LandSAGE Software Design and Development

v1.0: February 28, 2023

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Activity 7 – LandSAGE Software Development

This activity aimed to improve the LandSAGE software capability and consisted of the following sub-activities: Landslide data collection, drought and dengue data collection, flood data collection, 3D flood simulation, and software enhancement. Through the data collections and simulations, the disaster monitoring coverage of the software was expanded from the four original pilot sites in LandSAGE3 to include eight new pilot sites, resulting in a total of twelve pilot sites being monitored. The new pilot sites include:
- Luang Prabang and Thakhek capitals in Laos
- Phayao and Loei provinces in Thailand
- Kampong Cham and Kandal provinces in Cambodia
- Can Tho and Kon Tum cities in Vietnam

In addition, the monitoring coverage was expanded to include drought and dengue datasets in addition to landslides and floods. The collected data and generated simulations provided input to the visualization in the enhanced version of the LandSAGE software consisting of several new features.

Activity 7: Sub-activity 1 – Landslide Data Collection

Based on our prior study in LandSAGE3, we continued to focus on the collection of these landslide factors: Rainfall, DEM (Digital Elevation Model), slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density, and road density. The last three factors could be used to assess the impacts from landslides. The other factors could be used to assess the risks of landslides. Subsequent sections summarize the data sources, the obtained factors for each pilot site, and the processing of the data before importing them into the LandSAGE software. Note that we also collected data representing the whole countries that could be useful when data representing the pilot sites are unavailable.

<u>Landslide Data Sources</u>

ASTGTM (ASTER Global Digital Elevation Model Version 3) is a data product developed by a collaborative effort between National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). It provides a global digital elevation model of land areas at a spatial resolution of 1 arc second.

CDE (Centre for Development and Environment) is an interdisciplinary research center specializing in sustainability science and land systems that conducts research in many countries, and also offers courses in the field of sustainable development.

DALaM (Department of Agriculture Land Management) is the organization in Myanmar that is in charge of the management and development of agricultural land across the country.

City Population is a web service that provides statistics for several countries and also administrative divisions and major cities that visualized in data map raster image form.

World Bank Data Catalog is a portal for shared development data. The datasets especially the geospatial data are provided by regions and available for download.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) is an Australian Government agency responsible for the provisions of the Science and Industry Research.

FAO (Food and Agriculture Organization) is an international organization of the United Nations that leads international efforts to defeat hunger and improve nutrition and food security. FAO provides data maps and databases related to soil gathering from the systematic study of the soil of an area including classification and mapping of the properties and the distribution of various soil units.

Danida (Danish International Development Agency) is an operating organization as a part of the Ministry of Foreign Affairs of Denmark which works on the planning, implementation, and quality assurance of Denmark's development cooperation and development assistance to other countries, with a focus on developing countries.

EOC (Environment Operations Center) is an information and knowledge provision agency that service the Greater Mekong Subregion (GMS) Working Group on Environment with coordination and technical support to implement the Core Environment Program.

Worldometers is a reference website that provides counters and real-time statistics for diverse topics. It is owned and operated by a data company Dadax and covers subjects such as government, world population, economics, society, media, environment, food and water.

Ontheworldmap is a free-sharing community website that provides a collection of countries, regions, cities, and the world's resorts map.

UNITAR (United Nations Institute for Training and Research) provides innovative learning solutions to individuals, organizations, and institutions to enhance global decision-making training and capacity

development activities to assist mainly developing countries and communities that are most vulnerable, including those in conflict situations.

Nature is a British weekly scientific journal and information that features peer-reviewed research from a variety of academic disciplines, mainly in science and technology.

The Data User Element of ESA (European Space Agency) is an information provided agent as a part of the development of Earth Observation demonstration services.

Climate-data.org is a website provides the climate-data based on ECMWF data that has been collected for several years (1991 - Now) such as the data of variables temperature, precipitation, water temperature, humidity, rainy days.

Sentinel-2 is a time-series data map portal that utilizes the land use and land cover data from Sentinel-2 land observative satellites which are aimed at monitoring variability in land surface conditions.

MIT GeoWeb is a GIS Map Service website of the Massachusetts Institute of Technology that provides information on the geological environment.

GLOBIO (Global Biodiversity Model for Policy Support) is the data hub service provided the dataset of global road and transportation for use in global environmental and biodiversity assessment models

NCCS (NASA Center for Climate Simulation) is the GIS Map service of NASA that allows the user to access global information on landslide events that were provided supercomputing resources to emphasis on weather and climate prediction.

K4D (Knowledge for Development) is the information collection platform that provides researched data maps represented in several factors from various organizations to support the use of learning and evidence to improve the impact of development policy and programs.

Orr & Associates is a commercial insurance industry that provides geological services such as the various types of geotechnical data maps such as soil, geology, regolith, topography, and cadastral maps.

CCOP (Coordinating Committee for Geoscience Programmes in East and Southeast Asia) is an intergovernmental organization that aims to facilitate the implementation of applied geoscience programs in East and Southeast Asia in order to contribute to economic development and an improved quality of life. It offers geographic information system (GIS) web service that provides visualization of landslide factors such as geologic lithology.

MRC (Mekong River Commission) is an intergovernmental organisation established based on an agreement between Cambodia, Laos, Vietnam, and Thailand. The organisation serves as a knowledge hub of water resource management in the Lower Mekong River Basin (LMB). MRC provides various types of data for the LMB region including hydro-meteorological data (e.g. water level, discharge, rainfall, temperature, humidity), geometric data (e.g. cross-section, longitudinal profile of a river) and water quality data (e.g. sediment, salinity, turbidity, concentration, water temperature).

CNMC (Cambodia National Mekong Committee) is the national institution operating under direct supervision of the Royal Government of Cambodia which is responsible for the management, preservation, conservation, and development of water resources in the Mekong River Basin.

MAF (Ministry of Agriculture and Forestry) is one of the ministries of the government of the Lao People's Democratic Republic (Lao PDR) that was founded to formulate agricultural development policies and to advise the government on such policies relating to its administration.

LAOSIS (Lao Statistics Bureau) is the state agency responsible for the collection and publication of statistics related to the economy, population, and society of Laos.

DMR (Department of Mineral Resources) in Thailand serves as the governmental agency for fact-finding related to minerals and geology. Various types of digital and printed thematic geological maps are available for free download and for sale.

LDD (Land Development Department) in Thailand is the governmental organization responsible for soil survey, soil mapping, land improvement and land use planning.

DOPA (Department of Provincial Administration) in Thailand is responsible for administrative affairs nationwide at the levels of provinces, towns, and districts.

TMD (Thai Meteorological Department) is the governmental agency responsible for weather monitoring and forecasting. TMD provides climate data such as rainfall, humidity, and temperature for Ubon Ratchathani pilot site and other provinces.

RID (Royal Irrigation Department) of Thailand is an agency in the departments in the Ministry of Agriculture and Cooperatives of Thailand which is responsible for storing, controlling, distributing, draining, or allocating water for agricultural, energy, household consumption, or industrial purposes.

CRI (Chulabhorn Research Institute) is a biomedical and chemistry research institute in Thailand. The core activity is conducting fundamental and advanced research in the field o natural products, environmental toxicology, and biotechnology.

Upper Northern Region Irrigation Hydrology Center provides the hydrology monitoring information of rivers in the Upper Northern Region of Thailand

Hydrology Irrigation Center for Upper Northeastern Region provides the hydrology monitoring information of rivers in the Upper Northeastern Region of Thailand

NIURP (National Institute for Urban and Rural Planning) is the public service unit under the Vietnam Ministry of Construction that organize scientific research and apply technological advances to serve governmental management.

NASA (National Aeronautics and Space Administration) is an organization of the U.S. federal government that is responsible for science and technology related to air and space

GLC (Global Land Cover) is a dataset developed by NASA that provides information on the different types of land cover on Earth

GISThai (Geo-InformaticS Center for Thailand) is a research center in Thailand that provide knowledge and geological information

ODM (Open Development Mekong) is an open data platform providing objective data visualizations that illustrate the development and environmental challenges in the Mekong region. The platform provides data for five countries in the region including Cambodia, Laos, Myanmar, Thailand, and Vietnam.

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Landslide Data for Phayao Pilot Site in Thailand

The following table summarizes the data collection results for Phayao province. Example raster images of the collected factors are shown.

Summary of collected landslide data for Phayao pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Phayao	2021	Upper Northern Region Irrigation Hydrology Center	Excel
2	Rainfall	Phayao	2022	Upper Northern Region Irrigation Hydrology Center	Excel
3	Rainfall	Phayao	Unknown	CRI	Raster
4	Slope	Phayao	2013	Calculated from DEM (5)	Raster
5	DEM	Phayao	2013	ASTGTM	TIFF
6	Geologic Lithology	Phayao	2007	DMR	Raster
7	Geologic Lithology	Phayao	2022	LDD	Raster
8	Geomorphology	Phayao	2018	[5]	Raster
9	Geomorphology	Phayao	2019	LDD	Shapefile
10	Land Use	Phayao	2007	LDD	Raster
11	Land Use	Phayao	2009	LDD	Raster
12	Land Use	Phayao	2012	LDD	Raster
13	Land Use	Phayao	2015	LDD	Raster
14	Land Use	Phayao	2018	LDD	Raster
15	Land Use	Phayao	2018	[5]	Raster
16	Land Use	Phayao	2020	LDD	Raster
17	Land Use	Phayao	2022	LDD	Raster
18	Land Cover	Phayao	2023	LandSAGE4	Raster
19	Land Cover	Phayao	2009	ESA	Raster
20	Housing Distribution	Phayao	2014	LDD	Shapefile
21	Population Density	Phayao	2000	City Population	Raster
22	Population Density	Phayao	2010	City Population	Raster
23	Population Density	Phayao	2016	DOPA	Shapefile
24	Population Density	Phayao	2017	DOPA	Shapefile
25	Population Density	Phayao	2018	DOPA	Shapefile
26	Population Density	Phayao	2019	DOPA	Shapefile
27	Population Density	Phayao	2020	DOPA	Shapefile
28	Population Density	Phayao	2021	DOPA	Shapefile
29	Road Density	Phayao	2014	LDD	Shapefile
30	Landslide Susceptibility	Phayao	2004	DMR	Raster
31	Landslide Susceptibility	Phayao	2011	DMR	Raster
32	Landslide Susceptibility	Phayao	2020	DMR	Raster
33	Landslide Susceptibility	Phayao	2020	NASA	Shapefile
34	Landslide Inventory	Phayao	2021	DMR	Shapefile
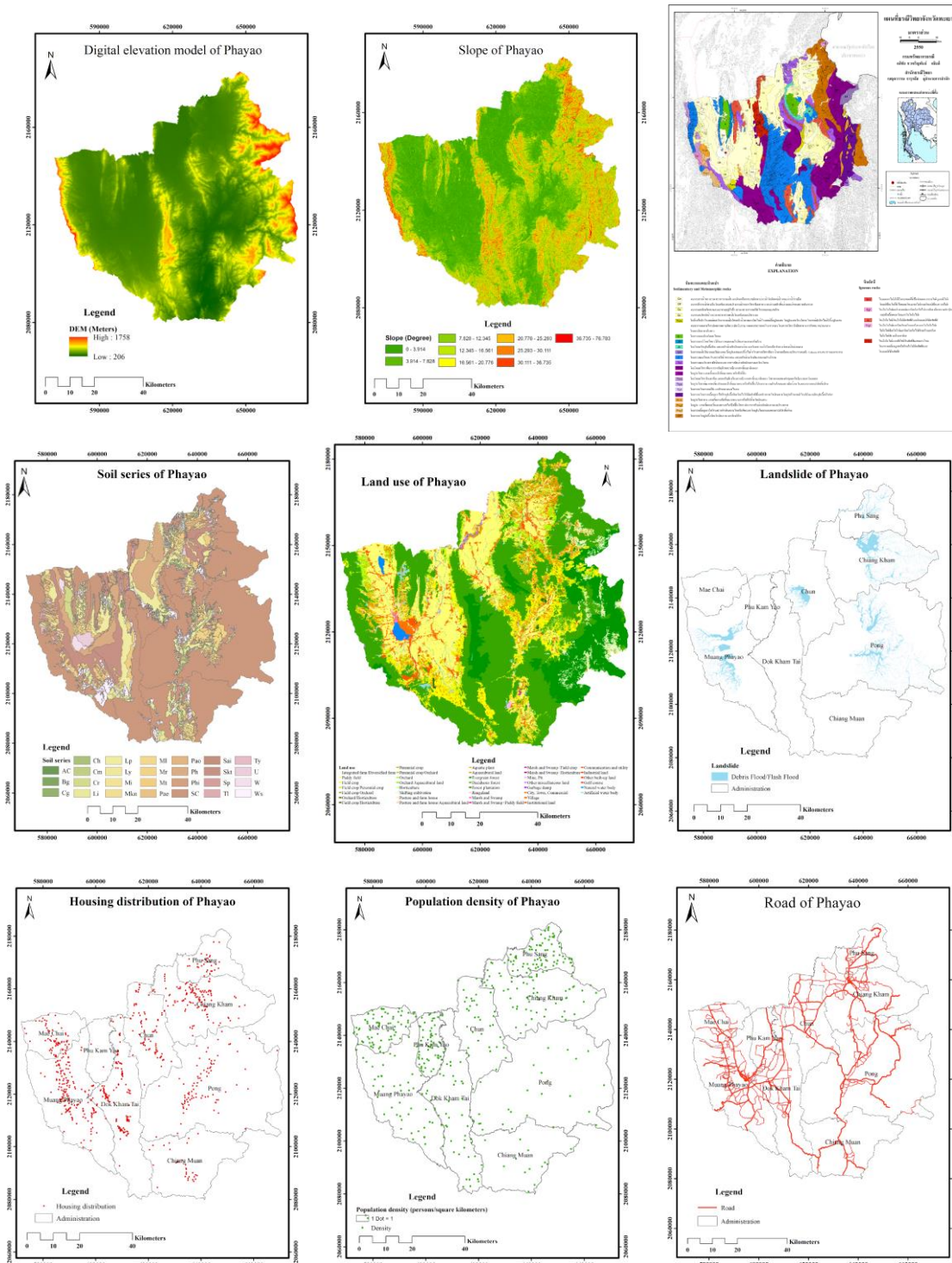
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Phayao pilot site.
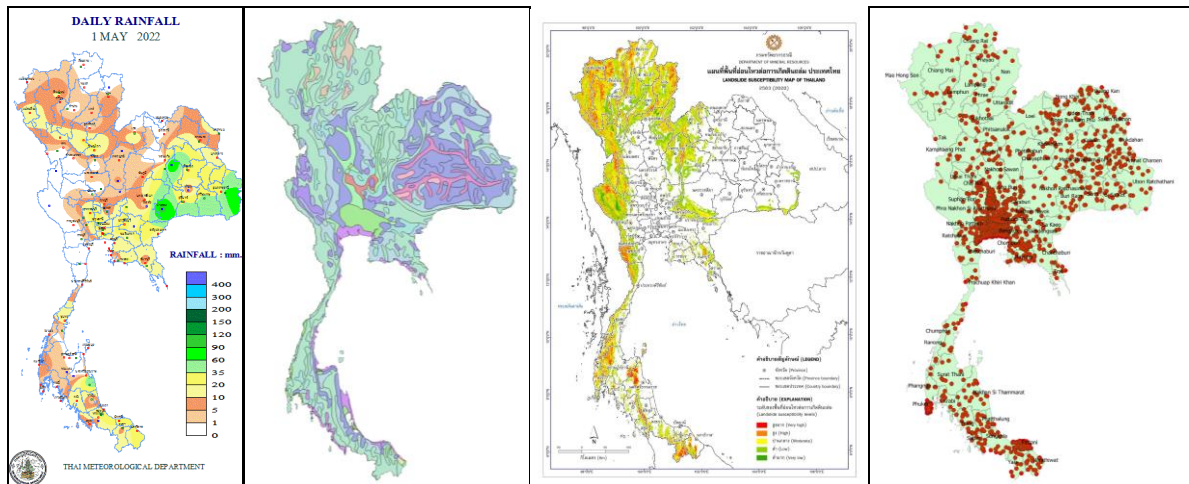
Landslide Data for Loei Pilot Site in Thailand

The following table summarizes the data collection results for Loei province. Example raster images of the collected factors are shown.

Summary of collected landslide data for Loei pilot site.

| No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Loei	2021	Hydrology Irrigation Center for Upper Northeastern Region	Excel
2	Rainfall	Loei	2022	Hydrology Irrigation Center for Upper Northeastern Region	Excel
3	Slope	Loei	2013	Calculated from DEM (4)	Raster
4	DEM	Loei	2013	ASTGTM	TIFF
5	Geologic Lithology	Loei	2007	DMR	Raster
6	Geologic Lithology	Loei	2022	LDD	Raster
7	Geomorphology	Loei	2019	LDD	Raster
8	Land Use	Loei	2007	LDD	Raster
9	Land Use	Loei	2009	LDD	Raster
10	Land Use	Loei	2013	LDD	Raster
11	Land Use	Loei	2016	LDD	Raster
12	Land Use	Loei	2017	LDD	Shapefile
13	Land Use	Loei	2018	LDD	Shapefile
14	Land Use	Loei	2019	LDD	Raster
15	Land Use	Loei	2022	LDD	Raster
16	Land Cover	Loei	2023	LandSAGE4	Raster
17	Land Cover	Loei	2009	ESA	Raster
18	Housing Distribution	Loei	2014	LDD	Shapefile
19	Population Density	Loei	2000	City Population	Raster
20	Population Density	Loei	2010	City Population	Raster
21	Population Density	Loei	2016	DOPA	Shapefile
22	Population Density	Loei	2017	DOPA	Shapefile
23	Population Density	Loei	2018	DOPA	Shapefile
24	Population Density	Loei	2019	DOPA	Shapefile
25	Population Density	Loei	2020	DOPA	Shapefile
26	Population Density	Loei	2021	DOPA	Shapefile
27	Road Density	Loei	2014	LDD	Shapefile
28	Landslide Susceptibility	Loei	2004	DMR	Raster
29	Landslide Susceptibility	Loei	2020	DMR	Raster
30	Landslide Susceptibility	Loei	2020	NASA	Shapefile
31	Landslide Inventory	Loei	2021	DMR	Shapefile
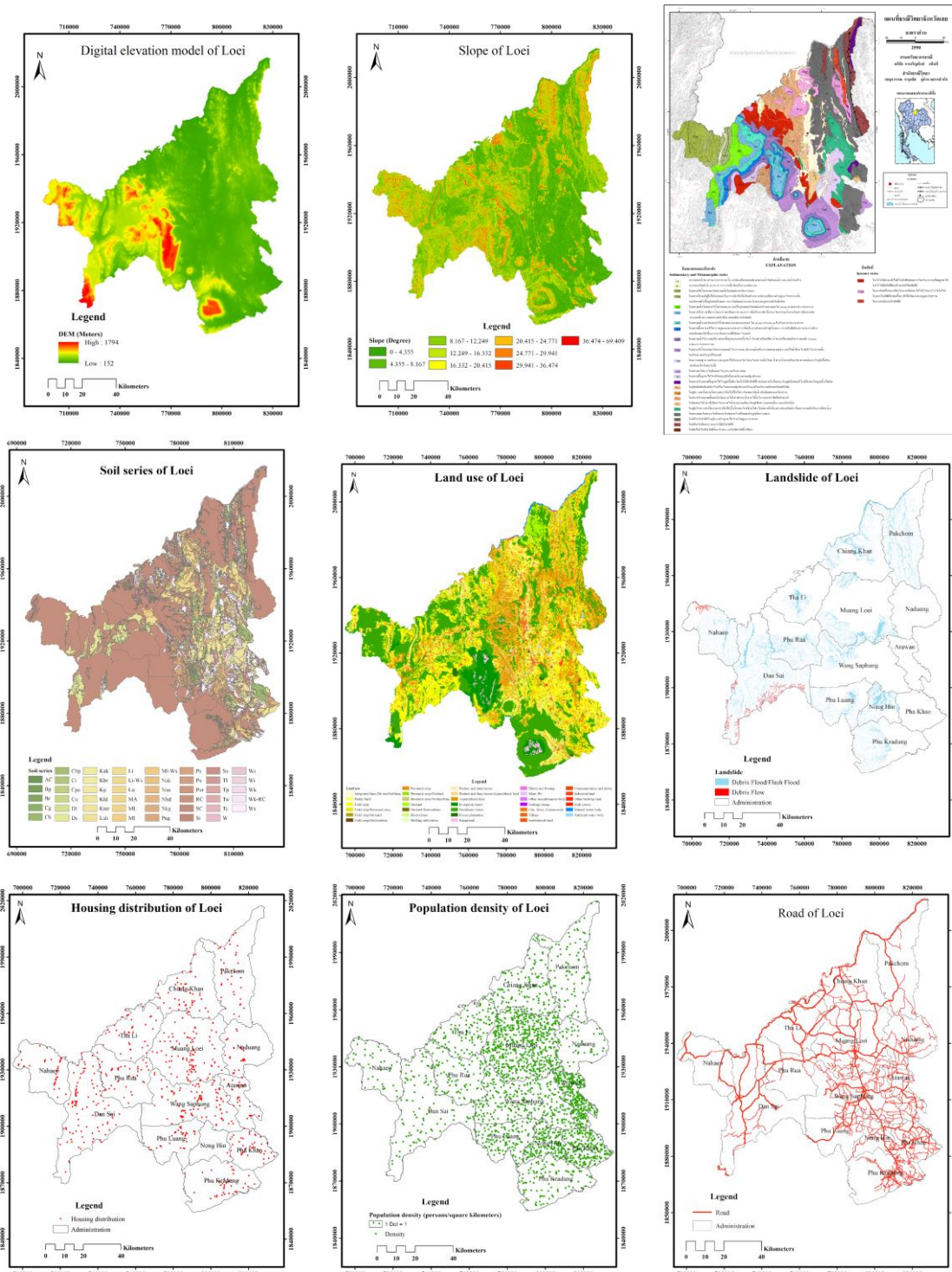
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Loei pilot site.

Other Landslide Data for Thailand

The following table summarizes additional data collection results for Thailand. Example raster images of the collected factors are shown.

Summary of additional landslide data for Thailand.

No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Thailand	2016	TMD	Raster
2	Rainfall	Thailand	2017	TMD	Raster
3	Rainfall	Thailand	2018	TMD	Raster
4	Rainfall	Thailand	2019	TMD	Raster
5	Rainfall	Thailand	2020	TMD	Raster
6	Rainfall	Thailand	2021	TMD	Raster
7	Rainfall	Thailand	2022	TMD	Raster
8	Rainfall	Northern	2016	TMD	Raster
9	Rainfall	Northern	2017	TMD	Raster
10	Rainfall	Northern	2018	TMD	Raster
11	Rainfall	Northern	2019	TMD	Raster
12	Rainfall	Northern	2020	TMD	Raster
13	Rainfall	Northern	2021	TMD	Raster
14	Rainfall	Upper Northeastern	2012	TMD	Raster
15	Rainfall	Upper Northeastern	2013	TMD	Raster
16	Rainfall	Upper Northeastern	2014	TMD	Raster
17	Rainfall	Upper Northeastern	2015	TMD	Raster
18	Rainfall	Upper Northeastern	2016	TMD	Raster
19	Rainfall	Upper Northeastern	2017	TMD	Raster
20	Rainfall	Upper Northeastern	2018	TMD	Raster
21	Rainfall	Upper Northeastern	2019	TMD	Raster
22	Rainfall	Upper Northeastern	2020	TMD	Raster
23	Rainfall	Upper Northeastern	2021	TMD	Raster
24	Geomorphology	Thailand	2021	ODM (Thailand)	Shapefile
25	Land Use	Thailand	2000	GISThai	Raster
26	Land Use	Thailand	2018	LDD	Raster
27	Land Cover	Thailand	2023	LandSAGE4	Raster
28	Population Density	Thailand	2021	Worldometers	Shapefile
29	Landslide Susceptibility	Thailand	2006	LDD	Raster
30	Landslide Susceptibility	Thailand	2013	DMR	Raster
31	Landslide Susceptibility	Thailand	2020	DMR	Raster
32	Landslide	Thailand	2020	NASA	Raster

Susceptibility				

From left to right: Example maps of rainfall, geomorphology, landslide inventory/susceptibility and population density for Thailand.

Landslide Data for Kampong Cham Pilot Site in Cambodia

The following table summarizes the data collection results for Kampong Cham province. Example raster images of the collected factors are shown.

Summary of collected landslide data for Kampong Cham pilot site.

| No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Kampong Cham	2022	CNMC	Raster
2	Slope	Kampong Cham	2013	Calculated from DEM (3)	Raster
3	DEM	Kampong Cham	2013	ASTGTM	TIFF
4	Geologic lithology	Kampong Cham	2006	ODM (Cambodia)	Shapefile
5	Geomorphology	Kampong Cham	2007	ODM (Cambodia)	Shapefile
6	Land Use	Kampong Cham	2017	Sentinel-2	TIFF
7	Land Use	Kampong Cham	2018	Sentinel-2	TIFF
8	Land Use	Kampong Cham	2019	Sentinel-2	TIFF
9	Land Use	Kampong Cham	2020	Sentinel-2	TIFF
10	Land Use	Kampong Cham	2021	Sentinel-2	TIFF
11	Land Cover	Kampong Cham	2009	ESA	Raster
12	Housing Distribution	Kampong Cham	2013	ODM (Cambodia)	Shapefile
13	Population Density	Kampong Cham	1998	ODM (Cambodia)	Shapefile
14	Population Density	Kampong Cham	2008	ODM (Cambodia)	Shapefile
15	Population Density	Kampong Cham	2019	ODM (Cambodia)	Shapefile
16	Road Density	Kampong Cham	2022	ODM (Cambodia)	Shapefile
17	Landslide Susceptibility	Kampong Cham	2020	NASA	Shapefile
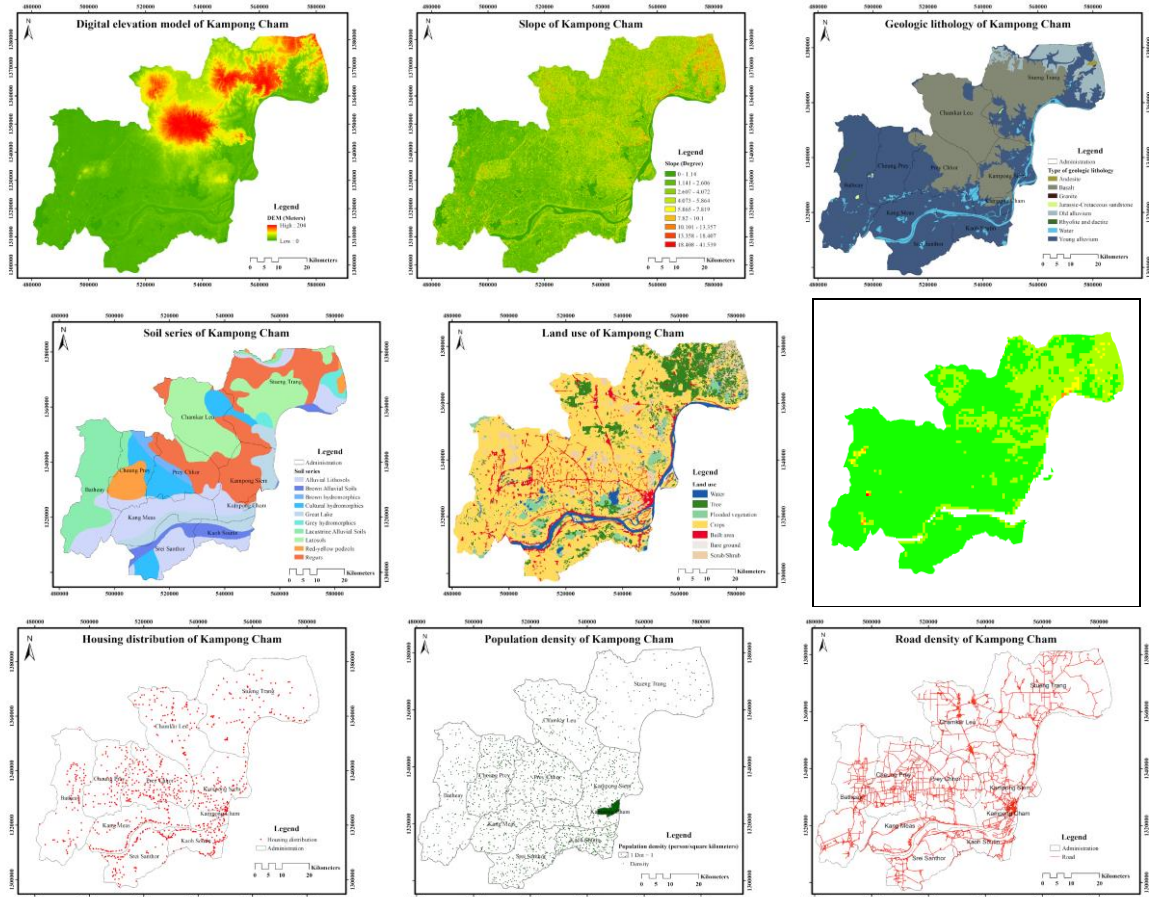
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Kampong Cham pilot site.

Landslide Data for Kandal Pilot Site in Cambodia

The following table summarizes the data collection results for Kandal province. Example raster images of the collected factors are shown.

Summary of collected landslide data for Kandal pilot site.

| No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Kandal	2022	CNMC	Raster
2	Slope	Kandal	2013	Calculated from DEM (3)	Raster
3	DEM	Kandal	2013	ASTGTM	TIFF
4	Geologic lithology	Kandal	2006	ODM (Cambodia)	Shapefile
5	Geomorphology	Kandal	2007	ODM (Cambodia)	Shapefile
6	Land Use	Kandal	2017	Sentinel-2	TIFF
7	Land Use	Kandal	2018	Sentinel-2	TIFF
8	Land Use	Kandal	2019	Sentinel-2	TIFF
9	Land Use	Kandal	2020	Sentinel-2	TIFF
10	Land Use	Kandal	2021	Sentinel-2	TIFF
11	Land Cover	Kandal	2009	ESA	Raster
12	Housing Distribution	Kandal	2013	ODM (Cambodia)	Shapefile
13	Population Density	Kandal	1998	ODM (Cambodia)	Shapefile
14	Population Density	Kandal	2008	ODM (Cambodia)	Shapefile
15	Population Density	Kandal	2019	ODM (Cambodia)	Shapefile
16	Road Density	Kandal	2022	ODM (Cambodia)	Shapefile
17	Landslide Susceptibility	Kandal	2020	NASA	Shapefile
18	Landslide Inventory	Kandal	2017	NASA (GLC)	Shapefile
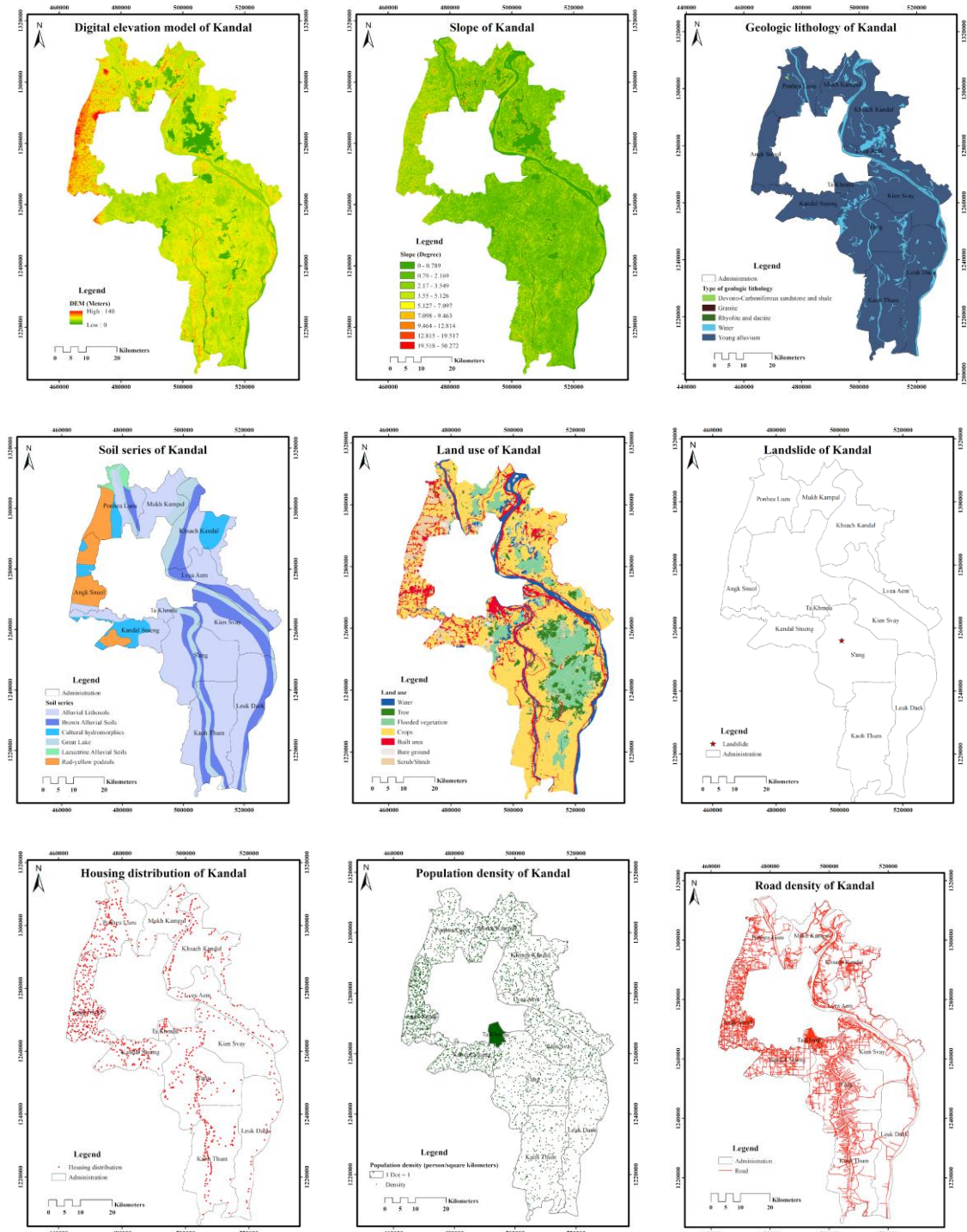
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Kandal pilot site.

Other Landslide Data for Cambodia

The following table summarizes additional data collection results for Cambodia. Example raster images of the collected factors are shown.

Summary of additional landslide data for Cambodia.

No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Cambodia	Unknown	FAO	Raster
2	Rainfall	Cambodia	2015	Danida	Raster
3	Slope	Cambodia	2007	EOC	Raster
4	Geologic Lithology	Cambodia	2006	ODM (Cambodia)	Raster
5	Geologic Lithology	Cambodia	Unknown	CCOP	Raster
6	Geomorphology	Cambodia	1962	ODM (Cambodia)	Raster
7	Geomorphology	Cambodia	2021	ODM (Cambodia)	Raster
8	Geomorphology	Cambodia	Unknown	FAO	Raster
9	Land Use	Cambodia	Unknown	FAO	Raster
10	Land Cover	Cambodia	2023	LandSAGE4	Raster
11	Land Cover	Cambodia	2012	ODM (Cambodia)	Raster
12	Land Cover	Cambodia	2013	ODM (Cambodia)	Raster
13	Land Cover	Cambodia	2014	ODM (Cambodia)	Raster
14	Land Cover	Cambodia	2015	ODM (Cambodia)	Raster
15	Land Cover	Cambodia	2016	ODM (Cambodia)	Raster
16	Land Cover	Cambodia	2017	ODM (Cambodia)	Raster
17	Land Cover	Cambodia	2018	ODM (Cambodia)	Raster
18	Land Cover	Cambodia	2019	ODM (Cambodia)	Raster
19	Land Cover	Cambodia	2020	ODM (Cambodia)	Raster
20	Population Density	Cambodia	2010	ODM (Cambodia)	Raster
21	Population Density	Cambodia	2021	Worldometers	Raster
22	Road Density	Cambodia	2021	Ontheworldmap	Raster
23	Road Density	Cambodia	2022	ODM (Cambodia)	Raster
24	Road Density	Cambodia	Unknown	CCOP	Raster
25	Landslide Susceptibility	Cambodia	2020	NASA	Shapefile
26	Landslide Inventory	Cambodia	2013	ODM (Cambodia)	Raster
27	Landslide Inventory	Cambodia	2017	NASA (GLC)	Shapefile
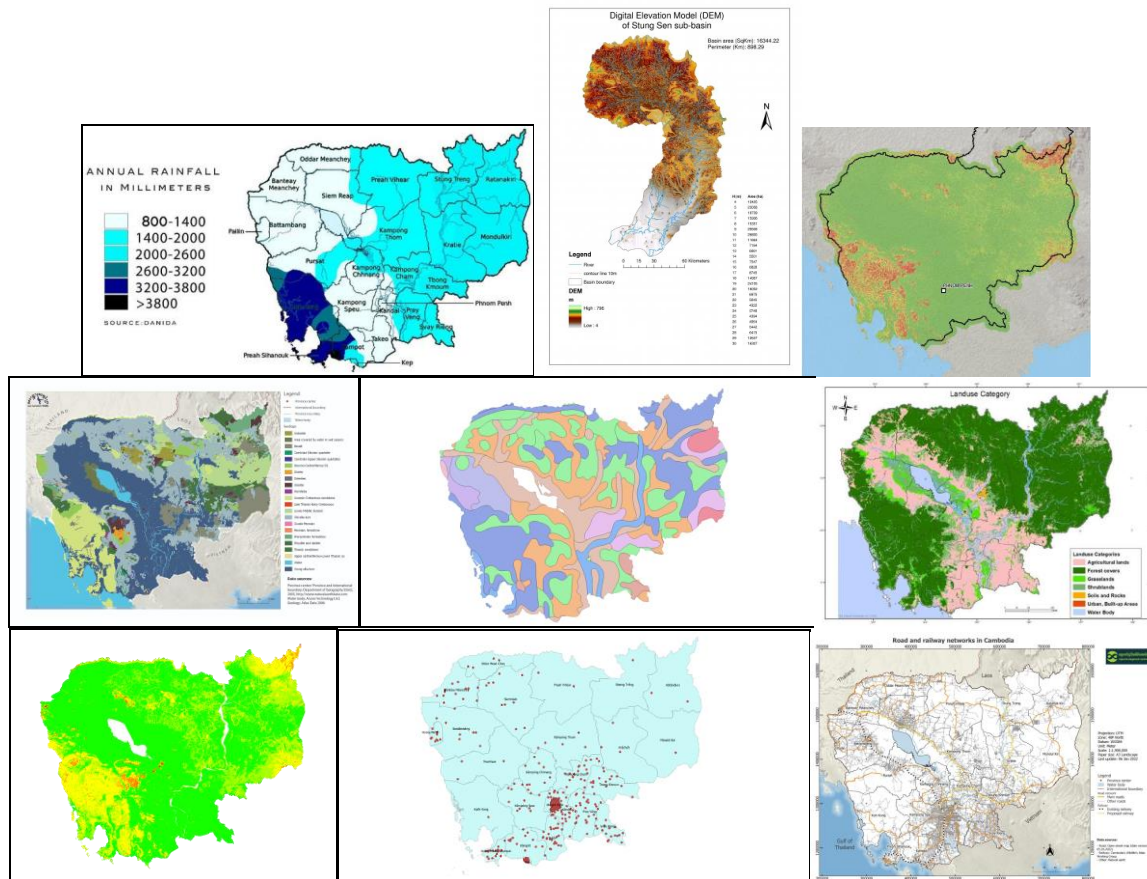
From top to bottom, left to right: Example maps of rainfall, DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, population density, and road density for Cambodia.

Landslide Data for Luang Prabang Pilot Site in Laos

The following table summarizes the data collection results for Luang Prabang pilot site. Example raster images of the collected factors are shown.

Summary of collected landslide data for Luang Prabang pilot site.

| No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Capital	2010	K4D (MAF)	Raster
2	Slope	Province	2013	Calculated from DEM (5)	Raster
3	Slope	Capital	Unknown	K4D (CDE)	Raster
4	Slope	Province	Unknown	[1]	Raster
5	DEM	Province	2013	ASTGTM	TIFF
6	DEM	Capital	Unknown	K4D (CDE)	Raster
7	DEM	Province	Unknown	[1]	Raster
8	Geologic Lithology	Province	2018	Orr & Associates	Shapefile
9	Geologic Lithology	Capital	2020	K4D (DALaM)	Raster
10	Geomorphology	Province	2007	ODM (Lao PDR)	Shapefile
11	Geomorphology	Capital	2002	K4D (DALaM)	Raster
12	Land Use	Province	2017	Sentinel-2	TIFF
13	Land Use	Province	2018	Sentinel-2	TIFF
14	Land Use	Province	2019	Sentinel-2	TIFF
15	Land Use	Province	2020	Sentinel-2	TIFF
16	Land Use	Province	2021	Sentinel-2	TIFF
17	Land Cover	Province	2007	[2]	Raster
18	Land Cover	Province	2009	ESA	Raster
19	Land Cover	Capital	2019	K4D (DALaM)	Raster
20	Housing Distribution	Province	2015	ODM (Lao PDR)	Shapefile
21	Housing Distribution	Capital	2005	K4D (LAOSIS)	Raster
22	Housing Distribution	Capital	2015	K4D (LAOSIS)	Raster
23	Population Density	Capital	2005	K4D (LAOSIS)	Raster
24	Population Density	Capital	2015	K4D (LAOSIS)	Raster
25	Road Density	Province	2018	GLOBIO	Shapefile
26	Road Density	Capital	2020	K4D (CDE)	Raster
27	Landslide Susceptibility	Capital	2020	NASA	Shapefile
28	Landslide Inventory	Province	2021	NCCS	Shapefile
29	Landslide Inventory	Capital	2011	K4D (MAF)	Raster
30	Landslide Inventory	Capital	2013	NASA (GLC)	Shapefile
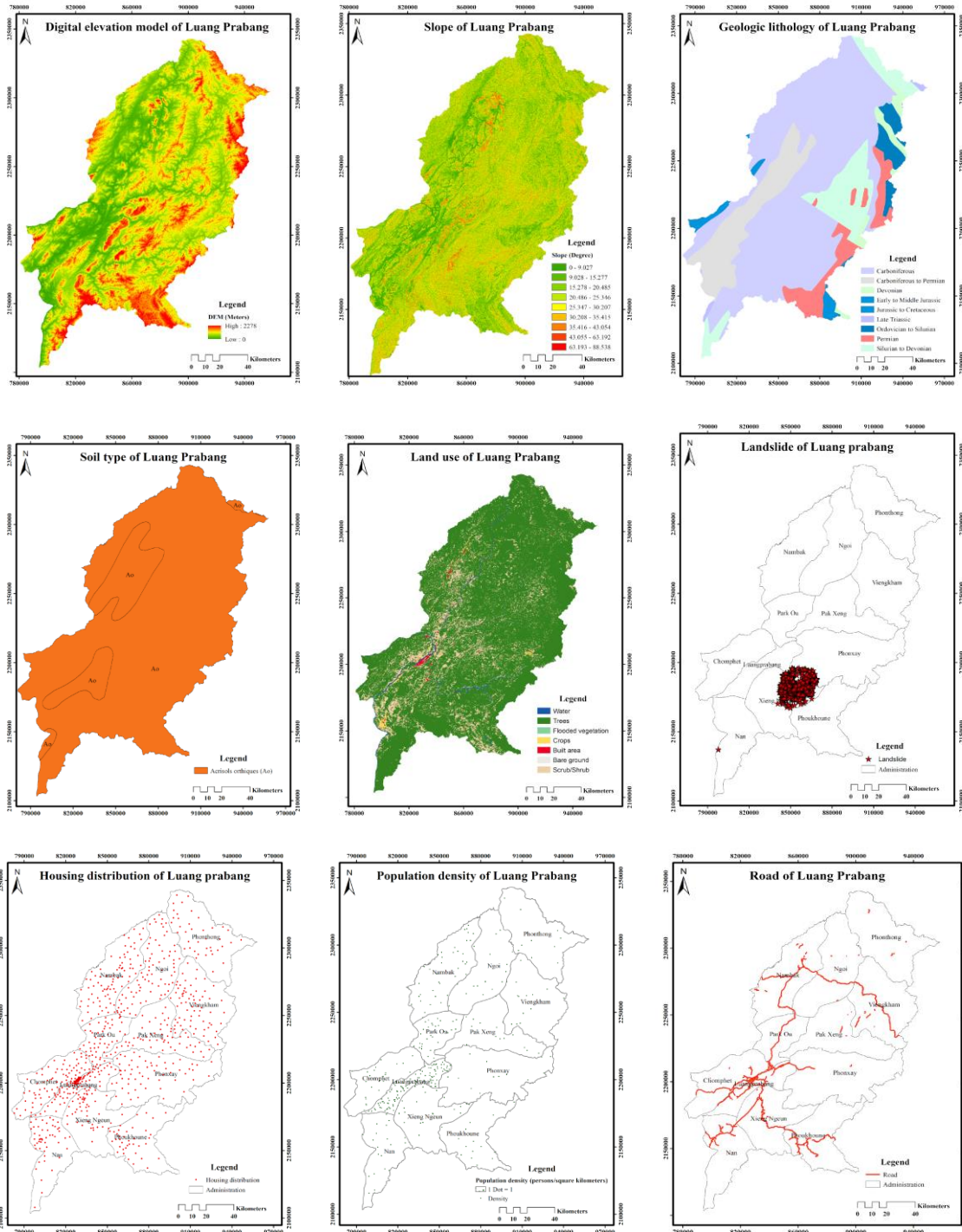
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Luang Prabang pilot site.

Landslide Data for Thakhek Pilot Site in Laos

The following table summarizes the data collection results for Thakhek pilot site. Example raster images of the collected factors are shown.

Summary of collected landslide data for Thakhek pilot site.

| No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Thakhek	2010	K4D (MAF)	Raster
2	Slope	Thakhek	2013	Calculated from DEM (4)	Raster
3	Slope	Thakhek	Unknown	K4D (CDE)	Raster
4	DEM	Thakhek	2013	ASTGTM	TIFF
5	DEM	Thakhek	Unknown	K4D (CDE)	Raster
6	Geologic Lithology	Thakhek	2018	ORR & ASSOCIATES	Shapefile
7	Geologic Lithology	Thakhek	2020	K4D (DALaM)	Raster
8	Geomorphology	Thakhek	2002	K4D (DALaM)	Raster
9	Geomorphology	Thakhek	2007	ODM (Laos)	Shapefile
10	Land Use	Thakhek	2007	Sentinel-2	TIFF
11	Land Use	Thakhek	2017	Sentinel-2	TIFF
12	Land Use	Thakhek	2018	Sentinel-2	TIFF
13	Land Use	Thakhek	2019	Sentinel-2	TIFF
14	Land Use	Thakhek	2020	Sentinel-2	TIFF
15	Land Cover	Thakhek	2021	Sentinel-2	TIFF
16	Land Cover	Thakhek	2009	ESA	Raster
17	Land Cover	Thakhek	2019	K4D (DALaM)	Raster
18	Housing Distribution	Thakhek	2005	K4D (LAOSIS)	Raster
19	Housing Distribution	Thakhek	2015	K4D (LAOSIS)	Raster
20	Housing Distribution	Thakhek	2015	ODM (Laos)	Shapefile
21	Population Density	Thakhek	1995	City Population	Shapefile
22	Population Density	Thakhek	2005	City Population	Shapefile
23	Population Density	Thakhek	2005	K4D (LAOSIS)	Raster
24	Population Density	Thakhek	2015	City Population	Shapefile
25	Population Density	Thakhek	2015	K4D (LAOSIS)	Raster
26	Population Density	Thakhek	2020	City Population	Shapefile
27	Road Density	Thakhek	2018	GLOBIO	Shapefile
28	Road Density	Thakhek	2020	K4D (CDE)	Raster
29	Landslide Susceptibility	Thakhek	2020	NASA	Shapefile
30	Landslide Inventory	Thakhek	2011	K4D (MAF)	Raster
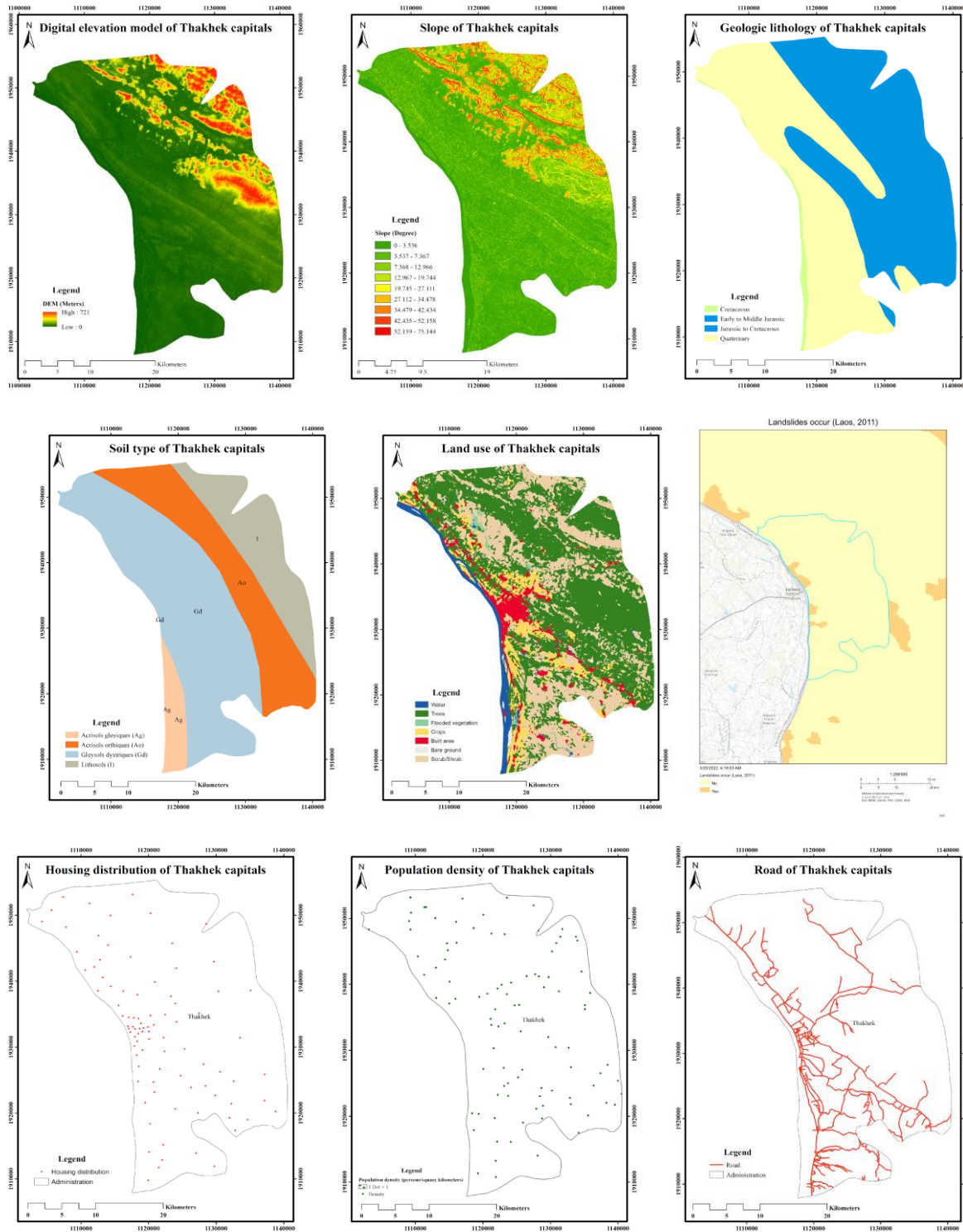
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Thakhek pilot site.

Other Landslide Data for Laos

The following table summarizes additional data collection results for Laos. Example raster images of the collected factors are shown.

Summary of additional landslide data for Laos.

No	Factor	Scope	Data Year	Data Source	Format
1	Rainfall	Laos	2006	ODM (Laos)	Raster
2	Slope	Laos	2007	EOC	Raster
3	DEM	Laos	2007	UNITAR	Raster
4	Geomorphology	Laos	2013	ODM (Laos)	Raster
5	Geomorphology	Laos	2021	ODM (Laos)	Shapefile
6	Land Cover	Laos	2023	LandSAGE4	Raster
7	Land Use	Laos	Unknown	[3]	Raster
8	Population Density	Laos	1995	[4]	Raster
9	Population Density	Laos	2021	Worldometers	Shapefile
10	Landslide Susceptibility	Laos	2020	NASA	Shapefile
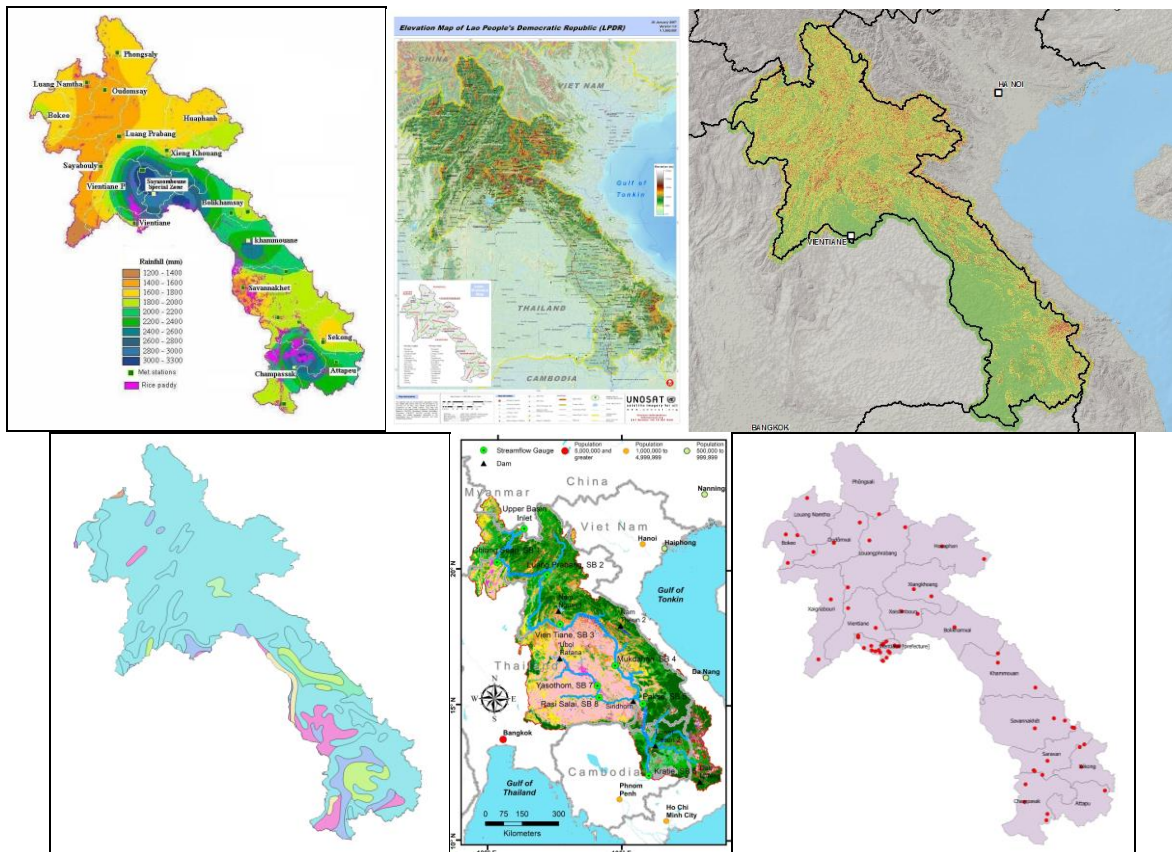
From top to bottom, left to right: Example maps of rainfall, DEM, slope, geomorphology, land use/cover and population density for Laos.

Landslide Data for Can Tho Pilot Site in Vietnam

The following table summarizes the data collection results for Can Tho city. Example raster images of the collected factors are shown.

Summary of collected landslide data for Can Tho pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Slope	Can Tho	2013	Calculated from DEM (2)	Raster
2	DEM	Can Tho	2013	ASTGTM	TIFF
3	DEM	Can Tho	2013	[6]	Raster
4	DEM	Can Tho	Unknown	[7]	Raster
5	DEM	Can Tho	Unknown	[8]	Raster
6	Geologic Lithology	Can Tho	2018	Orr & Associates	Shapefile
7	Geomorphology	Can Tho	2007	[9]	Raster
8	Geomorphology	Can Tho	2016	ODM (Vietnam)	Shapefile
9	Geomorphology	Can Tho	Unknown	[8]	Raster
10	Land Use	Can Tho	2006	[7]	Raster
11	Land Use	Can Tho	2007	[9]	Raster
12	Land Use	Can Tho	2010	[10]	Raster
13	Land Use	Can Tho	2017	Sentinel-2	TIFF
14	Land Use	Can Tho	2018	Sentinel-2	TIFF
15	Land Use	Can Tho	2019	Sentinel-2	TIFF
16	Land Use	Can Tho	2020	Sentinel-2	TIFF
17	Land Use	Can Tho	2021	Sentinel-2	TIFF
18	Land Cover	Can Tho	2003	[8]	Raster
19	Land Cover	Can Tho	2009	ESA	Raster
20	Land Cover	Can Tho	2017	[8]	Raster
21	Land Cover	Can Tho	Unknown	[11]	Raster
22	Housing Distribution	Can Tho	2015	MIT GeoWeb	Shapefile
23	Population Density	Can Tho	2004	[12]	Raster
24	Population Density	Can Tho	2009	City Population	Raster
25	Population Density	Can Tho	2010	[10]	Raster
26	Population Density	Can Tho	2019	City Population	Raster
27	Population Density	Can Tho	Unknown	[8]	Raster
28	Road Density	Can Tho	2006	[12]	Raster
29	Road Density	Can Tho	2018	GLOBIO	Shapefile
30	Road Density	Can Tho	Unknown	[8]	Raster
31	Landslide Susceptibility	Can Tho	2020	NASA	Shapefile
32	Landslide Inventory	Can Tho	2015	NASA (GLC)	Shapefile
33	Landslide Inventory	Can Tho	2020	ODM (Vietnam)	Shapefile
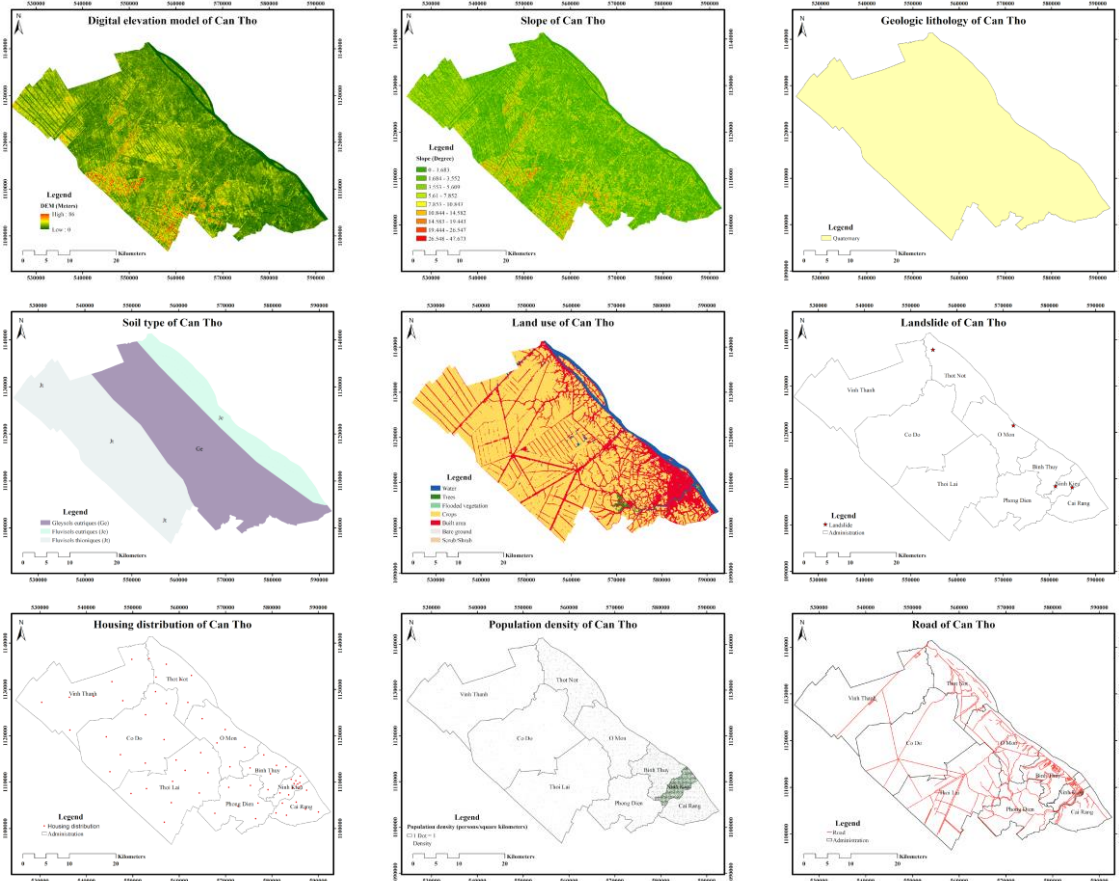
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Can Tho pilot site.

Landslide Data for Kon Tum Pilot Site in Vietnam

The following table summarizes the data collection results for Kon Tum city. Example raster images of the collected factors are shown.

Summary of collected landslide data for Kon Tum pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Slope	Kon Tum	2013	Calculated from DEM (5)	Raster
2	Slope	Kon Tum	Unknown	[13]	Raster
3	Slope	Kon Tum	Unknown	[14]	Raster
4	Slope	Kon Tum	Unknown	[15]	Raster
5	DEM	Kon Tum	2013	ASTGTM	TIFF
6	DEM	Kon Tum	Unknown	[13]	Raster
7	DEM	Kon Tum	Unknown	[14]	Raster
8	DEM	Kon Tum	Unknown	[15]	Raster
9	Geologic Lithology	Kon Tum	2018	Orr & Associates	Shapefile
10	Geologic Lithology	Kon Tum	Unknown	[13]	Raster
11	Geologic Lithology	Kon Tum	Unknown	[15]	Raster
12	Geomorphology	Kon Tum	2016	ODM (Vietnam)	Shapefile
13	Geomorphology	Kon Tum	Unknown	[15]	Raster
14	Geomorphology	Kon Tum	Unknown	[16]	Raster
15	Land Use	Kon Tum	2017	Sentinel-2	TIFF
16	Land Use	Kon Tum	2018	Sentinel-2	TIFF
17	Land Use	Kon Tum	2019	Sentinel-2	TIFF
18	Land Use	Kon Tum	2020	Sentinel-2	TIFF
19	Land Use	Kon Tum	2021	Sentinel-2	TIFF
20	Land Use	Kon Tum	Unknown	[13]	Raster
21	Land Use	Kon Tum	Unknown	[15]	Raster
22	Land Use	Kon Tum	Unknown	[16]	Raster
23	Land Cover	Kon Tum	2009	ESA	Raster
24	Housing Distribution	Kon Tum	2015	MIT GeoWeb	Shapefile
25	Population Density	Kon Tum	2009	City Population	Raster
26	Population Density	Kon Tum	2019	City Population	Raster
27	Road Density	Kon Tum	2018	GLOBIO	Shapefile
28	Landslide Susceptibility	Kon Tum	2020	NASA	Shapefile
29	Landslide Susceptibility	Kon Tum	Unknown	[13]	Raster
30	Landslide Inventory	Kon Tum	2009	NASA (GLC)	Shapefile
31	Landslide Inventory	Kon Tum	2020	ODM (Vietnam)	Shapefile
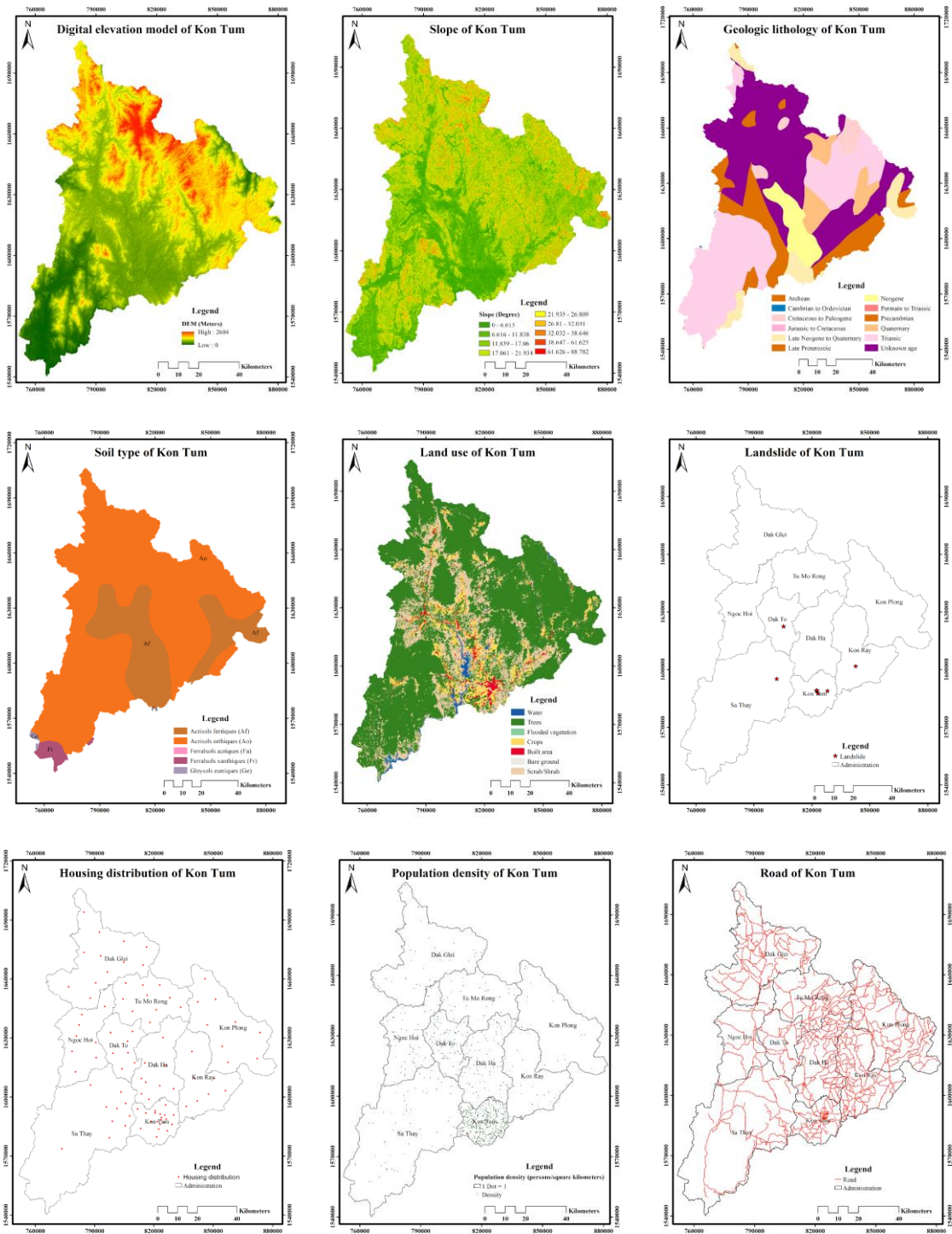
From top to bottom, left to right: Example maps of DEM, slope, geologic lithology, geomorphology, land use/cover, landslide inventory/susceptibility, housing distribution, population density and road distribution for Kon Tum pilot site.

Other Landslide Data for Vietnam

The following table summarizes additional data collection results for Vietnam. Example raster images of the collected factors are shown.

Summary of additional landslide data for Vietnam.

No	Factor	Scope	Data Year	Data Source	Format
1	Geomorphology	Vietnam	1996	ODM (Vietnam)	Raster
2	Geomorphology	Vietnam	2021	ODM (Vietnam)	Shapefile
3	Land Cover	Vietnam	2023	LandSAGE4	Raster
4	Land Cover	Vietnam	1990	Nature	Shapefile
5	Land Cover	Vietnam	2009	ODM (Vietnam)	Shapefile
6	Land Cover	Vietnam	2013	ODM (Vietnam)	Shapefile
7	Land Cover	Vietnam	2020	Nature	Raster
8	Population Density	Vietnam	2021	Worldometers	Shapefile
9	Road Density	Vietnam	2021	Ontheworldmap	Raster
10	Landslide Susceptibility	Vietnam	2020	NASA	Shapefile
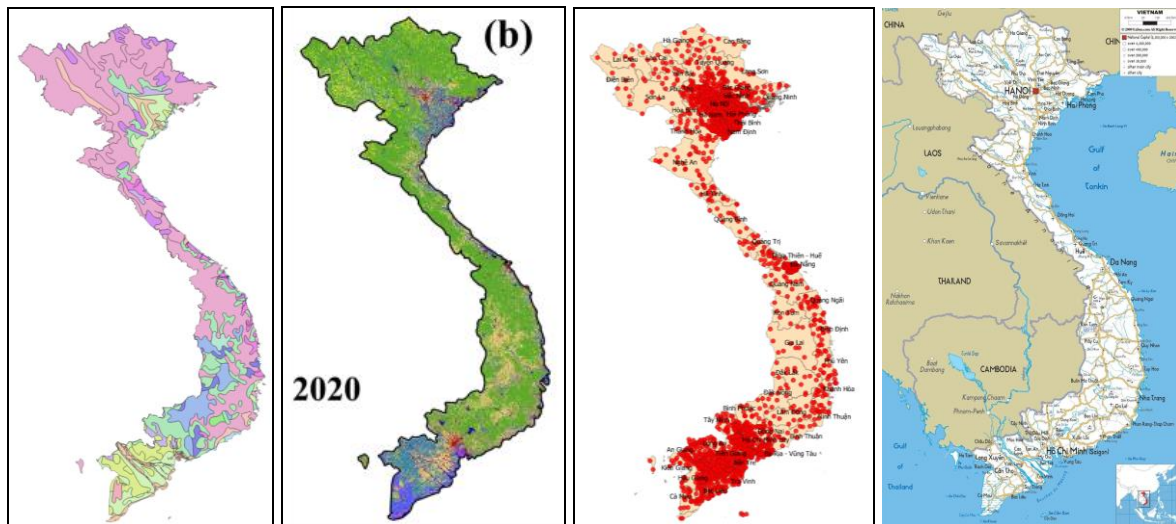
From left to right: Example maps of geomorphology, land use/cover, population density and road density for Vietnam.

Landslide Data for LandSAGE3 Pilot Sites

We also collected more landslide data for the LandSAGE3 pilot sites as summarized in the following table. Example raster images of the collected factors are shown.

Summary of additional landslide data for the LandSAGE3 pilot sites.

No	Factor	Scope	Data Year	Data Source	Format
1	Geologic Lithology	Ubon Ratchathani	2007	DMR	Raster
2	Geologic Lithology	Ubon Ratchathani	2010	DMR	Raster
3	Geomorphology	Ubon Ratchathani	2007	World Bank	Raster
4	Geomorphology	Ubon Ratchathani	2015	LDD	Raster
5	Land Use	Ubon Ratchathani	2019	LDD	Raster
6	Land Cover	Ubon Ratchathani	2023	LandSAGE4	Raster
7	Road Density	Ubon Ratchathani	2018	World Bank	Raster
8	Landslide Susceptibility	Ubon Ratchathani	2020	NASA	Shapefile
9	Landslide Susceptibility	Phnom Penh	2020	NASA	Shapefile
10	Landslide Susceptibility	Vientiane	2020	NASA	Shapefile
11	Landslide Susceptibility	Tan Chau	2020	NASA	Shapefile
12	Landslide Inventory	Vientiane	2008	NASA (GLC)	Shapefile
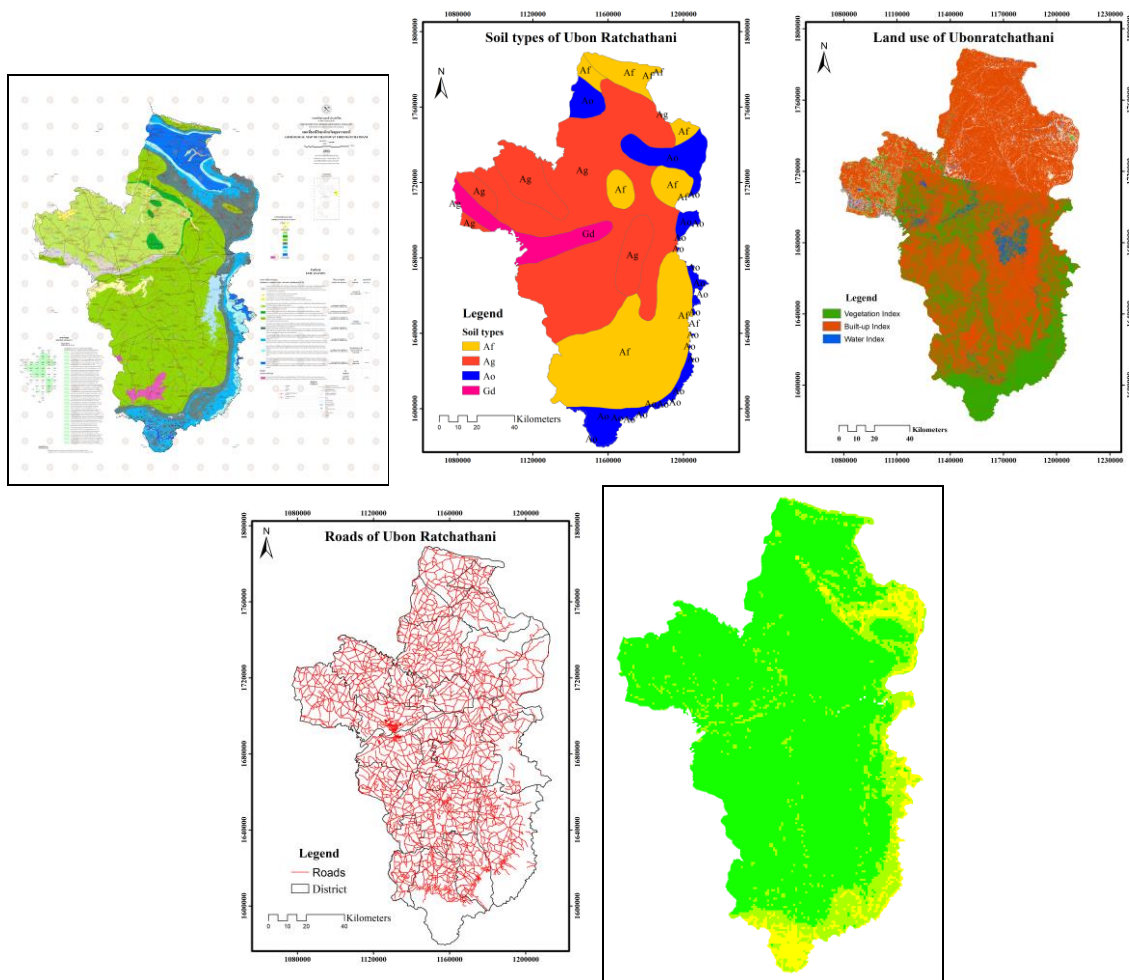
From top to bottom, left to right: Example maps of geologic lithology, geomorphology, land use/cover, road distribution, and landslide inventory/susceptibility for LandSAGE3 pilot sites.

Converting from Shapefile or TIFF to Raster Image

We used the ArcGIS mapping and analytics software to transform a Shapefile or a TIFF into a raster image in the PNG format required for importing into the LandSAGE software. The procedure is summarized below and illustrated only for the Loei pilot site.

DEM Raster Image Generation:
- In ArcGIS, select "Data Frame Properties" and then "Coordinate System", and choose "WGS 1984 UTM Zone 48N".
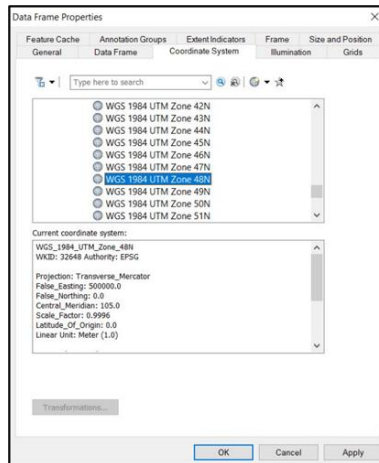
- Import DEM and administrative boundary.
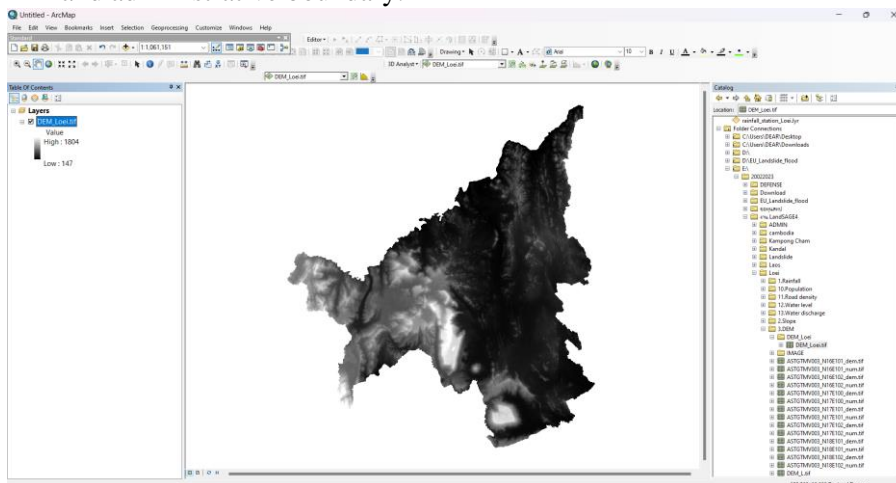
- Change "DEM Color Ramp" from the "Symbology" tab in the "Layer Properties" dialog box.
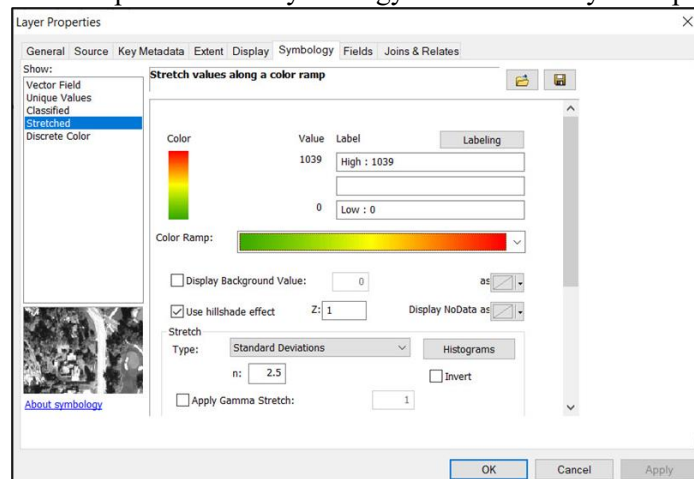
- Set map layout and add components such as north arrow, legends, grid, and title.
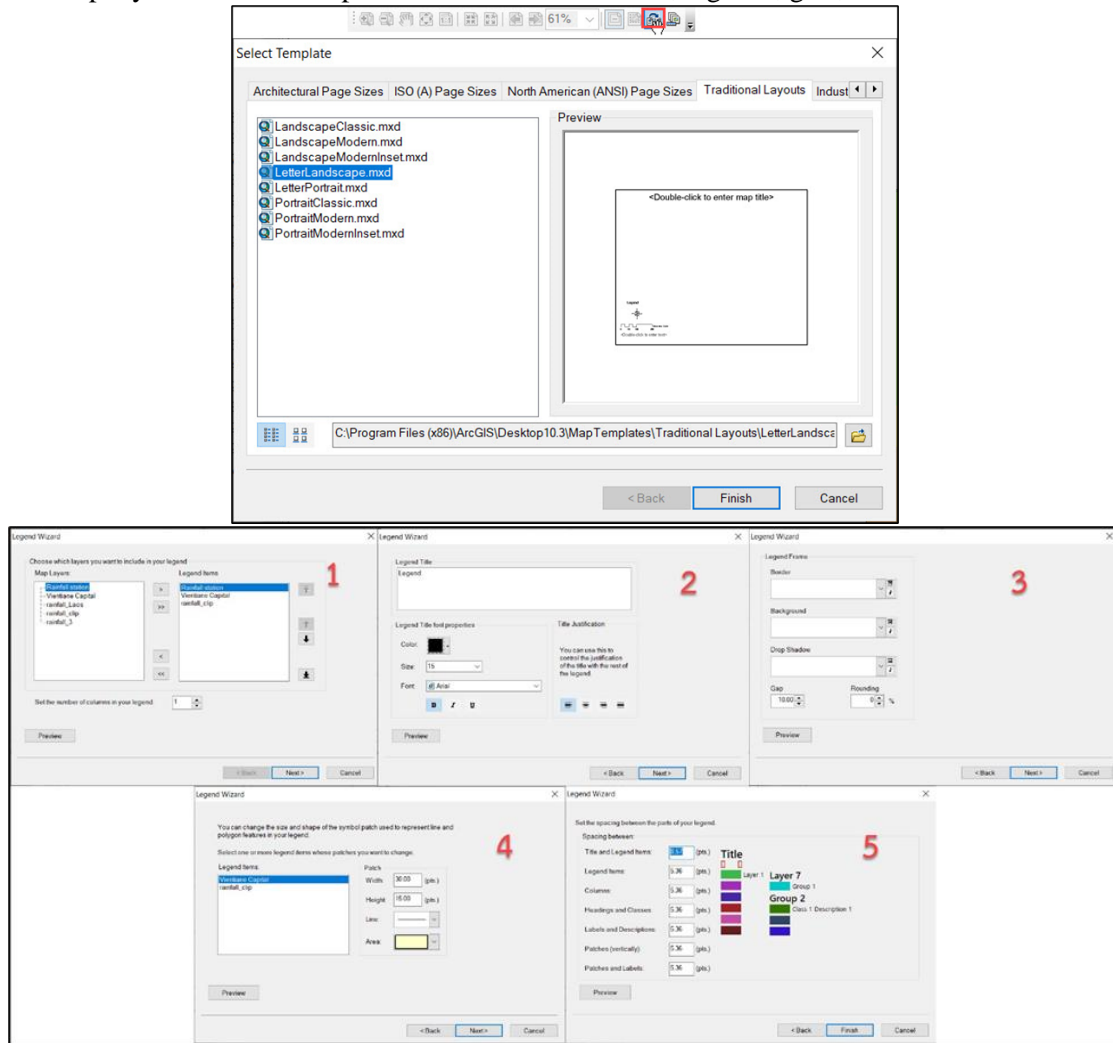
- Final result:
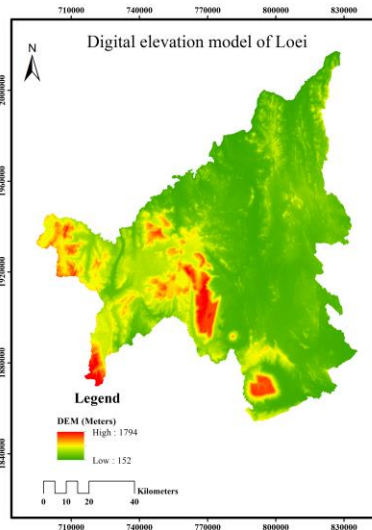
Slope Raster Image Generation:
- In ArcGIS, select "Data Frame Properties" and then "Coordinate System", and choose "WGS 1984 UTM Zone 48N".
- Import DEM and administrative boundary.
- Under "ArcToolbox" –> "Spatial Analyst Tools" –> "Surface", choose the "Slope" tool. Set the Z factor to 0.00000912.
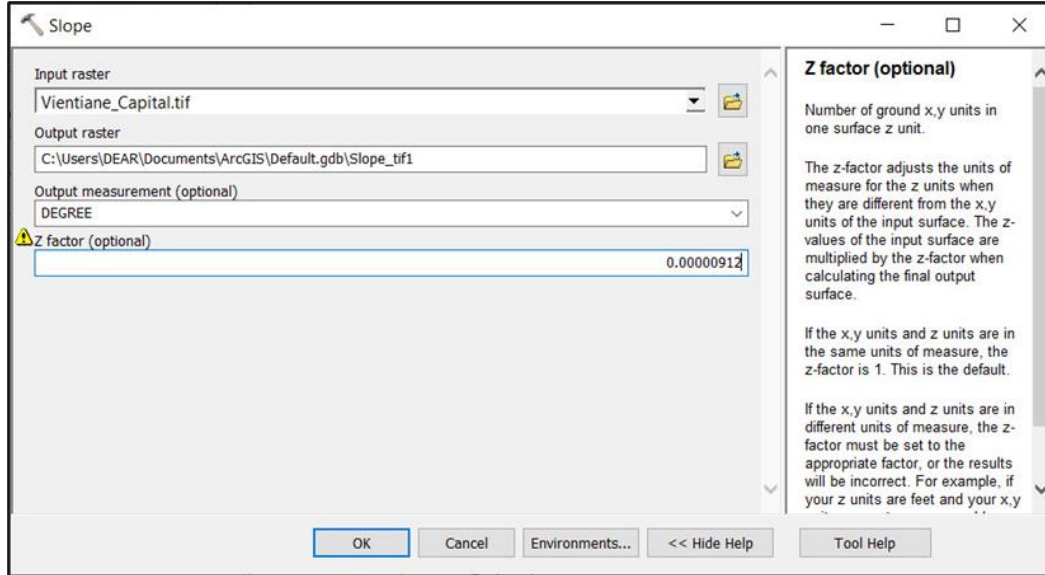
- Set map layout and add map components before generating the raster image using the steps explained for DEM.

Geologic Lithology Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N", and then import geologic lithology data and administrative boundary.
- From the "Symbology" tab of the "Layer Properties" dialog box, classify lithology by setting attribute values of the field "RCK_TYPE_E".
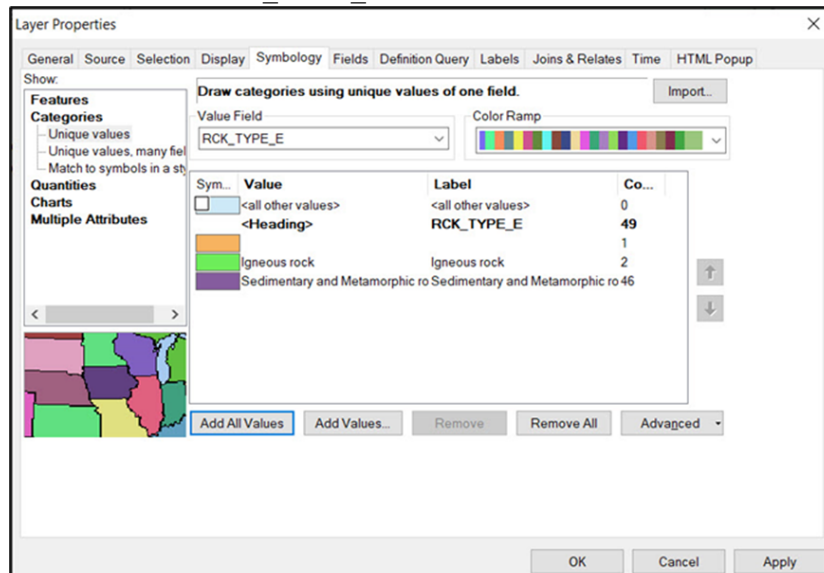
- Set map layout and add map components before generating the raster image.

Geomorphology Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N", and then import soil series data and administrative boundary.
- From the "Symbology" tab of the "Layer Properties" dialog box, classify soil groups by setting attribute values of the field "DOMSOI".
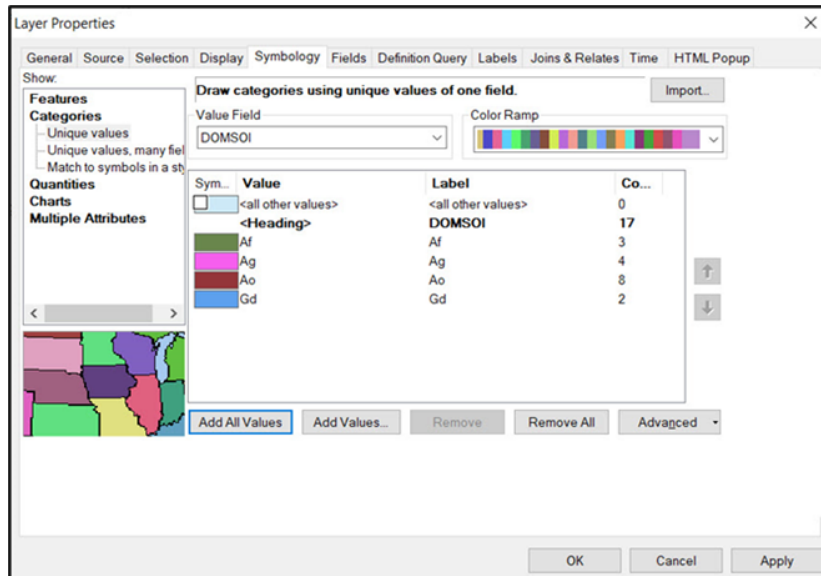
- Set map layout and add map components before generating the raster image.

Land Use Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N", and then import land use data and administrative boundary.
- From the "Symbology" tab of the "Layer Properties" dialog box, classify land use by setting attribute values of the field "MU_CODE". We used 1st level classification that consists of agriculture (A), forest (F), urban (U), water (W) and miscellaneous (M) areas.
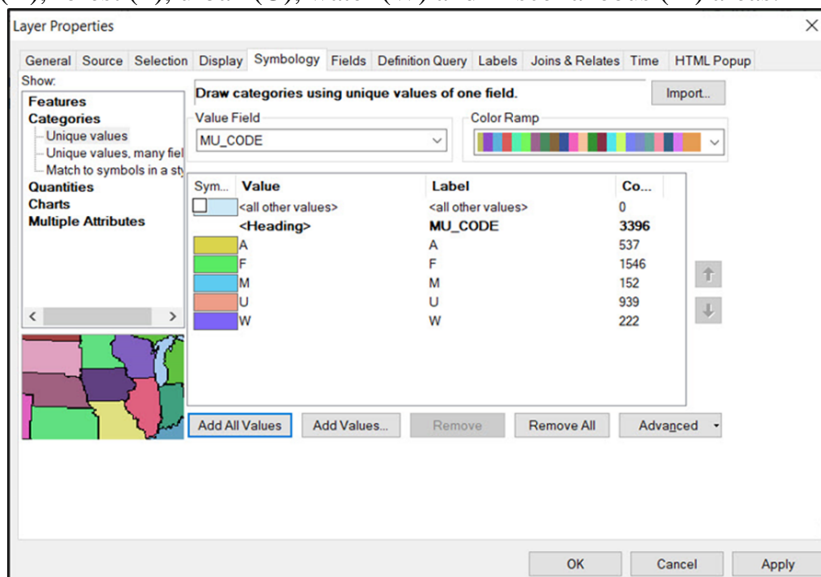
- Set map layout and add map components before generating the raster image.

Landslide Inventory Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N".
- Together with the administrative boundary, import landslide inventory data into ArcGIS. Data in the shapefile format can be imported directly. For data in tabular (Excel) format containing X and Y coordinates, we can use the "Display XY Data" function to add a new map layer based on the XY events from the table.
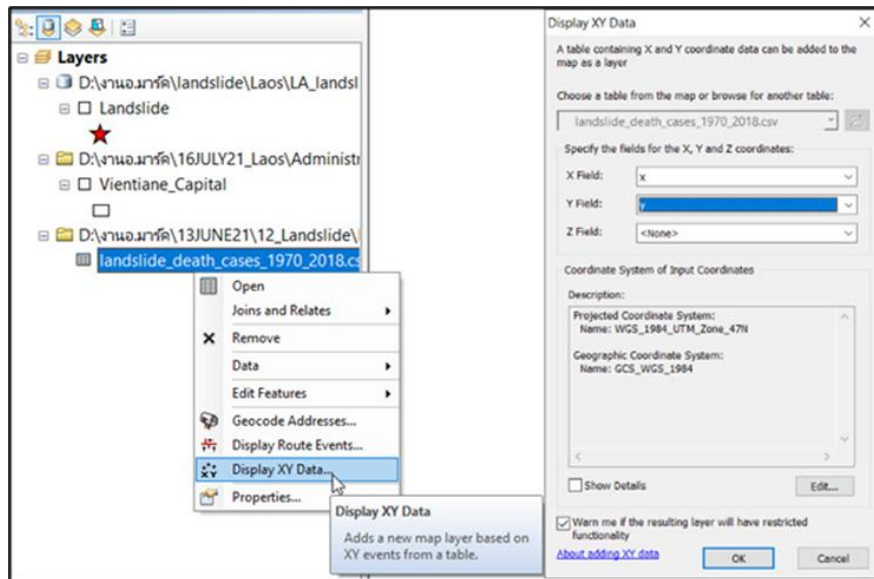
- Set map layout and add map components before generating the raster image.

Housing Distribution Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N", and then import housing distribution data and administrative boundary.
- Label each house using the "Labels" tab in the "Layer Properties" dialog box. Each house appears as a point on the generated map.
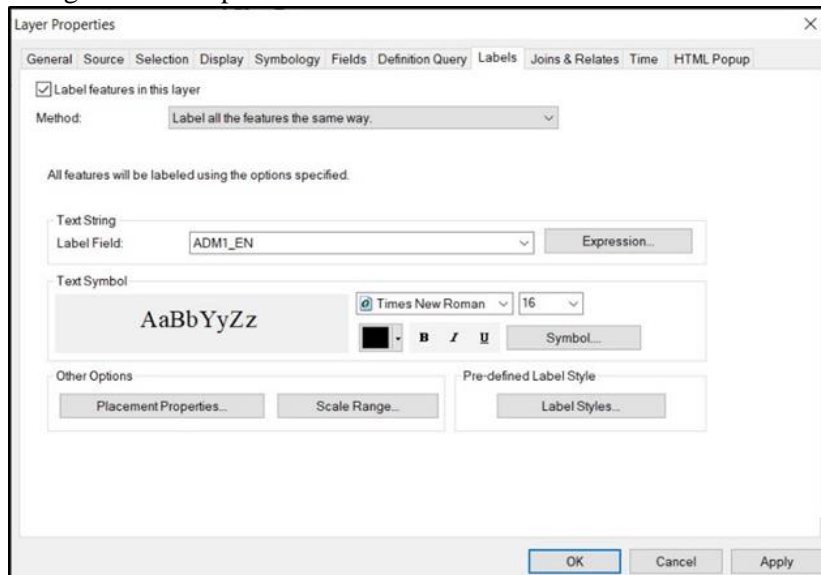
- Set map layout and add map components before generating the raster image.

Population Density Raster Image Generation:
- Set the coordinate system to "WGS 1984 UTM Zone 48N".
- Import administrative boundary data that contains population data.
- In the attribute table of administrative boundary, choose "Add Field" and then set "Name" to "Density", "Type" to "Double", "Precision" to "2", and "Scale" to "8".
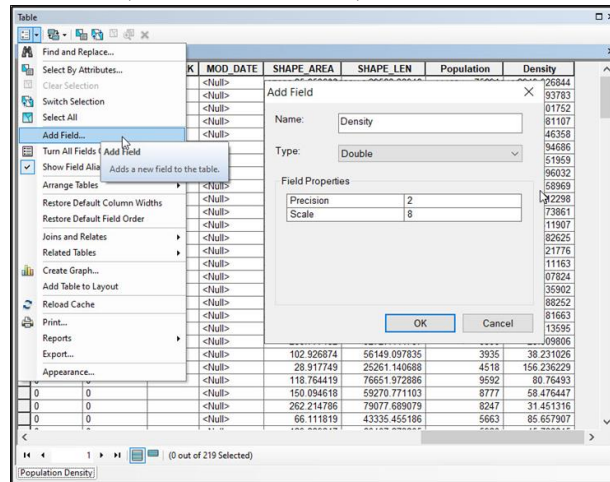
- In the table, right click the "Density" header and choose "Field Calculator" to calculate population density. Specify the density as "Population/Area".
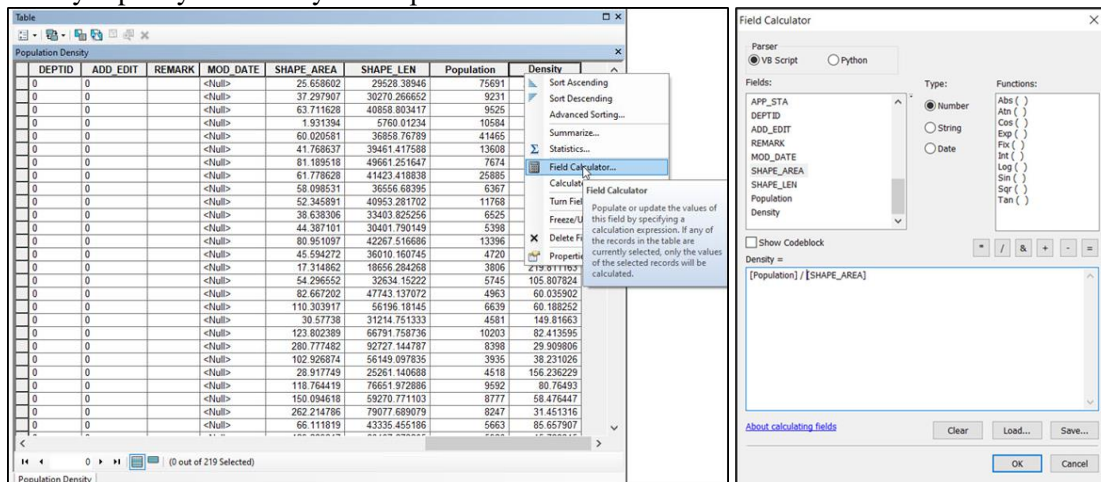
- Use "Dot Density" tool in the "Layer Properties" dialog box to symbolize population density map.
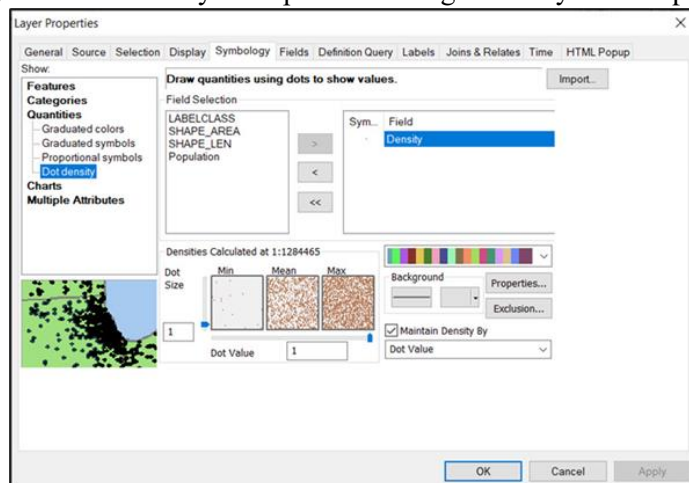
- Set map layout and add map components before generating the raster image.

Road Density Raster Image Generation:

- Set the coordinate system to "WGS 1984 UTM Zone 48N", and then import road data and administrative boundary.
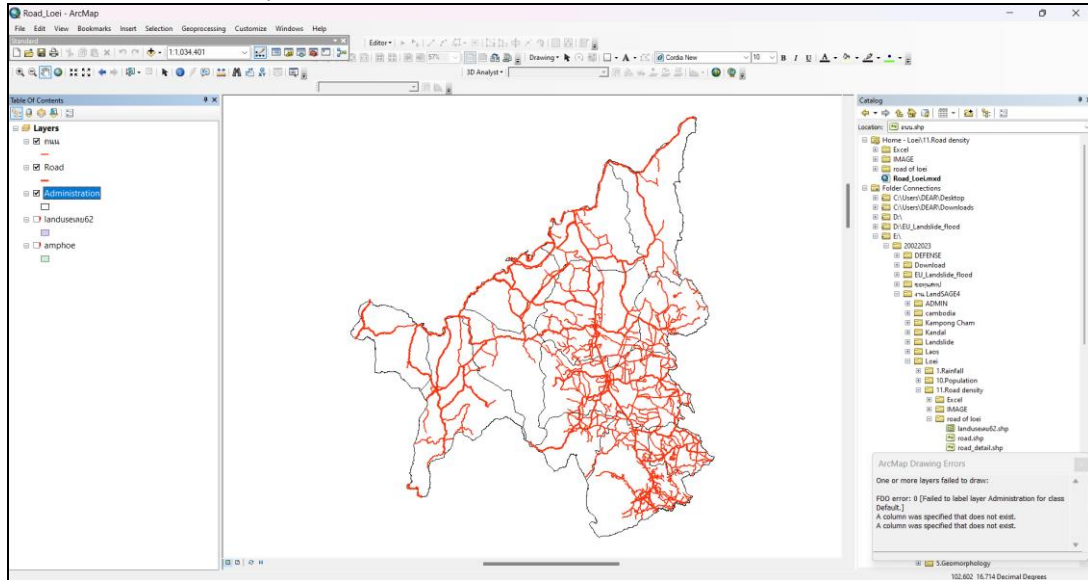
- Set map layout and add map components before generating the raster image.

Generating Land Cover Map from Landsat 8 Images

In the above landslide data collection tables, the land cover entries with the data sources marked as "LandSAGE4" were generated by a developer using the technique summarized below.

- Download Landsat 8 images for a desired area from an online source such as the Google Earth Engine or the USGS Earth Explorer. The picture below shows the Earth Explorer's "Search Tool" that enables the user to download data for a specific location and date as well as specifying other search criteria.
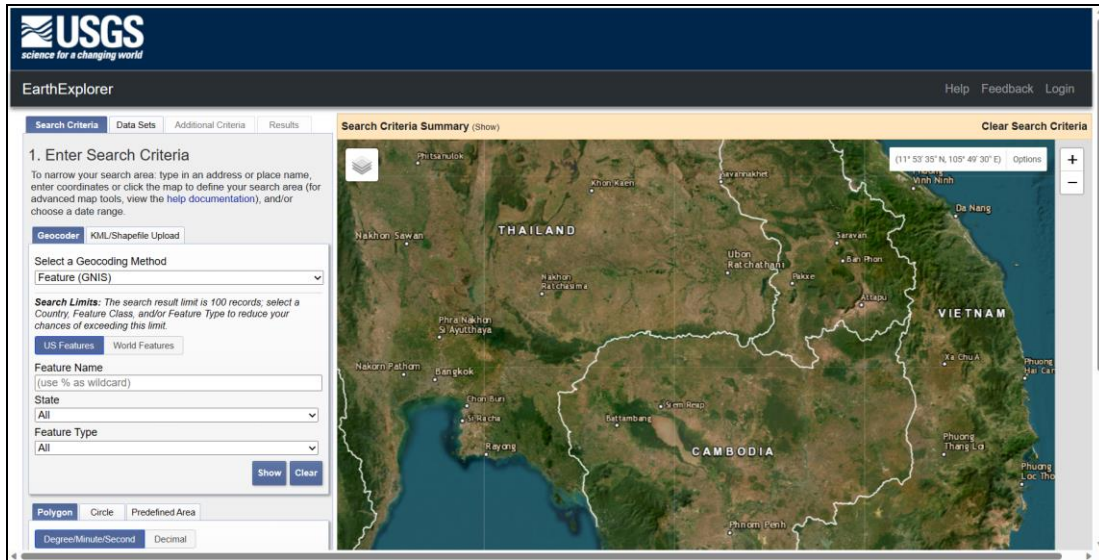
- In the ArcGIS software, import the bands needed for the calculation of a desired index. The table below shows band descriptions.

	Bands	Wavelength (micrometers)
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	Band 1 - Coastal aerosol	0.43 - 0.45
	Band 2 - Blue	0.45 - 0.51
	Band 3 - Green	0.53 - 0.59
	Band 4 - Red	0.64 - 0.67
	Band 5 - Near Infrared (NIR)	0.85 - 0.88
	Band 6 - SWIR 1	1.57 - 1.65
	Band 7 - SWIR 2	2.11 - 2.29
	Band 8 - Panchromatic	0.50 - 0.68
	Band 9 - Cirrus	1.36 - 1.38
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51

- In this example, we are interested in the NDVI (vegetation), NDBI (building), and NDWI (water) indices. The formula used for calculating each index is given below.

  NDVI   = (NIR – RED) / (NIR + RED)
  NDBI   = (SWIR1 – NIR) / (SWIR1 + NIR)
  NDWI = (GREEN – NIR) / (GREEN + NIR)

- Use the "Raster Calculator" tool and fill in the formula for an index. The example below shows the calculation for the NDWI index and the corresponding result.
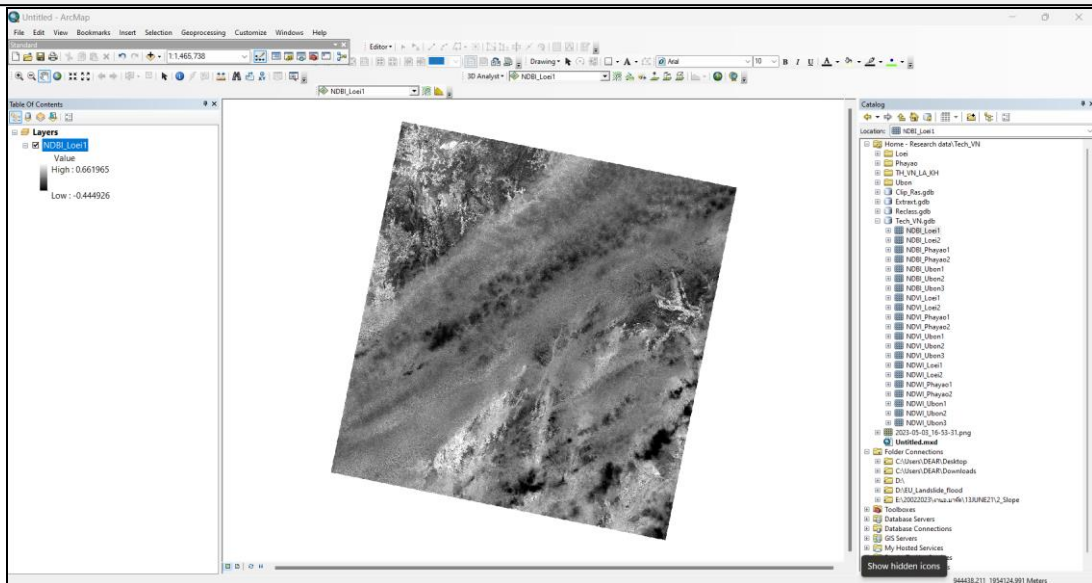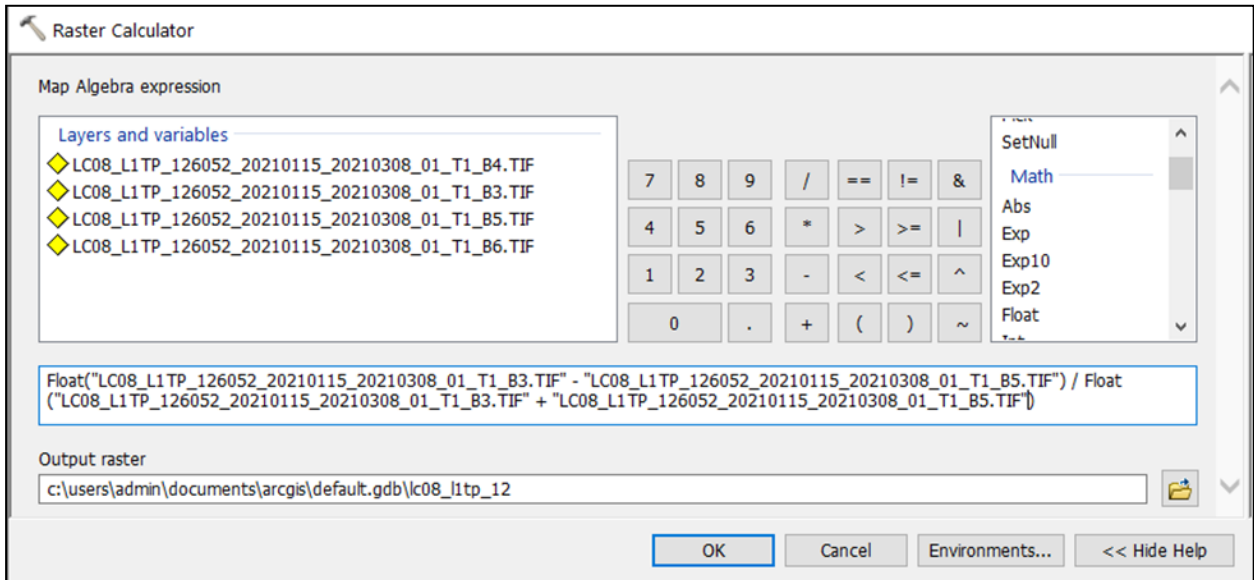
- Use the "Reclassify" tool to setup two classes and values as shown in the picture below.
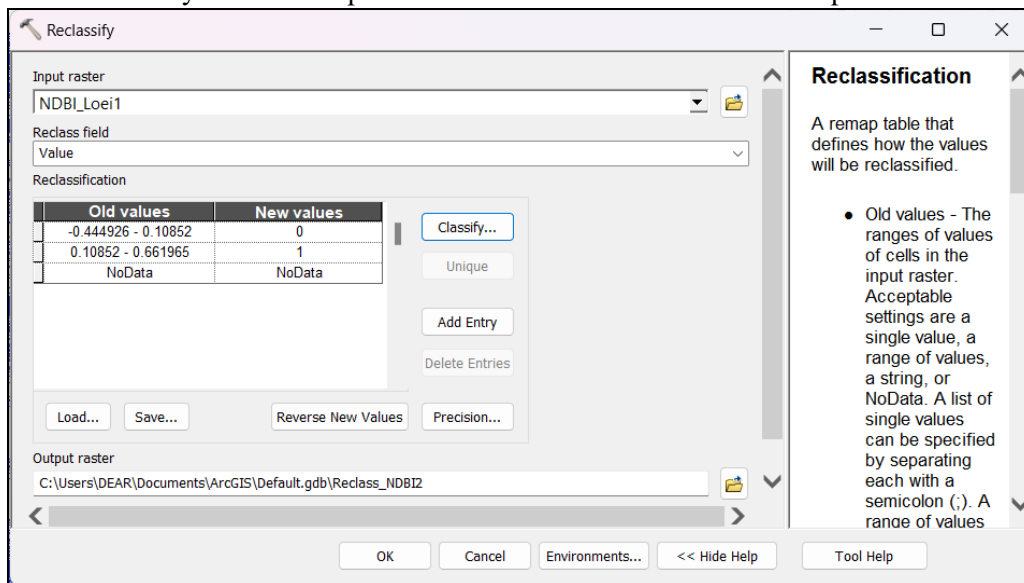
- This will result in a layer with water (1) and non-water (0) areas.
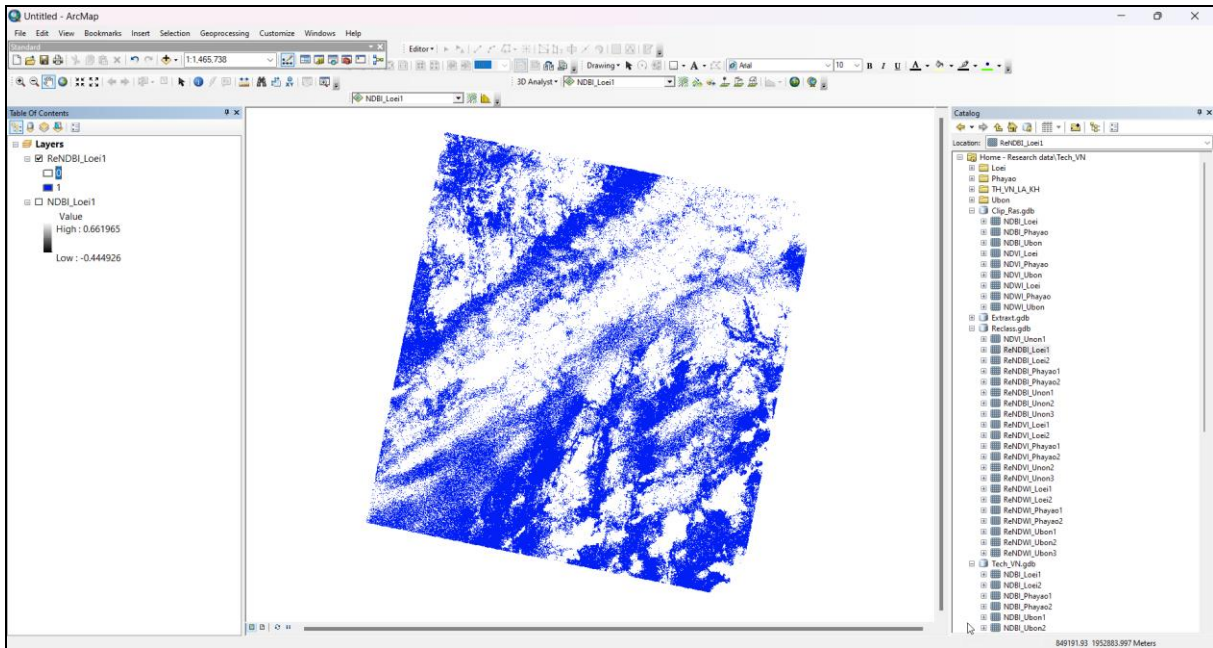
- Use the "Extract by Attributes" tool to extract only the water areas.
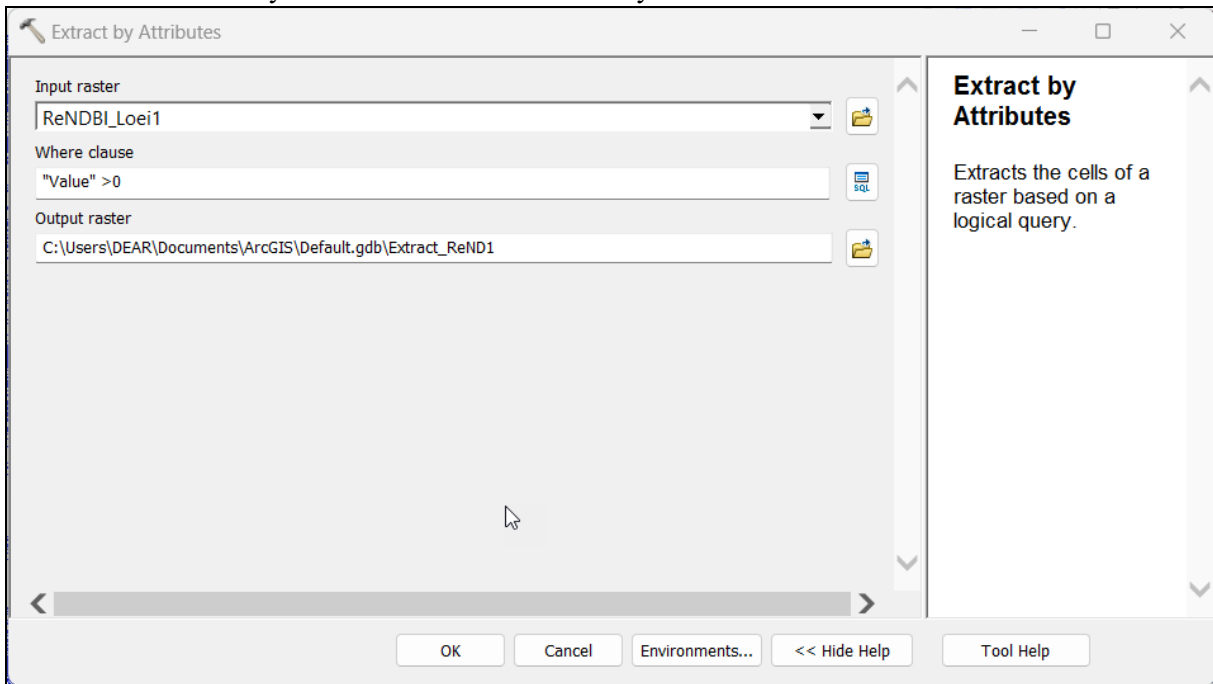
- Cut the layer to include only the region of interest. Perform similar steps for the NDVI and NDBI indices. Combine the results into a single land cover map consisting of vegetation (green), building (orange), and water (blue) areas. The pictures below show the land cover maps generated for the three Thailand pilot sites (including the pilot site from LandSAGE3).

Land use of Loei

Land use of Phayao

Land use of Ubonratchathani
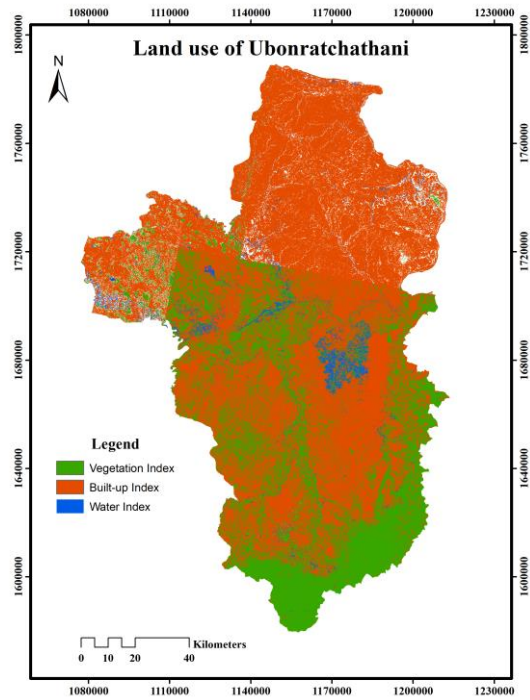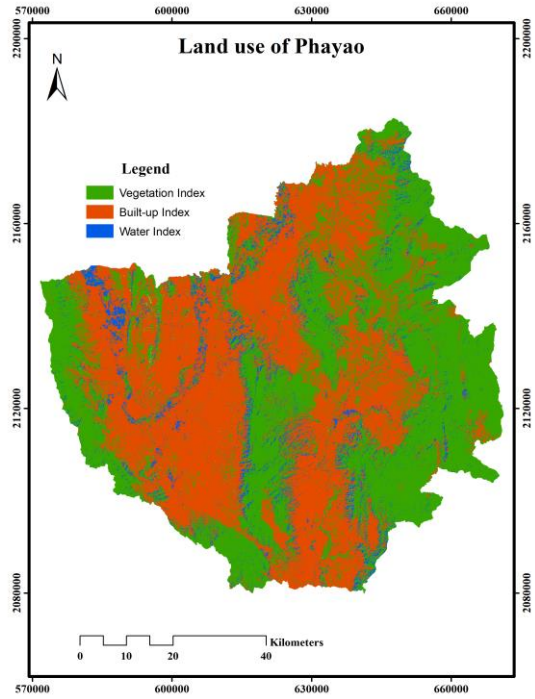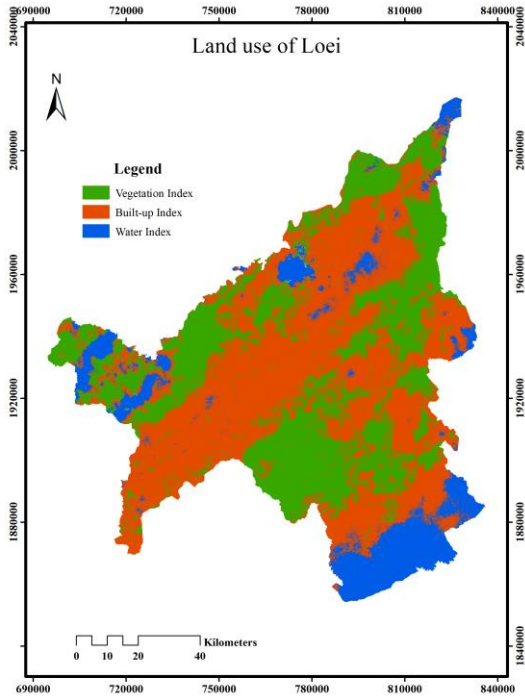
Map and Legend Extraction from Raster Image

Each of the collected raster images was processed as follows:
1. Using the Adobe Photoshop to separate the map from its legend and to add a metadata (origin and year) to the extracted legend.
2. Using Google Earth to find the latitudes and longitudes of the extracted map that precisely align it to a base map of the Lower Mekong Basin.

All the extracted maps with their latitudes, longitudes, and legends were imported into the LandSAGE database. In more detail,

Legend Extraction:
- Open the raster image in the Adobe Photoshop. Set the "Background Layer" to workable.
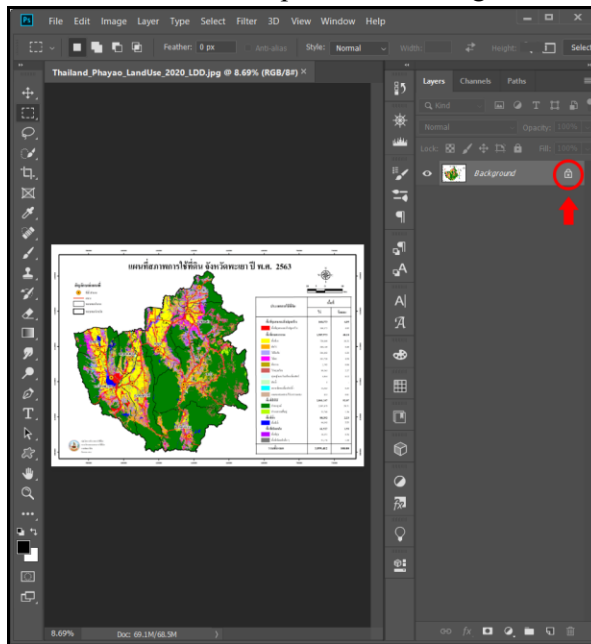
- Use the "Selection Tool" (1) to select the area of the legend (2) and then use the "Crop Tool" (3).
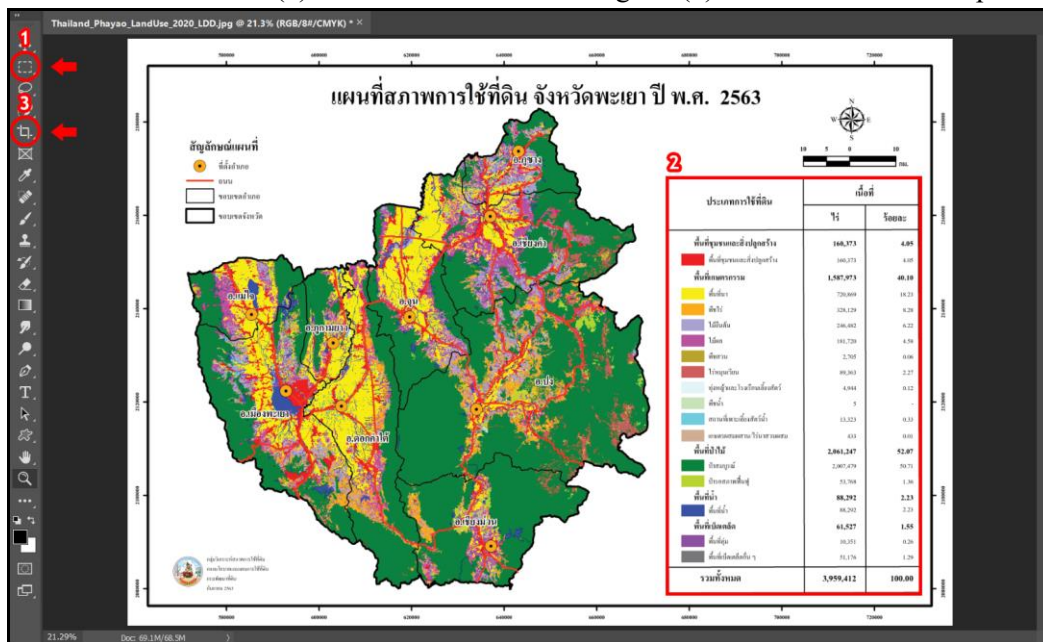
- Use the "Type Tool" (4) to add the data source and year to the extracted legend. The lower right picture shows the legend with the metadata added to the upper left corner.

Source: LDD
Year: 2020

ประเภทการใช้ที่ดิน	เนื้อที่	
	ไร่	ร้อยละ
พื้นที่ชุมชนและสิ่งปลูกสร้าง	160,373	4.05
พื้นที่ชุมชนและสิ่งปลูกสร้าง	160,373	4.05
พื้นที่เกษตรกรรม	1,587,973	40.10
พื้นที่นา	720,869	18.23
พืชไร่	328,129	8.28
ไม้ยืนต้น	246,482	6.22
ไม้ผล	181,720	4.58
พืชสวน	2,705	0.06
ไร่หมุนเวียน	89,363	2.27
ทุ่งหญ้าและโรงเรือนเลี้ยงสัตว์	4,944	0.12
พืชน้ำ	5	-
สถานที่เพาะเลี้ยงสัตว์น้ำ	13,323	0.33
เกษตรผสมผสาน/ไร่นาสวนผสม	433	0.01
พื้นที่ป่าไม้	2,061,247	52.07
ป่าสมบูรณ์	2,007,479	50.71
ป่ารอสภาพฟื้นฟู	53,768	1.36
พื้นที่น้ำ	88,292	2.23
พื้นที่น้ำ	88,292	2.23
พื้นที่เบ็ดเตล็ด	61,527	1.55
พื้นที่ลุ่ม	10,351	0.26
พื้นที่เบ็ดเตล็ดอื่น ๆ	51,176	1.29
รวมทั้งหมด	3,959,412	100.00

TH_PHY_LandUse_2020_LDD_Legend.psd @ 300% (Source: LDD Year: 2020, RGB/8) #

Source: LDD
Year: 2020

- Save the resulting image in the PNG "interlaced" format.

PNG Format Options

File Size
- ● Large file size (Fastest saving)
  - ☑ Interlacing
- ○ Medium file size (Medium saving)
- ○ Smallest file size (Slowest saving)

OK
Cancel
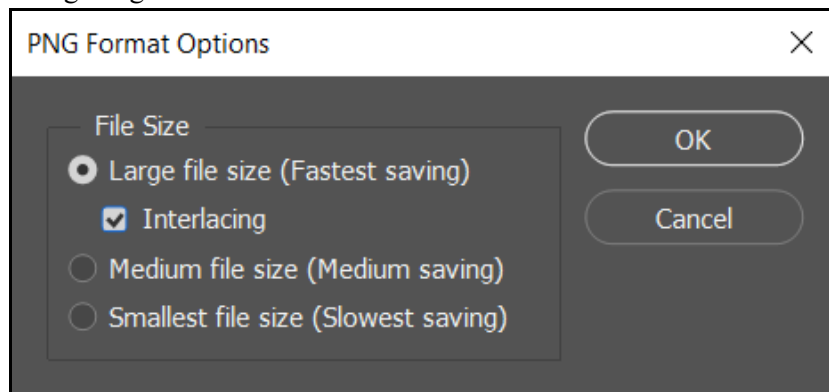
Map Extraction:
- Open the raster image in the Adobe Photoshop. Set the "Background Layer" to workable.
- Use the "Selection Tool" to remove unwanted objects such as the legend. Use the "Magic Wand Tool" (5) to remove an unwanted object that overlaps the map area.
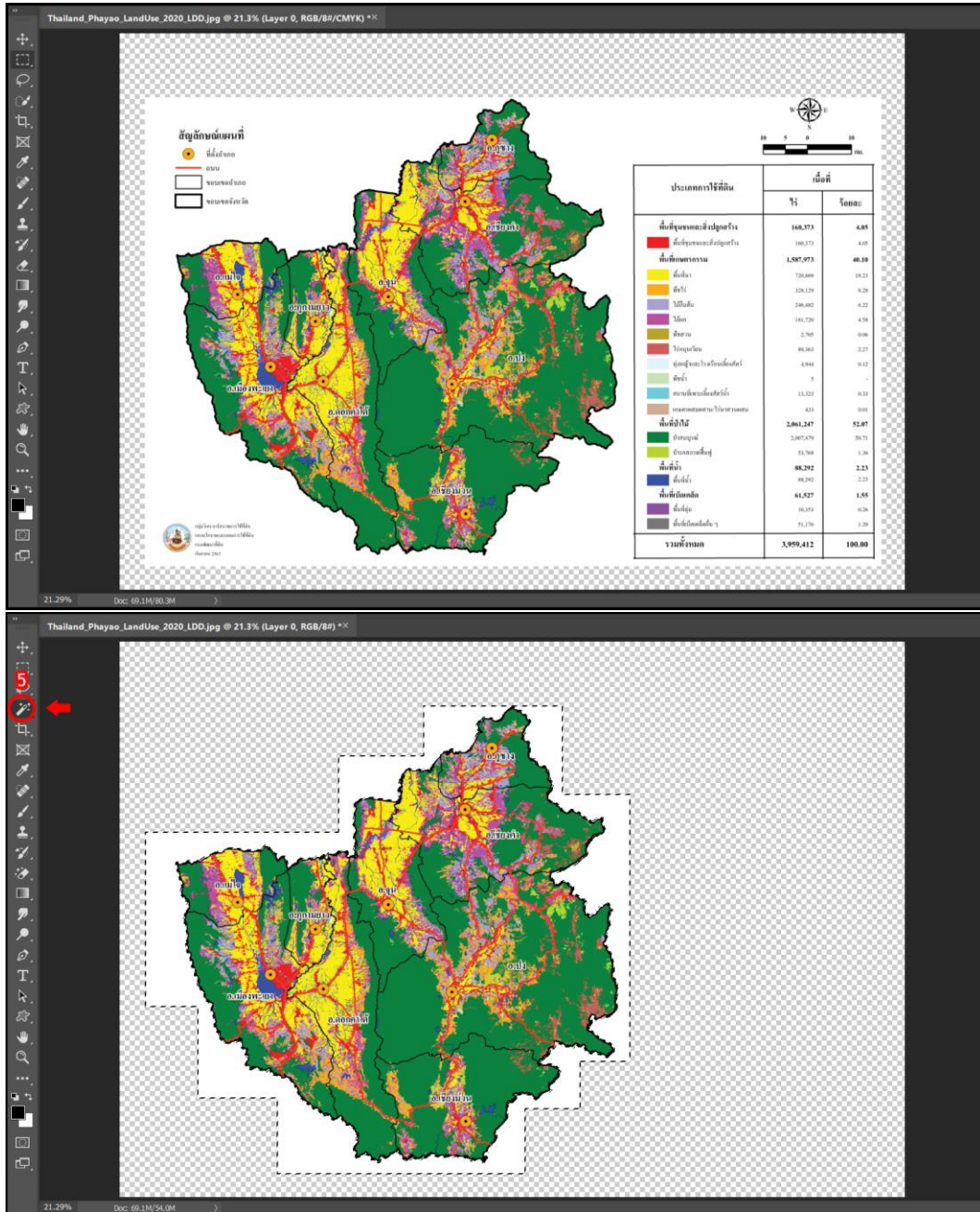
● Use the "Magic Wand Tool" to crop the map area.
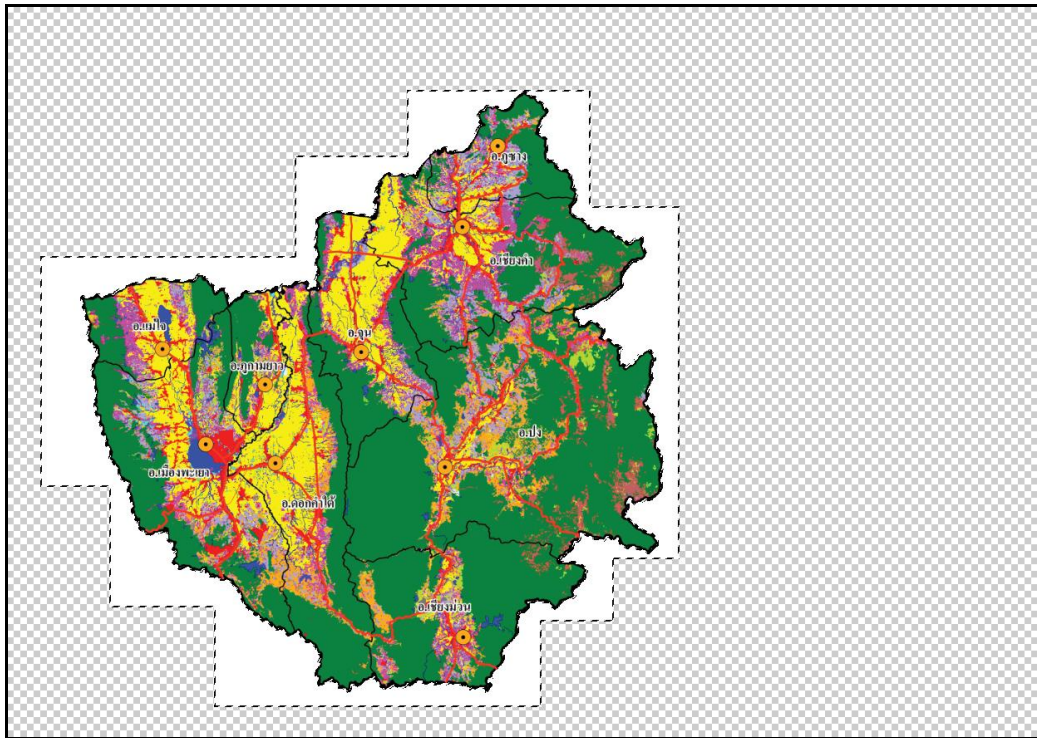
● Make sure that the map is centered on the raster image.
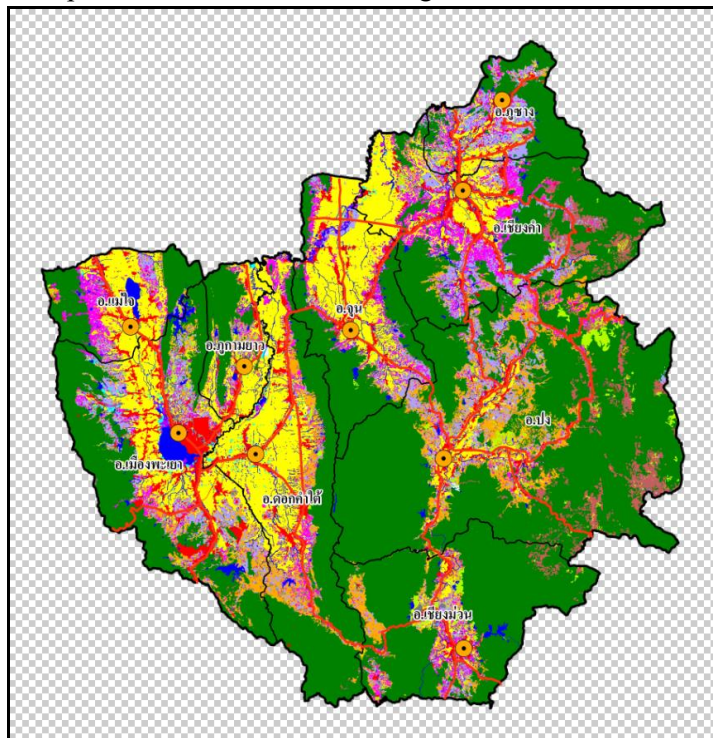
● Save the resulting image in the PNG "interlaced" format.

Map Alignment:
- In Google Earth Pro, look for the area of the extracted map, then click "Add Image Overlay".
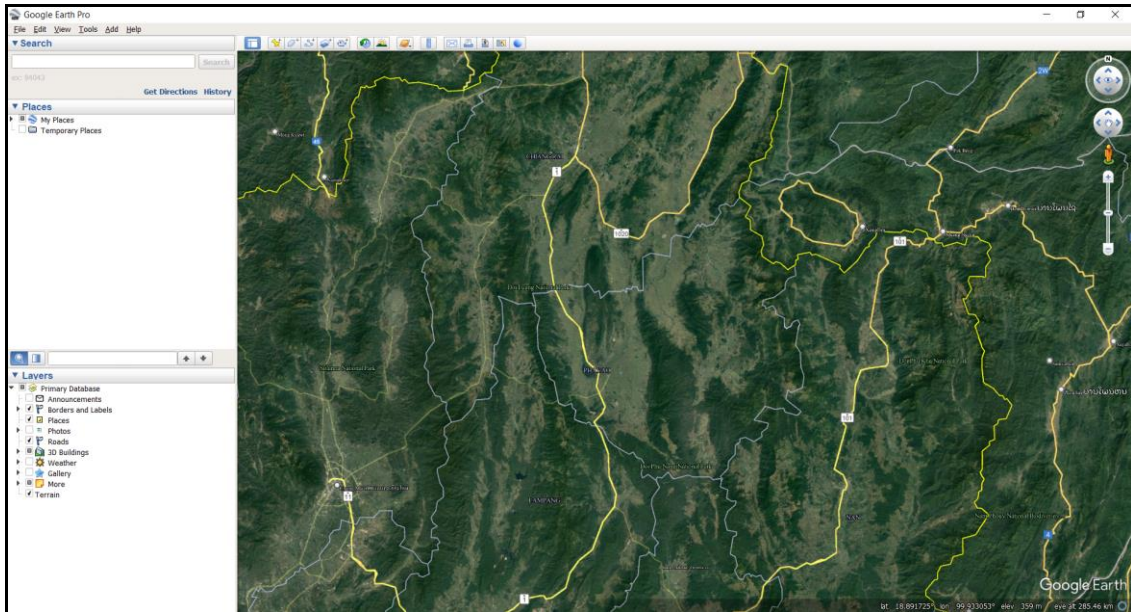
- Browse and upload the map to Google Earth Pro.
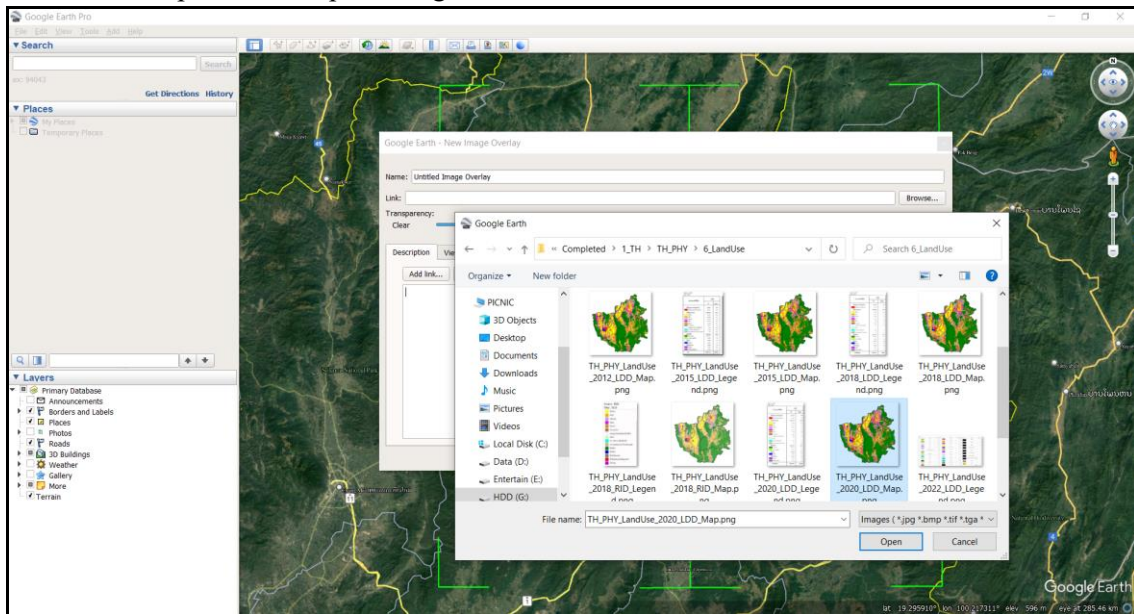
- Translate, rotate, and stretch the image to align it to the corresponding area on the base map as best possible.
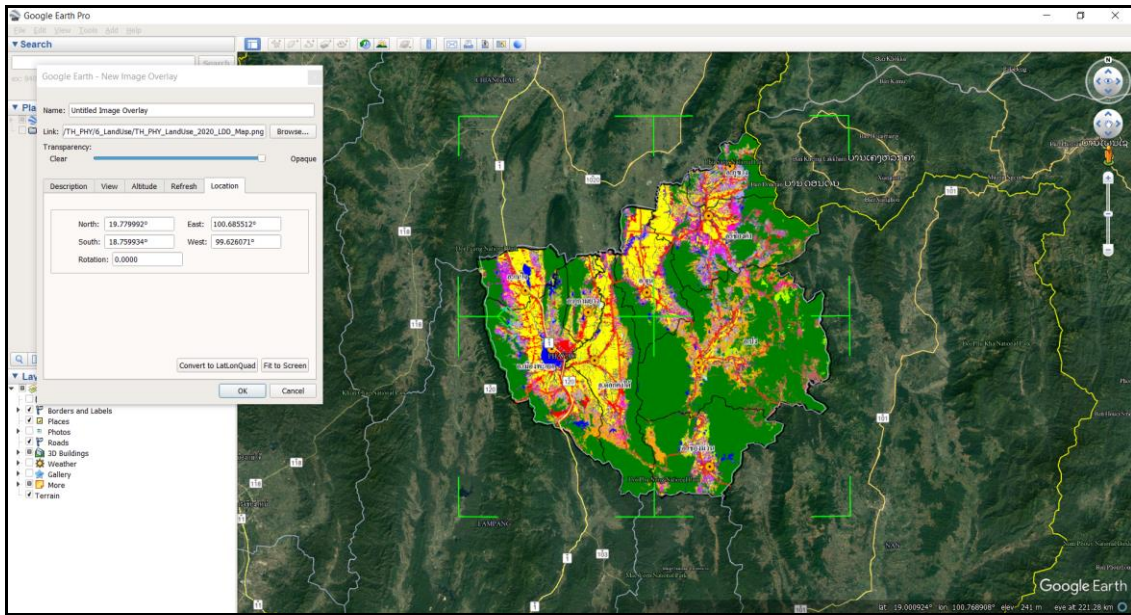
- After the alignment, save the latitudes and longitudes of the upper left and lower right corners of the map for importing into the LandSAGE database. If the alignment involves rotation, modify the original map in the Adobe Photoshop by applying rotation of the same amount before importing it into the LandSAGE database.
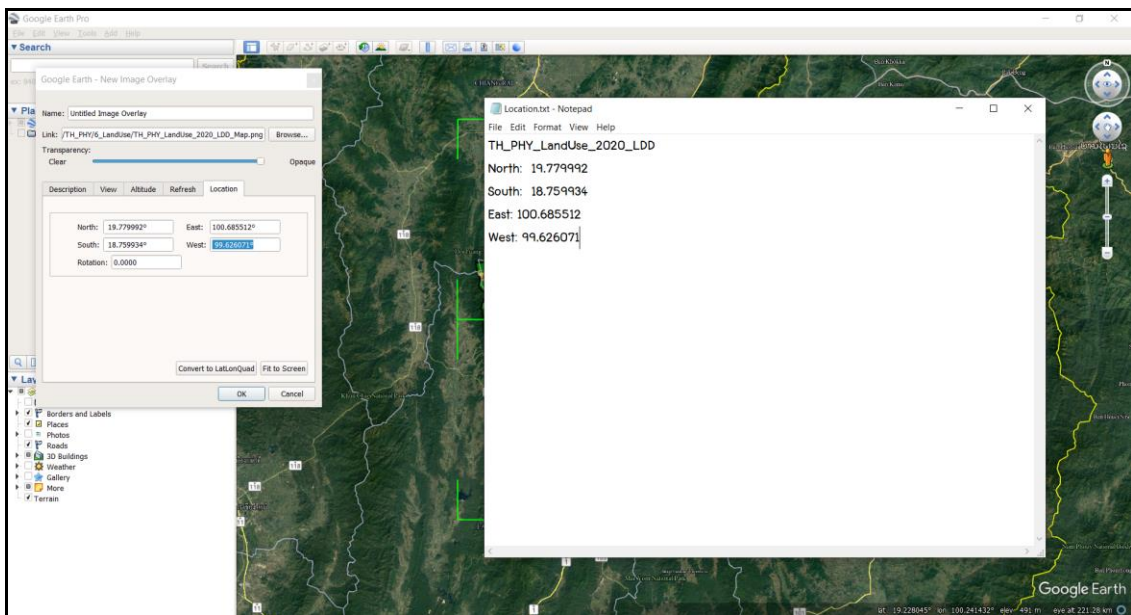
Activity 7: Sub-activity 2 – Drought and Dengue Data Collection

Drought is another important natural disaster in the Lower Mekong Basin according to researchers from the Mekong River Commission Secretariat and the National University of Laos. Natural disasters such as landslides and floods have been found to trigger the spread of diseases such as dengue and tuberculosis, with their relationships being a subject of interest from several researchers. To explore the requirements for a framework of reusable visualization tools for cyber-infrastructure-enabled decision support systems for different types of natural disasters, we additionally collected drought and dengue data for the Lower Mekong Basin to visualize them in the LandSAGE software. Based on our discussion with a natural disaster expert, we found important factors of droughts to be DEM, waterway, irrigation, land use, administrative boundary, soil type (geomorphology), groundwater, rainfall, distance to water resource, and drought history. Since DEM, land use, geomorphology, and rainfall had been collected for landslides, so we focused on the collection of the remaining factors. Subsequent sections summarize the data sources and the obtained factors for each pilot site. We applied the same map and legend extraction procedure, as described in Activity 7: Sub-activity 1 – Landslide Data Collection, to the obtained data before importing them into the LandSAGE software.

<u>**Drought and Dengue Data Sources**</u>

DWR (Department of Water Resources) is a government agency in Thailand that is responsible for managing and regulating the country's water resources.

RID (Royal Irrigation Department) of Thailand is an agency in the departments in the Ministry of Agriculture and Cooperatives of Thailand which is responsible for storing, controlling, distributing, draining, or allocating water for agricultural, energy, household consumption, or industrial purposes.

ODM (Open Development Mekong) is an open data platform providing objective data visualizations that illustrate the development and environmental challenges in the Mekong region. The platform provides data for five countries in the region including Cambodia, Laos, Myanmar, Thailand, and Vietnam.

DGR (Department of Groundwater Resources) is a Thai government organization that has the responsibility of managing and overseeing the regulation of the country's groundwater resources.

DMR (Department of Mineral Resources) in Thailand serves as the governmental agency for fact-finding related to minerals and geology. Various types of digital and printed thematic geological maps are available for free download and for sale.

LDD (Land Development Department) in Thailand is the governmental organization responsible for soil survey, soil mapping, land improvement and land use planning.

HDX (Humanitarian Data Exchange) is an online platform that was created by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) to facilitate the sharing of data and information related to humanitarian crises and disasters around the world.

WFP (World Food Programme) is a humanitarian organization that is part of the United Nations system. The WFP is the world's largest humanitarian agency that addresses hunger and promotes food security, working to deliver food assistance to millions of people in need around the world.

MOPH (The Ministry of Public Health) in Thailand is the governmental organization tasked with supervising public health in the country.

Drought Data for Phayao Pilot Site in Thailand

The following table summarizes the data collection results for Phayao province. Example raster images of the collected factors are shown.

Summary of collected drought data for Phayao pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Phayao	2020	DWR	Raster
2	Irrigation	Phayao	2018	RID	Raster
3	Administrative Boundary	Phayao	2020	ODM(Thailand)	Raster
4	Groundwater	Phayao	2001	DMR	Raster
5	Groundwater	Phayao	2017	DGR	Raster
6	Distance to Water Resource	Phayao	2020	Calculated from (1)	Raster
7	Drought History	Phayao	2020	LDD	Raster
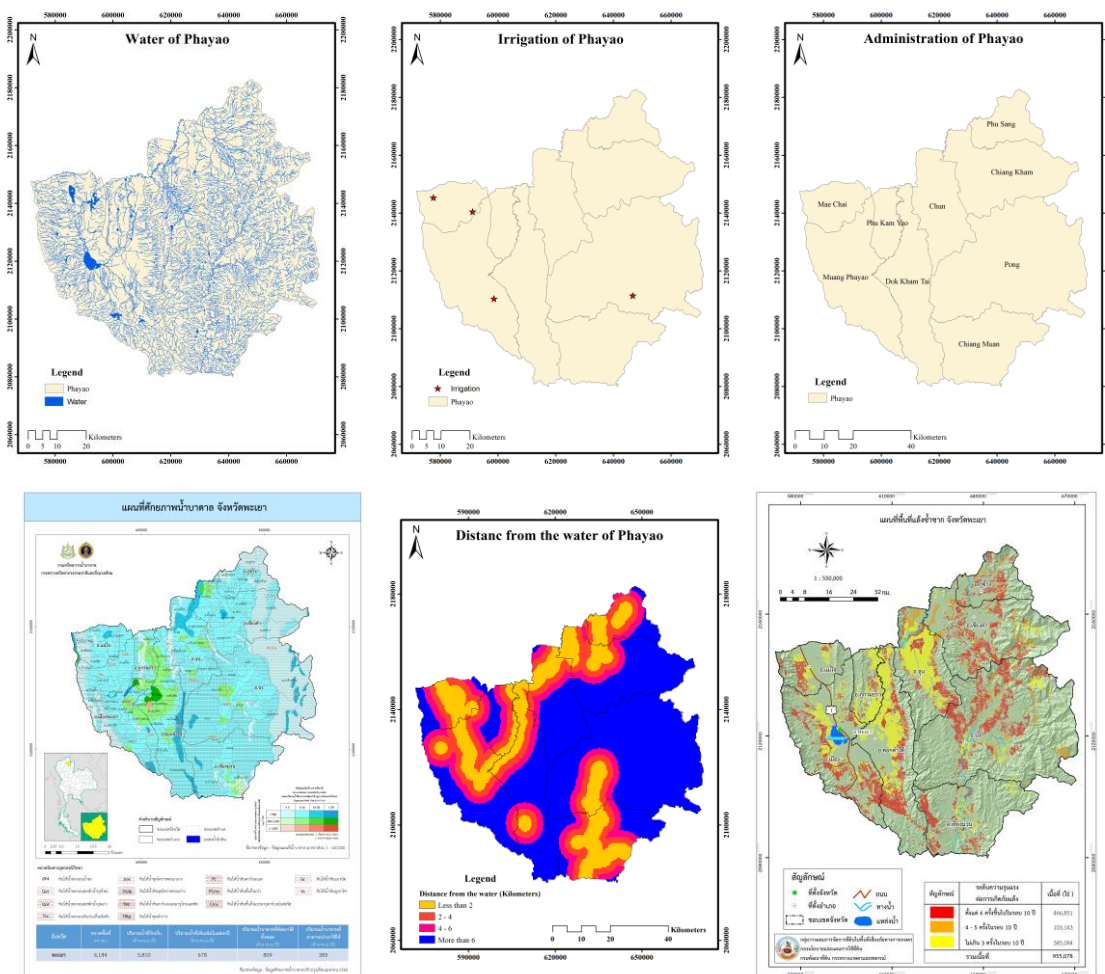
From top to bottom, left to right: Maps of waterway, irrigation, administrative boundary, groundwater, distance to water resource, and drought history for Phayao pilot site.

Drought Data for Loei Pilot Site in Thailand

The following table summarizes the data collection results for Loei province. Example raster images of the collected factors are shown.

Summary of collected drought data for Loei pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Loei	2020	DWR	Raster
2	Irrigation	Loei	2018	RID	Raster
3	Administrative Boundary	Loei	2020	ODM(Thailand)	Raster
4	Groundwater	Loei	1993	DMR	Raster
5	Groundwater	Loei	2017	DGR	Raster
6	Distance to Water Resource	Loei	2020	Calculated from (1)	Raster
7	Drought History	Loei	2020	LDD	Raster
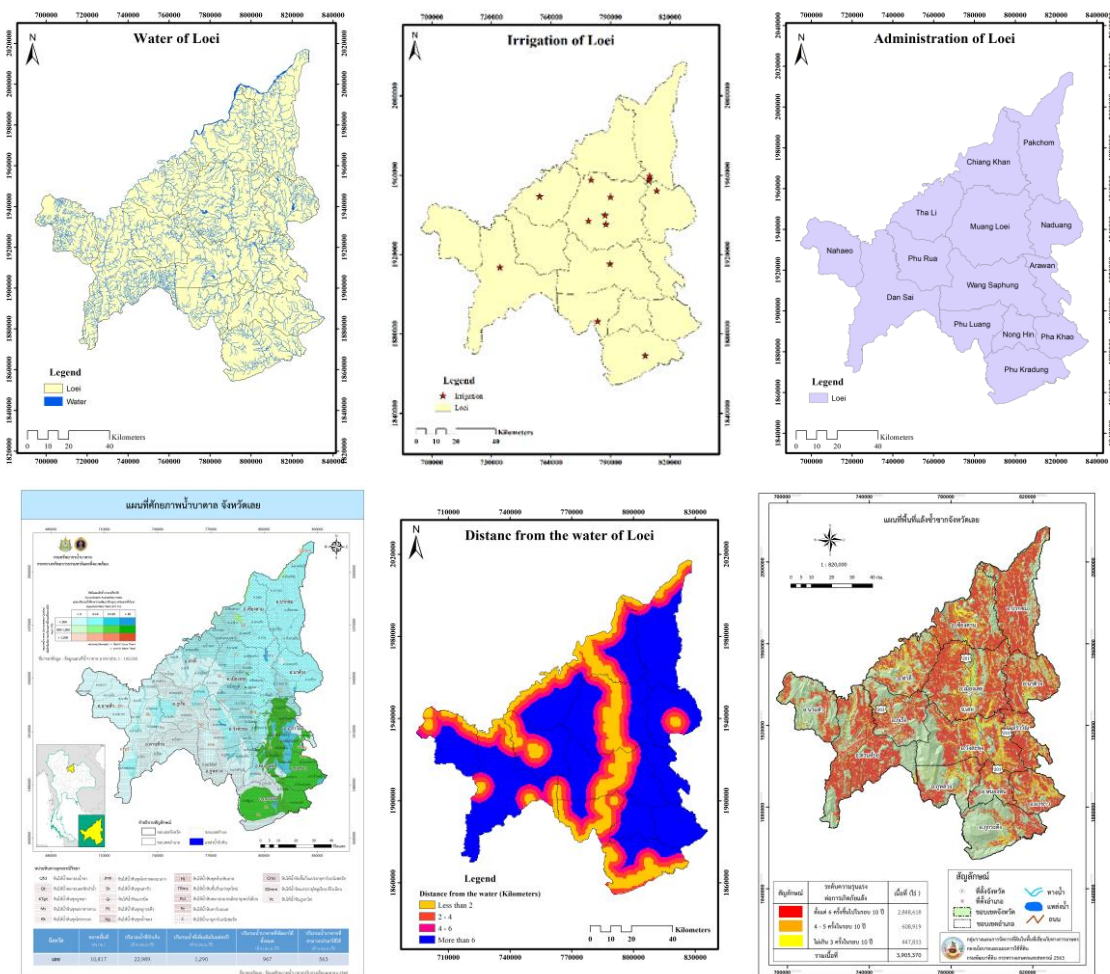
From top to bottom, left to right: Maps of waterway, irrigation, administrative boundary, groundwater, distance to water resource, and drought history for Loei pilot site.

Dengue Data for Ubon Ratchathani Pilot Site in Thailand

The following table summarizes the data collection results for Ubon Ratchathani province. The collected raster images are shown.

Summary of collected dengue data for Ubon Ratchathani pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Dengue Incidence in January	Ubon Ratchathani	2018	MOPH	Raster
2	Dengue Incidence in February	Ubon Ratchathani	2018	MOPH	Raster
3	Dengue Incidence in March	Ubon Ratchathani	2018	MOPH	Raster
4	Dengue Incidence in April	Ubon Ratchathani	2018	MOPH	Raster
5	Dengue Incidence in May	Ubon Ratchathani	2018	MOPH	Raster
6	Dengue Incidence in June	Ubon Ratchathani	2018	MOPH	Raster
7	Dengue Incidence in July	Ubon Ratchathani	2018	MOPH	Raster
8	Dengue Incidence in August	Ubon Ratchathani	2018	MOPH	Raster
9	Dengue Incidence in September	Ubon Ratchathani	2018	MOPH	Raster
10	Dengue Incidence in October	Ubon Ratchathani	2018	MOPH	Raster
11	Dengue Incidence in November	Ubon Ratchathani	2018	MOPH	Raster
12	Dengue Incidence in December	Ubon Ratchathani	2018	MOPH	Raster
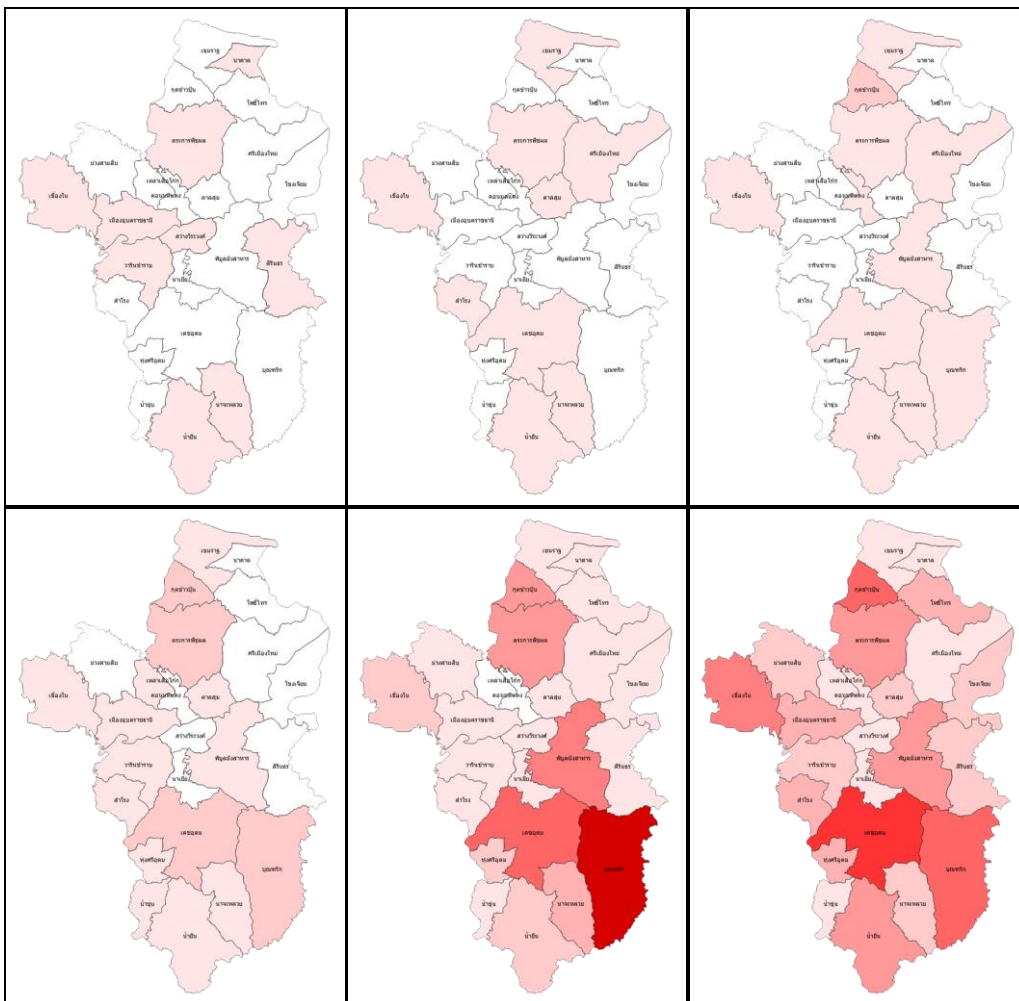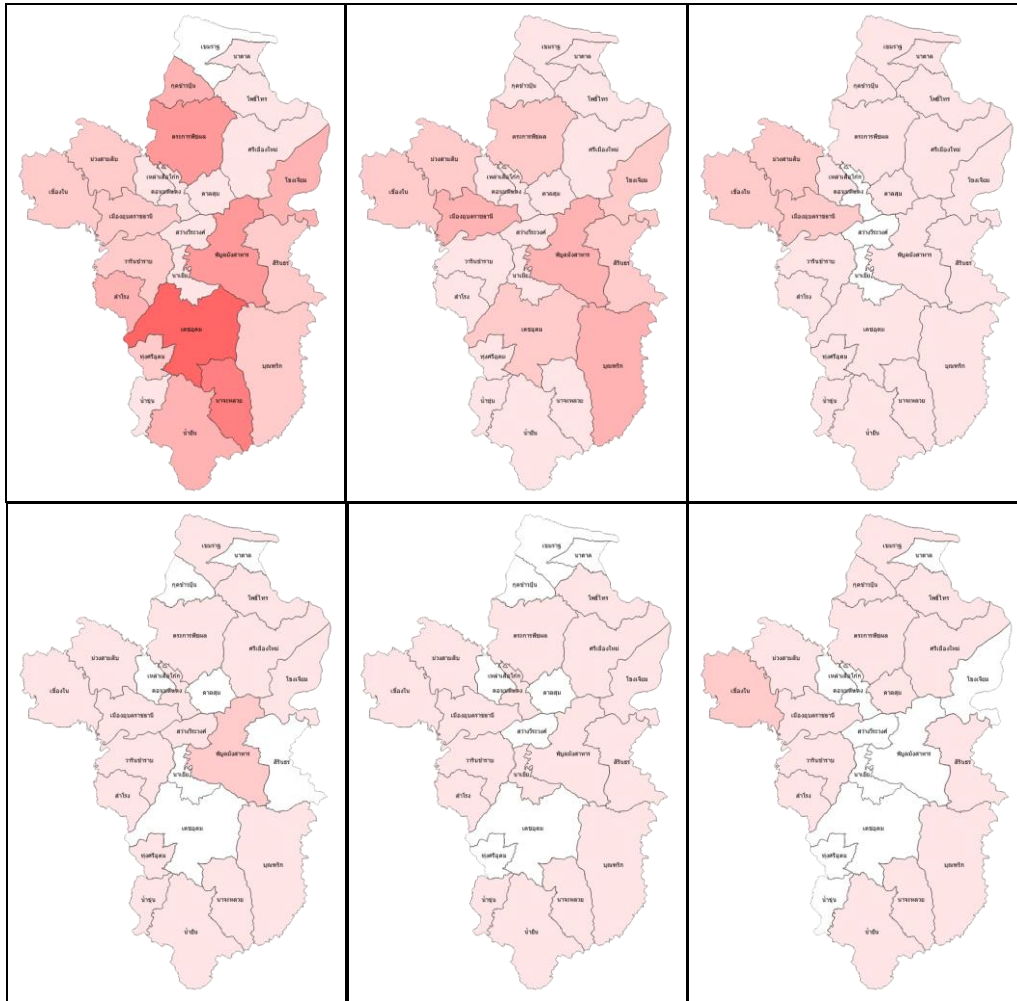
From top to bottom, left to right: Maps of dengue incidence in Ubon Ratchathani pilot site from January 2018 – December 2018. Notice that there were more cases in the rainy season (May – August) than in the other seasons.

Drought Data for Kampong Cham Pilot Site in Cambodia

The following table summarizes the data collection results for Kampong Cham province. Example raster images of the collected factors are shown.

Summary of collected drought data for Kampong Cham pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Kampong Cham	2022	ODM (Cambodia)	Raster
2	Administrative Boundary	Kampong Cham	2018	HDX	Raster
3	Distance to Water Resource	Kampong Cham	2022	Calculated from (1)	Raster
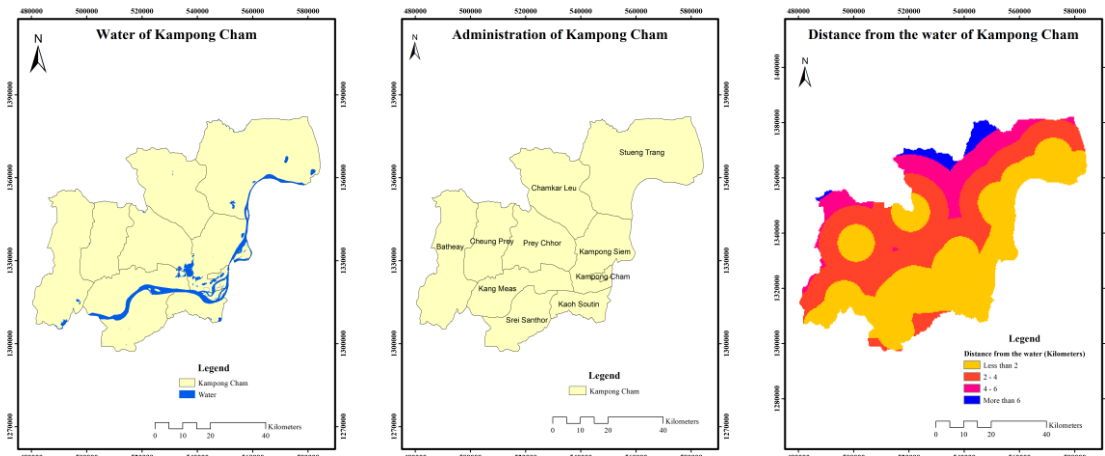
From left to right: Maps of waterway, administrative boundary, and distance to water resource for Kampong Cham pilot site.

Drought Data for Kandal Pilot Site in Cambodia

The following table summarizes the data collection results for Kandal province. Example raster images of the collected factors are shown.

Summary of collected drought data for Kandal pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Kandal	2022	ODM (Cambodia)	Raster
2	Administrative Boundary	Kandal	2018	HDX	Raster
3	Distance to Water Resource	Kandal	2022	Calculated from (1)	Raster
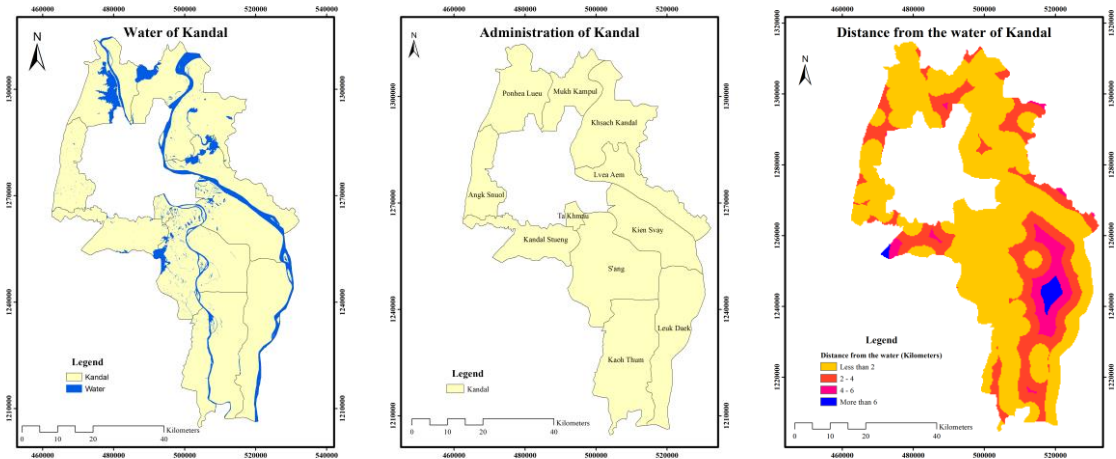
From left to right: Maps of waterway, administrative boundary and distance to water resource for Kandal pilot site.

Other Drought Data for Cambodia

The following table summarizes additional data collection results for Cambodia. Example raster images of the collected factors are shown.

Summary of additional drought data for Cambodia.

No	Factor	Scope	Data Year	Data Source	Format
1	Drought History	Cambodia	2014	WFP	Raster
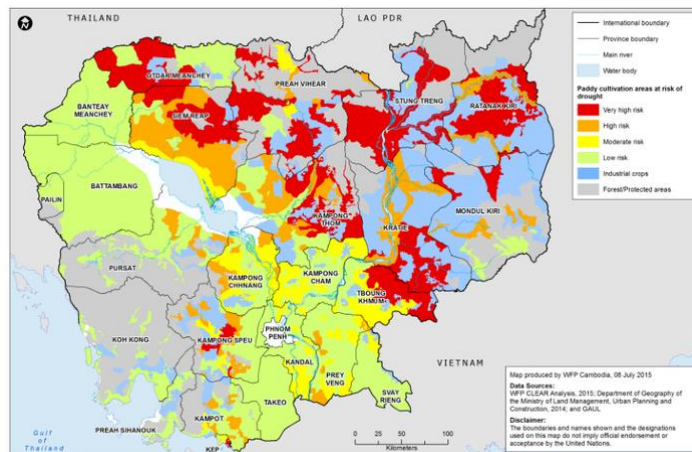
Map of drought history for Cambodia.

Drought Data for Luang Prabang Pilot Site in Laos

The following table summarizes the data collection results for Luang Prabang pilot site. Example raster images of the collected factors are shown.

Summary of collected drought data for Luang Prabang pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Province	2019	ODM	Raster
2	Administrative Boundary	Province	2019	HDX	Raster
3	Distance to Water Resource	Province	2019	Calculated from (1)	Raster
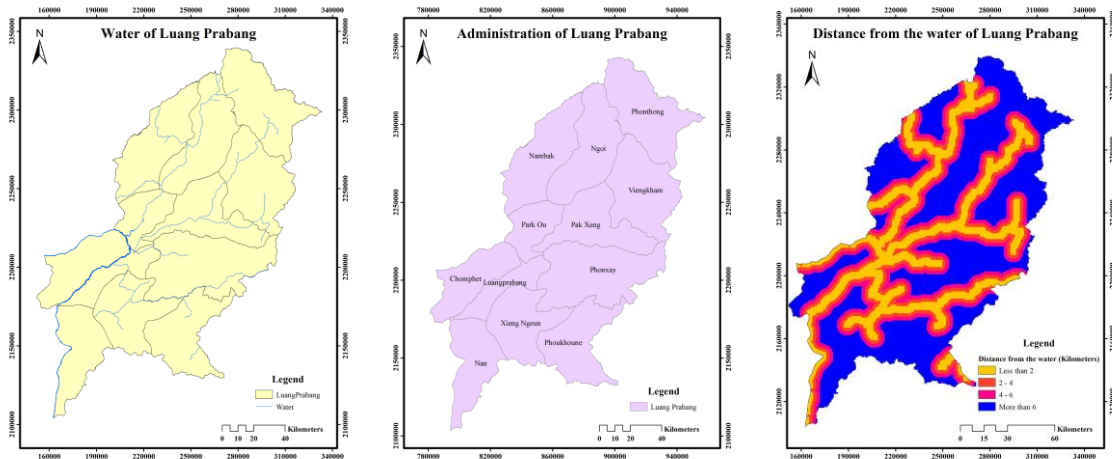
From left to right: Maps of waterway, administrative boundary and distance to water resource for Luang Prabang pilot site.

Drought Data for Thakhek Pilot Site in Laos

The following table summarizes the data collection results for Thakhek pilot site. Example raster images of the collected factors are shown.

Summary of collected drought data for Thakhek pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Thakhek	2019	ODM	Raster
2	Administrative Boundary	Thakhek	2019	HDX	Raster
3	Distance to Water Resource	Thakhek	2019	Calculated from (1)	Raster
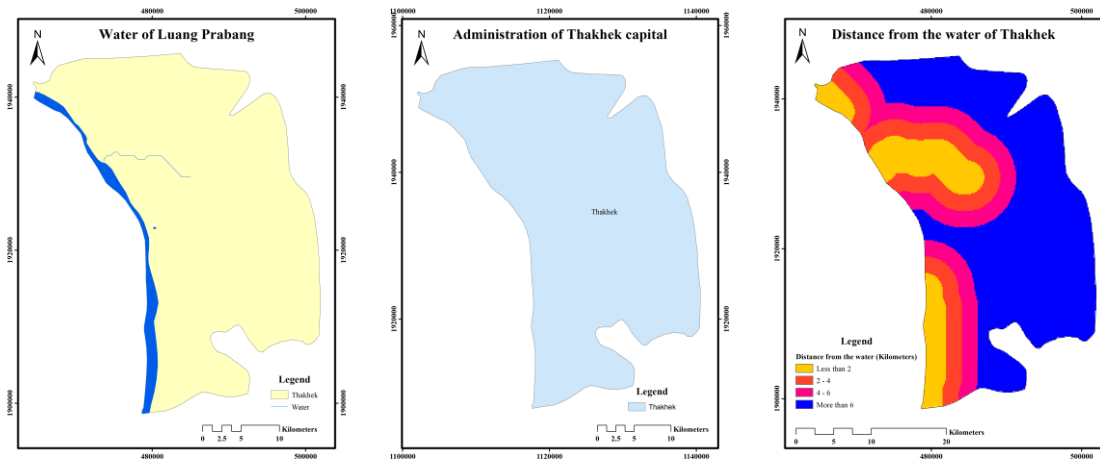
From left to right: Maps of waterway, administrative boundary and distance to water resource for Thakhek pilot site.

Drought Data for Can Tho Pilot Site in Vietnam

The following table summarizes the data collection results for Can Tho city. Example raster images of the collected factors are shown.

Summary of collected drought data for Can Tho pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Can Tho	2019	ODM	Raster
2	Administrative Boundary	Can Tho	2020	HDX	Raster
3	Distance to Water Resource	Can Tho	2020	Calculated from (1)	Raster
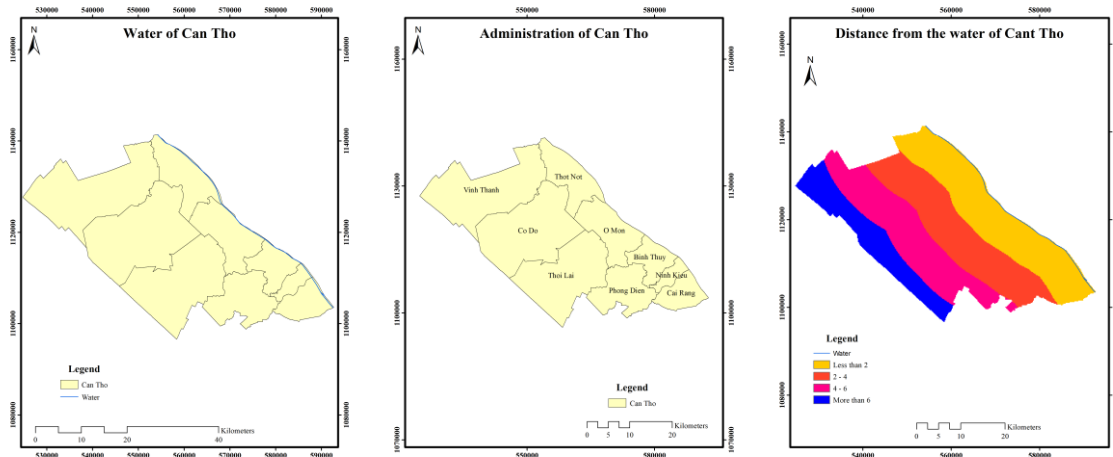
From left to right: Maps of waterway, administrative boundary, and distance to water resource for Can Tho pilot site.

Drought Data for Kon Tum Pilot Site in Vietnam

The following table summarizes the data collection results for Kon Tum city. Example raster images of the collected factors are shown.

Summary of collected drought data for Kon Tum pilot site.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Kon Tum	2019	ODM	Raster
2	Administrative Boundary	Kon Tum	2020	HDX	Raster
3	Distance to Water Resource	Kon Tum	2020	Calculated from (1)	Raster
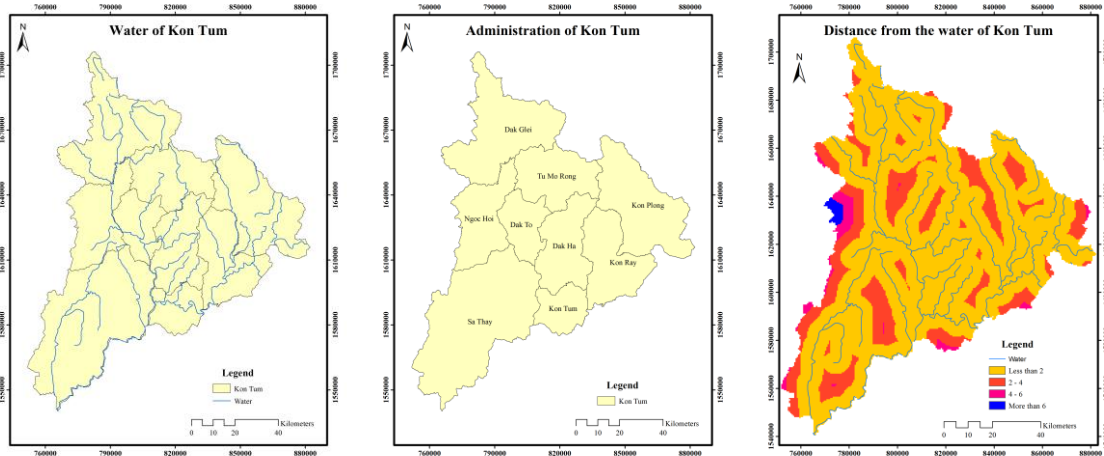
From left to right: Maps of waterway, administrative boundary and distance to water resource for Kon Tum pilot site.

Drought Data for LandSAGE3 Pilot Sites

We also collected drought data for the LandSAGE3 pilot sites as summarized in the following table. Example raster images of the collected factors are shown.

Summary of drought data for the LandSAGE3 pilot sites.

No	Factor	Scope	Data Year	Data Source	Format
1	Waterway	Ubon Ratchathani	2020	DWR	Raster
2	Irrigation	Ubon Ratchathani	2018	RID	Raster
3	Administrative Boundary	Ubon Ratchathani	2020	ODM(Thailand)	Raster
4	Groundwater	Ubon Ratchathani	2017	DGR	Raster
5	Distance to Water Resource	Ubon Ratchathani	2020	Calculated from (1)	Raster
6	Drought History	Ubon Ratchathani	2020	LDD	Raster
7	Waterway	Phnom Penh	2022	ODM (Cambodia)	Raster
8	Administrative Boundary	Phnom Penh	2018	HDX	Raster
9	Distance to Water Resource	Phnom Penh	2022	Calculated from (1)	Raster
10	Waterway	Vientiane	2019	ODM	Raster
11	Administrative Boundary	Vientiane	2019	HDX	Raster
12	Distance to Water Resource	Vientiane	2019	Calculated from (1)	Raster
13	Waterway	An Giang	2019	ODM	Raster
14	Administrative Boundary	An Giang	2020	HDX	Raster
15	Distance to Water Resource	An Giang	2020	Calculated from (1)	Raster
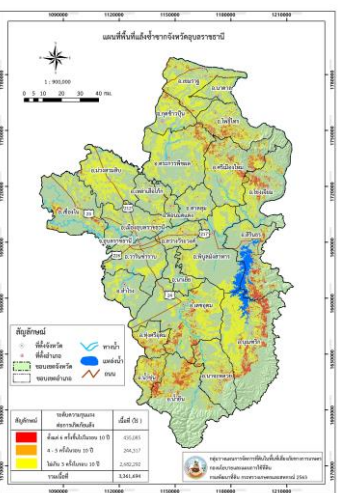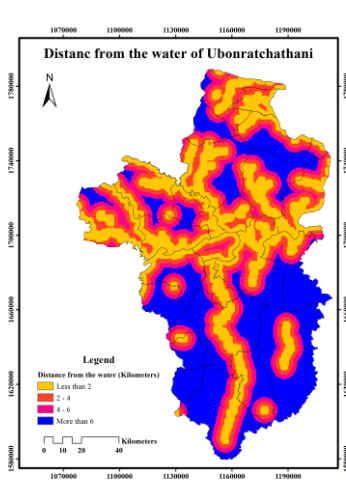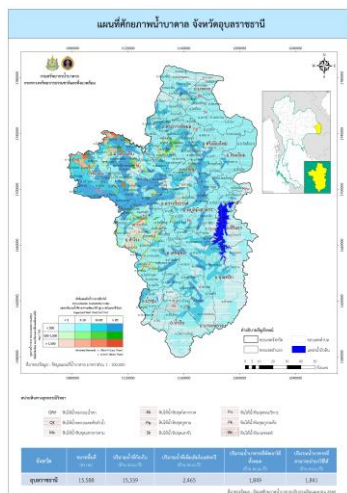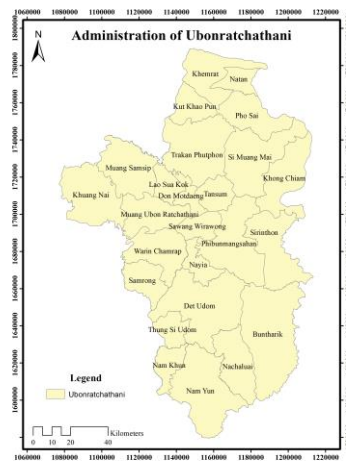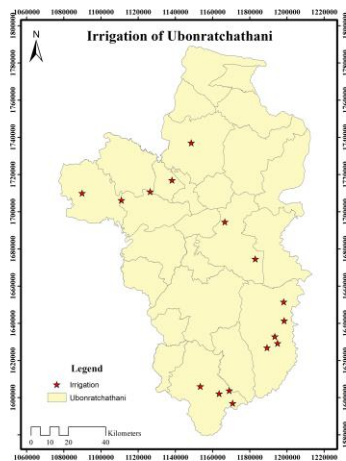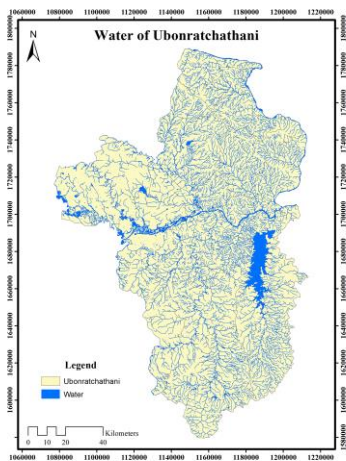
From top to bottom, left to right: Example maps of waterway, irrigation, administrative boundary, groundwater, distance to water resource and drought history for the LandSAGE3 pilot sites.

Activity 7: Sub-activity 3 – Flood Data Collection

Based on our prior study in LandSAGE3, we continued to focus on the three important factors for flood monitoring including rainfall, water level, and water discharge. The data source was *MRC (Mekong River Commission)*. MRC is an intergovernmental organization established based on an agreement between Cambodia, Laos, Vietnam, and Thailand. The organization serves as a knowledge hub of water resource management in the Lower Mekong River Basin. MRC provides various types of data for the region including hydro-meteorological data (e.g., water level, discharge, rainfall, temperature, humidity), geometric data (e.g., cross-section and longitudinal profile of a river) and water quality data (e.g., sediment, salinity, turbidity, concentration, and water temperature).

MRC provided 73 hydro-meteorological monitoring stations in the Lower Mekong Basin. We identified the eight stations providing data for our eight pilot sites as follows:

Eight MRC monitoring stations used in LandSAGE4.

Station Name	Location	Station Code	Latitude	Longtitude
Ban Huai Tham	Phayao, TH	190009	19.0667	100.0667
Wang Saphung	Loei, TH	150101	17.29953	101.77634
Kompong Cham	Kampong Cham, KH	019802	11.99418	105.46891
Prek Kdam	Kandal, KH	020102	11.81117	104.80678
Can Tho	Can Tho, VN	039803	10.0528	105.78714
Kon Tum	Kon Tum, VN	440201	14.34739	108.03416
Luang Prabang	Luang Prabang Capitals, LA	011201	19.89266	102.13389
Thakhek	Thakhek Capitals, LA	013102	17.3933	105.8067

These stations provided a total of 34 time-series datasets of rainfall, water level, and discharge summarized in the table below. For the collection methods, "Manual" means the data were manually measured by human, "Telemetry" means the data were automatically collected by a machine, "Calculated" means the data were calculated or derived from other data, "Maximum" means using the maximum data of each day, and "DSMP" means the collection was done under the "Discharge and Sediment Monitoring Project".

Per station, for each factor with multiple datasets, we chose the one dataset with the most up-to-date data. Consequently, 13 datasets were discarded (highlighted in the table) and only 21 were used in the project, i.e., 3 datasets per pilot site except for the water level and discharge datasets of Phayao pilot site and the discharge dataset of Luang Prabang that were unavailable from MRC. In the future, we will seek substitute datasets from other sources.

34 hydro-meteorological datasets from the 8 stations considered in LandSAGE4.

Station Name	Dataset	Collection Method	Start Date	End Date
Ban Huai Tham	Rainfall	1-6 times p/day, Manual	1979	2008
Wang Saphung	Discharge	Unknown, Calculated	1967	2022
Wang Saphung	Rainfall	1-6 times p/day, Manual	1975	2022
Wang Saphung	Rainfall	15 minutes, Telemetry	2012	2022
Wang Saphung	Water Level	1-6 times p/day, Manual	1966	2022
Wang Saphung	Water Level	15 minutes, Telemetry	2010	2022
Kompong Cham	Discharge	Daily, Calculated	1960	2022
Kompong Cham	Rainfall	1-6 times p/day, Manual	2007	2022
Kompong Cham	Water Level	1-6 times p/day, Manual	1930	2022
Prek Kdam	Discharge	Unknown, DSMP	2011	2018
Prek Kdam	Discharge	Daily, Calculated	1960	1973
Prek Kdam	Rainfall	15 minutes, Telemetry	2010	2022
Prek Kdam	Rainfall	1-6 times p/day, Manual	2007	2022
Prek Kdam	Water Level	15 minutes, Telemetry	2010	2022

Prek Kdam	Water Level	1-6 times p/day, Manual	1960	2022
Can Tho	Discharge	Daily, Calculated	2001	2007
Can Tho	Rainfall	15 minutes, Telemetry	2010	2022
Can Tho	Rainfall	1-6 times p/day, Manual	2006	2022
Can Tho	Water Level	15 minutes, Telemetry	2008	2022
Can Tho	Water Level	Daily, Maximum	1969	2006
Can Tho	Water Level	1-6 times p/day, Manual	1979	2022
Kontum	Discharge	Unknown, Calculated	1967	2013
Kontum	Rainfall	15 minutes, Telemetry	2010	2022
Kontum	Rainfall	1-6 times p/day, Manual	2007	2022
Kontum	Water Level	15 minutes, Telemetry	2010	2022
Kontum	Water Level	1-6 times p/day, Manual	1966	2022
Luang Prabang	Rainfall	1-6 times p/day, Manual	2005	2022
Luang Prabang	Water Level	15 minutes, Telemetry	2009	2022
Luang Prabang	Water Level	1-6 times p/day, Manual	1960	2022
Thakhek	Discharge	Daily, Calculated	1924	2006
Thakhek	Rainfall	1-6 times p/day, Manual	2006	2022
Thakhek	Rainfall	15 minutes, Telemetry	2021	2022
Thakhek	Water Level	1-6 times p/day, Manual	1960	2022
Thakhek	Water Level	15 minutes, Telemetry	2021	2022

We scanned the chosen datasets to determine their qualities. The results are summarized below:

Qualities of the 21 chosen hydro-meteorological datasets.

Dataset	Completeness (%)	Imputation	Downsampling
D01: Rainfall – Ban Huai Tham	92.66	Yes	–
D02: Discharge – Wang Saphung	88.97	Yes	–
D03: Rainfall – Wang Saphung	88.92	Yes	–
D04: Water Level – Wang Saphung	86.96	Yes	Yes
D05: Discharge – Kompong Cham	100	–	–
D06: Rainfall – Kompong Cham	79.34	Yes	–
D07: Water Level – Kompong Cham	100	–	Yes
D08: Discharge – Prek Kdam	3.85	Yes	–
D09: Rainfall – Prek Kdam	79.45	Yes	Yes
D010: Water Level – Prek Kdam	86.03	Yes	Yes
D011: Discharge – Can Tho	87.67	Yes	–
D012: Rainfall – Can Tho	66.36	Yes	Yes
D013: Water Level – Can Tho	70.46	Yes	Yes
D014: Discharge – Kontum	71.53	Yes	–
D015: Rainfall – Kontum	57.81	Yes	Yes
D016: Water Level – Kontum	56.43	Yes	Yes
D017: Rainfall – Luang Prabang	82.84	Yes	–
D018: Water Level – Luang Prabang	55.21	Yes	Yes
D019: Discharge – Thakhek	99.80	Yes	–
D020: Rainfall – Thakhek	84.34	Yes	–
D021: Water Level – Thakhek	98.16	Yes	Yes

Only one dataset (D05) was complete and ready to be formatted for visualization. The remaining datasets either had missing values and/or contained multiple samples per day (e.g., water levels were measured 1-6 times per day in some stations). To standardize the datasets for visualization, we performed the following data processing:

Imputation: 19 datasets were incomplete. We used data interpolation to fill the missing values in the gaps no larger than one week.
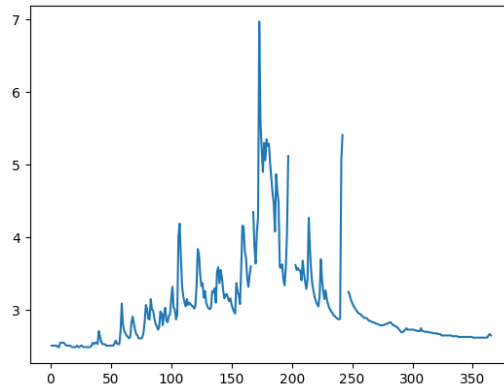
The original water level data from Wang Saphung station that included missing values.
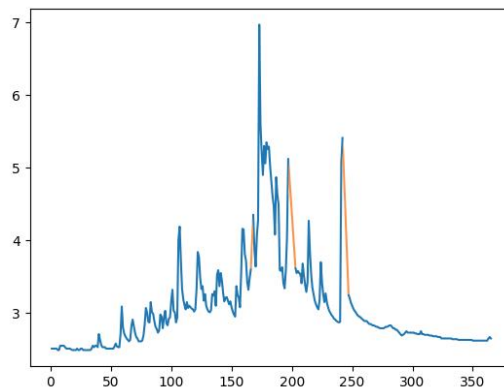
The water level data for Wang Saphung station after applying data imputation.

Downsampling: 10 datasets contained multiple data points on some days. We downsampled these datasets to a single value per day by using the maximums as the representative values.

```
                                                           WaterLevel
                      Date    WaterLevel    Date
0        1966-05-24T00:00Z          3.41    1966-05-24          3.41
1        1966-05-25T00:00Z          3.71    1966-05-25          3.71
2        1966-05-26T00:00Z          3.92    1966-05-26          3.92
3        1966-05-27T00:00Z          4.52    1966-05-27          4.52
4        1966-05-28T00:00Z          3.71    1966-05-28          3.71
...                    ...           ...           ...           ...
20106    2022-10-01T00:00Z          7.40    2022-09-29          3.43
20107    2022-10-01T12:00Z          8.08    2022-09-30          5.90
20108    2022-10-02T00:00Z          7.78    2022-10-01          8.08
20109    2022-10-02T12:00Z          7.78    2022-10-02          7.78
20110    2022-10-03T00:00Z          7.76    2022-10-03          7.76
```

Water level of Loei before (Left) and after (Right) downsampling

After the data processing, we formatted all the datasets into the CSV (Comma-Separated Values) format before importing them into the LandSAGE software. The imputation, downsampling, and formatting were implemented using Python scripting, pandas, NumPy and Matplotlib libraries.

Activity 7: Sub-activity 4 – 3D Flood Simulations

We used the ArcScene 3D visualization application to generate flood simulations in the MP4 3D animation video format, for the eight new pilot sites in LandSAGE4 and for the four earlier pilot sites from LandSAGE3. In the simulation, the flood begins at an area with the lowest elevation which usually corresponds to a waterway or water resource. As the water builds up, it is expanded into the surrounding areas according to their elevations. The simulation could help researcher identify which parts of a pilot site would be affected if a flood were to occur. The picture below shows snapshots of the simulations for all the pilot sites.
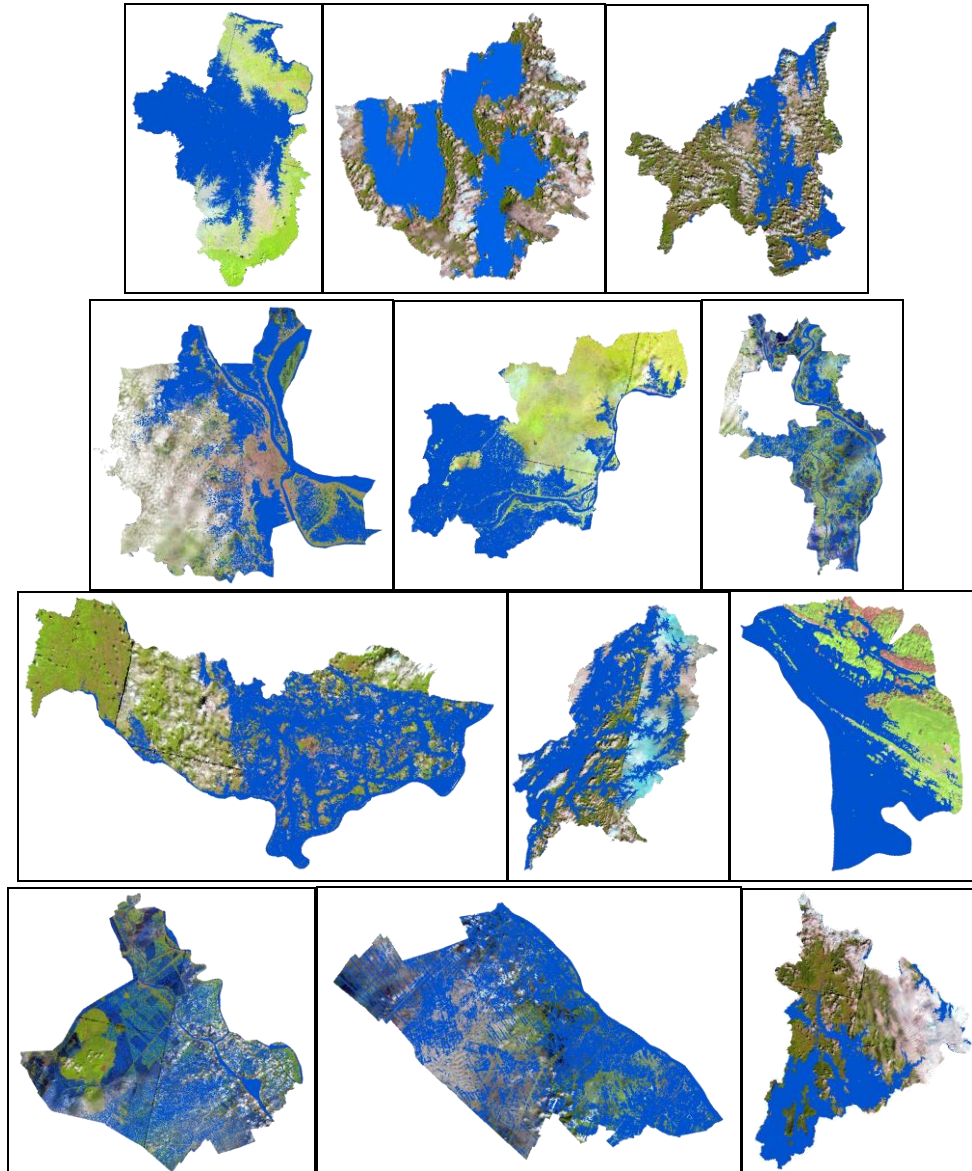
From top to bottom row: Snapshots of the flood simulations for the pilot sites in Thailand, Cambodia, Laos, and Vietnam.

We summarize the steps in ArcScene to generate the flood simulations, illustrated for the Phayao province.

- Import a DEM, a satellite image (Landsat 8), and a waterway/water resource data of an area into ArcScene by going to "Catalog", choose the folder that stores the data, and drag them into the "Table of Contents" panel.
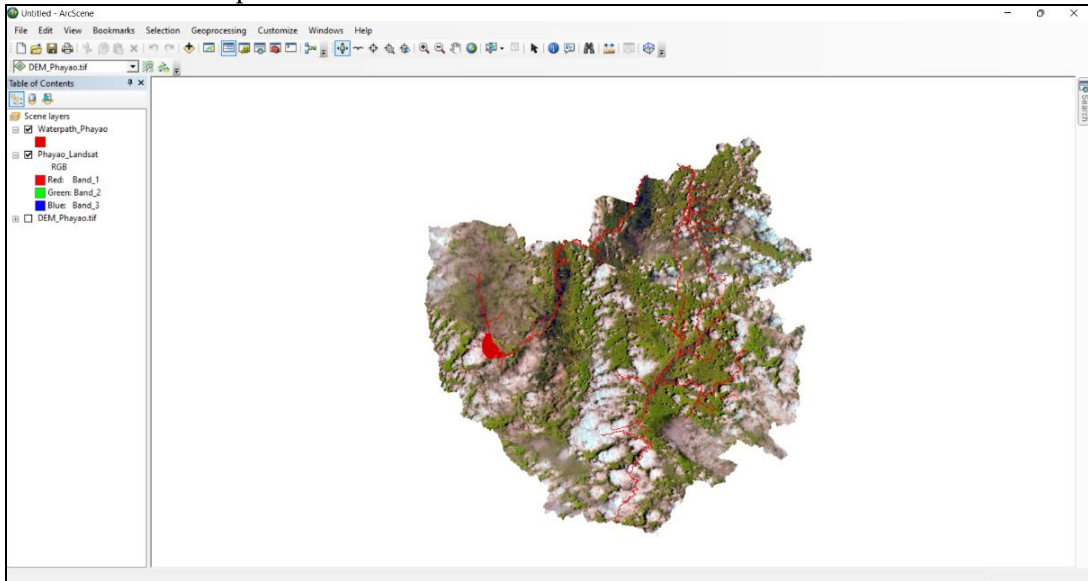
- To assign the DEM to the satellite image, in the "Table of Contents", right click at the satellite image, choose "Properties", check the "Floating on a custom surface*" radio button*, choose the DEM, and click "OK".
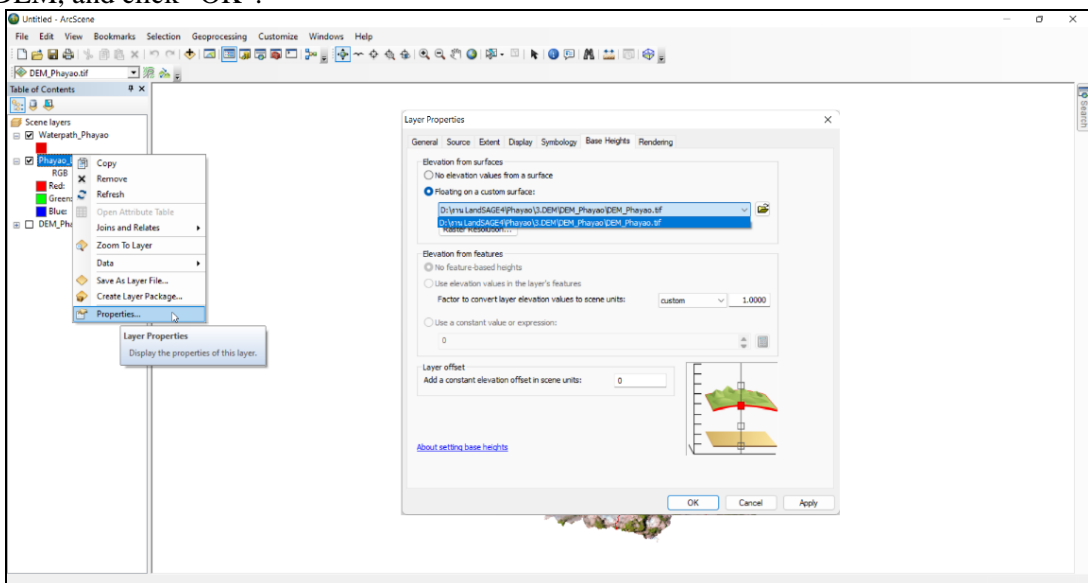
- Repeat the previous step for the waterway/water resource layer.

- To fix the visual artifact after assigning the DEM, right click on the "Scene layers", choose "Scene Properties", click "General", "Calculate from Extent", and "OK".
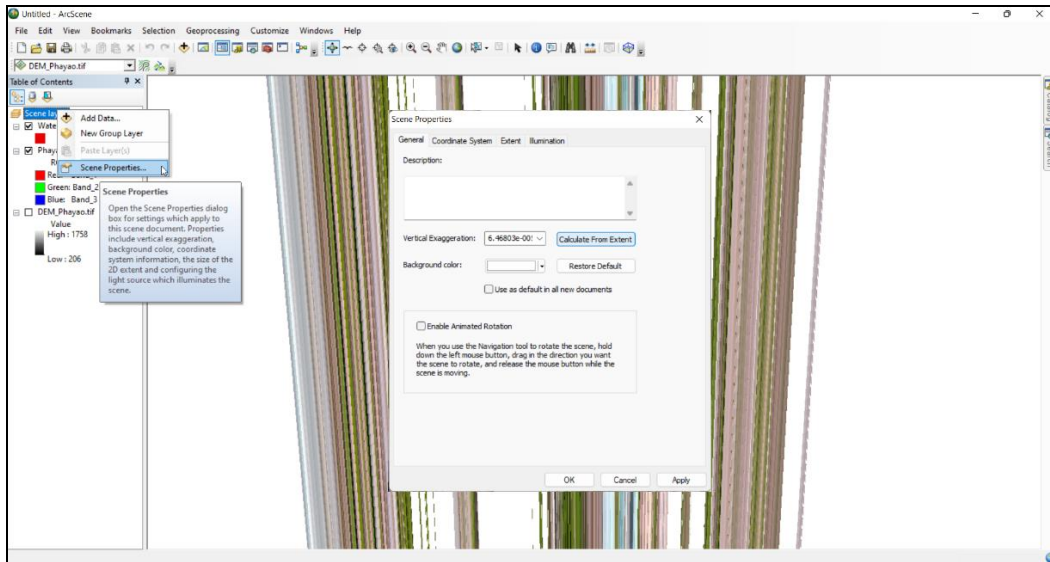
- To simulate flood (generate flood animation), import a polygon of the area.
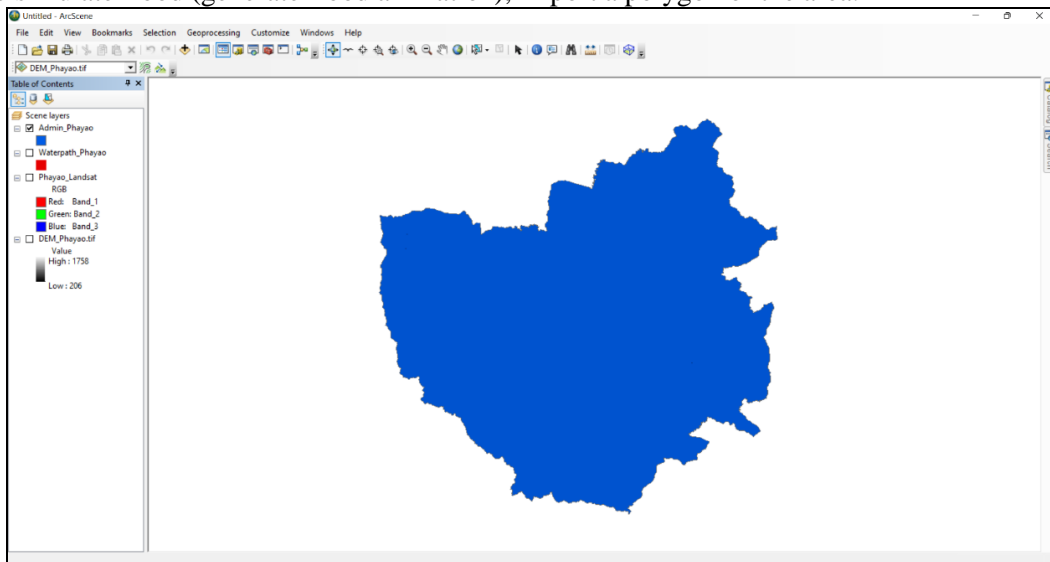
- Click "Customize" on the top menu, then click "Toolbars", and "Animation".
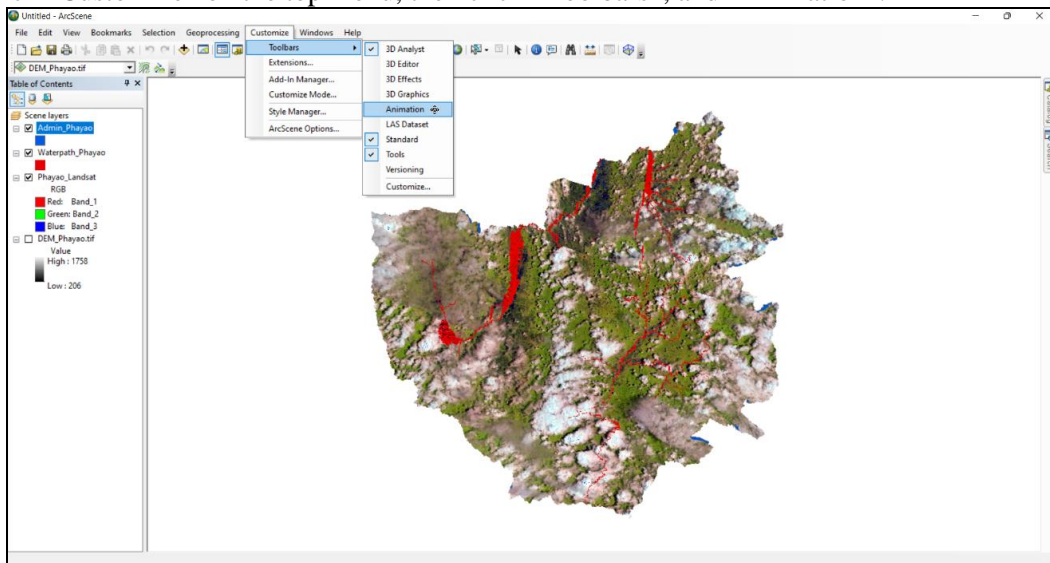
- Choose "Animation Manager". In the pop-up dialog, click "Create" to open the "Create Animation Keyframe" dialog, set "Type" to "Layer", click "New", and then "Create".
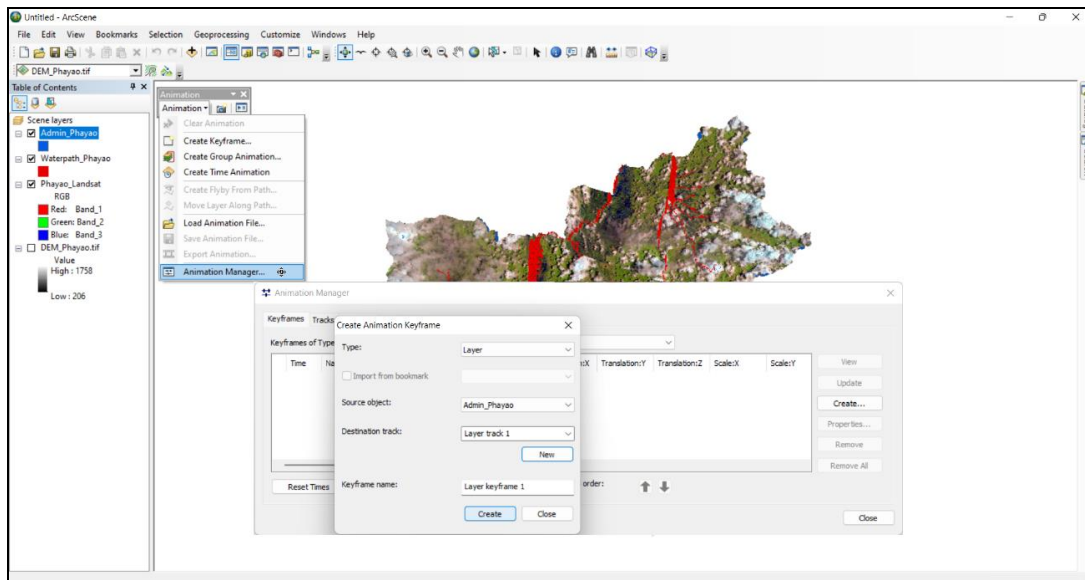
- Repeat the previous step to create more keyframes, approximately 10 keyframes in total, with increasing value of Z translation using the increment of 50 meters.
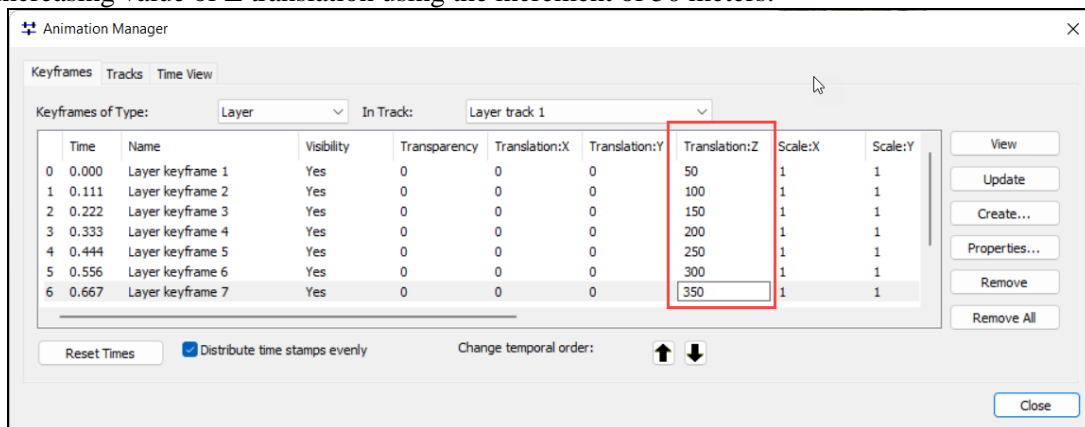
- To test the animation, choose "Open Animation Control" and click "Play".
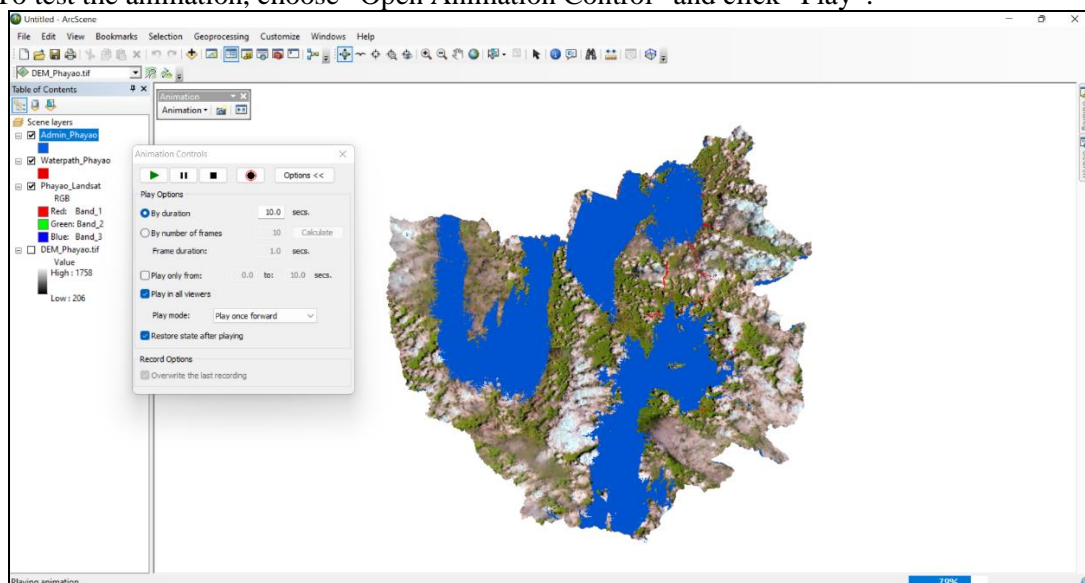
- To export a video, choose "Export Animation", a folder to store the video, and click "Export".
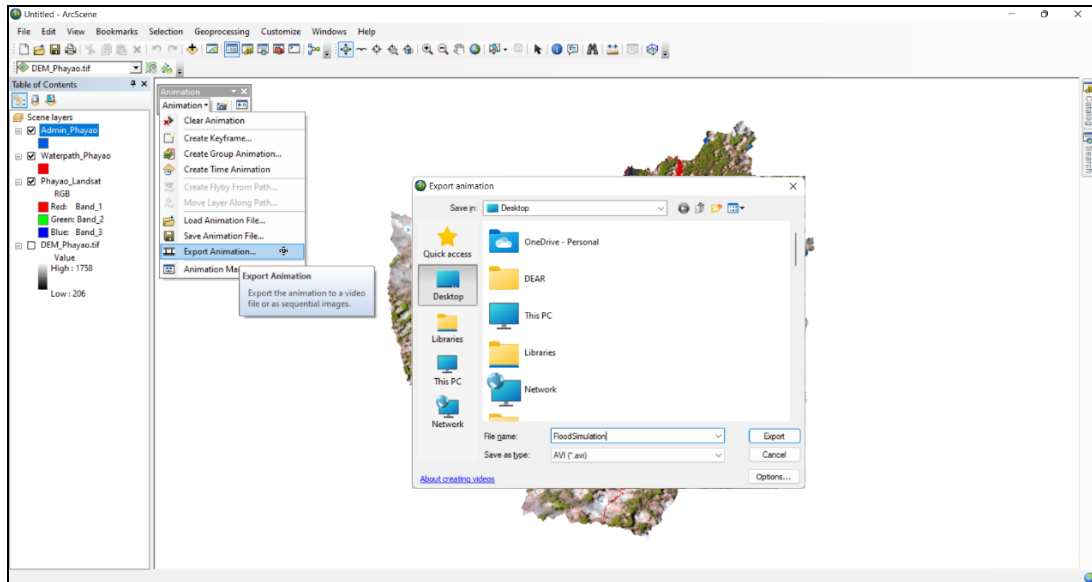
Activity 7: Sub-activity 5 – Software Enhancement

We improved the intelligence, usability, and utility of the (old) LandSAGE software developed in LandSAGE3 via the following enhancement:

- Leaping to the new NSF's flagship collaboration and visualization platform (SAGE3)
- Development of the new backend module
- Integration with (near) real-time hydro-meteorological sensor data
- Enhancement of the frontend module
- Adding flood prediction and landslide risk analysis

Leaping to the New NSF's Flagship Collaboration and Visualization Platform (SAGE3)

We improved the usability of the LandSAGE software by migrating from SAGE2 to SAGE3. Whereas SAGE2 was designed for collaboration in front of large display walls (CyberCANOEs), SAGE3 is designed for a post-pandemic life where it is possible for teams of researchers to work collaboratively, either collocated or remotely, in front of display walls or even at home on mere laptops, treating them like digital canvases for juxtaposing large amounts of data and visualizations enabling the researchers to make decisions with greater speed and confidence. LandSAGE users in different countries or organizations can now collaborate on making sense of natural disaster data from their own display walls or laptops, using a much easier setup. The picture below shows our testing of SAGE3 to synchronize LandSAGE data exploration across three display walls over the Asi@Connect's network. SAGE3 will push the Asi@Connect's bandwidth utilization beyond SAGE2's because more users could be joined in the collaborative environments. As an additional benefit, SAGE3 provides visual indicators revealing the active users of the LandSAGE software on top of the visualization. The lack of these indicators was found to be problematic for some users of the old LandSAGE software.

SAGE3 is led by our Co-PI Jason Leigh and is funded by a $5M NSF grant until 2025. Its developers have been working on introducing an AI to autonomously manage and link disparate datasets, and to orchestrate services on behalf of the user. To achieve this objective, SAGE3 has proposed two new concepts: SmartBits (data building blocks equipped with AI capabilities) and SmartSpaces (shareable and customizable AI-enhanced workspaces).

SmartBits integrate both the view (graphical user interface) and the AI into a single component. For instance, a table SmartBit knows not only how to display tabular data (e.g., CSV or Excel formats) but can also infer the semantic values of the columns (e.g., address, person's first and last names, an IP

address, or a credit card number) and can propose semantically valid and meaningful actions on the data (e.g., group rows by geographical proximity, augment data by adding link to users' social media accounts, find IPs that originate in red-listed countries, or search transactional record for credit card purchases). SAGE3 will provide a suite of fundamental SmartBits designed for handling foundational datatypes such as tabular data, time series, latitude and longitude, point clouds, graphs, etc.

These SmartBits will be composed into custom sophisticated and complex interfaces that adequately summarize the information gathered by analysts. These interfaces will be integrated together using the SmartSpaces, resulting in a notebook where "pages" are connected facilitating more intuitive and effective communication of the analysis results. Once available, SmartBits and SmartSpaces could further improve the usability of the LandSAGE software by automating various tasks for the user.

Development of the New Backend Module

We improved the utility of the LandSAGE software by expanding its monitoring coverage. The old LandSAGE prototype supported visualization of only one area (pilot site) per country. The new LandSAGE software supports visualization of multiple areas per country. To support this and additional requirements in LandSAGE4, we re-designed the backend module consisting of a database and an administrator dashboard, with its extensibility and usability in mind. The dashboard begins with a login page.
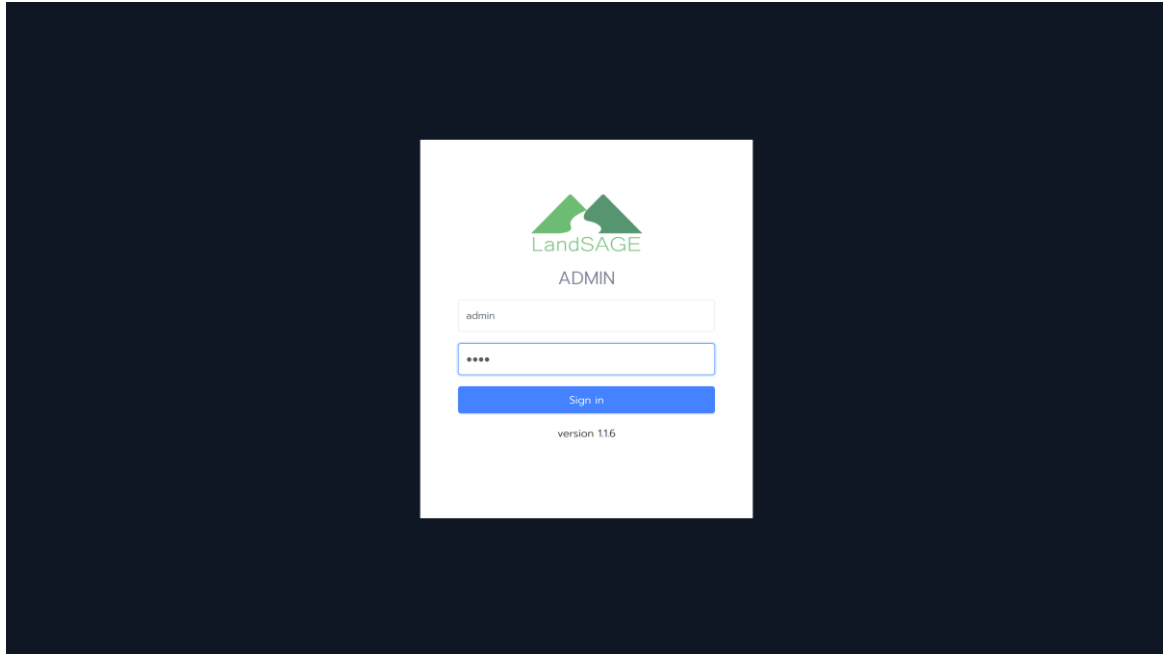
Administrator dashboard login page for improved security.

Afterward, the user is presented with a screen summarizing the database statistics (number of stored records). The database contains the data collected in both LandSAGE4 and LandSAGE3.
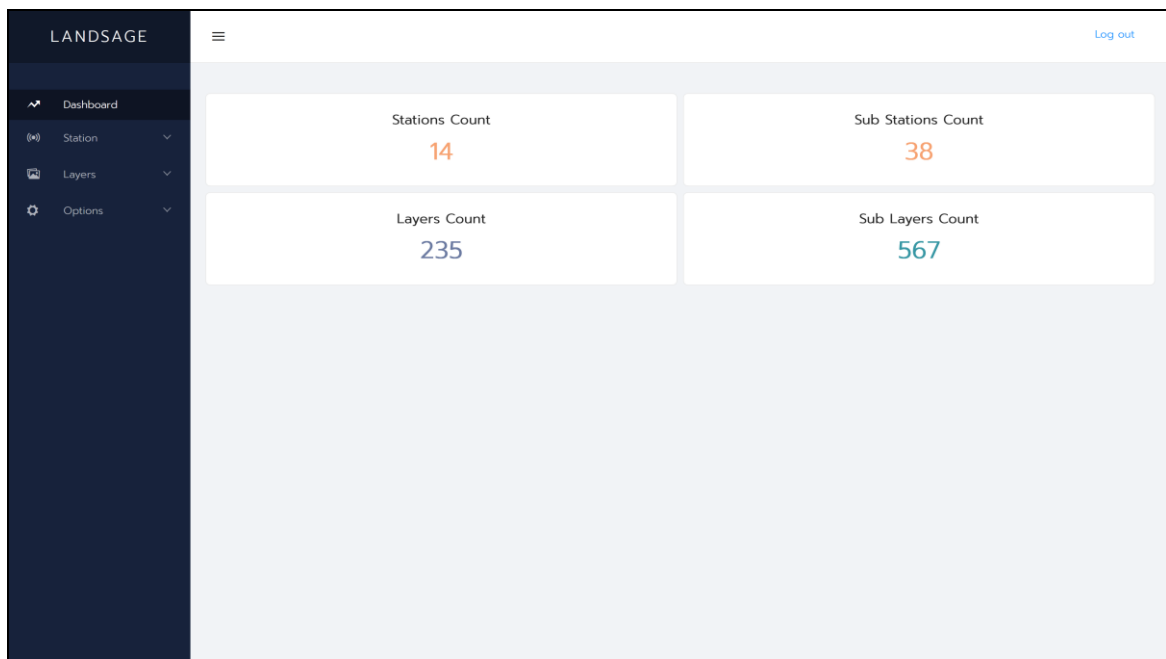
The dashboard screen showing database statistics.

The "Station" page is used to manage (add, edit, and delete) hydro-meteorological stations primarily from MRC. The MRC stations for all the pilot sites of both LandSAGE4 and LandSAGE3 were added.
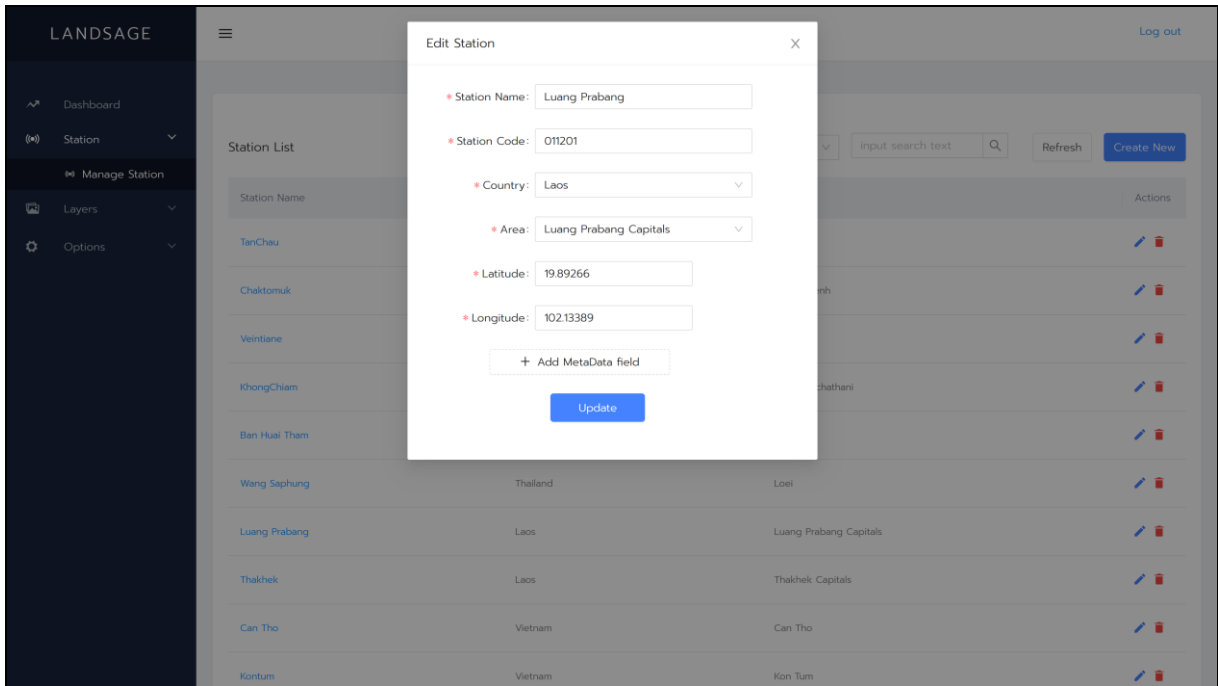
Entering an MRC hydro-meteorological station into the database. The current list of stations is shown in the background.

For each station, rainfall, water level, and discharge datasets in the time-series format (CSV) were added. For the rainfall dataset, five intensity levels were defined. For the water level dataset, the alarm and flood levels were defined.
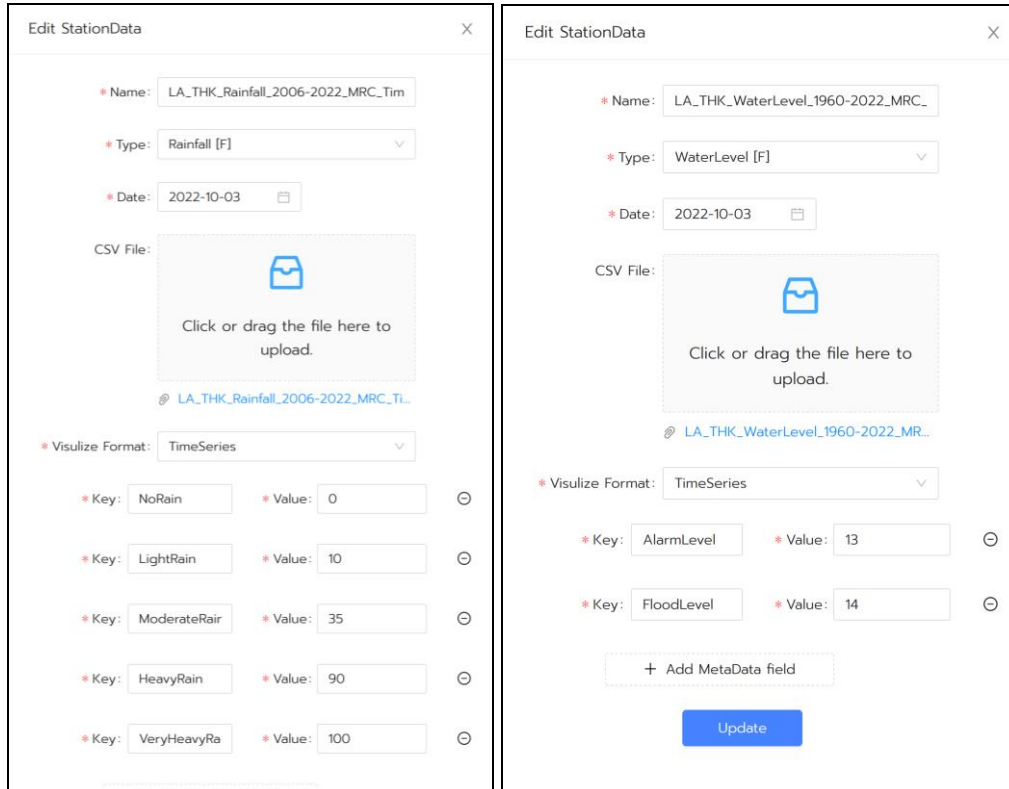
Left: Entering rainfall data for a station. Right: Entering water level data for a station. In both cases, the time-series data in the CSV format were uploaded and metadata were specified.

The "Layers" page is used to manage (add, edit, and delete) raster images representing landslide, drought, and dengue factors. To add a factor, the user must specify the type of factor (geomorphology,

DEM, population density, etc.), the scope of the factor or "Layer index" (country, province, district, etc.), country and area of the factor. Then the user must upload the map and legend portions of the raster image in the PNG format, specify the latitudes and longitudes of the upper left and lower right corners of the map, and specify the date of the data represented by the map.
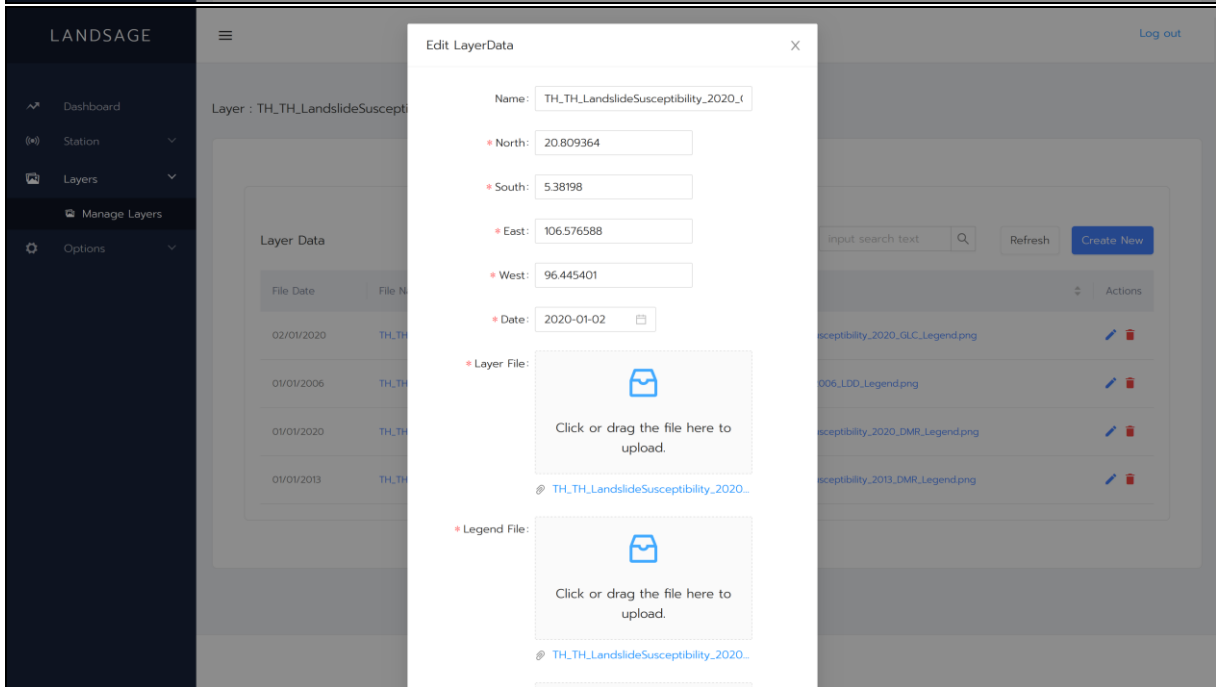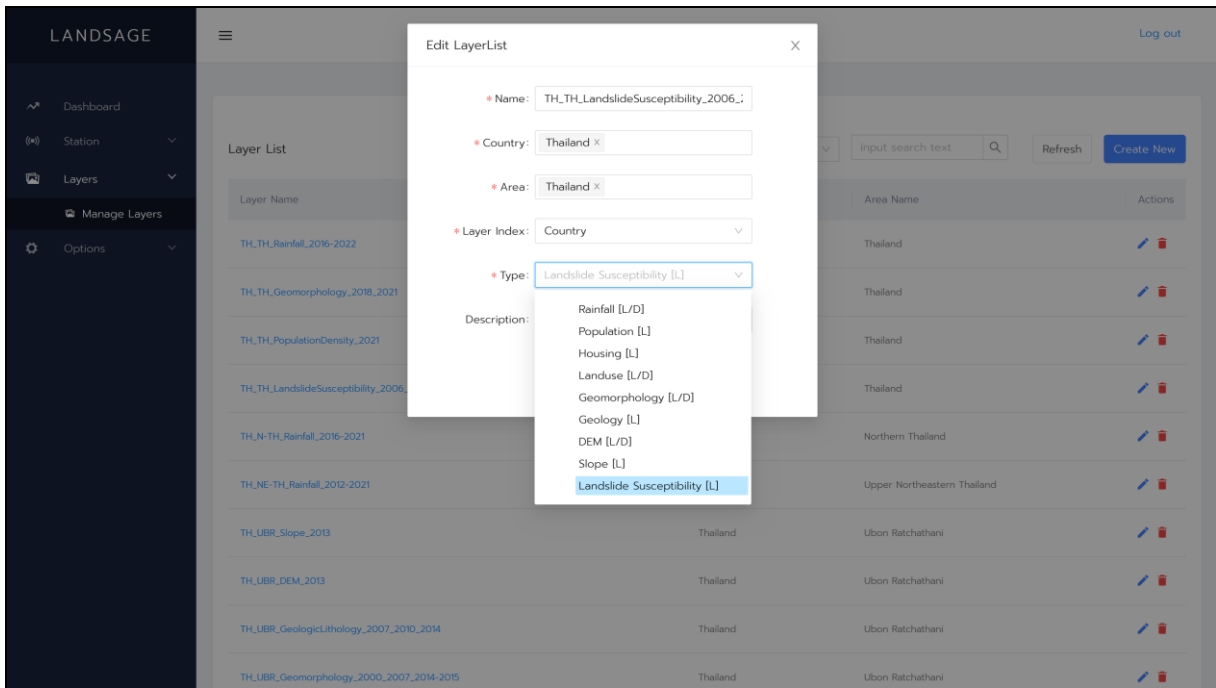
Entering a raster image representing a landslide, drought, or dengue factor into the database.

To assist in the data management, the user can hover the mouse cursor over a map or legend entry to reveal the uploaded image on the fly.
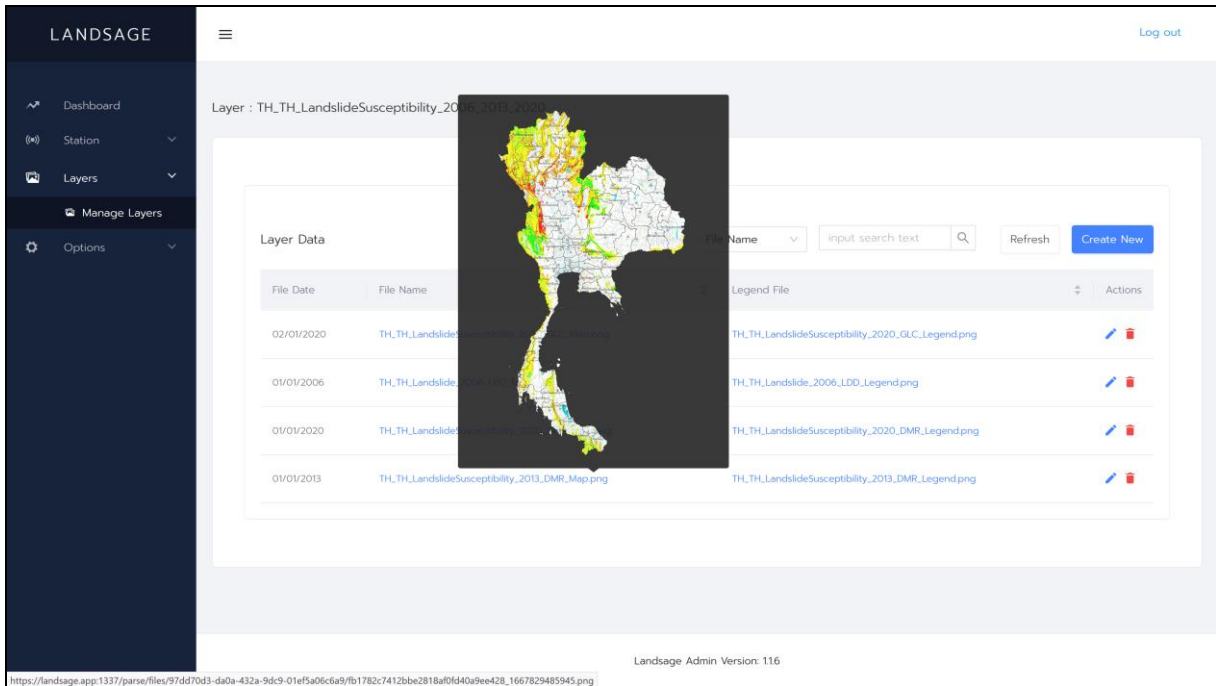
Hovering the mouse cursor over a map or a legend entry to reveal the uploaded image.

The "Option" page allows the administrator to manage the dashboard users and various other data for the LandSAGE software. Multiple user types and their permissions can be defined. For example, we can designate that a guest user can only view the database while an administrator can create, edit, and delete data.
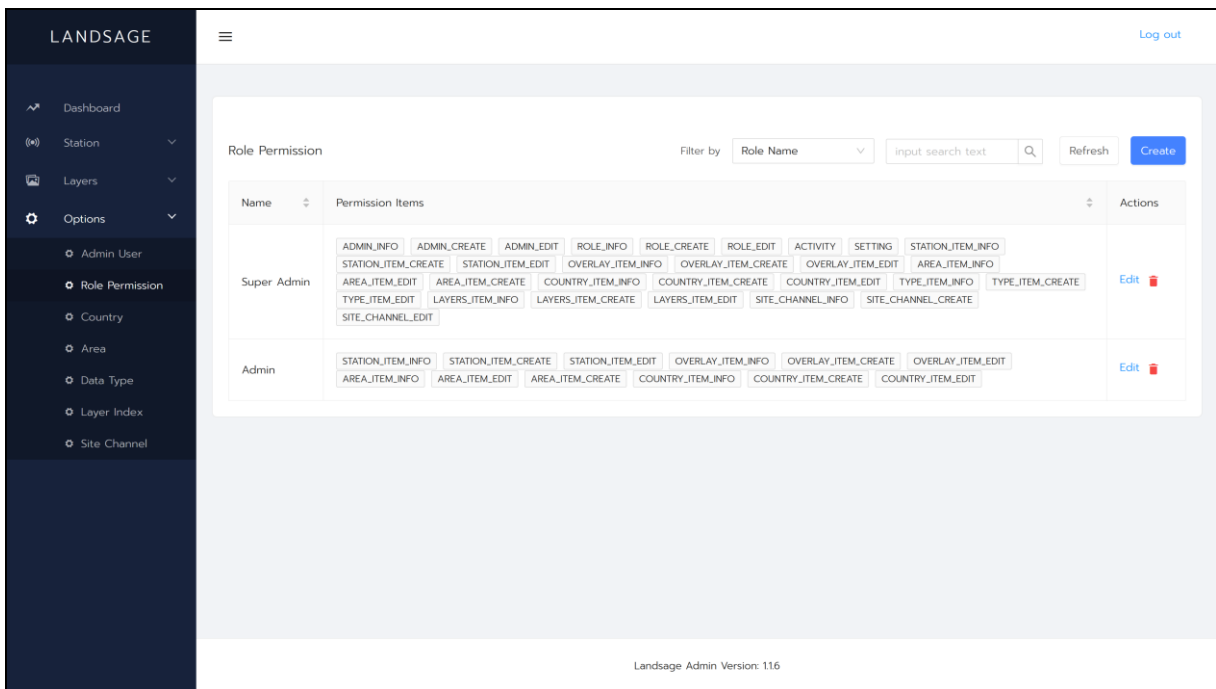
User types and their permissions for accessing the database.

Countries, scopes, areas, and factors can be managed to support a future expansion of the monitoring coverage.
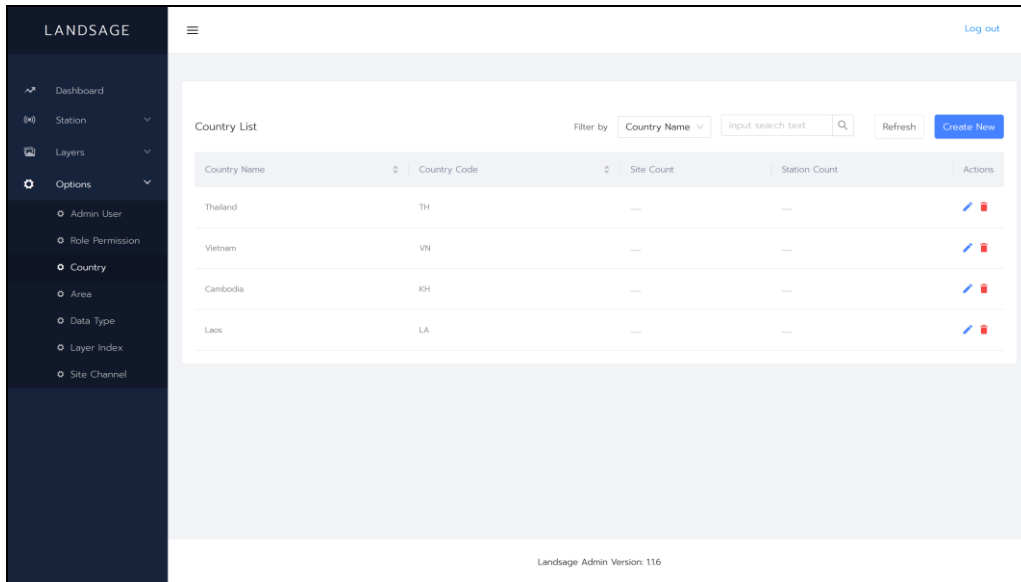
Countries can be added, edited, or deleted.
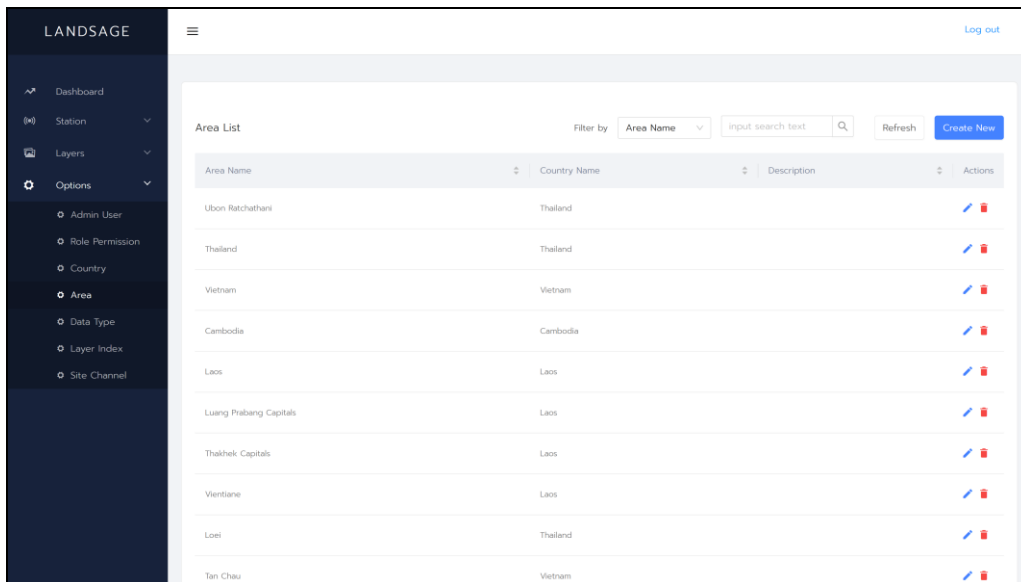
Areas can be added, edited, or deleted.
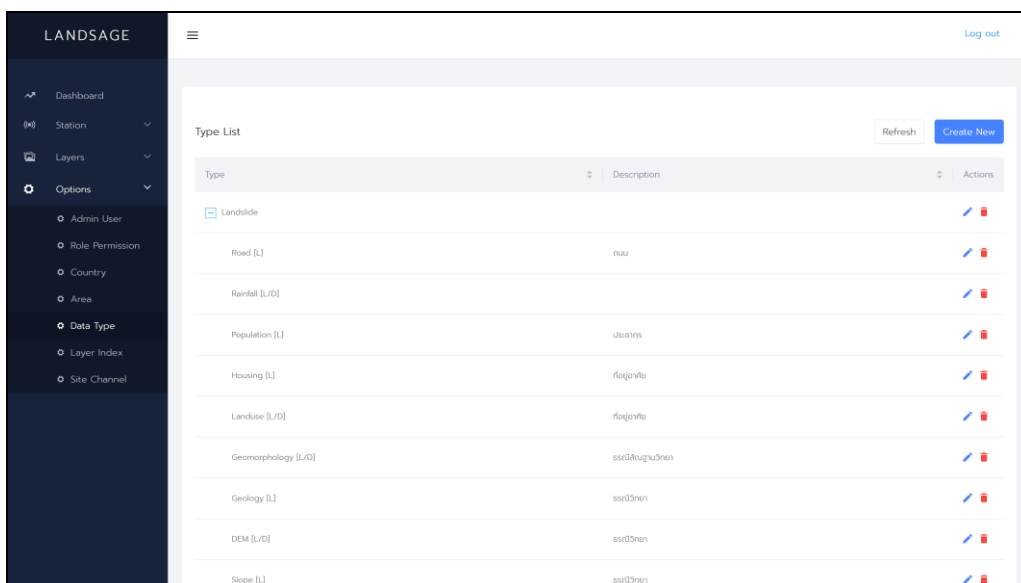
Factors can be added, edited, or deleted.

Integration with (Near) Real-Time Hydro-meteorological Sensor Data

We improved the utility of the LandSAGE software by integrating with the (near) real-time hydro-meteorological sensor data from multiple sources that expands the LandSAGE monitoring coverage. For disaster monitoring, real-time data are very useful on top of historical data and pave the way to the third tier which is predictive data.

Integration with the Rainfall and Water Level Data from Mekong River Commission (MRC)

To obtain the (near) real-time rainfall and water level data from MRC, we sent an "HTTP GET" request to the following URL:

https://api.mrcmekong.org/api/v1/nrtm/station

The response was obtained in the JSON format. The following picture shows a partial response depicting the sensor data for one monitoring station. The full response contained sensor data from 73 monitoring stations.
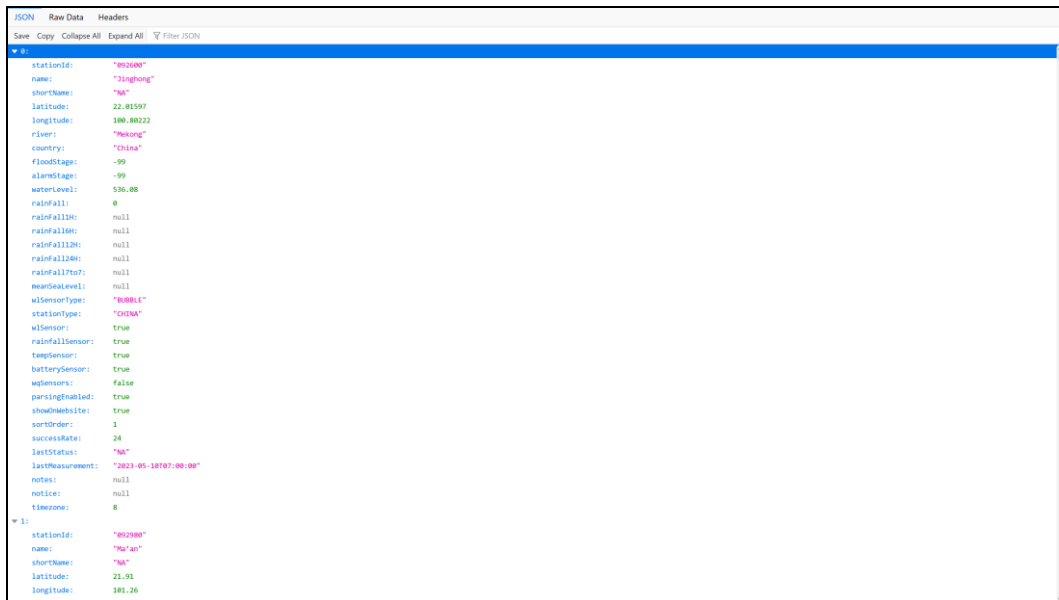
Partial response from MRC server showing sensor data fields.

The returned data fields for each monitoring station included such information as *stationId, name (of station), latitude, longitude, country, waterLevel and rainfall*. To grow our rainfall and water level time-series data (see Activity 7: Sub-activity 3 – Flood Data Collection) for prediction purposes, we send a data request to the MRC server every 15 minutes and add the obtained data to the newly created LandSAGE daily hydro-meteorological database.

Daily hydro-meteorological database for storing MRC sensor data captured every 15 minutes.

Since the smallest time unit of the visualization in the LandSAGE software is "day", at 0.01am of everyday the backend module computes the representative values for the rainfall and water level of yesterday using the maximums. The two pictures below show the visualizations of MRC hydro-meteorological stations with near real-time data.
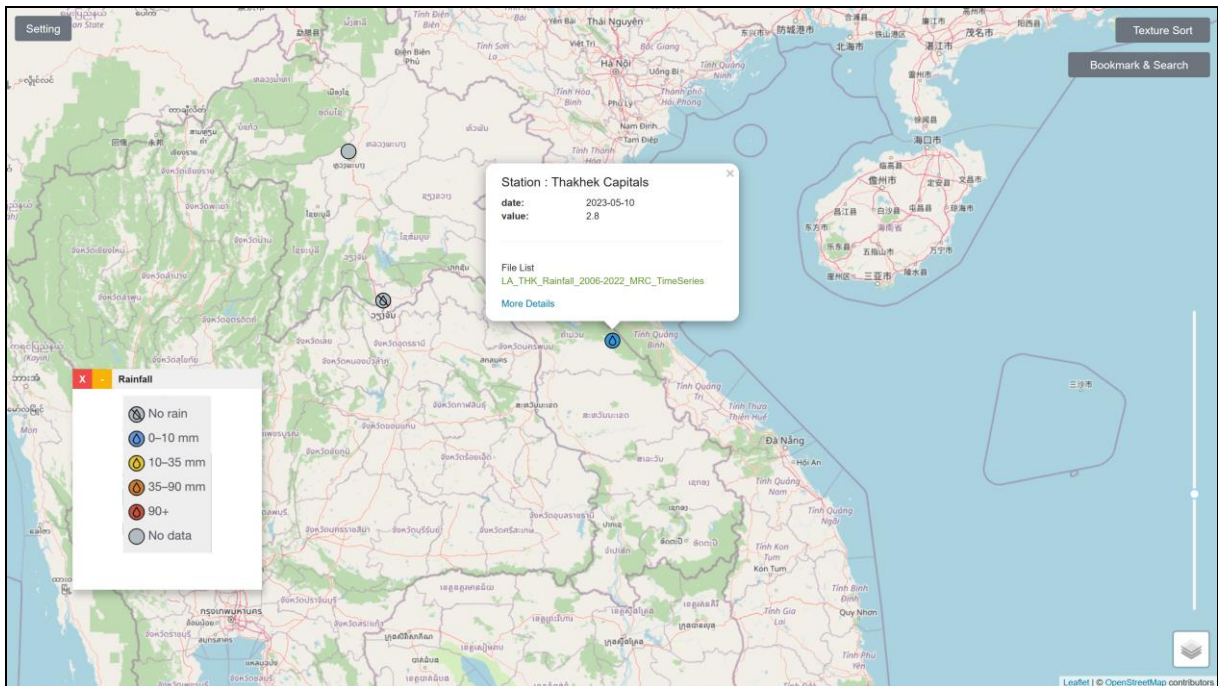
Rainfall data are up to date because of the integration with the near real-time sensor data from MRC.
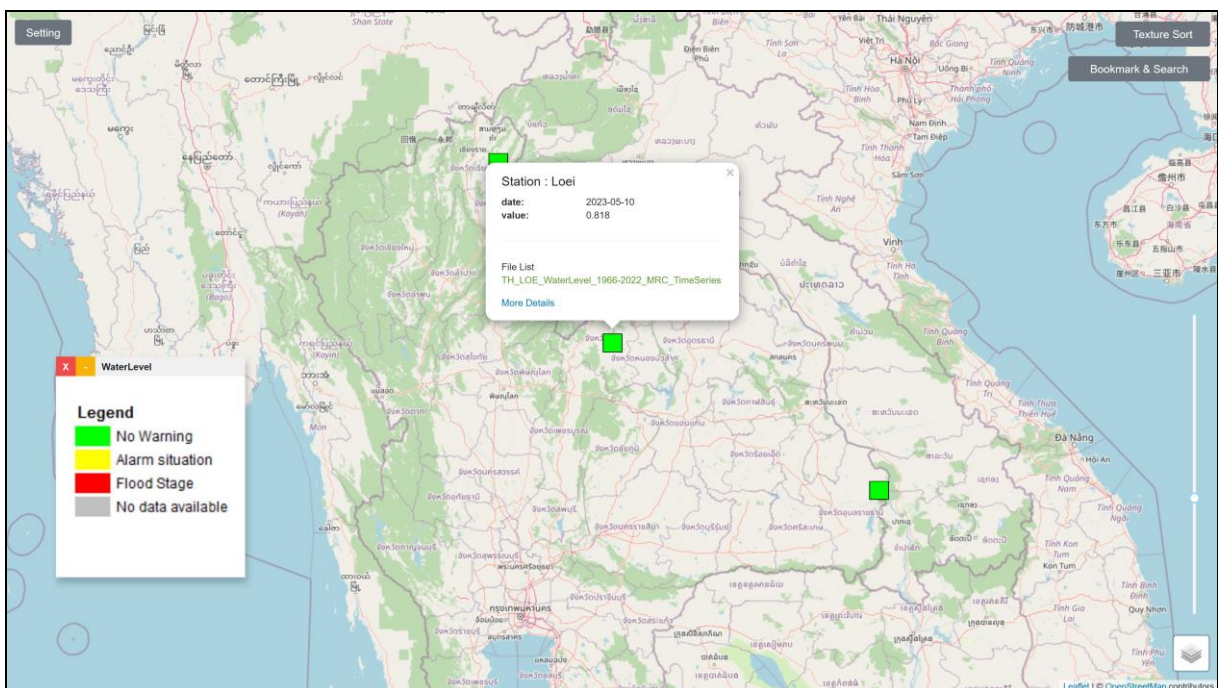
Water level data are up to date because of the integration with the near real-time data from MRC.

Integration with the Rainfall and Water Level Data from the National Hydroinformatics Data Center (NHC) in Thailand

The rainfall and water level sensor data from NHC were integrated into the LandSAGE software. The picture below shows the visualization of water level in LandSAGE. The color of each monitoring station (depicted by a square) indicates the current water level status, e.g., red indicates flood, green indicates normal level, and dark yellow (bottom of the legend) indicates severely depleted level. The up and down arrows indicate if the current water level is increased or decreased from the previous measurement, respectively.
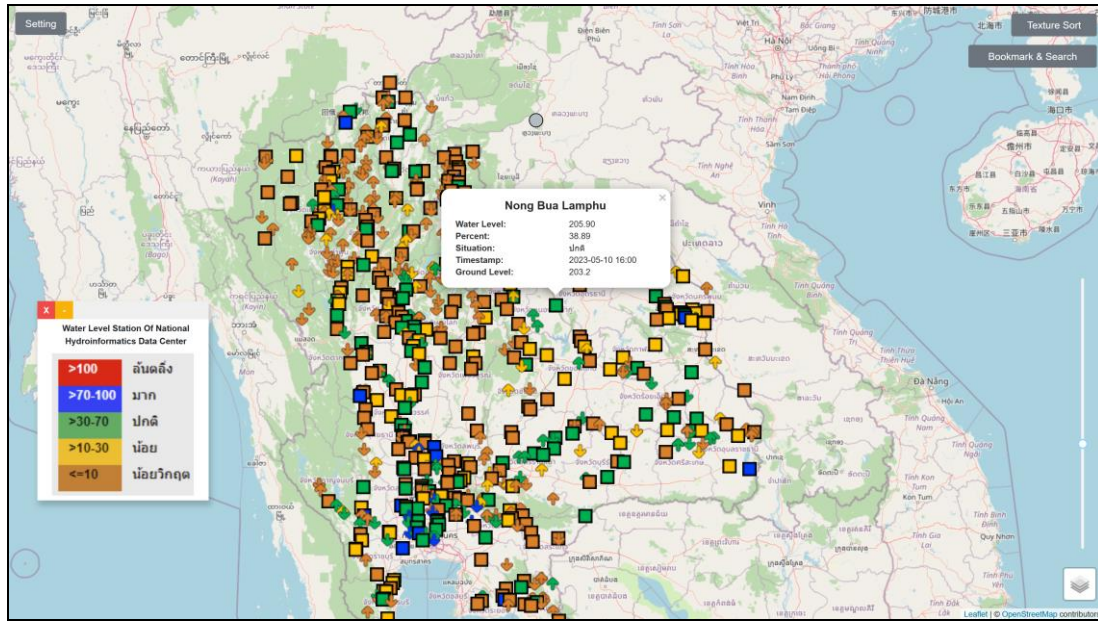
Visualization of the (near) real-time water level data from NHC. It can be enabled by clicking "Setting" on the upper left of the screen and then choose "Water Level Station of National Hydroinformatics Data Center" from the "Select External Data" menu.

The picture below shows the visualization of rainfall data from NHC. The color of each monitoring station (depicted by a waterdrop) indicates the current rainfall status, e.g., blue indicates light rainfall, green indicates moderate rainfall, and red indicates very heavy rainfall.
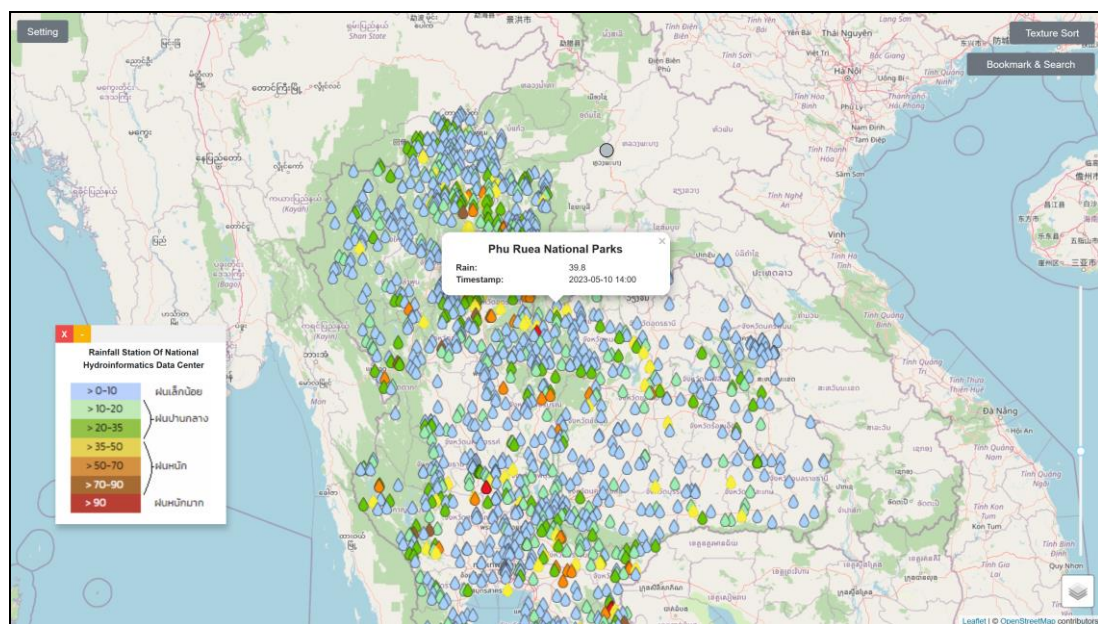
Visualization of the (near) real-time rainfall data from NHC. It can be enabled by choosing "Rainfall Station of National Hydroinformatics Data Center" from the "Select External Data" menu.

To obtain rainfall sensor data from NHC, we sent an "HTTP GET" request to the following URL:

https://api-v3.thaiwater.net/api/v1/thaiwater30/public/rain_24h

The response was obtained in the JSON format. The following picture (left) shows a partial response depicting the sensor data for one monitoring station. The full response contained sensor data from 2,648 monitoring stations.
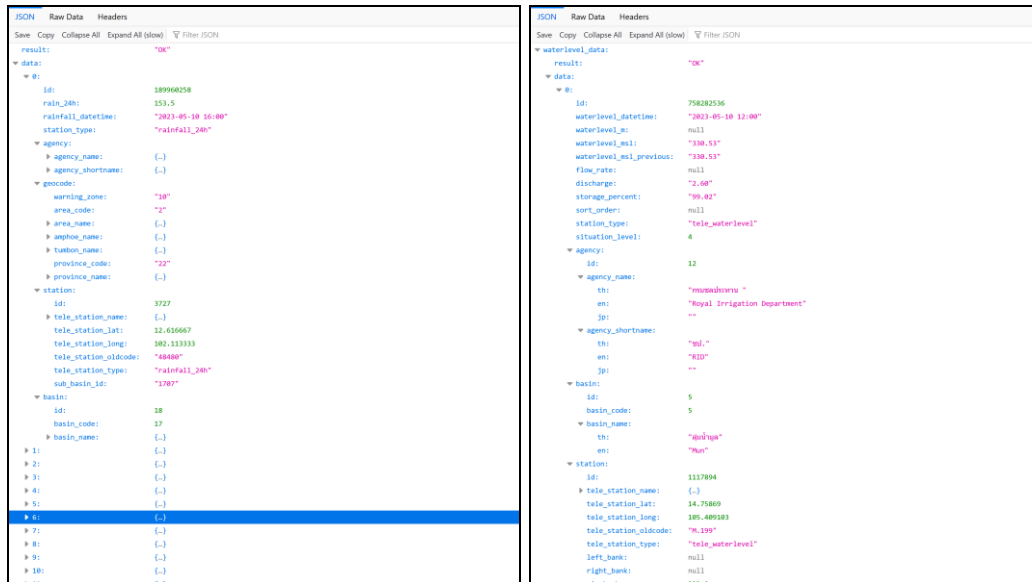
Left: Partial response from NHC server showing rainfall data fields. Right: Partial response from NHC server showing water level data fields.

The returned data fields for each monitoring station included such information as:
- tele_station_lat – Latitude of the rainfall station.
- tele_station_long – Longitude of the rainfall station.
- tele_station_name.en – Name of the rainfall station in English.
- tele_station_name.th – Name of the rainfall station in Thai.
- rain_24h – Cumulative rainfall amount over the past 24 hours.
- rainfall_datetime – Date and time the rainfall amount is calculated.

To obtain water level data from NHC, we sent an "HTTP GET" request to the following URL:

https://api-v3.thaiwater.net/api/v1/thaiwater30/public/waterlevel_load

The response was obtained in the JSON format. The above picture (right) shows a partial response depicting the sensor data for one monitoring station. The full response contained sensor data from 1,480 monitoring stations. The returned data fields for each monitoring station included such information as:
- tele_station_lat – Latitude of the water level station.
- tele_station_long – Longitude of the water level station.
- waterlevel_datetime – Date and time the water level is measured.
- storage_percent – Water level percentage (100% means full capacity of the water storage)
- situation – Water level situation comparing between the current and the ground level.
- waterlevel_msl – The current water level.
- waterlevel_msl_previous – The water level from the previous measurement.
- ground_level – The ground water level.

We send a data request to the NHC server every 30 minutes to refresh the visualization.

Integration with the Rainfall Data from the Thai Meteorological Department (TMD)

The rainfall sensor data from TMD were integrated into the LandSAGE software. The picture below shows the visualization of the rainfall data in LandSAGE. The color of each monitoring station (depicted by a waterdrop) indicates the current rainfall status, e.g., blue indicates light rainfall, green indicates moderate rainfall, and red indicates very heavy rainfall.
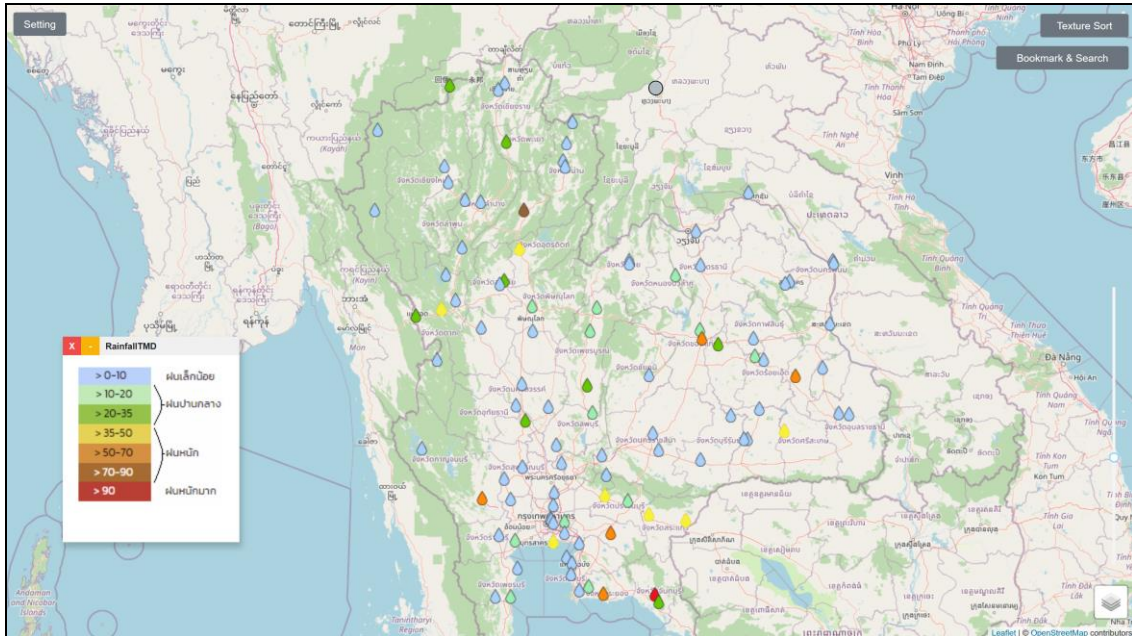
Visualization of the (near) real-time rainfall data from TMD. It can be enabled by clicking "Setting" on the upper left of the screen and then choose "RainfallTMD" from "Select External Data" menu.

To obtain rainfall sensor data from TMD, we sent an "HTTP GET" request to the following URL:

http://data.tmd.go.th/api/Weather3Hours/V2/?uid=api&ukey=api12345

The response was obtained in the XML format. The following picture shows a partial response depicting the sensor data for one monitoring station. The full response contained sensor data from 116 monitoring stations.

Partial response from TMD server showing rainfall data fields.

The returned data fields for each monitoring station included such information as:
- latitudeValue – Latitude of the rainfall station.
- longitudeValue – Longitude of the rainfall station.
- stationNameEnglish – Name of the rainfall station in English.
- stationNameThai – Name of the rainfall station in Thai.
- rainfall24Hr – Cumulative rainfall amount over the past 24 hours.
- dateTime – Date and time the rainfall amount is calculated.

We send a data request to the TMD server every 30 minutes to refresh the visualization.

Enhancement of the Frontend Module

We improved the utility and usability of the LandSAGE frontend module (map and graph visualizers) by adding several new features and improving its user interface. See also the previous and the next sections for more features (real-time sensor data and predictions).

User Interface Redesign and Addition of Satellite View

We added the satellite view to the map visualizer that could be useful for revealing the slopes and other details in an area, e.g., if the area is agricultural or has high housing density.

Satellite view in the map visualizer: The user can toggle between the satellite and street views by using the lower right icon.

To reduce the clutter of UI elements on the map view, we moved most elements to collapsible panels. The picture below shows the "Setting" collapsible panel containing all the functions from the earlier software version as well as the new functions added in LandSAGE4.
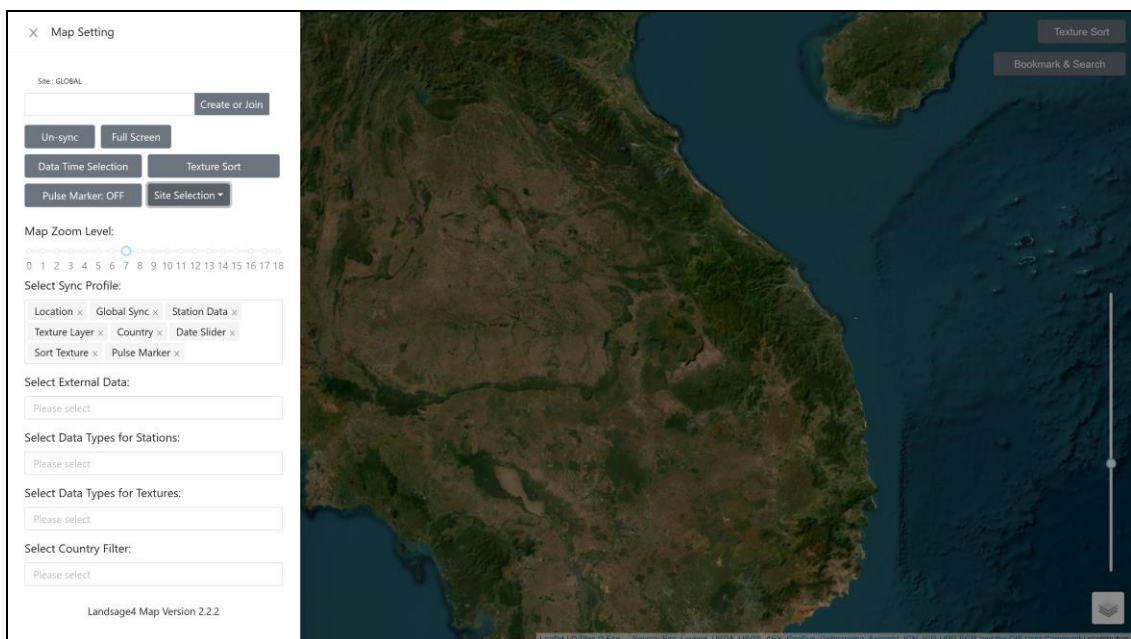
The new UI uses collapsible panels to reduce clutter on the screen.

Visualization of Multiple Areas Per Country

Expansion of monitoring coverage requires visualization of multiple areas per country. In the earlier software prototype, only one area could be visualized per country. The new software lifts this restriction as shown below.
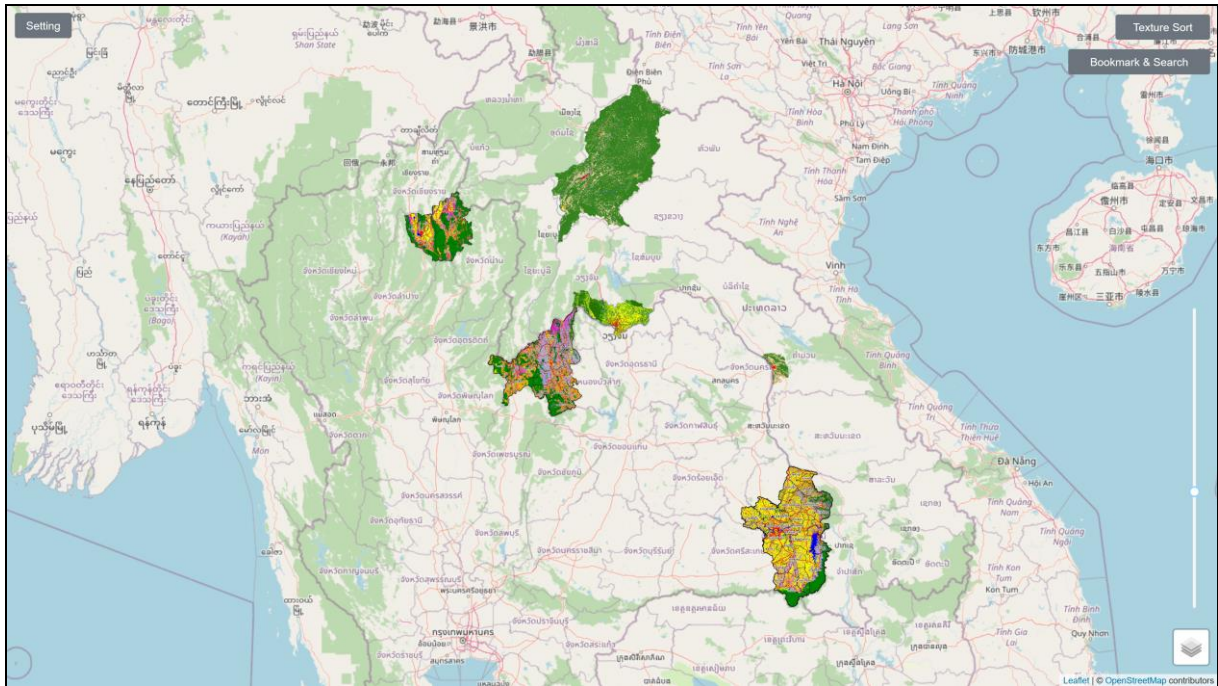

Visualizing land use factors at three pilot sites in each of Thailand and Laos.
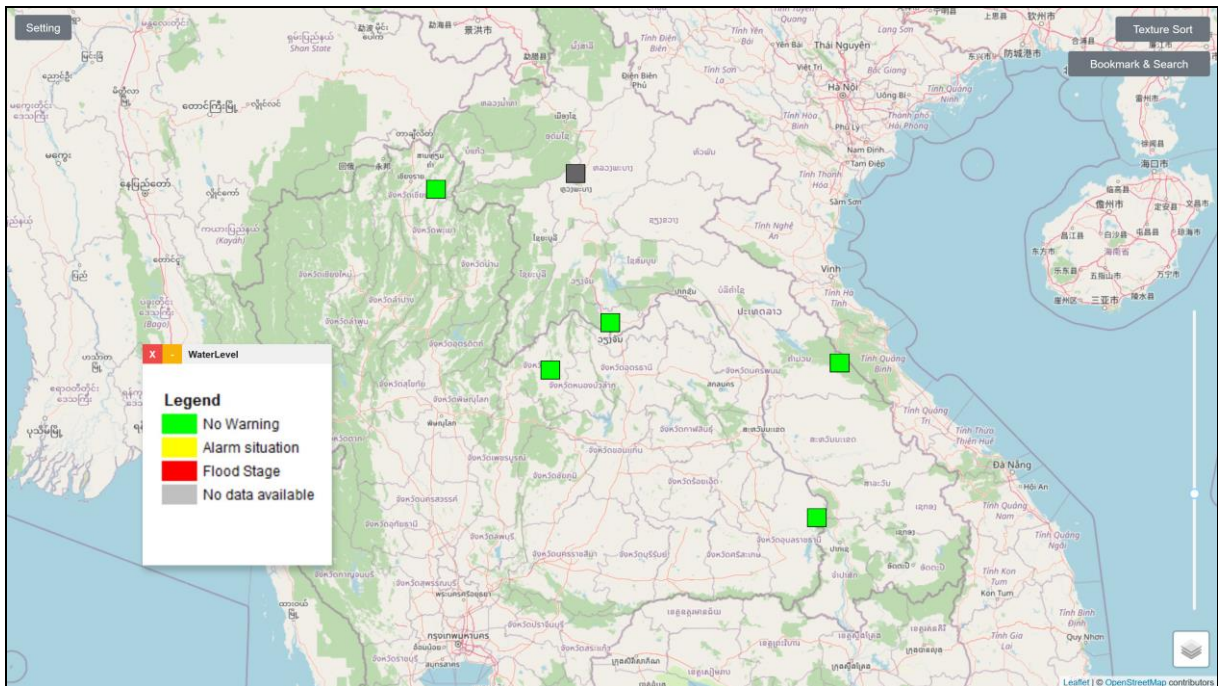
*Visualizing water level stations at three pilot sites in each of Thailand and Laos.*

Map Sorting, Pulse Marker, and Dynamic Synchronization Profile

In the new software, multiple maps can overlap the same region, e.g., a province map overlaps with the country map resulting in occlusion. We added a map sorting feature to resolve the occlusion by giving the user the ability to specify the order in which the maps in an overlapping area are rendered.
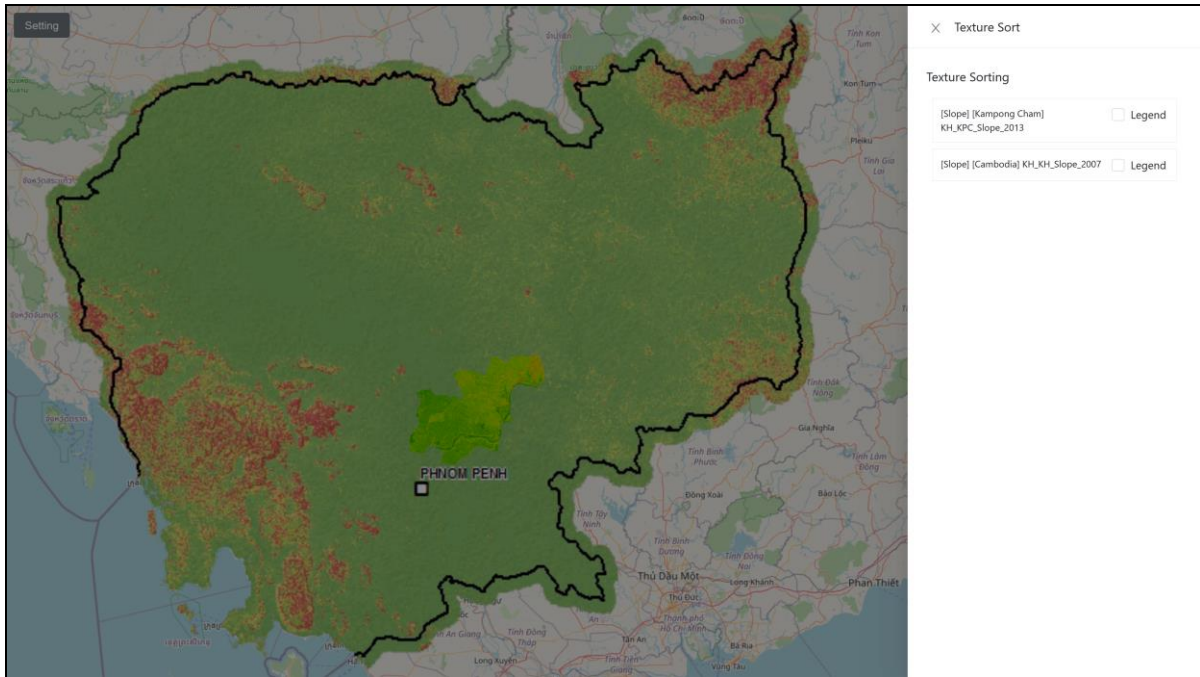

The map (texture) sorting panel (collapsible) enables the user to make the slope map of Kampong Cham appear above the slope map of Cambodia. It can be opened by clicking the "Texture Sort" button on the upper right of the screen.

To aid collaboration, we added a pulse marker feature that lets the user display a visual marker in the form of animating red circle anywhere on the base map. The marker can be seen by remote collaborators and is intended to grab their attention.
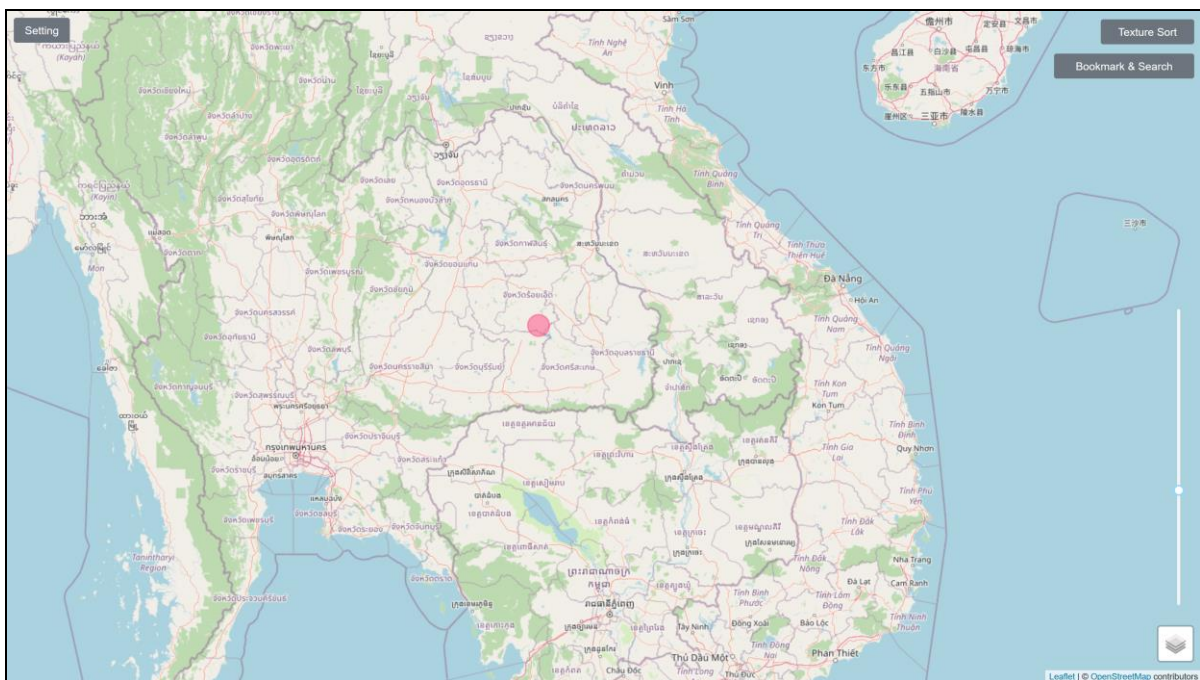
A pulse marker (red circle) can be triggered on the map to grab the attention of remote users. This can be done by looking for the "Pulse Marker" button in the "Setting" panel.

An instance of the LandSAGE frontend can have its visualization synchronized with that of another instance using the same synchronization profile. In the earlier version of the LandSAGE software, only five synchronization profiles were supported leading to unintended synchronization when multiple users accidentally selected the same synchronization profile. In this new version of LandSAGE, the user can create any number of synchronization profiles on the fly which can be deleted later via the administrator dashboard using the "Site Channel" menu under "Options". We also added additional synchronization options including synchronization of pulse marker display and map (texture) sorting.
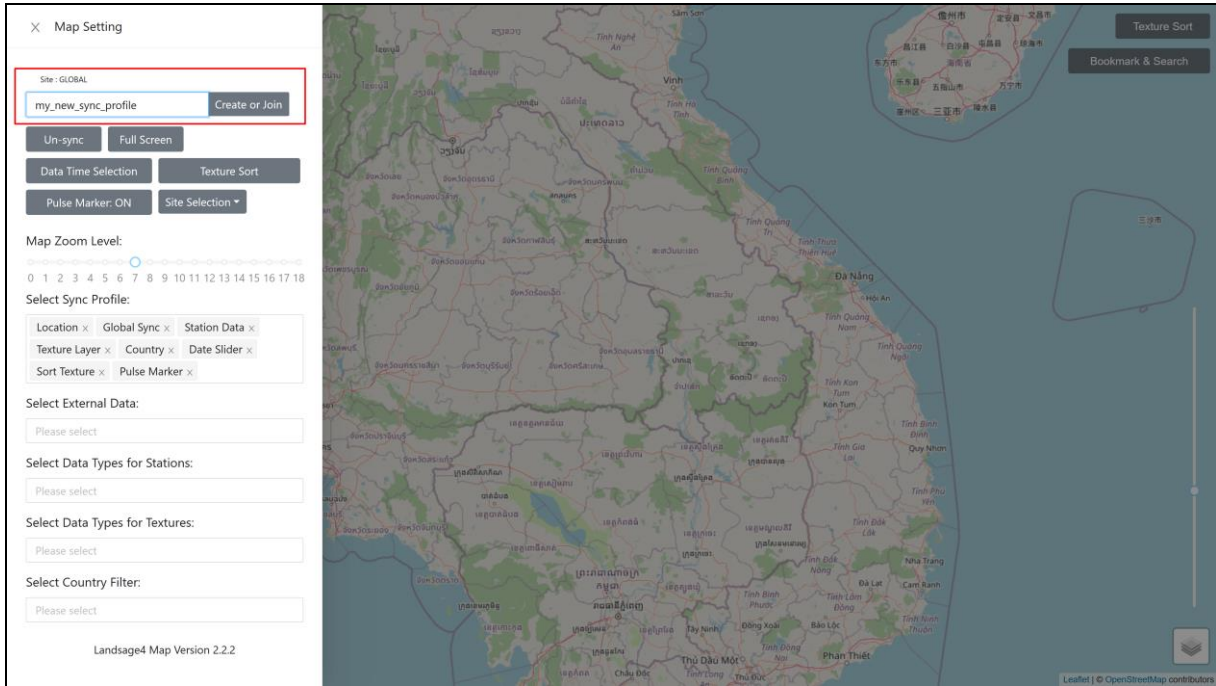
Dynamic synchronization profile (see the upper left of the screen): The user can create or join a profile by typing its name and click "Create or Join". The currently joined profile is indicated by the "Site" label.
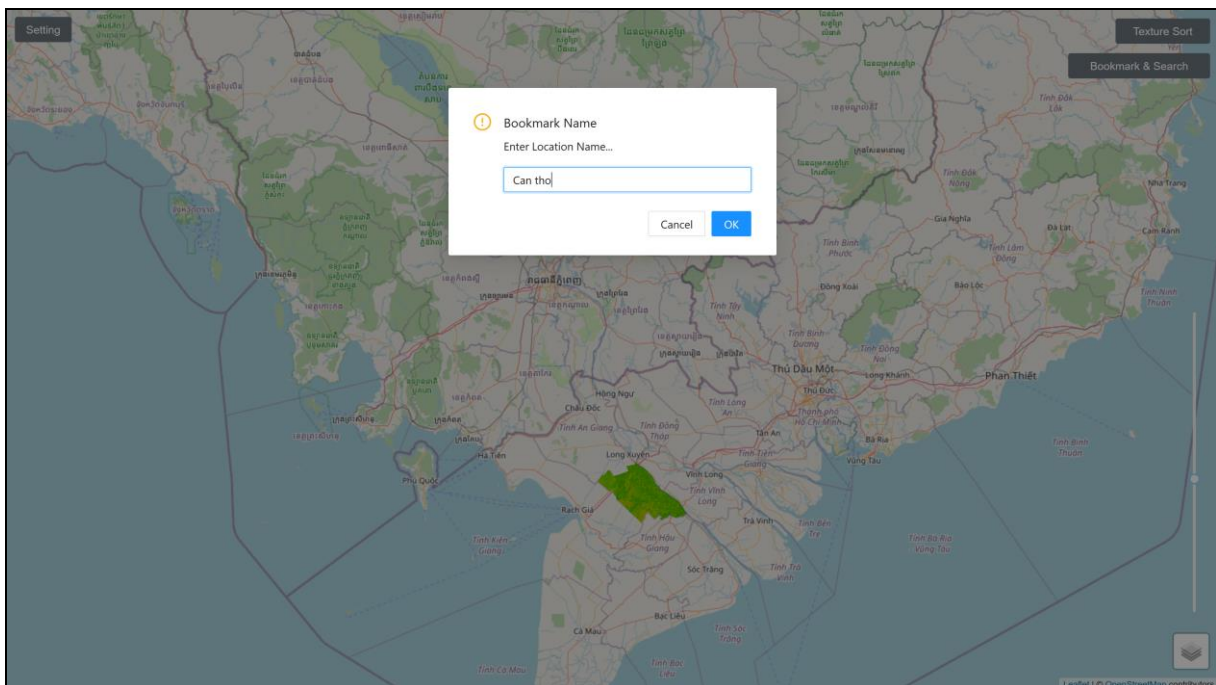
Location Search and Bookmark

To easily jump to another location on the base map, the user can enter the target location in the "Location Search" box.
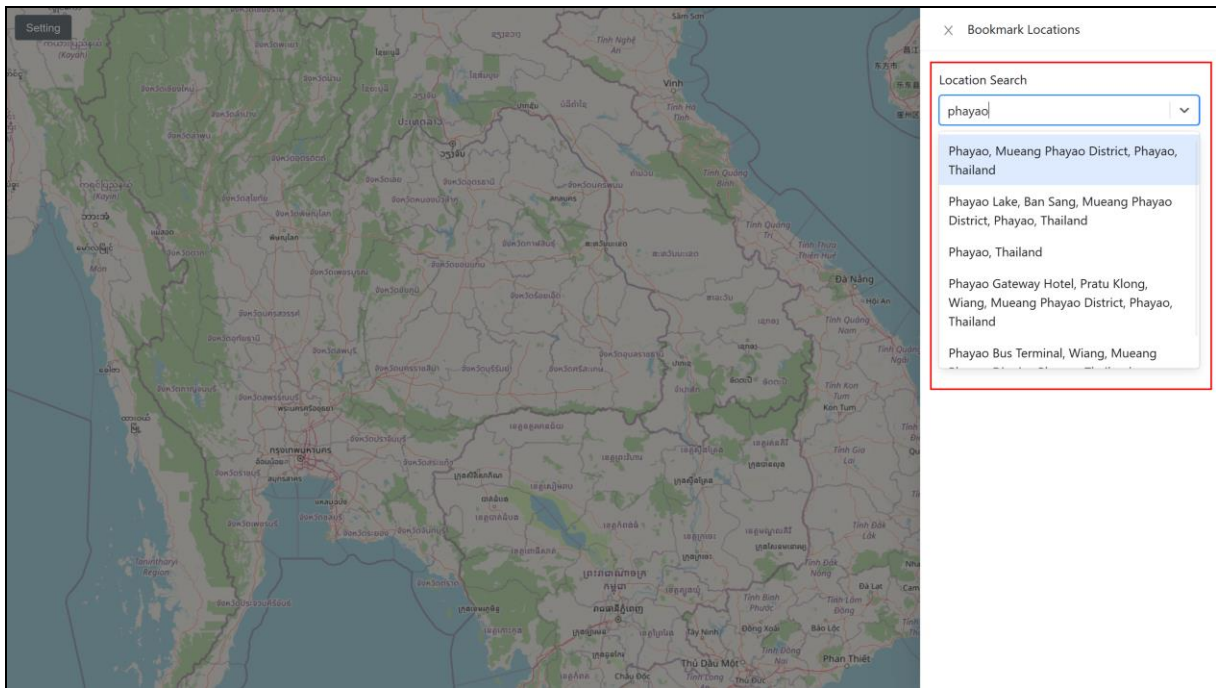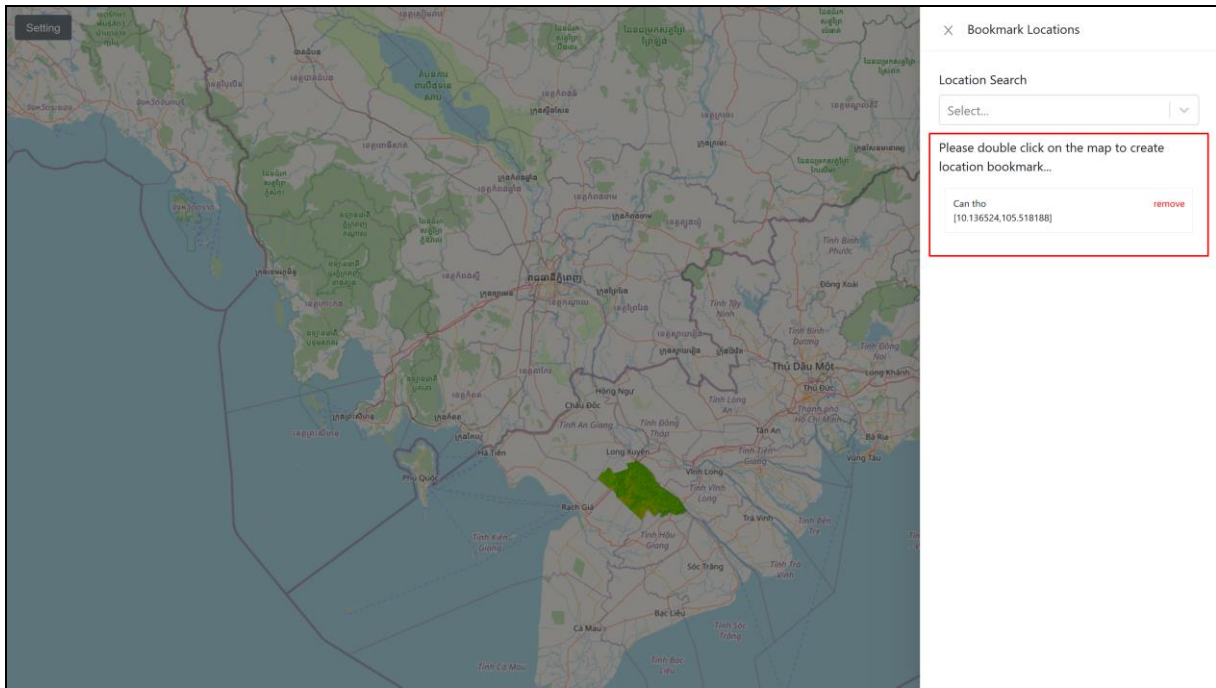

Using location search to quickly jump to a target location. The function can be accessed from the "Bookmark & Search" button on the upper right of the screen.

In addition, the user can create a location bookmark by double-clicking on the base map.


Creating a location bookmark.

The user can jump to a bookmarked location by choosing it from the "Bookmark and Search" panel.

"Bookmark and Search" panel (collapsible) showing the saved and selectable location bookmarks. The saved bookmarks can be deleted via the "remove" button.
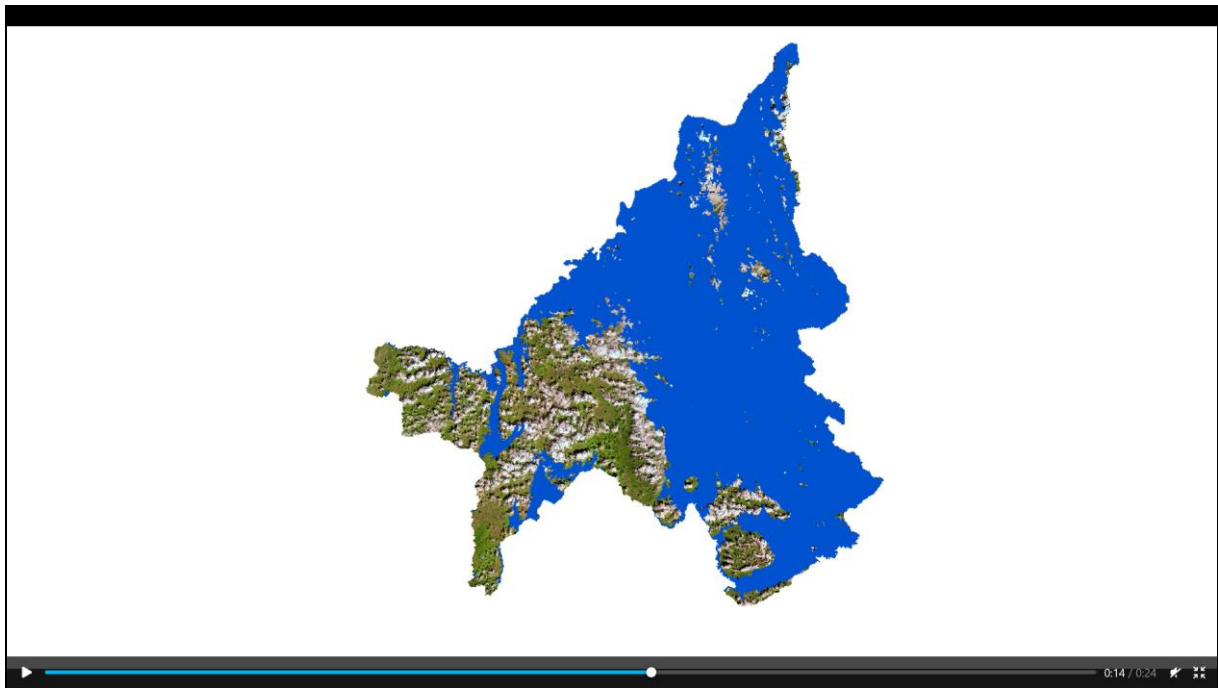
Flood Simulation Visualization

The flood simulation video for each pilot site can be played back in the map visualizer to help the user identify which parts of a pilot site would be affected if a flood were to occur.
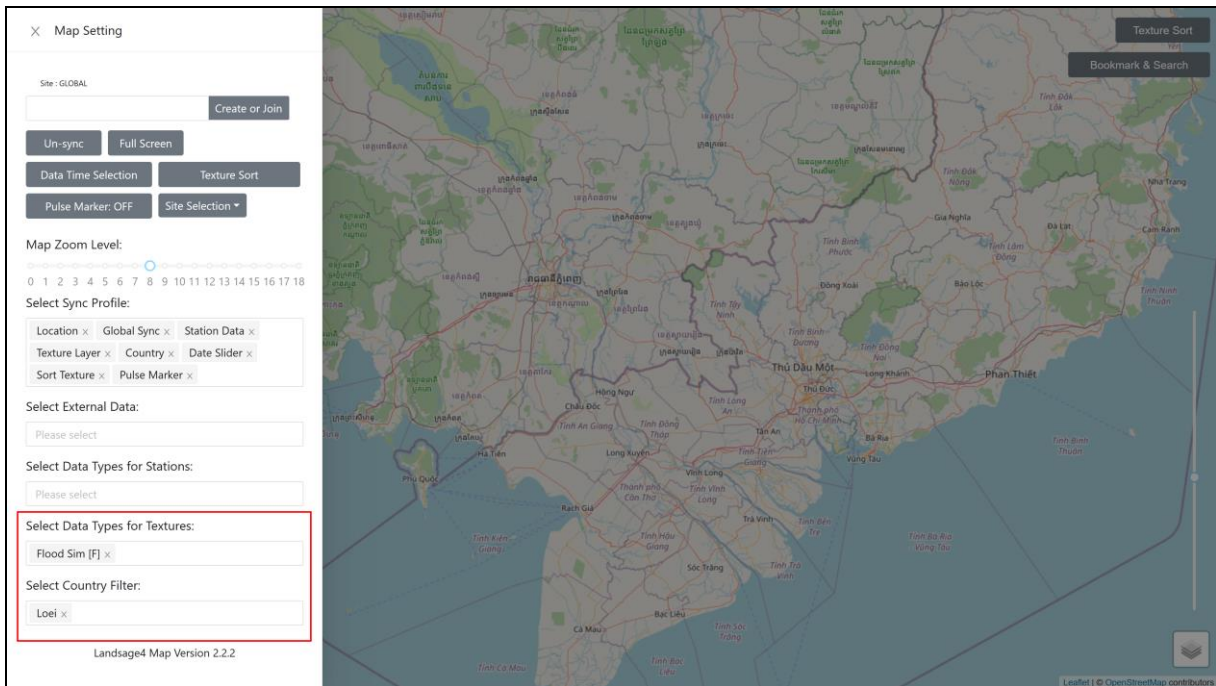
Step1 of flood simulation visualization – Choosing "Flood Sim" and selecting the pilot site from the "Setting" panel.
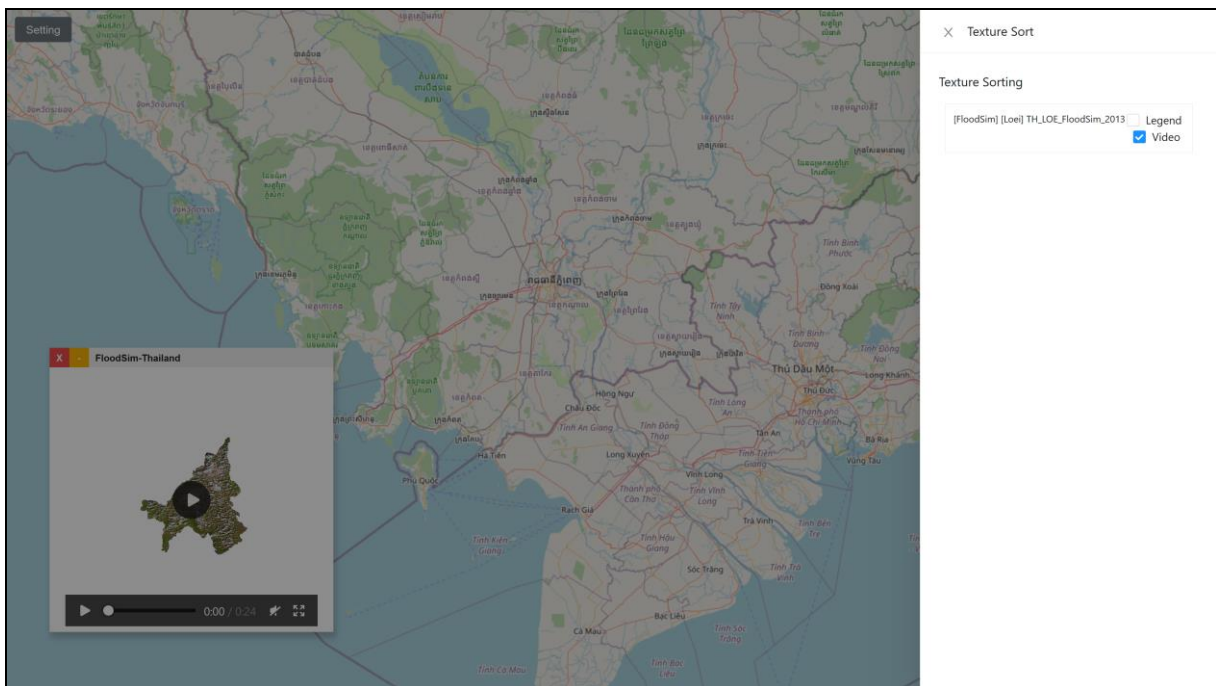

Step2 of flood simulation visualization – In the "Texture Sort" panel (collapsible), tick the "Video" checkbox of each pilot site to visualize.

The flood simulation video player.

Enhanced Graph Visualizer

The graph visualizer was enhanced to show the up-to-date data from MRC and the threshold levels for both rainfall and water level datasets. For the water level, the 7-day prediction was also shown (see the next section).
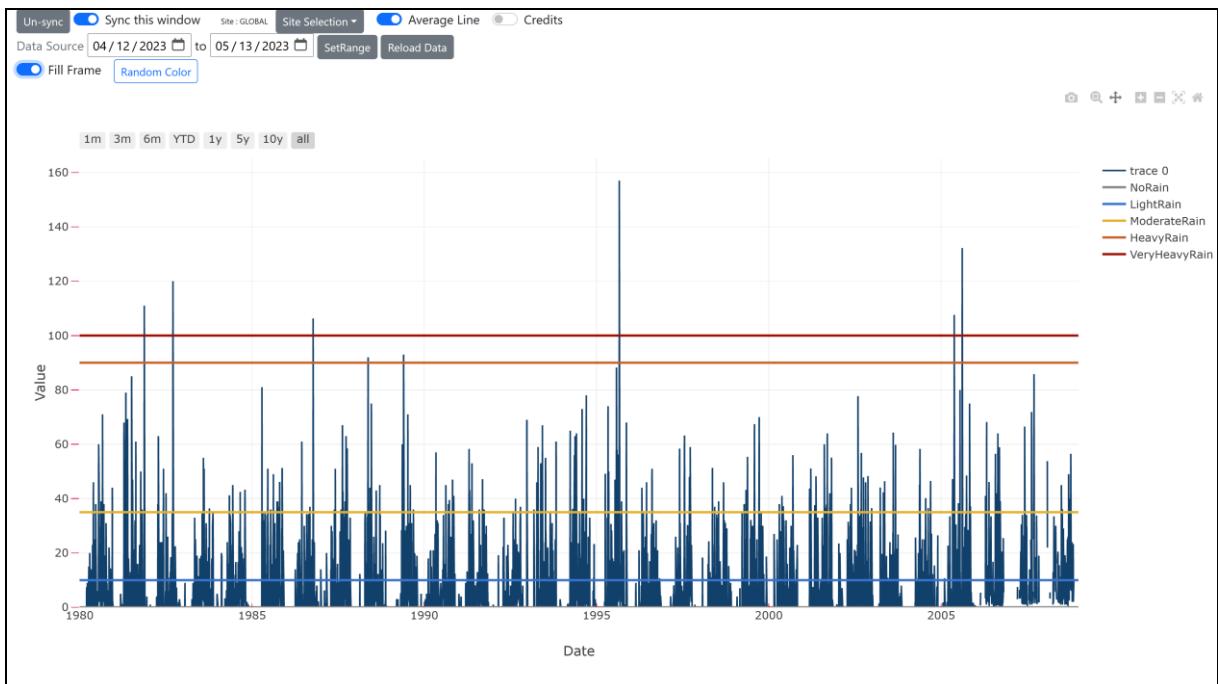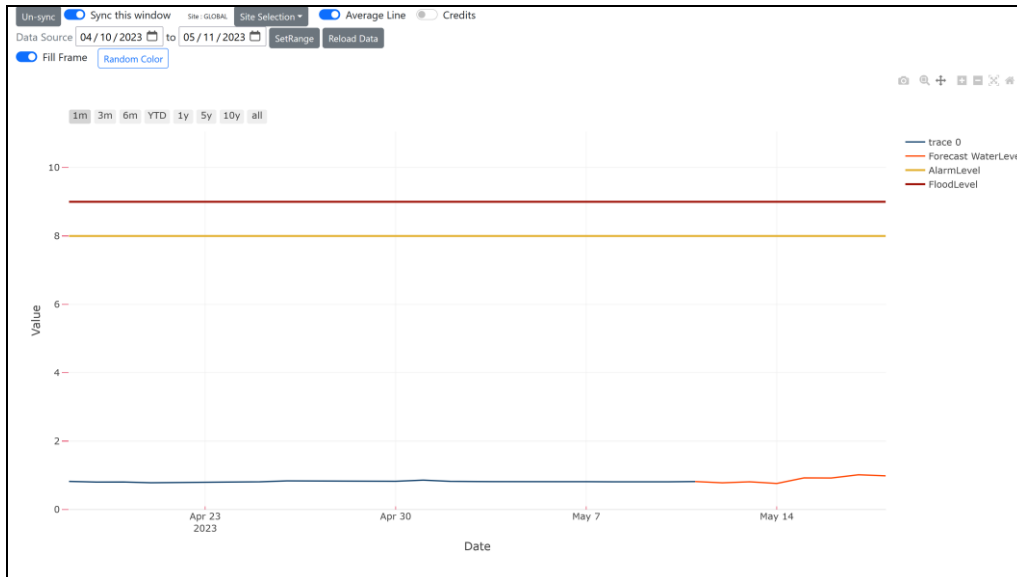

The enhanced graph visualizer for rainfall datasets showing up-to-date data from the integration with the (near) real-time sensors from MRC. The colored horizontal lines indicate the threshold levels for each rainfall intensity given in the legend.

Adding Flood Prediction and Landslide Risk Analysis

In the old LandSAGE software, the user looked at landslide and flood visualizations to determine the risks manually. In LandSAGE4, we improved the intelligence of the LandSAGE software by adding flood prediction and landslide risk analysis capabilities.

Flood Prediction for MRC Monitoring Stations

We used machine learning to compute 7-day water level predictions for the MRC monitoring stations of all the pilot sites. The picture below shows a graph of water levels containing the 7-day prediction.


The enhanced graph visualizer for water level datasets – At the bottom, the blue line shows the current and historical water levels and the (light) red line shows the 7-day prediction. At the top, the (dark) red and yellow lines indicate the flood and alarm levels for the MRC monitoring station, respectively.

The predicted values are compared against the flood and alarm levels of the monitoring stations to determine the risks of floods. When there is a predicted value exceeding the station's flood level, the LandSAGE software will alarm the user as shown below.
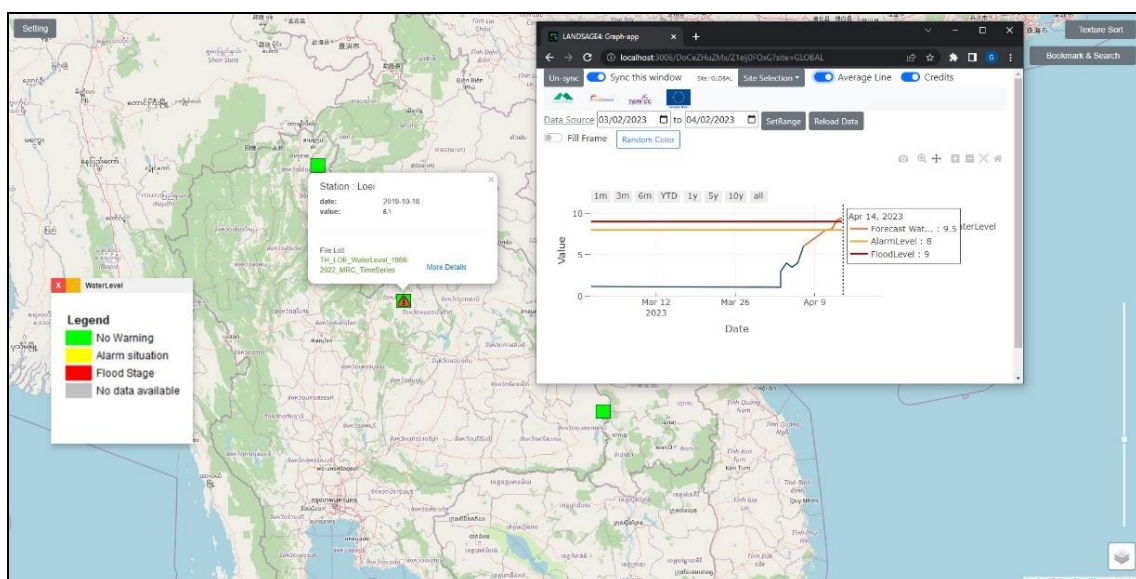
Flood warning is indicated by the red exclamation appearing on an MRC station icon.

Given that there is no predicted value exceeding the flood level, the next analysis is performed – If there is a predicted value exceeding the station's alarm level, the LandSAGE software will alarm the user as shown below.
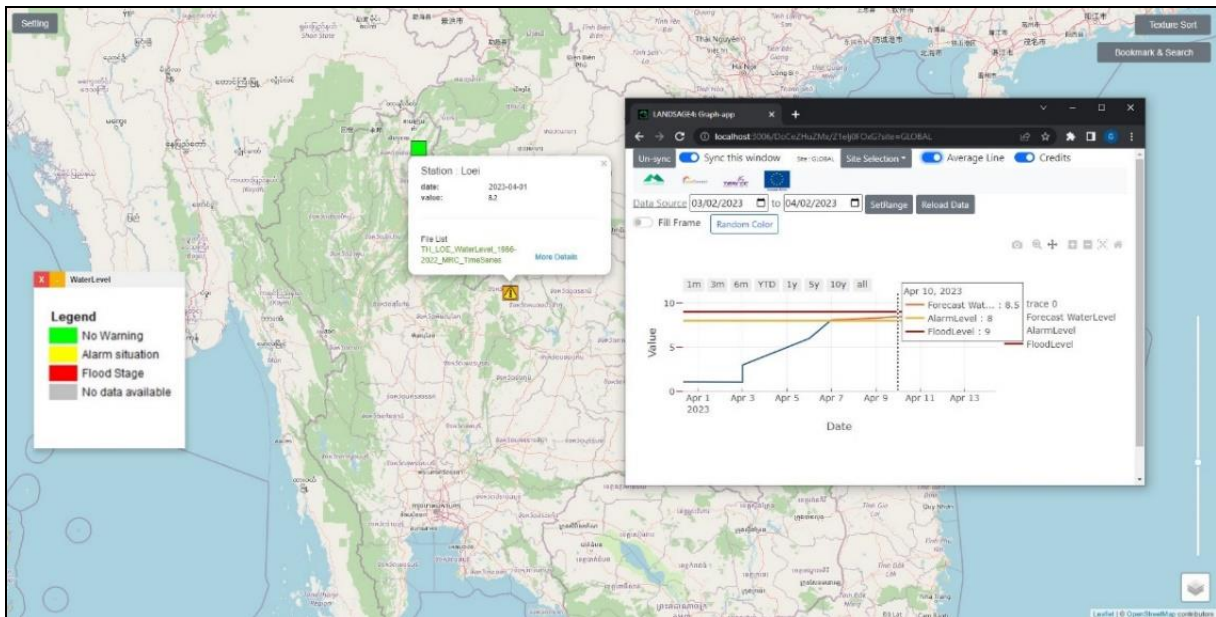
Potential flood warning is indicated by the yellow exclamation appearing on an MRC station icon.

For each MRC station, the prediction is re-calculated at the beginning of each day for the next seven days. We chose the LightGBM model (gradient boosting machine learning algorithm) for training our prediction because of its efficiency in handling large datasets and complex relationships. The water level data from MRC were used to create the training and testing datasets with two original features including date and water level. We generated additional time-related features to assist the model in discovering patterns or trends. These features included hour, day of the week, quarter, month, year, day of the year, sine and cosine of the day of the year, day of the month, and week of the year.

Landslide Risk Analysis

We implemented an adaptation of a landslide risk analysis method published by the Department of Mineral Resources in Thailand. Our method considers the landslide susceptibility of an area, the cumulative rainfall, soil types, and slopes to determine the risk of landslide in the area. Specifically:

- For an area with 1st level landslide susceptibility, there is a risk of landslide if the cumulative rainfall is over 100 millimeters per day, the area has a thick soil layer with minimal holding roots, and the slope of the area is greater than 30 degrees.
- For an area with 2nd level landslide susceptibility, there is a risk of landslide if the cumulative rainfall is over 150 millimeters per day, the area has a thick soil layer with minimal holding roots, and the slope of the area is greater than 30 degrees.
- For an area with 3rd level landslide susceptibility, there is a risk of landslide if the cumulative rainfall is over 200 millimeters per day, the area has a thick soil layer with minimal holding roots, and the slope of the area is greater than 30 degrees.
- For an area with 4th level landslide susceptibility, there is a risk of landslide if the cumulative rainfall is over 250 millimeters per day, the area has a thick soil layer with minimal holding roots, and the slope of the area is greater than 30 degrees.
- For an area with 5th level landslide susceptibility, there is a risk of landslide if the cumulative rainfall is over 300 millimeters per day, the area has a thick soil layer with minimal holding roots, and the slope of the area is greater than 30 degrees.

As a proof of concept, we chose the Phayao province in Thailand as the pilot site for the implementation. We determined the landslide susceptibility, soil characteristic, and slope of a location from the most recent landslide susceptibility map, soil (geomorphology) map, and slope map collected for the Phayao pilot site, respectively. For the rainfall data, we use the (near) real-time rainfall sensor data from the National Hydroinformatics Data Center (NHC). If there is a risk of landslide based on the above rules, the LandSAGE software will display a warning in the map visualizer.
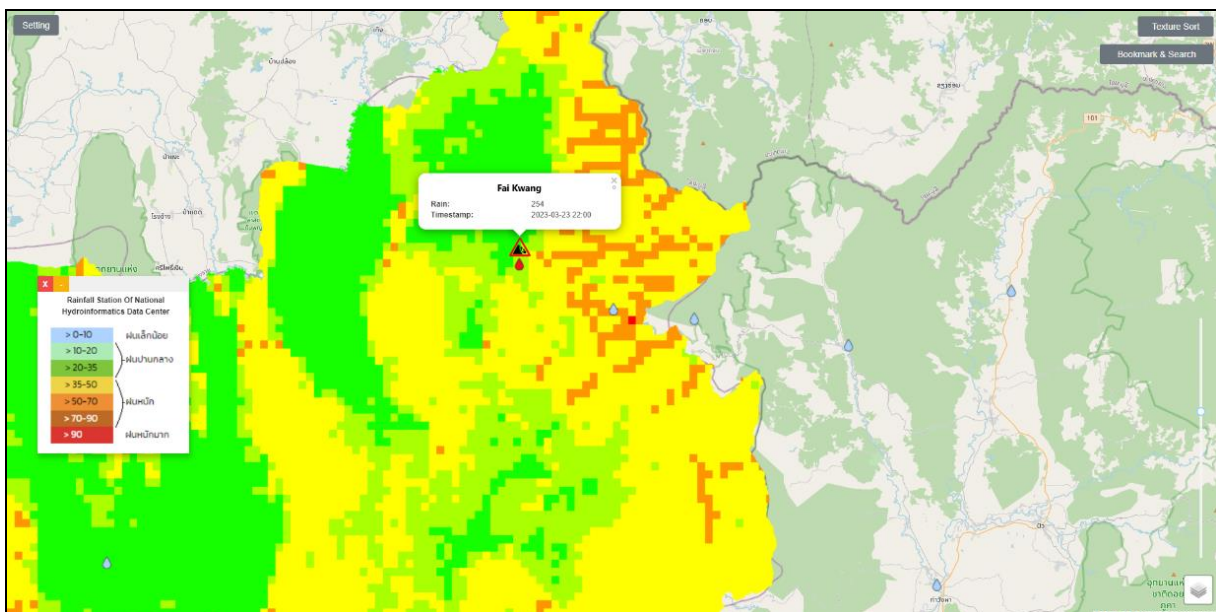
The LandSAGE software alerts its user of a landslide risk by displaying a warning triangular icon above an NHC rainfall station.