1st International Conference on
Natural Hazards and Disaster Management

A real-time landslide monitoring and early warning systems by using Wireless sensor network

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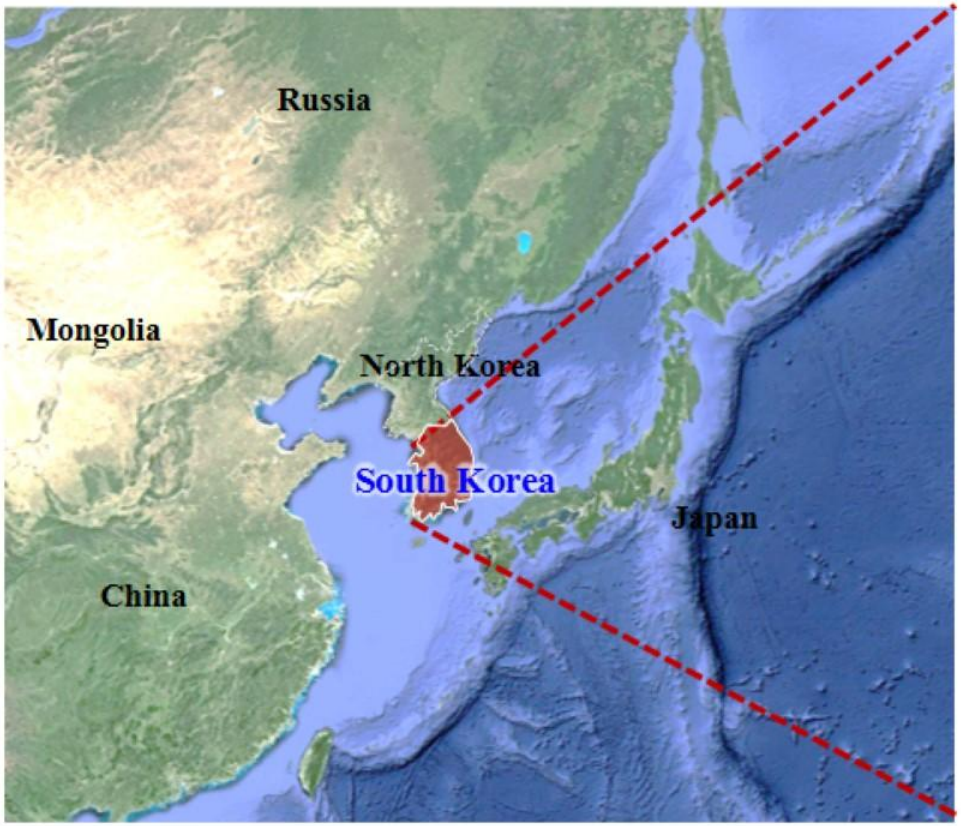
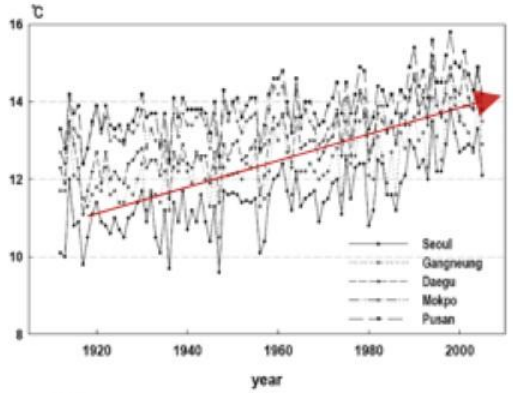
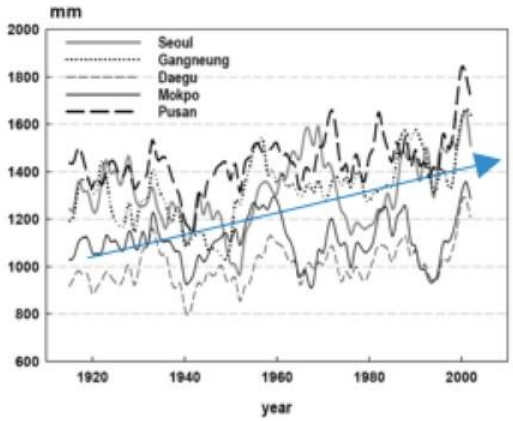
1. Introduction

1.1 Climate change







Warming

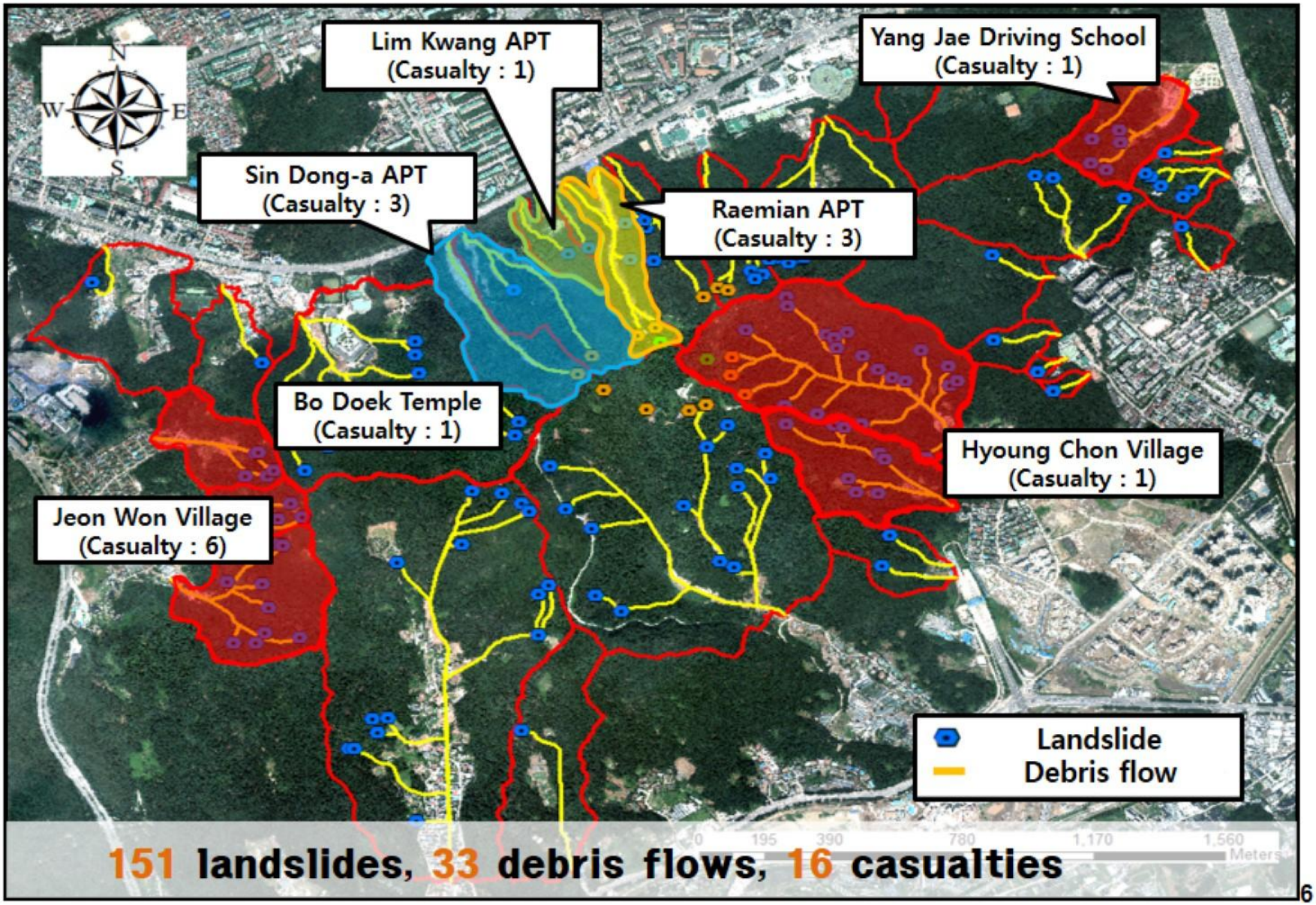
Rainfall increase

✓ *Climate change*

- **More severe fluctuation in rainfall patterns**
  (Rainfall intensity, frequency and quantity)
- **Triggering the slope instability**

1.2 Umyeonsan(Mt.) landslide, 2011

❖ Damage by Debris Flows around Umyeonsan(Mt.)



❖Umyeonsan landslide event(July 27, 2011)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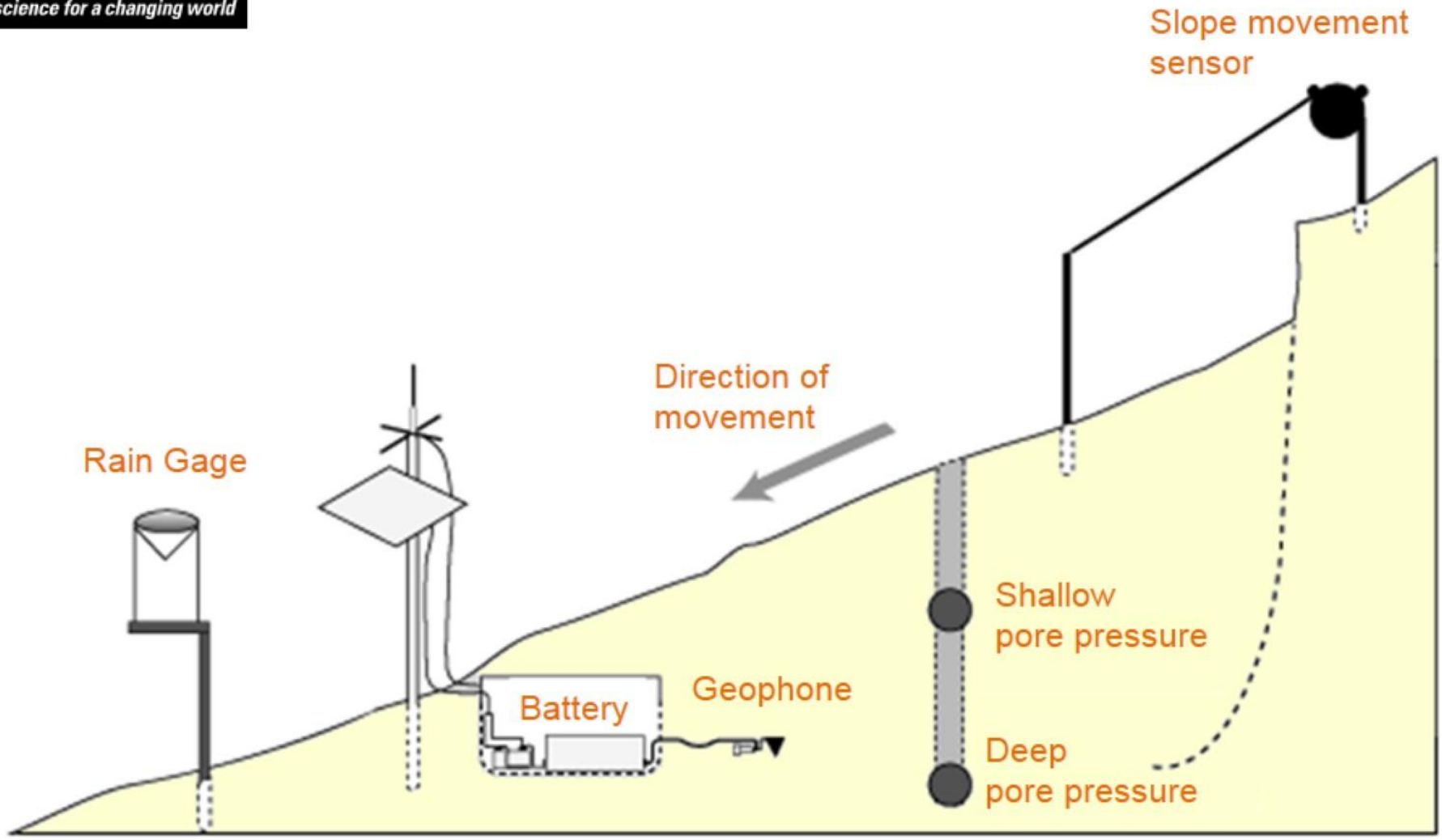
1.3 Objectives

How to recognize the signs of impending landslide or debris flow ?

2. Monitoring and Early warning system

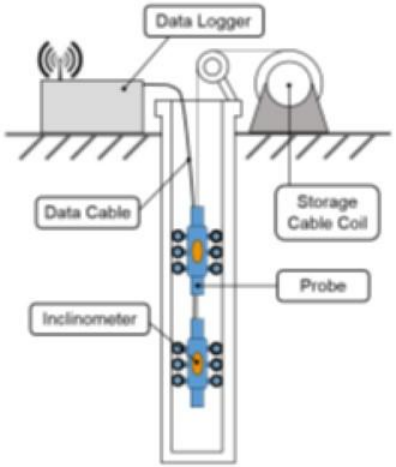
2.1 Local scale landslide monitoring, USA

USGS
science for a changing world



2.2 Problems in monitoring systems

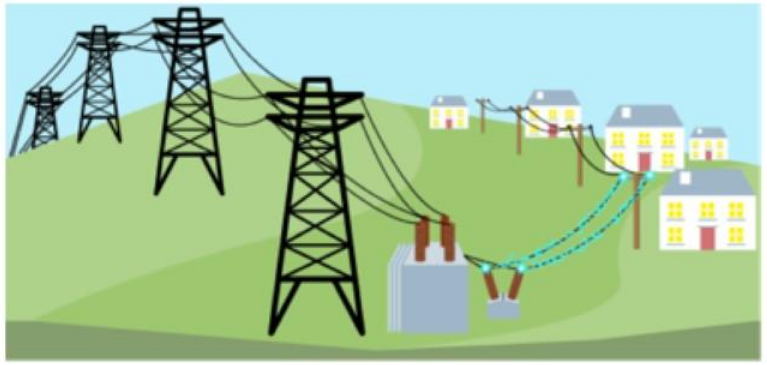
Installation



Wiring

Expensive

Electricity



2.3 Wireless sensor network (Using 'MEMS')

❖ Wireless sensor network (WSN) :

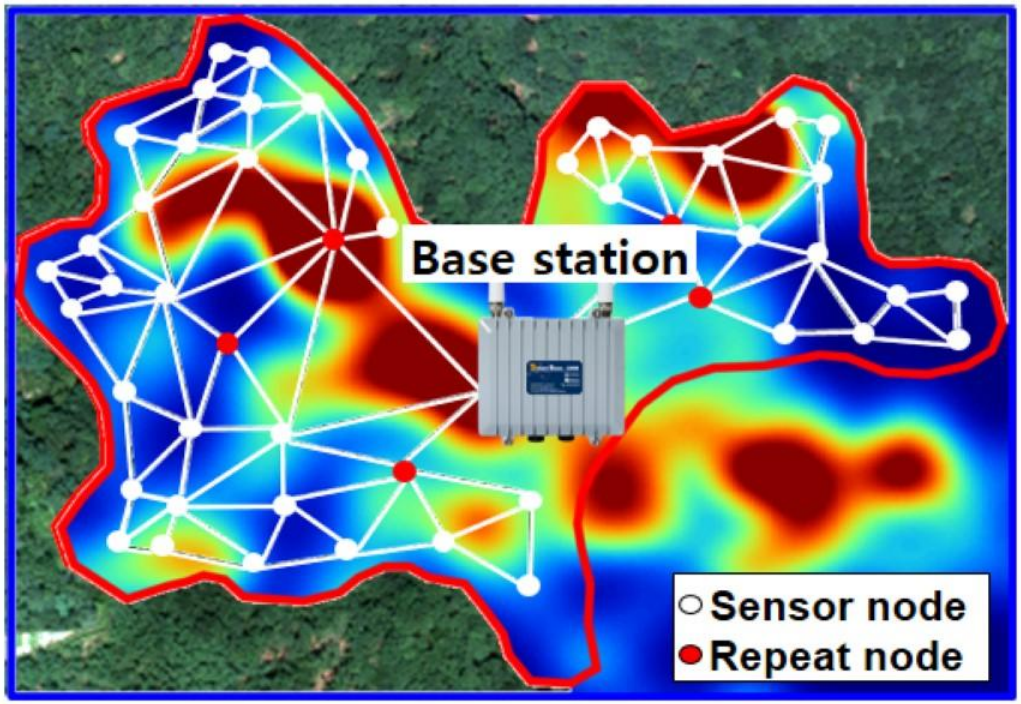
- It make up sensor to network for monitoring geotechnical information

Node

Water content

Rainfall collector

Inclinometer



Web server

Regional scale monitoring system (WSN)

LANDSLIDE EARLY WARNIG SYSTEM

Base station

- Collect data from sensor nodes
- Send data to web server

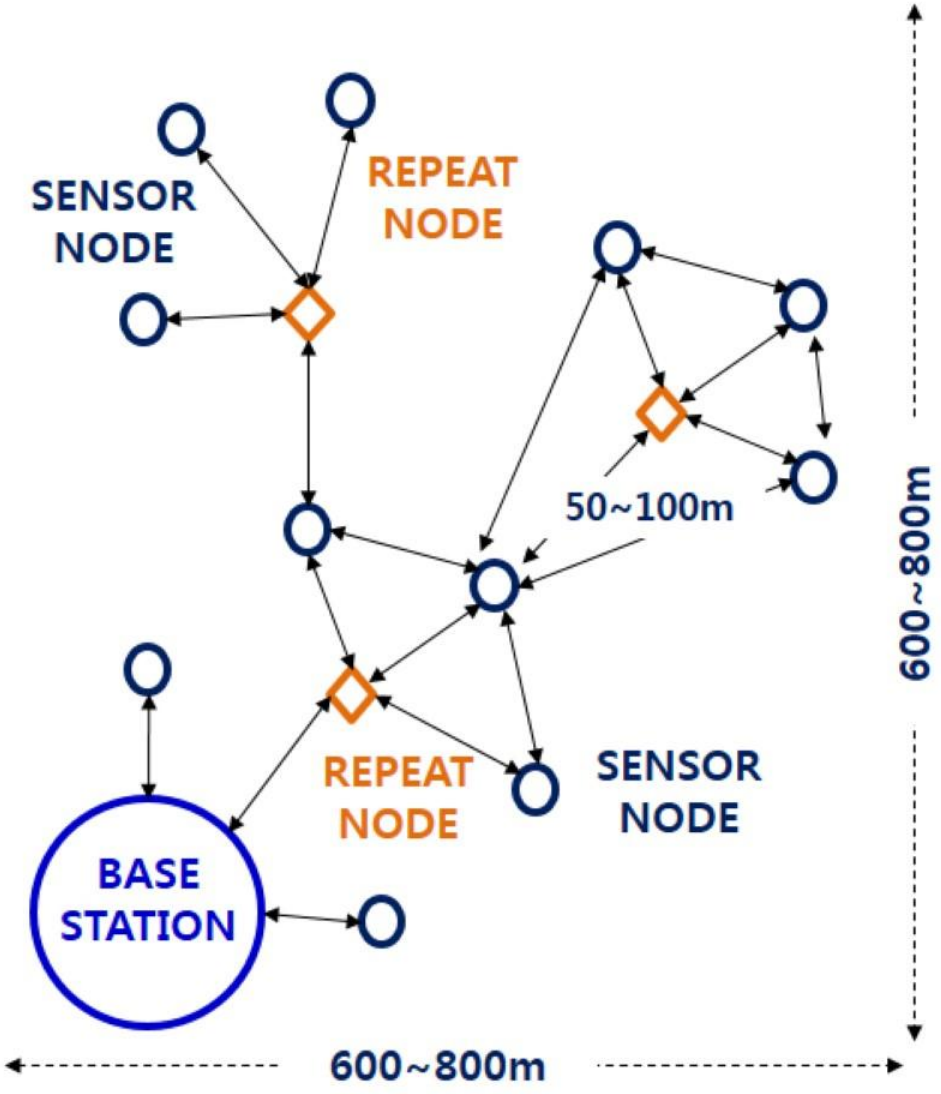
Sensor node

- Field data measurement
- Transmit the data to base station

Repeat node

- Applied to increase distance between sensor node and base station

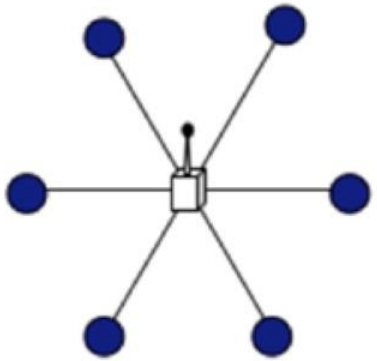
Multipoint measurement
Reduced power and cost
Advanced communication technology



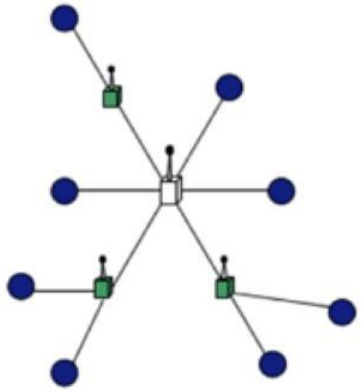
Wireless Sensor Network Topologies

Star method	Mesh method
✓ Simple network configuration	✓ Attractive in principle for self healing and multi-hop
✓ Low power consume	✓ Extremely low power consume
✓ Uninterrupted node to hub communication	✓ Nodes pass through nodes to reach hub
✓ Long range from hub to node (14km:900MHz)	✓ Reduced range from hub and between node (1.5km:2.4GHz)

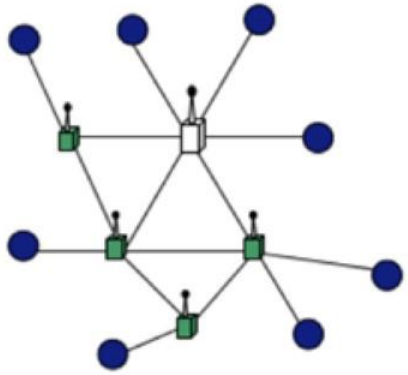
<Star method>



<Tree method>



<Mesh method>



Gateway

Node

Repeat node

3. Landslide warning system and Field application

3.1 Instrumentations

Rainfall

- Rainfall collector
- Real-time rainfall data
- **Rainfall threshold**

Soil moisture

- Soil moisture sensor
- Real-time soil moisture data

  Corresponding to each of

  depths

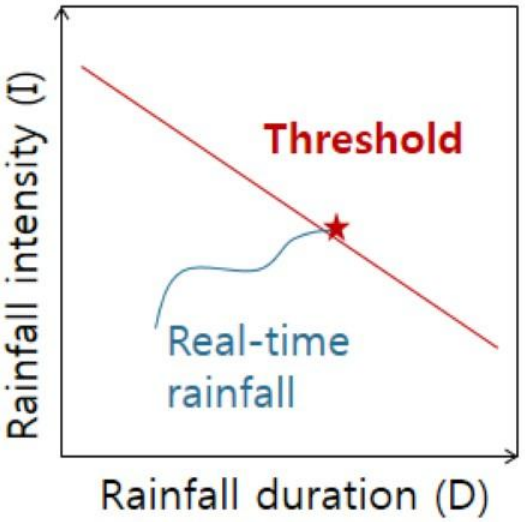
Tilt

- Inclinometer
- Real-time tilt
- **Sensing the sudden**

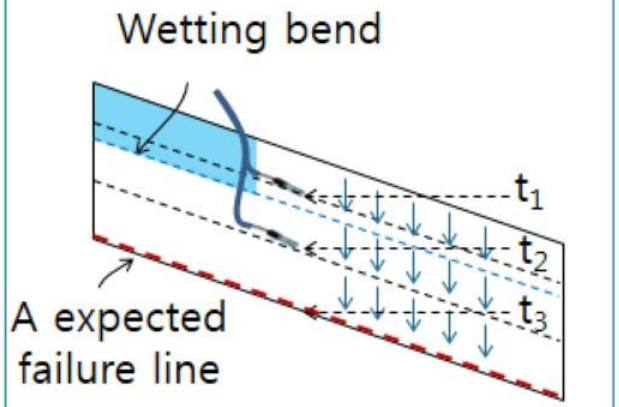
  Changes in tilt

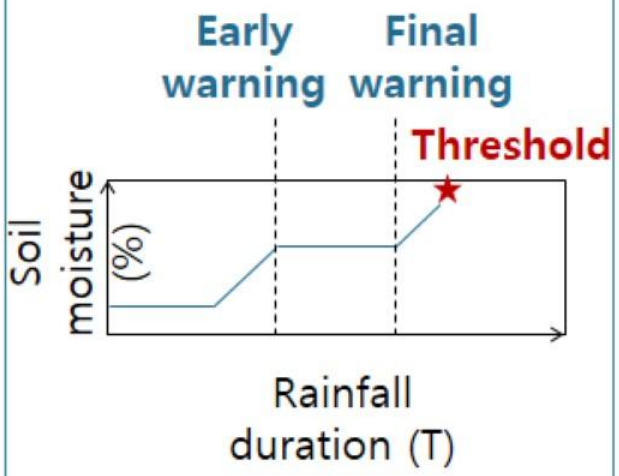
3.2 Threshold

Rainfall

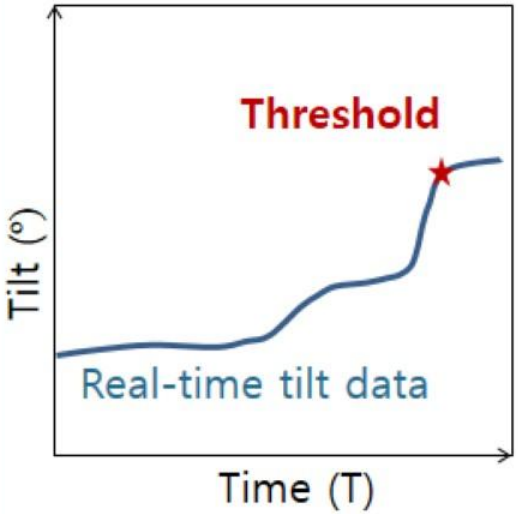


Soil moisture





Tilt



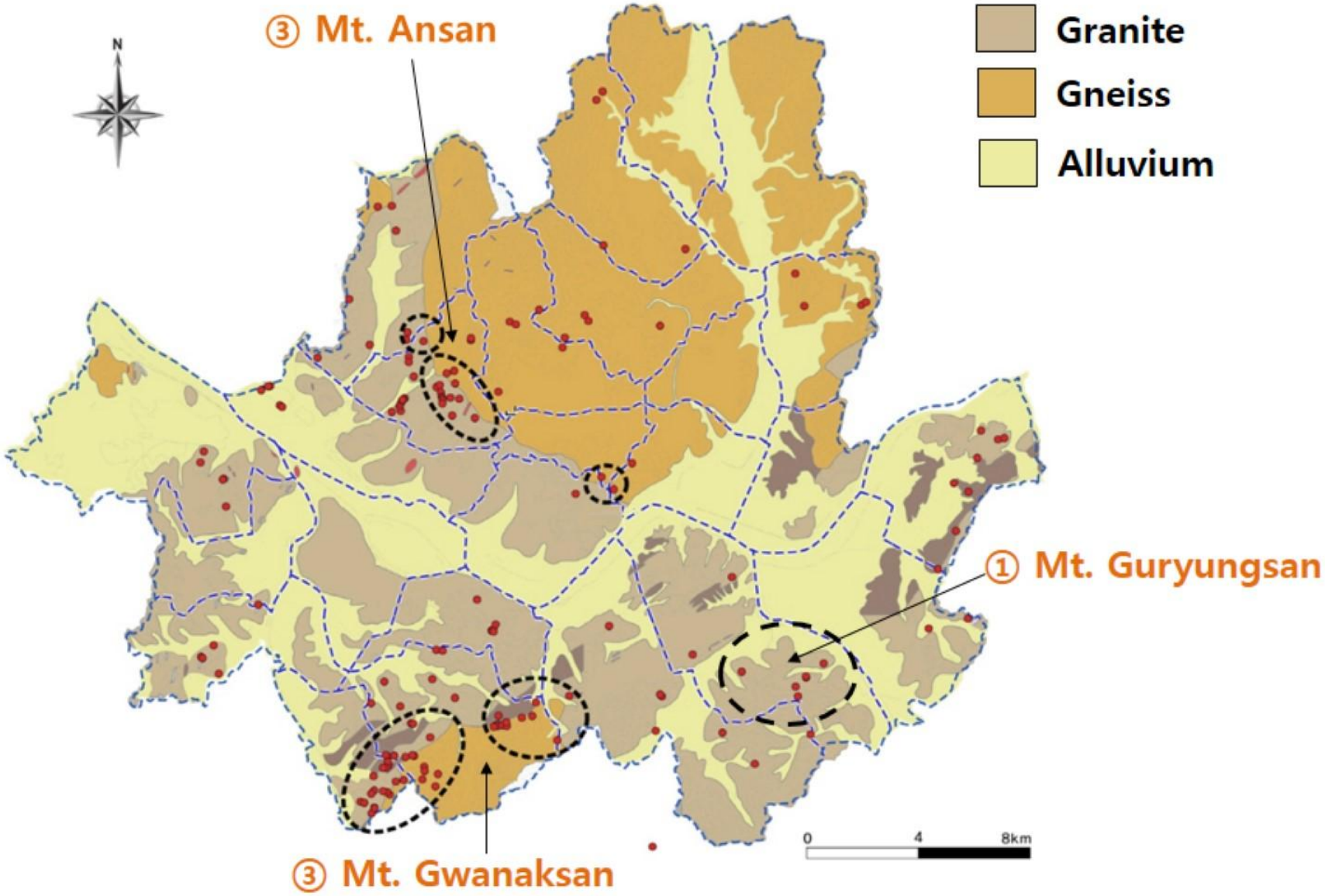
Photograph

Location

Gateway

Node

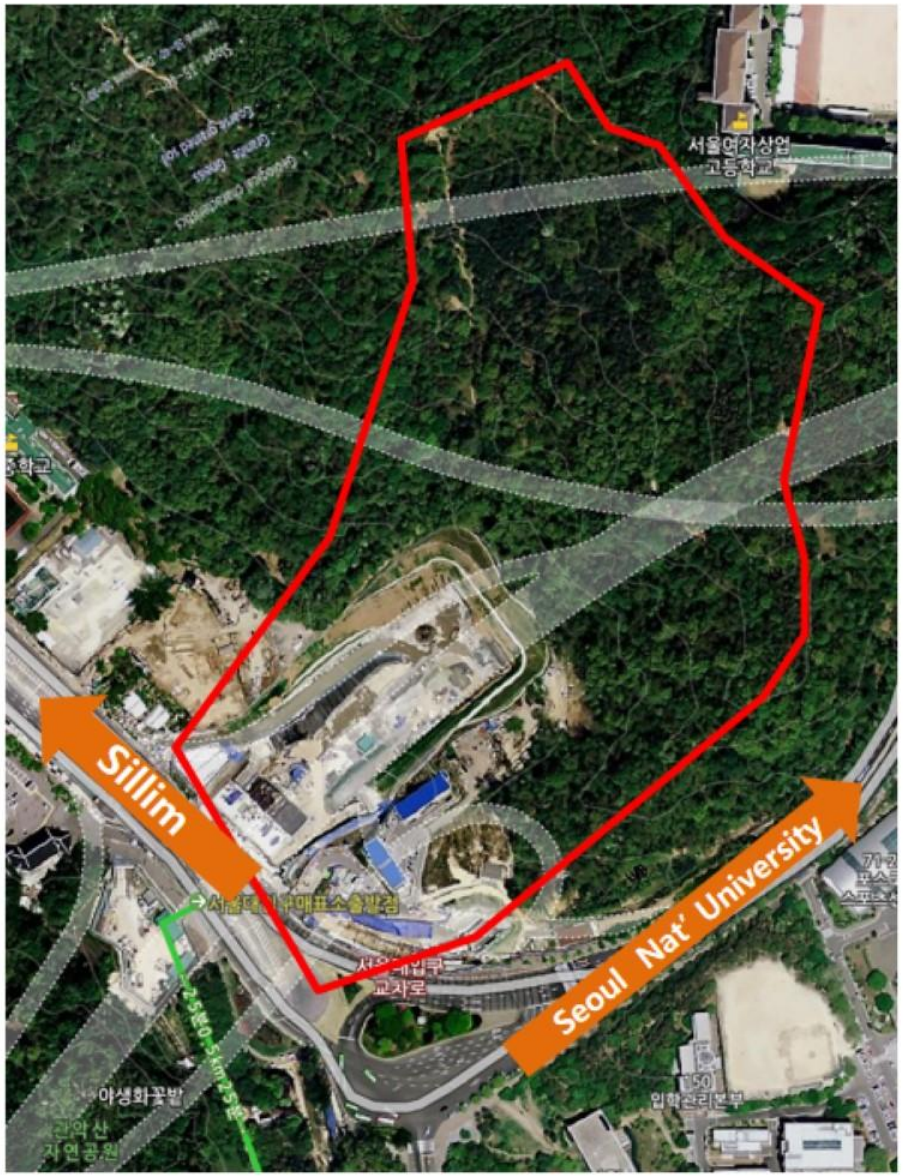
3.3 Test-bed in Seoul, Korea



① Mt. Guryungsan

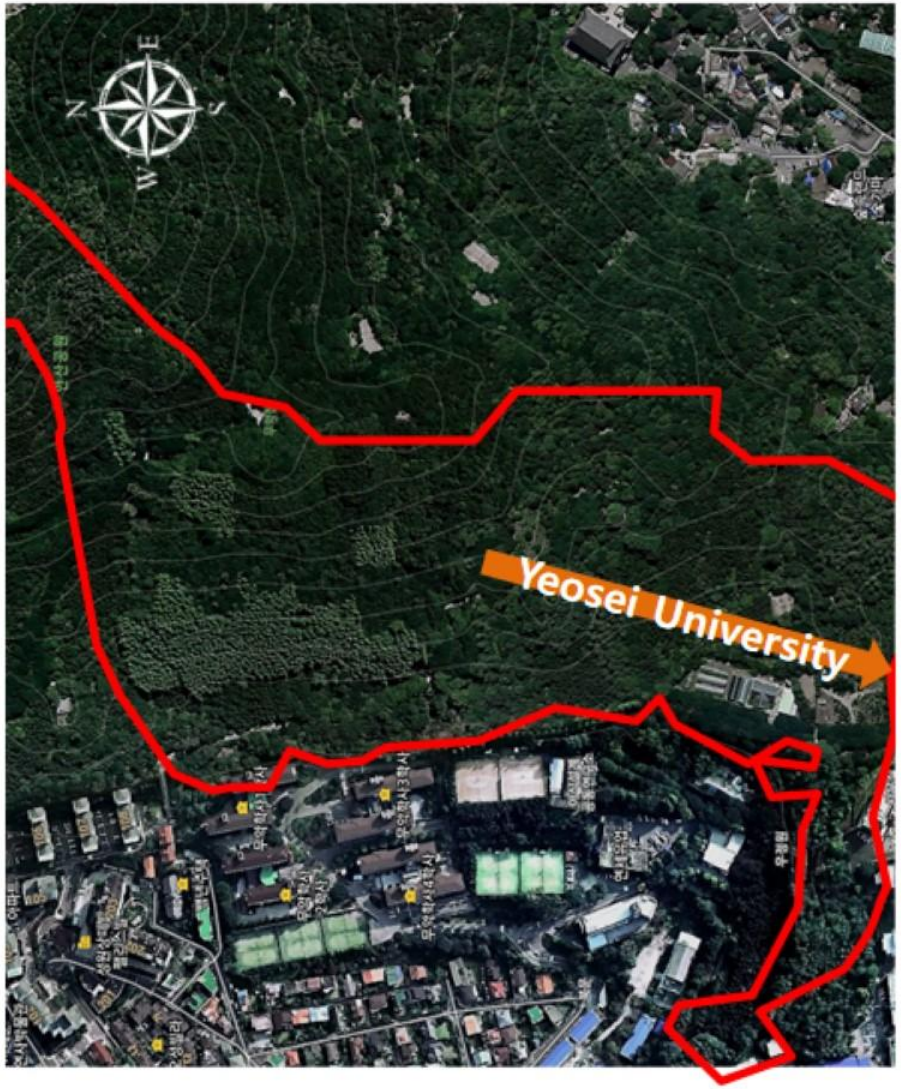
- Geological characteristics
  - Gneiss
  - Mixed coarse grained soil and fine grained soil
- Slope : 16~50°
  - Upward 30~50°
  - Downward 16~30°
- Soil depth : 3~9m

② Mt. Gwanaksan



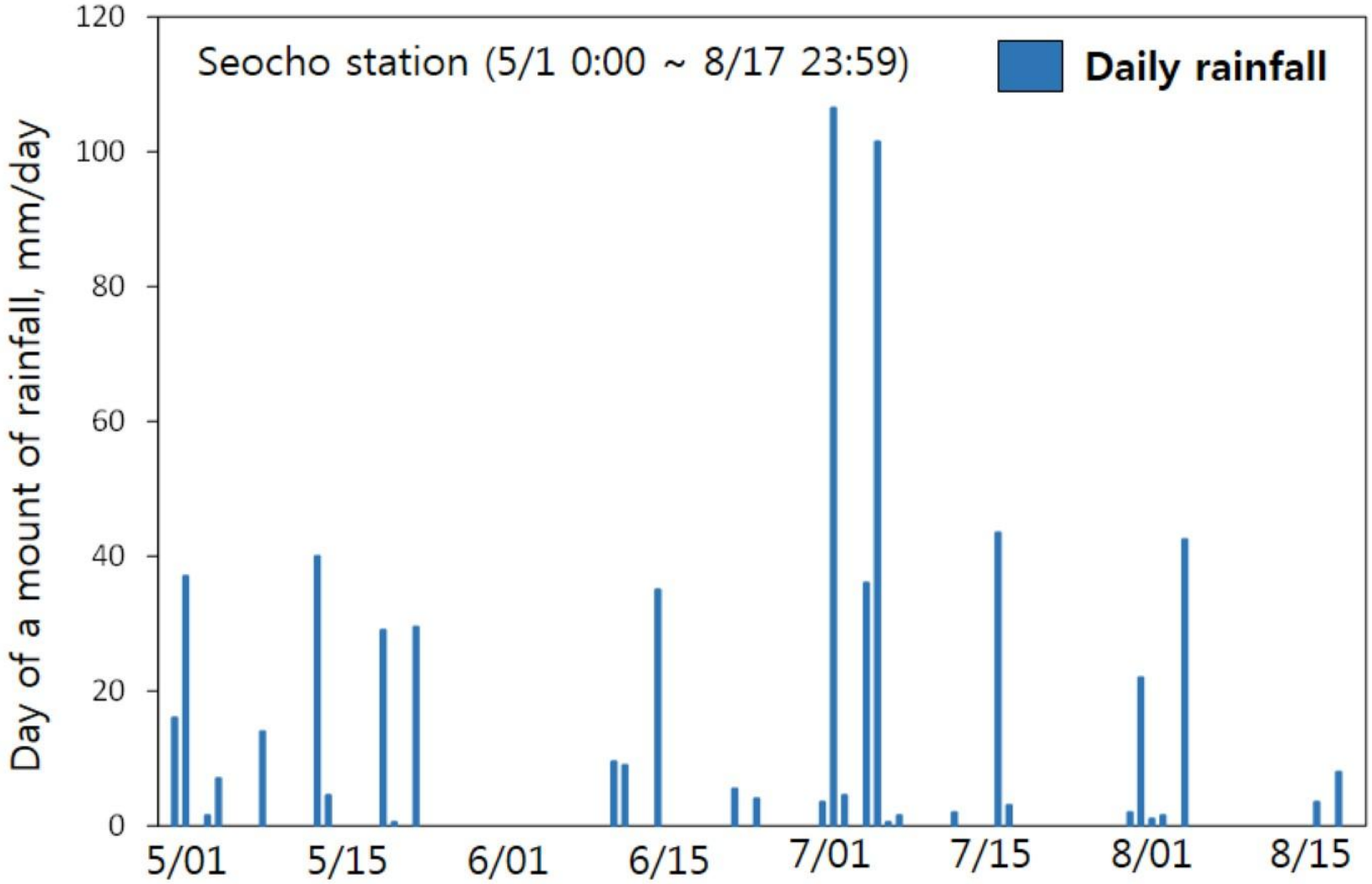
- **Geological characteristics**
  - **Granite , Gneiss**
  - **Coarse grained soil**
- **Slope : 15~40°**
  - **Upward 30~40°**
  - **Downward 10~30°**
- **Soil depth : 4~10m**

③ Mt. Ansan



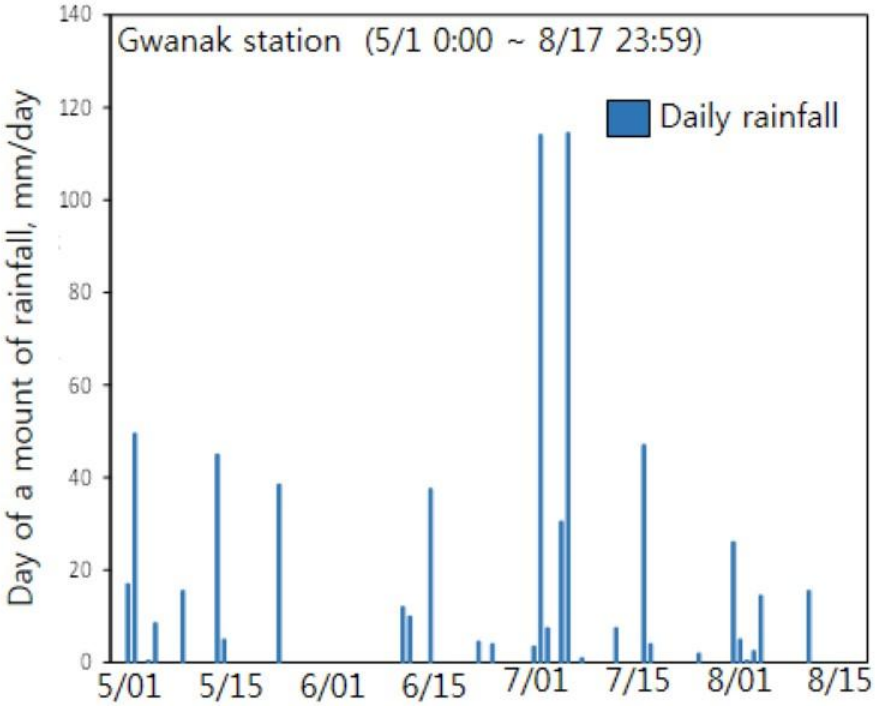
- Geological characteristics
  - Banded biotite gneiss
  - Mixed coarse grained soil and fine grained soil
- Slope : 15~40°
  - Upward 20~40°
  - Downward 10~20°
- Soil depth : 4~8m

3.4 Field measurement (Mt. Guryungsan)

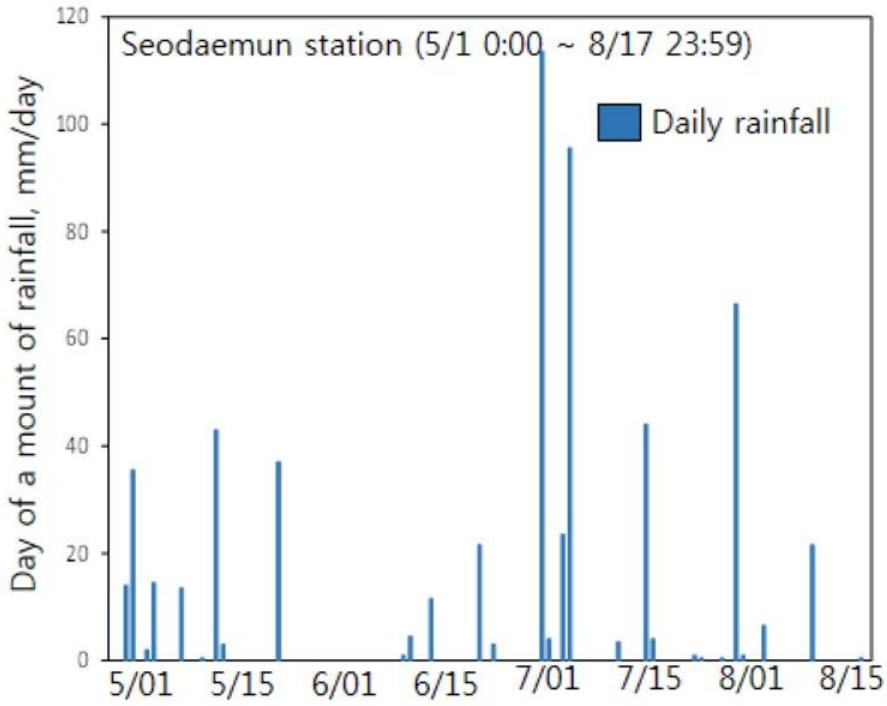


❖Rainfall data (Mt. Gwanaksan, Mt. Ansan)

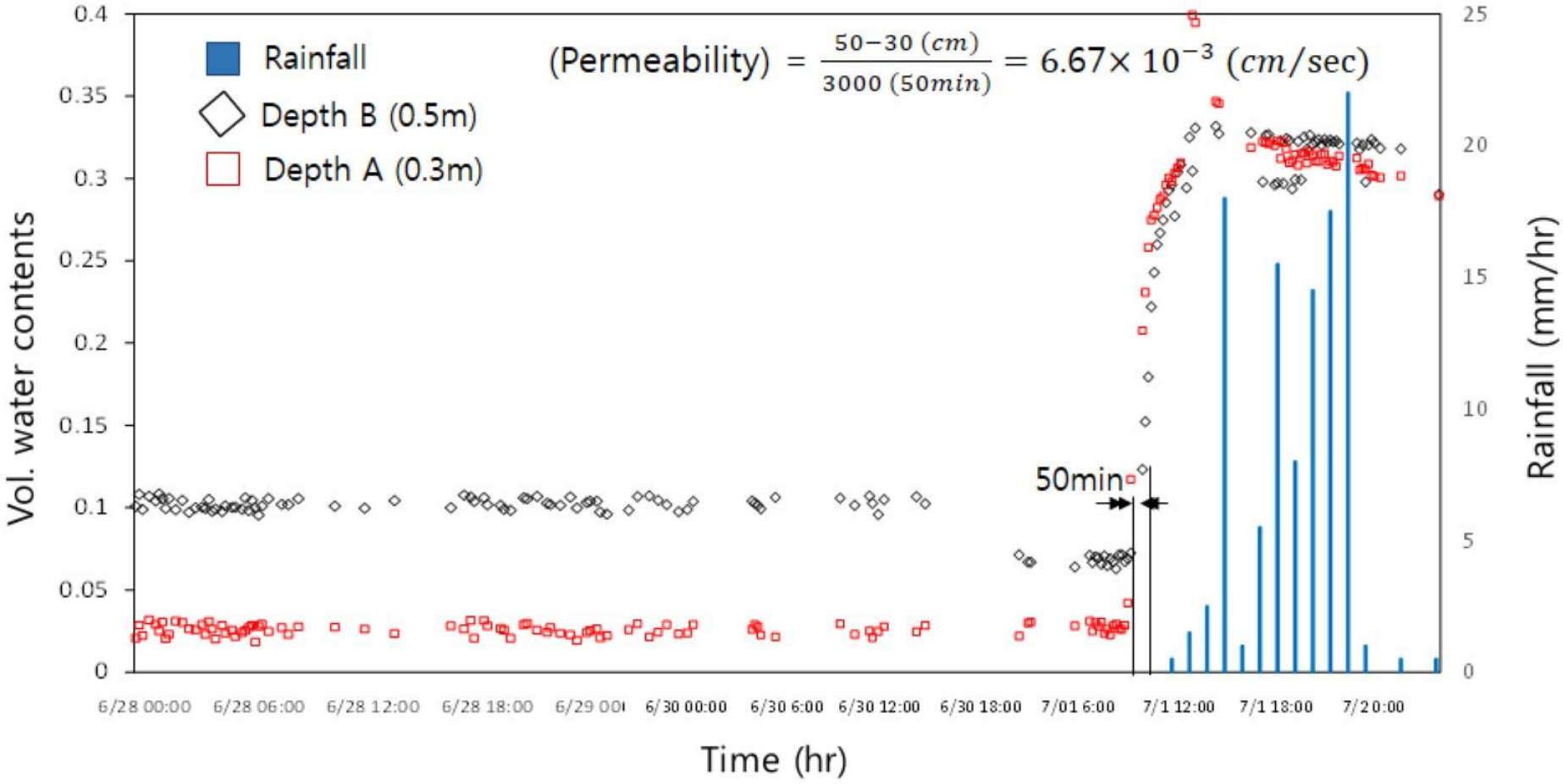
Mt. Gwanaksan



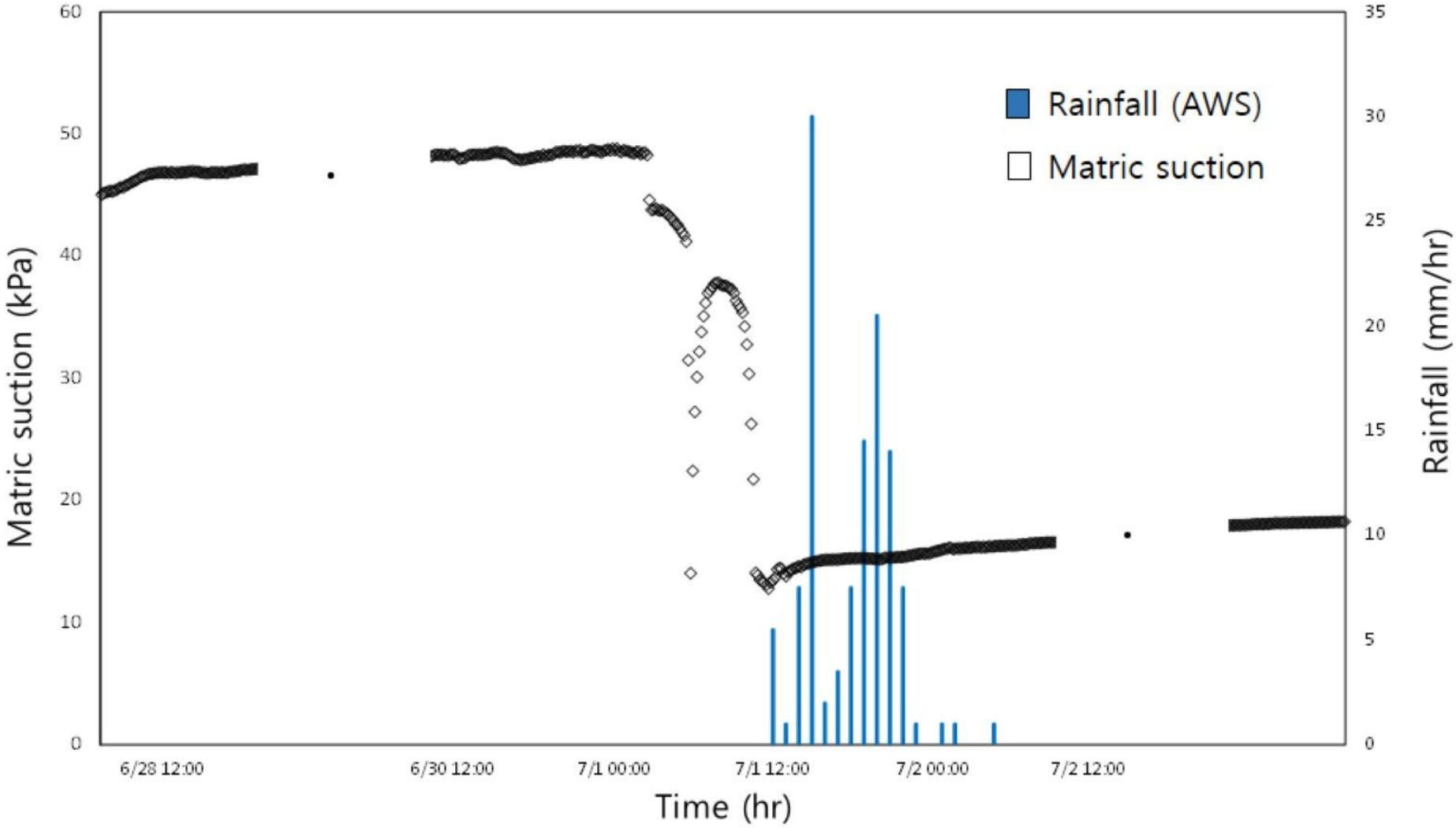
Mt. Ansan



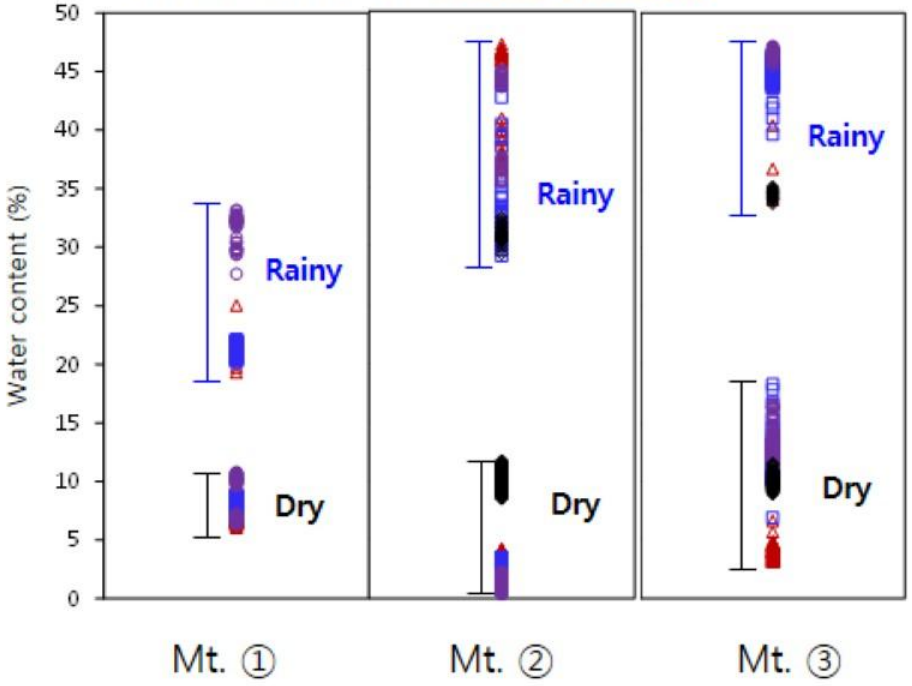
❖Volumetric Water content (Mt. Guryongsan)



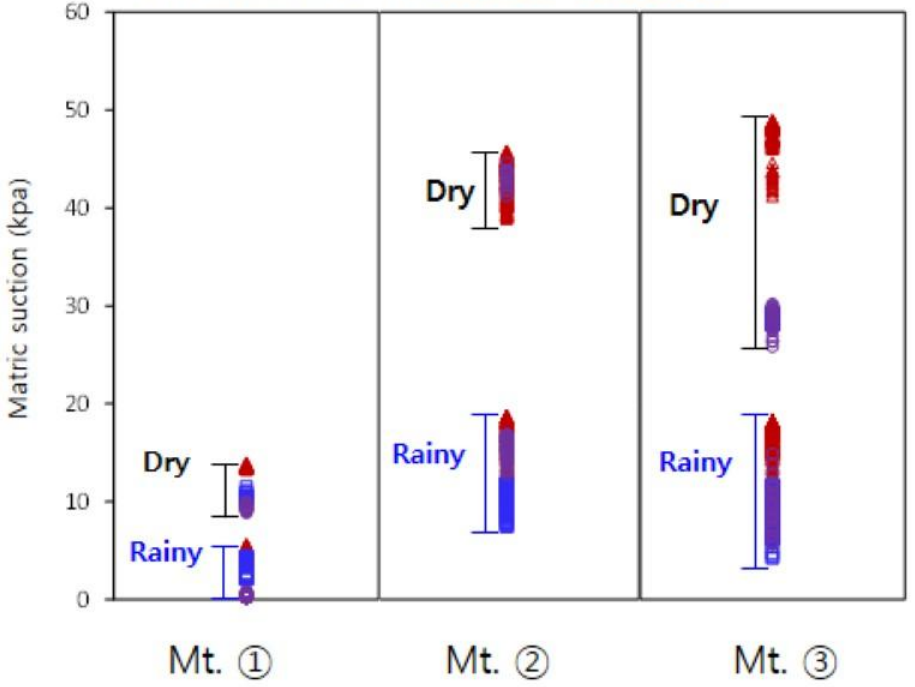
❖Matric Suction (Mt. Ansan)



Distribution of Water Content

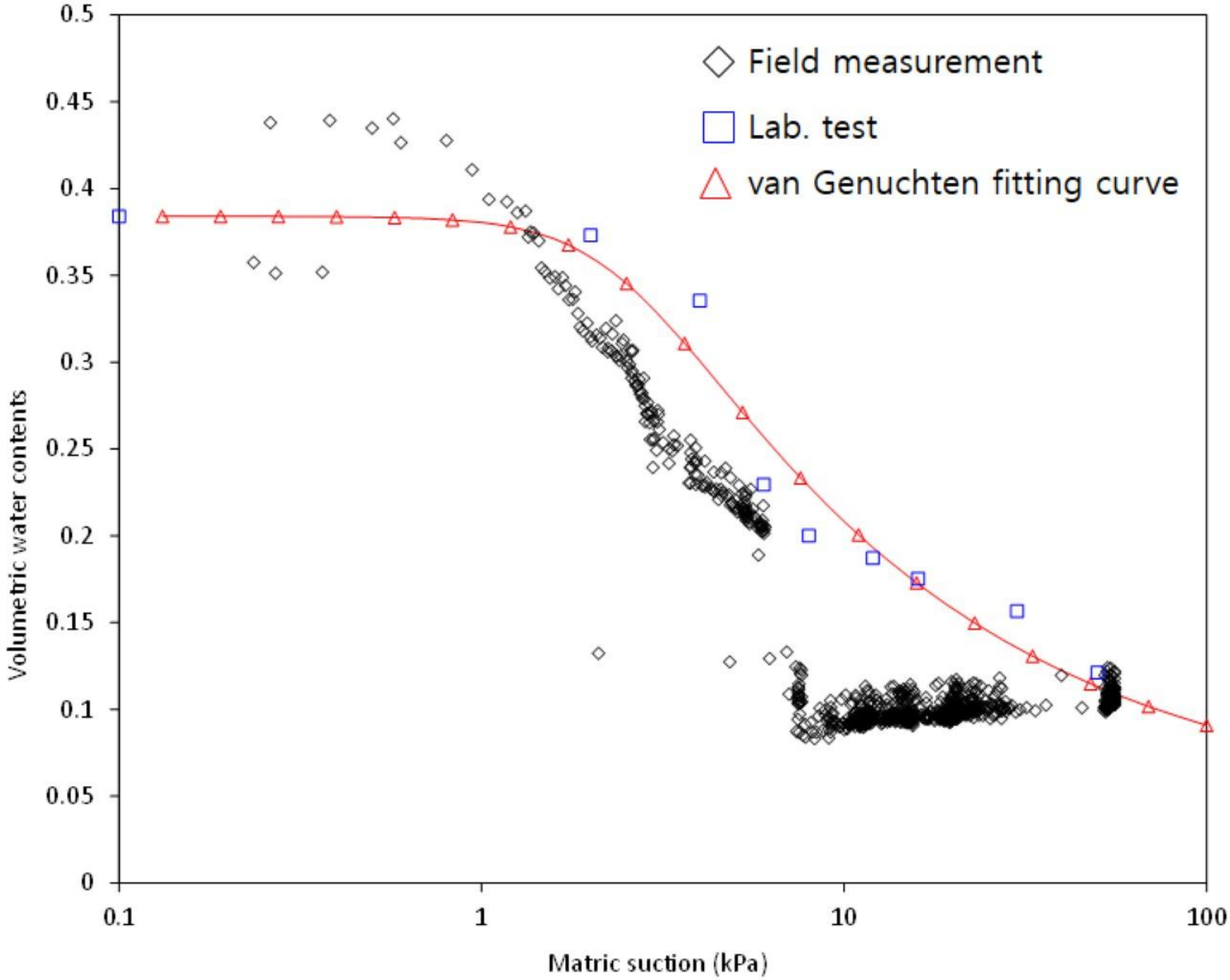


Distribution of Matric Suction



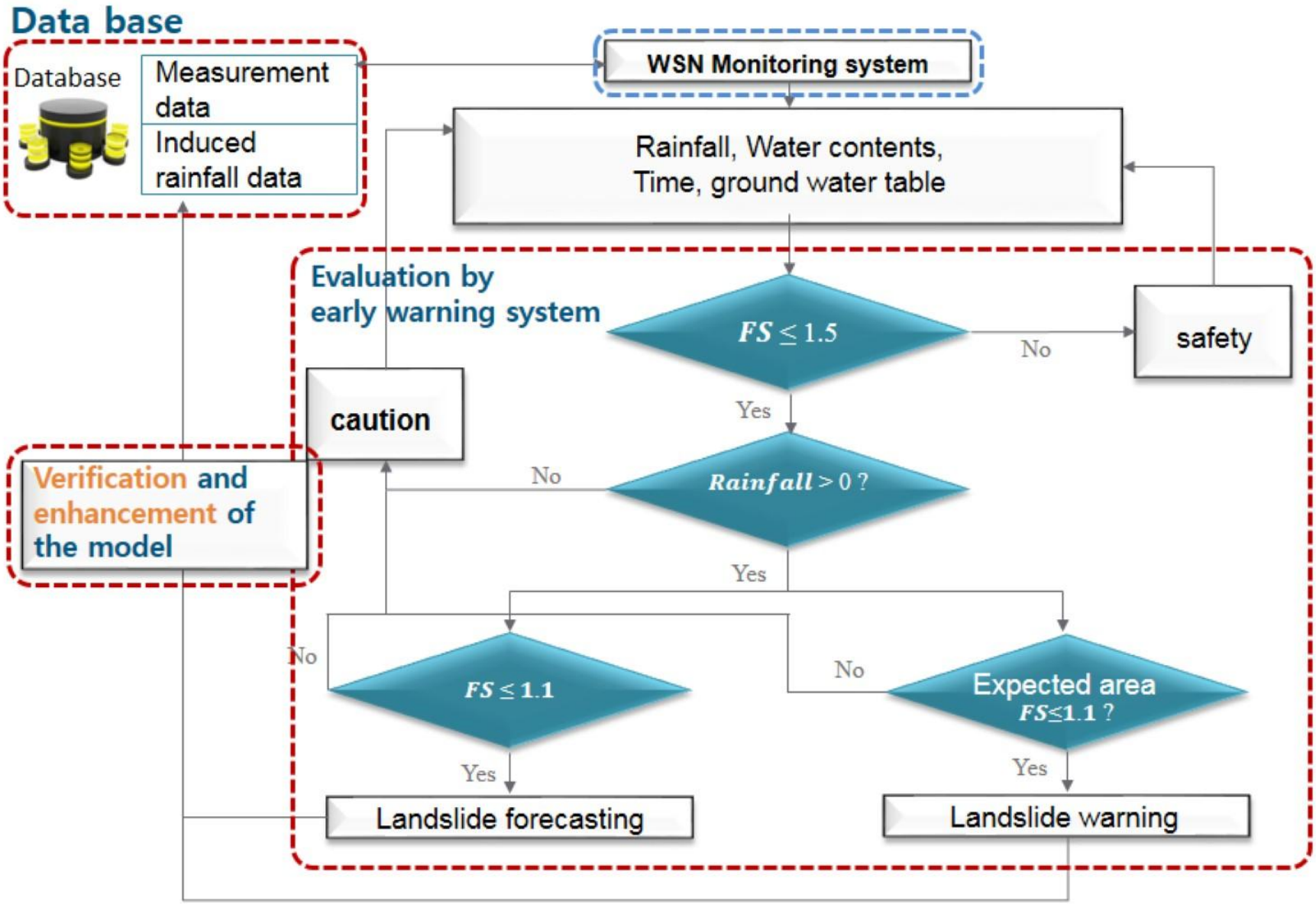
Types	① Mt. Guryongsan		② Mt. Gwanaksan		③ Mt. Ansan	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
Water Content (%)	5 ~ 12	18 ~ 34	2 ~ 12	27 ~ 45	4 ~ 17	35 ~ 45
Matric suction (kPa)	10 ~ 15	0.2 ~ 5	38 ~ 45	7 ~ 18	28 ~ 50	4 ~ 20

❖ Soil water characteristic curve (Mt. Gwanak)



4. I-D curves for bed rock types

4.1 Flow chart

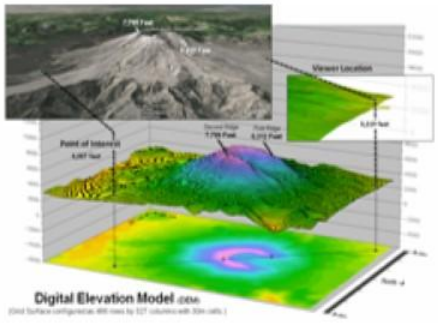


4.2 YS-Slope model

- **Prediction model for rainfall-induced landslide based on 3D spatial data**
- **Real-time web based hazard map (by using real-time rainfall data)**

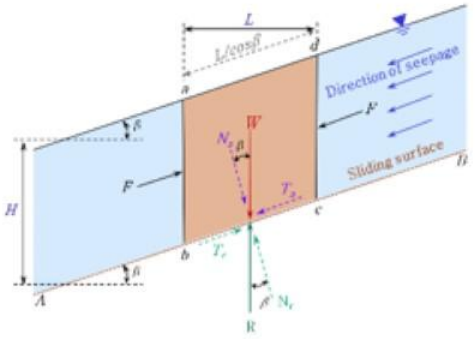
Rainfall data

3D Special Data in Seoul



- Topography: Slope, Slope direction
- Hydrology: Precipitation data
- Spatial data : Soil and forestry

Physical Model



- Geotechnology
- Hydrological model
- GIS

Web-based (or GIS-based) forecasting for landslide

❖ Geotechnical model

✓ **Considering geotechnical characteristics**

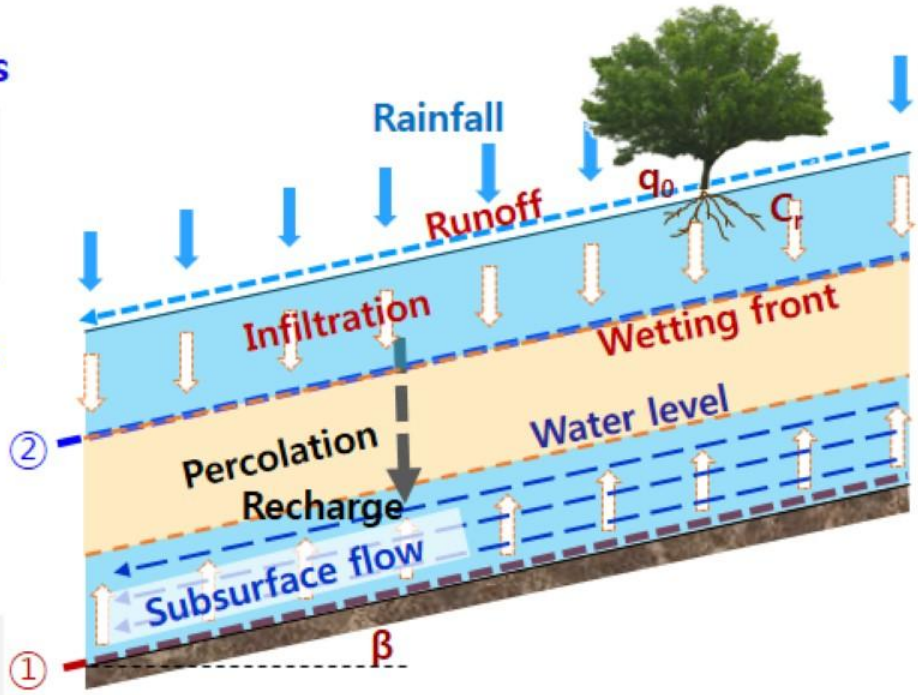
c_s : cohesion of the soil
γ_t : total unit weight of the soil
ϕ' : internal friction angle of soil

✓ **Considering topographic characteristics**

β : angle of the slope

✓ **Considering the effect of vegetation**

q_0 : uniform load from trees
c_r : constant number of additional shear strength from the roots of trees



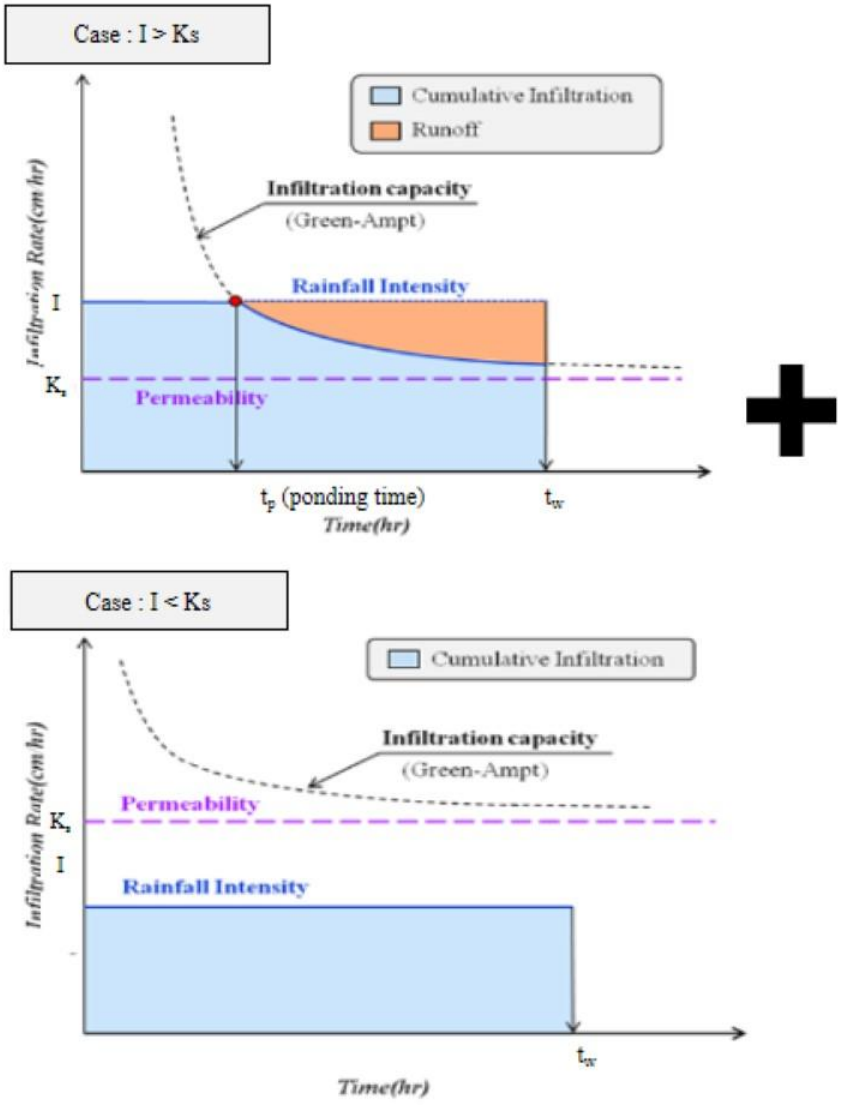
① *Failure on the bedrock*
② *Failure under the wetting front*

$$FS = \frac{(c_s^{'} + c_r^{'}) + (\gamma_t \cdot D_s + q_0 + (\gamma_{sat} - \gamma_w) \cdot D_w) \cdot \cos^2 \beta \cdot \tan \varphi^{'}}{(\gamma_t \cdot D_s + \gamma_{sat} \cdot D_w + q_0) \cdot \sin \beta \cdot \cos \beta}$$

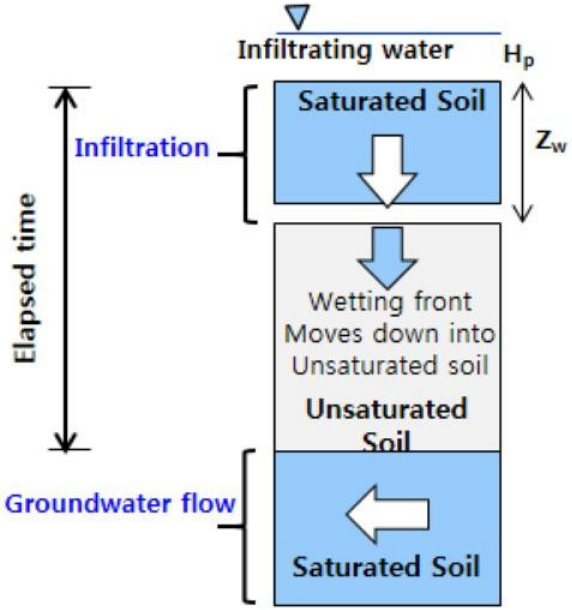
where, $D_w = D_{wm} + D_{wn}$, $D_s = D_{mn}$

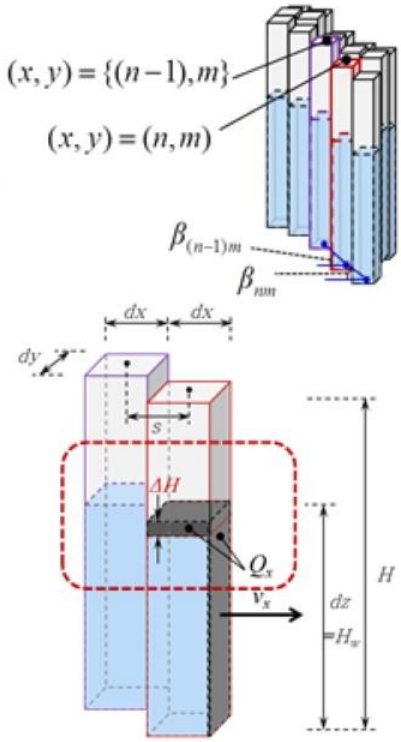
❖ Hydrology model

✓Rainfall infiltration



✓Ground water flow





❖ Comparison of physically-based landslide model

Item	TRIGRS	SINMAP	SLIP	YS-Slope
Hydrological model	*1D infiltration*	*2D groundwater (capacity)*	*1D infiltration*	***1D infiltration 2D-groundwater flow***
Topography	○	○	○	○
Soil strengths	○	○	○	○
Unsaturated soil characteristic	○	×	○	○
Groundwater flow	×	○ ***(time independent)***	×	○
Groundwater condition for slope stability analysis	*Wetting band*	*Groundwater level*	*Groundwater level*	***Wetting band Groundwater level***
Rainfall record	○	×	○	○

(Kim et al., 2014 Engineering geology)

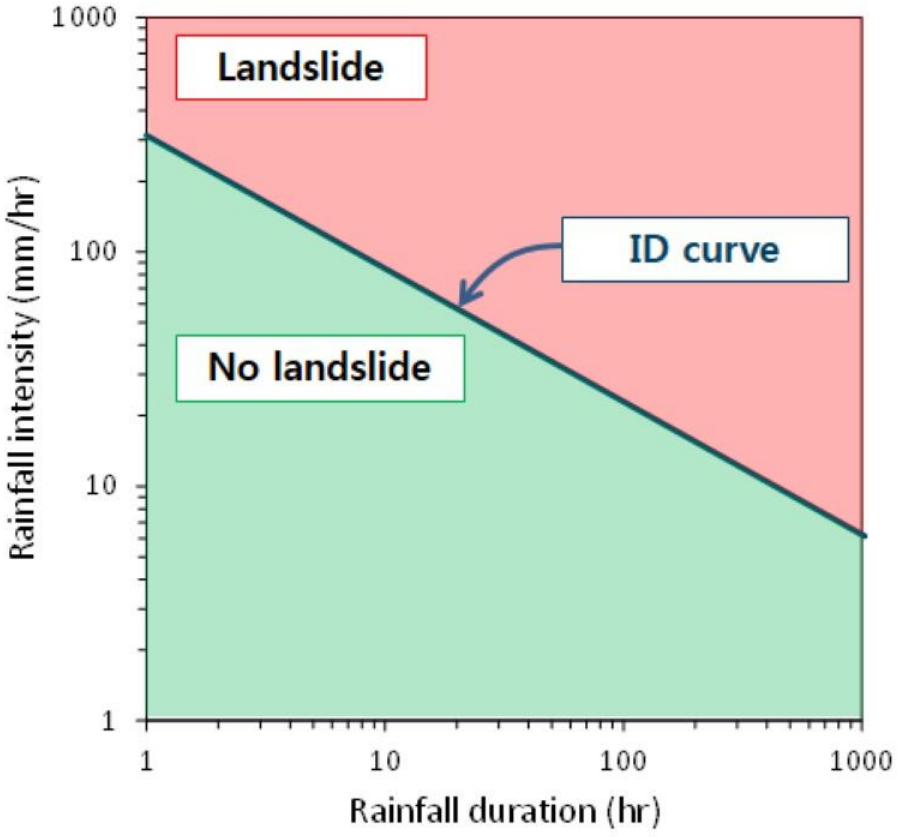
4.3 Suggestion of I-D curve for Rock Types

- **ID curve :** $I = \alpha D^{\beta}$

I : Rainfall intensity

D : Rainfall duration

α, β : coefficient factor



- ✓ Gneiss
- ✓ Granite
- ✓ Biotite banded Gneiss

❖ 2 types of proposed method

1) Landslide simulation (Probability rainfall, IDF)

- **Propose a rainfall-induced landslide criteria and comparison**
- Test bed : **Mt. Guryoungsan, Mt. Gwanaksan, Mt. Ansan**
- Rainfall condition : **Probability rainfall (IDF)**
  - ✓ Frequency : 3, 5, 10, 30, 50, 100 years
  - ✓ Rainfall duration time : 6, 12, 24, 48 hrs

2) Rainfall-induced landslide criteria using statistical estimation method

- **Use rainfall data and landslide occurrence**
- Classify the rock types considering the geological serve

  (Gneiss, Granite, Biotite banded gneiss)

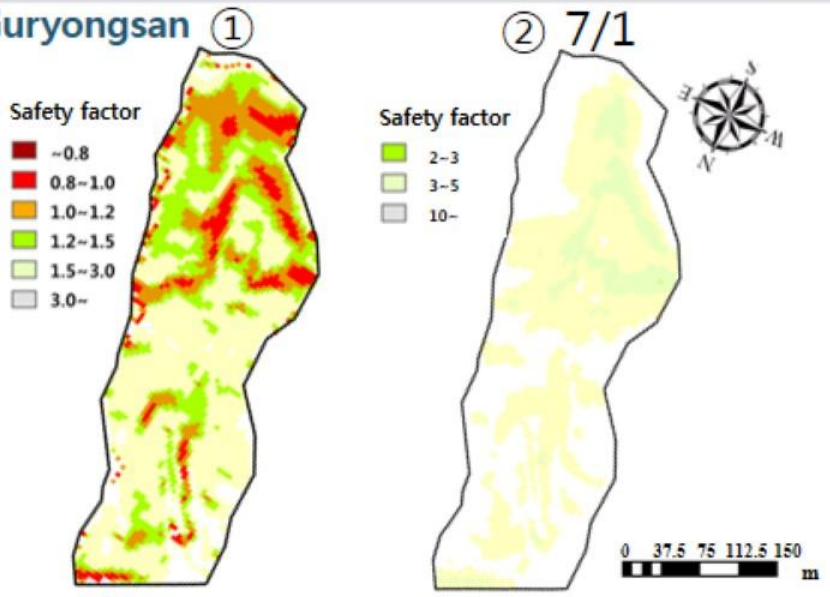
4.4 Landslide analysis

① Probabilistic rainfall : 15.9 mm/hr

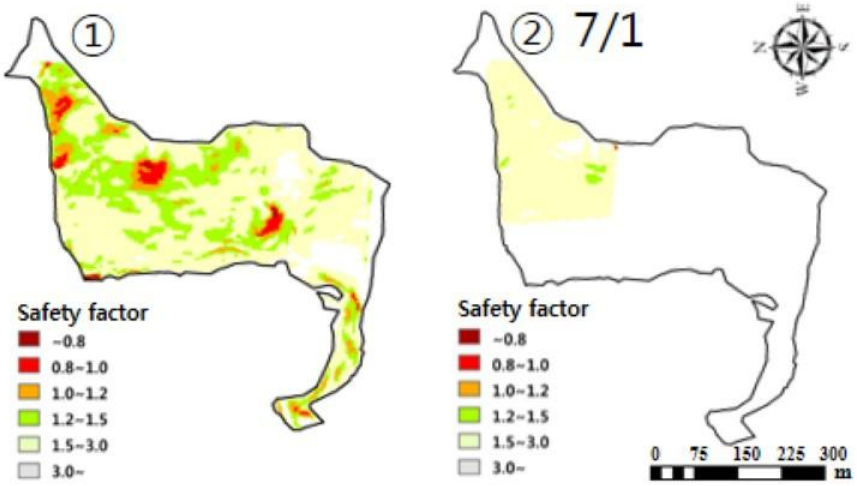
② 24 hours Real-time rainfall (in 2016)

- In 2016 : Landslide Risk ⬇
- 5 mm/hr, maximum of 24-hour average

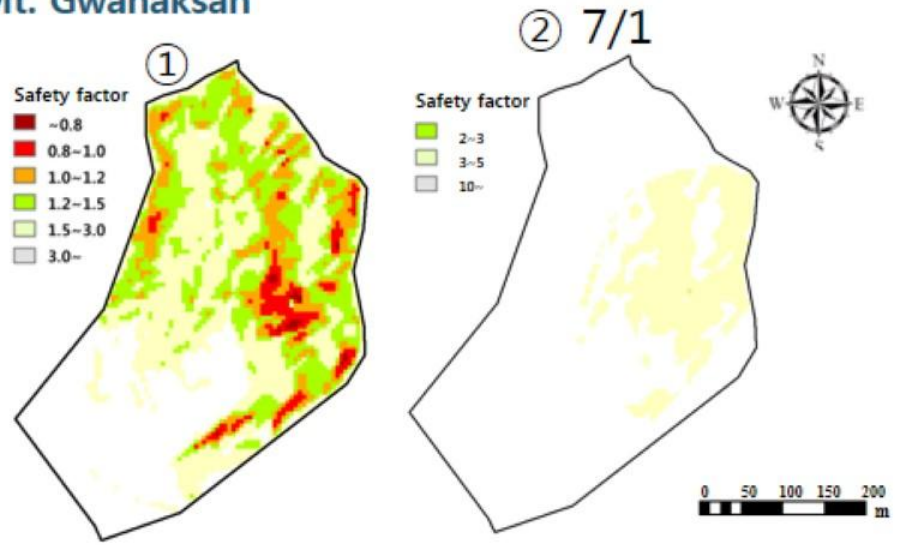
Mt. Guryongsan



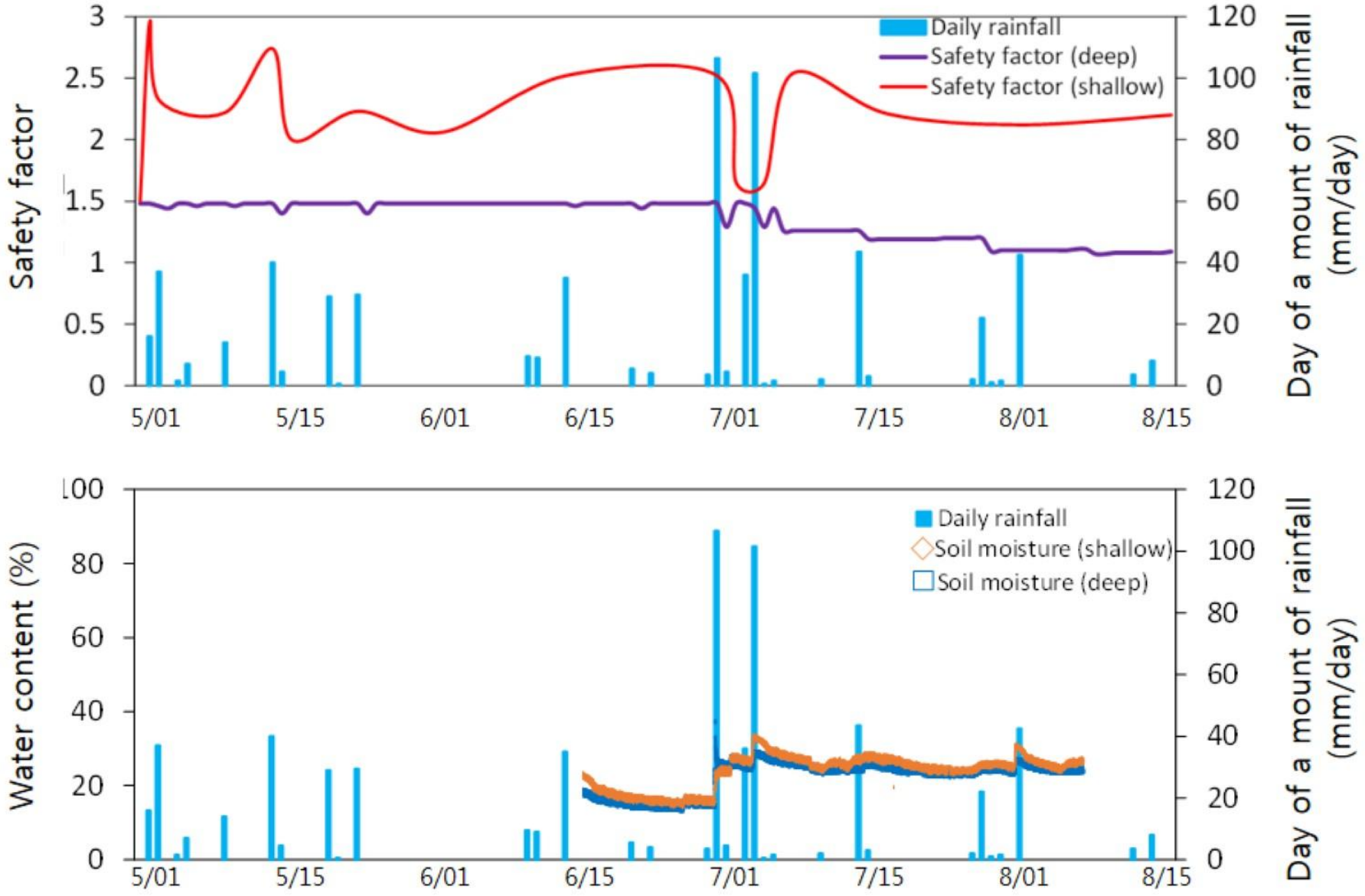
Mt. Ansan



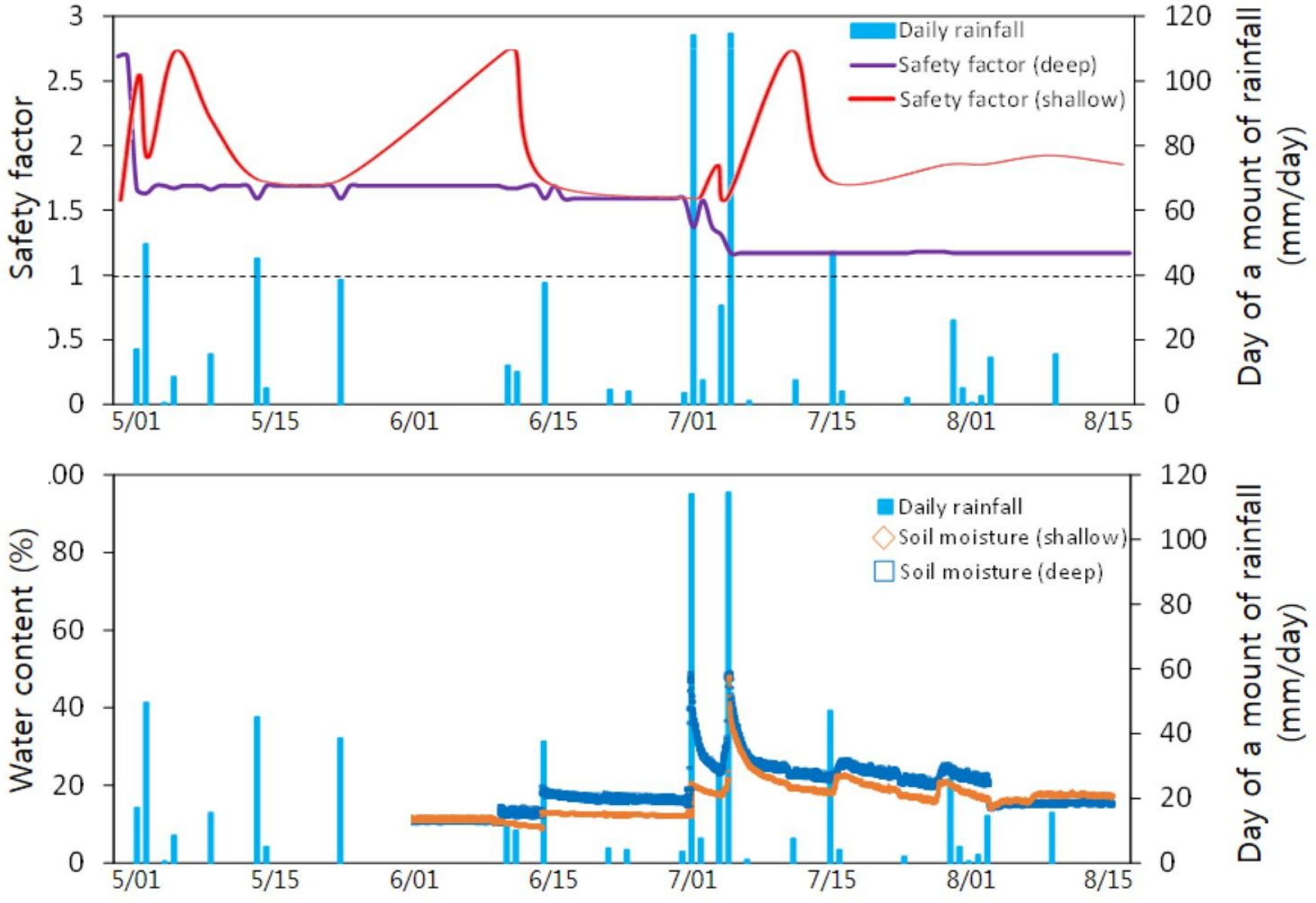
Mt. Gwanaksan



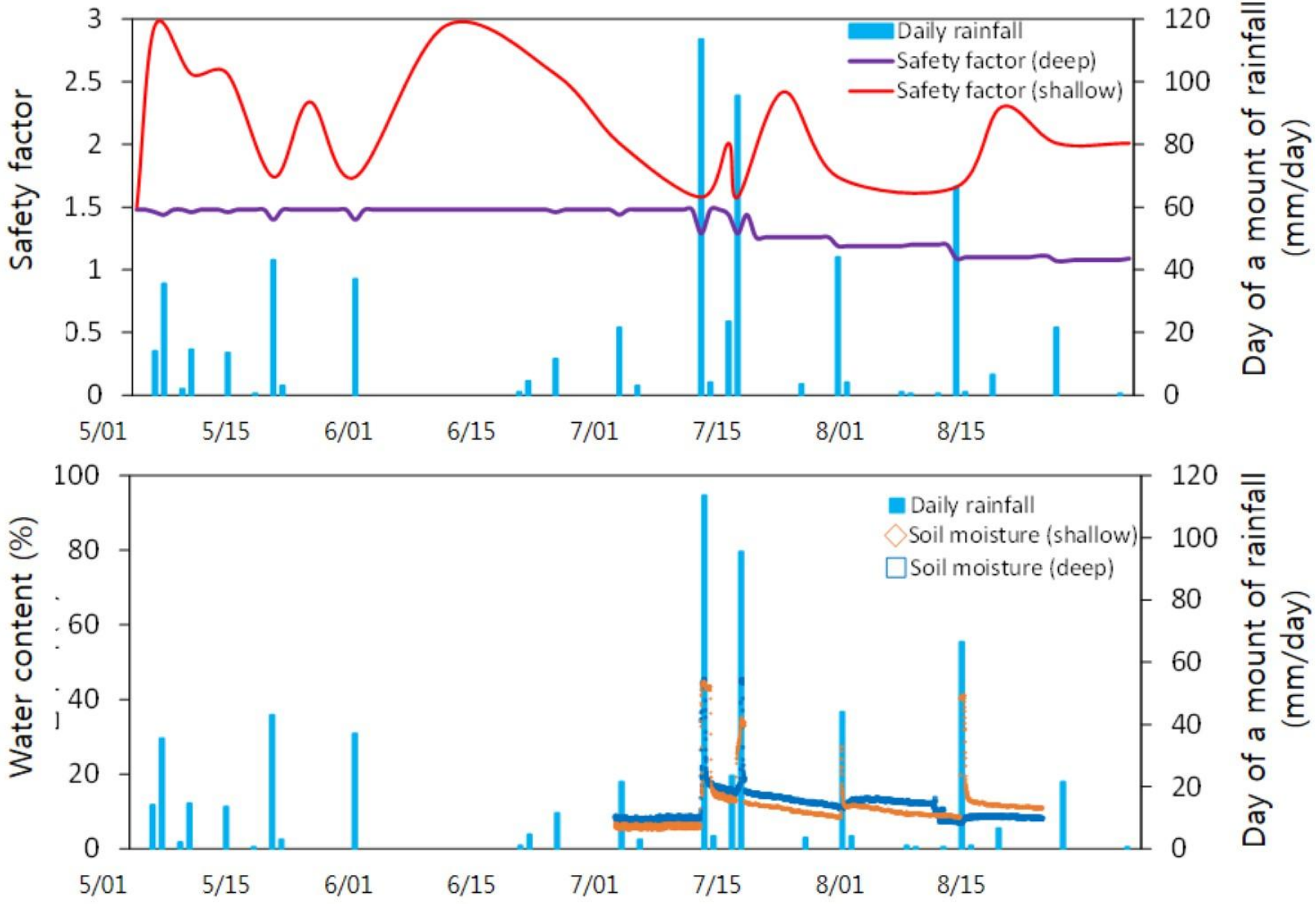
❖ Analysis result & measured data (Mt. Guryungsan)



❖ Analysis result & measured data (Mt. Gwanaksan)

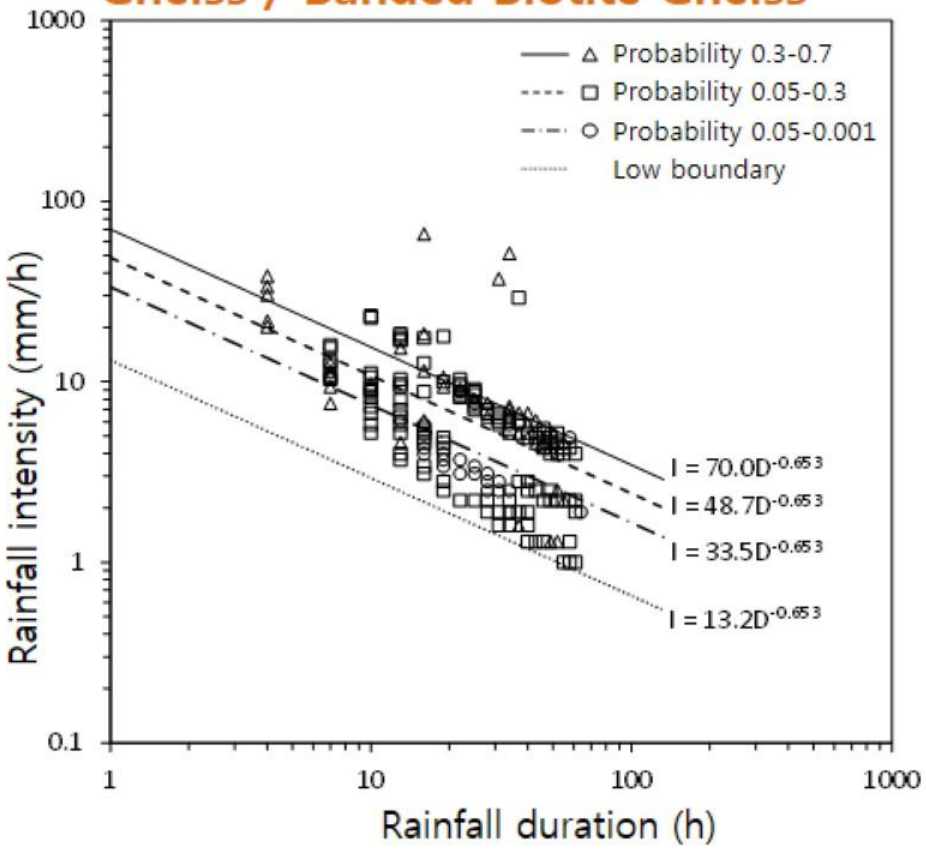


❖ Analysis result & measured data (Mt. Ansan)



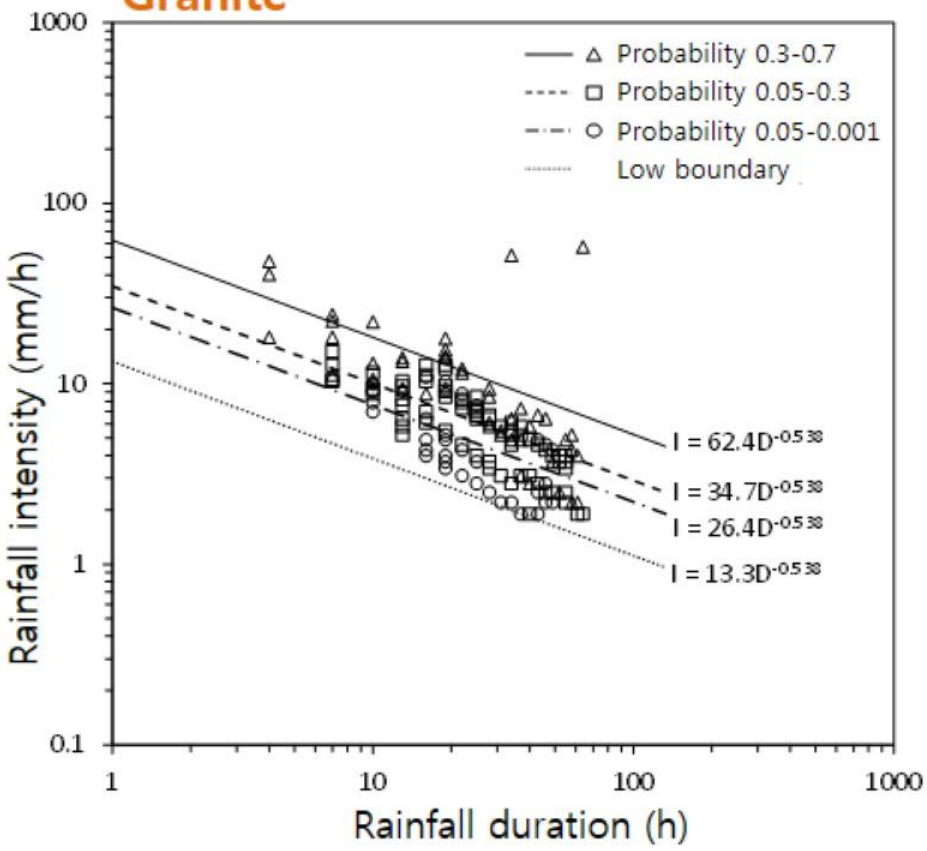
4.5 proposed I-D curves

Gneiss / Banded Biotite Gneiss



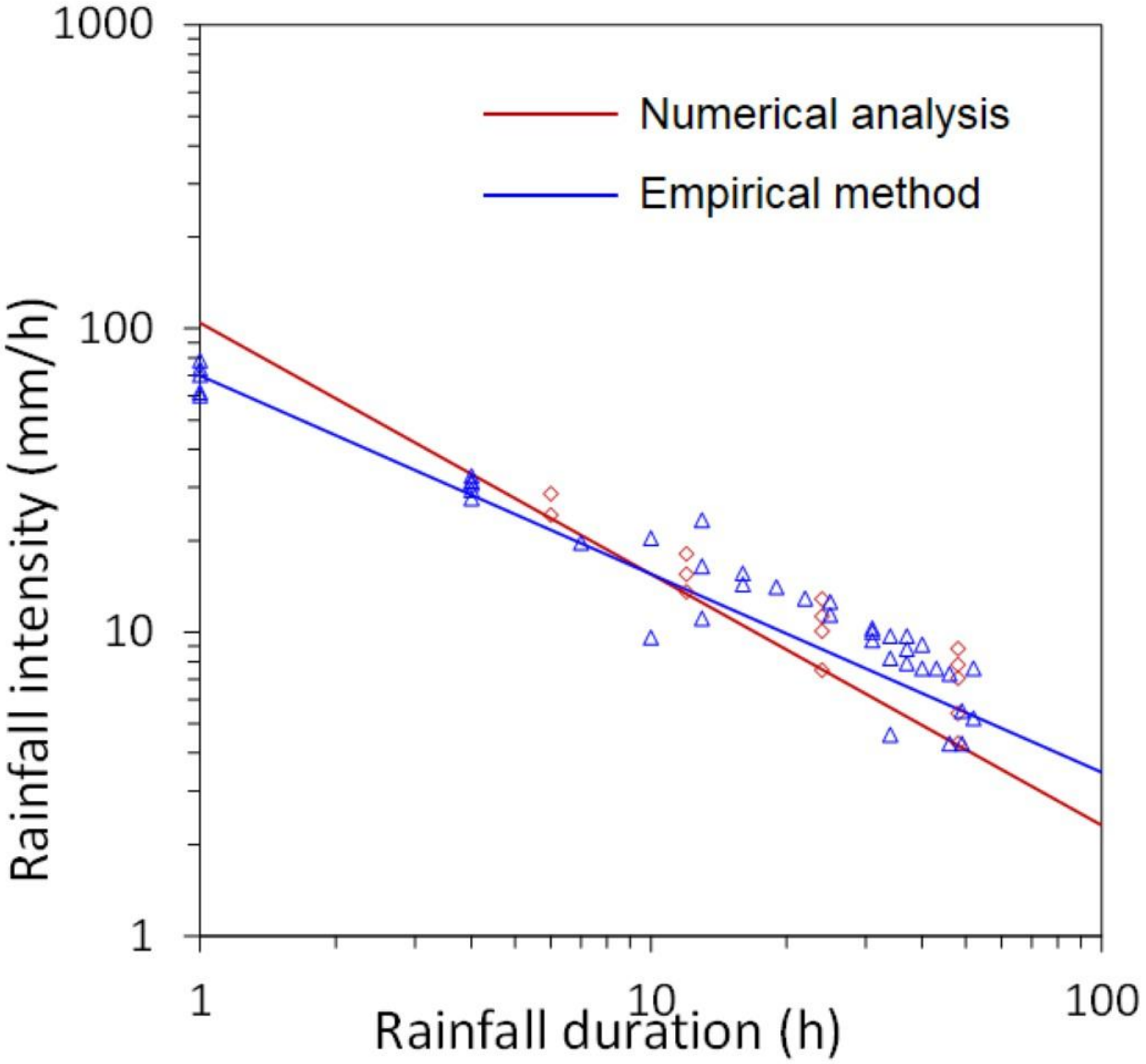
Landslide probability	ID curve	Duration range
Low boundary	$I = 13.2 \times D^{-0.653}$	$1 < D < 133$
0.001–0.05	$I = 33.5 \times D^{-0.653}$	
0.05–0.0.3	$I = 48.7 \times D^{-0.653}$	
0.3–0.7	$I = 70.0 \times D^{-0.653}$	

Granite



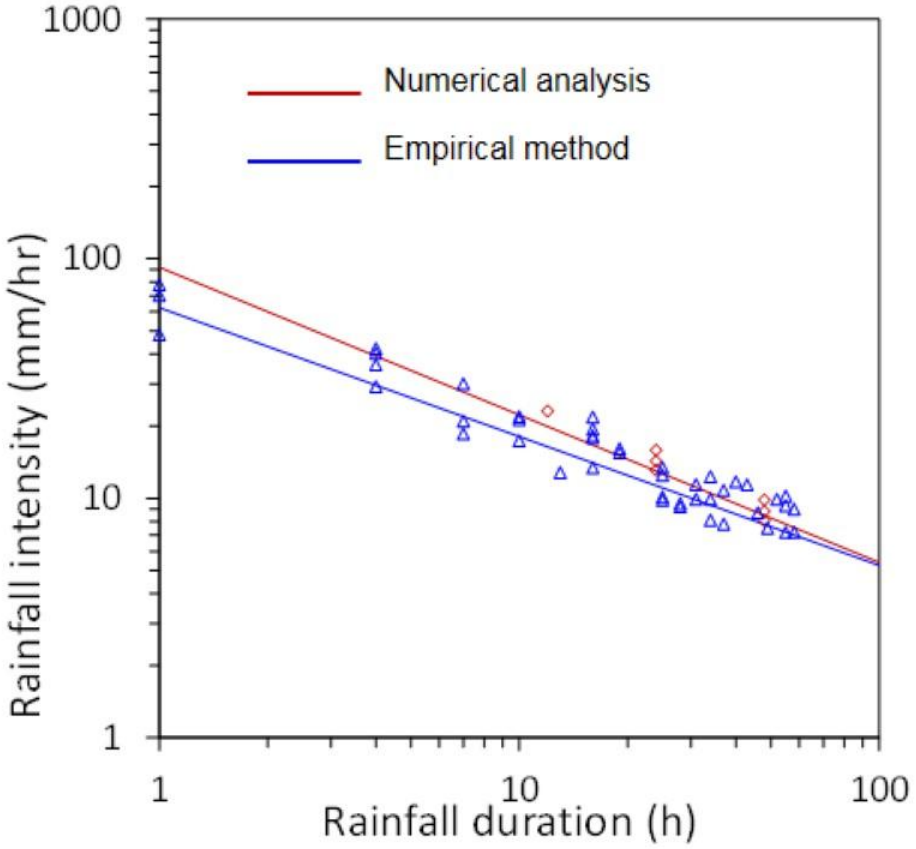
Landslide probability	ID curve	Duration range
Low boundary	$I = 13.3 \times D^{-0.538}$	$1 < D < 133$
0.001–0.05	$I = 26.4 \times D^{-0.538}$	
0.05–0.0.3	$I = 34.7 \times D^{-0.538}$	
0.3–0.7	$I = 62.4 \times D^{-0.538}$	

❖Comparison of I-D curves (Mt. Guryongsan)

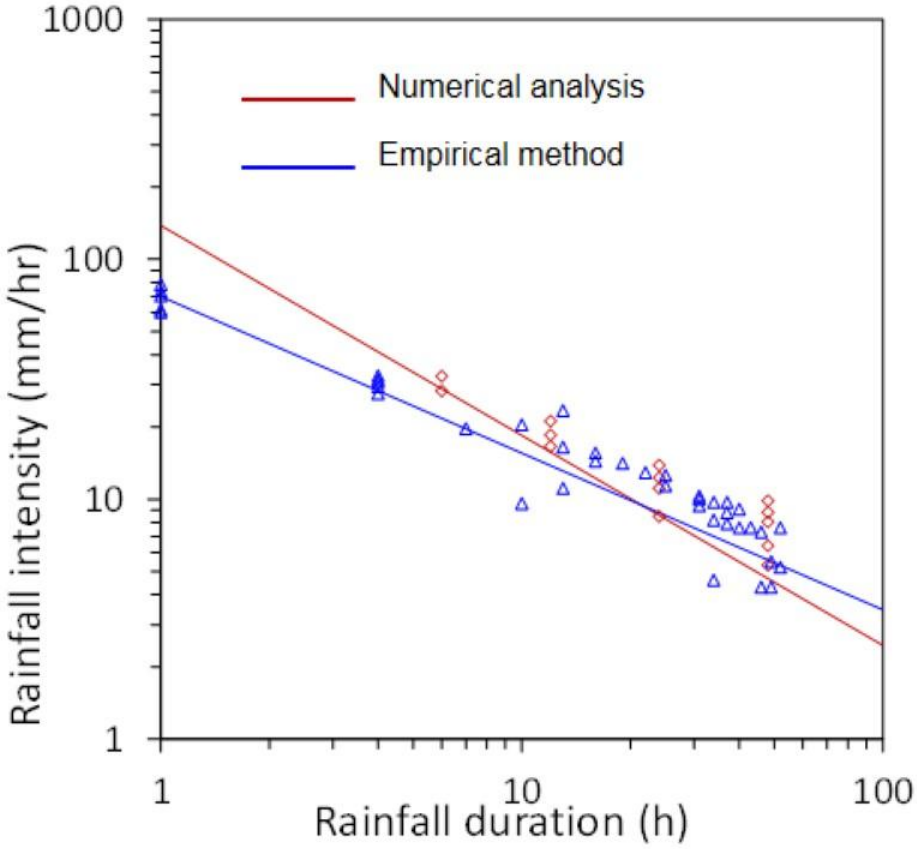


❖Comparison of I-D curves (Mt. Gwanaksan, Mt. Ansan)

Mt. Gwanaksan (Granite)



Mt. Ansan (Banded biotite gneiss)



5. Conclusion

Conclusion

1) A **real-time landslides monitoring** that can be applied to a watershed mountain area was developed by **using a wireless sensor network (WSN)**.

2) **Three test beds** (based on bed-rocks : Gneiss, Banded biotite gneiss, Granite) were **selected and operated** to verify the system.

Conclusion

3) In order to **predict extreme conditions and time of collapse**, **numerical analysis (YS-slope)** which verified through measured data was performed **to confirm the collapse point**.

4) The **I-D curve is proposed** that can cause landslide by analyzing the measurement data and analysis results.