# Modeling the impacts of predicted climate changes on landslide frequency in the Philippines

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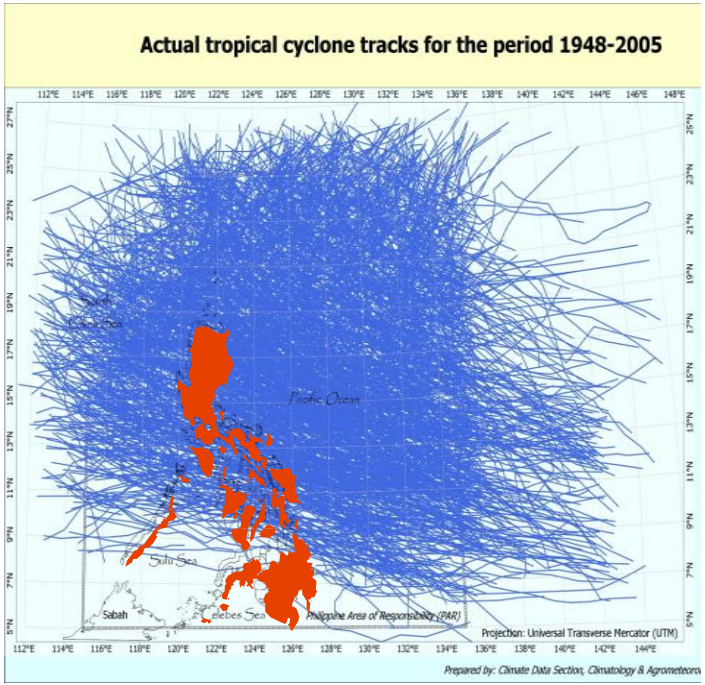
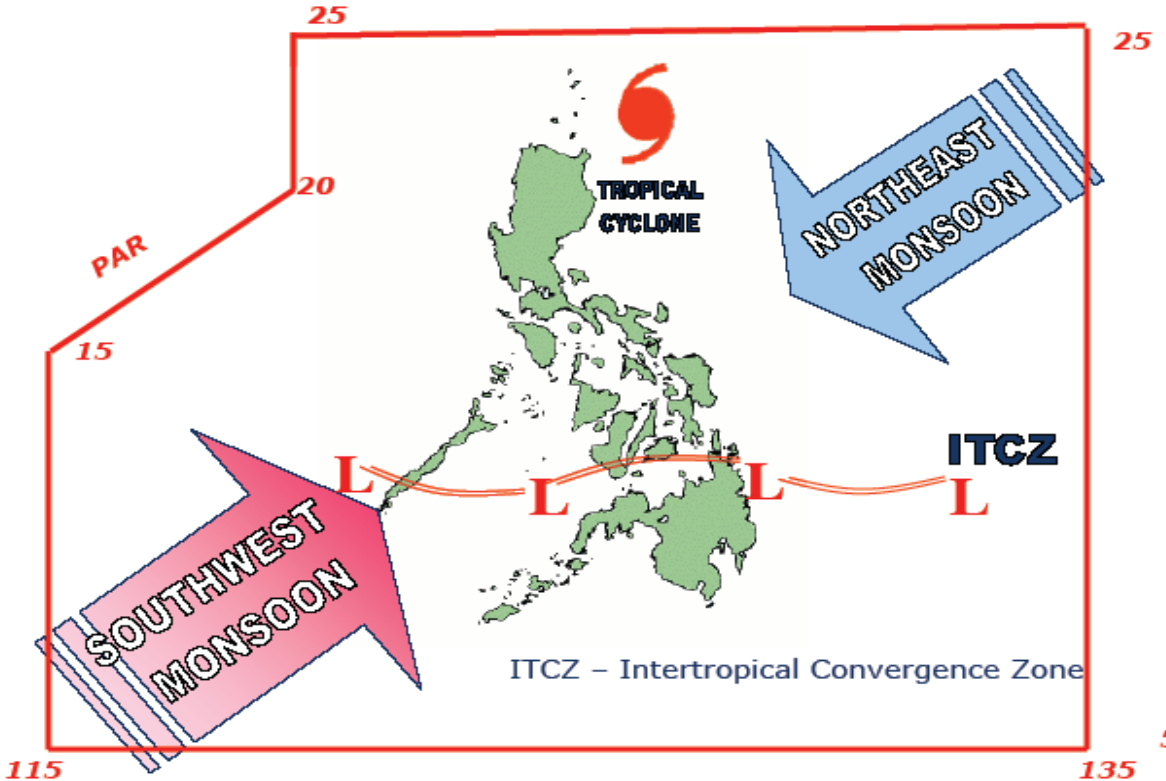
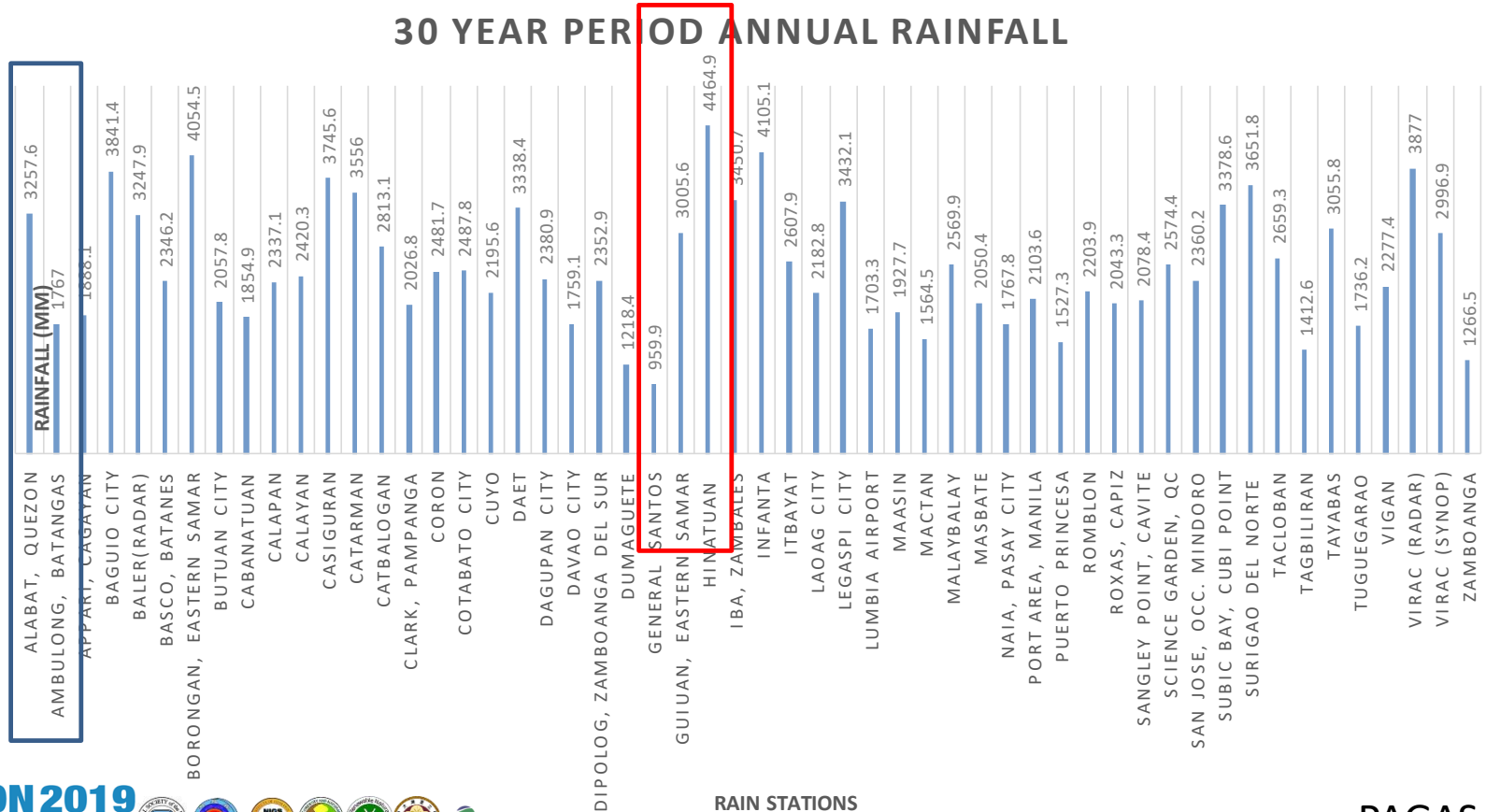
GEOCON 2019
Geoscience for a resilient and sustainable Philippines
December 4-5, 2019 | Manila Hotel

# Philippine meteorologic setting

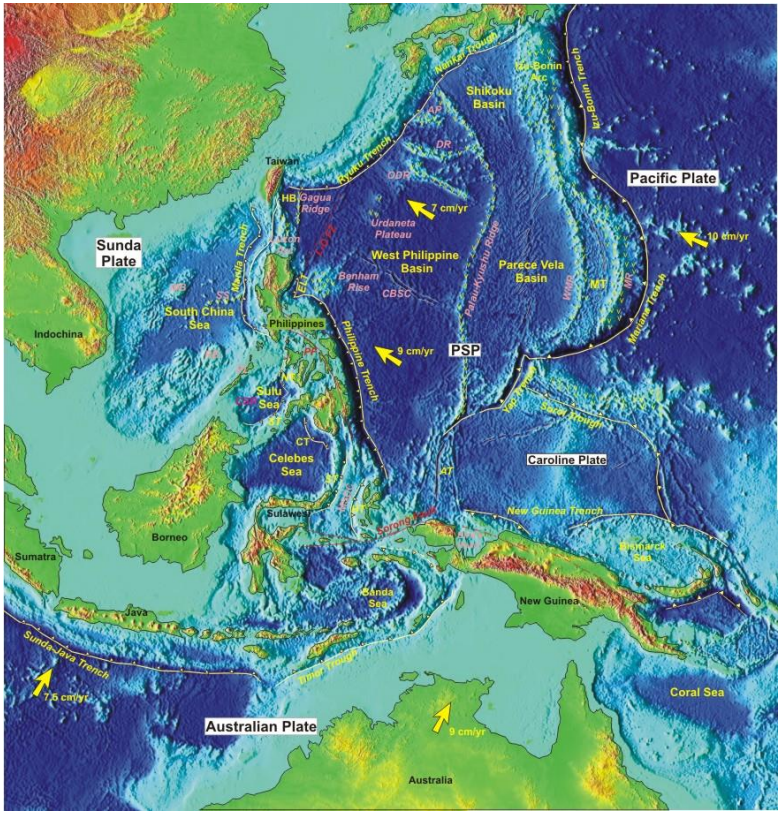


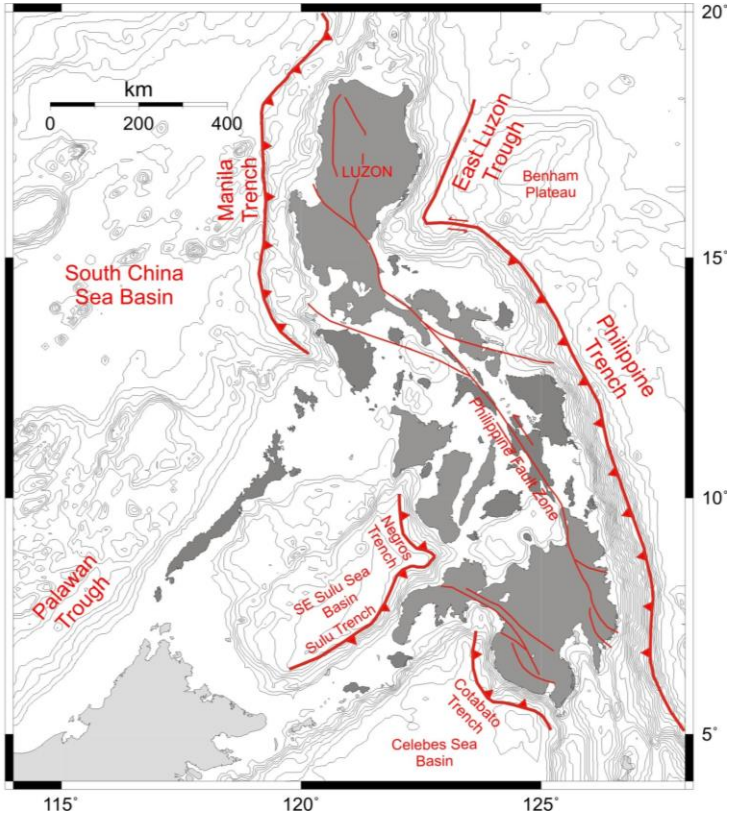



# Philippine meteorologic setting



# Philippine tectonic setting

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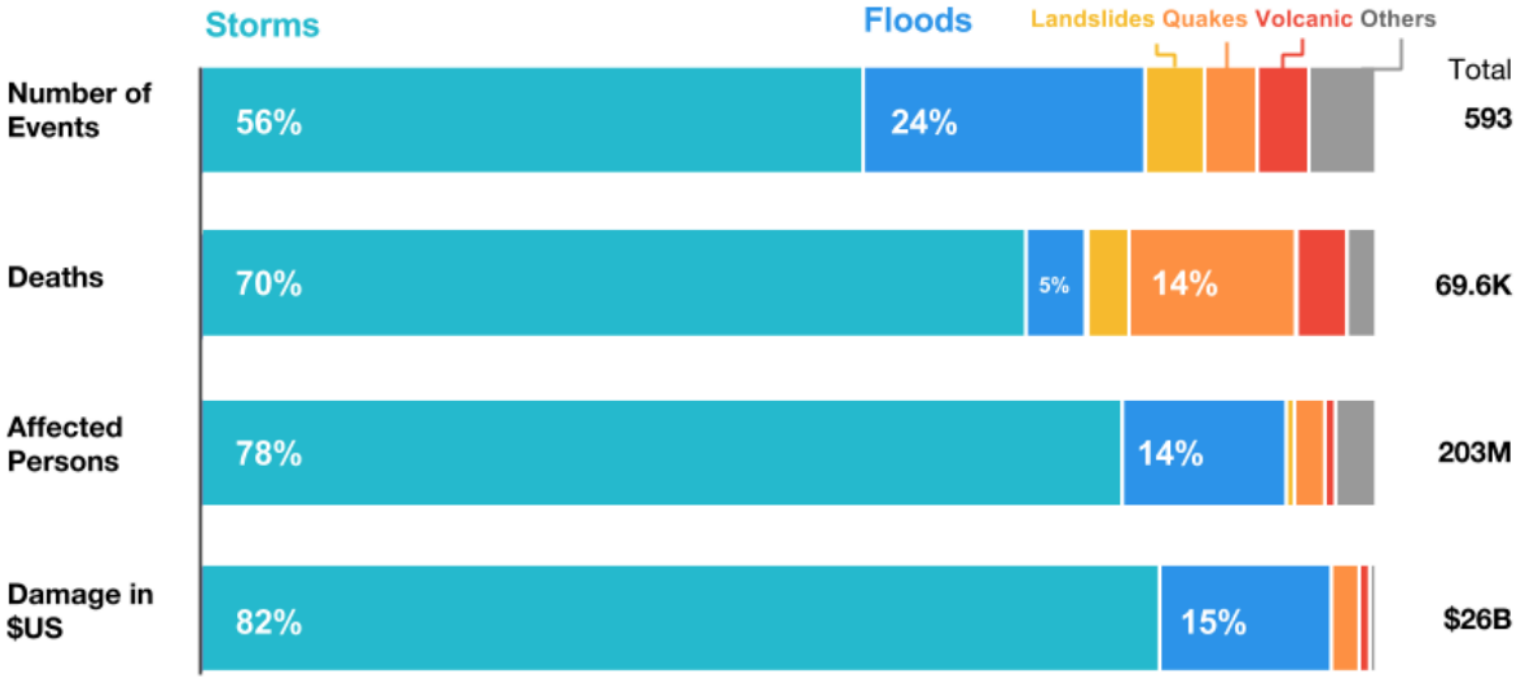
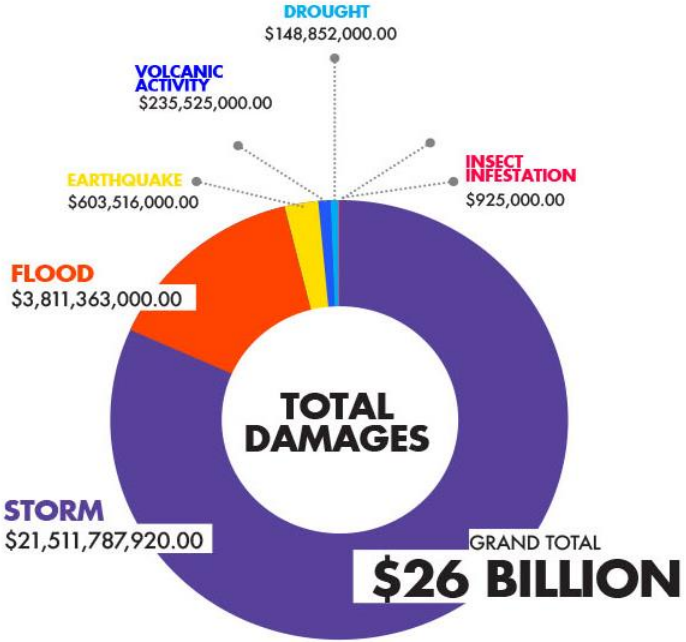
# Impact of disasters in the Philippines

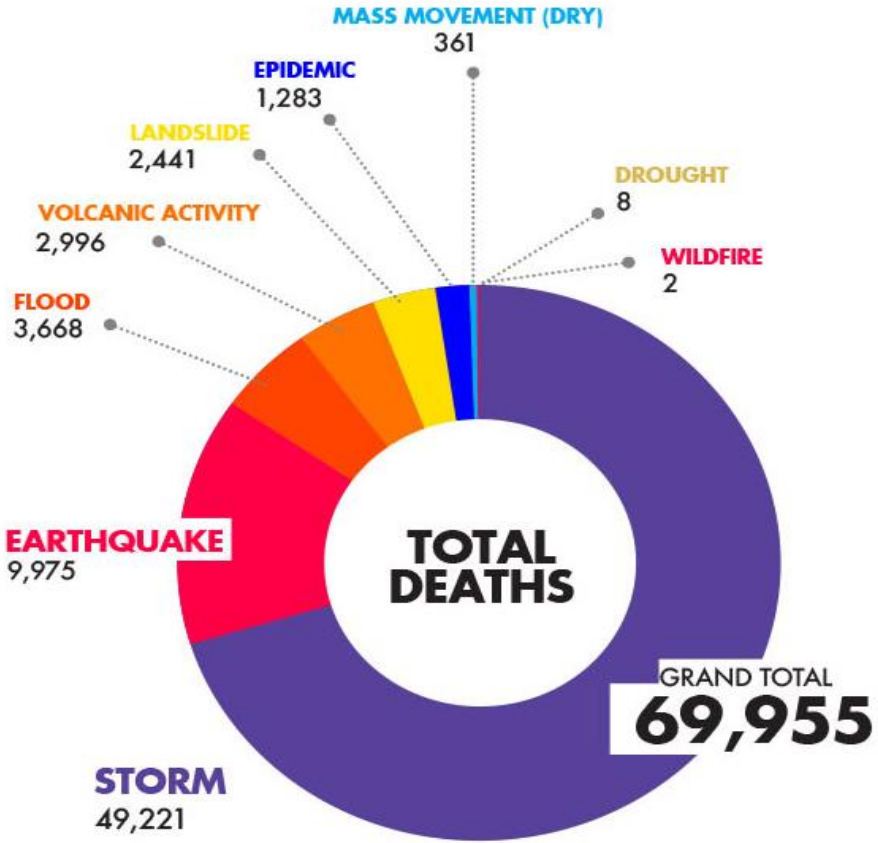
*1901-2015*




Data Source: Emergency Events Database (emdat.be)

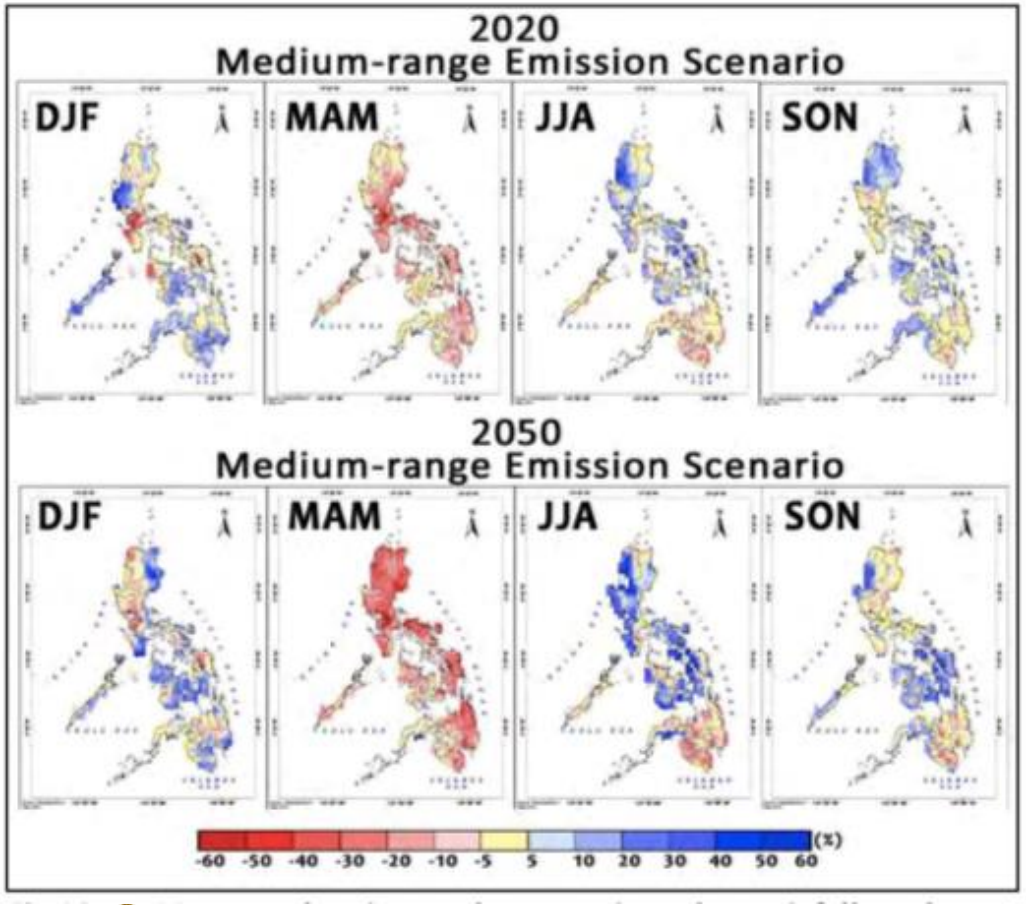
# Impact of disasters in the Philippines
1911-2018




Emergency Events Database (EM-DAT)-Centre for Research on the Epidemiology of Disasters (CRED), 2018

# Climate change



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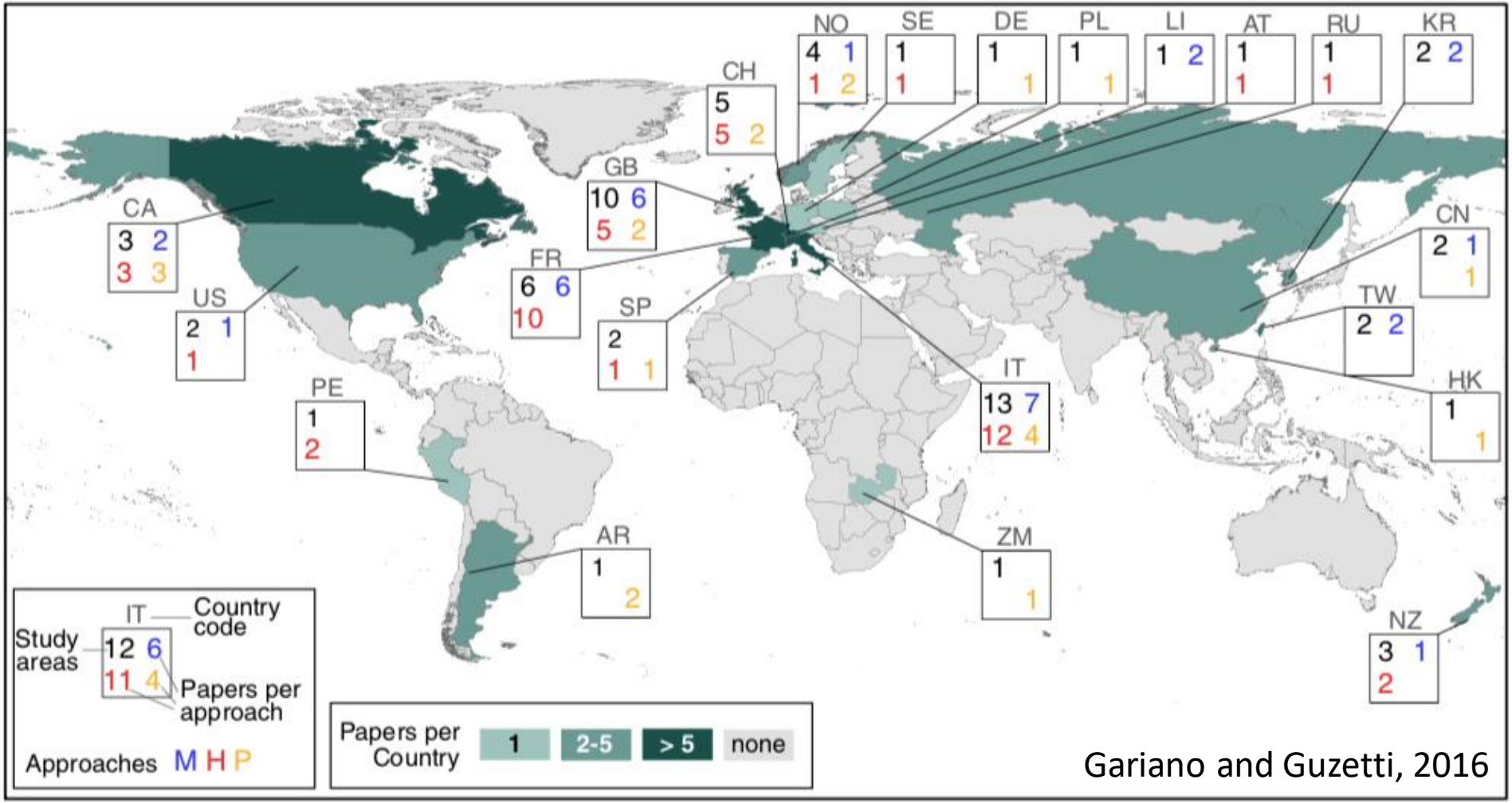
# Climate change and landslides

- ***Climate change impacts sediment processes:*** *changes in temperatures, intensity and frequency of rain events, and sea levels*
- Unequivocal: Earth is warming up
- Undisputable: Stability of natural and engineered slopes is affected by climate changes
- **Less clear: type, extent, magnitude and direction of the changes, location, abundance, activity and frequency of landslides in response to CC**

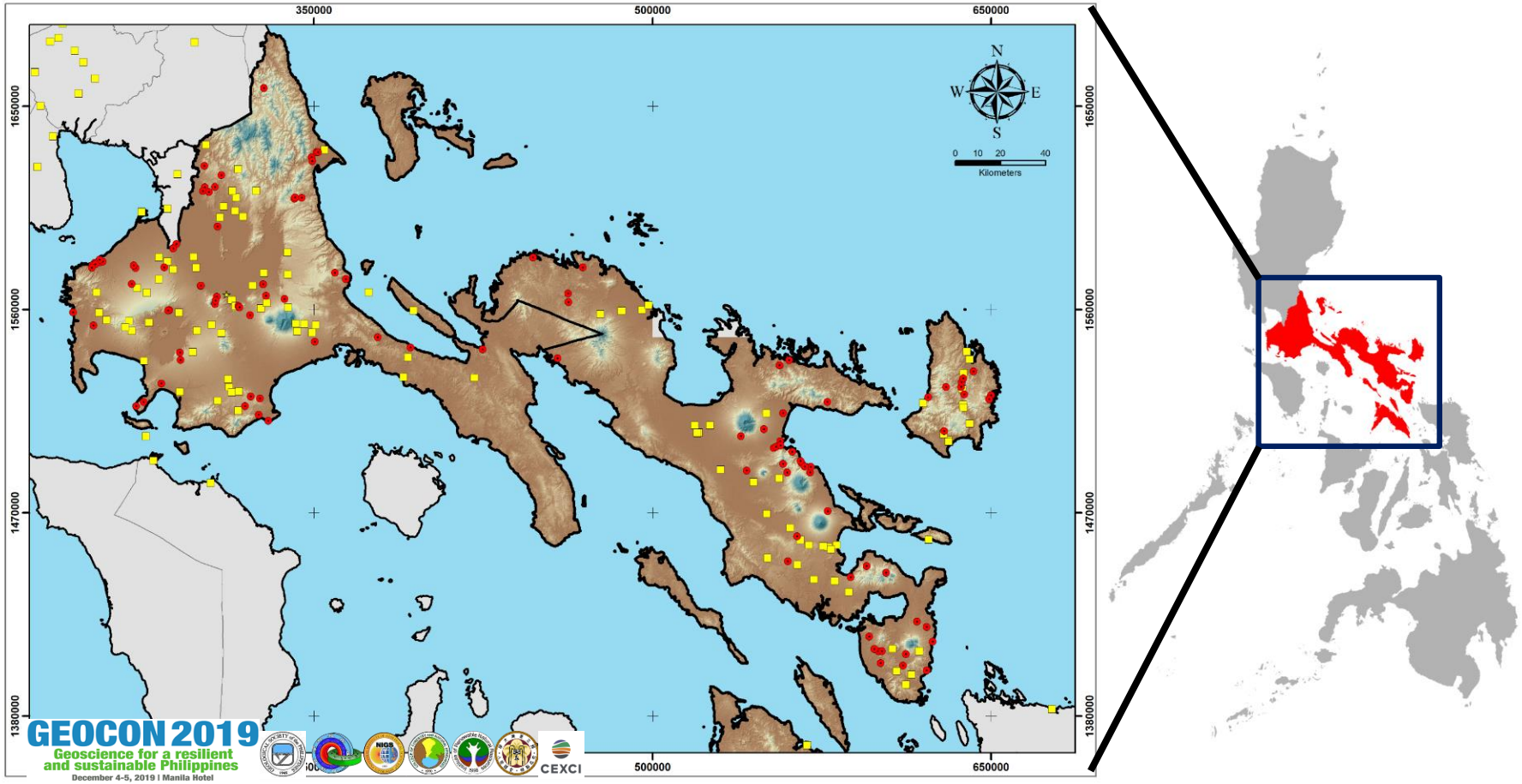



Gariano and Guzetti, 2016

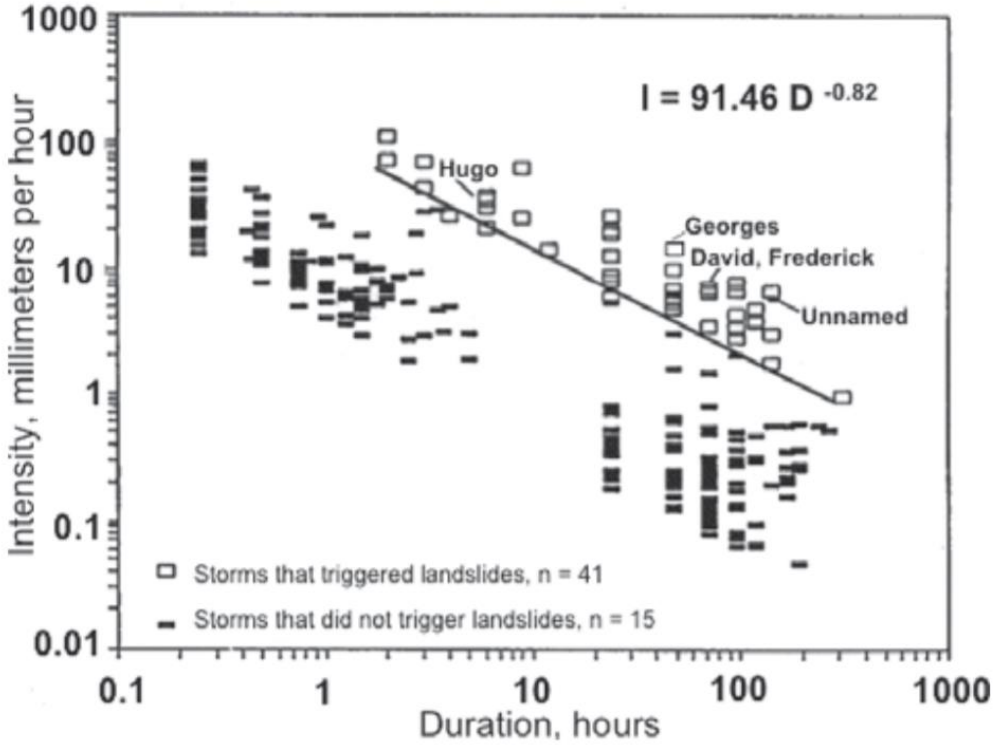
# Methods

- Consolidate a landslides database
- Utilize projected future scenarios (as simulated by Regional Climate Models (RCM))
- Combine rainfall-landslide threshold estimates with regionally downscaled climate change projections
- Estimate changes in frequency of events

# Study area: Southern Tagalog + Bicol



# I-D Thresholds




$$I = c + aD^B$$

**I** = average rainfall intensity (mm/h)

**D** = duration (h) from the beginning of a rainfall event to landslide occurrence

(Negri et al, 2005)

# Application for Early Warning

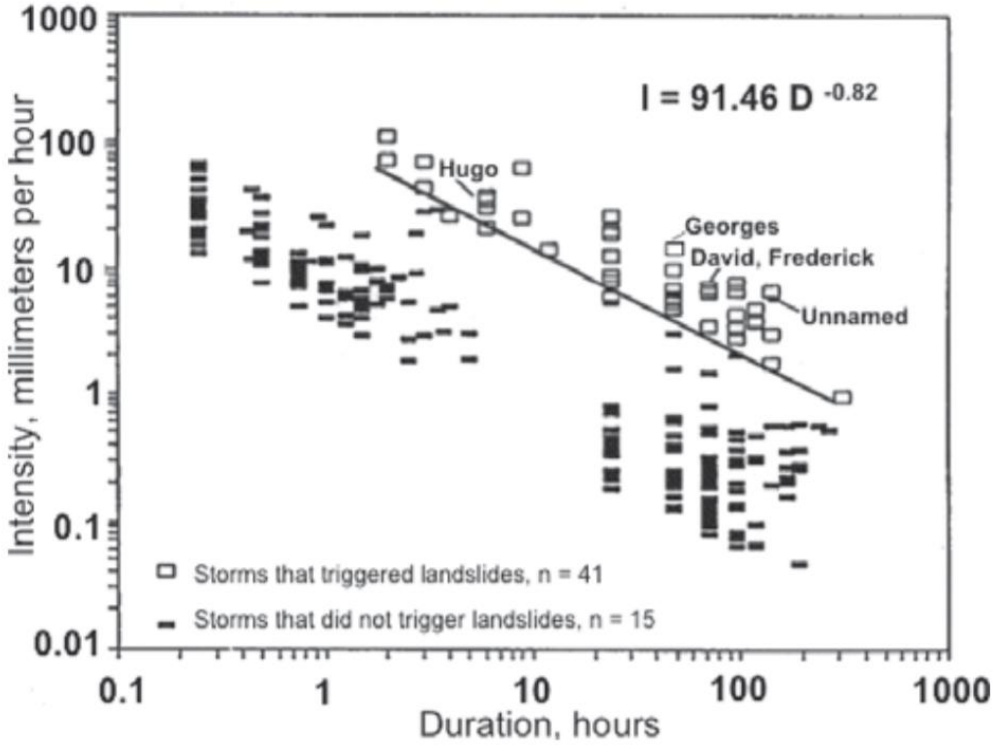

| Duration (hours) | Taiwan | | Manito (Manalo and Daag, 2012) | | Baguio (Javier and Kumar, 2017) | This work: steep to very steep slopes | |
|---|---|---|---|---|---|---|---|
| | Chen et al.,2015 | Chien-Yuan et al., 2005 | Median | Critical | Critical | Median | Critical |
| 1 | 36.6 | 115.47 | 22.28 | 15.7 | 6.5 | **21.8** | **9.6** |
| 8 | 31.0 | 21.88 | 7.88 | 5.7 | 3.6 | **8.5** | **4.9** |
| 24 | 28.4 | 9.08 | 4.55 | 3.3 | 2.7 | **5.1** | **3.5** |
| 48 | 26.8 | 5.22 | 3.22 | 2.4 | 2.2 | **3.7** | **2.8** |
| 72 | 26.0 | 3.77 | 2.63 | 1.9 | 2.0 | **3.1** | **2.4** |
| 96 | 25.4 | 3.00 | 2.27 | 1.7 | 1.8 | **2.7** | **2.2** |
| 120 | 24.9 | 2.51 | 2.03 | 1.5 | 1.7 | **2.5** | **2.1** |
| 144 | 24.6 | 2.17 | 1.86 | 1.4 | 1.6 | **2.3** | **2.0** |
| 168 | 24.3 | 1.92 | 1.72 | 1.3 | 1.5 | **2.1** | **1.9** |

# I-D thresholds in the Philippines

| Deposit type | Equation | Threshold Location/Author |
|---|---|---|
| unconsolidated pyroclastics | $I=9.23D^{-0.37}$ | Pasig-Portrero River (Pinatubo) (Arboleda et al., 1996) |
| | $I=5.94D^{-1.5}$ | Sacobia River (Pinatubo) (Tuñgol et al., 1996) |
| older volcanic deposits | $I=15.69D^{-0.49}$ | Manito in Bicol (Manalo and Daag, 2012) |
| | $I=27.3D^{-0.38}$ | Mayon - (Rodolfo et al., 1991) |
| Mineralized, highly tectonized | $I=6.46D^{-0.28}$ | Baguio (Javier and Kumar, 2017) |

**Huge variations = operationalization issue**
**SITE-SPECIFIC**

# I-D Thresholds



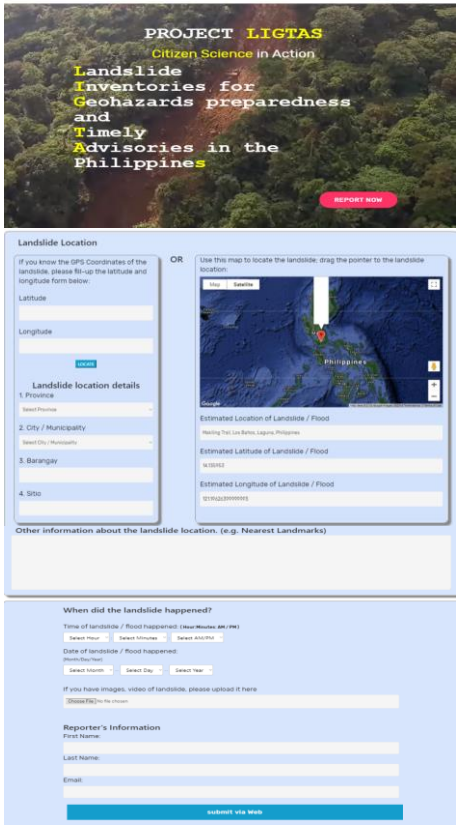

$$I = c + aD^B$$

**I** = average rainfall intensity (mm/h)

**D** = duration (h) from the beginning of a rainfall event to landslide occurrence

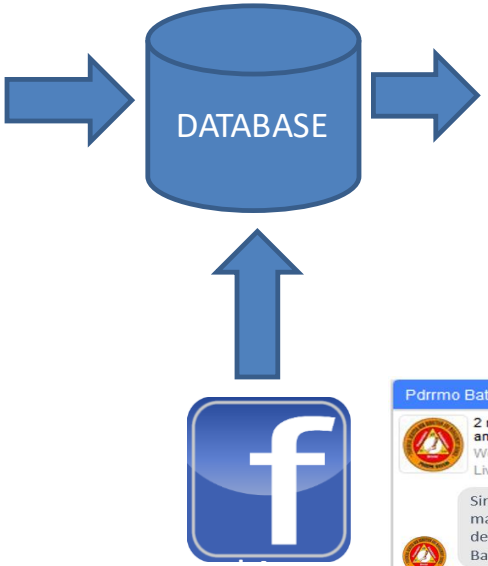
(Negri et al, 2005)

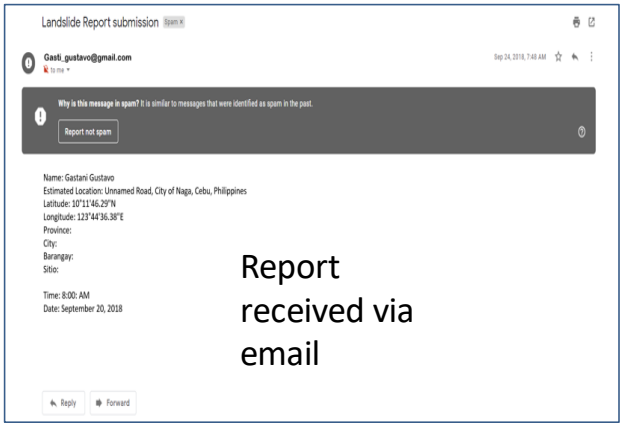
# Crowd-sourcing/Citizen Science



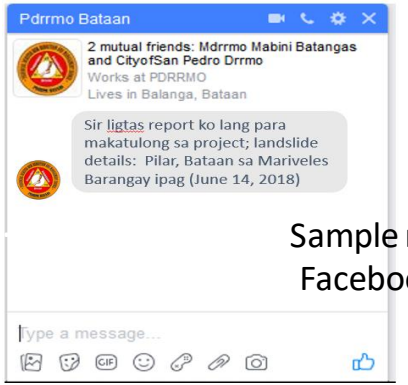

LIGTAS ONLINE PORTAL
www.ligtas.uplb.edu.ph

**INFO FROM PORTAL IS UPLOADED TO DATABASE AND SENT TO EMAIL FOR REDUNDANCY**



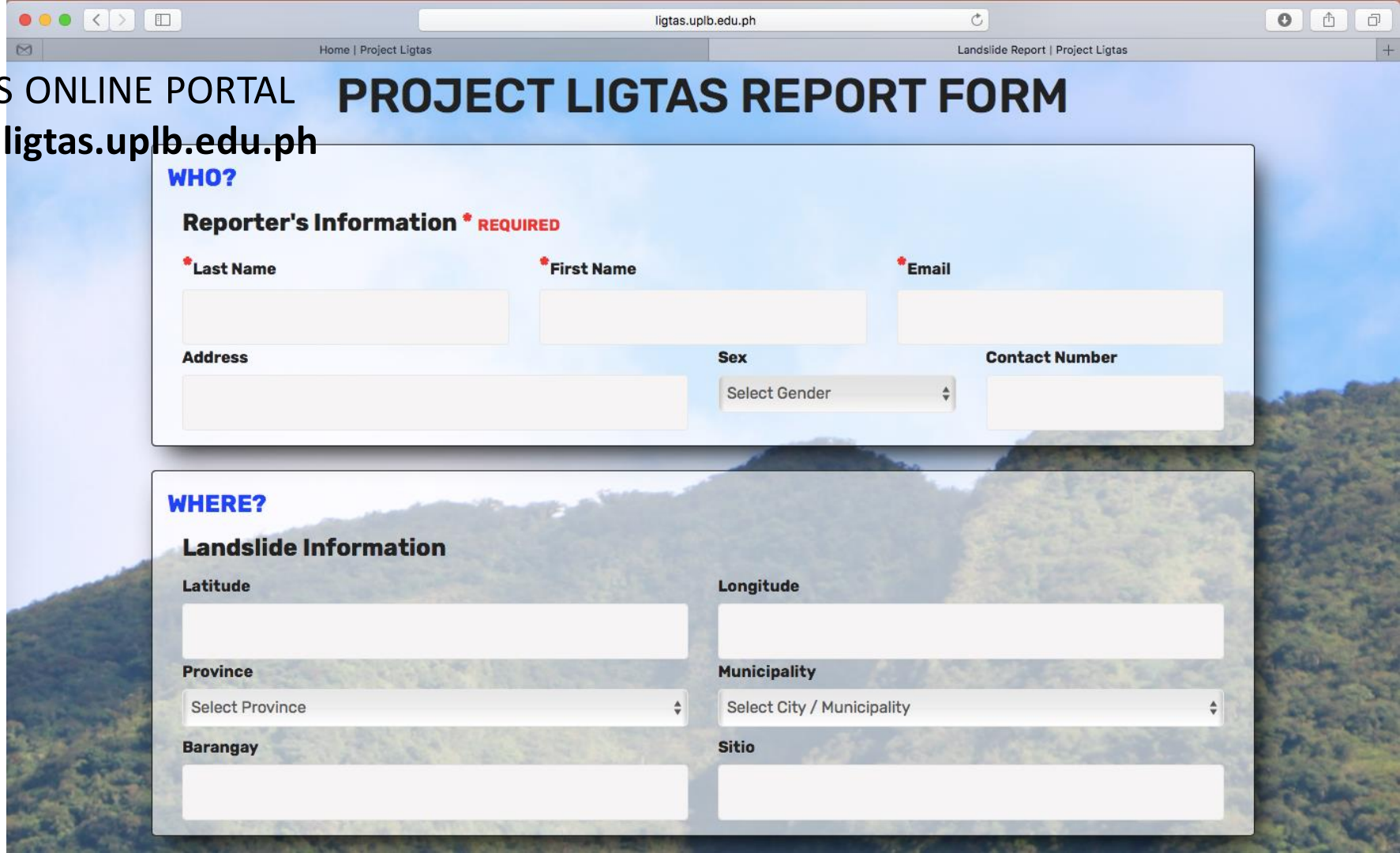

Report received via email




Sample report from Facebook Account

LIGTAS ONLINE PORTAL

**www.ligtas.uplb.edu.ph**




Show 10 entries

Search:

| ID | Latitude | Longitude | Date | Time | Location | Event / Trigger |
|---|---|---|---|---|---|---|
| 1 | 13.5107 | 123.0319 | 11/7/1988 | 0:00 | Sta. Rosa del Sur | continuous_rain |
| 2 | 14.616158 | 121.194867 | 8/3/1999 | around 7:30pm | Cherry Hills subdivision in Antipolo City, Rizal province, | Typhoon Olga |
| 3 | 7.256442 | 126.144589 | 3/19/2001 | | Barangay Kingking, Pantukan, Compostella Valley | Rainfall |
| 4 | 7.864686 | 126.029094 | 3/12/2003 | | Compostella Valley | Rainfall |

# Open data

| Landslide | Date | Time | Total Accumulated (mm) | Event Duration | Intensity | Land Cover | Landslide Susceptibility | Slope | Region | Climate Types |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 17 July 2018 | 4:00 AM | 140.80 | 13 | 10.83 | Shrubs | H | 18.68 | IV-A | I |
| 2 | 13 July 2010 | Evening | 160.50 | 24 | 6.69 | Shrubs | H | 41.16 | IV-A | II |
| 3 | 2 November 1995 | Unknown | 225.70 | 72 | 3.13 | Open Forest | H | 16.56 | IV-A | I |
| 4 | 15 July 2014 | Unknown | 174.00 | 24 | 7.25 | Perennial Crop | H | 16.31 | IV-A | IV |
| 5 | 23 July 2018 | 7:30 AM | 167.98 | 27.5 | 6.11 | Grassland | H | 15.85 | IV-A | II |
| 6 | 8 June 2011 | 7:00 PM | 129.26 | 48 | 2.69 | Perennial Crop | L | 23.59 | IV-A | I |
| 7 | 3 March 2016 | 1:30 PM | 186.68 | 13.5 | 13.83 | Perennial Crop | H | 12.26 | IV-A | III |
| 8 | 1 November 2017 | Evening | 177.00 | 24 | 7.38 | Perennial Crop | M | 20.23 | IV-A | II |
| 9 | 1 November 2017 | 2:30 AM | 161.31 | 17.5 | 9.22 | Perennial Crop | M | 27.62 | IV-A | II |
| 10 | 9 November 2017 | Everning | 275.61 | 21 | 13.12 | Perennial Crop | H | 35.64 | IV-A | III |
| 11 | 9 November 2017 | Evening | 275.61 | 21 | 13.12 | Perennial Crop | H | 30.07 | IV-A | III |
| 12 | 25 October 2012 | Unknown | 135.95 | 48 | 2.83 | Shrubs | M | 28.8 | IV-A | III |
| 13 | 12 September 2017 | 3:00 AM | 247.10 | 22 | 11.23 | Perennial Crop | H | 47.15 | IV-A | III |
| 14 | 12 September 2017 | Evening | 133.94 | 25 | 5.36 | Perennial Crop | H | 35.64 | IV-A | II |
| 15 | 12 September 2017 | 9:00 AM | 218.80 | 25 | 8.75 | Cultivated | M | 43.19 | IV-A | III |
| 16 | 12 September 2017 | Morning | 149.90 | 10 | 14.99 | Shrubs | M | 39.22 | IV-A | II |
| 17 | 12 September 2017 | 2:00 AM | 71.85 | 4 | 17.96 | Built Up | M | 32.41 | IV-A | I |
| 18 | 19 September 2013 | 6:10 AM | 89.57 | 48 | 1.87 | Perennial Crop | H | 26.5 | IV-A | I |
| 19 | 22 September 2013 | 4:30 PM | 185.10 | 120 | 1.54 | Perennial Crop | H | 32.82 | IV-A | I |
| 2 | 23 September 2013 | Unknown | 112.76 | 144 | 0.78 | Perennial Crop | M | 28.73 | IV-A | I |
| 21 | 23 September 2013 | Unknown | 267.82 | 144 | 1.86 | Cultivated | M | 19.86 | IV-A | I |
| 22 | 23 September 2013 | Unknown | 114.05 | 48 | 2.38 | Built Up | M | 21.53 | IV-A | I |

# Rainfall event definitions

- If **only daily rainfall data** is available:
  - Starts when daily rainfall > 7.5mm and above;
  - Ends: < 7.5 mm for 2 consecutive days

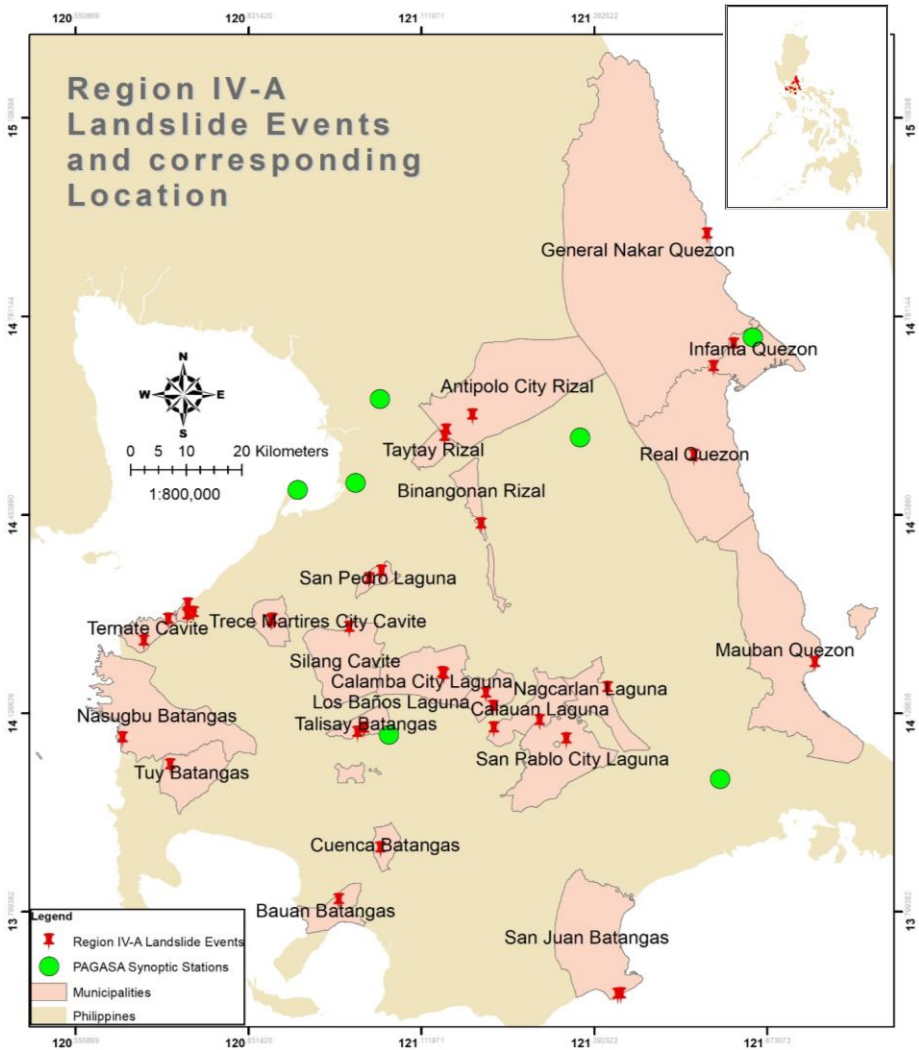
- If **hourly rainfall data**:
  - starts when hourly rainfall > 4mm;
  - Ends when hourly rainfall < 4mm over the next 6 consecutive hours (e.g., Chang et al. 2011)

- **Antecedent rainfall** (every 24 hrs) starts with > 7.5mm and above/day.

# Rainfall data

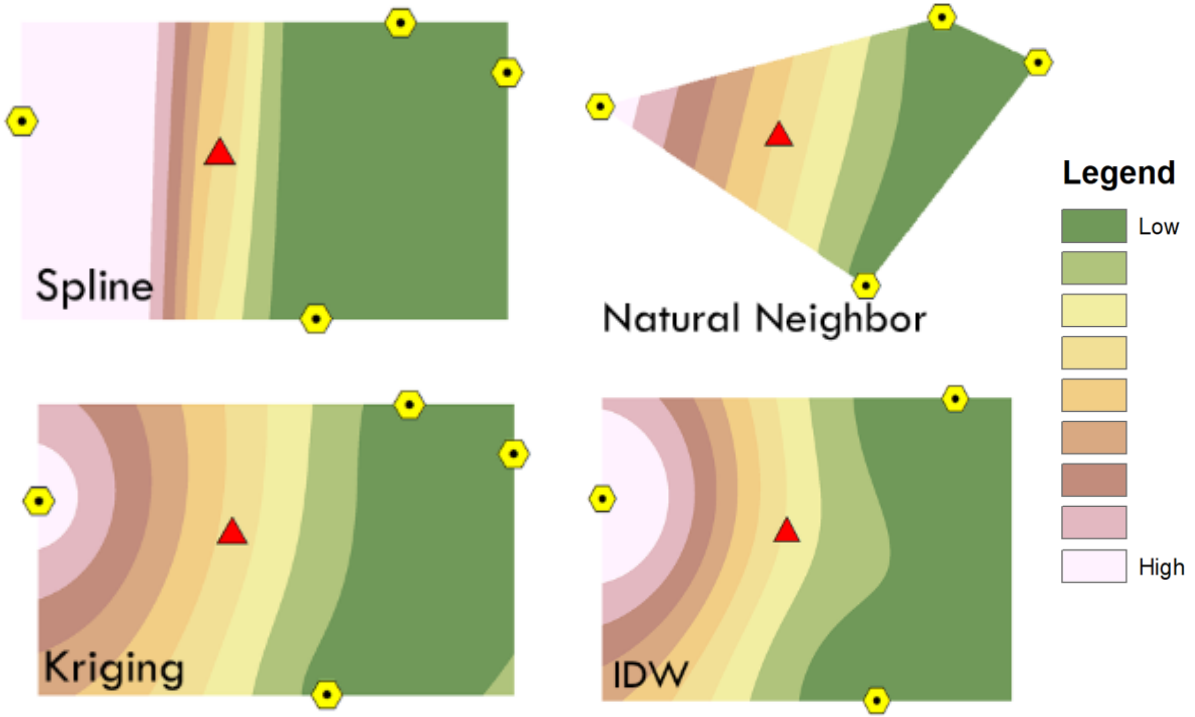
Landslide event locations vs nearest Synoptic Stations

| Province | Number of Landslide Events (1999-2018) |
|---|---|
| Batangas | 8 |
| Cavite | 8 |
| Laguna | 10 |
| Quezon | 7 |
| Rizal | 4 |
| TOTAL | 37 |



# Rainfall data

- Spline: minimizing the overall curvature
- Natural Neighbor (NN): sets a certain polygon that will cover certain points where the estimation will be associated.
- Kriging: measures certainty or accuracy.
- Inverse Distance Weighted (IDW): the closer the values are to the study area the closer the value will be assigned to the location of interest



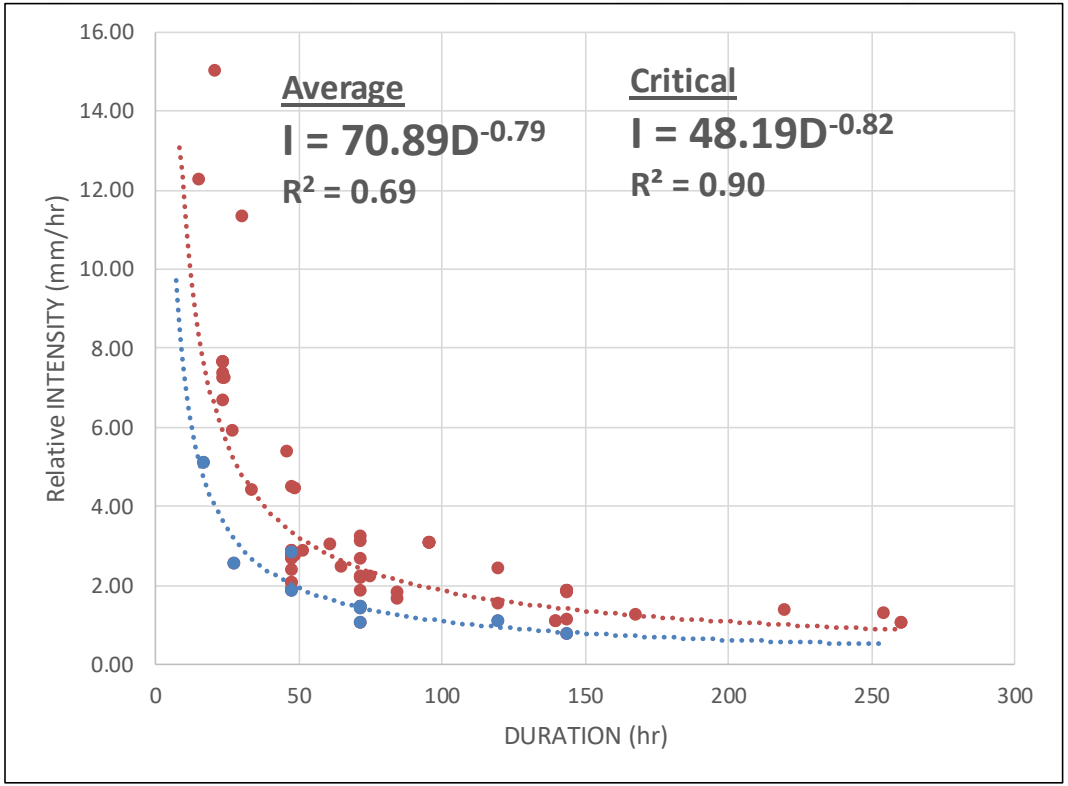
# Rainfall data

ACCUMULATED TOTAL RAINFALL (Jan et al. 2015)

$$R_t(t) = R(t) + \sum_{i=1}^{7} \alpha^i R_i = ETR1 + \sum_{i=1}^{7} \alpha^i R_i = ETR2$$

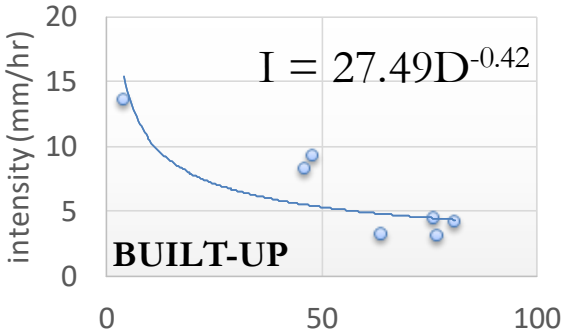
- R(t) : the amount of the accumulated rainfall at time t in the considered rainfall event
- $R_i$ : the amount of the antecedent i day's rainfall
- $\alpha$ : a weighting factor and is set to be 0.7

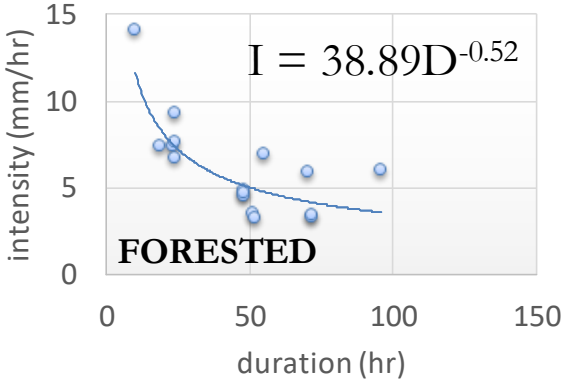
# Rainfall – landslide relationship

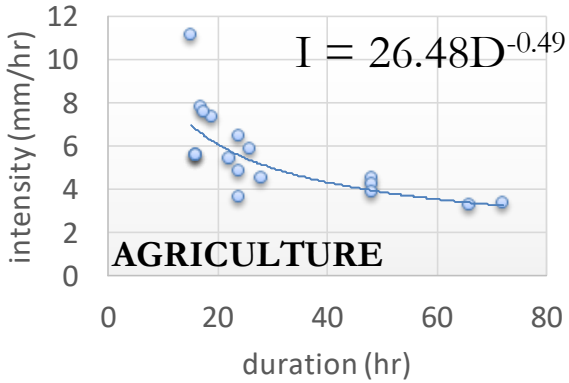


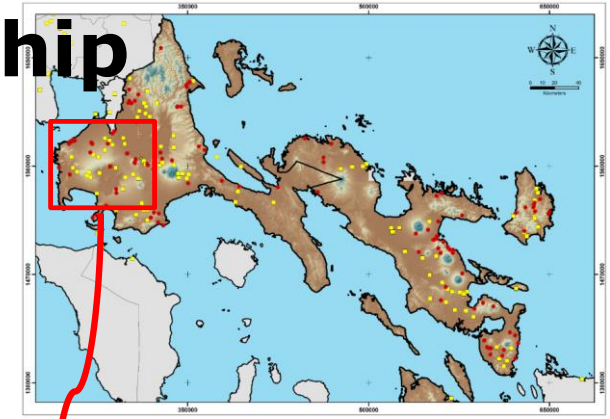

| Duration (hr) | Average | | Critical | |
|---|---|---|---|---|
| | Intensity (mm/hr) | Accumulated (mm) | Intensity (mm/hr) | Accumulated (mm) |
| 1 | 70.89 | 70.89 | 48.19 | 48.19 |
| 5 | 19.88 | 99.40 | 12.88 | 64.38 |
| 10 | 11.50 | 114.97 | 7.29 | 72.94 |
| 24 | 5.76 | 138.17 | 3.56 | 85.39 |
| 48 | 3.33 | 159.83 | 2.02 | 96.73 |
| 72 | 2.42 | 174.03 | 1.45 | 104.06 |
| 96 | 1.93 | 184.87 | 1.14 | 109.59 |
| 120 | 1.61 | 193.74 | 0.95 | 114.08 |
| 144 | 1.40 | 201.30 | 0.82 | 117.89 |
| 168 | 1.24 | 207.92 | 0.72 | 121.20 |

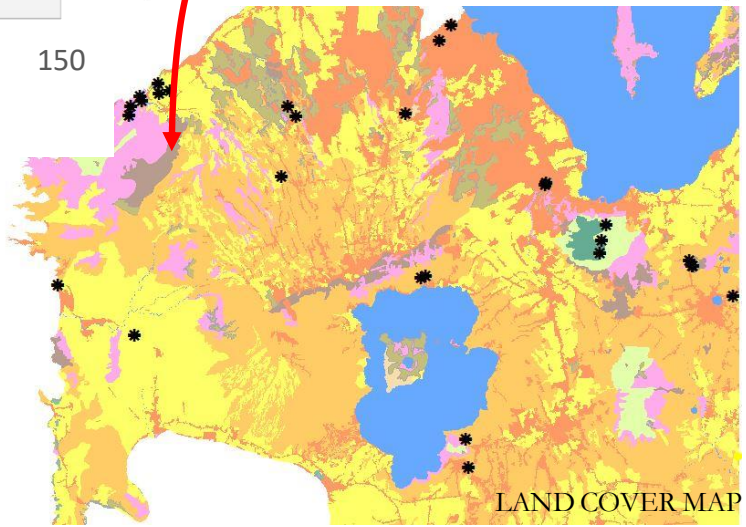
# Rainfall – landslide relationship



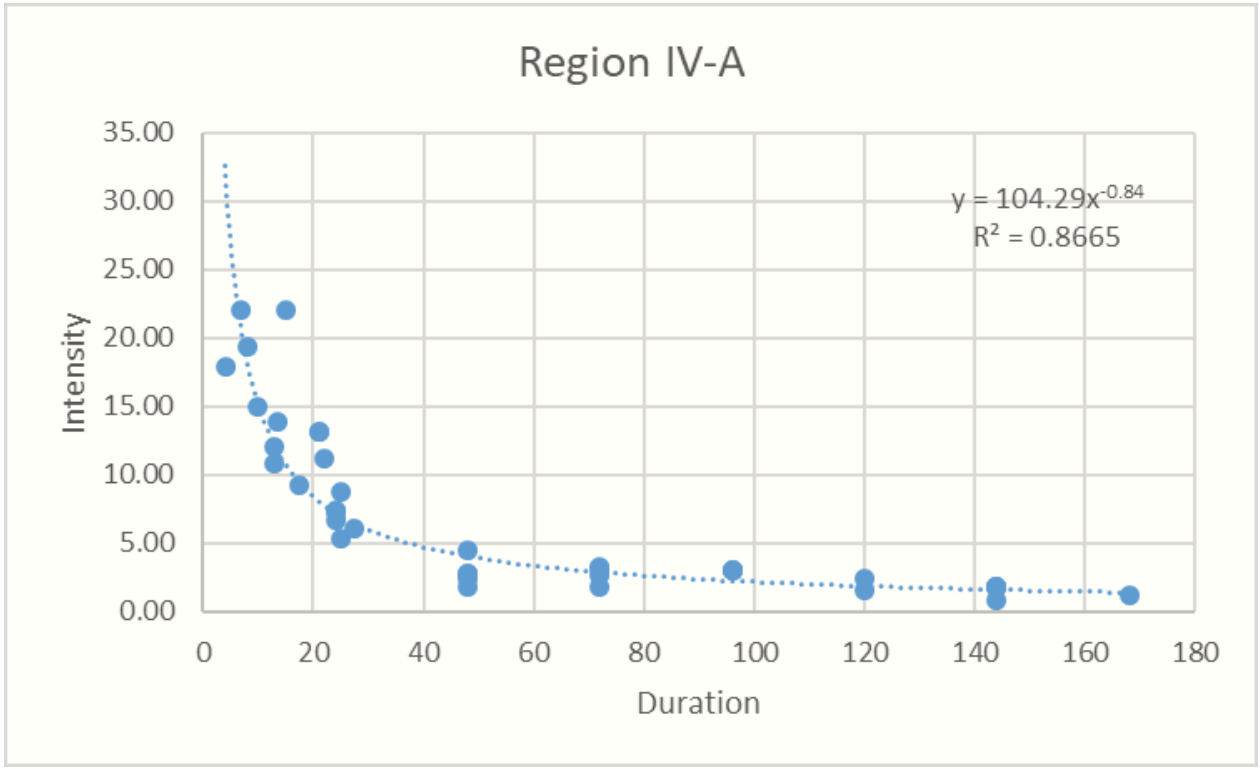





# Rainfall – landslide relationship



# Landslide – rainfall thresholds

Lowest thresholds:

**Accumulated**: **72mm** (18mm antecedent + 54mm event rainfall)

Lowest **antecedent**: **7mm** + 143mm event rainfall

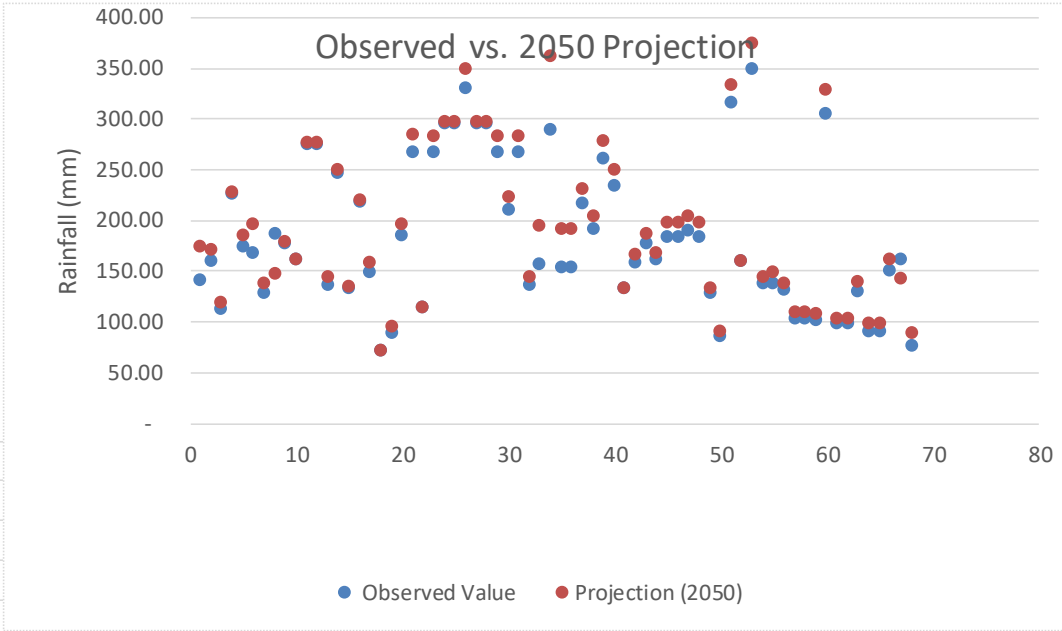
Lowest **event** rainfall: **20mm** + 134mm antecedent

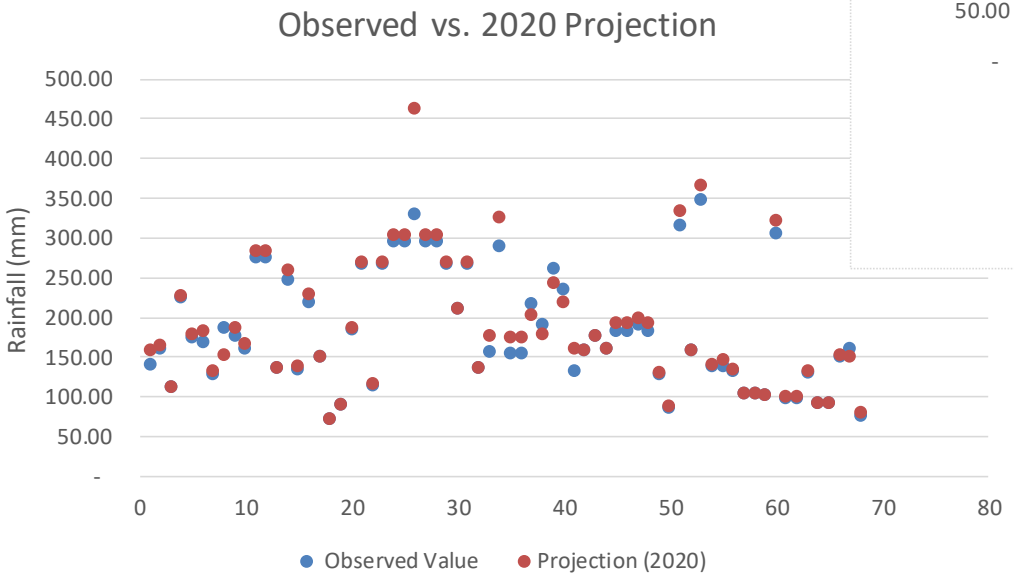
# CC projections: Rainfall changes

Table b: Seasonal rainfall change (in %) in 2020 and 2050 under medium-range emission scenario in provinces in Region 4-A

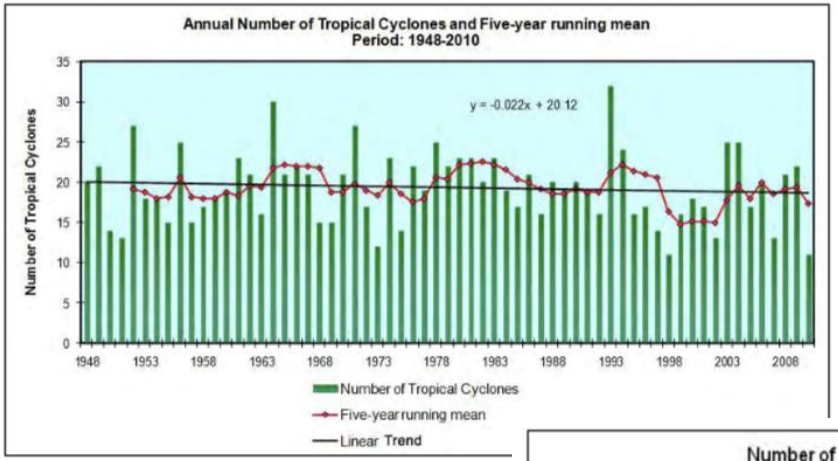
| | OBSERVED BASELINE (1971-2000) mm | | | | CHANGE in 2020 (2006-2035) | | | | CHANGE in 2050 (2036-2065) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DJF | MAM | JJA | SON | DJF | MAM | JJA | SON | DJF | MAM | JJA | SON |
| Region 4-A | | | | | | | | | | | | |
| BATANGAS | 231.0 | 280.4 | 856.5 | 746.4 | -29.9 | -24.1 | 9.1 | 0.5 | -11.1 | -23.1 | 17.2 | 6.3 |
| CAVITE | 124.9 | 242.8 | 985.7 | 579.0 | -26.1 | -28.2 | 13.1 | 0.4 | -19.1 | -30.5 | 24.2 | 5.9 |
| LAGUNA | 629.2 | 386.8 | 845.0 | 1066.5 | -20.2 | -31.5 | 2.9 | 2.9 | 0.1 | -34.8 | 6.8 | 0.4 |
| QUEZON | 827.7 | 382.7 | 670.0 | 1229.3 | -6.5 | -18.6 | 2.9 | 5.2 | 6.6 | -20.6 | 6.5 | 0.9 |
| RIZAL | 262.4 | 241.5 | 1001.3 | 821.8 | -13.1 | -30.7 | 12.4 | -0.9 | -11.5 | -39.8 | 24.8 | -0.8 |

# Rainfall changes



# Extreme weather events

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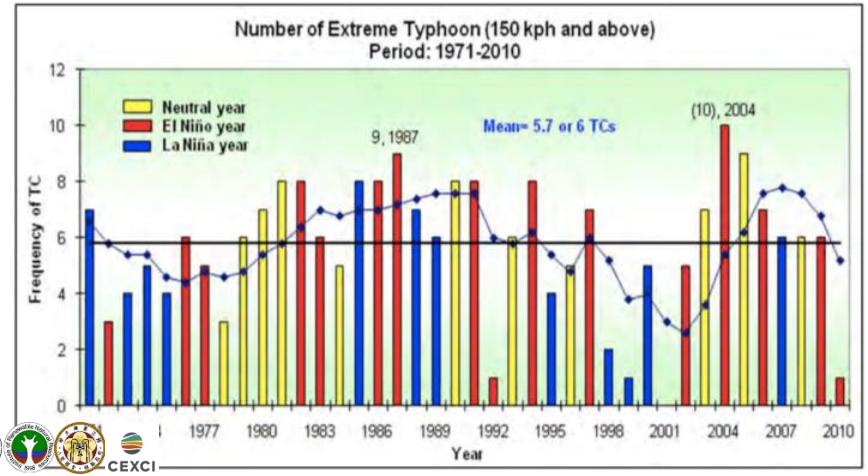



| Year | Count |
|---|---|
| 2010 | 11 |
| 2011 | 19 |
| 2012 | 17 |
| 2013 | 25 |
| 2014 | 19 |
| 2015 | 15 |
| 2016 | 14 |
| 2017 | 22 |
| 2018 | 21 |
| 2019 | 20 |
| Total | 183 |
| Average | 18.3 |
| Mean | 17.8 |

# Extreme weather events

Table c: Frequency of extreme events in 2020 and 2050 under medium-range emission scenario in provinces in Region 4-A

| Provinces | Stations | No. of Days w/ Tmax >35 °C | | | No. of Dry Days | | | No. of Days w/ Rainfall >200mm | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | OBS (1971-2000) | 2020 | 2050 | OBS | 2020 | 2050 | OBS | 2020 | 2050 |
| BATANGAS | Ambulong | 928 | 8010 | 8016 | 8226 | 6081 | 6049 | 6 | 14 | 9 |
| CAVITE | Sangley | 630 | 1697 | 2733 | 7352 | 6635 | 6565 | 6 | 9 | 9 |
| QUEZON | Alabat | 53 | 132 | 733 | 6629 | 7025 | 7042 | 20 | 58 | 70 |
| | Tayabas | 22 | 791 | 1434 | 6771 | 4717 | 4668 | 17 | 9 | 12 |
| | Casiguran | 575 | 1720 | 2768 | 6893 | 4520 | 4887 | 23 | 54 | 57 |
| | Infanta | 350 | 378 | 1112 | 5903 | 4006 | 4015 | 22 | 39 | 34 |

Most extreme:

Typhoon: 2009 Ondoy, 556mm (4 days)

Monsoon: 2013 Habagat, 1,120 (5 days)

# Landslide – rainfall thresholds

Lowest thresholds:

**Accumulated**: **72mm** (18mm antecedent + 54mm event rainfall)

Lowest **antecedent**: **7mm** + 143mm event rainfall

Lowest **event** rainfall: **20mm** + 134mm antecedent

**LOWER THAN PUBLISHED CC PROJECTION CONSIDERED: 200mm**

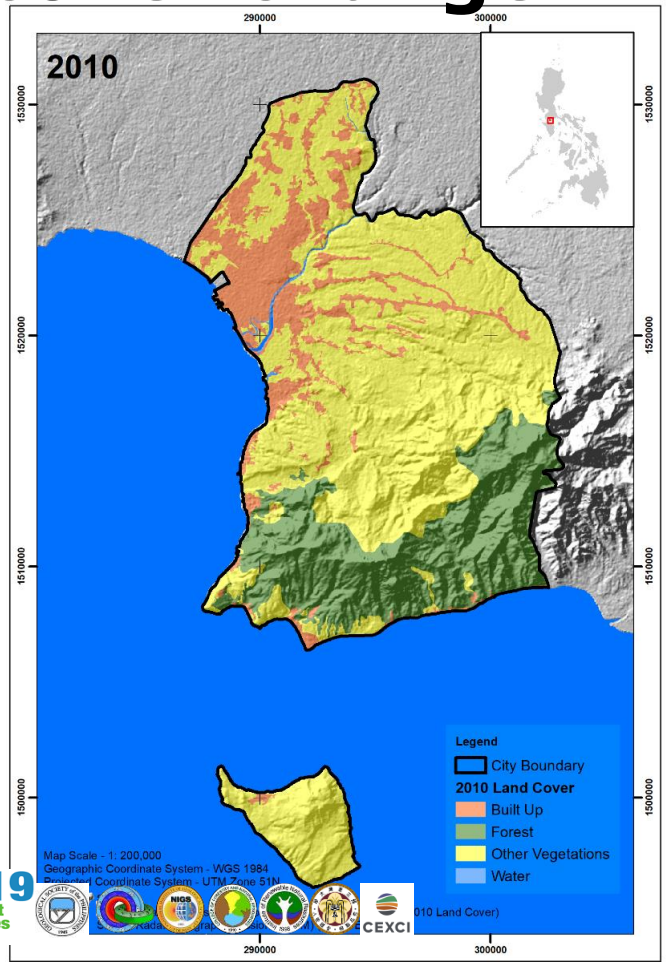
# Extreme weather events

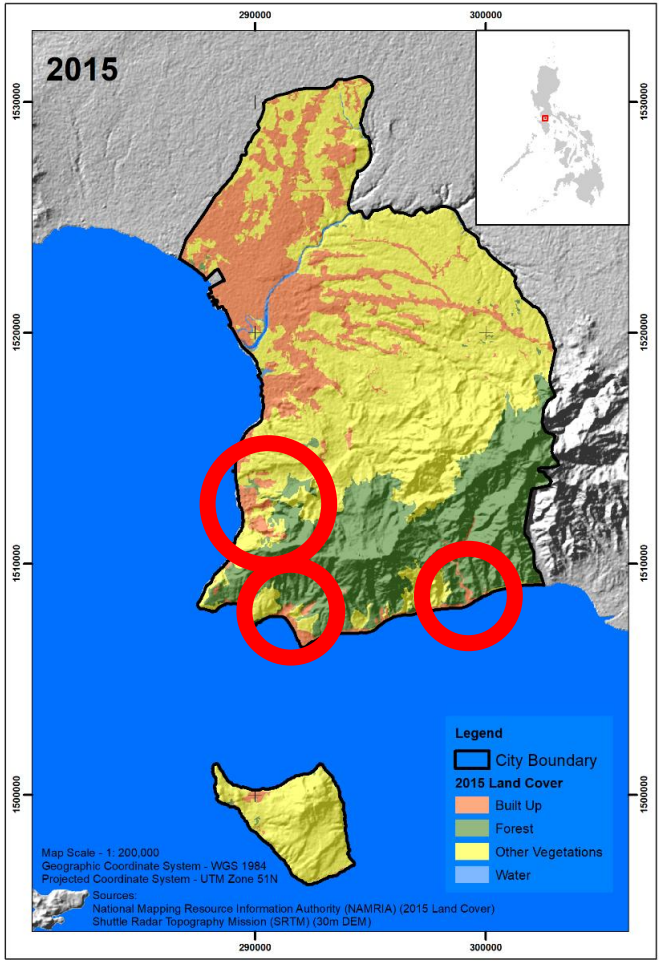
Quezon extreme rainfall:
1971-2000: 1 every 2 yrs
2020: 1.2 every year (+140%)
2050: 1 every year (+100%)

Quezon:
Database: 21 entries from 2010-2019
2020: ~50 events?
2050: ~40 events?

| Date | Time | Location | Hour of Antecedent Rainfall | Antecedent Rainfall (mm) | Event Rainfall (mm) | Total Accumulated (mm) |
|---|---|---|---|---|---|---|
| 2 November 1995 | Unknown | Brgy. Tumayan, Gumaca, Quezon | 72 | 225.6961 | - | 225.70 |
| 13 July 2010 | Evening | Mount Banahaw, Lucban, Quezon | 24 | 160.5 | - | 160.50 |
| 4 December 2011 | 1:00 PM | Brgy. Agos-Agos, Infanta, Quezon | 48 | 216.328 | - | 216.33 |
| 15 July 2014 | Unknown | Brgy. Hagakhakin, Gumaca, Quezon | 24 | 174 | - | 174.00 |
| 16 December 2015 | 12:00 MN | Brgy. Magsaysay, Infanta, Quezon | 72 | 191.7916 | - | 191.79 |
| 19 December 2015 | 5:00 PM | Brgy. Tanuan, Real, Quezon | 144 | 261.0355188 | - | 261.04 |
| 3 March 2016 | 1:30 PM | Brgy. Cagsiay I, Mauban, Quezon | 48 | 157.675 | 29 | 186.68 |
| 12 September 2017 | 9:00 AM | Lucena City, Quezon | 24 | 9.8 | 209 | 218.80 |
| 12 September 2017 | 3:00 AM | Atimonan, Quezon | 24 | 16.1 | 231 | 247.10 |
| 1 November 2017 | Evening | Maharlika Highway, Plaridel, Quezon | - | - | 177 | 177.00 |
| 30 December 2018 | Unknown | Brgy. Cagsiay II, Mauban, Quezon | 72 | 234.612 | - | 234.61 |

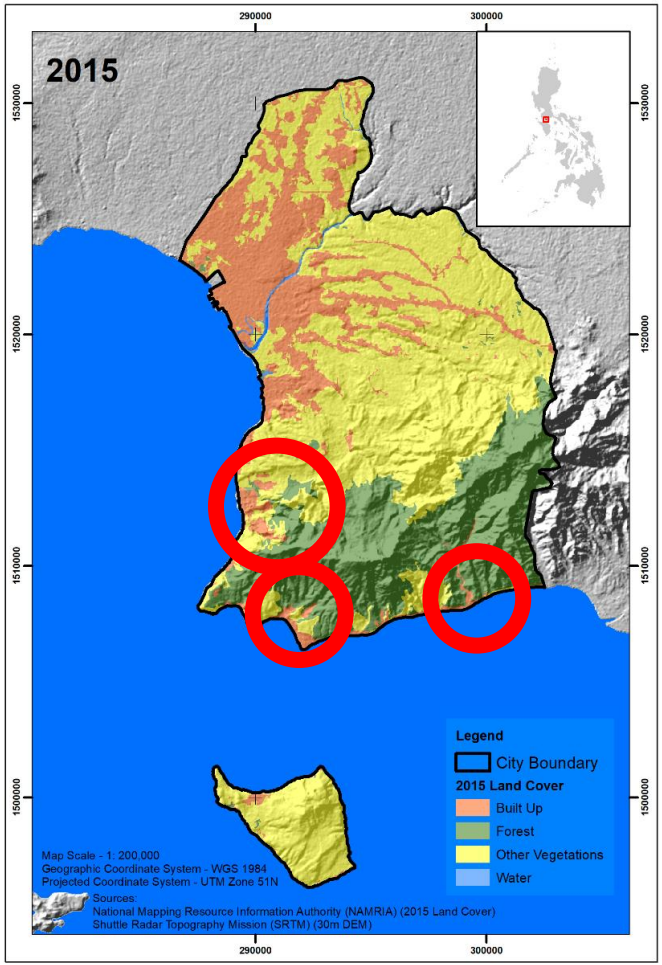
# Land cover change



# Land cover changes

| 2015 Land Cover | 2010 Land Cover | | | | | |
|---|---|---|---|---|---|---|
| | Built Up | Other Vegetation | Forest | Water | Grand Total | Percent Change (%) |
| **Built Up** | 4,070 | 1,397 | 158 | - | 5,625 | 38 |
| **Other Vegetation** | 15 | 13,944 | 944 | - | 14,903 | (11) |
| **Forest** | 3 | 1,377 | 5,361 | - | 6,741 | 4 |
| **Water** | - | - | - | 142 | 142 | - |
| **Total** | 4,087 | 16,719 | 6,463 | 142 | 27,411 | |



# Climate change and landslides: challenges and actions

- Climate projections:
  - Precipitation changes more significant for dry periods
  - Changes in extreme rainfall more a concern, not the annual averages

- Number of landslide events:
  - Will likely increase: reporting, detection, actual increase in landslide events

- ID thresholds:
  - Will likely change: seasonal T, $H_2O$, event characteristics

# Climate change and landslides: challenges and actions

- Landslide database: too few and far between
  - Database buildup, continuous monitoring

- Lowest rainfall thresholds: < what CC models account for
  - Needs: adjust thresholds, downscale

- Landslides, CC, land use changes: More fun! It's complicated! Transdisciplinary approaches

# THANK YOU!

https://ligtas.uplb.edu.ph
http://sesam.uplb.edu.ph

HEAVY RAIN MONITORING AND FORECASTING IN MOUNTAINOUS AREAS AND EARLY WARNING FOR LANDSLIDES

PROJECT LIGTAS