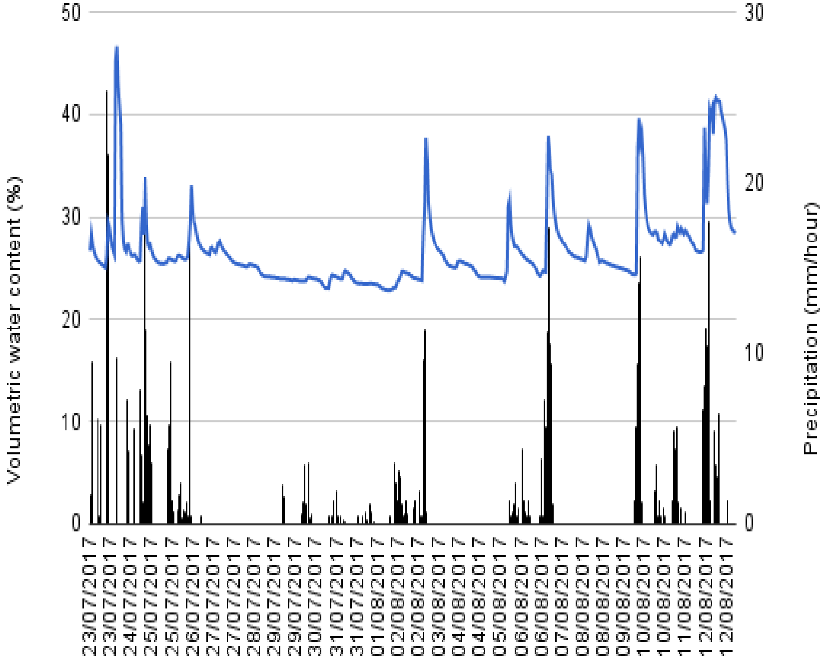
Variations in angle of inclination and moisture content in Tilt Sensor 3 from the start of subsidence



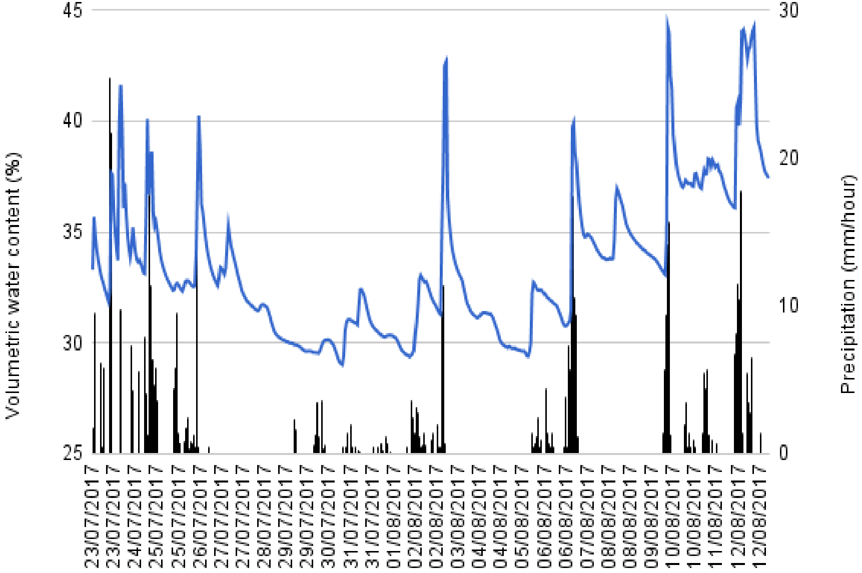


(Dikshit et al , NH, 2018)

Comparative analysis of volumetric water content from the start of subsidence



Tilt sensor 2



Tilt Sensor 3

(Dikshit et al , NH, 2018)

Field observations at the ground near Tilt Sensor 2

At tilt Sensor 2 near Pyarieni Jhora , subsidence during 2017 monsoon

(Dikshit et al , NH, 2018)

Observations for TS 2 (Pyarieni Jhora)

The soil present near Pyarieni Jhora are mainly silty clay (low PI) with moderately thick forest and cardamom plantation (GSI Report, 2017).

Seepage has been observed at various locations both within the old slide debris. It has been observed that the surface runoff along the streamlets is entering the old slide debris and causes oversaturation.

Slope instability is caused by active toe erosion on either bank of Pyarieni Jhora and the evidence is indicated by the subsidence (as shown in Figs in last slide).

On 24/07/2017 rainfall event lasted for 5 hours with a tilt angle variation at 0.008 deg/hr, however after 5 hours of rainfall, the tilt variation increased to 0.012 deg/hr which emphasizes the importance of infiltration. Similar observation was recorded on 12/08/2017 after 4 hours of rainfall.

(Dikshit et al , NH, 2018)

Subsidence at TS 3

Aug, 2017

Intense slope instability in the form of slide and subsidence has been observed along both the banks of the OC Jhora.

Slope instability is mainly restricted along the jhora; subsidence of the road indicates removal of finer materials by seepage of water.

(Dikshit et al , NH, 2018)

Variation in event rainfall and the tilting rate for various displacement periods

Season	Event Rainfall (mm)	Max. Intensity (mm/h)	3-day antecedent (mm)	5-day antecedent (mm)	7-day antecedent (mm)	10-day antecedent (mm)	X tilting rate (°/h)	Y tilting rate (°/h)
2017 - 1	222.6	25.4	120	142.64	144.34	269.83	0.016	0.012
2017 - 2	109.65	17.8	64.2	146.9	155.6	208.6	0.08	0.01
2018 - 1	24	5	9.4	11.1	15.2	21.4	0.03	0.015
2018 - 2	24	4	3.1	6.7	8.2	15.1	0.05	0.02
2019-1	452.5	3.96	210	210	217.5	230.5	0.057	0.21

(Abraham et al , Sensors, 2020)

Enhancing the performance of statistical thresholds

1. Using antecedent moisture content

- SHETRAN - Hydrological model to simulate drainage pathways and processes in river basins, which is being used extensively.
- The partial differential equations governing water flow are solved using the spatially distributed input data.
- The input data is in the form of a three dimensional grid, formed using the digital elevation model (DEM).

Parameters	**Calibrated value**
Strickler overland flow coefficient	0.50 $m^{1/3}s^{-1}$
Maximum Rooting Depth	1.6 m
AE/PE at field capacity	1
Canopy storage	5 mm
Saturated water content	0.40
Saturated hydraulic conductivity	1.14 m/day
vanGenuchten-n	1.17
Residual water content	0.08
Leaf Area Index	1
vanGenuchten- alpha	0.03 cm^{-1}

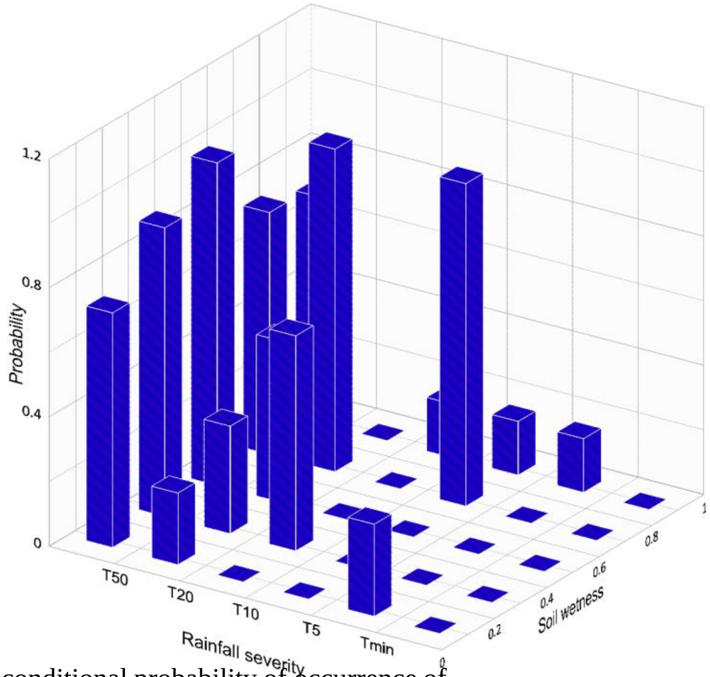
(Abraham et al , Water, 2020)

Enhancing the performance of statistical thresholds

1. Using antecedent moisture content

Integration with statistical thresholds – using Bayesian approach

$$P\,(A|B,C) = \frac{P(B,C|A) * P(A)}{P\,(B,C)}$$



Histogram of conditional probability of occurrence of landslides based on rainfall severity and antecedent soil moisture

The maximum probability of 1 was obtained in three cases:

a) the rainfall severity greater than T_{50} and the soil wetness between 0.4 and 0.6

b) the rainfall severity between T_{20} and T_{50} and the soil wetness between 0.6 and 0.8

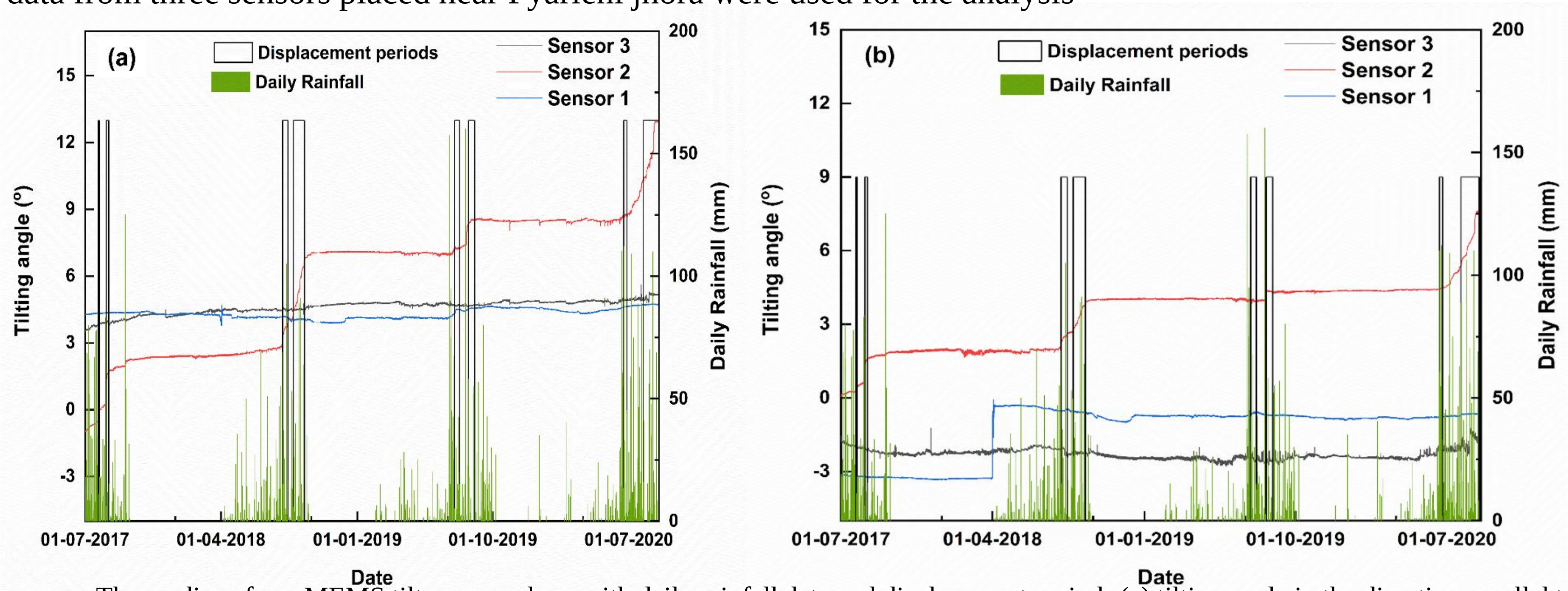
c) the rainfall severity event between T_5 and T_{10} and the soil wetness between 0.6 and 0.8

(Abraham et al , Water, 2020)

Enhancing the performance of statistical thresholds

2. Using field based monitoring data

The data from three sensors placed near Pyarieni jhora were used for the analysis



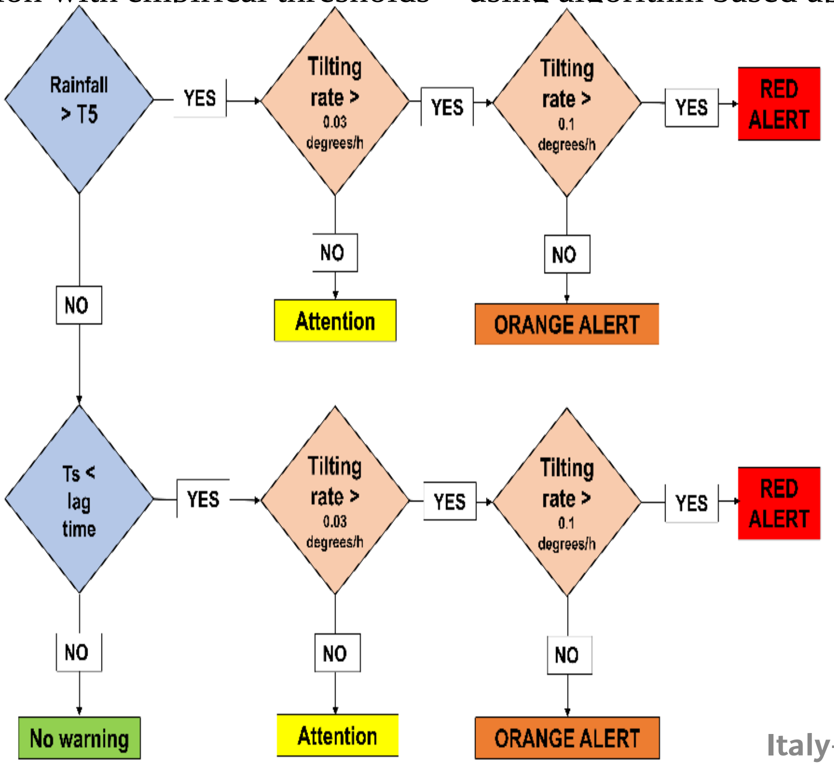
The readings from MEMS tilt sensors along with daily rainfall data and displacement periods (a) tilting angle in the direction parallel to slope, and (b) tilting angle in the direction perpen-dicular to slope

(Abraham et al , Water, 2021)

Enhancing the performance of statistical thresholds

2. Using field based monitoring data

Integration with empirical thresholds – using algorithm based approach



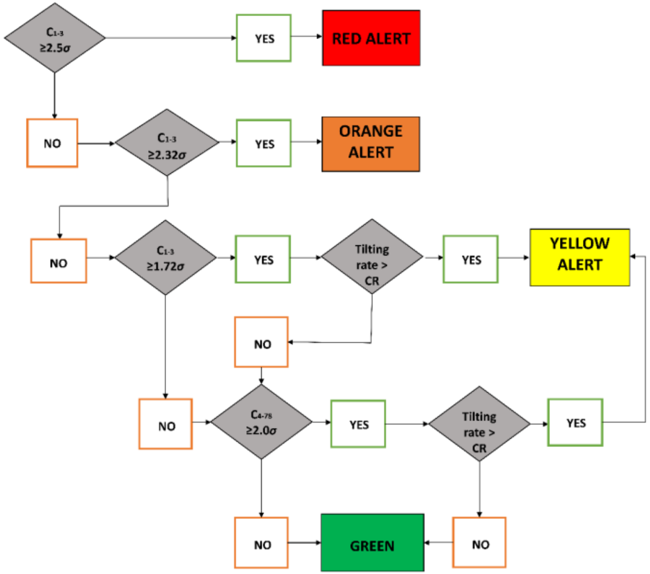
Statistical Attributes	ED + Tilt	ED only	Tilt only
True positives	66	50	86
False positives	63	118	273
False negatives	32	48	12
True negatives	997	942	787
Efficiency	0.92	0.86	0.75
Specificity	0.94	0.89	0.74
Sensitivity	0.67	0.51	0.88
Likelihood ratio	11.33	4.58	3.41

(Abraham et al , Water, 2021)

Enhancing the performance of statistical thresholds

3. Using field based monitoring data

Integration with SIGMA model – using algorithm based approach



Statistical Attributes	SIGMA + Tilt	SIGMA only
True positives	88	88
False positives	38	70
False negatives	34	34
True negatives	1028	996
Efficiency	0.94	0.91
Specificity	0.96	0.93
Sensitivity	0.72	0.72
Likelihood ratio	20.23	10.98

THANK YOU