International Workshop on Landslide Risk Assessment and Management

# Climate Change and Potential Impacts on Landslides

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# Outline

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- Quantification of Climate Change
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# Introduction

## Landslides …

- Occur when masses of rock, earth or debris move down a slope
- Mudslides develop when water rapidly accumulates in the ground. Usually starts on steep slopes and can be activated by natural disasters
- Areas where vegetation is destroyed due to human activity or by wildfires, especially on slopes, are particularly vulnerable during and after heavy rain
- Rapidly moving water and debris can lead to trauma; broken electrical, water, gas and sewage lines that can result injury or illness

# Introduction (Cont...)

## Facts and Figures: 2015 Asia-Pacific losses by disaster type

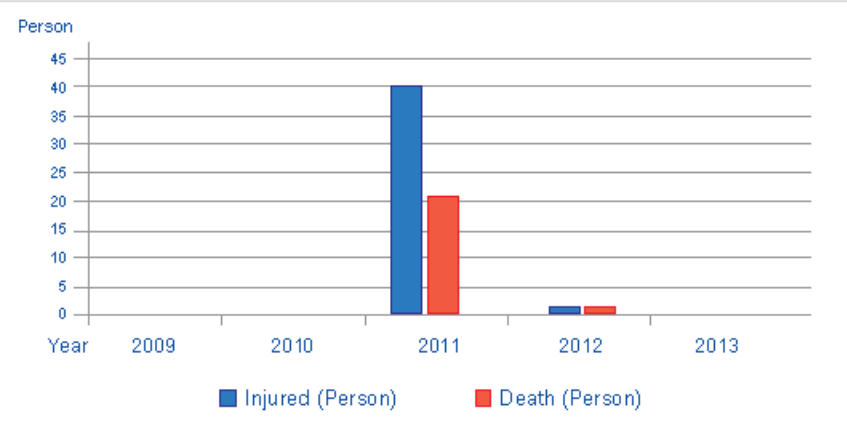
| Disaster Type | Occurrence | Deaths | Affected | Economic Damage (billion US$) |
|---|---|---|---|---|
| Flood | 63 | 1863 | 21,661,443 | 11.5 |
| Storm | 43 | 446 | 9,135,551 | 11.8 |
| Earthquake | 17 | 9327 | 6,484,533 | 5.2 |
| Landslide | 15 | 626 | 45,234 | - |
| Extreme temperature | 4 | 3536 | 1,045,000 | - |
| Others | 18 | 248 | 20,883,788 | 16.7 |
| Total | 160 | 16046 | 59,255,549 | 45.1 |

Source: Disasters in Asia and the Pacific: 2015 year in Review, UNESCAP

- Landslides are 7$^{th}$ ranked killer; Asia suffered 220 landslides in the past century
- North, Central and South America have caused the most deaths and injuries (25,000+)
- Europe landslides are the most expensive ($ 23 million / landslide)

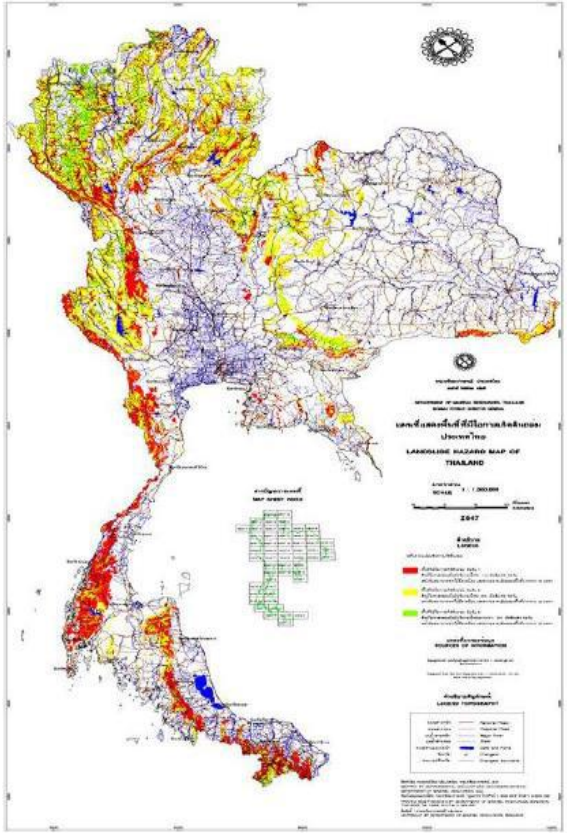
# Introduction (Cont...)

- Thailand has experienced an increasing occurrence and intensity of landslides due to:
  - anthropogenic activities like deforestation, cultivation of cash crops in sloping area, destruction of land's surface etc.




Impacts of landslides in Thailand (2009 -2013)

## Landslides in Thailand




Landslide Hazard Map

Source: National Disaster Risk Management Plan (2015)

# Introduction (Cont...)

## Common Causes…

| Natural Factors | Anthropogenic Factors |
|---|---|
| • **Gravity:** Works more effectively on the steeper slopes<br>• **Earthquakes:** Areas with steep slopes, the soil and rock slips<br>• **Geological factors:** Geologically weak areas with permeable sands and gravels above bedrocks<br>• **Heavy rainfall:** Storm water runoffs results in the rise of the groundwater level, making some slopes unstable and slides occur<br>• **Forest fires:** Cause soil erosion and induce floods<br>• **Volcanoes:** Stratovolcanoes, prone to sudden collapse in wet conditions | • Deforestation, improper land use practices in agriculture and irregular settlement patterns<br>• In-appropriate drainage system increases the vulnerability<br>• Deep excavations on slopes for building, roads, canals and mining makes critical slopes vulnerable |

Areas at risk

- Channels along a stream or a river
- Areas, Where landslides have occurred before
- Steep slopes and the areas at the bottom of the canyons
- Areas where vegetation has been destroyed
- Areas where surface runoff is directed
- Slopes that have been modified or altered for construction purposes
- Areas with improper drainage system

# Climate Change and landslide

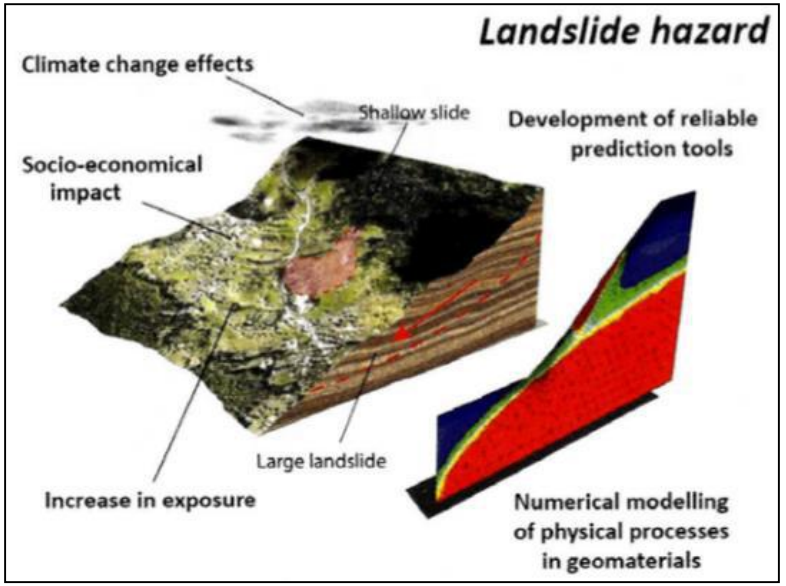
## Climate Variables…

- **Precipitation:**

  Increase in annual rainfall totals for stormy events and their intensities appear to be increasing. Precipitation falling on higher altitudes can cause increase of shallow landslides in steep mountainous slopes

- **Temperature:**

  Glacial retreat and the melting of permafrost will cause more landslides, debris flows, and rock falls




Climate Change and increased human activities in landslide prone areas will increase the risk of landslides

Source: Laloui et al., 2010 | Effect of Climate Change on Landslide Behaviour

# Climate Change and Landslide (Cont...)

## Climate Change and Pathways to Impacts

| Climate Change | Condition/Process affected | Potential slope stability response |
|---|---|---|
| Increase in precipitation totals | Wetter antecedent conditions | • Less rainfall required to reach the critical water content<br>• Reduction in soil capillary suction, softened layers can act as lubricants<br>• Higher water tables – reduction in shear strength |
| | Increased weight | • Increased bulk density, leading to decrease in shear strength/stress ration in cohesive material |
| | Higher water tables for longer periods | • More frequent attainment of critical water content during rainfall events |
| | Increased lubrication of contact surfaces between minerals | • Reduction on friction |
| | Increase in river discharge | • Increase bank scour and removal of lateral and basal support from slopes<br>• Higher lake levels increase in bordering slope water tables |

Source: Crozier (2010) | Deciphering the effect of climate change on landslide activity: A review

# Climate Change and Landslide (Cont...)

## Climate Change and Pathways to Impacts

| Climate Change | Condition/Process affected | Potential slope stability response |
|---|---|---|
| Increase in rainfall intensity | Infiltration more likely to exceed subsurface drainage rates | • Landslide triggering by reduction in effective normal stress leading to reduction in shear strength |
| | Rapid build up of perched water tables | • Increase in cleft water pressure |
| | Increased through flow | • Increase in seepage and drag forces, particle detachment and piping. Enhances drainage unless blockage occurs. |
| Shift in cyclone tracks and other rain bearing weather systems | Areas previously unaffected, subject to high rainfall | • Rapid adjustment of slopes to new climate regime |
| Increased variability in precipitation and temperature | More frequent wetting and drying cycles | • Increase fissuring, widening of joint systems<br>• Reduction in cohesion and rock mass joint friction |

Source: Crozier (2010) | Deciphering the effect of climate change on landslide activity: A review

# Climate Change and Landslide (Cont...)

## Climate Change and Pathways to Impacts

| Climate Change | Condition/Process affected | Potential slope stability response |
|---|---|---|
| Increase temperature | Reduction in antecedent water conditions through evapotranspiration | • Lower antecedent water status - more rain required to trigger slides |
| | Reduction in interstitial ice and permafrost | • Reduction in cohesion in jointed rock masses, debris and soil |
| | Rapid snow melt- runoff and infiltration | • Build up of porewater pressure and strength reduction |
| | Reduction in glacier volume | • Removal of lateral support to valley slide slopes |
| | Increased sea level | • Enhanced basal erosion on coasts, increase in groundwater levels on coastal slopes |
| Increased wind speed and duration | Enhanced evapotranspiration | • Reduction of soil moisture<br>• Enhanced drying and cracking |
| | Enhanced root levering by trees | • Loosening and dislodging joint blocks |
| | Increased wave action on shorelines | • Removal of slope lateral support |

Source: Crozier (2010) | Deciphering the effect of climate change on landslide activity: A review

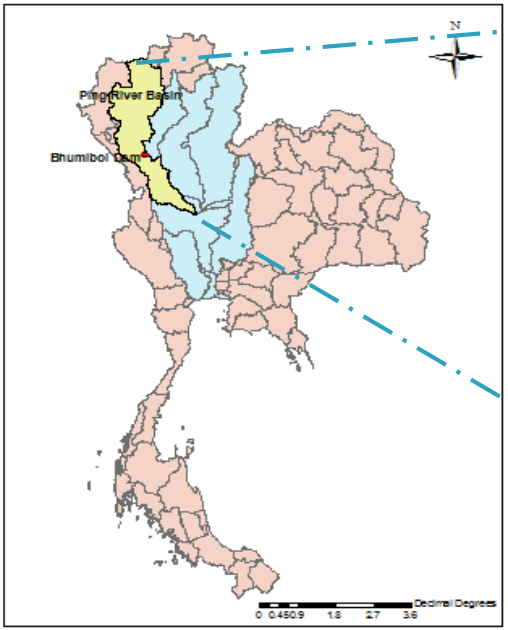
# Quantification of Climate Change

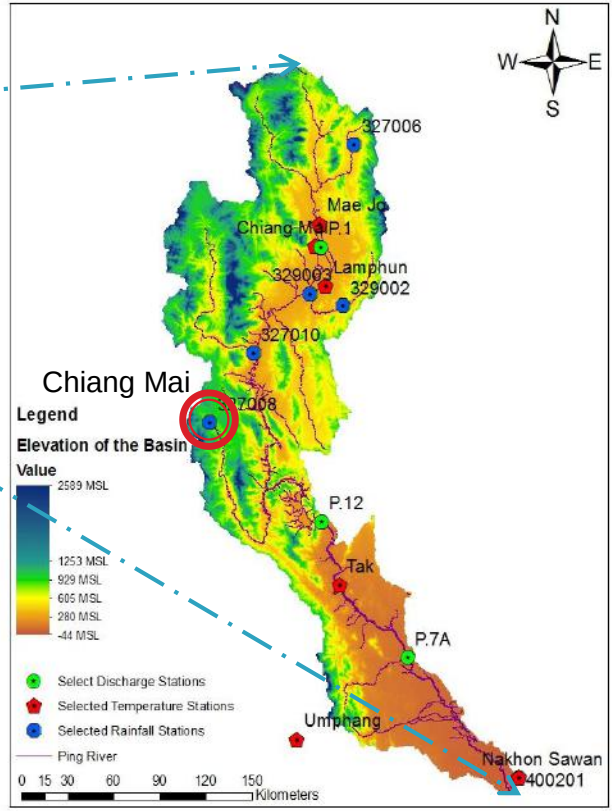
- Change in climate: quantified using climate trends and variability in the climate indices

| Climate Change | Index | Definition | Unit |
|---|---|---|---|
| Precipitation totals | PRCPTOT | Annual total precipitation in wet days (RR> = 1mm) | mm |
| | R99p | Annual total precipitation when RR>99$^{th}$ percentile in baseline | mm |
| | R95p | Annual total precipitation when RR>95$^{th}$ percentile in baseline | mm |
| | Rx1 day | Monthly maximum 1-day precipitation | mm |
| | Rx5 day | Monthly maximum consecutive 5-day precipitation | mm |
| | R40mm | Annual count of days when precipitation >= 40 mm | days |
| Rainfall intensity | SDII | Annual total precipitation/ number of wet days | mm/day |
| Variability in precipitation and temperature | CDD | Maximum number of consecutive days with RR<1mm | days |
| | $R_{cv}$ or $T_{cv}$ | Coefficient of variance | % |
| Temperature | TXx | Monthly maximum value of daily maximum temp | $^{o}$C |
| | TNn | Monthly minimum value of daily minimum temp | $^{o}$C |

# Case study:
# Analysis of changes in climate indices in Ping River Basin, Thailand

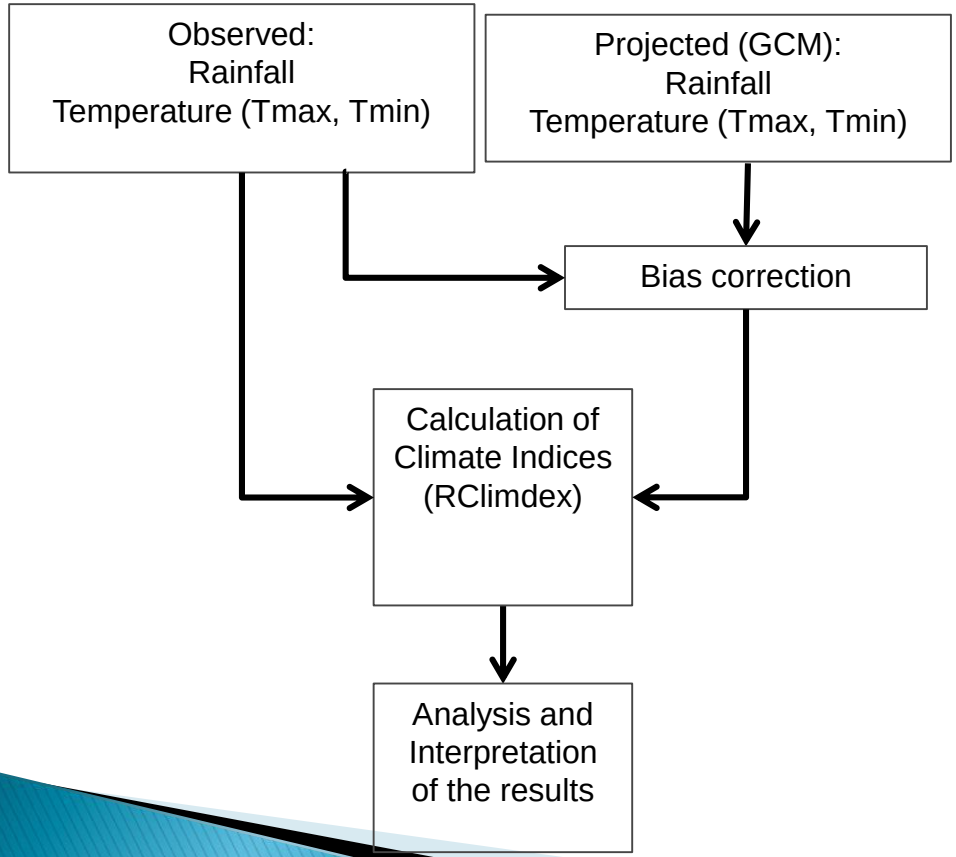
# Study Area – Ping River Basin




- Area : 35,000 km$^2$
- Annual Average Rainfall : 1079 mm
- Annual Average Temp. : 26.3 $^oC$
- Mainly affected by Monsoon
- Agro-based Economy
- Elevation Range ~ 44m - 2500m
- Series of landslide activities are reported in the upper part of the basin
- In May 2006, north of Thailand, including Uttaradit, Sukhothai, Phrae, Lampang and Nan were subjected to serious flash flooding and deadly landslides: 87 deaths

# Methodology




- **Time Windows:**
  Historical 1: 1959 – 1988
  Historical 2: 1983 – 2012
  Future : 2016 – 2045

- **Climate Projections (GCM):**
  CISRO Mk3.6 (suitable for Ping river)

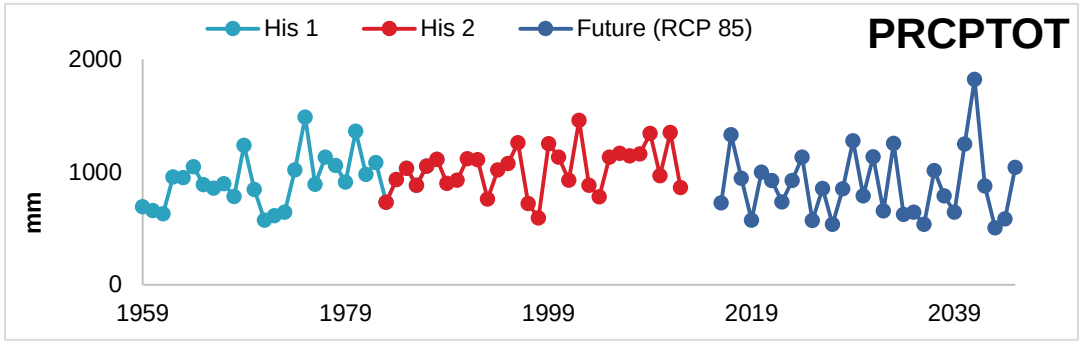
- **Future Pathway:**
  RCP 8.5 scenario (extreme)

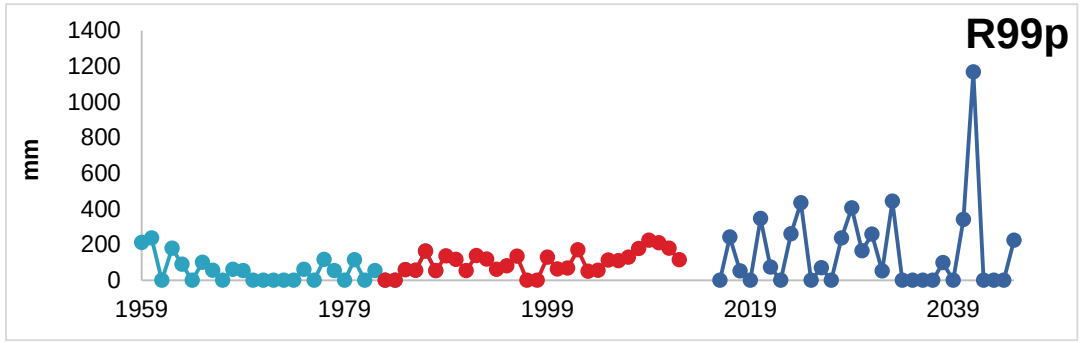
- **9 rainfall related climate indices are analyzed**

# Hypothesis

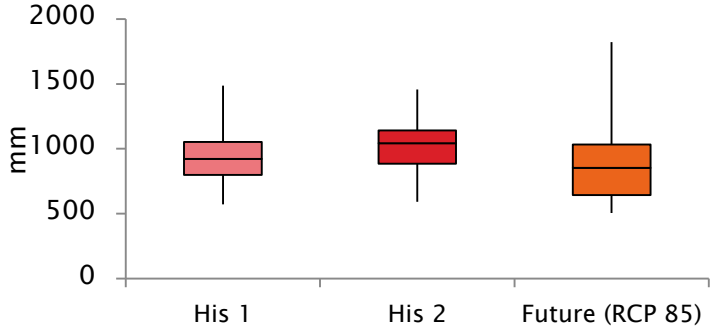
| Index | Condition | Potential slope stability response |
|---|---|---|
| PRCPTOT (mm) | Increase | More rainfall; As soil reaches to the critical water content, reduction in slope stability and more possibility of occurrence of landslide |
| R99p (mm) | Increase | |
| R95p (mm) | Increase | |
| Rx1 day (mm) | Increase | |
| Rx5 day (mm) | Increase | |
| R40mm (days) | Increase | Number of heavy rainfall days are increasing; slope stability may be reduced; High chance of occurrence of landslide |
| SDII (mm/day) | Increase | Infiltration can exceed subsurface drainage rates; or increase of through flow; more possibility of occurrence of landslide |
| CDD (days) | Increase | Less number of rainy days; less likely to occur a landslide |
| $R_{cv}$ (%) | Increase | More frequent wetting and drying cycle; likely to induce a landslide |

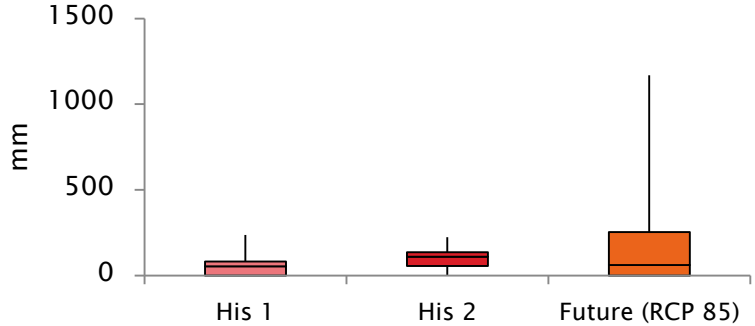
# Results



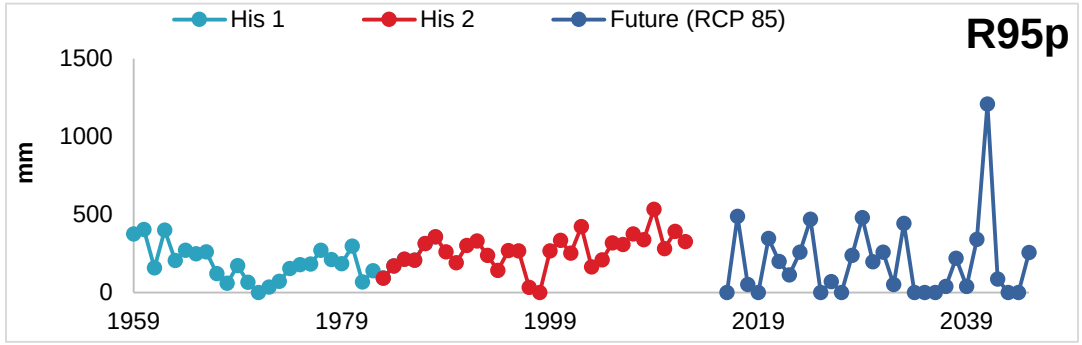

## Precipitation Totals

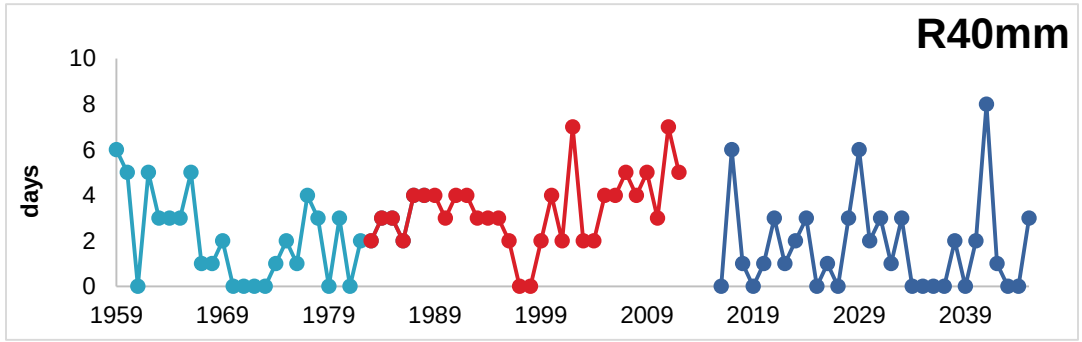


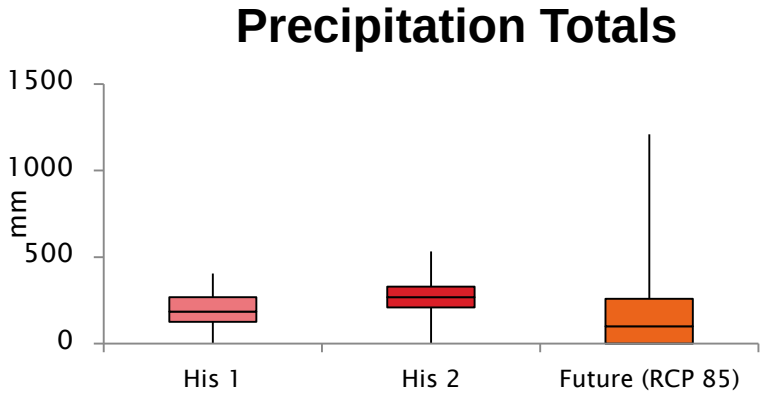



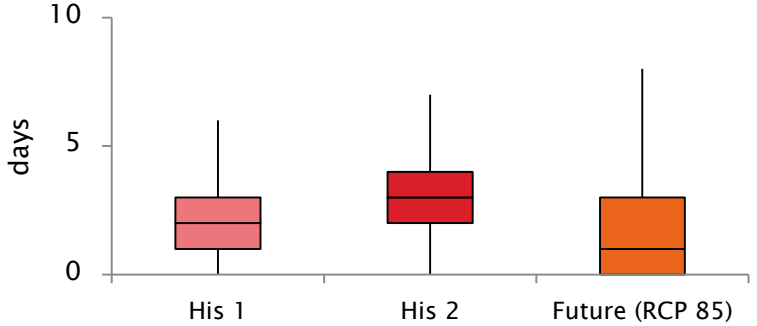

- Both PRCPTOT and R99p show slight increase in His 2 period;
- For future scenario, although median decreasing but uncertainty is increasing

# Results (Cont...)



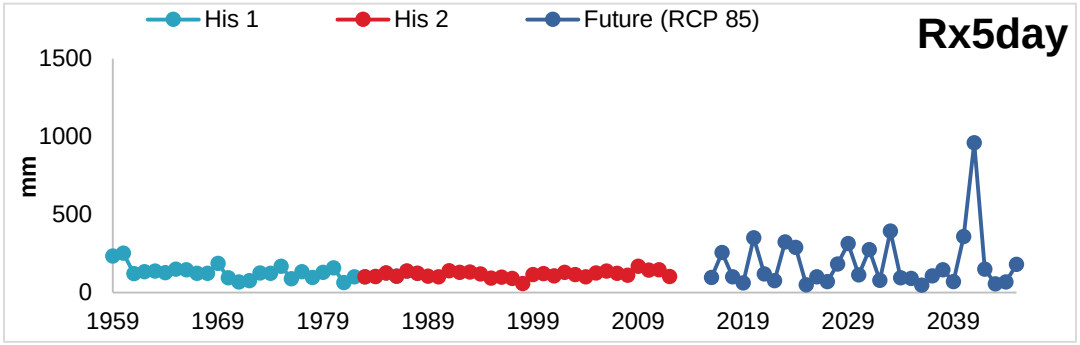



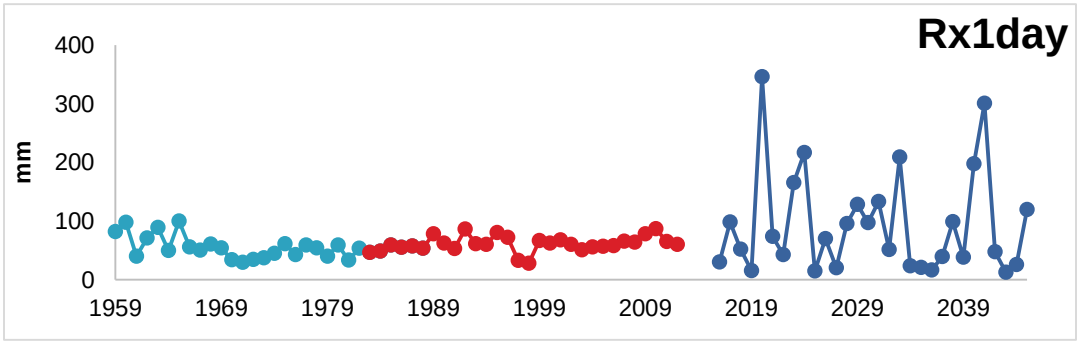



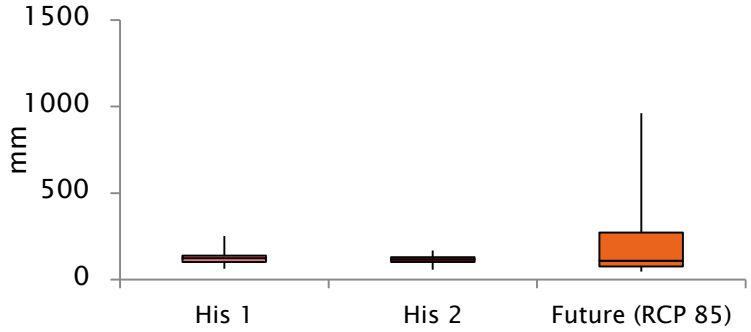

- Both indices are increasing in His 2 period but in the future time period, variability is increasing

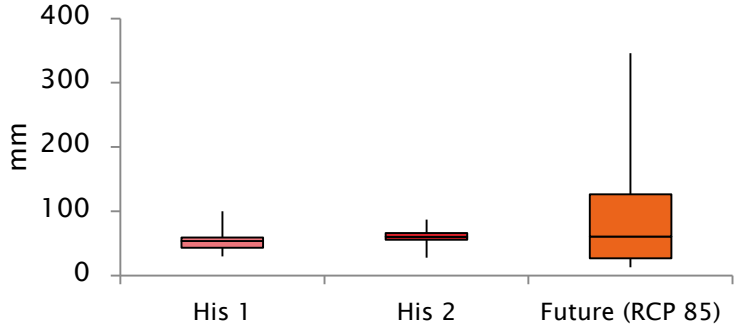
# Results (Cont...)




## Precipitation Totals

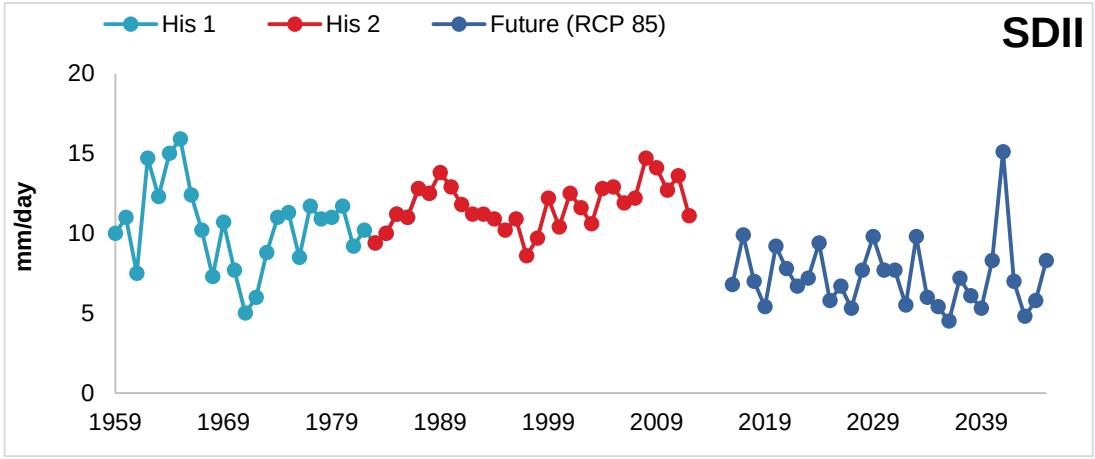


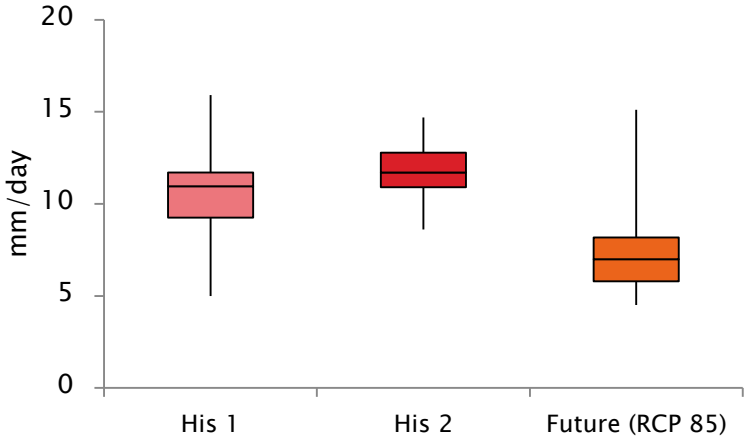




- In both indices the trend and change is insignificant but in the future variability is projected to increase compared to His 1 and His 2 periods

# Results (Cont...)

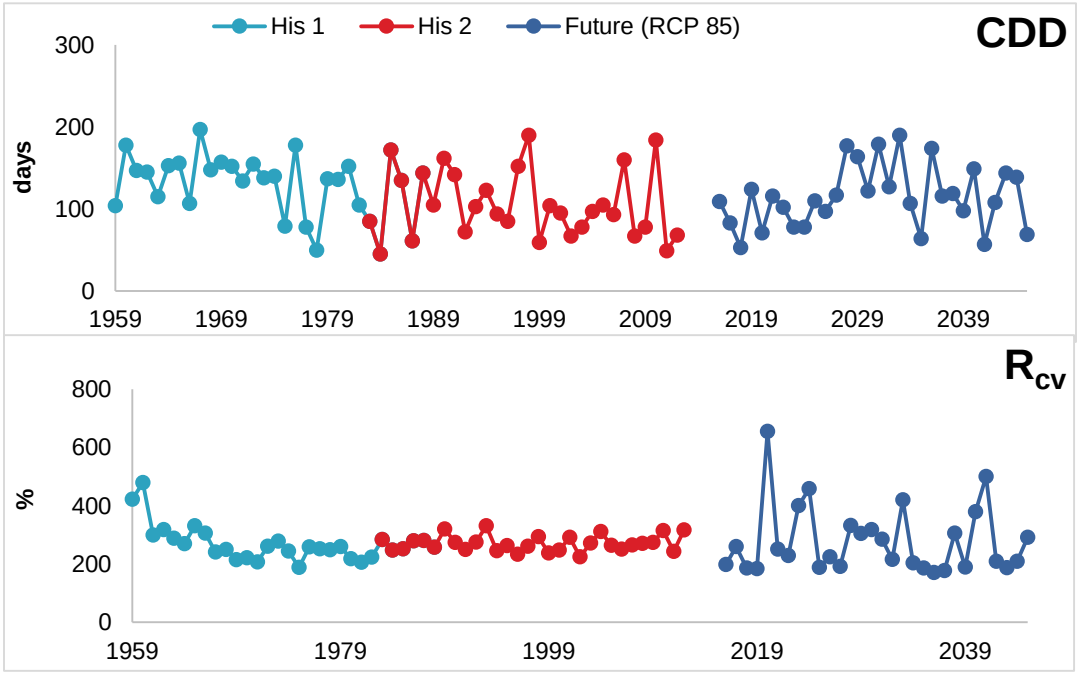
## Rainfall Intensity



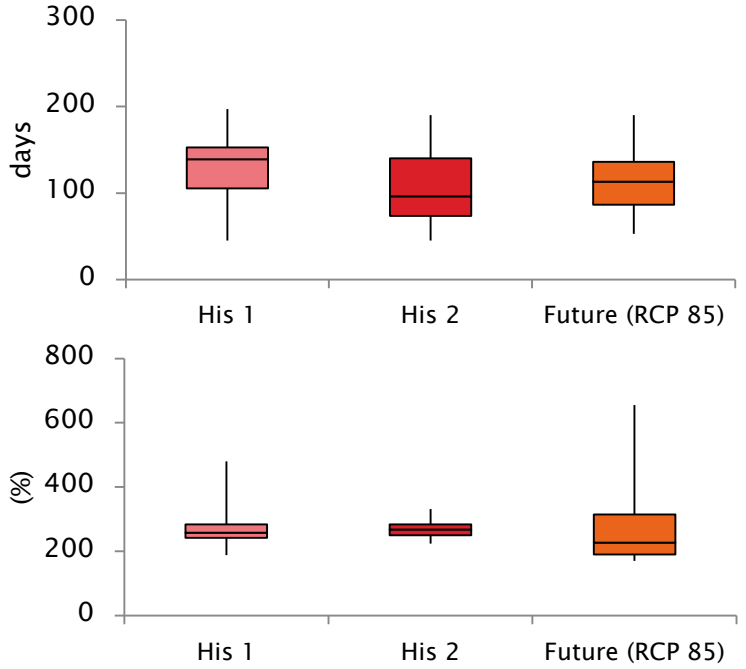




- SDII index shows a slight increase in trend and decrease in the variability in His 2 period with respect to His1
- In future, the trend shows significant increase in the variability

# Results (Cont...)




## Variability in precipitation




- CDD index displays gradual decrease in the historical period; in future it is expected to increase slightly, variability almost remains same
- Annual rainfall shows a decrease in the variability for his period 2 but significant increase in variability in future

# Conclusions

- Study of the historical data indicated that various indicators used to reflect precipitation totals have increased in past.
- Although median values of the studied indices showed a decrease in the future compared to historical period, but a higher variability has been projected which may trigger more landslides.
- This case study considered only precipitation in the future but there are many other factors which may influence occurrence of landslides.
- Only one GCM was used in this study; further study using multi-models and multi-scenarios is suggested.

# Thank you !!!

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