United Nations Office for Disaster Risk Reduction

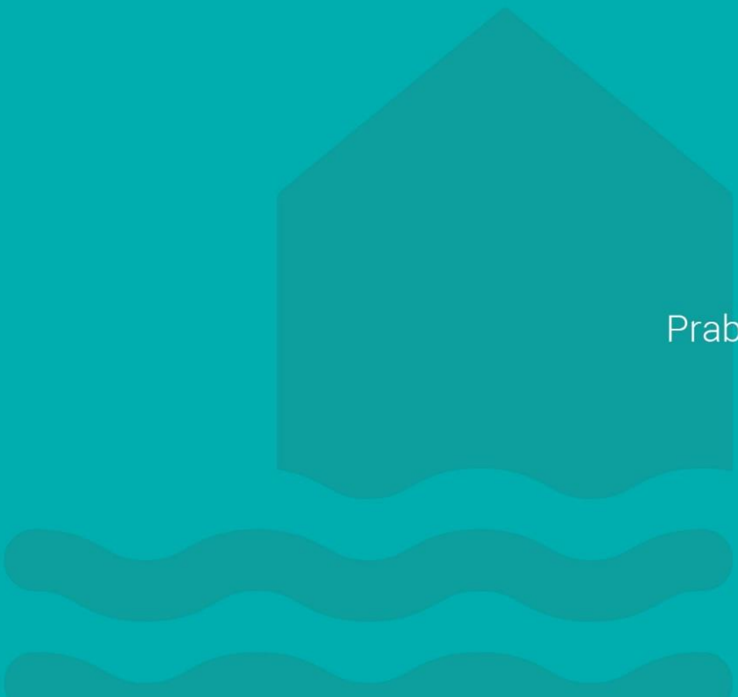
GAR

Global Assessment Report
on Disaster Risk Reduction

2022

CONTRIBUTING
PAPER

Disaster Risk Reduction in the ASEAN region: Understanding and assessing systematic risks of floods and landslides in a river basin context



Pimvadee Keaokiriya
Prabhakar Sivapuram Venkata Rama Krishna
Binaya Raj Shivakoti
Toshihiro Goto
Hirokazu Sakai
Anggraini Dewi
Susantha Jayasinghe
Senaka Basnayke
Rendy Dwi Kartiko
N.M.S.I. Arambepola

Disclaimer:

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities or concerning the delimitations of its frontiers or boundaries. The designations of country groups in the text and the tables are intended solely for statistical or analytical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of the names of firms and commercial products does not imply the endorsement of the United Nations.

Note: The designations employed and the presentation of maps in this report do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities or concerning the delimitation of its frontiers or boundaries.

Some rights reserved. This work is made available under the Creative Commons Attribution-NonCommercial 3.0 IGO licence (CC BY-NC IGO); https://creativecommons.org/licenses/by-nc/3.0/igo/legalcode

Under the terms of this licence, this work may be copied, redistributed and adapted for non-commercial purposes, provided that the work is appropriately cited. In any use of this work, there should be no suggestion that UNDRR endorses any specific organization, products or services.

The use of the UNDRR logo is not permitted. If a translation of this work is created, it must include the following disclaimer along with the required citation below: "This translation was not created by the United Nations Office for Disaster Risk Reduction (UNDRR). UNDRR is not responsible for the content or accuracy of this translation. The original English edition shall be the authoritative edition."

Users wishing to reuse material from this work that is attributed to a third party, such as tables, figures or images, are responsible for determining whether permission is needed for that reuse and for obtaining permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user. Sales, rights and licensing.

UNDRR information products are available for non-commercial use. Requests for commercial use, rights and licensing should be submitted via: **https://www.undrr.org/contact-us**

This publication may be freely quoted but acknowledgement of the source is requested.

Citation: UNDRR (YYYY), *Insert full name of publication*, United Nations Office for Disaster Risk Reduction (UNDRR).

© 2022 UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION

For additional information, please contact:

United Nations Office for Disaster Risk Reduction (UNDRR)
9-11 Rue de Varembé, 1202 Geneva, Switzerland, Tel: +41 22 917 89 08

Disaster Risk Reduction in the ASEAN Region: Understanding and Assessing Systematic Risks of Floods and Landslides in a River Basin Context

Pimvadee Keaokiriya, Climate Change Adaptation - Bangkok Regional Centre, Institute for Global Environmental Strategies, Bangkok, Thailand

Prabhakar Sivapuram Venkata Rama Krishna, Natural Resources and Ecosystem Services, Institute for Global Environmental Strategies, Kanagawa, Japan

Binaya Raj Shivakoti, Natural Resources and Ecosystem Services, Institute for Global Environmental Strategies, Kanagawa, Japan

Toshihiro Goto, Watershed Management Department, CTI Engineering International Co. Ltd, Tokyo, Japan

Hirokazu Sakai, Water Resources Management Division, CTI Engineering International Co. Ltd, Tokyo, Japan

Anggraini Dewi, Geospatial Information Department, Asian Disaster Preparedness Center, Bangkok, Thailand

Susantha Jayasinghe, Climate Resilience Department, Asian Disaster Preparedness Center, Bangkok, Thailand

Senaka Basnayake, Climate Resilience Department, Asian Disaster Preparedness Center, Bangkok, Thailand

Rendy Dwi Kartiko, Landslide Hazard Specialist (Researcher), Geological Engineering Department, Bandung Institute of Technology, Indonesia

N.M.S.I. Arambepola, Senior Expert for Landslide Risk Management

Keywords: disaster risk reduction; climate change adaptation, water-related disasters; risk assessment; risk mapping; systematic risks; ASEAN

Contents

Introduction

The Southeast Asian Nations are undergoing rapid socio-economic transformations with associated dynamic changes in the hazard, vulnerability and risk characteristics. Climate change and human induced factors such as dense human settlements and socio-economic activities near fragile areas are expected to exacerbate these risks acting as a threat multiplier. Institutions in Southeast Asian countries are putting in place overarching disaster risk reduction plans and policies from national to local level; and rapidly progressing towards localizing them to specific sectors with robust implementation at the community level. There is a need to strengthen these efforts by addressing the systemic risks[1] brought by climate change affecting the disaster vulnerability.

This project followed a recent study[2] on the status of disaster risk reduction (DRR) and climate change adaptation (CCA) integration in institutional and policy framework in ASEAN, identifying, flood and landslide as two most common disasters in the ASEAN region (JICA 2019). Furthermore, it also pointed to hazard and risk assessments integrating future climate change projections as the region's highest priority. ASEAN Member States (AMSs) concurred with these findings and further committed their efforts to address the direct effect of climate change on disasters by linking DRR and CCA as outlined in the ASEAN Agreement on Disaster Management and Emergency Response (AADMER) Work Programme 2016-2020[3]. Backed up by these evidences from the ground, ASEAN Leaders, through the ASEAN Committee on Disaster Management (ACDM) stepped up efforts towards further study.

Keeping the above background in view, a project was implemented to assess the systemic risks of floods and landslides in selected river basins by integrating climate change projections into risk assessments in cooperation with the ASEAN Working Group on Prevention and Mitigation (WG P&M) of the ASEAN Committee on Disaster Management with support from the Japan-ASEAN Integration Fund (JAIF). This paper presents the results of the project succinctly and outlines the guidelines developed for practitioners and decision-makers to understand systemic risks and address systemic risks through planning processes. Developing forward-looking risk assessments equipped decision-makers with the ability to manage rapidly changing risk profiles because of climate change and related uncertainties.

Methodology

The project on 'Disaster Risk Reduction by Integrating Climate Change Projections into Flood and Landslide Risk Assessment' was jointly implemented by ASEAN and a consortium of knowledge institutions consisting of the Institute for Global Environmental Strategies (IGES), CTI Engineering International Co., Ltd. (CTII) and the Asian Disaster Preparedness Center (ADPC). The focus was on selected river basins in Lao PDR and Myanmar with two separate river basins for floods and landslides, constituting four river basins in two countries. Each river basin was treated as a case study to develop the methodology necessary for flood and landslide risk assessment integrating climate change projections relevant for the ASEAN

---

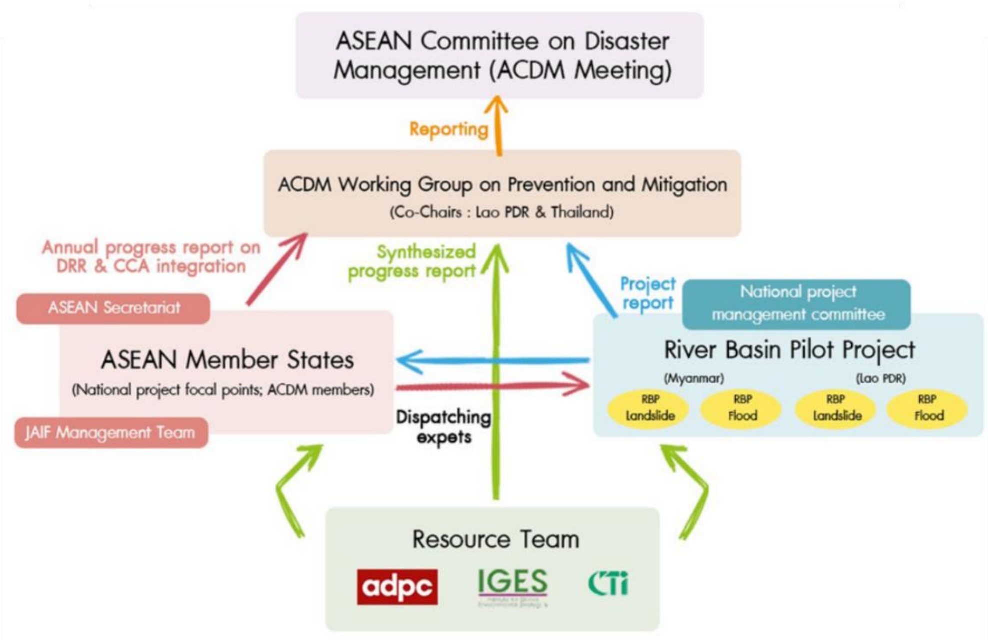
[1] Systemic risk is defined as "risk that is endogenous to, or embedded in, a system that is not itself considered to be a risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change." UNDRR, GAR 2019.

[2] http://libopac.jica.go.jp/images/report/12303509.pdf

[3] https://www.asean.org/wp-content/uploads/2016/02/AADMER-Work-Programme-2016-2020-v1.6.pdf

region. The final output of case studies developed a common methodology for flood and landslide risk assessments as guidelines to assist practitioners and policymakers incorporate climate change projections into flood and landslide risk assessments. Each case study also developed a technical report[4] that elaborates the technical results of risk assessments that support the guidelines prepared in the project. The systemic risks were assessed for floods and landslides. Sectors covered included disaster management, water resources, urban planning including housing sector, road sector, natural resources and agriculture.

Figure 2-1. Implementation Structure of the Project.



The project adopted a methodological framework, highlighting 4 key stages as presented in Figure 2-2.

The first *risk assessment preparatory* stage consists of a conceptual understanding of flood and landslide risk and the role of climate change in shifting the risk profile dynamics, as well as getting acquainted with essential assessment strategies, institutional arrangement, data and information preparation. The next step in the process is characterizing flood and landslides based on the changing profile of hazards triggered by extreme hydrological events, biophysical (topographic, soil, geological, land use and land cover) factors, and developmental and environmental changes.

The second stage is the *development of future climate change projection and scenarios* which included (1) predicting future climate changes scenarios with using GCM datasets, (2) developing climate change projections, (3) selecting suitable climate scenarios, (4) global climate model projections, (5) downscaling and (6) impact modelling and estimating the uncertainties. These steps introduce recent advances in climate scenario development and explains scenario application for flood and landslide hazard& risk assessment.

---

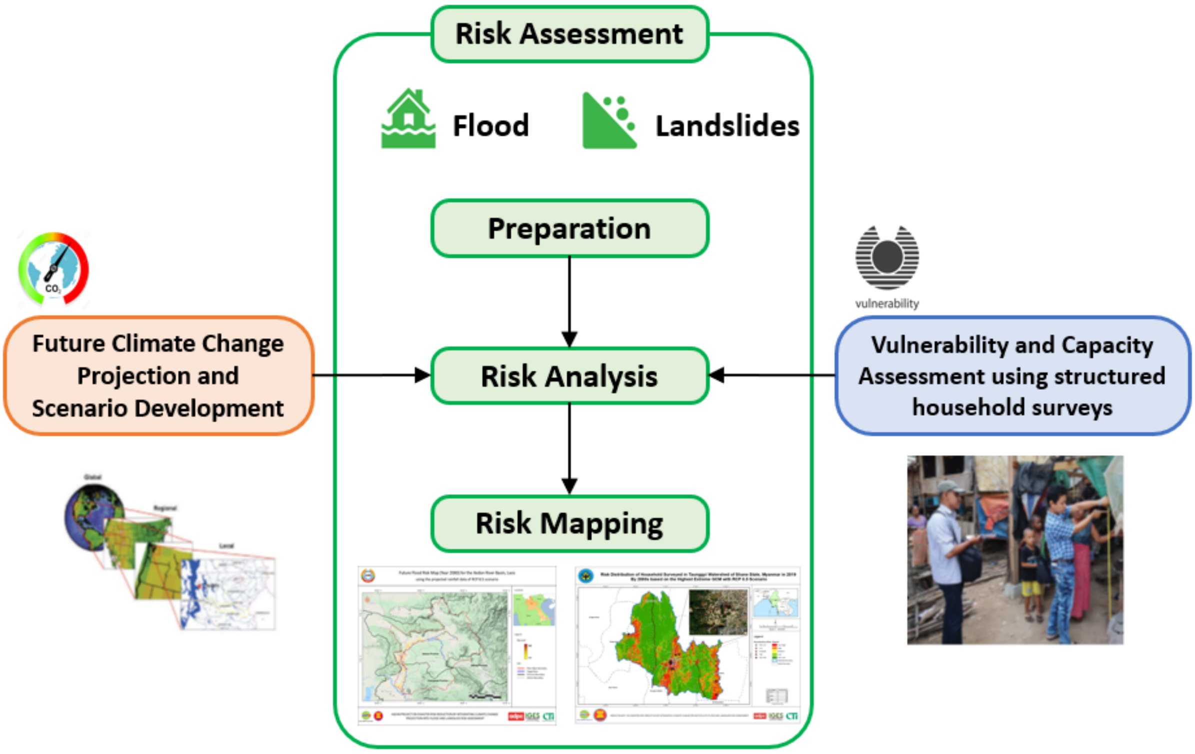
[4] https://aseandrr.org/guideline/flood-guideline ; https://aseandrr.org/guideline/landslide-guideline

The third stage is the *vulnerability and capacity assessment* using structured household surveys. A set of questionnaires were designed to collect indirect/direct impacts of disasters, collect socio-economic data to assess their vulnerability and capacity to respond to disaster. Disaggregated data (e.g. by sex, age, disability, ethnicity, income or geographic location) helped revealed the differential impacts and experiences of people in specific contexts, elements under risk and gender specific vulnerabilities and response capacity.

The fourth stage as the last stage involves *risk assessment combining flood and landslide hazard (which integrated future climate scenarios), vulnerability and capacity assessments*. Hazard and risk maps covering the study areas at river-basin scale with and without climate change with different RCP/climate scenarios, different special scales were developed. These model-based projections of future climate indicated changing temperatures, precipitation and rise in disaster risks.

River basin pilot (RBP) teams were formed at national and sub-national level, comprising of members from different line ministries. The team engaged and contributed to the data collection and analysis on hazard, vulnerability and risk assessment. Data collection was carried out at national, river basin and sub-river basin levels, supplemented by open-source data.

Figure 2-2 Overall methodological framework.



Methodology for flood risk assessment

Target flood

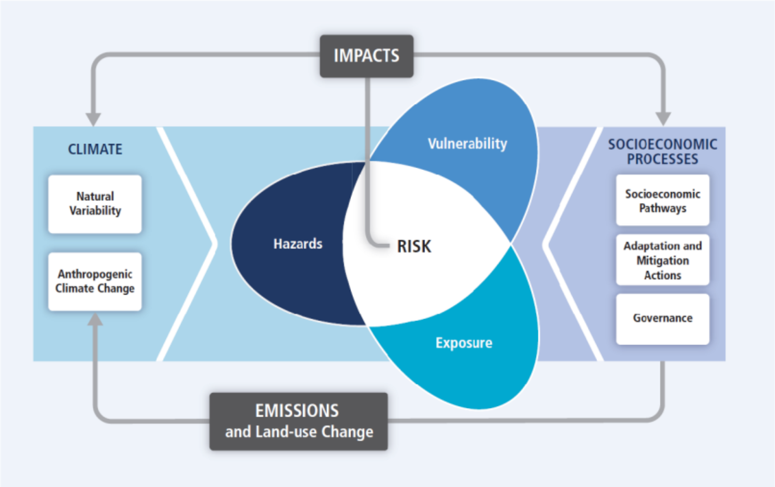
The study focuses on fast flood caused by extreme rainfall where water level rises over the danger level and down to the safe level within one week (relatively short duration), and excludes floods from sewage system origin (inland flood due to poor drainage). Climate change impact on rainfall and sea level rise is also incorporated in the project.

Flood risk was defined as a combination of the probability and the potential consequences of flooding. Based on IPCC's Fifth Assessment Report (AR5), risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems as shown in Figure 2-3.

Flood risk in this project is defined by the following equation:

$$Flood\ Risk = Hazard\ with\ probability \times Exposure \times Vulnerability$$

Figure 2-3. Core concepts of climate-related risks.



Source: IPCC AR5 WGII SPM Figure SPM.1

Flood hazard and risk analysis framework

There is a general awareness on necessity of conducting flood risk assessments in the ASEAN countries as indicated by the series of consultation meetings organized by the project team. However, this general awareness has not resulted in developing robust risk assessment methods and using the risk assessments for decision making on the ground for various reasons. Some of these reasons, as understood by the project team through consultations, is the lack of adequate technical skills on how to conduct these risk assessments at the level (both in the number of experts and their accessibility to the stakeholders engaged in disaster risk reduction planning and implementation). Other limitations include gaps in hydrometeorological/geological data, and lack of sufficient budget. Hence, there is a need to develop a methodology that is simple and is based on the local needs, strengths and weaknesses so that various stakeholders can readily utilize the methodology.

The flood hazard and risk analysis framework was decided based on project objective, data availability, target river basin characteristics, etc. The method was developed using free software to be widely applicable and used in the region. Figure 2-4 outlines the flood risk analysis in the two case studies and Figure 2-5 illustrates the flood simulation process adopted for this project.

Figure 2-4. Flood hazard and risk analysis outline adopted in the project.

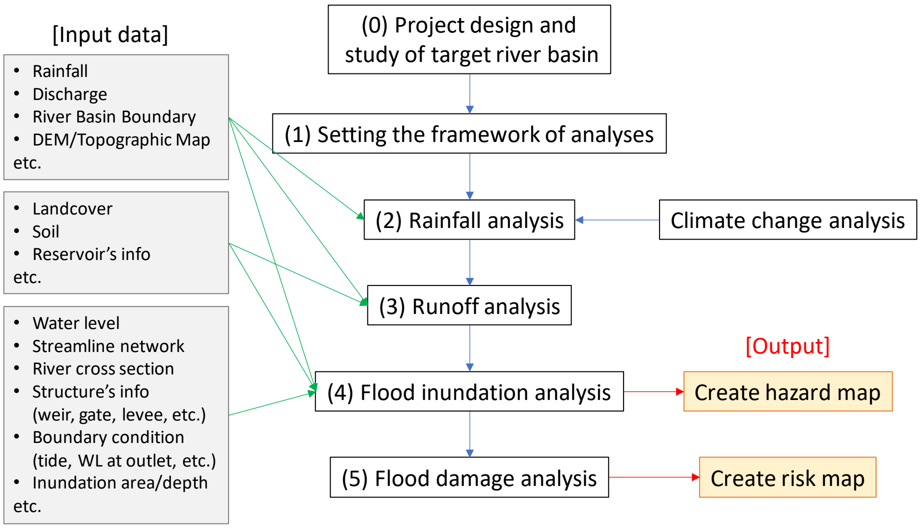
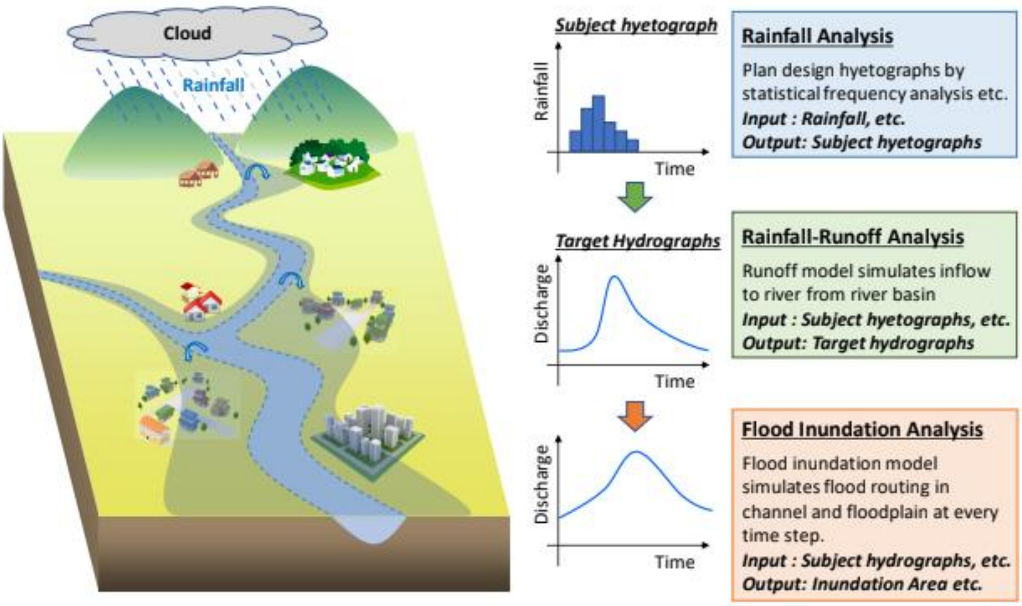


Figure 2-5. The flood simulation process adopted in the project.



Target flood planning

Identifying target floods based on observed discharge or rainfall

Identifying probable floods requires statistical frequency analysis based on either observed discharge data or observed rainfall data. Strengths and weaknesses of the two methods are summarized in Table 2-1. Based on the hydrometeorological data collected, only few observed discharge data were available. Therefore, rainfall based statistical frequency analysis was adopted for this case study due to limited discharge data.

Table 2-1. Statistical frequency analysis comparison based on discharge and rainfall.

	Discharge based	Rainfall based
Strengths	• Able to set probable flood hydrographs based on observed data	• More rainfall than discharge data is likely available (statistical frequency analysis requires a long period of records) • If there is no observed rainfall data, satellite rainfall data can be used as an alternative
Weaknesses	• Samples should be processed before the analysis, considering the effects of upstream inundation and flood control by dams, retarding ponds, etc. • May exclude the effects of human activity (land-use change, city development, river improvement works, etc.)	• Includes errors and uncertainty from the adopted rainfall-runoff model (A rainfall-runoff model is required to set probable flood hydrographs)

Identifying the flood reference point (flood control point)

Since hazardous rainfall patterns are different, even in the same watershed, a flood reference point (flood control point) should be identified to define the target hyetograph when assessing flood hazard based on rainfall data. Flood reference points define the target area for rainfall analysis and serves as locations for hydrological and hydraulic analyses. They should be set in consideration of the following:

- Availability of sufficient hydrological data for hydrological and hydraulic analysis;
- Locations just/around upstream of most important target areas for the flood mitigation plan;
- Locations that have a close relationship with other plans (national/city development plans, etc.)

If there are more than two flood reference points set in a river basin, flood hazard and risk analysis should be conducted for each point. Since flood reference point was not planned in the target river basins, one flood reference point was identified for each target river basin in this case study.

Selecting target hazard magnitude

Majority of ASEAN countries adopted no more than 100-year flood as the design flood in their mitigation plan. A 100-year flood was therefore set as the maximum, with 2, 5, 10, 20, 30, 50 and 100-year probable floods.

Incorporating climate change impact in target hyetographs

The impacts of climate change on rainfall increase and sea level rise were considered in this study. The amount of rainfall increase was projected based on GCMs (general circulation models) (method and results are explained in a separate document), with the projected rainfall increase ratio incorporated into a rainfall based hyetograph by stretching the hyetograph with the rainfall increase ratio. Sea level rise was assumed based on a literature review, and this rise was incorporated into the boundary condition of a stage hydrograph in a flood inundation model. Case studies for climate change are shown in Table 2-2. A total of 12 cases (2 risk levels times 2 scenarios times 3 target years) were studied.

Table 2-2. Climate change case studies

Item	Target case
Risk level (selection of GCM)	High risk case, (Low risk case)
Scenario	RCP4.5, RCP8.5
Target year	2030, 2050, 2080

Study cases

The study cases for flood hazard and risk mapping are shown in Table 2-3. In addition to the 6-cases with climate change impacts explained above, 1-case without climate change impacts and 1-case representing historical flood were studied.

Table 2-3. Flood hazard and risk mapping case studies

Item	Study case
Target river basin	2 (Xedon river basin/Bago river basin)
Flood reference point	1 for each target river basin
Watershed condition	1 for current conditions (scheduled projects and future land-use change are not considered)
Meteorological condition	50 cases total
for representative historical flood	1 case
without climate change impacts	1 case with the 7 different probabilities
with climate change impacts	6 cases with the 7 different probabilities

Modeling structure

The overall structure of modeling was considered before starting as rainfall analysis, runoff analysis and flood inundation analysis are all connected. Modeling requirements are summarized in Table 2-4.

Table 2-4. Modeling requirements

Target outputs	Flood hazard maps and risk maps
Target scale (area)	Whole river basin scale
Target flood	Probable floods with/without climate change impacts
Priorities of model	✓ High applicability for various situations, including low data availability in ASEAN countries ✓ High computation reliability and stability ✓ Free and user-friendly software is desirable

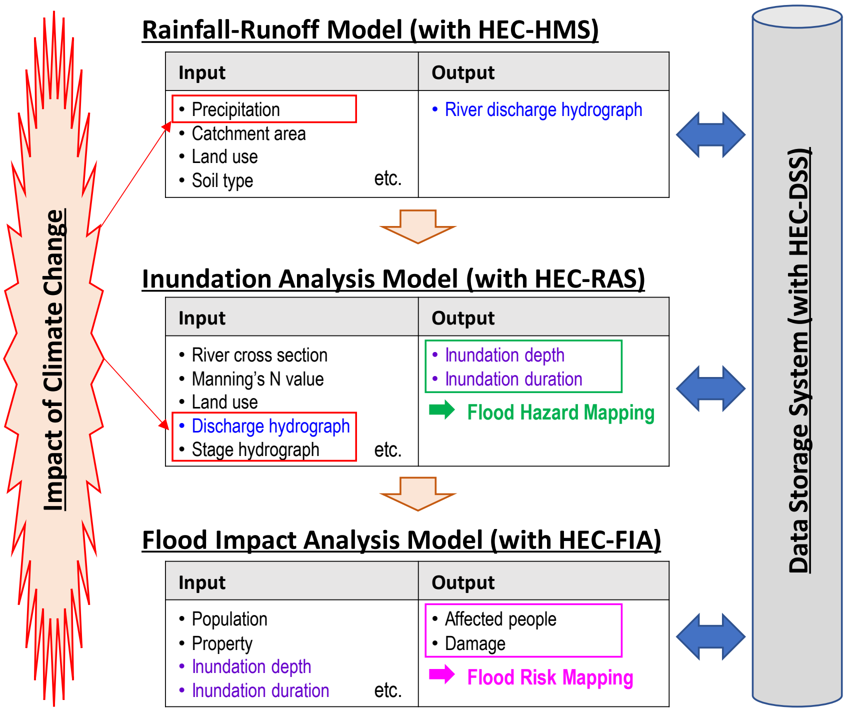
Software selection

A set of open-source software (OSS) were used (1) the OSSs are available for public use for free of charge, and (2) suitable for the users' needs. The HEC-HMS (Hydrologic Modeling System), HEC-RAS (River Analysis System) and HEC-FIA (flood impact analysis) developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (CEIWR-HEC) were selected for rainfall-runoff analysis, flood inundation analysis and flood damage analysis for the following reasons:

- Free, but equipped various sophisticated functions;
- Widely acknowledged to be reliable with stable computation scheme;
- Widely used with available reference materials (user guide, manual, thesis, training courses, etc.).

The HEC software series can simulate a rainfall-runoff model, a flood inundation model and a flood impact (damage) model as shown in Figure 2-6.

Figure 2-6. Flood hazard and risk analysis modeling framework



In rainfall-runoff modeling, Semi-distributed model applying the SCS curve number method was created by HEC-HMS (Figure 2-5). The workflow appears in Figure 2-7. In flood inundation modeling, the coupled 1D and 2D unsteady flow model was created by HEC-RAS (Figure 2-6). The workflow appears in Figure 2-8. In flood damage modeling, HEC-FIA (Flood Impact Analysis) was used to evaluate the consequences from events defined by hydraulic model output such as gridded data (for example, depth, duration and arrival time grids). The workflow appears in Figure 2-9. The HEC-FIA computed economic losses (losses to structures and their contents), agricultural losses, and expected life loss. The direct damage to structures and crops were the key target for this study, other indirect damages such as business income and labor pool reduction due to infrastructure damage, house cleaning costs, etc. were not included.

Figure 2-5. HEC-HMS modeling workflow

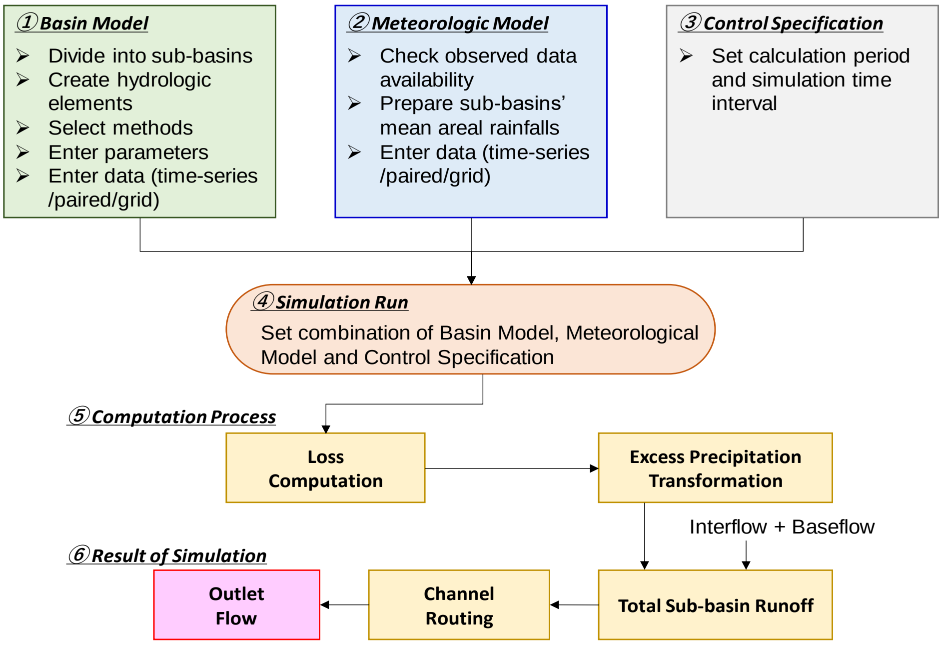


Figure 2-6. HEC-RAS modeling workflow

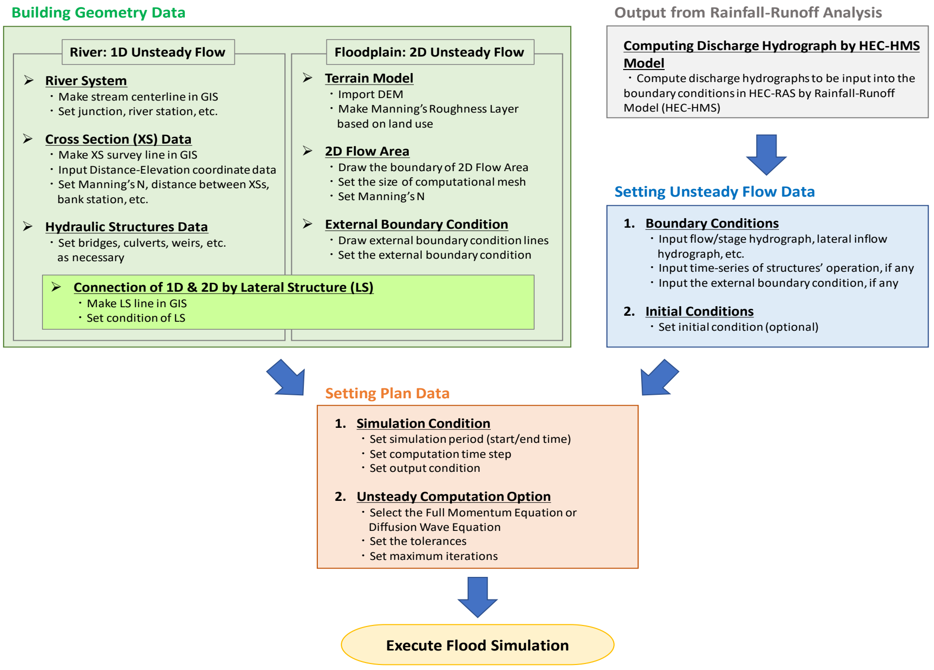
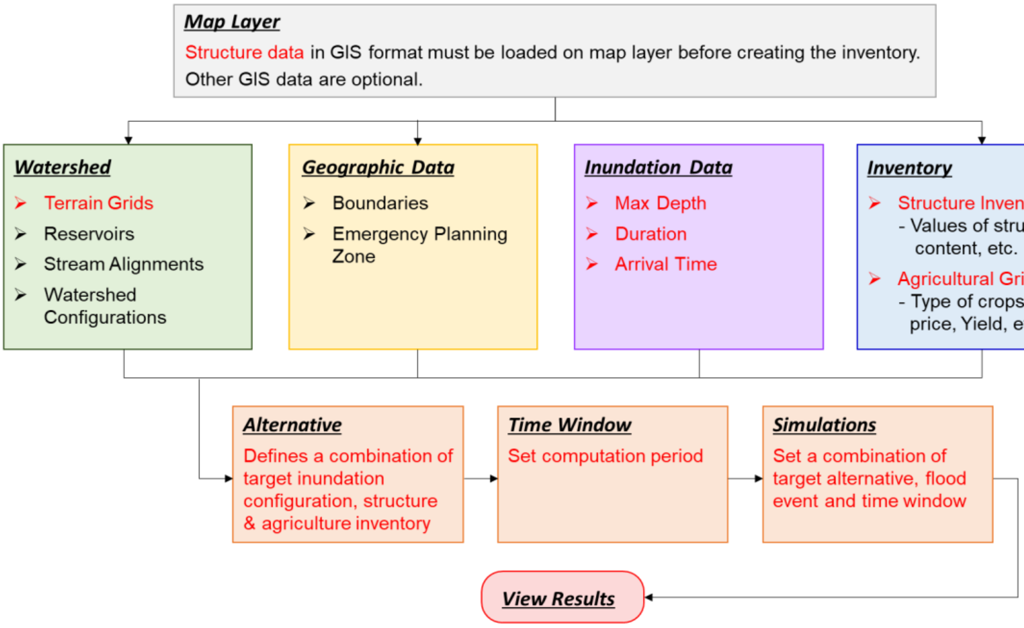


Figure 2-7. 9 HEC-FIA modeling workflow



*Red colored data must be created to compute HEC-FIA structural and agricultural damage. Other is optional.

The three created models (HEC-HMS, RAS, FIA) should be calibrated with historical representative floods, although the HEC-FIA model was not calibrated due to limited economical loss data. All the simulation cases were tested and results were checked. The average annual damage (AAD) were calculated as follows:

$$AAD = \sum_{1}^{n} \frac{(D_{i-1} + D_i)}{2} \times (P_{i-1} - P_i)$$

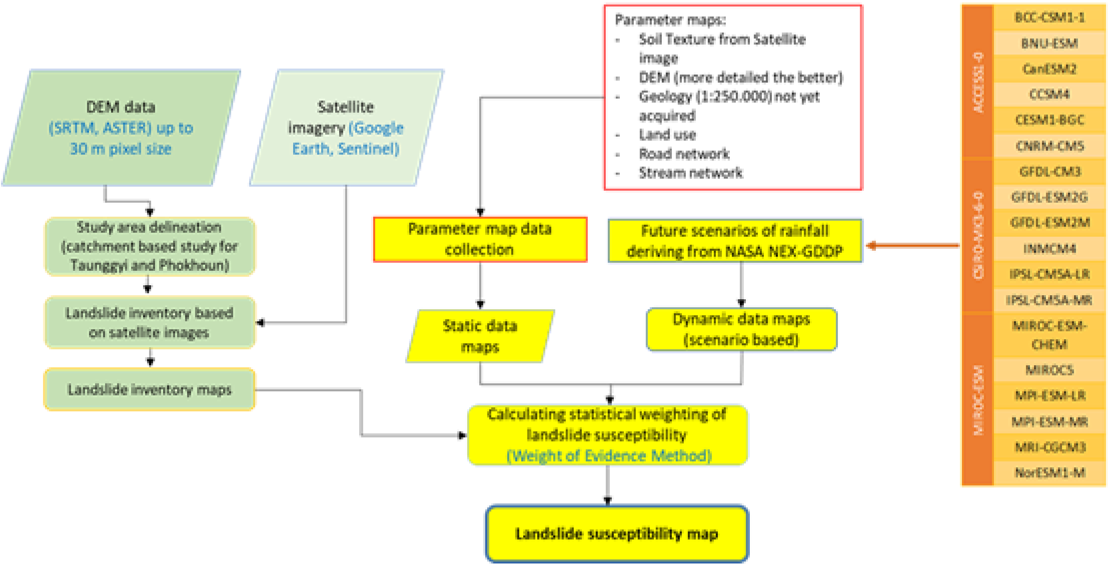
Where: AAD is the average annual damage, P_i is the annual exceedance probability (AED), D_i is the damage caused by the flood event of the AED (P_i)

After the computation of AAD by calculation grids, the computed AAD were visualized using GIS software (QGIS was used in the case studies) for flood risk mapping.

Methodology for landslide risk assessment 2.2.1. Landslide susceptibility mapping

The main conditional factors (static maps) considered for susceptibility mapping were lithology, land use and land cover, slope, aspect and landslide inventory. The causative factor (dynamic maps) considered was rainfall derived from climate projection scenarios. The methodology adopted in this study is shown in Figure 2-8.

Figure 2-8. Landslide susceptibility analysis flowchart using Weight of Evidence



The preparation and analyses have been done in a GIS environment, and the results are presented as maps. Conditional factors and parameters spatial data were built in the GIS environment using QGIS as discussed in the following section. Slope gradient was generated from the DEM of a 30-meter pixel SRTM. Before generating a slope gradient, the map projection was translated into a specific geographical area UTM (meter units), for example UTM zone 48N (for Lao PDR).

Figure 2-9. Slope gradient process

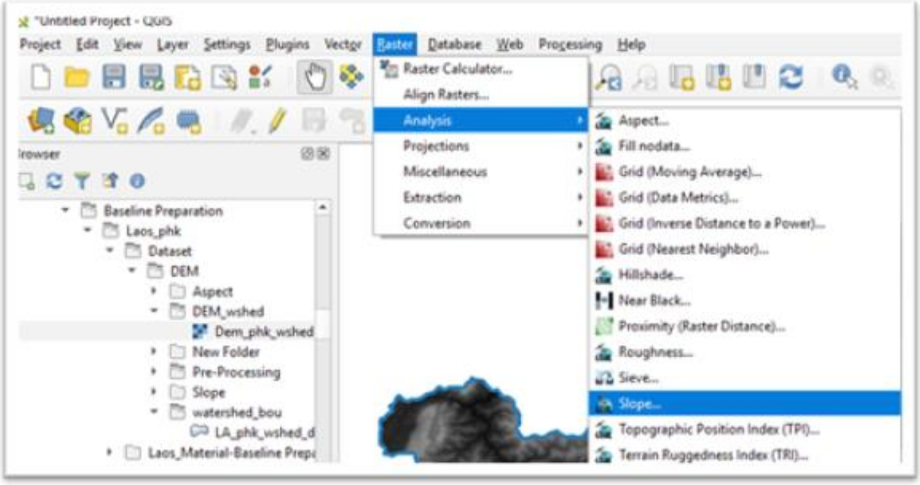
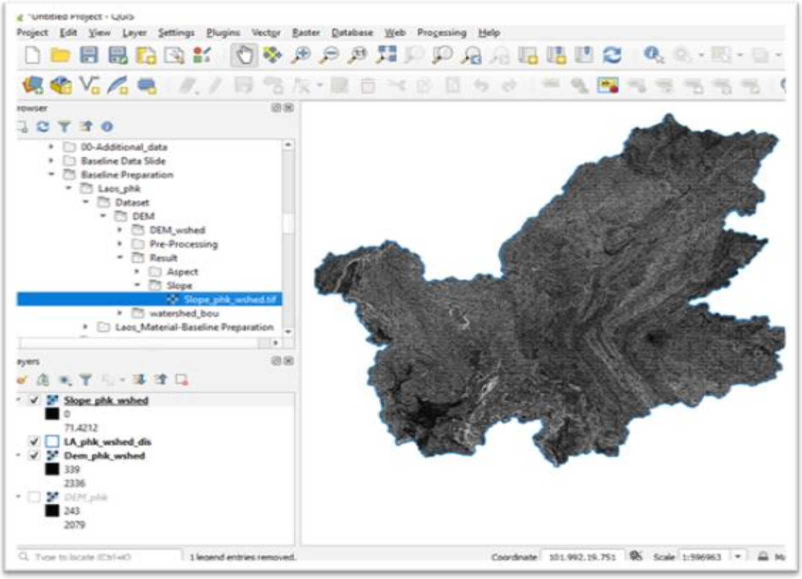
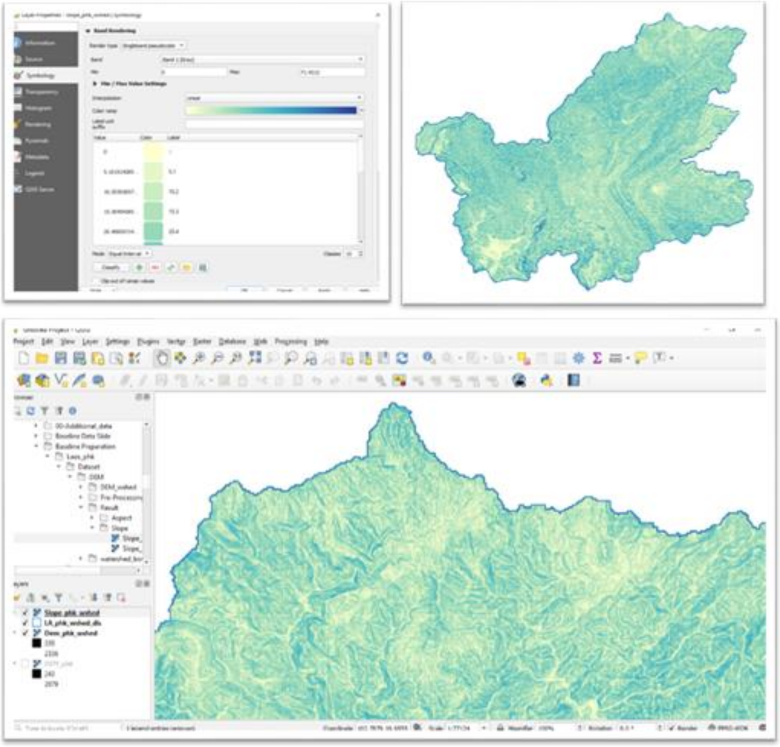


Figure 2-10. Slope in QGIS



Slope gradient was generated from a Digital Elevation Model (DEM) of SRTM 30-meter pixel. The slope gradient varied from 0° to around 71.42° within the watershed area. The mean value of slope was 20.71°, with a standard deviation of approximately 8.99. Slope gradient was reclassified into 15 classes for the landslide susceptibility analysis.

Figure 2-11. Slope classification



Aspect was classified according to the slope angle with a descriptive direction. An output aspect raster (horizontal lines composed of individual pixels) typically result in several slope direction classes. Aspect was measured clockwise starting north at 0° and returning back to 360° north. After running the aspect tool, the output raster symbolizes aspect direction based on slope angle. Each slope direction will represent a slope angle range. Reclassifying the aspect map can be done through changing the symbols and setting the number of classes. Aspect was reclassified into 9 classes for the landslide analysis.

Proximity to roads was considered a potentially important factor because road construction usually includes land or material excavation in some slope areas and the addition of land or materials to the slope in other areas. This may result in slope line changes, artificial slope creation or road cuts that might be affected by landslide activities (Che et al., 2011). Proximity to road were regrouped into six classes.

Proximity to a river may adversely affect slope stability due to slope toe undercutting, or saturation in the lower part of the slope, resulting in a water level increase. The land use and land cover map were derived from the regional land cover monitoring system developed by the SERVIR-Mekong program. Series of annual land cover maps with multi-purpose typologies using Landsat images from 2000-2017 at a 30-meter resolution were produced. Hydro-meteorological data consisted of precipitation (mainly rainfall) time-series. Temperature and humidity were collected from ground observation stations, and remote sensing sources. In this study, rainfall datasets used for the RBPs was derived from historical climate data and future climate projections. Historical disaster data (location, type, damage scale, response, etc.) and subsequent landslide inventory preparation are important for generating landslide hazard/susceptibility maps. The map exercise and risk assessment process is based on statistical methods. A landslide inventory was built using past records and high-resolution satellite imagery, such as Google Earth or Sentinel. Currently there are no comprehensive landslide inventory databases covering the case study area. In the absence of these detailed inventories, an inventory covering the study areas was created using free access satellite images, such as those from Google Earth. This additional landslide inventory data would help generate better landslide susceptibility prediction accuracy.

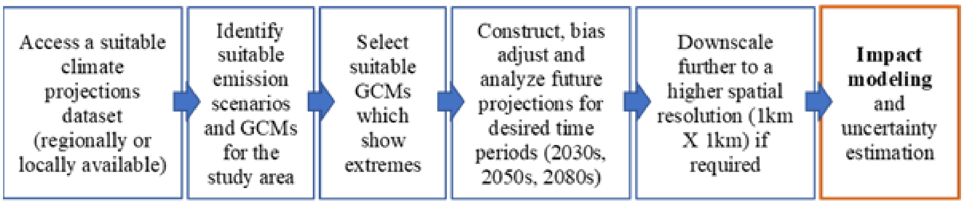
Hydro-meteorological data consists of precipitation (mainly rainfall) time-series data was derived from historical climate data and future climate projection scenarios.

Downscaling of climate change projections

One of the critical challenges for scenario development is to downscale global and regional scale projections into a watershed scale. This process is fraught with high uncertainty. As a result, utilization of downscaled results at the local or watershed level is far from straightforward. It needs to adopt a cautious approach and filter the results by contrasting them with the local context. A good understanding of observed data, climate simulations and projections mechanisms and uncertainties is essential to develop realistic scenarios and properly assess the risks in each local context.

The climate impact modeling process for identification of extreme events at the watershed or local scale consists of six methodological steps as shown in Figure 2-12.

Figure 2-12. Impact modeling steps for assessing risk from extreme landslides at the watershed scale using downscaled GCMs



The Coupled Model Inter-comparison Project Phase 5 (CMIP5) is the latest dataset available with simulation from the new generation of GCMs (Rupp et al., 2013). There are more than 40 GCMs in the CMIP5 archive developed by various meteorological organizations and agencies that include different spatial resolutions. In the Fifth Assessment Report (AR5) of the IPCC, climate simulations have been carried out for the 21st century according to representative concentration pathways (RCPs) based on four greenhouse gas (GHG) concentration trajectories (Demirel and Moradkhani, 2016).

RCPs are the latest generation of scenarios that provide input to climate models. These pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in future years. There are four pathways: RCP8.5 (high emissions), RCP6.0 (intermediate emissions), RCP4.5 (intermediate emissions) and RCP2.6 (low emissions). The goal of working with scenarios is not to predict the future but to better understand uncertainties and alternative futures, in order to consider how robust different decisions or options may be under a wide range of possible futures.

The NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30) dataset is the only globally available set of downscaled climate scenarios that is derived from the GCM runs conducted under CMIP5 (Taylor et al. 2012) and across the four GHG emission scenarios known as RCPs (Meinshausen et al. 2011) developed for IPCC AR5. The dataset includes downscaled projections from 21 models, as well as ensemble of statistics calculated for each RCP from all available model runs. The purpose of these datasets is to provide a set of high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions. Each of the climate projections includes monthly averaged maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2005 (retrospective run) and from 2006 to 2099 (prospective run).

The bias correction and spatial disaggregation (BCSD) approach used in downscaling the dataset inherently assumes that the relative spatial patterns in temperature and precipitation observed from 1950 through 2005 will remain constant under future climate change. Other than the higher spatial resolution and bias correction, this dataset does not add information beyond what is contained in the original CMIP5 scenarios and preserves the frequency of periods of anomalously high and low temperature or precipitation (i.e., extreme events) within each individual CMIP5 scenario. The purpose of these datasets is to provide a set of global, high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients, as well as evaluate the effects of local topography on climate conditions. The sets also assist the science community for understanding climate change impacts at local, national and regional levels and to enhance public understanding of these impacts' possible consequences. Table 3.1 summarizes the data field description for the NASA Earth Exchange-Global Daily Downscaled Projections (NEX-GDDP).

CHIRPS precipitation data from Climate Hazard Group (CHG), with 5x5 km2 resolution, is available from 1981 to date. APHRODITE project precipitation data from Research Institute for Humanity and Nature(RIHN) and the Meteorological Research Institute of Japan Meteorological Agency (MRI)/JMA), with 25x25km2 resolution, is available from 1951 to 2007. For temperature, ERA5 reanalysis temperature data (https://cds.climate.copernicus.eu), is available starting from 1950. In addition, in-situ observed meteorological data (rain gauge, temperature data) over a longer period is also needed for result verifications and GCM bias corrections.

Climate projection data selection needs a thorough review to access and acquire future climate change data with acceptable horizontal resolution to assess impacts of future climate relevant sectors in target countries. The NEX models (CMIP5 models), which has future climate change scenarios from 21 GMCs under two emission scenarios (RCP 4.5 and 8.5) with 25x25 km2 resolution provides a good database for starting analyses, in particular for a regional analysis.

Table 2-5. Field Description for NEX-GDDP

CMIP5 models included	21 GCMs ACCESS1-0, CSIRO-MK3-6-0, MIROC-ESM, BCC-CSM1-1, GFDL-CM3, MIROC-ESM-CHEM, BNU-ESM, GFDL-ESM2G, MIROC5, CanESM2, GFDL-ESM2M, MPI-ESM-LR, CCSM4, INMCM4, MPI-ESM-MR, CESM1-BGC, IPSL-CM5A-LR, MRI-CGCM3, CNRM-CM5, IPSL-CM5A-MR, NorESM1-M
RCP scenarios	RCP 4.5 and RCP 8.5
Temporal resolution	Daily from 1950-01-01 to 2100-12-31 from 1950 through 2005 ("Retrospective Run") and from 2006 to 2100 ("Prospective Run")
Spatial Resolution	0.25 degrees x 0.25 degrees
Climate Variables	Precipitation, maximum and minimum temperature
Dataset Projection and Datum	Geographic, WGS84
Data Access	https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp

All CMIP5 GCMs are not applicable for all regions of the globe. Based on the region of interest, GCMs should be selected from those available under CMIP5. For example, in the case of the RPB in Phoukhoun, Lao PDR, a selection of suitable GCMs for the target areas was carried out based on published reports and journal papers such as *Evaluating the performance of the latest climate models over Southeast Asia* published by CSIRO, Australia for the Asian Development Bank (ADB) (Hernaman et al., 2017). The report was used to identify and select suitable models for the Southeast region, including Lao PDR and Myanmar. This literature identified a subset of CMIP5 models based on a set of metrics that avoided least realistic models but included models to capture the maximum possible range of change with satisfactory performance across all the metrics. On the basis of these studies, target area GCMs were selected as shown in Table 2-5 and Table 2-6.

Table 2-6. Target area GCMS selected for Lao PDR and Myanmar

Target Area	Selected GCMs
Lao PDR	bcc-csm1-1, BNU-ESM, CanESM2, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-MR, MPI-ESM-LR, MPI-ESM-MR
Myanmar	bcc-csm1-1, BNU-ESM, CanESM2, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-MR, MPI-ESM-LR, MPI-ESM-MR

Landslide Susceptibility Map Zoning using Weight of Evidence

Calculation of each particular predictive hazard variable involves assigning a positive weight (W+), when the event occurs and a negative weight (W-), when the event does not occur. The weights are measures of correlation between evidence (predictive variable) and event, making them easy to interpret in relation to empirical observation. Formulation is based on density functions. Weights (Wi) of each cell (ith pixel) are determined by the equation:

$$Wi = \Sigma(j = l)^n \, Wj^k$$

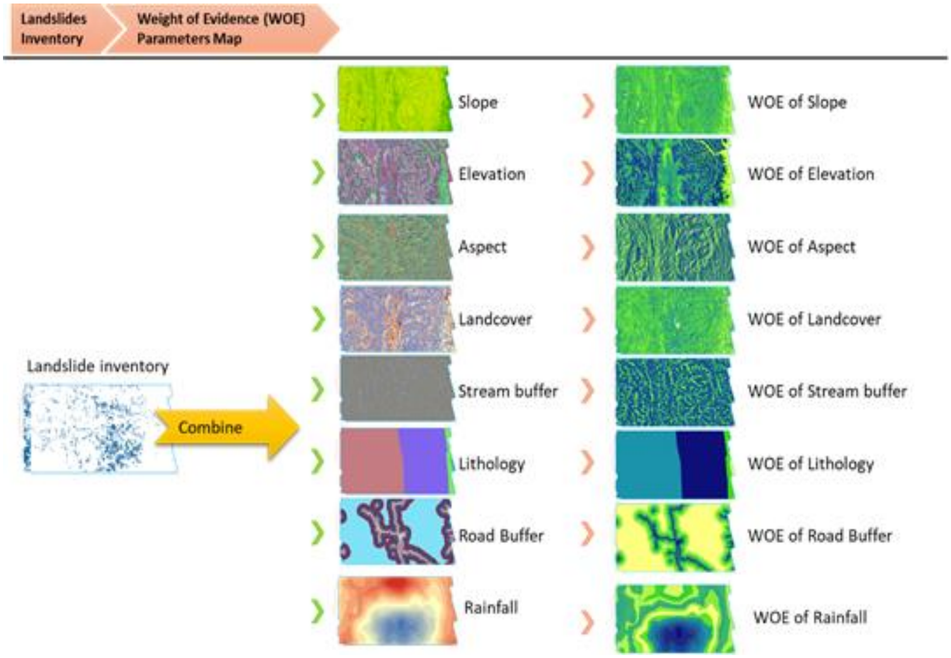
Where Wj is a parameter of the jth class and Wk signifies positive and negative weight values. Controlling landslide factors can be mapped with this method. The weights can be used to produce a contrast value (C) for the specific susceptibility variable.

$$C = W^\wedge + -W^\wedge -$$

The difference between weights (C) provides a measure of strength of correlation between the analyzed variable and the landslide.

Susceptibility zoning uses GIS to overlay the WOE (weight of evidence) parameter maps. The overlaid map is first divided into approximately 255 classes (the more classes the better) at equal intervals from high to low WOE. These classes are then analyzed with a landslide occurrence using the raster analysis.

Figure 2-13. Landslide susceptibility assessment using WOE (where rainfall data was derived from future climate scenarios)



Vulnerability and Capacity Assessment

Indicator identification and prioritization: An exhaustive list of landslide vulnerability and capacity indicators were listed from the published literature in Asia and beyond. These indicators were entered into an Excel worksheet and these indicators were tallied with the available data with the official data sources in the project countries during the reconnaissance stage of the project and during the consultation meetings with the policy makers, administrators and research and expert communities. These consultations have helped the project team to narrow down to a limited list of vulnerability and capacity indicators that the project team could utilize. Considerations such as human and financial resource availability, length of time taken for conducting detailed data collection exercises etc. also helped to narrow down the list of indicators as this process helped indicators to be more location-specific.

Landslide vulnerably scoring (LVS) was used for assessing household landslide vulnerability. It is a qualitative method of assessing landslide vulnerability of individual households wherein the scores are assigned to individual indicators based on the value an indicator takes and how those values correspond to the overall vulnerability that is constructed as a range (i.e. 0 means no vulnerability and 1 means high vulnerability).

Assigning scores: The basis for LVS is the published literature (e.g. for below poverty line, etc.), wherever possible, and expert judgements. For assigning the ratings, a structural elements resistance factor is used. However, due to lack of resistance factors for the location-specific condition, literature available was used to decide the gradient of ratings allocated to different structural elements (for example, an reinforced concrete (RC) building is considered to have a high resistance factor compared to stone masonry structures; framed structures over load bearing structures etc.). Similarly, recent construction (less than 10 years old) can be considered to have higher resistance than older construction. Scoring mostly follows a binary classification wherever possible to simplify the vulnerability and capacity assessments and for ease in understanding the results. Wherever more resolution is necessary for scoring, ternary and quaternary scores are also assigned.

1) **Data normalization:** Since various indicators can have different ratings that are based on different units of measurement (such as km, years etc.), a linear normalization method has been employed to bring all indicators in a 0-1 scale so that the values can be combined within a category.

   The formula for normalizing the indicator values is given as:

   Normalized value: $$Z_i = \frac{x_i - T_{min}(x)}{T_{max}(x) - T_{min}(x)}$$

   Where:

   x_i is the value of the indicator
   T_{min} is the minimum threshold value of the indicator xi.
   T_{max} is the maximum threshold value of the indicator xi.

2) **Mutual dependencies and hierarchy of indicators:** There is a mutual dependency/hierarchy among the indicators. For example, RC constructions that are recent but have a shallow foundation, or those that do not satisfy the basic conditions of anchoring to bedrock, could be more vulnerable to damage than other types of framed structures, such as bamboo, that are anchored to the bedrock. However, such interdependencies were not considered for this preliminary analysis. These results will therefore have to be updated at the next stage to show these mutual dependencies.

3) **Weightages:** Indicators could take on relative weightings depending on the importance they play in the final vulnerability. For example, if structural vulnerability plays a larger role, due to its physical location or the type of structure, than social vulnerability, structural vulnerability can be given higher weightage in the overall vulnerability. However, such weightages need careful consideration based on evidence (i.e. empirical studies). Since no such studies were available for the study location, all vulnerabilities in this study were considered equal in the final vulnerability determination.

4) **Proxy indicators** were derived for more relevance to the vulnerability and capacity assessment. For example, the distance to the health care center is converted into minimum response time (MRT) equivalent distance (MED) to imply that the difference between the actual distance and the MRD results in higher vulnerability. Similarly, the number of people at home is converted into a household residence time (HRT) to imply the higher the HRT, the higher the vulnerability.

Table 2-6. Priority Socio-Economic Sensitivity Indicators

Indicator	Description
Family without educated members	Counts all households without an educated person. This household has a landslide vulnerably scores (LVS) rating (landslide risk sensitivity)
Vulnerable population	Counts all households with a woman, child, and/or elder older than 60 years. A household that satisfies at least one of these conditions is given an LVS rating of 1, two conditions LVS 2, and 3 conditions LVS 3. This data is then normalized to a 0-1 scale to combine with other indicators.
Female headed household	Counts households that do not have a living male elder. Given an LVS of 1.
Differently abled	Counts households with a physically disabled family member. Given an LVS of 1. This is in addition to gender and age considerations (for example a household with a disabled female will get two LVS values).
Poverty	Counts the monthly poverty income line. Households below the income poverty line are given an LVS of 1.
Access to health	Counts the household’s distance to a health center. Households beyond a 4.5 km radius from the health center are treated with an LVS of 1.
Home vacant time (HVT)	Counts amount of time during the day a household is vacant. Those with less vacant time are considered the most sensitive. Vacant hour values are linear and are given to fall within the LVS range of 0-1.
Rate of service interruption	Counts the average rate of service (such as water, electricity etc.) interruption (in percentage) with linear values and is given an LVS range of 0-1.
Interruption duration	Counts number of days of interruption (of water, electricity, etc.) with linear values, and is given an LVS of 0-1.

Table 2-7. Priority Physical Sensitivity Indicators

Indicator	Description
Slope of the land	Counts all households located on a slope of greater than 15%. These are considered sensitive and are given an LVS of 1.
Living floor	Counts household living on the ground floor. This household type is considered sensitive (in accordance with earthquake literature), and given an LVS of 1.
Building age	Counts buildings more than 10 years old, given an LVS of 1.
Architectural Approval	Counts buildings without architectural/formal approval, given an LVS of 1.
Foundation type	Counts buildings that used clay aggregates or rubble in construction, given an LVS of 1.
Bedrock anchoring	Counts buildings with foundations reaching or anchored in bedrock and are given an LVS of 0 (not sensitive).
Nature of walls	Counts load bearing wall structures, and given an LVS of 1.
Damage susceptibility rating	Self-assessed damage susceptibility ratings ranging between 1-10 are linear, normalized to LVS values.

Capacity Assessment

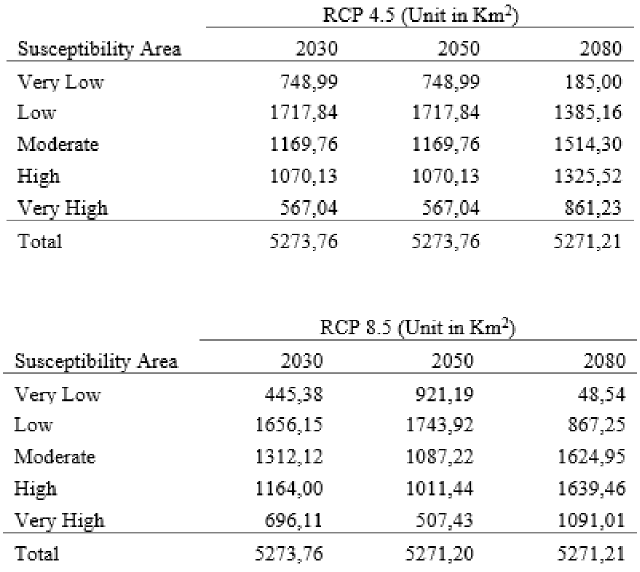
Capacity is a combination of all the resources that exist within a household, community, group, or organization that can reduce the level of risk or disaster impact.[5] A capacity assessment identifies the strengths and resources available to each individual, household and community to cope, defend, prevent, prepare, reduce risk, or recover quickly from disaster. Six capacity assessment indicators were used, with data collection, as shown in Table 2-8.

As part of the risk assessment methodology, the collection of vulnerability and capacity components are essential. For these purposes, this study used a household survey to collect individual perception and experience on landslide disaster, and socio-economic data to assess landslide disaster vulnerability and capacity.

Table 2-8. Capacity indicators

Indicator	Description
Disaster risk management participation	Counts households that have reported DRM participation and given an LVS of 0.
Microfinance	Counts household that participate in microfinance programs and given an LVS of 0.
Landslide discussions	Counts households that discuss landslides and given an LVS of 0.
Migration readiness	Counts households that report having landslide preparedness measures in place and given an LVS of 0.
Disaster risk management awareness	Counts households that expressed having disaster risk management awareness measures in place and given an LVS of 0.
Alternative roads	Counts households that have more than one access road and given an LVS of 0.

Table 2-9. Total area of landslide susceptibility in Phoukhoun Watershed, RCP 4.5 and RCP 8.5



	RCP 4.5 (Unit in Km^2)		
Susceptibility Area	2030	2050	2080
Very Low	748,99	748,99	185,00
Low	1717,84	1717,84	1385,16
Moderate	1169,76	1169,76	1514,30
High	1070,13	1070,13	1325,52
Very High	567,04	567,04	861,23
Total	5273,76	5273,76	5271,21

	RCP 8.5 (Unit in Km^2)		
Susceptibility Area	2030	2050	2080
Very Low	445,38	921,19	48,54
Low	1656,15	1743,92	867,25
Moderate	1312,12	1087,22	1624,95
High	1164,00	1011,44	1639,46
Very High	696,11	507,43	1091,01
Total	5273,76	5271,20	5271,21

---

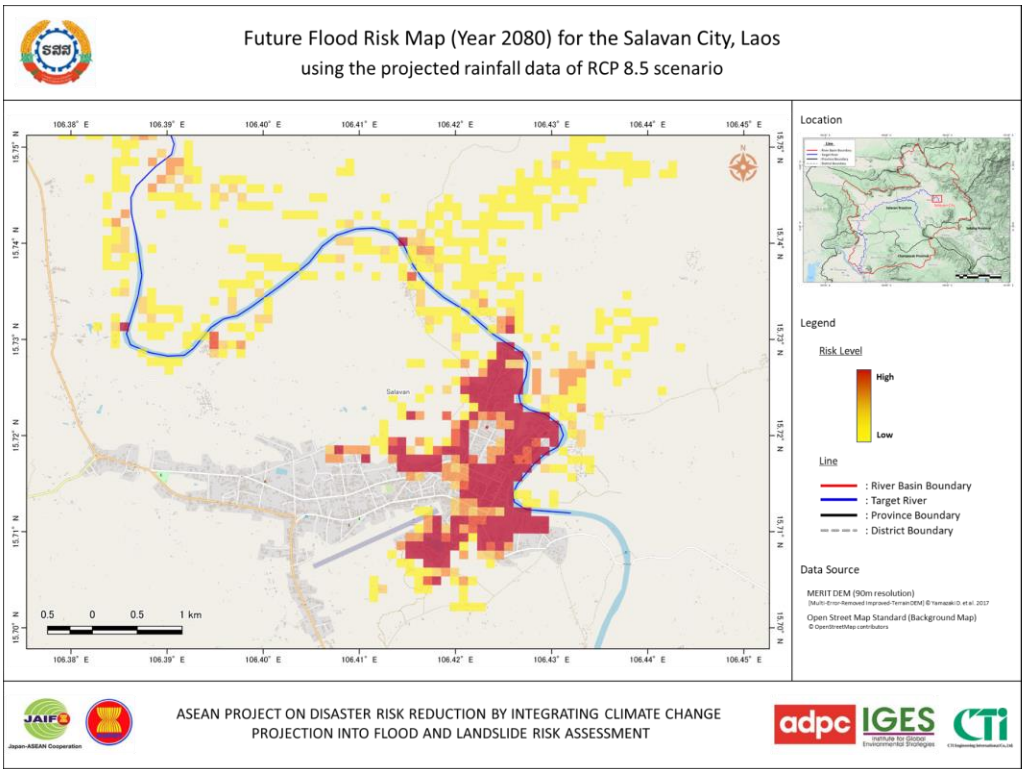
[5] Capacity is defined as "The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience" UNGA, 2016

The increase in area susceptibility can be seen in the RCP 4.5 from 2050 to 2080. Both areas of high and very high zones increase from 1070.13 to 1325.52 and 567,04 to 861.23 km2 respectively. A similar trend was also found in the 2050 to 2080 for RCP 8.5 scenario. The total areas fall into high and very high categories, increasing from 1011.44 km2 to 1639.46 km2 and from 507.43 to 1091.01 km2 respectively. The trend can be seen in Figure 2-15. The hazard and risk assessment in this case study was carried out using scientific tools and relevant methods with the outputs generated to the appropriate scale. For this extensive hazard assessment and mapping, several datasets were required, including geological, hydro-meteorological, geo-morphological and other related data.

Results and Discussions

Flood: An example of the created *flood risk* map is presented in Figure 3-1.

Figure 3-1. Example of flood risk map in Lao PDR incorporating climate change projections



Flood hazard maps are used to identify areas at risk of flooding, and consequently to improve flood risk management and disaster preparedness. In this case study, preliminary flood hazard maps at the river basin scale were created in accordance with the seven different probabilities and the six climate change scenarios. These hazard maps give the expected extent and depth of flooding in a given location based on various scenarios, which will be fundamental tools for flood management.

Hazard maps have many uses. For example, they can be used for appropriate land use planning in flood prone areas. They are also used to create evacuation plans, emergency response plans, flood mitigation and adaptation plans, etc. In addition, flood hazard maps are useful to increase awareness among the public, local authorities and other organizations of the likelihood of flooding.

Flood risk maps are used to identify areas for potential adverse consequences associated with floods. These maps are a result of aggregating losses based on various scenarios. In this case study, preliminary flood risk maps at the river basin scale were created showing categorized flood-risk level based on annual average damage in accordance with the 6 simulation cases (Case 1, Case 2 with the 3 target years, Case 3 with the 3 target years). Risk maps illustrate flood risk area and level. This will help prioritize areas and projects for flood prevention and mitigation. As the risk maps were created based on annual average damage, their results in monetary value can also be used to evaluate expected benefits of projects, while heeding map limitations.

In addition to the flood hazard and risk maps, the models that were created and the simulated results were also submitted to counterpart agencies in this project. These outputs also have many uses. For example, the HEC-RAS Mapper can show other results, such as flow velocity, shear stress, depth x velocity2, etc. This type of information is useful in planning evacuation plans, emergency response plans, etc. With their continuous development, the created models can also be useful for river planning and flood mitigation project evaluation.

Limitations of the results including hazard and risk maps should be considered when they are used. The main limitations are explained as follows.

The created flood hazard maps show a model simulated maximum inundation depth in a given condition. Accordingly, the target hazard and usage limitations should be taken into account. The limitations of flood hazard maps derive from methodology, data source, used models etc. As an example of methodology-origin limitations, the target flood was set based on a historical representative rainfall through a rainfall-runoff model. Accordingly, the target flood includes errors and uncertainty from the adopted rainfall-runoff model.

Limitations derived from models can be divided into two main types: the first is based on characteristics of the selected models and the other is based on input conditions and simulation settings in the model. For example, the function of dam release in HEC-HMS is limited, so that the dam outflow computation based on rule curves is unavailable. If this computation is required, HEC-ResSim (the Reservoir System Simulation software in the HEC series) should be used. In this case study, the HEC-ResSim was not used and the “outflow structures” method in HEC-HMS was applied assuming no gate operation. The created flood risk maps show a flood risk level based on the simulated annual average damage in a model in a given condition. Accordingly, target hazard and risk, as well as usage limitations, should be taken into account.

Flood risk maps have the same limitations related to flood hazard as the flood hazard maps because the simulated inundation data of the flood hazard maps was also used to create the flood risk maps. The target flood risk in this study was focused on direct damage to structure, structure content, and crops. Other direct damage such as that to infrastructure, etc. and indirect damage such as loss of industrial production, post-flood recovery costs, etc. was not considered in the flood risk maps.

Flood risk map limitations are mainly the result of how assets and agricultural products subject to flood risks are evaluated. The assumed unit values of structure, structure content and crops, their spatial distribution and the applied damage curves largely affects flood risk analysis results. In addition, the single water depth-damage function was applied for structure, its content and crops, respectively, and different damage curves based on structure types, etc.

were not applied in this case study. The accuracy of the estimation of these assets value is another flood risk map limitation.

Landslide: A set of example of the created *landslide susceptibility* maps is presented in Figure 3-2 showing different susceptibility zones from two different future climate scenarios of RCP 4.5 and RCP 8.5.

Based on the sorted classes, landslide susceptibility zones are defined as follows:

- 50% of landslide occurrence is classified as very high zone
- 20% of landslide occurrence is classified as high zone
- 15% of landslide occurrence is classified as medium/moderate zone
- 10% of landslide occurrence is classified as low zone
- 5% of landslide occurrence is classified as very low zone

Figure 3-2. Landslide susceptibility map results of Phoukhoun Watershed from 2 different future climate scenarios of RCP 4.5 and RCP 8.5

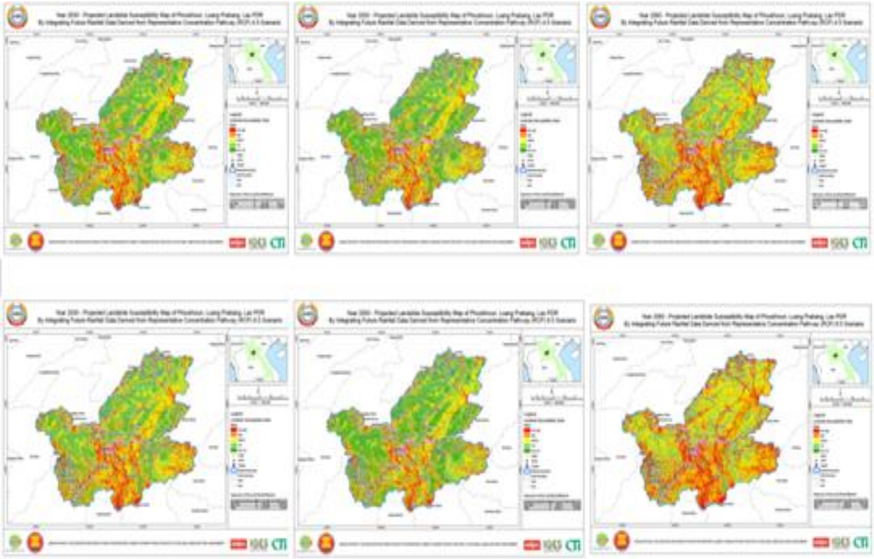
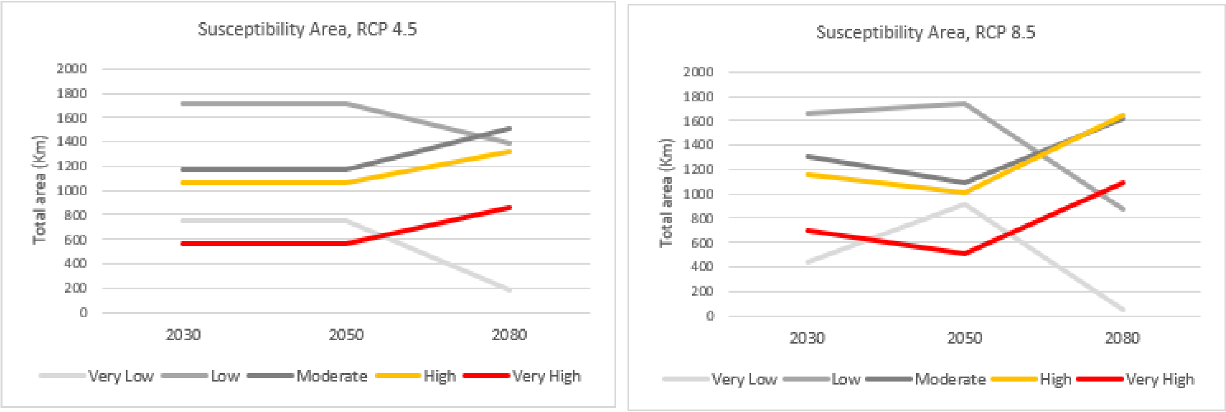


Figure 3-3. Total area of landslide susceptibility in Phoukhoun Watershed from two different future climate scenarios at RCP 4.5 and RCP 8.5



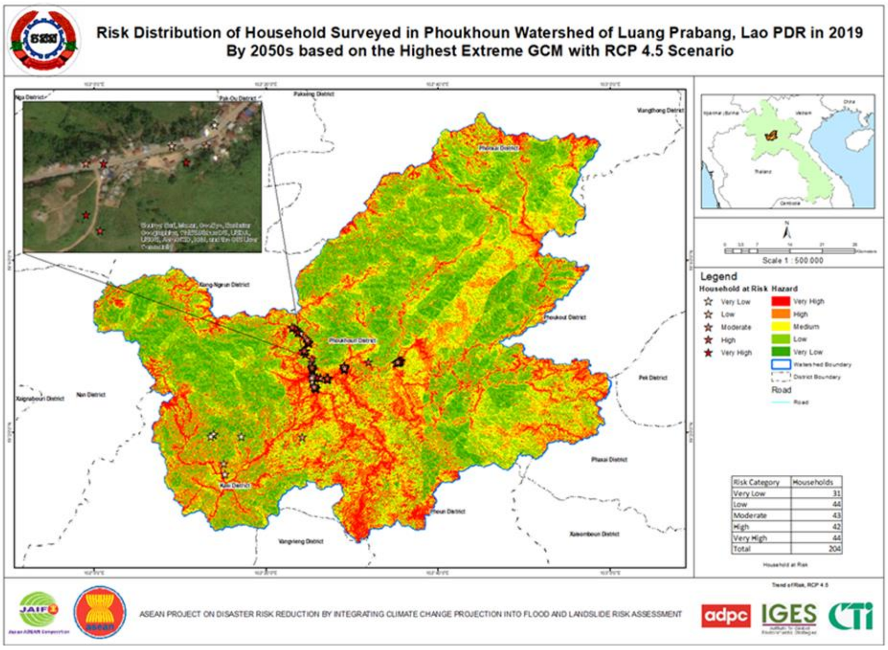
The case study show-case potential application of developing landslide risk assessment by integrating future climate change scenarios. The result can be used as a reference to design landslide risk reduction and management strategies/program, and prioritize the high and very high-risk areas and households that have been identified through the case study. Table 3-1 depicts samples of the suggested action level based on the identified risk condition.

Table 3-1. Suggested risk level and DRR related action level

Risk Level	Color Code	Action level
Very high	Red	**Urgent action** – Very high -risk condition with highest priority for risk reduction & contingency planning.
High	Orange	**Immediate action** – High risk condition with high priority for risk reduction & contingency planning.
Moderate	Yellow	**Prompt action** – Moderate to high-risk condition with risk addressed by reduction & contingency planning.
Low	Light Green	**Planned action** – Risk condition sufficiently high to give consideration for further reduction & contingency planning.
Very low	Green	**Advisory in nature** – Low risk condition with additional reduction and contingency planning.

The data of the surveyed households can also provide an important information on vulnerability and capacity, especially for the households located in high and very high prone to landslides. Such details and systematic data can help the decision makers to design appropriate DRR strategies. Using the GIS technology, where open-source option such as QGIS and Google Earth are also available to use, the surveyed households can be presented in an easy and user-friendly tool to help in the decision-making process. Figure 3-4 shows a sample of household located in high prone landslide with detailed information/attribute collected and mapped in the Google Earth, where one can easily see its level of landslide hazard, vulnerability, capacity and risk.

Figure 3-4. A sample of household located in high prone landslide mapped on Google Earth.



Risk Category	Households
Very Low	31
Low	44
Moderate	43
High	42
Very High	44
Total	204

Conclusions

The rapidly changing socio-economic landscape of the Southeast Asian countries is an important driver for systemic risks such as climate change and hydro-geological disasters. Global processes such as the SFDRR, the Paris Agreement and the Sustainable Development Goals (SDGs) encourage cross-sectoral coordination and integration of strategies to address the emerging disaster and climate change risks. Similar emphasis on integration and coordination between DRR and CCA can be found in various regional and national processes in the ASEAN.

The region has put in place far-reaching disaster risk reduction and climate change adaptation plans, laws, and regulations at both regional and national levels, and progressing to localize them to sectoral and community level. One important element that countries needed to make significant progress is in integrating climate change projections into disaster risk assessments to help address future systemic risks.

The above needs are captured in this project and has produced guidelines for practitioners and policymakers to incorporate climate change projections into flood and landslide risk assessments based on pilot exercises carried out in Lao PDR and Myanmar. The systemic risks associated with floods and landslides were assessed using a multi-stakeholder consultation processes, and community engagement at the river basin level in combination with dynamic simulation models and tools for assessing systemic risks.

Disaster risk assessments based on the future climate projections provided an important prospective view to the planners. Developing climate-proof risk assessments helped in understanding the systemic risks and build the capacity of institutions, policies and planning processes. Such forward-looking risk assessments have empowered decision-makers with the ability to manage rapidly changing risk profiles because of climate change and related uncertainties. The ability to understand uncertainties in assessing future systemic risks is a step forward in risk reduction planning and implementation. The paper articulated important learnings and present findings of the systemic risk assessments.

To reduce flood risk, flood hazard and risk should be analyzed as a first step. It is important to prioritize target river basins, to formulate reasonable flood control plans and to invest for flood risk reduction. Similarly, landslide risk assessment is a process-oriented intervention and has to be carried out first, in order to prioritize the mitigation measures. However, there remains large areas where flood and landslide hazard risk has not yet been assessed in the ASEAN countries. The obstacles are limited data availability, lack of technical capacities, budget limitation, etc. Therefore, the two case studies were conducted to demonstrate how to assess flood and landslide hazard and risk incorporating the impacts of climate change in river-basin scale. In the context of urgent need to conduct flood and landslide hazard and risk analysis for many watersheds and of limited data availability, a preliminary method for flood and landslide hazard and risk analysis supplemented with available global data was adopted in the project. Through collaborative work with the working teams (we called the river basin pilot (RBP) team) of the case studies, the methodology of flood and landslide hazard and risk assessment was adjusted to incorporate the local needs.

For future similar study in the country (to replicate the methodology in different river basins), it is recommended that risk assessment data collection process can be systematized at agency level. That way the respective agencies will be able to consider different essential factors for example: scale, frequency, coverage etc. to suit the needs of baseline data production for conducting flood and landslide risk assessment at different levels. The responsibility for collection of such baseline data is with large number of national agencies with official mandates for data collection, data maintenance, data verification, data sharing etc. Such agencies and their current responsibilities need to be reviewed as such responsibilities and mandates not necessarily cover the collection of data to satisfy the needs of flood and landslide risk assessments mentioned above.

Bibliography

Ahmadalipour A, et al. 2015. Multi-Criteria evaluation of CMIP5 GCMs for Climate Change Impact Analysis. Theoretical and Applied Climatology.

Beven, K. J, 2012. Rainfall-Runoff Modelling: The Primer (2nd ed.): Wiley-Blackwell.

Che, V. B., et al. 2011. Systematic documentation of landslide events in Limbe area (Mt Cameroon Volcano, SW Cameroon): geometry, controlling, and triggering factors. *Natural Hazards*, *59*(1), 47–74.

Christensen, J.H., B. Hewitson, et al. 2007. Regional climate projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, pp. 847-940.

Demirel, M.C. and Moradkhani, H. 2016. Assessing the impact of CMIP5 climate multi-modeling on estimating the precipitation seasonality and timing, Climatic Change. 135(2); 357–372.

Devi, G. K., et al. 2015. A Review on Hydrological Models. Aquatic Procedia, 4, 1001-1007. doi: http://dx.doi.org/10.1016/j.aqpro.2015.02.126

Hernaman V, Grose M and Clarke JM. 2017. Evaluating the performance of the latest climate models over Southeast Asia. CSIRO, Australia; Report for ADB, 2017

Knutti, R., G. Abramowitz, et al, 2010b: Good practice guidance paper on assessing and combining multi model climate projections. In: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and Combining MultiModel Climate Projections [Stocker, T.F., Q. Dahe, G.-K. Plattner, M. Tignor, and P.M. Midgley (eds.)]. IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland, pp. 1-13.

Luis, D. Frank, B. Nuno, et al, 2014. Flood Risk Mapping - Methodological Guide at: http://cciam.fc.ul.pt/prj/cirac/outputs/guia-metodologico/guia-risco-en.pdf

Meinshausen MSJ, Smith K, Calvin JS, et al.: (2011) The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change. 109: 213-241.

Randall, D.A., R.A. Wood, S. Bony, et al. 2007: Climate models and their evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, pp. 589-662.

Seneviratne, S.I., N. Nicholls, D. Easterling, et al. 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sitterson, J., Chris Knightes, R. Parmar, K. Wolfe, M. Muche, AND B. Avant. 2017. An Overview of Rainfall-Runoff Model Types. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-17/482. Available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=339328&Lab=NERL

Taylor KE, Ronald JS and Gerald AM. 2012. An Overview of CMIP5 and the Experiment Design. Bull. Amer. Meteor. Soc. 93: 485–498.

UNDRR. 2019. Systemic risks, the Sendai Framework and the 2030 agenda. In Global Assessment Report on Disaster Risk Reduction, Geneva, Switzerland, United Nations Office for Disaster Risk Reduction (UNDRR).

UNGA. 2016. Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. United Nations, New York, Available at https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf

USACE. 2000. Hydrologic Modeling System HEC-HMS Technical Reference Manual, March 2000. CPD-74B.

USACE. 2018. Hydrologic Modeling System HEC-HMS User’s Manual version 4.3, September 2018. CPD-74A.

USACE. 2016. HEC-RAS River Analysis System User’s Manual version 5.0, February 2016. CPD-68.

USACE. 2016. HEC-RAS River Analysis System Hydraulic Reference Manual version 5.0, February 2016. CPD-69.

Ward, R.C. 1975. Principles of hydrology. McGuaw-Hill Book Company (UK) Limited, London.

World Meteorological Organization. 2009. Guide to Hydrological Practices, Volume II, Management of Water Resources and Application of Hydrological Practices. Available at: http://www.whycos.org/chy/guide/168_Vol_II_en.pdf

Yamazaki D., D. Ikeshima, R. Tawatari, et al. 2017. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017 doi: 10.1002/2017GL072874