Technical Report

in supporting for modelling and development of risk maps in Lao PDR

Implemented by:

Integrated Water Resources Management and Ecosystem based Adaptation in Xe BangHieng River basin and Luangprabang City

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Executive Summary

Introduction

This project addresses climate change-induced flood and drought risks in the Xe Bang Hieng (XBH) River Basin, focusing on the integration of climate vulnerability assessments and hydrological models. By producing high-resolution hazard maps and evaluating community vulnerabilities, we identified risks at district and community levels. The approach builds on the efforts of MONRE, DMH, and FAO, building upon existing knowledge and incorporating best practices. In addition to this report, deliverables include a detailed methodology, calibration reports, draft risk maps, GIS-based maps, and training materials.

The Xe Bang Hieng River Basin, covering 19,600 km² in Savannakhet province, is crucial for Lao PDR's agriculture and food security. Despite significant forest coverage, deforestation and unsustainable practices threaten water security and agricultural productivity. The province is highly vulnerable to climate hazards, with recent floods and droughts causing extensive damage. Long-term projections indicate increased temperature and rainfall, exacerbating these risks.

Methodological Framework

The project employed the IPCC AR6 risk assessment framework, focusing on modeling hazards, mapping elements, assessing exposure, defining vulnerability, and calculating impacts. The methodology, consistent across different scales, integrates quantitative assessments of hazards, assets, exposure, and vulnerability.

The flood hazard mapping improved and employed existing hydrological (SWAT) and hydrodynamic (HEC-RAS) models to simulate rainfall-runoff and flood scenarios, integrating data from local and satellite sources. The models were recalibrated to enhance their accuracy, resulting in the development of flood maps for various return periods. These maps highlighted areas requiring additional data collection and infrastructure improvements. For the drought hazard assessment, the focus was on meteorological drought using the CHIRPS dataset to analyse rainfall deficiency. This included evaluating consecutive dry days and utilizing the Standardized Precipitation Index (SPI) to assess drought impacts at both district and village levels.

Asset, exposure, vulnerability, and risk mapping involved using Bing Maps and OpenStreetMap to map infrastructure and identify other facilities, such as health, education, and other service provision facilities, which was supplemented by field data. Agricultural areas were extracted from the ESA WorldCover data. Exposure mapping identified elements at risk within flood-prone areas, incorporating population data and hazard scenarios to estimate potential impacts. This comprehensive approach enabled a detailed understanding of the regions' risks to natural hazards and informs potential strategies for mitigation and adaptation.

Results

Flood Hazard:

Flood hazard maps were generated for 2, 10, 50, and 100-year return periods. With the 50-year return period simulation the 2019 flood event in the region. The western part of Savannakhet is particularly vulnerable, with frequent flooding of the Xe Bang Hieng and Xe Champhone rivers during the rainy season. The low-lying topography and insufficient flood management infrastructure exacerbate the impact on agriculture, infrastructure, and local communities.

Drought Hazard:

Drought analysis, based on consecutive dry days and Standardized Precipitation Index (SPI), revealed some variation between western flood plains and eastern upper catchment areas. The western flood plains experience more severe dry conditions when assessing a 6 month drought, while the eastern upper catchment seems more impacted by drought over a shorter 3 month periods. The differences in drought conditions are relatively minor however as it is a regional phenomena and the assessment is based on meteorological drought. The observed differences however highlight the need for tailored drought management strategies across the region.

Exposure:

Flood exposure analysis at different return period events identified the assets at risk, including dwellings and schools in villages like Dong Mueng, Kaeng Donh, Phia Kao, and Song Khon Tai. The number of exposed assets increases with the severity of the flooding event, and the analysis revealed that real storm events influence the distribution and impact of exposure differently across the basin.

Vulnerability:

Physical vulnerability assessments focused on infrastructure and agriculture. Infrastructure damage was estimated using damage curves based on flood height. Agricultural vulnerability was assessed using simplified damage curves for floods and international literature-based curves for droughts, focusing on crop damage over a 6-month period.

Risk:

The overall results indicate that the western region of the basin faces both higher flood and drought risks. However, a closer examination of the study's limitations provides a more nuanced perspective. While fluvial flood risk is indeed higher in the western area of the basin, the upstream areas are more vulnerable to flash floods, which were not assessed due to limitations in the model coverage. Drought risks at an administrative level are also higher in the west due to more intensive agriculture. On a household level, however, the impact is likely comparable across the basin.

This report highlights the areas at risk across the Xe Bang Hieng river basin and underscores the critical need for improved flood and drought management strategies tailored to the specific vulnerabilities of different regions within the basin.

1 Introduction

The study area, covering Savannakhet province of Laos, has been historically prone to natural disasters such as floods. Notably, the devastating flooding events of 2019, exacerbated by Tropical Cyclone Podul and Tropical Depression Kajiki, underscore the region's vulnerability to extreme weather phenomena. These events resulted in significant human and infrastructure losses, including fatalities, displacements, and extensive damage to critical facilities and agricultural lands. Such occurrences highlight the urgent need for comprehensive flood risk mapping and monitoring systems to enhance preparedness and response capabilities. By understanding the spatial distribution and temporal dynamics of flooding hazards, stakeholders can implement targeted mitigation strategies and resilient infrastructure development to safeguard communities and promote sustainable development in the face of future climate uncertainties.

For this project, we have formulated a well-defined methodology for mapping flood and drought risks induced by climate change. This involves the integration of bottom-up assessments of climate vulnerability and adaptive capacity in targeted communities, utilizing existing hydrological models, climate change projections, and data on planned upstream dam developments. By considering these factors, we ensured a thorough assessment of risk zones at both district and community levels.

To meet the specifications, we generated high-resolution flood and drought hazard maps, detailed land-use maps and identified the different infrastructure assets. This level of precision enhances the efficacy for pinpointing and addressing specific areas at risk. Additionally, we underscore the importance of evaluating community vulnerability, ensuring that the risk maps accurately reflect the unique challenges faced by local communities in the Xe Bang Hieng (XBH) River Basin.

The approach has drawn upon analogous and supporting efforts undertaken by organizations such as the Ministry of Natural Resources and Environment (MONRE) the Department of Meteorology and Hydrology (DMH) and the FAO, highlighting our commitment to building upon existing knowledge and incorporating best practices. This strategy not only enhances the accuracy and reliability of the risk maps but also fosters collaboration and knowledge-sharing among stakeholders.

At the end of the project, the following deliverables were presented to the client:

- A methodology for climate-change induced flood and drought risk mapping, reported in English and Lao.
- Brief calibration report on the existing hydrodynamic model for the Xe Bang Hieng River Basin including field data needs, to be drafted in English and Lao.
- Presentation of draft risk maps at a stakeholder workshop;
- Full set of GIS based maps in pdf and digital formats
- All training materials developed.

2 Context

The Xe Bang Hieng river basin encompasses a catchment area of 19,600 km², predominantly spanning Savannakhet province, where the river flows westward before converging with the Mekong at Khemarat. Within the meandering downstream stretch of Xe Bang Hieng, notable features include the Keng Done and Keng Tangane falls (Figure 1). Significant tributaries such as Xe Champhone and Xe Xangxoy join the main river through the Xe Noy, approximately 15 km upstream of Reng Done.

The province of Savannakhet is in the southern part of the country and is the largest province in Laos. It borders Khammouane province to the north, Quảng Trị and Thừa Thiên–Huế provinces of Vietnam to the east, Salavan province to the south, and Nakhon Phanom and Mukdahan provinces of Thailand to the west. The Second Thai–Lao Friendship Bridge over the Mekong River connects Mukdahan province in Thailand with Savannakhet in Laos. Its capital, Savannakhet, also known as Kaysone Phomvihane or Muang Khanthabouly is Laos' second largest city after Vientiane. It forms an important trading post between Thailand and Vietnam.

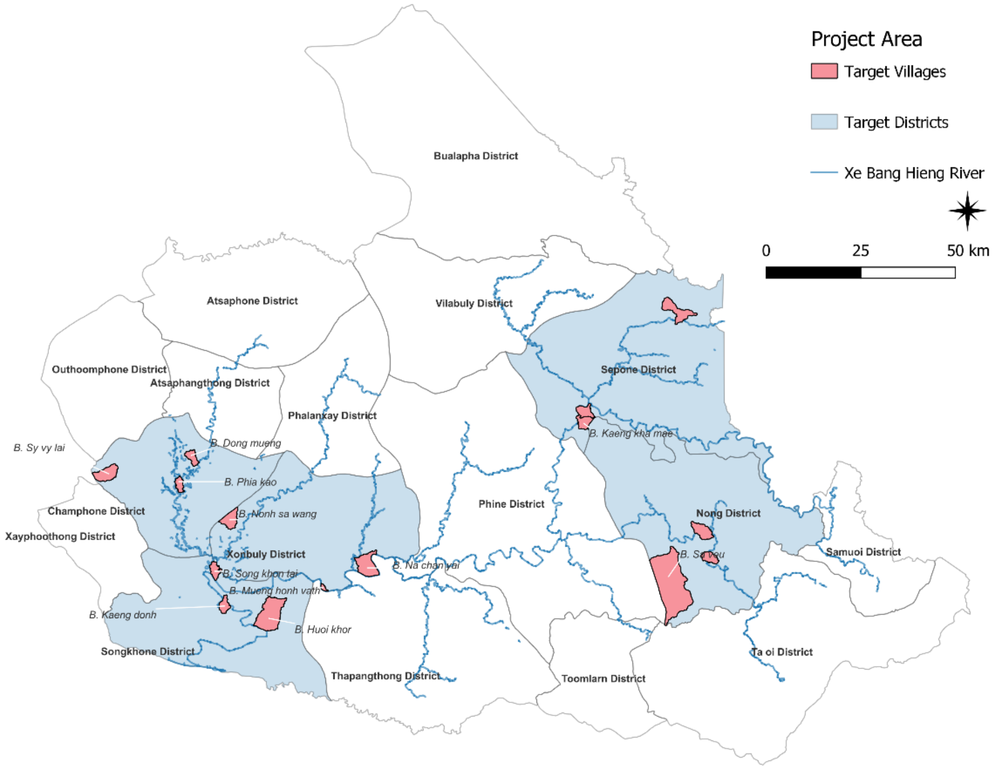


Figure 1: Study area focused on the Xe Bang Hieng River basin and the target districts and villages

The Xe Bang Hieng River, a key watercourse in the basin, serves as a tributary to the Mekong River. Originating on the western side of the Annamite Range, it meets the Mekong near Savannakhet city at an elevation of 110 meters above sea level. In the Xe Bang Hieng basin, flooding primarily occurs during the southwest monsoon season, spanning from May to September. Two distinct types of floods impact the study area:

- Seasonal floods from the Mekong River, directly affecting the Xe Bang Hieng Flat plain.
- Flash floods originating from main tributaries, notably Xe Bang Hieng, Xe Bangfai, Xe Champhone, and others.

Savannakhet Province, situated in the central region of Lao PDR, is the country's largest and most populous province, hosting over a million people. The majority, more than 75%, reside in rural areas, relying on subsistence agriculture in small villages. The province's significance lies in its connection to the Xe Bang Hieng river basin, particularly the lowlands' crucial agriculture. These areas contribute approximately 25% of the rice consumed in Lao PDR, playing a pivotal role in the nation's food security.

Despite Savannakhet's considerable forest coverage, reaching about 75% of the province, the headwaters of the Xe Bang Hieng River face deforestation and degradation due to unsustainable farming practices.[1] This negatively impacts water retention, livestock grazing areas, and the supply of non-timber forest products (NTFPs), leading to decreased water security and agricultural productivity. Additionally, the province faces challenges from concessions granted for commercial agriculture and forestry, contributing to forest clearing and limiting community access to vital resources. [2]

Communities within the Xe Bang Hieng river basin are particularly vulnerable to climate hazards, such as floods (Figure 2) and droughts. Notable floods in recent years, such as those in 2017, 2018, and 2019, resulted in significant economic losses, displacement of populations, and damage to infrastructure. Savannakhet is also identified as the most vulnerable province to drought in Lao PDR, impacting water resources, agriculture, and overall food security.[3]

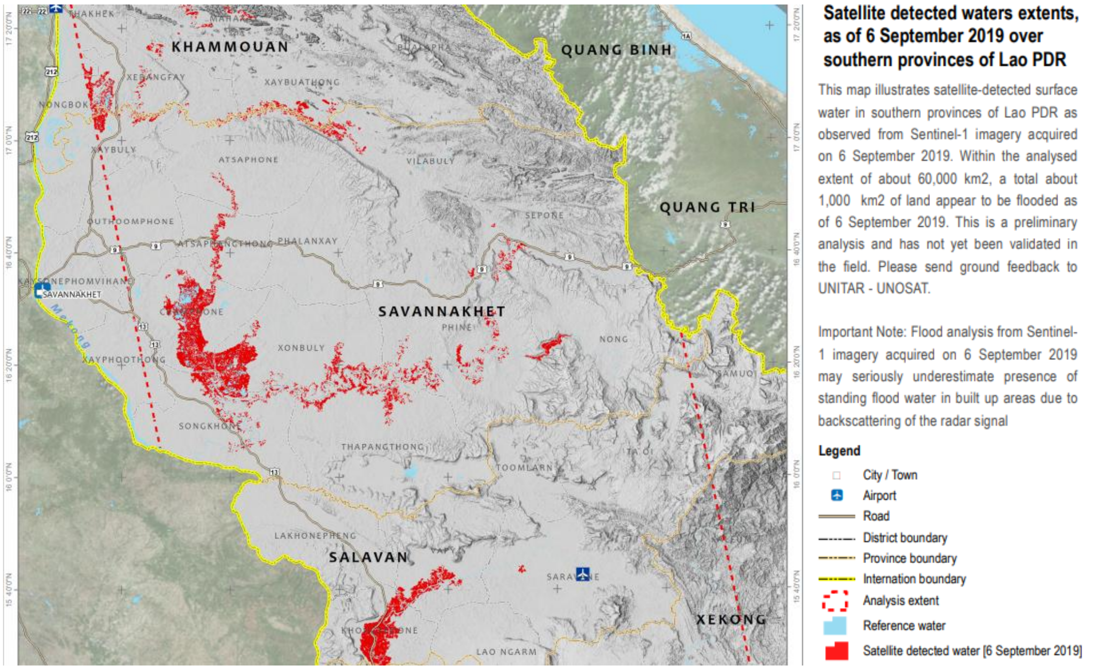


Figure 2: The extent of flooding in Savannakhet Province in August/September 2019[4]

Projections for the Xe Bang Hieng river basin over the long term indicate an anticipated warming of approximately 1.7°C by the year 2050, coupled with a projected rise in annual average rainfall by about 21%.[5] These local forecasts, in conjunction with national and regional assessments, suggest an escalation in the intensity of both droughts and floods within the Xe Bang Hieng river basin. The lowland regions of the basin have already faced significant flooding, rendering them susceptible to more severe inundations under future climate conditions. Communities residing in the basin's headwaters face heightened vulnerability to increasingly intense droughts, further exacerbated by

[1] Andriesse E, Phommalath A. 2012. Provincial Poverty Dynamics in Lao PDR: A Case Study of Savannakhet. Journal of Current Southeast Asian Affairs 31(3): 3-27. https://doi.org/10.1177/186810341203100301
[2] GEF ProDoc – IWRM and EbA in the Xe Bang Hieng River Basin and Luan Prabang City
[3] National Disaster Management Committee, Government of Lao (GoL) and UNDP. 2010. National Risk Profile of Lao PDR.
[4] United Nations Institute for Training and Research. 2019. Satellite detected waters extents as of 6 September 2019 over southern provinces of Lao PDR.
[5] Department of Disaster Management and Climate Change, MoNRE, Lao PDR, 2016, Report on the Historical Climate Change, Climate Vulnerability and Climate Change Projection for Lao PDR

local land degradation and deforestation. The anticipated impacts of both droughts and floods include: i) damage to crops and grazing lands; ii) loss of or harm to livestock; iii) increased prevalence of crop and livestock pests and diseases; iv) diminished water security; and v) exacerbated land degradation due to heightened soil erosion. Additionally, the prospect of more unpredictable rainfall patterns amplifies the risk of crop failure for farmers.

The project has focused on 15 targeted villages for the field visits and risk mapping (Table 1, Figure 1):

Table 1 Target villages for the field visit and risk mapping

Village name	Village name	Village name
Syvylai village	Nachanhyai village	Kaenghuapa village
Dongmueng village	Songkhone village	Sopsalou village
Phiakia village	Kaengdon village	Nongvilai village
Nonhsawang village	Houikhor village	TangAlai village
Meuanghonh village	Kaengthamae village	Saveu village

3 Methodology

3.1 Methodological framework

The IPCC (Intergovernmental Panel on Climate Change) Sixth Assessment Report (AR6) introduces a comprehensive risk assessment framework to evaluate the impacts of climate change (Figure 3). This framework is designed to integrate multiple dimensions of risk, including the likelihood of different outcomes, the severity of impacts, and the vulnerabilities of various systems and populations. The risk mapping approach used in the project is derived from this framework and can be split into 5 parts:

- Modeling the hazards
- Mapping the elements
- Assessing the exposure
- Defining the vulnerability
- Calculating the impact

The risk maps were produced on the scale of the districts and target villages in the Xe Bang Hien river basin. The methodology is the same for the different scales. However, more information about the impacts are highlighted at the village level since it includes the results from the field work.

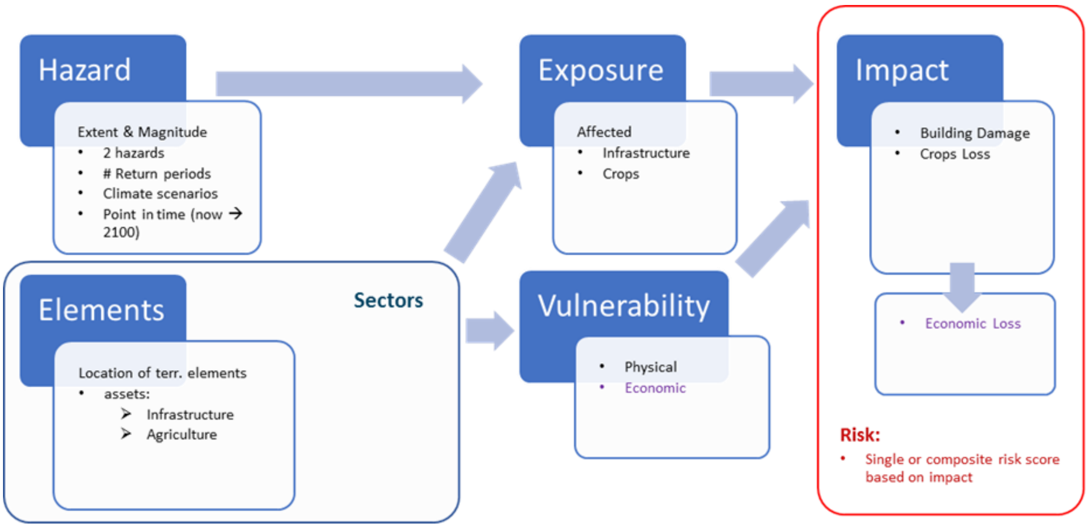


Figure 3: Overview of the risk mapping method

The method entails a quantitative assessment based on input data for the hazards, elements and vulnerabilities. For example for flooding answers were developed to the questions:

- Does is flood in location X? (hazard)
- Where are all the assets? (elements)
- Is there an asset in location X? (exposure)
- What is the damage the asset in location X might have linked to the severity of the flooding? (vulnerability)
- What is the damage to the asset in location X? (impact)
- What is the monetary value of the asset in location X?
- What is the relative cost of the damage to the asset in location X? (impact)

3.2 Flood Hazard Mapping

The flood hazard mapping was done using the existing hydrological and hydrodynamic models developed for the basin. In total there are two types of model used in the Xe Bang Hien (XBH) river basin by the government. First is the hydrological SWAT (Soil & Water Assessment Tool) model, which covers the whole basin. The model provides the rainfall-runoff of the XBH and its tributaries. Second is a Hydrodynamic model (HEC-RAS) which covered the main floodplain area.

3.2.1 Developing Storm Events

3.2.1.1 Current Climate

The development of storm events for return periods of 2, 10, 50, and 100 years involved analyzing historical rainfall data and using the Gumbel distribution for extreme value analysis. For the 2, 10, and 50-year return periods, we examined 50 years of maximum daily rainfall data to identify significant storms and their frequency. This historical analysis included calculating the mean and standard deviation of the annual maximum rainfall, fitting the data to the Gumbel distribution, and using this to estimate the intensity of past storms. The 100-year return period storm (T100) was modeled using the Gumbel distribution to predict the intensity of an extreme storm event likely to occur once in 100 years. This statistical method involved estimating the location and scale parameters of the Gumbel distribution and calculating the rainfall amount corresponding to the 100-year return period using the Gumbel cumulative distribution function.

- T2: Historical storm
    - from 19/08/2000 to 10/10/2000
- T10: Historical storm
    - 05/09/2013 to 12/11/2013
- T50: : Historical storm
    - 11/08/2019 to 31/10/2019
- T100: Synthetic storm

For each return period, with 2, 10 and 50 based on historical data, and T100 based on an extreme value analysis, we designed a storm event to simulate realistic conditions by analyzing rainfall patterns for the lead-up, peak, and end phases of each storm. This approach ensured an accurate representation of how water builds up and recedes in the basin during extreme weather events, crucial for flood modeling. The spatial distribution of rainfall was also considered, with historical storms showing specific characteristics, such as the T2 storm being concentrated in the northern part of the basin and the T10 storm being more dispersed.

3.2.1.2 Future Climate

For the future climate the 2, 10, 50 and 100 year return periods were developed for the RCP 8.5 scenario for 2050. The precipitation dataset used (daily maximum rainfall) was developed by MoNRE in 2016 as part of the national Climate Change Projection for Lao PDR. The dataset, spanning 2021-2050 (Figure 16), was used to develop a design storm for each return period in the same way as described above for the T100 current climate storm.

3.2.2 Hydrological Model

The Soil and Water Assessment Tool (SWAT), developed by the United States Department of Agriculture (USDA), is a widely used hydrological model designed to evaluate the impact of land management practices on water quantity and quality in watersheds. For the Xe Bang Hieng (XBH) basin, SWAT provides essential rainfall-runoff data, covering the entire basin. Figure 4 shows the overview of the sub-catchments in the SWAT model of the study area.

Figure 4: Overview of the sub-catchments in the SWAT model of the study area

3.2.2.1 Data Used:

The existing SWAT model that was used for the hydrological modeling was updated in this project through new/additional datasets and recalibration. If new data was included it is indicated below.

Rainfall Data:

- Local stations: Precipitation data available from the Mekong River Commission (MRC) and Department of Meteorology and Hydrology (DMH) from 1999 until 2008 at Daily resolution in mm.
- *Updated model* – Virtual rainfall stations prepared for higher altitude areas based on Satellite Data (Global Precipitation Measurement (GPM) by NASA). (Figure 5)

Climate Data:

- Daily temperature (C°), relative humidity (%), solar radiation (MJ/m^2/d), and wind speed (m/s) were gathered from climate stations in Donghen, Seno, Saravan and Xepon. The data is available at MRC and DMH.

Topographic Data:

- DEM (30x30m) produced by NASA.

Land Use Data:

- Forest and Land Cover 2010 dataset: Mekong River Commission (MRC).

Soil Data:

- Soil maps from the MRC, generated through field surveys and older map (1998) interpretations (scale 1:250,000).

Hydrometeo Data:

- Water level measurements from various stations converted using Q-H relationships (Figure 6).
- Available stations include Kengdone, Lahanam, M Chan, Nong, Phalanxai, Sopnam, and Kengkok.

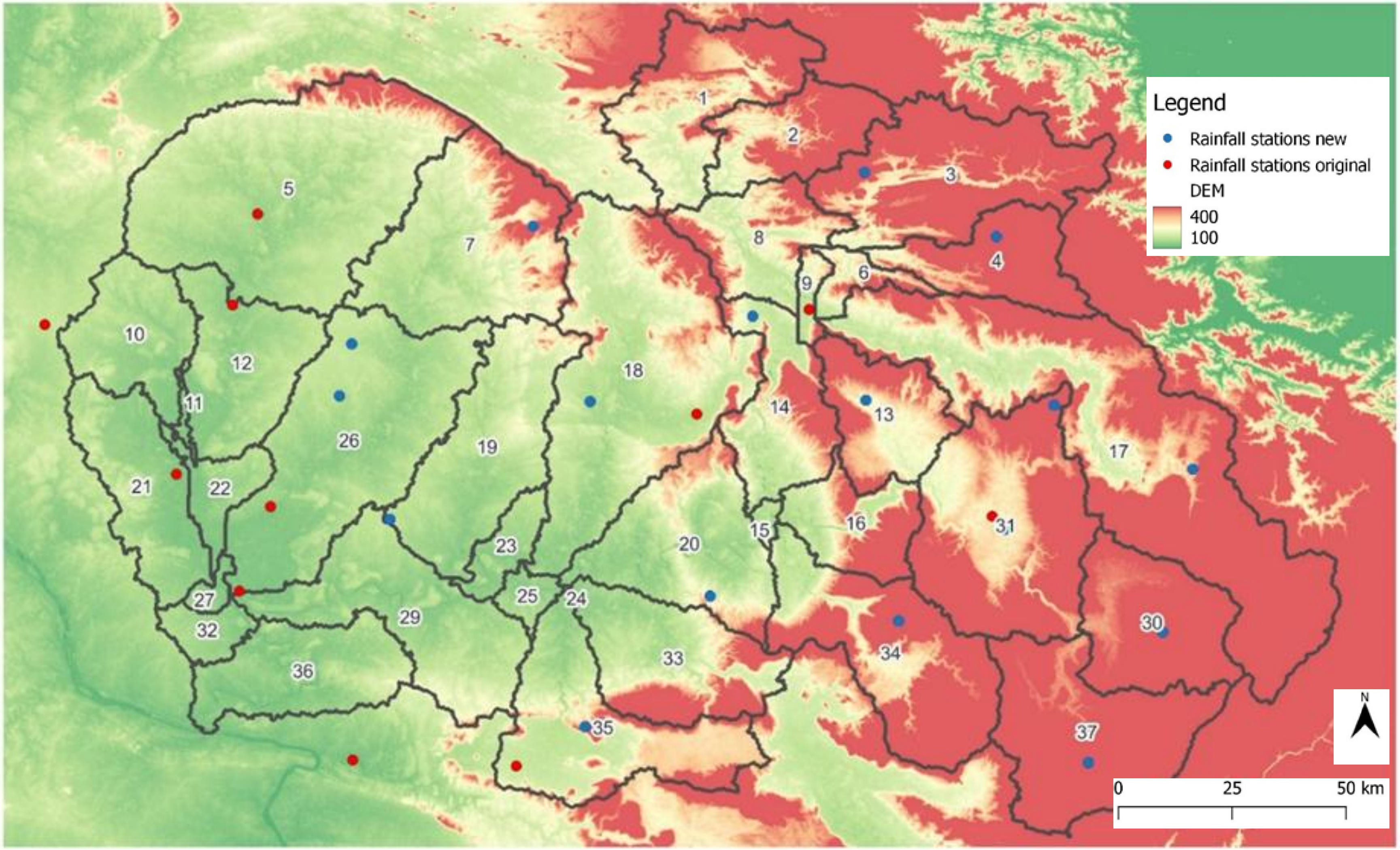


Figure 5: Comparison of locations of original and new (virtual) rainfall stations used in the SWAT model.

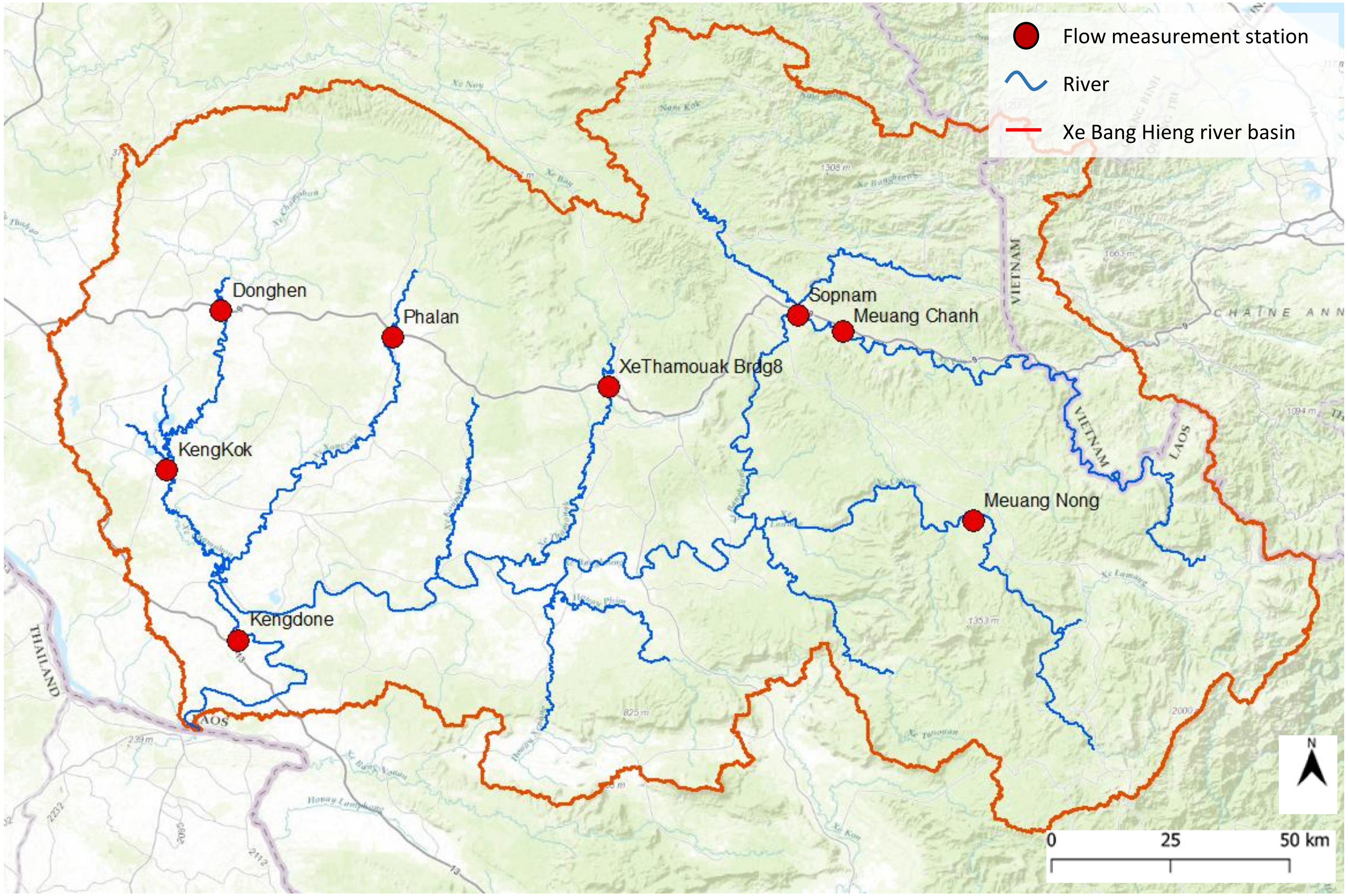


Figure 6 Flow measuring stations in Xe Bang Hieng basin.

3.2.2.2 Model Calibration:

The SWAT model was calibrated using the SUFI-2 program in SWAT-CUP, focusing on eight observation stations with available measurements (Figure 7). We used the observed flow data from 2000-2004 that was included in the existing model, to re-calibrate the model. SWAT is a hydrological model, it doesn't include detailed geographical info or cross sections to simulate precise water levels (they are not calculated). The output (flow/discharge) is be used as a boundary condition in the HECRAS model, here water levels can be calculated for flood modelling. Calibration involved sensitivity analysis, validation, and uncertainty analysis, with a specific focus on high flow events to better represent peak flows. Despite several calibration iterations, challenges remained in accurately simulating the highest streamflow peaks. In order to solve this new 'virtual' rainfall stations were developed based on the use of satellite rainfall data as shown in Figure 5. Together with these new stations adjustments in model parameters resulted in a much more accurate representation of the hydrology in the basin, including the peak flows.

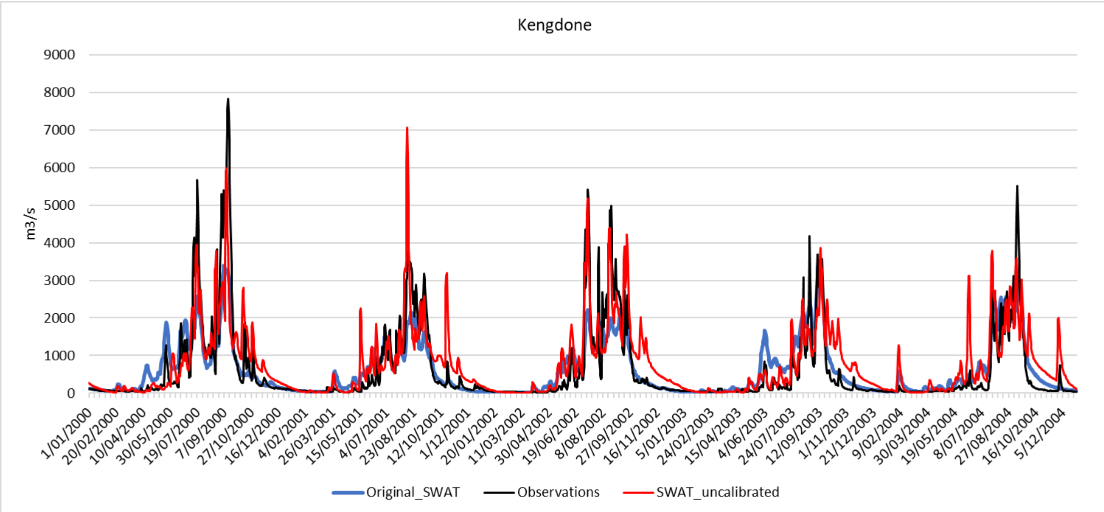


Figure 7: Comparison flow at Kengdone of new SWAT model (still uncalibrated) to observations and original SWAT model.

3.2.3 Hydrodynamic Model

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) model is a hydrodynamic tool used for floodplain mapping in the XBH basin. It incorporates detailed topographical data and river cross-sections to simulate flood scenarios under different return periods. Figure 8 shows the overview of the existing HEC-RAS model extent.

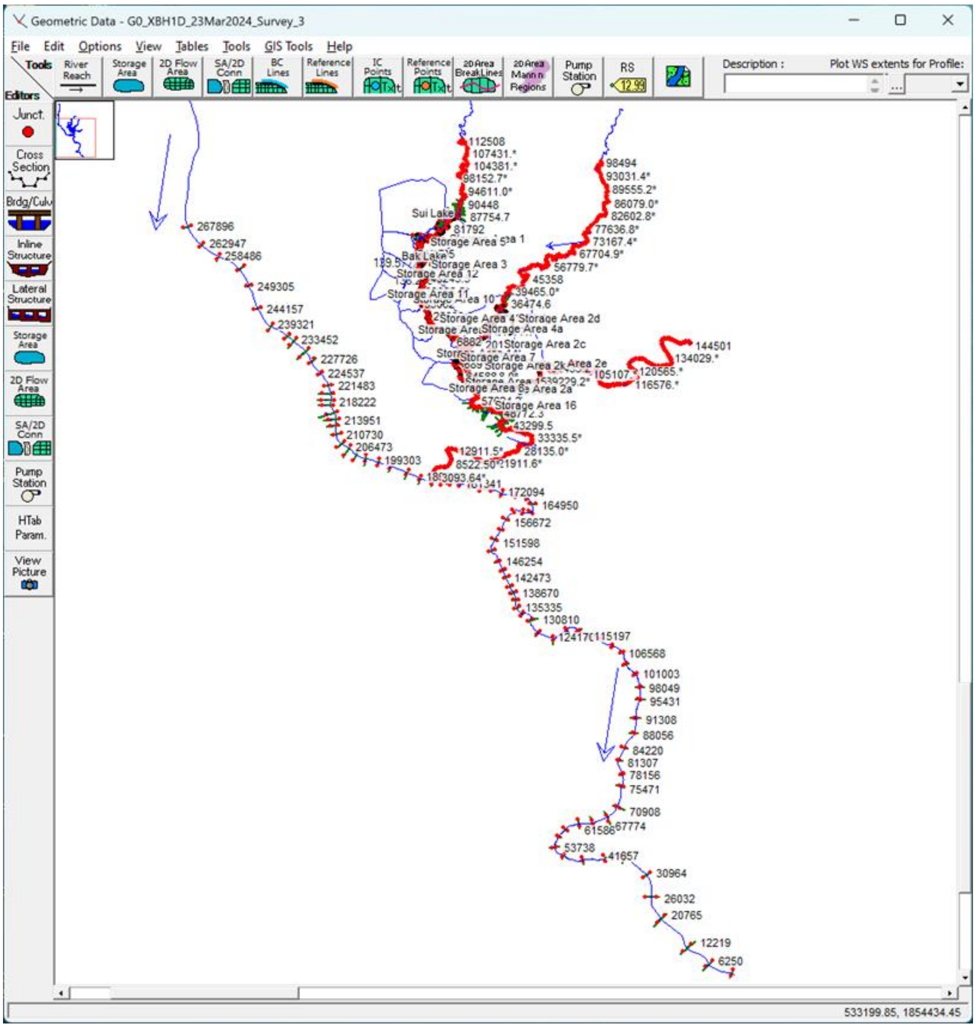


Figure 8: Overview of the existing HEC-RAS model extent and cross sections.

3.2.3.1 Data Used:

Topographical Data:

- DEM (10x10m) derived from contour lines obtained through drone surveys.

River Cross-Sections:

- Surveyed data and theoretical cross-sections for the Mekong River.Model

Boundary conditions:

- Outflow data from the SWAT model, flow and water level of the Mekong at Savannakhet and Pakse.

Calibration:

- Water levels updated using new gauge stations at Kengkok and Kengdon.

3.2.3.2 Calibration:

The HEC-RAS model calibration focused on aligning simulated flood extents with observed data, taking into account the improved inflow data (1985-2022) from the updated SWAT model and new zero gauge surveys from Kengkok and Kengdon. Calibration faced challenges in the original model due to outdated zero gauge levels and changes in the floodplain's physical conditions, such as new irrigation canals and infrastructure. To improve the model the storage area based on the irrigation canals and roads was improved and the newly surveyed zero gauges were used to update the water level data for the calibration. The resulting modeled flows give a good representation of the actual measured flows as shown in Figure 9. The model provided a comprehensive set of flood maps for current and future climate scenarios and return periods of 2, 10, 50 and 100 years.

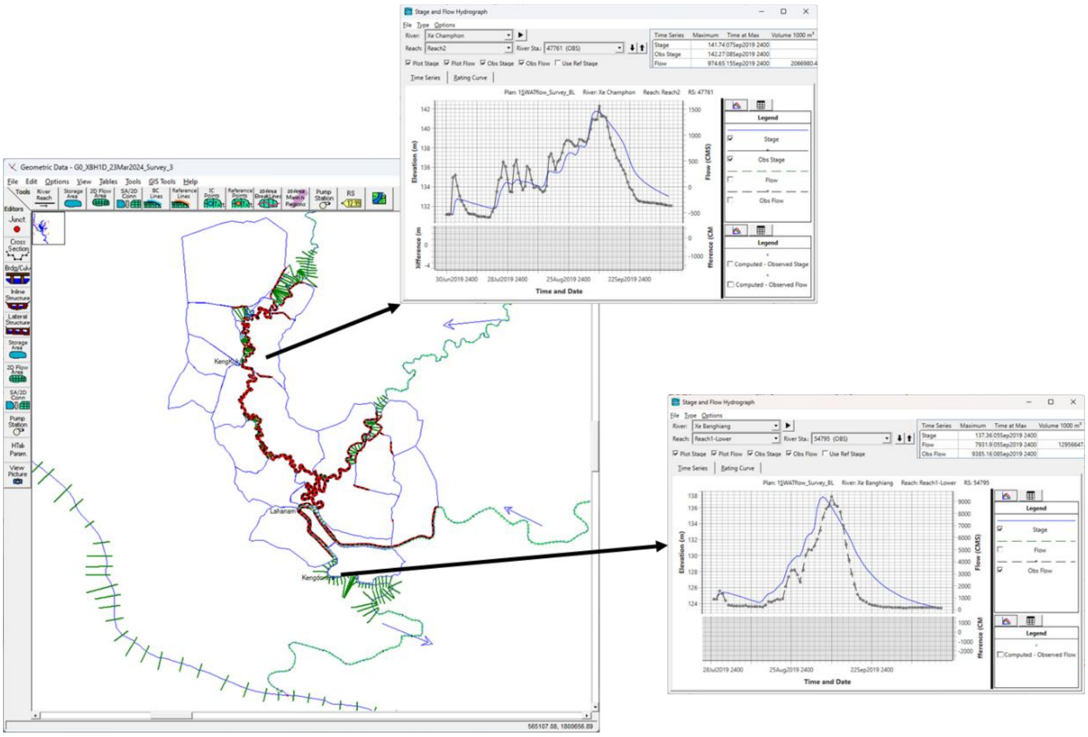


Figure 9: Stage Hydrograph and station locations (Blue = Stage, Black = Observed Stage)

3.2.4 Remote sensing

The flood modeling was limited to the boundary of the HEC-RAS model. This covers the floodplain and main flood areas in the basin, but it makes it impossible to include flooding information for the upstream catchment. Because the T2, T10 and T50 scenarios are based on historical storms we analyzed the Sentinel 1 and 2 satellite images to see if the flood extended beyond the HEC-RAS model Boundaries and whether we could improve the coverage of the flood extend (Figure 10).

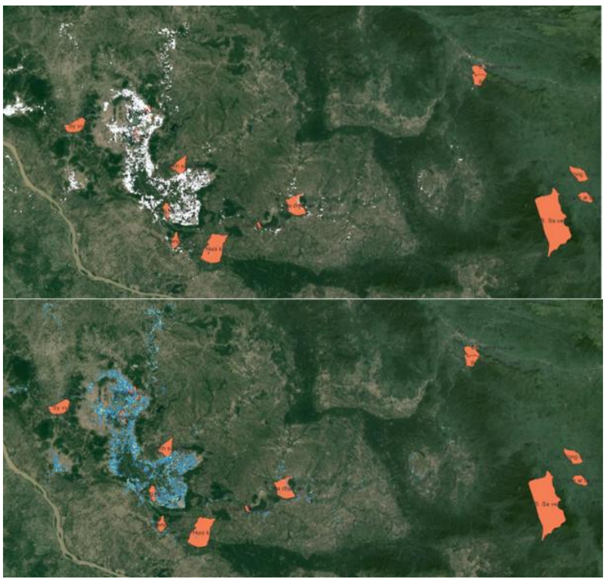


Figure 10 (above) GloFAS flood extend, (below) turned into flood depth using FwDET

The T50 scenario, which is based on the 2019 flooding event, is well captured in the satellite images. As a result we were able to use it to validate the flood extend, and after finding that the extend is a good match, extract the additional flooded areas outside the HEC-RAS model boundary, calculate the flood depth, and merge it to the modeled T50 flood map, extending it's coverage.

3.2.5 Refinement of Models

3.2.5.1 Implemented Improvements:

- Calibration Enhancements: Continued iterations with SWAT-CUP and focused calibration on high flow events.
- Data Integration: Adoption of GPM satellite rainfall data for better spatial coverage and accuracy.
- Model Adjustments: New SWAT model setup using unified soil types and improved rainfall data.
- Validation: Comparison of model outputs with satellite imagery for validation of flood extents.
- New zero gauge of Kengkok and Kengdon for water levels in the HEC-RAS model.
- Extension of the flooding area covered in the HEC-RAS model for the 50 year return period based on observed flooding through remote sensed Sentinel images (Global Flood Awareness System) (Figure 11).

3.2.5.2 Suggested Improvements:

- Model Expansion: Extend HEC-RAS coverage to the entire project area, not just the floodplain.
- If the coverage of the HEC-RAS model is extended, develop additional flash-flood scenario's to capture flooding events in the villages in the upstream catchment.
- Survey Updates: Conduct new river cross-section and topographical surveys to reflect current conditions.
- Checks: Update model calibrations using newly surveyed water levels for more extreme events to assess how well the model performs in these situations.
- Infrastructure Inclusion: Incorporate new infrastructure changes in the floodplain to better simulate current conditions.
- Enhanced Data Usage: Use additional remote sensing data to fill gaps in flood mapping and improve overall model accuracy.
- Hydromet Statioins: Currently, all existing monitoring stations are located at lower elevations, which contributed to an underestimation of precipitation at higher altitudes. We propose the construction of additional stations at higher altitudes through the basin for better coverage.
- Climate projections: The current dataset with climate projections for 2050 is a little outdated and has a rather course resolution. New climate projections should be developed for 2050 and 2100 at a higher resolution

By addressing these limitations and implementing suggested improvements, the reliability and accuracy of flood risk assessments in the XBH basin can be enhanced, especially for the upstream villages.

3.3 Drought Hazard Mapping

The definitions of drought vary depending on context, reflecting regional differences, specific needs, and disciplinary backgrounds. These definitions can be categorized into meteorological, agricultural, hydrological, socioeconomic, and more recently, ecological droughts (Figure 11). The National Drought Mitigation Center (NDMC) in the USA provides a comprehensive summary of these drought types:

- **Meteorological drought** is defined usually on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.
- **Agricultural drought** links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity.
- **Hydrological drought** is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with and are delayed w.r.t. the occurrence of meteorological and agricultural droughts.
- **Socioeconomic drought** occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts.
- A more recent effort focuses on **ecological drought** defined as "a prolonged and widespread deficit in naturally available water supplies — including changes in natural and managed hydrology — that create multiple stresses across ecosystems."

Figure 11 provides an overview of how these drought types are interconnected, highlighting their relation to vulnerable assets at risk. Note how all of these are related to the perceived assets at risk and, hence, their respective vulnerabilities. The distinction in different drought types actually relates to the vulnerability of the exposed assets.

Meteorological drought formed the basis for this hazard assessment. Agricultural drought would be an even more apt option, however, based on our understanding, there aren’t enough groundwater level & soil-moisture timeseries available to implement a detailed (grid-based) data-assimilation on coupled soil-moisture content and groundwater level. Hence, the focus on meteorological drought and therefore rainfall deficiency.

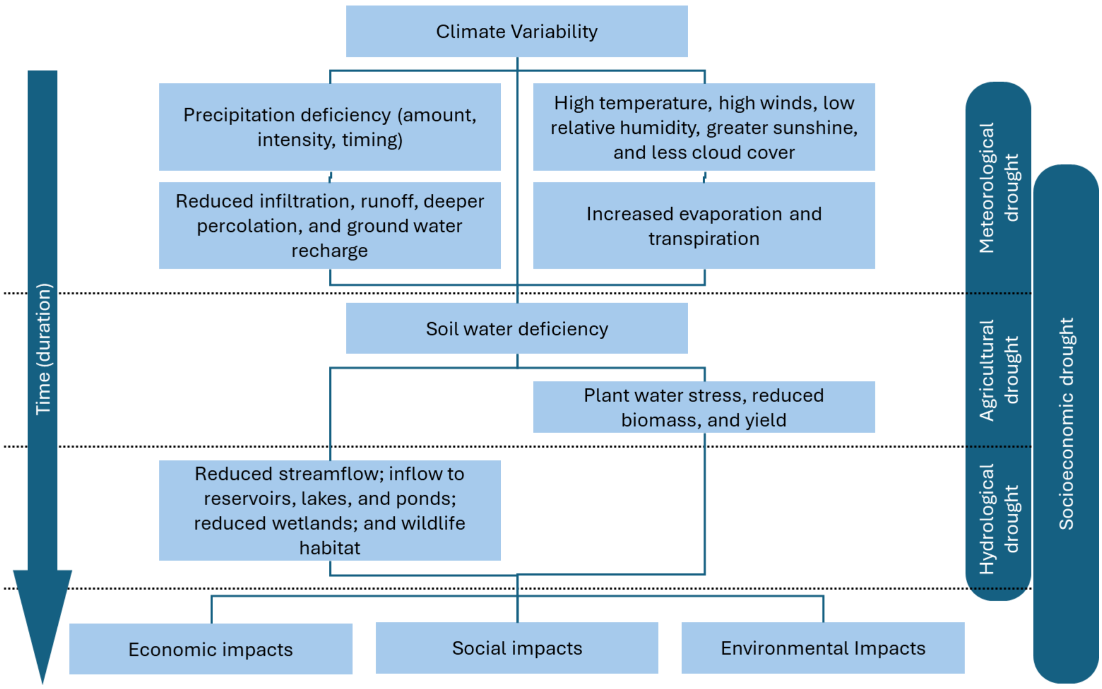


Figure 11 How different types of drought are connected[6].

3.3.1 Developing Drought Events

3.3.1.1 Current Climate

Drought events were analyzed for 5, 10, 50, and 100-year return periods using extreme value analysis on a hydrometeorological gridded dataset. To achieve this, the daily rainfall dataset was transformed into two types of drought datasets, as detailed in sections 3.3.3 and 3.3.4. This involved calculating the maximum dry spell per year and the Standardized Precipitation Index (SPI) for 3-month, 6-month, and 1-year periods.

The calculated dry spells and SPI values from the historical dataset were then subjected to extreme value analysis using the Gumbel distribution for the dry spells and a normal distribution for the SPI values. This process enabled the determination of drought events for the specified return periods.

3.3.1.2 Future Climate

The same process was performed for the future climate but with the climate projection precipitation dataset developed by MoNRE in 2016.

3.3.2 Input Data

With the primary focus being on meteorological drought, specifically rainfall deficiency, the CHIRPS Dataset (Climate Hazards Group InfraRed Precipitation with Station data) was used for current historical and current scenarios. This dataset is developed by the Climate Hazards Group at the University of California. The CHIRPS dataset:

- Integrates satellite imagery and ground station data for accurate precipitation estimates.
- Covers the period from 1981 to the present, making it ideal for historical climate analysis and current weather pattern monitoring.

[6] Venton P, Venton CC, Limones N, Ward C, Pischke F, Engle N, Wijnen M, Talbi A. 2019. Framework for the assessment of benefits of action/cost of inaction (BACI) for drought preparedness.

- Suitable for drought monitoring and forecasting, assessing water availability over long time ranges.

An additional analysis on climate projections provided insights into how drought hazards might change in the future. For future scenarios the project rainfall data - RCP85 was used.

The assessment represents drought through two key variables: consecutive dry days and the Standardized Precipitation Index (SPI).

3.3.3 Consecutive Dry Days:

Measures the duration of dry spells in number of days, indicating regions prone to extended periods without rainfall. Consecutive Dry Days were assessed for return periods of 5, 10, 50, and 100 years.

3.3.4 Standardized Precipitation Index (SPI):

SPI quantifies precipitation deficits relative to local climate, allowing for comparisons across different climatic regions (Table 2). The SPI was created to investigate the precipitation deficit over different timescales and could be used to assess not only meteorological drought, but also agricultural- and hydrological drought[7] (WMO, 2012). Therefore, the index is calculated using accumulation periods of 3 months, 6 months and 1 year.

- Standardized to determine drought rarity and classify drought intensities based on systems such as McKee et al. (1993)[8].
- Calculated for accumulation periods of 3 months, 6 months, and 1 year to reflect relevance for agricultural practices.
- It is classified into seven classes (Table 2)

Table 2 Classification of the SPI Index (McKee et al., 1993)

SPI index	Description
2.00 and above	extremely wet
1.50 to 1.99	very wet
1.00 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.00 to -1.49	moderately dry
-1.50 to -1.99	severely dry
-2.00 and below	extremely dry

Drought hazards were mapped at district and village levels to provide detailed local insights. By focusing on rainfall deficiency through consecutive dry days and SPI, this assessment provides a comprehensive understanding of drought hazards in the Xe Bang Hieng basin, aiding in better drought preparedness and management.

[7] Svoboda M, Hayes M, Wood D. 2012. Standardized precipitation index: user guide.
[8] McKee TB, Doesken NJ, Kleist J. 1993. The relationship of drought frequency and duration to time scales. InProceedings of the 8th Conference on Applied Climatology 17 (22): 179-183.

3.4 Asset, exposure, vulnerability and risk mapping

3.4.1 Asset mapping

The pursuit of effective urban planning and resource management, accurate asset mapping is important. This was done using a methodology tailored to gather, optimize, and analyze building footprints alongside associated amenities for spatial asset mapping. Leveraging data from Bing Maps and OpenStreetMap (OSM), our approach integrates these data sources to improve dataset quality (Figure 12).

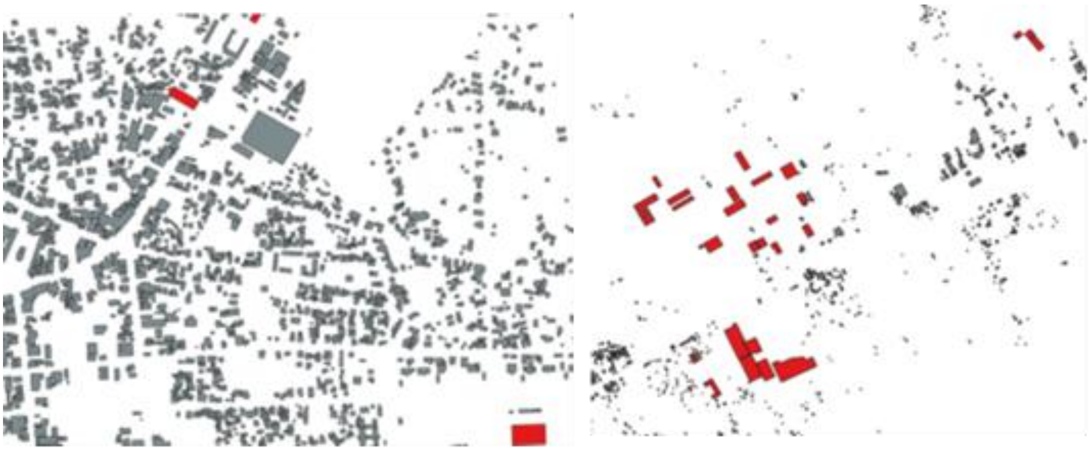


Figure 12 Building Footprints extracted from Microsoft Bing (Grey) and OSM (Red).

The desk-based assessment produced 2 asset maps (Figure 13).

- One indicating the locations of all the infrastructure (where available with information on the type of building (dwelling, school, hospital etc.)
- One indicating the locations of agricultural areas.

Data was collected from fieldwork to supplement this information.

For Infrastructure:

- Validating the locations of important infrastructure (schools, hospitals, police stations, etc.)
- Supplementing this information to the asset map (if a building is a police station, but this is not indicated based on the desktop asset mapping then it can be added.
- Collecting information on the price of these different assets. (what is the price to construct a dwelling, police station, etc.?). This price was converted to USD/m^2 and applied when calculating the damage and cost.

The data was presented at both district/basin and village scales. At the district/basin scale, asset mapping was performed based on the information obtained from OSM and Microsoft Bing. Building footprints from both sources were merged, with overlaps removed. Building function assignments were conducted using buffering and proximity logic to ensure accurate representation. A similar procedure was followed at the village scale, where amenities and infrastructure information obtained from fieldwork were used to assign building functions. During the fieldwork names/functions of critical buildings (such as schools, health centres, etc) were collected at village level and added to the asset maps.

Figure 13 Example of the asset mapping of B. Kaeng donh village.

For agriculture:

For agricultural asset mapping, we initially considered using the Lao national land use map, obtained from Mekong River Commission. But due to its limitation in accuracy and completeness in spatial coverage, we used the ESA World Cover map, which offers a fine resolution of 10x10 meters and comprehensive coverage of the entire region and its coverage. Unfortunately, no information on the types of crops that are grown is available in a geospatial dataset. To supplement this, we conducted a statistical analysis using agricultural census data (census of 2022) to determine crop fractions, thereby enriching our understanding of local agricultural practices beyond what the geospatial datasets could provide (Table 7-Annex 4). The provincial data available from the 2022 agricultural census was the highest administrative resolution and includes information on the main crop types and the number of hectares where they are grown. By using the ESA WorldCover land use map to define the areas where agriculture is practiced and combining this with the fractions of different agricultural crops that are grown in Savannakhet, the agricultural land is mapped and the crop types are statistically assigned to the administrative areas. This does not provide information on the exact location of for example a rice field, but it allows for an assessment of exposure that gains accuracy at a lower resolution. Table 1Table 3 and Figure 14 present the distribution of cropland per districted calculated from the ESA WorldCover data.

Table 3 Cropland distribution per district-extracted from ESA WorldCover data.

Districts	Area (ha)
Champhone District	50266.82
Nong District	8498.85
Sepone District	13159.67
Songkhone District	48509.81
Xonbuly District	29368.43
Total	**149803.58**

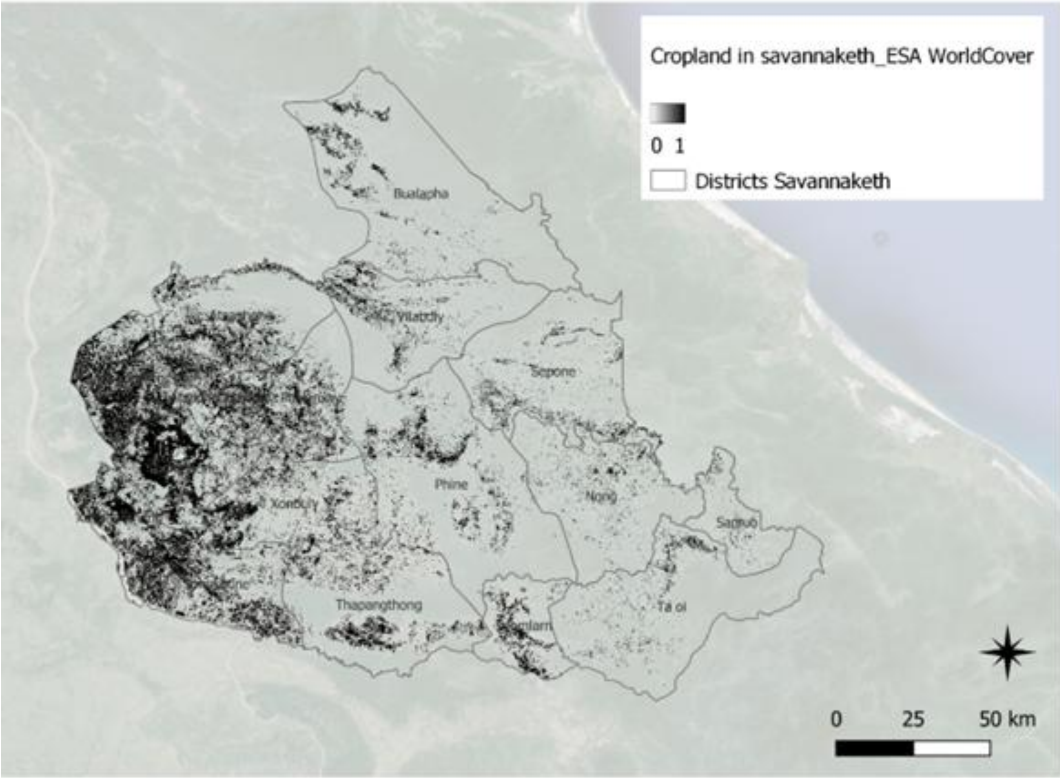


Figure 14 Cropland in the Savannakhet basin based on ESA World Cover

3.4.2 Exposure mapping

The exposure mapping for flood hazards involves identifying and visualizing the elements at risk within a flood-prone area. This involves identification of all people and assets that are exposed to hazardous events. This consists of all elements mapped during the asset mapping that fall within the extent of the hazardous events. Different hazard maps were developed in relation to each hazard for different scenarios from which exposure datasets were derived.

Based on the asset mapping, a statistical analysis was done for estimating the location of the exposed population. This is done by looking at the population numbers in the population census data of Laos (census of 2015), matching it with the number of mapped dwellings per district, and developing an estimation of the number of people in each dwelling. This results in an estimation of the number of people exposed to the floods.

3.4.3 Vulnerability mapping

The vulnerability assessment for infrastructure and agricultural assets focused on physical vulnerability. Socio-economic vulnerability was also assessed qualitatively through fieldwork, evaluating community preparedness and response capacity. To evaluate the risk of flooding in the districts and villages outside the flood model domain, extensive fieldwork was conducted. This fieldwork aimed to gather qualitative data on past flash flood events and assess the level of risk in these areas. During the visits, information was collected from the communities about the frequency and impact of flooding in the upper catchment villages. However, the actual risk assessment for these villages was not conducted due to insufficient data available for a reliable quantitative analysis. Instead, the fieldwork provided a qualitative indication of flooding occurrences and community suggestions on increasing their adaptive capacity. Future extensions of the HEC-RAS flood model or the inclusion of another flood model capable of assessing flash flood hazards would be necessary to conduct a detailed risk analysis.

- Physical vulnerability: The likelihood of physical elements being damaged or destroyed by climate hazards. For example, unpaved roads are more susceptible to flood damage than paved roads.
- Socio-economic vulnerability: The combination of socio-economic factors that make a population less capable of managing climate-related risks.

3.4.3.1 Physical Vulnerability

Physical vulnerability was assessed using ***damage functions***, which establish a mathematical relationship between hazard intensity (e.g., flood height) and expected damage (Figure 15). These functions, developed from fieldwork data, relate the repair cost to the total replacement cost for various infrastructure and agricultural assets.

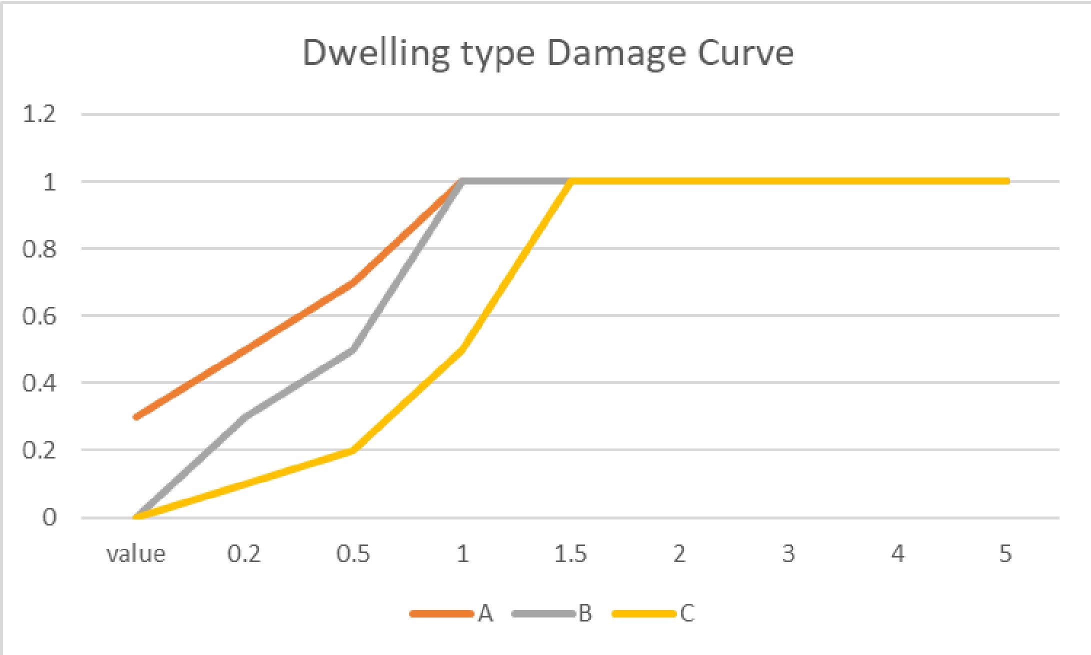


Figure 15 Buildings – Flood Damage Functions developed with the villagers during the fieldwork for different building types based on the census data-2015 (construction materials used)

Infrastructure: Fieldwork data were collected to estimate damage based on flood heights, with different damage percentages assigned to various flood levels. A table of asset types, informed by housing census data (2015) on building materials at the district level, is created to categorize and analyze infrastructure vulnerability. These methods were globally applied at all scales – basin, district and village levels.

Agriculture: Damage curves were used to assess agricultural vulnerability to both floods and droughts. For flooding, a simplified damage curve with a threshold value of 0.5 meters is applied. For drought, damage curves are based on Standardized Precipitation Index (SPI) values over a 3-month period, using international literature to focus on crop damage in tropical climates. The damage curves were globally used for vulnerability assessment of the agricultural sector at all scales, particularly basin, district, and village levels.

3.4.3.2 Socio-economic vulnerability

A qualitative assessment is developed based on fieldwork to evaluate community preparedness and response strategies to climate hazards, specifically flooding and drought. This assessment examines the knowledge and expertise of villagers regarding warning signals, evacuation procedures, loss reduction actions, and adaptation practices. The assessment also includes proposing potential adaptation interventions to local partners for feedback.

3.5 Impact and Risk mapping

Impact and risk levels were developed based on hazard, exposure, and vulnerability data. The direct impact of a flood or drought on an asset was calculated by combining the severity of the hazard, the vulnerability of the asset, and the estimated asset value. This cost was then aggregated at the village or district level.

3.5.1 Infrastructure Flood Impact

Monetary data for infrastructure assets were collected during fieldwork. Values were assigned to most assets based on unit measurements (area for buildings, distance for line assets). These values were converted into costs incurred due to a flood event using damage curves.

3.5.2 Population Flood Impact

Population impact was assessed by linking exposure mapping to flood heights and infrastructure exposure and impacts. For example, the expected damage to buildings from a 2-meter flood height was used to estimate potential casualties, assuming no effective warning and evacuation practices.

3.5.3 Flood Risk

The flood risk score was derived from potential casualties and damage costs. First, the maximum casualties and damage costs were computed and normalized to a 0-1 scale. The Risk Score was then calculated by averaging the normalized casualties and damage costs. This score reflects the combined impact of flooding on potential casualties and damage costs, providing a framework for evaluating and managing flood risk.

3.5.4 Drought Risk and Agricultural Impact

For agriculture, total cropping area per village was derived using the ESA WorldCover map. The SPI drought hazard mapping was applied to each cell, attributing relevant SPI values based on periods of 90 and 180 days of window and return periods of 5, 10, 50, and 100 years. Agricultural vulnerability data from international literature was used to determine potential crop losses. Crop types and their distribution were derived from the Agricultural census (2022). The average price per hectare was estimated from fieldwork data. Using these values, the cost incurred per village due to drought was estimated. The drought risk in relation to agriculture was mapped, showing the varying impacts across different villages.

4 Result and Discussion

4.1 Climate scenarios

4.1.1 Rainfall trends

Figure 16 shows the timeseries plots of both the CHIRPS (current scenarios) and RCP85 (future scenario) rainfall datasets. We checked the temporal trends of the datasets using a linear regression model. The linear regression analysis of the CHIRPS dataset reveals a statistically significant but very modest positive trend in annual precipitation over time. Approximately 4.3% of the variability in annual precipitation is explained by the linear relationship with the year suggesting an estimated increase of 0.03 mm per year in annual precipitation while the linear regression analysis of the RCP85 dataset shows no significant trend in annual precipitation (pr) over time (year). Detailed figures (Figure 37 and Figure 38) with trend lines for both the CHIRPS and RCP85 datasets can be found in Annex 1, illustrating these temporal patterns graphically.

In contrast to the almost negligible change in annual precipitation, there is a significant predicted shift in seasonal precipitation patterns. According to the 2016 MoNRE Climate Change Projection report, longer dry seasons with decreased rainfall and shorter but more intense wet seasons featuring an increase in extreme events are expected to become the norm. This trend is also evident in Figure 16.

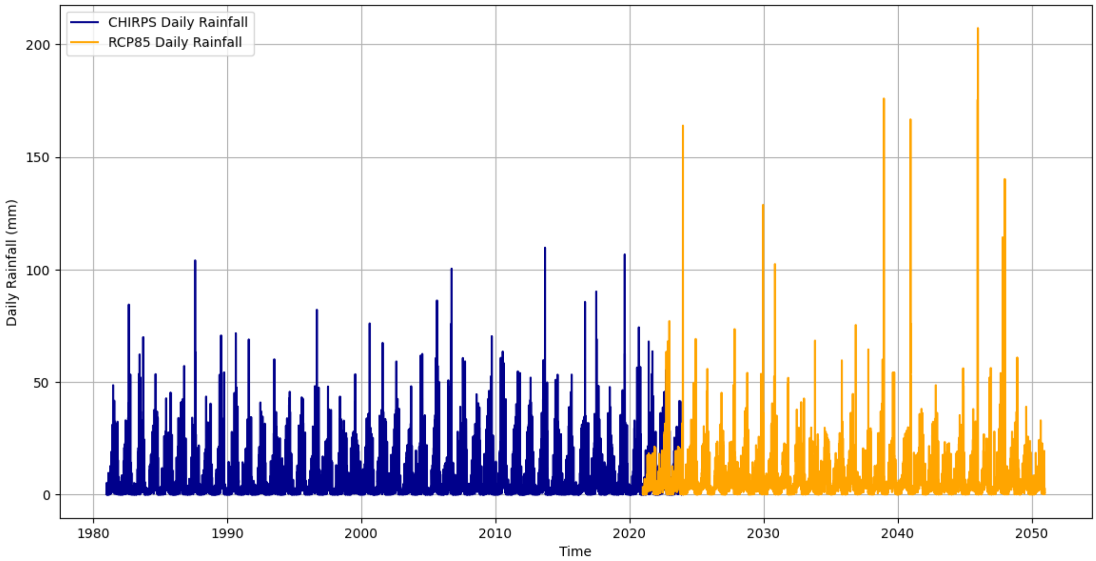


Figure 16 Temporal trend of historical (CHIRPS) and projected (RCP85) rainfall datasets for Laos

4.2 Flood hazard

4.2.1 Current scenario

Figure 17 and the figures in Annex 2 (Figure 39 Figure 42) give an overview of the flood hazard mapping results for 2, 10, 50 and 100 year return periods, respectively . For all return periods the flood mapping is limited by the coverage of the HEC-RAS model. Only the 50 year return period flood map covers a larger area due to the remote sensing exercise that was done to extend the area. This was possible because the RT50 map is based on the 2019 flooding event in the basin, of which there is satellite data available.

As the maps show, most of the flood prone areas are located in the western part of Savannakhet, particularly covering the Champhone, Xonbuly and Songkhone districts. These districts are notably affected by flooding, primarily due to their geographical and hydrological characteristics. These districts are traversed by several rivers, including the Xe Bang Hieng and Xe Champhone rivers, which are prone to overflow during the rainy season. The topography of this region is predominantly low-lying, making it more susceptible to water accumulation and flood events. During periods of heavy rainfall, the rivers capacity is often exceeded, leading to widespread inundation of the surrounding areas. Additionally, the lack of robust flood management infrastructure exacerbates the situation, resulting in significant impact on agriculture, infrastructure, and local communities.

The floods modelled here are fluvial floods caused by high rainfall throughout the catchment, including the upper catchment, that mainly impact the downstream floodplain. The basin also has different flood dynamics that this study was not able to cover due to the model restraints. During heavy peak rainfall events the upstream catchment also suffers from flash floods. It will then depend on the severity and duration of this event whether or not it also results into fluvial floods downstream.

4.2.2 Future scenario

Just like for the current climate the western part of Savannakhet, particularly the Champhone, Xonbuly, and Songkhone districts, remains notably affected. The predominantly low-lying topography, together with the presence of Xe Bang Hieng and Xe Champhone rivers, continues to make these areas susceptible to water accumulation and flood events.

Figure 17 and figures in Annex 2 (Figure 43 Figure 46) provide an overview of the projected flood hazard mapping results for 2, 10, 50, and 100-year return periods under the RCP8.5 scenario for the period 2021-2050. As the maps indicate, the projected flood-prone areas under the RCP8.5 scenario show a pattern different to the current situation, especially for the lower return periods the flood extend is indicated to be lower, contrary to the expectations. This can be attributed to the data that was used. The 2 and 10 year events for the current climate are based on historical events where the amount of rainfall was geographically more concentrated resulting in a larger flood for that area. The future events were more evenly distributed. The 50 and 100 year events however show results that are more in line with the expectations. The flood extend does not change that much as the flood basin is already nearly fully flooded, but the flood depth increases significantly.

4.2.3 Comparing the RT 50/2019 scenario

The current RT 50 scenario represents the 2019 flood, allowing for assessment and comparison with real-world experiences. During the validation workshop and training sessions in Savannakhet, both the extent and depth of the 50-year return period flood were validated. Given the severity of the 2019 flood, comparing it with future scenarios can provide insight into future expectations.

Figure 17 illustrates the flood depth map of the 2019 flood (current climate 50-year return period) compared to the 50-year return period scenario for the future climate. A visual comparison reveals significant differences, with the future RT 50 flood scenario appearing notably worse. This prompted a discussion during the training sessions about the return period of the 2019 flood under future climate conditions. An assessment of the extreme value analysis data revealed a troubling trend: the precipitation levels of the 2019 event resemble those of the 5- and 10-year return periods for future climate scenarios, varying by location. Figure 17 visually demonstrates that the 2019 flood depth and extent (current RT50) are only slightly worse than the future RT 10 scenario. Given the impact of the 2019 flood on the basin, these findings are alarming.

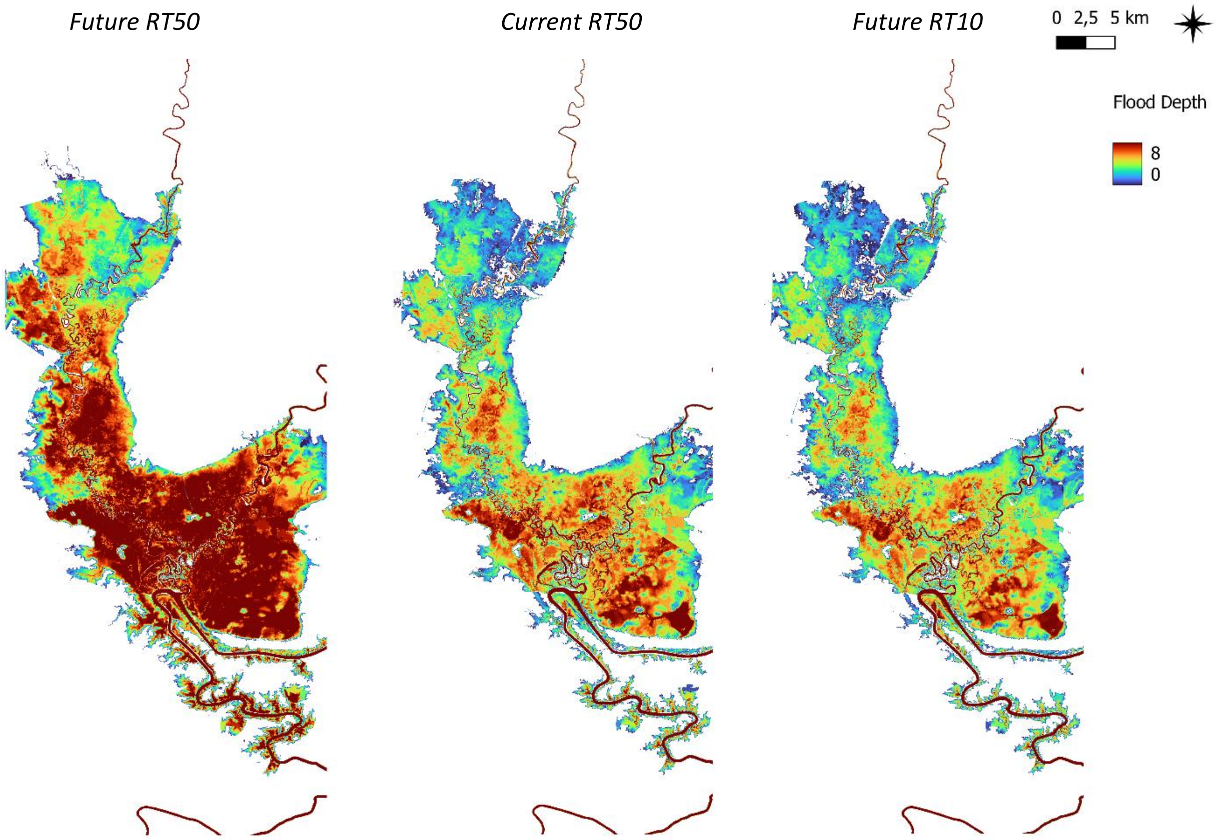
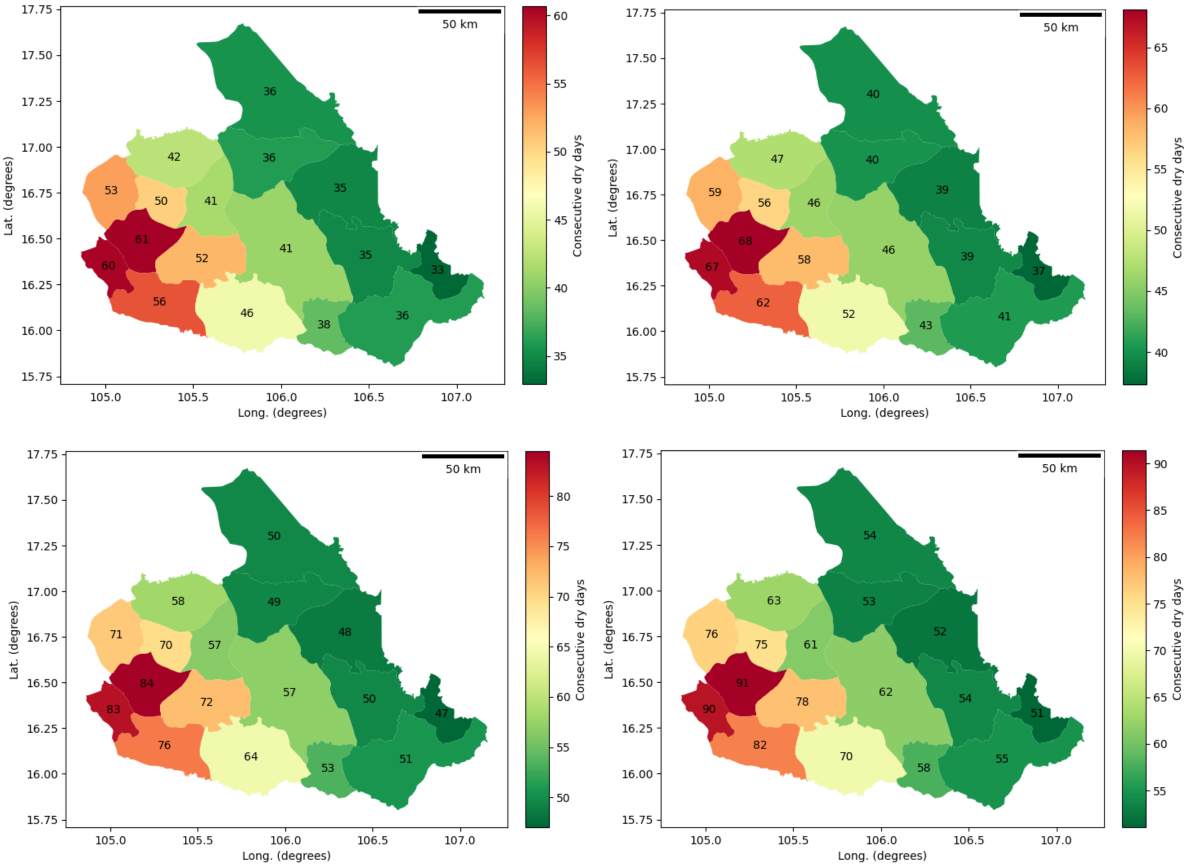


Figure 17: Comparison of the RT50/2019 flood event with the expected future climate events. Left: Future RT 50 (RCP85-2021-2050) Scenario, Middle: Current RT50 scenario. Right: Future RT 10 scenario. The map illustrates the flood extents for the 2019 event and the relevant return periods that it corresponds to, showing differences in inundation areas between the current and projected future climate scenarios.

4.3 Drought Hazard

4.3.1 Current Scenario

Comparing the consecutive dry days and SPI it clearly shows that the flood plains in the West are a lot more likely to have long periods without rainfall, it is likely however that these occur during the dry season, and though these extremes are significant, the SPI shows that they are less divergent from a regular year, compared the upper catchment in the East (


50 km
Consecutive dry days
Lat. (degrees)
Long. (degrees)
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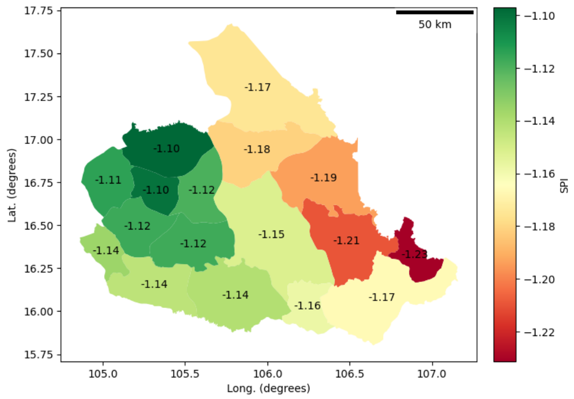
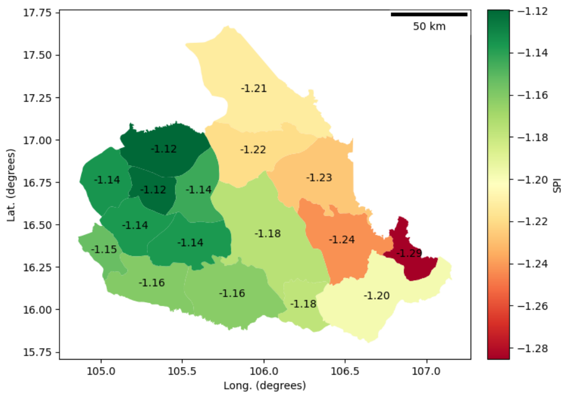
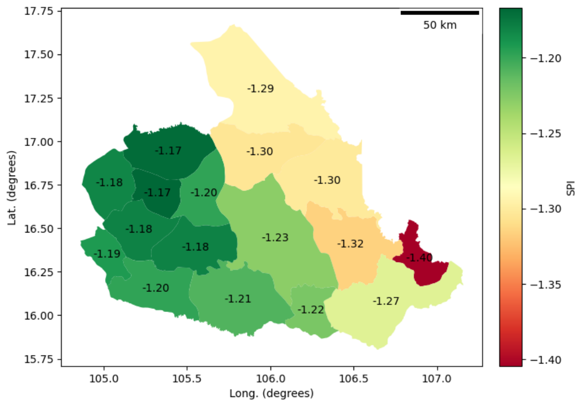


Figure 18 and





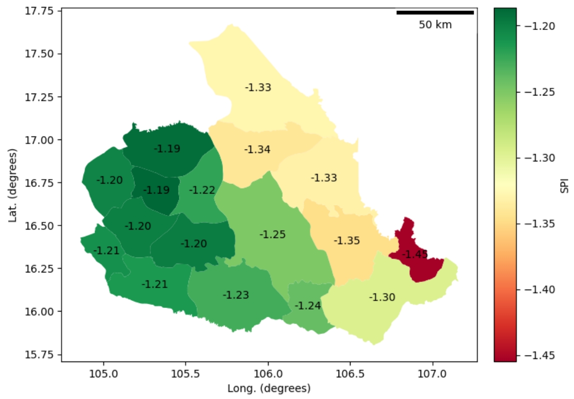


Figure 19). The SPI shows for a 3 month moving average shows a rainfall deficit indicating that the West is likely to suffer from moderately dry conditions, while the eastern part is more likely to face 'severely dry' conditions over a 3 month period.

The western flood plains experience long periods without rainfall, particularly during the dry season. While these periods are considerable, the SPI suggests that they are closer to normal variations in a regular year, implying only a moderate deviation from average conditions. In addition, because of the flood plains' proximity to major rivers the low-lying topography might still retain some moisture, mitigating the overall impact of drought during short dry spells.

In contrast, the upper catchment areas in the east are more likely to experience drought conditions for a three-month moving average. When considering the SPI for the 6 month period (Figure 20) however the special distribution of the drought severity changes. The longer 6 month drought period shows a more severe drought with lower SPI values throughout the basin, but in this case the western area where the flood basin is located is likely to experience a more severe drought. For a 1 in 100 year event for a 6 month period, the more severe drought seems to occur in the downstream areas of the catchment in the South-West (Figure 20). Note the SPI values however, to realize that the entire catchment faces extreme drought in this 1 in 100 year event, only the upper catchment seems to be affected a little less; -1.94 is very close to an extreme drought.

The contrast in drought conditions between the two landscapes implies the need for region-specific strategies to manage and mitigate the impacts of drought in the region.

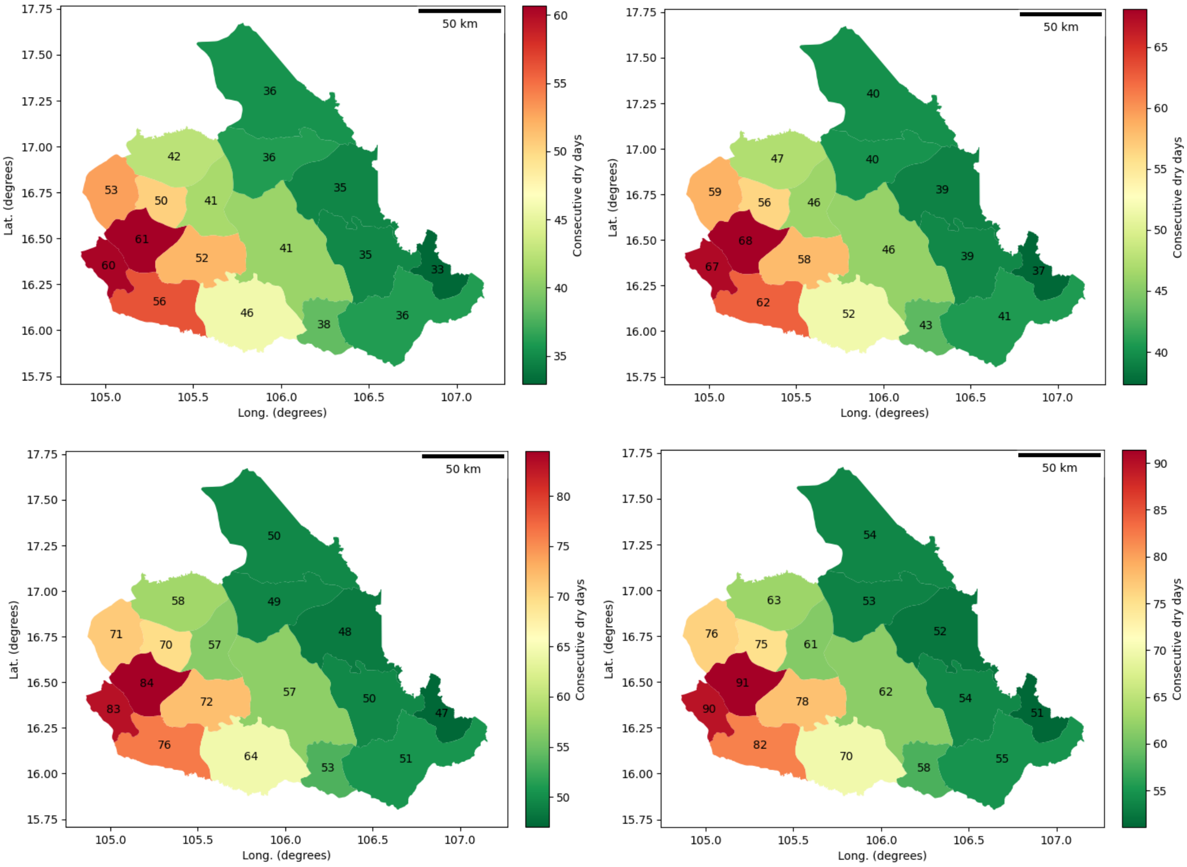


Figure 18 Consecutive Dry Days (Yearly mean per district): Return level (days) of a 1/5 year (Left top), 1/10 year (right top), 1/50 year (Left bottom) a 1/100 year (Right bottom)

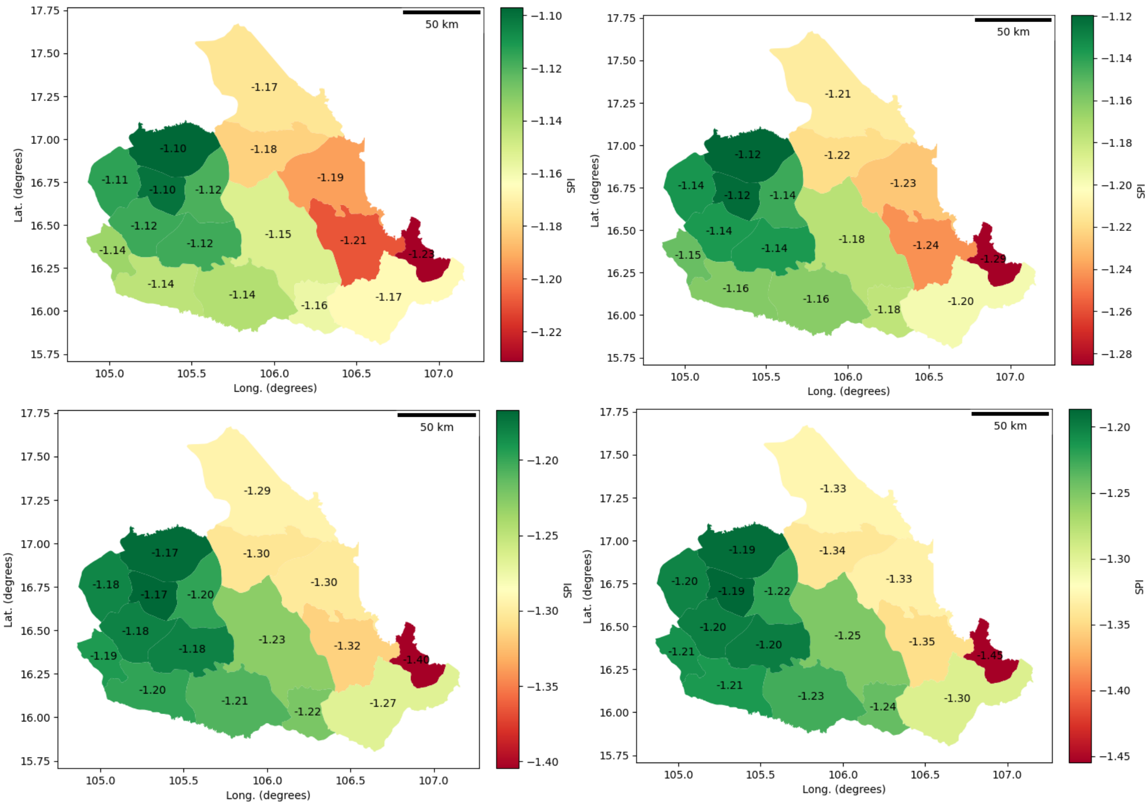


Figure 19: Drought Hazard maps giving the mean SP per district for a 3 month moving average with return period 1/5 (Left top), return period 1/10 (Right top), return period 1/50 (Left Bottom), return period 1/100 (Right Bottom).

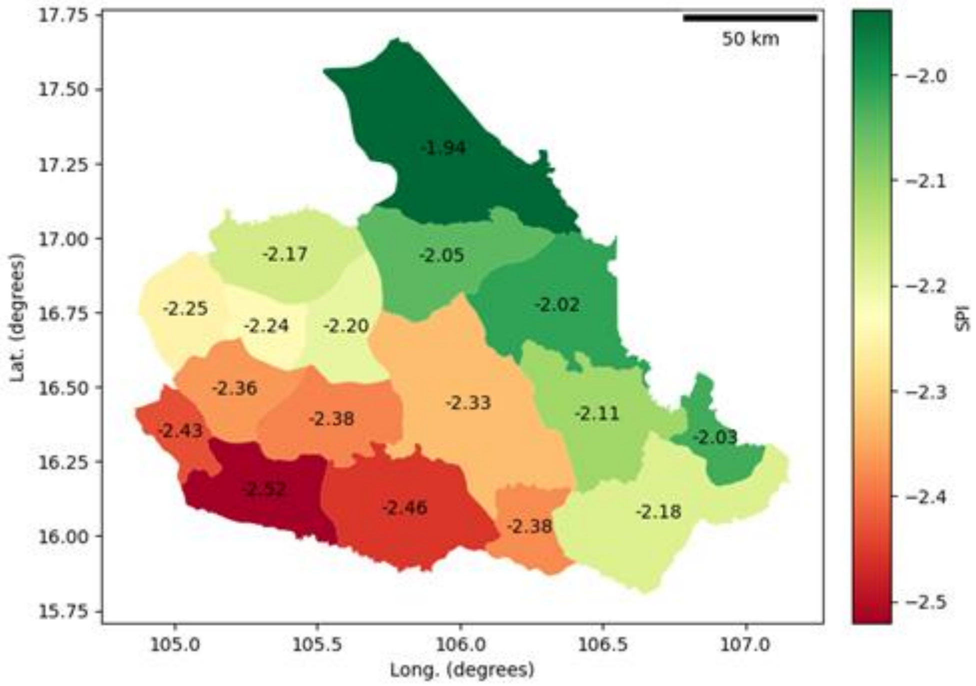


Figure 20: Drought Hazard map giving the mean SP per district for a 6 month moving average with return period 1/100.

A similar pattern of drought is observed when we map the drought at village level (Annex 3- Figure 47Figure 48). At 3 months moving average, the SPI at village level for a return period of 100 years depicts that the villages in the western part of the district experience more extreme drought conditions (Figure 21). Temporal variability further complicates the understanding of drought dynamics within the region. This suggests that regional climatic influences may contribute to differential impacts over longer time horizons. The observed patterns highlight the complex interplay of climatic and other factors in shaping drought dynamics.

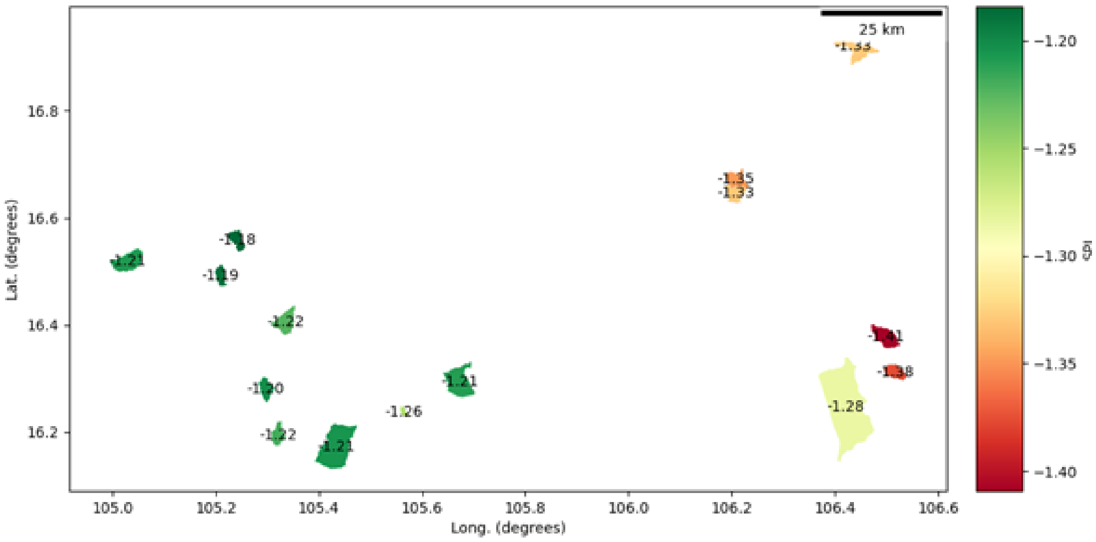


Figure 21 Example of the SPI on Village level for a return period of 100 years and a 3 month moving average.

Village	SPI
B. Dong mueng	-1.179
B. Huoi khor	-1.208
B. Kaeng hua pa	-1.326
B. Kaeng kha mae	-1.327
B. Mueng honh vath	-1.256
B. Na chan yai	-1.209
B. Nong vi lai	-1.413
B. Nonh sa wang	-2.443
B. Phia kao	-1.184
B. Sa veu	-1.350
B. Sopsalou	-1.351
B. Sy vy lai	-1.220
B. Tang ar lai neua	-1.383
B. Tha kham lien	-1.188

4.3.2 Future scenario

The analysis of the Standardized Precipitation Index (SPI) based on projected climate scenarios (RCP85) reveals significant fluctuations in extreme low precipitation values across districts, particularly for the 6-month period. This variability is crucial for understanding future drought conditions and their spatial distribution within the region (Figure 22, and Figure 49 in Annex 3).

Over a 90-day window and a 100-year return period, mean SPI values ranged from -1.21 to -1.46, showing minimal difference from the current climate scenario. However, the 6-month period (180-day window) exhibits a substantial change. For the current climate, the lowest SPI value of -2.52 was calculated for the 100-year event, whereas the future scenario predicts a significant worsening with the lowest SPI value at -3.11, and a very severe drought across the entire basin. Notably, there is considerable variability among districts, with the eastern regions projected to experience more extreme drought conditions within a three-month aggregation period, and the western regions facing worse droughts within a six-month period.

These findings show that the special distribution of drought is likely to remain similar in the future, and it underscore the spatial heterogeneity of drought conditions in the region, with certain districts projected to face more severe droughts compared to others in future scenarios. The observed spatial variation in drought can be attributed to diverse factors, including topographical features and biophysical characteristics of the districts. Consequently, these results highlight the necessity for targeted interventions and resource allocation strategies tailored to the specific drought conditions of each district. Understanding the temporal and spatial patterns of drought severity is essential for formulating effective drought resilience strategies, including water resource management, crop selection, and infrastructure development.

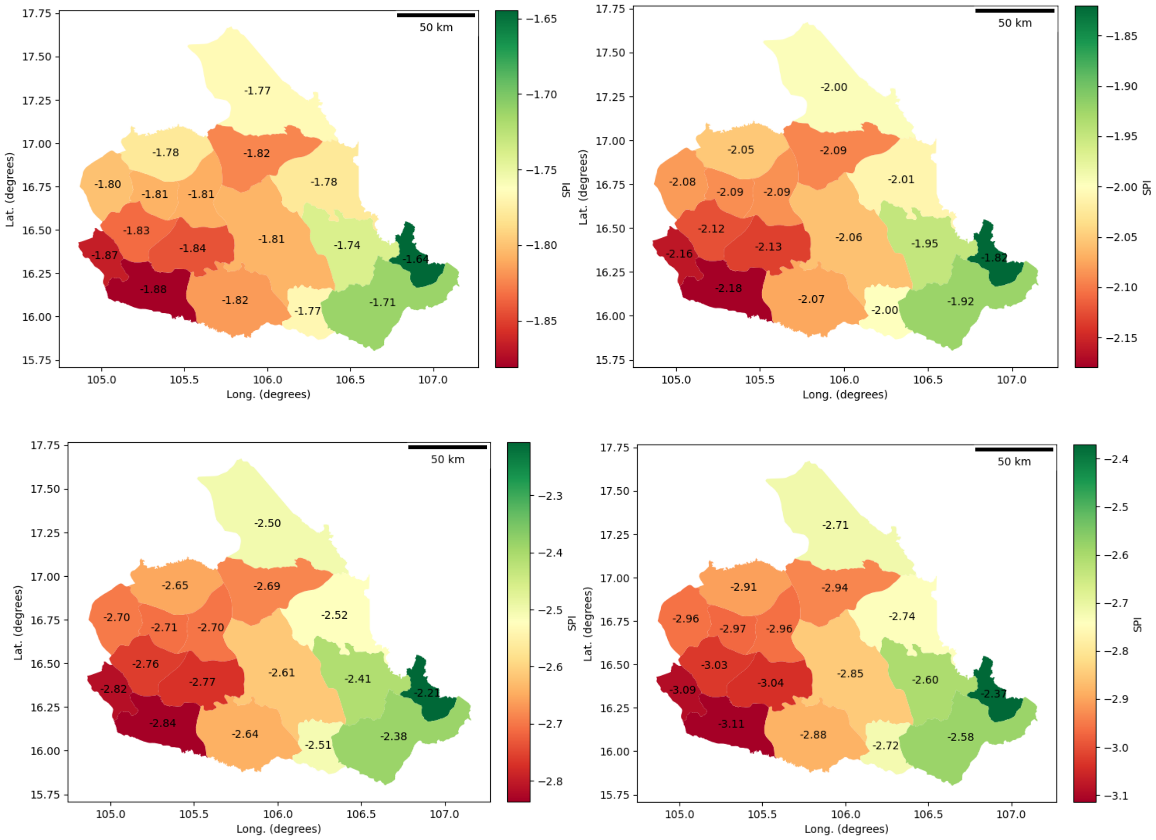


Figure 22 Future scenario (RCP85): Drought Hazard maps giving the mean SP per district for a 6 month moving average with return period 1/5 (Left top), return period 1/10 (Right top), return period 1/50 (Left Bottom), return period 1/100 (Right Bottom).

Derived from the regional drought dynamics, villages are anticipated to exhibit distinct susceptibilities to future drought conditions (Figure 23). The trends observable for the district level are of course mirrored at the village level, though due to the higher resolution some of the mean SPI values are even lower. The SPI levels are indicating severe to devastating droughts in the future for respectively the 1 in 5 and 1 in 100 year scenario’s.

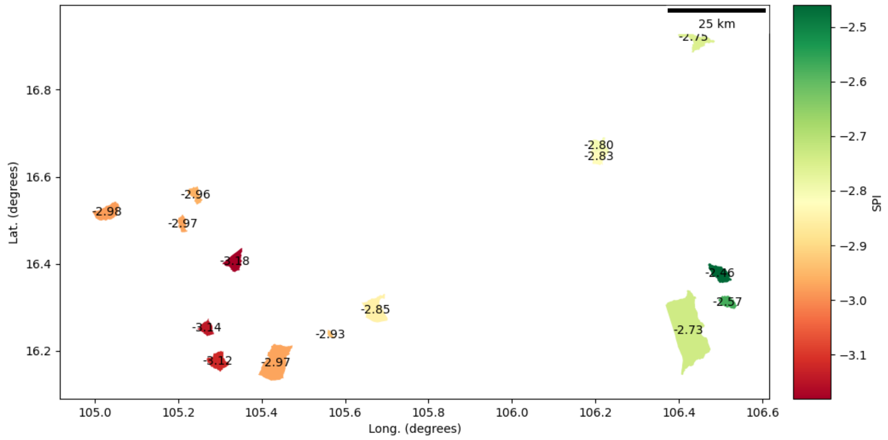


Figure 23 Future scenario (RCP85): Example of the SPI on Village level for a return period of 100 years and a 6 month moving average.

Village	SPI
B. Dong mueng	-2,959
B. Huoi khor	-2,974
B. Kaeng hua pa	-2,803
B. Kaeng kha mae	-2,827
B. Mueng honh vath	-2,935
B. Na chan yai	-2,852
B. Nong vi lai	-2,460
B. Nonh sa wang	-3,120
B. Phia kao	-2,972
B. Sa veu	-2,734
B. Sopsalou	-2,753
B. Sy vy lai	-2,981
B. Tang ar lai neua	-2,574
B. Tha kham lien	-3,143

4.4 Exposure

The maps in Figure 24 show the flood extent during a 1 in 100 year event, overlayed with the asset maps for Dong Mueng, Kaeng Donh, Phia Kao and Song Khon Tai. When this overlay is done, it also gives the number of different assets that are exposed to a specific flood height.

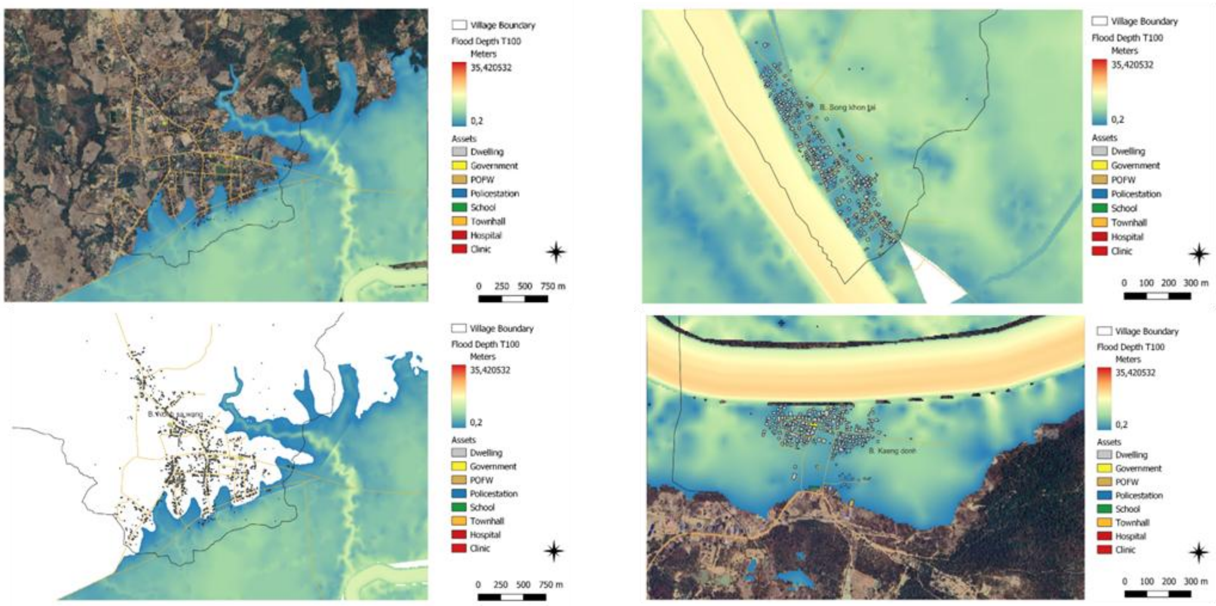


Figure 24 Flood exposure mapping of infrastructure assets.

The number of dwellings and schools exposed to flooding, along with the villages they are located in and the flood heights they face, are mapped (Annex 5 –Figure 50 Figure 52). This mapping allows for a comparison between different return periods. The figures indicate a general increase in exposed assets with the severity of the flood event. Return periods of 2, 10, and 50 years are based on actual storms from the past 50 years, while the T100 is a design storm developed from an extreme value analysis. The use of real storms is evident, as the T2 storm was concentrated more in the northern part of the basin, whereas the T10 storm was more dispersed. Consequently, Dong Mueng experiences worse flooding during the T2 storm, resulting in more exposed dwellings compared to the T10 storm.

Using census data from 2015, the average household size per village was calculated and matched with the exposed dwellings. On average, there are six people per household per village (Table 4). The number of people exposed per village increases with the severity of the flooding, corresponding to the return period. As shown in Figure 25, an estimated 2,000 people are exposed to flooding in Song Khan Tai village during a 100-year flood event.

Table 4 Average household size of the villages

Village	Average Household Size
B. Dong mueng	6.05
B. Kaeng donh	6.00
B. Mueng honh vath	5.99
B. Na chan yai	6.68
B. Nonh sa wang	6.09
B. Phia kao	5.41
B. Song khon tai	5.97

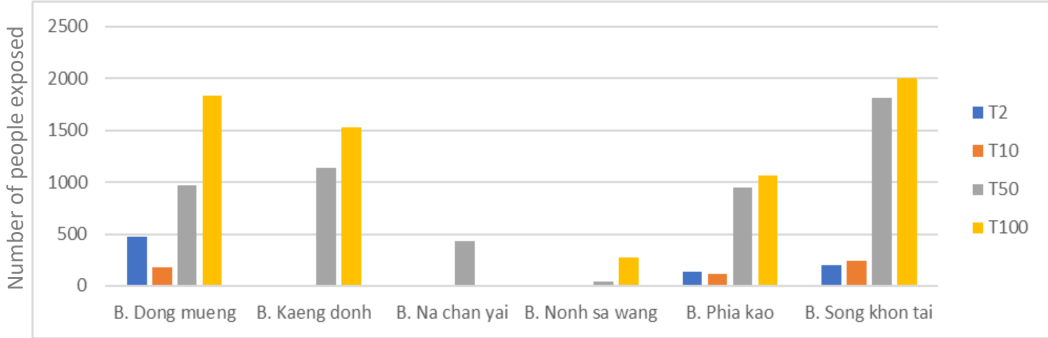


Figure 25: Number of people exposed to flooding in the exposed villages

4.5 Vulnerability

4.5.1 Physical vulnerability

4.5.1.1 Infrastructure

The physical vulnerability provides a relationship between the expected damage to the at-risk elements and hazard intensity. It is defined by both the properties of the element (building material, geometry) and the nature of the occurring hazard.

Damage function ('vulnerability function') were used in this assessment. They present a mathematical relation between the damage or loss ratio, which is a ratio of repair cost to the total replacement cost, and the hazard intensity. In other words, the damage function links the magnitude of a natural disaster (e.g. flood height) to expected damage through damage functions.

Vulnerability functions have been developed and widely used for several decades. However, we were unable to obtain curves specifically developed and calibrated for Mao PDR. Hence, information was gathered during the fieldwork and used to finetune damage curves based on international literature for the South-East Asia region. For example, the degrees of damage were assessed based on this scaling: 0.2m = 0% damage, 0.5m = 20% damage, 1m = 50% damage, 2m = 80% damage, 3m = 100% damage. The degree of damage to different types of assets is given in Table 5. In this case the housing census datasets (2015) provides information on the building materials used at district level.

The floods of 2019, which caused extensive damage to infrastructure across several provinces in Laos, serve as a significant example of the impacts on infrastructure. According to the AHA Centre ((AHA Centre, 14 Oct 2019), approximately 97 bridges, 747 schools, and 43 health centers and hospitals were affected by floodwaters across Lao PDR. Additionally, 462 road sections sustained damage, disrupting transportation networks crucial for accessing affected communities and delivering emergency relief.

A complete comparison of these figures with our results for the 2019 flood was not possible, as detailed asset information was only gathered for the target villages during the fieldwork. Our estimation indicated that 5 schools and 1 hospital were affected in these target villages, suggesting that a basin-wide asset mapping could yield more comparable results. While the basin-wide district assessment lacked detailed asset type information, the results showed a similar impact to those assessed by NDMO. Our calculations estimated a higher number of damaged buildings, but the number of people exposed was comparable. AHA reported 14,206 people exposed in Songkone and 16,587 in Xonnabouly. Our assessment estimated 3,441 and 4,224 dwellings exposed, respectively, which, with a ball park average of 4 people per dwelling, results in 13,764 and 16,896 people exposed—closely matching AHA's post-disaster assessment.

A detailed assignment with complete asset mapping for the provinces provides valuable insights and could suggest improvements to the damage functions given in Table 5. The scale of infrastructure destruction experienced during the event, as predicted in this risk assessment, underscores the need for robust infrastructure resilience measures and adaptive planning strategies to enhance disaster preparedness and response capabilities in flood-prone areas.

Table 5 Amount of damage for infrastructure assets

Flood Depth	A	B	C	Earth road	Bitumen road	Concrete road	Asphalt road	Bridge	Power station	Tubewell	Crops
0.2	0.3	0	0	0.1	0.05	0	0	0	0.3	0	0
0.5	0.5	0.3	0.1	0.3	0.1	0	0	0	0.5	0	0.2
1	0.7	0.5	0.2	0.9	0.5	0.15	0.05	0	0.8	0.5	1
1.5	1	1	0.5	1	0.9	0.5	0.1	0	0.9	0.9	1
2	1	1	1	1	0.95	0.7	0.3	0	1	1	1
3	1	1	1	1	1	0.8	0.7	0	1	1	1
4	1	1	1	1	1	0.9	0.9	0.1	1	1	1
5	1	1	1	1	1	0.95	0.95	0.3	1	1	1
6	1	1	1	1	1	0.98	0.98	0.4	1	1	1

4.5.1.2 Agriculture

Agriculture is assessed using damage curves to evaluate the impacts of both floods and droughts on agricultural lands. Due to limited data on crop types, the flood damage curve was simplified to a threshold of 0.5 meters, representing 0% damage below this level and 100% damage above it. For drought assessment, damage curves were derived from international literature, focusing on crop damage based on SPI values over a 3-month period in tropical climates (Table 6). Similar to the impact on infrastructure, the 2019 flooding event shows the devastating impact an extreme flood event can have on agriculture. Significant losses were reported, further exacerbating the economic hardships faced by rural populations dependent on agriculture.

Table 6 Amount of damage for agriculture assets based on SPI values.

SPI value (Drought)	Crop X damage %
<0	0.1
<-1	0.2
<-1.5	0.4
<-2	0.6
<-3	0.8

4.5.2 Socio-economic vulnerability

Finally, for socio-economic vulnerability, a qualitative assessment was made based on data from fieldwork. The fieldwork identified recurring flooding in the upper catchment villages, with detailed information collected as described in the field report. However, due to insufficient data, a reliable quantitative risk assessment for these villages was not feasible. The fieldwork report provides qualitative indications that flooding is indeed a recurring issue in these areas. Additionally, the communities offered suggestions on measures to enhance their adaptive capacity to flooding. These findings highlight the need for extending the HEC-RAS flood model or incorporating another flood model capable of assessing flash flood hazards, facilitating a comprehensive and detailed risk analysis for these villages.

The targeted villages face two primary climate hazards: flooding and drought. However, according to villagers, flooding poses a much greater challenge in terms of frequency and damage. Only a small number of villages experience both phenomena, with the majority facing primarily flooding, and a smaller group struggling predominantly with drought.

People living in flood-prone villages have faced repeated flooding incidents. The August 2019 flood was a disastrous event in many provinces of Laos, including Savannakhet. This flood left significant casualties and led to the migration of people from villages. The 2019 flooding events in Laos, caused by Tropical Cyclone Podul and Tropical Depression Kajiki, tragically resulted in at least 28 fatalities, underscoring the severe toll on local communities. This loss of life highlights the critical importance of effective disaster preparedness and early warning systems to mitigate such tragic outcomes in the future. These events prompted the development of preparedness measures and response strategies, including understanding warning signals, evacuation procedures, and actions to reduce losses.

In comparison, communities affected by drought often suffer from a lack of knowledge and expertise. Villagers' heavy dependence on agriculture makes them particularly vulnerable due to their inexperience with response strategies. During droughts, individuals may feel unprepared and uncertain about adapting their practices, conserving water, or finding alternative income sources. This emphasizes the need for targeted mitigation and adaptation strategies tailored to drought-prone villages, empowering residents to cope with this emerging threat.

Several potential adaptation interventions were proposed to our local partners for feedback and comment. These sites include:

Syvylai village

The village is located close to the national road, making it easily accessible. Despite being far from the district capital, this village is actually closer to Kaysone Phomvihane city than to Champhone capital. With an area of 575 hectares of rice paddy fields and a population of 1,683 (280 households), this place is at risk of water scarcity caused by drought. During the dry season, there is a significant issue with water scarcity. The main sources of water include tube wells and bottled water. Drought was the most frequent occurrence, happening once in the past decade, while there were no instances of flooding. The village, with its strong sense of community, is actively working towards implementing climate change adaptation measures. This includes constructing a water reservoir and elevated water storage for agricultural usage and consumption.

Adaptaion insights**:** Given the village's vulnerability to drought and water scarcity, its current efforts towards climate change adaptation are crucial. The construction of a water reservoir and elevated water storage facilities demonstrates a proactive approach to managing water resources, ensuring both availability and quality for agricultural and domestic use. The strong sense of community in the village supports these adaptation measures, fostering collective action and resilience.

Dongmueng village

The village is close to a river, with 910 people living in 118 households. Most of the villagers are engaged in farming, specifically rice cultivation, which spans across approximately 266 hectares of land (but is frequently affected by flooding). The forest monkey is a popular attraction for tourists and can bring in revenue for the local villagers. The main sources of water are tube wells and bottled water. The most frequent natural disaster in the past decade has been flooding, which happened twice. On the other hand, there were no occurrences of drought. The community has never been involved in any initiatives to promote climate resilience. The village is considering implementing flood control measures, such as enhancing levees and creating water storage, to improve resilience to climate-related issues.

Adaptioan insights: Given the village's frequent flooding issues and lack of previous involvement in climate resilience efforts, there is a critical need for proactive adaptation measures. The community's consideration of flood control measures, such as enhancing levees and creating water storage, is a positive step towards improving resilience. These measures are essential not only to protect agricultural activities but also to safeguard the livelihoods and revenue from tourism.

Phiakao village

The village is close to a river and has a population of 689 individuals, residing in 104 households. The available water resources include rivers, wells, and a water pipeline network. Water bottles are widely used by the residents. Most of the population are either farmers or laborers from the neighboring country. The main sources of water are tube wells and water bottles. Over the past decade, flooding was the most frequent occurrence, happening 30 times, while there were no instances of drought. Previously, this village has not been involved in any climate resilience initiatives. The village is looking to implement flood control measures, which include providing shelters for evacuations and increasing the height of the levee.

Adaptaion insights: The village's frequent exposure to flooding necessitates urgent and effective adaptation measures. The community's consideration of flood control measures, such as providing shelters for evacuations and increasing the height of the levee, indicates an awareness of the need to enhance resilience. These measures are critical to protecting the village's infrastructure, livelihoods, and water resources.

Nonhsawang village

The village is in the capital district and serves as the central location for all administrative offices in the district. It has a population of 3333, with 545 households. Most of the residents are engaged in farming and various forms of labor. The area of the rice paddy field is 406.12 hectares. The primary sources of water are tube wells and bottled water. Flooding has been more frequent, happening ten times in the past decade, while drought occurred only six times. Until now, the village has not been involved in any climate resilience initiatives. The village has expressed its desire to implement flood control measures, which include the construction of three small-scale dykes to retain water during the rainy season and store it for the dry season.

Adaptation insights: Given its role as the administrative center of the district, the village is strategically positioned to implement and benefit from comprehensive climate resilience measures. The frequent flooding and occasional drought underscore the need for adaptive strategies to manage water resources effectively. The community's expressed desire to construct three small-scale dykes to retain water during the rainy season and store it for the dry season indicates a proactive approach to enhancing resilience.

Muenghonh village

The village is in the southern part of Xonbouly district, and it is isolated from other villages and only accessible during the dry season. It has a population of 1115, with 378 households. Most of the residents are engaged in farming. The area of the rice paddy field is 350 hectares. The primary sources of water are rivers, tube wells and springs. Flooding has been more frequent, happening two times in the past decade (extreme event), there were no instances of drought. Until now, the village has not been involved in any climate resilience initiatives. The village has expressed its desire to implement flood control measures, which include the construction of small-scale dykes to retain water during the rainy season and store it for the dry season.

Adaptation insights: The village's isolation and limited accessibility heighten its vulnerability to flooding, emphasizing the need for targeted adaptation measures. The residents' dependence on farming and the absence of droughts suggest a critical focus on flood management. The community's expressed interest in constructing small-scale dykes to retain water during the rainy season and store it for the dry season is a positive step toward enhancing resilience.

Nachanhyai village

The village is situated in the eastern part of Xonbouly district, isolated from neighboring villages and accessible only during the dry season. It has a population of 1095 people living in 223 households, primarily engaged in agriculture. The village spans 87.75 hectares of rice paddy fields, relying mainly on rivers and tube wells for water supply.

In the past decade, the village has experienced frequent flooding, occurring twice (considered extreme events), and drought has affected the area ten times. Currently, the village has not participated in any climate resilience initiatives. However, there is an expressed intention to enhance flood mitigation measures. This includes the use of a large boat for evacuating residents, their belongings, and animals to a designated shelter.

Adaptation insights: Given its isolation and dependence on agriculture, the village's vulnerability to both flooding and drought highlights the need for comprehensive adaptation strategies. The expressed intention to enhance flood mitigation measures is a positive step, but the frequent occurrence of drought also necessitates a broader approach to resilience.

Songkhone tai village

The village, located near a river, is home to 1264 residents living in 227 households. Access to water is facilitated through rivers, tube wells, and a network of water pipelines. Most of the population is engaged in farming or labor activities. The village boasts a total rice paddy field area of 343.74 hectares.

In the past decade, the village experienced frequent flooding, occurring five times, with no reported instances of drought. Previously, the village actively participated in a climate resilience initiative. Currently, there is a proactive effort to enhance flood control measures, which include the provision of megaphones, a large boat equipped with an 8 horsepower engine for efficient evacuation, raising road levels for better access, canal improvements, installation of early warning equipment, and heightening levees.

Adaptation insight: The village's proactive approach to enhancing flood control measures demonstrates a strong commitment to building resilience against natural disasters. The previous participation in a climate resilience initiative has likely provided valuable experience and knowledge that can be leveraged in current and future efforts.

Kaengdon village

The village is near a river and home to 1255 people living in 187 households. The water sources that are accessible include rivers, tube wells, and water bottles. Most people in the population work as farmers or laborers. The total land area of the rice paddy field is 104.25 hectares. Over the past decade, flooding was the most frequent occurrence, happening six times, while there was once drought. Earlier, this village had not been engaged in any climate resilience initiatives. The village is actively working towards implementing a range of flood control measures, such as the establishment of shelter, procurement of a large boat equipped with an 8 horsepower engine, protection of pond banks, improvement of irrigation canals, and installation of solar panels and power storage.

Adaptation insight: The village's proactive approach to flood control indicates a significant shift towards enhancing resilience and preparedness. The focus on a range of measures shows an understanding of the multifaceted nature of flood risks and the need for comprehensive solutions.

Houikhor village

The village is close to the river and home to 932 people living in 296 households. Most of the population is employed in agricultural or manual labor occupations. With an area of 326 and 110 hectares of rice paddy fields and cassava plantation respectively, this place is at risk of water scarcity caused by drought. During the dry season, there is a significant issue with water scarcity. The main sources of water include tube wells, streams/creeks and bottled water. Drought was the most frequent occurrence, happening ten times in the past decade, while there were four instances of flooding. Despite the drought being more common than floods, the village is actively implementing climate change adaptation measures with its strong sense of community. To address the needs of the community and prevent flooding, the initiative includes the construction of a water reservoir and elevated water storage. Additionally, drought-resistant rice seedlings will be provided to support agriculture in flood-prone areas in the village.

Adaptation insights: The village's proactive stance on climate change adaptation, particularly in the context of frequent droughts, indicates a community that is aware of its vulnerabilities and is taking steps to mitigate them. The focus on both flood and drought resilience highlights a comprehensive approach to adaptation.

Kaengthamae village

The village is near a river and home to 674 people living in 110 households. The water sources that are accessible include rivers, streams/creeks and tube wells. Most people in the population work as farmers or laborers. The rice paddy field covers a total land area of 28.48 hectares, while the swidden land spans 215.09 hectares. Also, about 70 hectares of land is dedicated to industrial tree plantation. In the last ten years, flooding was the most common event, occurring twice, whereas there were no instances of drought. On the other hand, water scarcity becomes a major problem during the dry season. This village had been actively engaged in a climate resilience initiative. The village is actively working towards implementing a range of flood control measures, such as the establishment of shelters, acquisition of a large boat with an 8 horsepower engine, and the provision of an early warning system consisting of a water level station and automatic warning system.

Adaptation insight: The village's proactive engagement in climate resilience initiatives demonstrates a community-driven approach to addressing both frequent flooding and seasonal water scarcity. This initiative reflects a strong commitment to enhancing local resilience against climate-related challenges.

Kaenghuapa village

The village is near a river and home to 935 people living in 200 households. The water sources that are accessible include rivers and tube wells. Most of the population are engaged in farming or manual labor. Over the past decade, flooding was the most frequent occurrence, happening three times, while there was no instance of drought. Earlier, this village had not been engaged in any climate resilience initiatives. The village is actively working towards implementing a range of flood control measures, such as the establishment of shelters, procurement of a large boat equipped with an 8 horsepower engine.

Adaptation insights: Despite the lack of previous engagement in climate resilience initiatives, the village's proactive steps towards implementing flood control measures signify a growing awareness of climate risks and a commitment to safeguarding the community against flood-related impacts.

Sopsalou village

The village is close to the river and home to 302 people living in 68 households. Most of the population is employed in agricultural or manual labor occupations. With an area of 50 hectares of rice paddy fields. The main sources of water include rivers, and streams/creeks. Flooding was the most frequent occurrence, happening three times in the past decade, while there was no instance of drought. Previously, this village had not been involved in any initiatives related to climate resilience. The village, with its strong sense of community, is actively working towards implementing climate change adaptation measures. To meet the needs of the community and mitigate flooding, the flood response measures encompass the implementation of an early warning system, enhancement of mobile phone signal for improved communication and information exchange, and the utilization of a megaphone to disseminate information to the village.

Adaptation insights: The village's proactive approach to implementing climate change adaptation measures underscores its commitment to enhancing community resilience against recurring flood events. The initiatives reflect a strong community spirit and proactive engagement in safeguarding livelihoods and infrastructure.

Nongvilai village

The village is near a river and home to 2640 people living in 483 households. The water sources that are accessible include rivers, water pipeline networks and tube wells. Most of the population is engaged in farming or manual labor. The total land area of the rice paddy field is xxx. Over the past decade, flooding was the most frequent occurrence, happening three times, while there was no instance of drought. Earlier, this village had been engaged in a climate resilience initiative. The village is actively working towards implementing several flood control measures. These measures encompass the acquisition of a large boat equipped with an 8 horsepower engine, the enhancement of riverbank protection in the Temple area, the improvement of dykes and irrigation canals, and the rehabilitation of schools damaged by flooding.

Adaptation insights: The village's proactive engagement in climate resilience initiatives highlights its commitment to mitigating flood risks and enhancing community resilience. The ongoing efforts underscore a community-driven approach to safeguarding livelihoods and infrastructure from recurrent flood events.

Tangarlai village

The village is near a river and home to 455 people living in 95 households. The water sources that are accessible include rivers, wells and tube wells. Most individuals within the population are employed as farmers or laborers. The total land area of the rice paddy field is 20 hectares, while swidden land is 60 hectares, it is interesting that the cassava land is 65 hectares which is the largest agricultural land practice. Over the past decade, flooding was the most frequent occurrence, happening two times, while there was no instance of drought. Earlier, this village had been engaged in a climate resilience initiative. The village is actively working towards implementing several flood control measures. These measures include the provision of shelter, megaphones, seedlings, and animals to provide relief to mitigate the consequences of flooding, alongside the enhancement of the electrical grid network.

Adaptation insights: The village's proactive engagement in climate resilience initiatives underscores its commitment to mitigating flood risks and enhancing community resilience. The ongoing efforts demonstrate a community-led approach to safeguarding livelihoods and infrastructure from recurring flood events.

Saveu village

The village is in the southern part of Nong district and home to 657 people living in 164 households. The accessible water sources are tube wells and gravity-feed water. Most individuals within the population are employed as farmers or laborers. The total land area of the rice paddy field is 58 hectares, while swidden land is 80 hectares, it is interesting that the banana land and cassava land is 30 and 10 hectares respectively. Over the past decade, flooding was the most frequent occurrence, happening two times, while there was one instance of drought. Earlier, this village had been engaged in a climate resilience initiative. The village is actively working towards carrying out flood control measures. These measures include the establishment of a village office, the clearance of land for cultivation purposes, the improvement of access roads and bridges at Houichaloi, and the demarcation of the HouiAleng headwater forest and cemetery area.

Adaptation insights: The village's proactive approach to climate resilience reflects its commitment to safeguarding agricultural livelihoods and infrastructure from recurring flood and drought events.

Overall, for all the villages situated near rivers and relying heavily on agriculture, implementing a comprehensive village-based adaptation strategy is crucial. Given the recurring challenges of floods and occasional droughts, a unified approach could include several key measures. (1) establishing early warning systems tailored to local conditions will enhance preparedness and response capabilities during flood events. (2) promoting sustainable agricultural practices, such as crop diversification and soil conservation techniques, can mitigate the impacts of climate extremes on livelihoods. (3) investing in community infrastructure like flood-resistant housing, improved water management systems, and strengthened local governance structures will foster resilience.

Moreover, fostering collaboration among villages, local authorities, and relevant stakeholders is essential for sharing resources, knowledge, and experiences to collectively build resilience and ensure sustainable development in the face of climate change impacts.

4.6 Impact and Risk

4.6.1 Flood impact and risk-current scenario

4.6.1.1 Infrastructure – Flood impact

The monetary data for infrastructure was collected during fieldwork, focusing on assets where costs could be accurately determined (Table 8 - Annex 6). The costs were based on discussions with the households in combination with the expertise of the national climate vulnerability and risk expert. This table includes only those assets for which costs have been attributed. Most assets were valued based on unit measurements, such as the area for building footprints or the distance for linear assets. These measurements were then used to calculate the costs incurred during a flood event, utilizing damage curves specific to each asset type.

Figure 26 illustrates the culmination of this analysis, depicting the potential costs incurred due to flooding in the villages for the 2, 10, 50, and 100 year return periods or storm scenarios. This visual representation offers a clear depiction of how financial exposure varies with the intensity and frequency of flooding events, aiding in informed decision-making for flood risk management strategies.

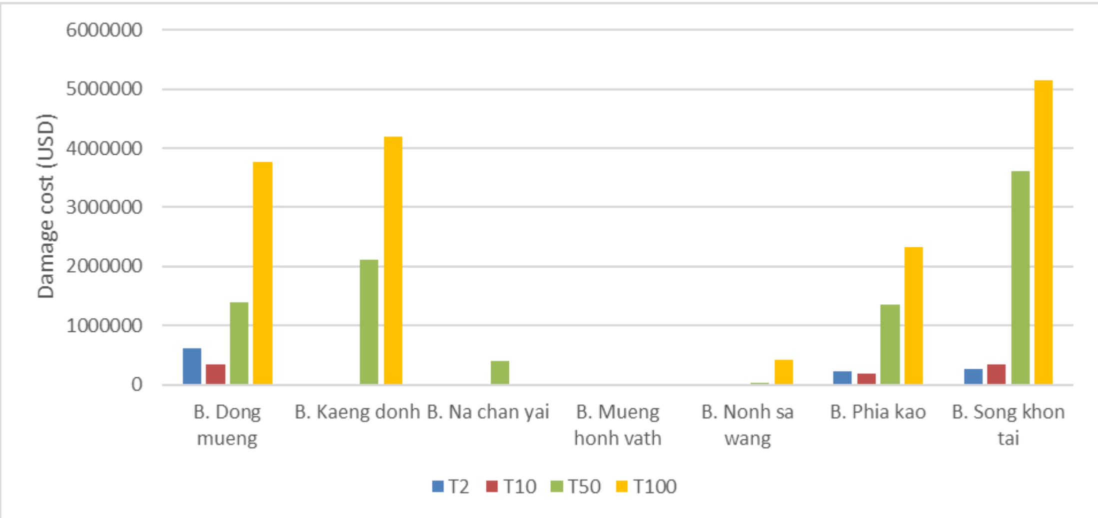


Figure 26 Potential costs incurred in each flood scenario for the villages that are exposed to the modeled flood extend.

A detailed examination of the data shows the count of dwellings exposed to specific flood depths associated with a designated Return Period. An example of Dong Mueng village is shown in Table 9 - Annex 6). This data is crucial as it allows for an assessment of the potential impact. By correlating this exposure data with the associated costs and total area affected, an aggregated cost per flood depth range or combination of ranges can be determined for each building, and consequently the village. Table 9 in the annex presents a comprehensive snapshot of this analysis, outlining the distribution of dwellings and corresponding costs across different flood depth ranges in Dong Mueng village. This analysis is conducted across multiple Return Periods, providing insights into the potential economic implications of various flood events.

The financial impact map for infrastructure due to flooding reveals varying effects across different villages. The flood model delineates flood extents within the basin, and the figures below (Figure 27, and Figure 53Figure 56 in Annex 6) provide an overview of the associated damage costs, highlighting villages where potential costs are incurred for current scenarios. Villages outside the flood area or the HEC-RAS modeling area do not have a calculated potential cost and are shaded in grey or positioned outside the main image for visualization purposes.

It is important to note that some upstream villages, which lie outside the HEC-RAS model extent and are not shown on the impact map, are still affected by flash floods, as indicated by anecdotal evidence collected during field visits. Unfortunately this could not be modeled during this project and as a result there are no quantitative risk and impact figures for these villages.

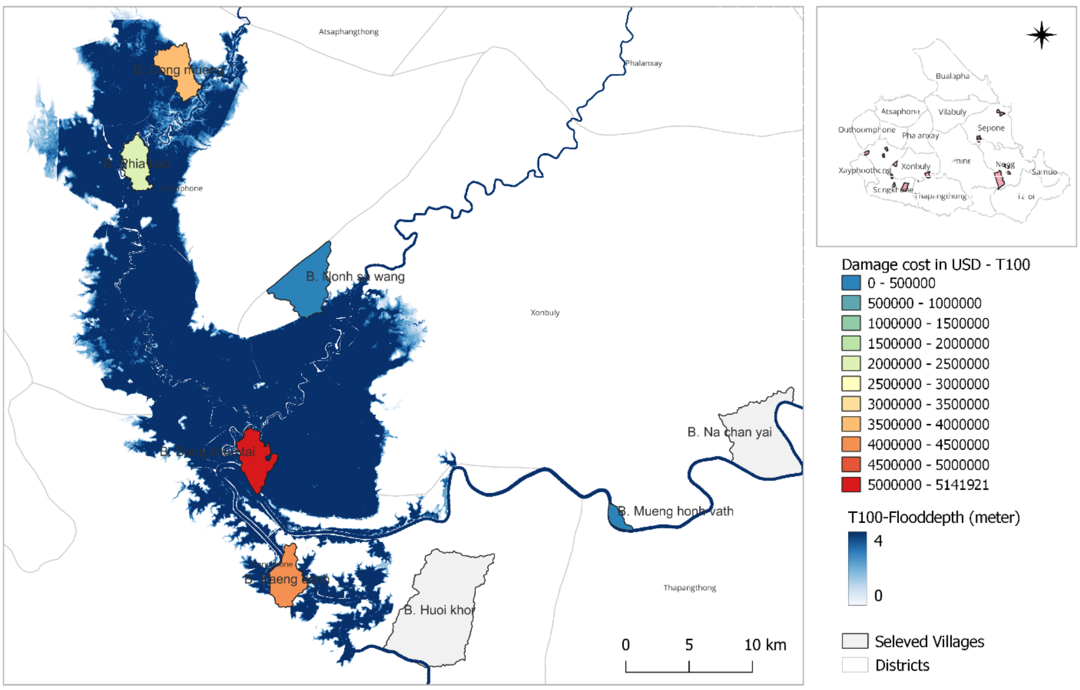


Figure 27 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 100 year event.

4.6.1.2 Population – flood impact

When looking at the impact on the population we can apply the exposure mapping for the population and link it to the flood height and impact to the infrastructure. Based on the expected damage to buildings for a flood height of 2 meter, if no good warning and evacuation practices are in place, this flood could result in a potential number of casualties as shown in Figure 28 (and Figure 60Figure 62 in Annex 6). This assumes that the flood is above head-height, dwellings are all severely damaged, and the people are not evacuating. In reality, this number would be lower as evacuation plans are in place in most villages and adaptive capacity is not considered. It still gives a good indication of the number of people that are exposed and severely impacted.

For the current climate there is a very clear distinction between the T2, T5 and T50 future scenario's vs the T100 scenario. Therefore, understanding these patterns helps in fostering community awareness and preparedness, as residents can be better informed about the risks they face and the necessary steps to safeguard themselves. By integrating these projections into planning and policy-making, understanding the difference in impact between a 50 year and 100 year storm communities can enhance their resilience to future flooding events, ultimately saving lives and reducing the overall impact of natural disasters.

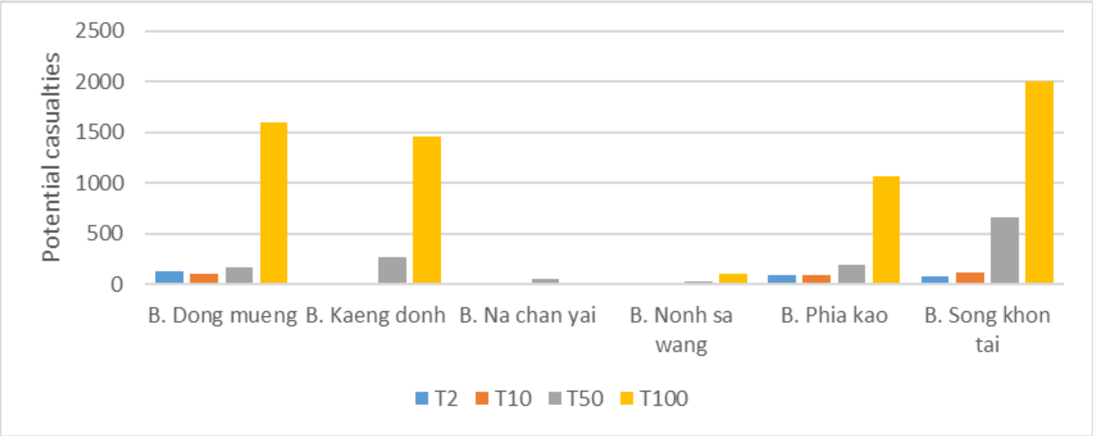


Figure 28 Potential number of casualties for each flood scenario per exposed village due to a flood height of 2 meter.

4.6.1.3 Flood risk

The flood risk score was derived from the potential casualties and damage costs. The following figures (Figure 29, and Figure 66Figure 68in Annex 6)) give the flood risk related to the return period of the flood exposed villages based on the flood modeling. The highlighted villages in red are the most at risk and the focus here is on comparing the risk between villages, not flood scenario's. The level of risk between the different scenario's cannot be compared as the risk is given as a score between 0 and 1 based on the scenario. In other words, a village that has a high risk score for a 1 in 10 year flood, and also for a 1 in 100 year flood will be high risk/red in both maps. To compare the scenario's the financial impact of the infrastructure and exposed population can be used. The village with the highest flood risk are is Song khon tai, with Dong mueng showing to have a low risk score for low to medium floods, and a very high risk score for more severe floods.

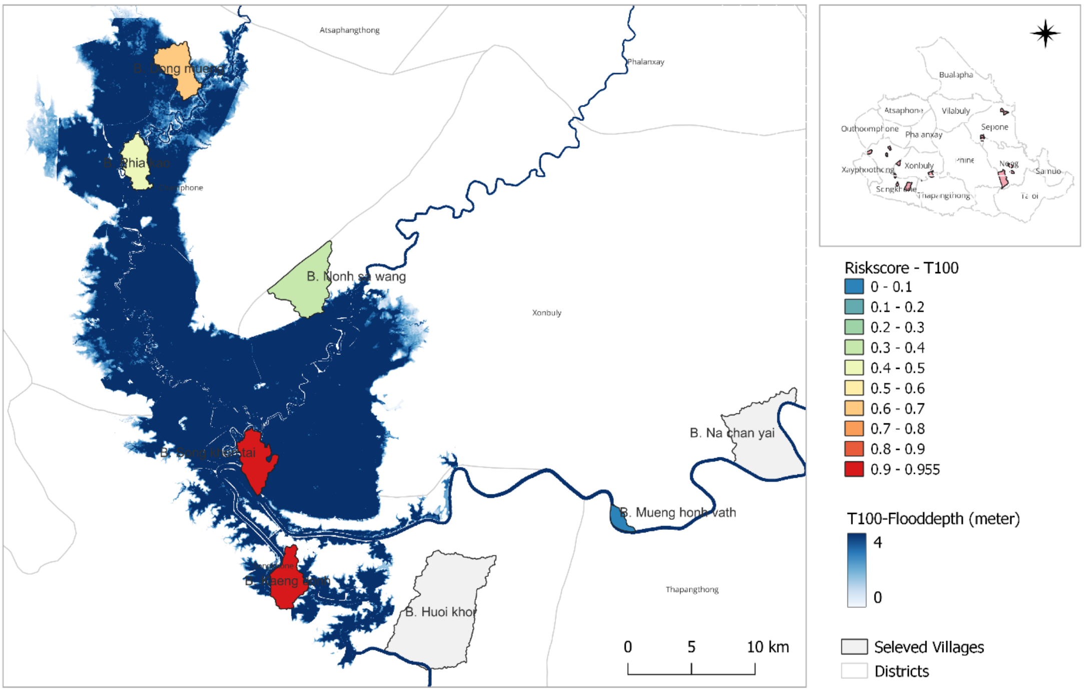


Figure 29 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 100 year flood event.

4.6.2 Flood impact and risk-future scenario

4.6.2.1 Infrastructure

Figure 30 and Figure 31 (and Figure 57Figure 59 in Annex 6) project the anticipated costs incurred in villages for 2, 10, 50, and 100-year return periods or storm scenarios for 2050. These visualizations highlight the varying financial impacts associated with different intensities and frequencies of potential future flooding events. They serve as valuable tools for strategic planning and informed decision-making in flood risk management, emphasizing the importance of proactive measures and adaptive strategies to mitigate future flood impacts.

For some villages, the damage costs between the T50 and T100 return period storms are the same. The reason for this is that the flood height is deterministic to the amount of damage and the shape of the flood basin is such that for both the T50 and T100 most of the basin is flooded to a height that already damages most of the buildings, and the water level only rises while the amount of land that is flooded (or the flood extend) remains relatively the same. The 30-year (2021-2050) future rainfall dataset (RCP85) used for estimating storms has been critical in developing the impact data and observing differences in damage costs and casualties between the different return periods. This extended timeframe could capture fluctuations in climate patterns and variability over decades, influencing the frequency and intensity of rainfall events. As climate dynamics evolve, the dataset provides a contemporary basis for projecting flood risks, potentially highlighting increased occurrences of flood events similar to the 2019 flood with more frequency, as discussed in section 4.2.3.

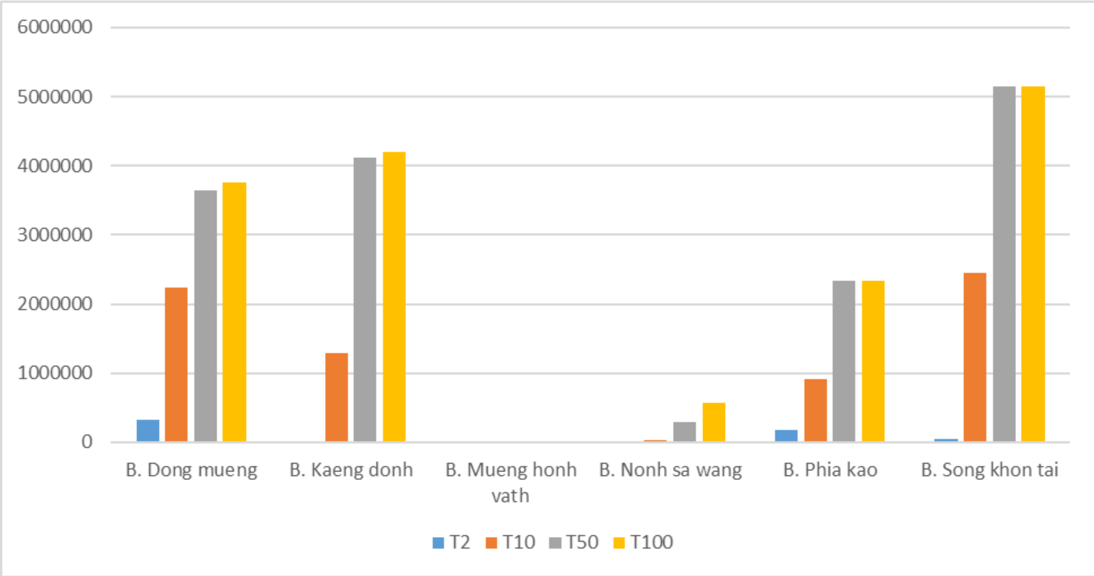


Figure 30 Potential costs incurred in each flood scenario for the villages that are exposed to the modeled flood extend-future scenario

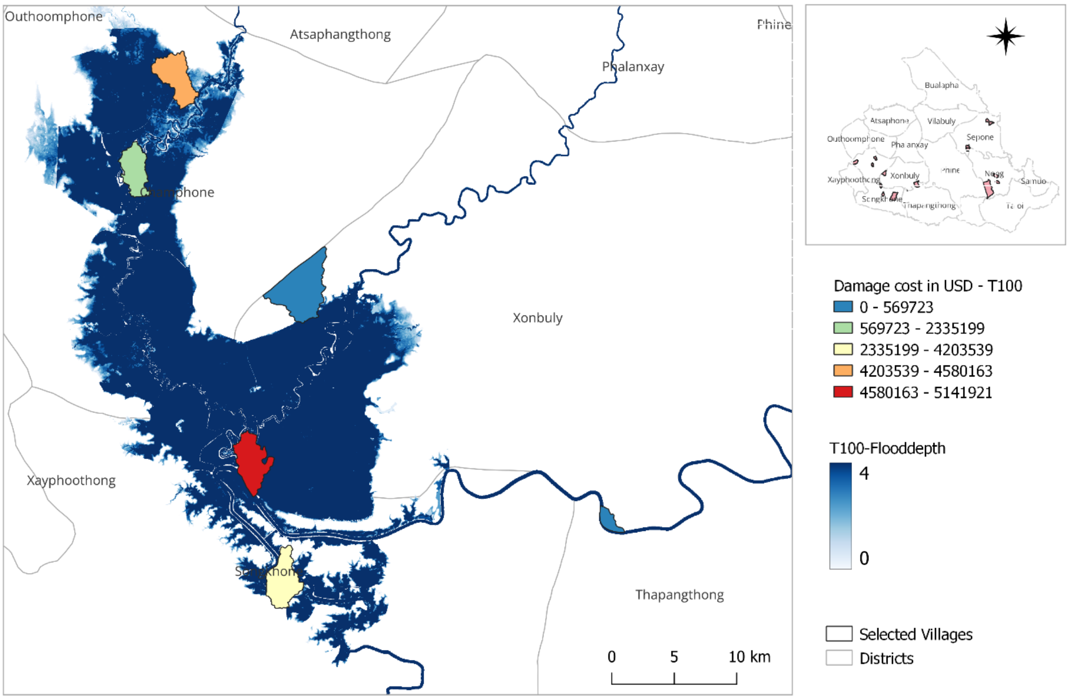


Figure 31 Damage cost (USD) for villages exposed to flooding based on the flood modelling a 1 inr 100 year return period-future scenario.

4.6.2.2 Population – flood impact

Figure 32Figure 32 (Figure 63Figure 65 in Annex 6) illustrate the projected casualties in the villages in 2050 (RCP 8.5) for 2, 10, 50, and 100 year return periods or storm scenarios. This figure provides a crucial visualization of how the intensity and frequency of future flooding events could impact human life. The difference compared to the current climate is striking, especially when examining the T50 flood. In this future scenario, the 2-meter threshold used to determine potential casualties is surpassed in he same areas for the T50 and T100 floods. The discussion from section 4.2.3 is also reflected here, as the future T10 scenario approaches the severity of the current T50 scenario (or the 2019 flood).

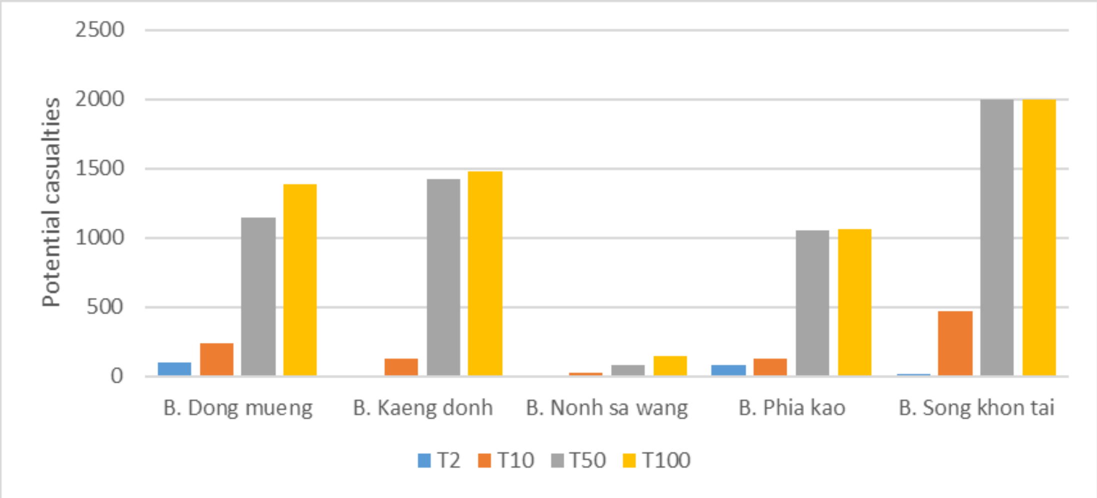


Figure 32 Potential number of casualties for each flood scenario per exposed village due to a flood height of 2 meter-future scenario

4.6.2.3 Population – flood risk

The future flood risk score is derived from the projected casualties and damage costs. The following figures (Figure 33, Figure 69Figure 71 in Annex 6) illustrate the flood risk associated with the return periods of flood-exposed villages based on advanced flood modeling. In these future scenarios, a 1 in 100 year flood highlights the most at-risk villages in red. However, the distribution of risk might vary significantly for different return periods, such as a 1 in 10 year flood. The level of risk between different return periods, such as 1 in 10 and 1 in 100, cannot be directly compared due to the substantial variation in projected impacts.

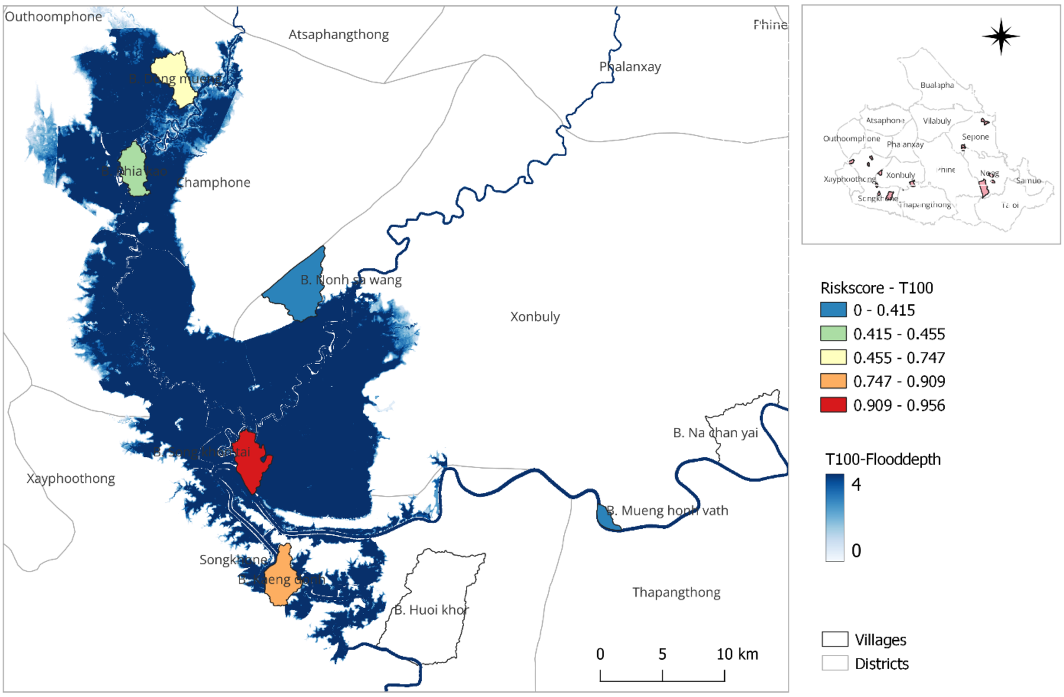


Figure 33 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 100 year flood event-future scenario.

4.6.3 Drought impact and risk

Table 10 (Annex 6) details the economic landscape of crop prices per hectare in Lao Kip (LAK) alongside their equivalent values in US dollars (USD) at the time of writing, providing insights into the financial dynamics of agricultural production. Among the crops listed, lowland rainfed paddy stands out as the most prominent crop in the region, accounting for approximately 75% of all crops produced. This reflects its substantial contribution to the overall agricultural income. For each crop, the theoretical fraction per hectare was calculated for the region, resulting in an average income per hectare of approximately 755.5 USD. Other significant contributors include dry season paddy and maize, along with cash crops such as starchy roots and vegetables. The table underscores the varying economic importance of different crop types within the agricultural sector, illustrating their role in local economies and livelihoods.

Based on the average price per hectare and the vulnerability of crops to drought, the estimated potential costs incurred per village were determined for different return periods. Figure 34 and Figure 35 (also Figure 72 in Annex 6) highlight the disparities between SPI values for 90-day and 180-day drought periods for a 1-in-100-year drought scenario. These figures also reveal significant variations in estimated costs incurred per village. The extent of agricultural activity within each village plays a pivotal role in defining its drought risk. Villages with more intensive agriculture, primarily located in the western area of the basin, are likely to face higher costs due to severe drought impacts. While drought hazard maps suggest relatively uniform drought severity levels across the basin with a slight increase to the west, the risk to agriculture presents a much more pronounced scenario, emphasizing the differential impact on villages depending on their agricultural intensity and geographical location.

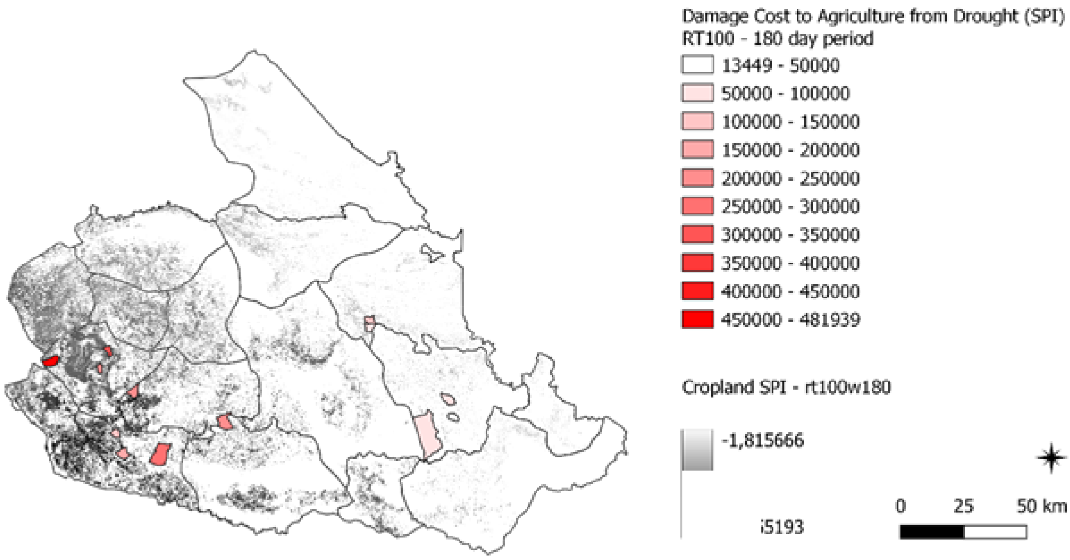


Figure 34 Damage Cost (USD) to Agriculture for a 1 in 100 year event a 0 day period

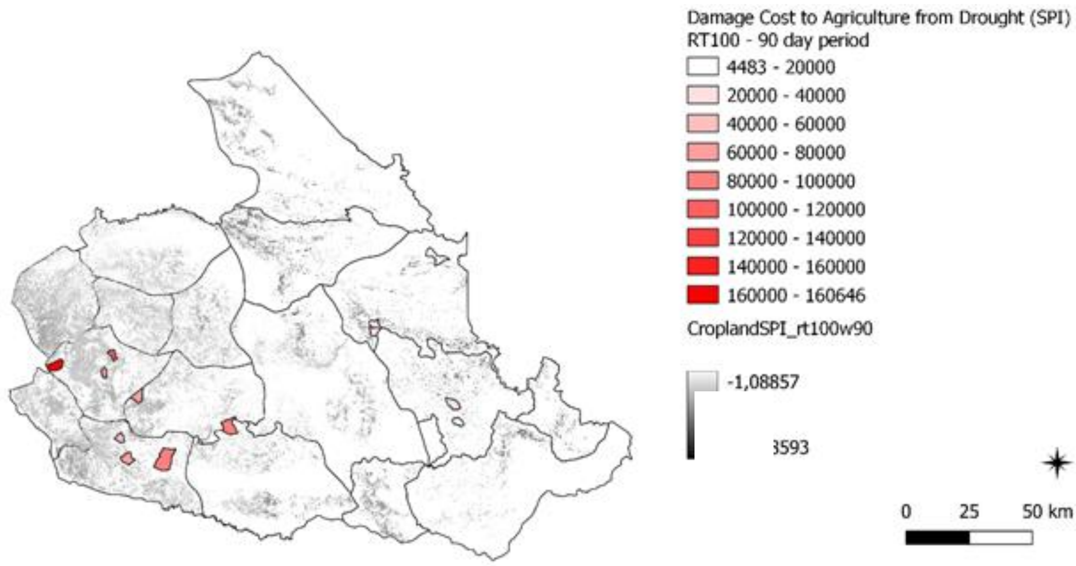


Figure 35 Damage Cost (USD) to Agriculture for a 1 in 100 year event and a 90 day period

5 Conclusion and recommendations

5.1 Key findings and limitations

The study provided valuable insights into the impacts of flood and drought within the Xe Bang Hieng river basin. Key limitations included the restricted coverage of the flood model and the availability of data. Efforts were made to address these limitations by integrating additional remote sensed data for the RT50 storm, utilizing gridded open-source hydrometeorological data, and updating water levels through new gauges. Despite these efforts, the flood model's coverage and the resolution and parameters included in the drought mapping can be improved. Expanding the HEC-RAS model to cover more upstream villages and enhancing the downscaling efforts of the hydrometeorological data would benefit future risk assessments.

Fieldwork significantly contributed to asset mapping and understanding community perceptions of flood and drought impacts. It was noted that critical infrastructure such as schools, hospitals, and government buildings were largely absent from available online datasets but were included in the impact assessment through fieldwork efforts for the target villages. A quick win for future efforts would be to upload the prepared asset maps with the field data into OpenStreetMap. The fieldwork also makes it clear that some of the upstream villages suffer from flash floods. This was not assessed as it is outside the boundaries of the existing flood model, but a study to map the risks in those villages is advised.

By developing the 50-year return period (RT50) to represent the 2019 flood, both remote sensing and anecdotal validation efforts of the flood mapping were possible. Both the remote-sensed flood extent images and the validation efforts with local stakeholders confirmed that the flood extent and flood depth levels accurately represented the floods caused by Tropical Storm Podul and Tropical Depression Kajiki. Using the RT50 storm for a comparative analysis of current and future climate floods also made the findings more relatable. The flood extents and impacts reveal notable differences between current and future scenarios in the study area. When comparing the 2019 flood (RT50) with future scenarios (RCP85), it becomes apparent that the RT50 scenario for the current climate closely compares with the RT10 scenario of the future climate. This suggests that devastating events like the one in 2019 would significantly increase in frequency. Although the most extreme climate scenario was used for the modeling, and the future might not be as bleak as these results indicate, the trend showing a significant increase in flood severity in the future is undeniable.

The study shows varying flood risks across the basin, with downstream villages such as B. Song Khon Tai, B. Dong Mueng, and B. Phia Kao generally facing higher risks. Based on historical data, these villages are already susceptible to more frequent, less intense floods occurring every 5 to 10 years, and they become severely impacted by less frequent, more extreme floods. B. Kaeng Donh, located slightly upstream, also showed susceptibility to less frequent but more severe floods with a return period of 50 to 100 years. In contrast, upstream villages like B. Nonh Sa Wang and B. Na Chan Yai, while exposed to flooding, experience lower impact levels due to their location and lower flood levels.

High drought risks for agriculture are particularly prevalent in western regions with extensive agricultural activities. Villages like B. Sy Vy Lai face significant potential losses during droughts, estimated at approximately 500,000 USD based on damaged crops. Upstream villages like B. Tang Ar Lai Neua and B. Nong Vi Lai, although experiencing severe drought conditions, have lower agricultural intensity, resulting in comparatively lower regional impact but likely similar impacts on farming households. It is key to understand that the meteorological drought risk on a farm/household level varies only slightly across the basin. Without potential mitigation measures such as irrigation, a family reliant on agriculture in the east will face a similar impact as a comparable family in the west. On an administrative scale, however, there is much more intensive agriculture on the western side of the basin, resulting in a shift of the risk levels to that side.

The study provided valuable insights into flood and drought impacts within the Xe Bang Hieng river basin. Key limitations included the restricted coverage of the flood model and the availability of suitable data. Efforts were made to address these limitations by integrating additional data for the RT50 storm, utilizing gridded open-source hydrometeorological data and updating the water levels through new gauges. Despite these efforts, the coverage of the flood model and the resolution and included parameters of the drought mapping can be improved. Expanding the HEC-RAS model to cover more of the upstream villages and enhanced downscaling efforts of the hydrometeorological data would benefit future risk assessment efforts.

Fieldwork significantly contributed to asset mapping and understanding community perceptions of flood and drought impacts. It was noted that critical infrastructure such as schools, hospitals and government buildings were basically absent in available online datasets but were included in the impact assessment through fieldwork efforts for the target villages. A quick win for future efforts would be to upload the prepared asset maps with the field data into Open Streat Map.

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The study shows varying flood risks across the basin, with downstream villages such as B. Song Khon Tai, B. Dong Mueng, and B. Phia Kao generally facing higher risks. Based on historical data, these villages are already susceptible to more frequent, less intense, floods occurring every 5 to 10 years and become severely impacted by the less frequent and more extreme floods. B. Kaeng Donh, located slightly upstream, also showed susceptibility to less frequent but more severe floods with a return period of 50 to 100 years. In contrast, upstream villages like B. Nonh Sa Wang and B. Na Chan Yai, while exposed to flooding, experience lower impact levels due to their location and lower flood levels.

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Figure 36 shows the final results for the flood and drought risk assessment for the target villages at current climate conditions for the most extreme event of 1 in 100 years.

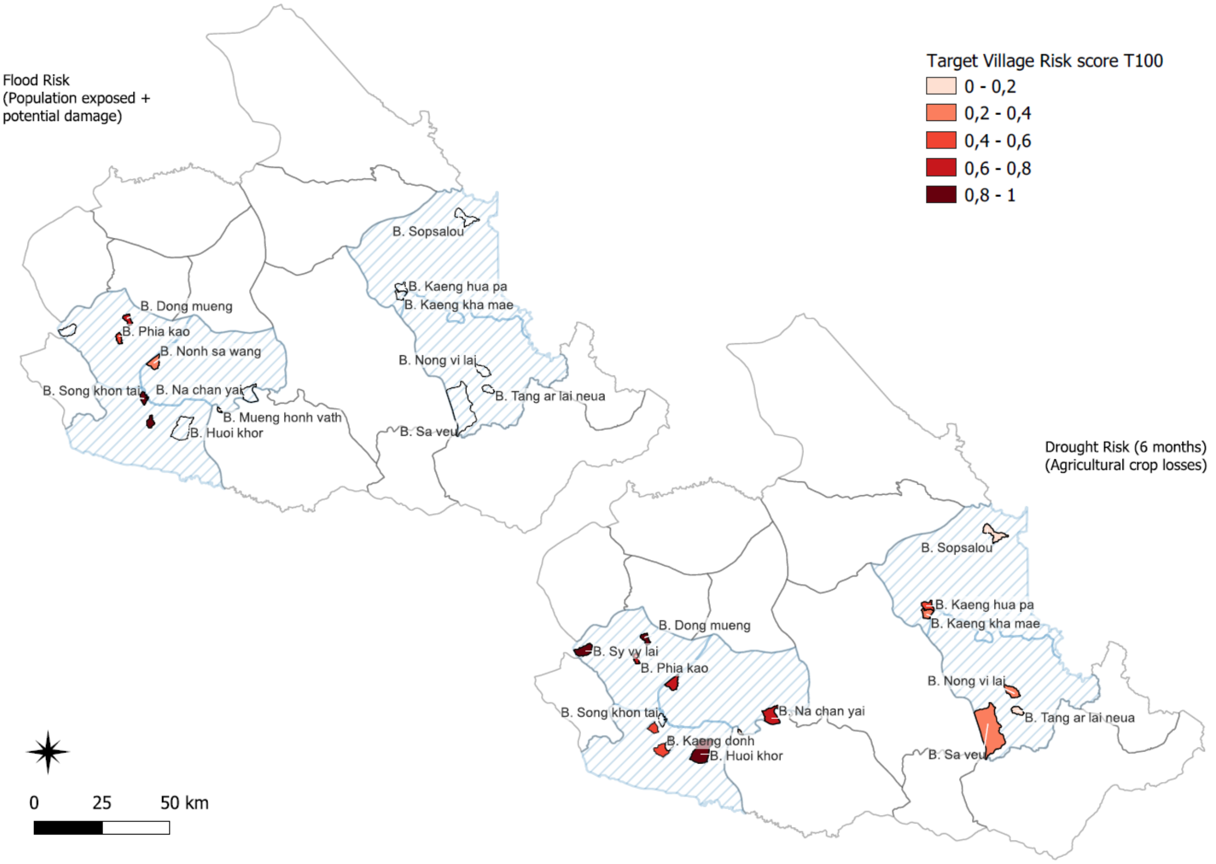


Figure 36: Flood and drought risk scores for the target villages based on current climate conditions and for a 1 in 100 year event.

5.2 Concluding remarks

The accurate flood maps developed using SWAT and HEC-RAS models provide valuable insights into areas most vulnerable to flooding across various return periods. These maps serve as essential tools for planning and implementing effective flood management strategies. Similarly, the assessment of meteorological drought using the CHIRPS dataset and the Standardized Precipitation Index highlights the severe impacts of rainfall deficiency at district and village levels, emphasizing the need for targeted drought mitigation measures.

The comprehensive asset, exposure, vulnerability, and risk mapping reveal the extensive risks posed to infrastructure and agricultural areas in flood-prone regions. By identifying at-risk elements and incorporating population data, the study provides a clear picture of potential impacts, aiding in the formulation of robust risk management strategies. Overall, the findings demonstrate the importance of integrating advanced modelling techniques with extensive data sources to enhance hazard preparedness and resilience at both local and regional levels.

Furthermore, the findings promote the importance of proactive measures to mitigate flood and drought impacts in the Xe Bang Hieng river basin. By addressing data gaps, updating modelling tools, and empowering local communities, policymakers and planners can effectively reduce vulnerabilities and enhance resilience to climate change. These recommendations aim to guide future initiatives aimed at safeguarding livelihoods and promoting sustainable development in the region.

The devastating flooding events of 2019 in Savannakhet and several other provinces of Laos, triggered by Tropical Cyclone Podul and Tropical Depression Kajiki, underscores the region's vulnerability to extreme weather phenomena. These events resulted in significant human and infrastructure losses, including numerous fatalities, displacements, and extensive damage to schools, health facilities, and agricultural lands. The results of this study provide critical insights into the potential recurrence of such events within certain return periods, highlighting the urgent need for robust flood risk management strategies at the basin, district, and village levels. Integrating these insights into planning and preparedness efforts can enhance resilience against future flood hazards in the region.

5.3 Recommendations

The recommendations are derived from the assessments and modelling efforts, as well as input from the community and stakeholders during fieldwork. They include proposed improvements to the simulations and adaptation/mitigation measures relevant to the basin.

Simulations:

Improved model coverage: Update the existing HEC-RAS model to include additional infrastructure and expand the coverage. Alternatively, develop a new model that also covers the upstream area and can simulate flash floods to better estimate the flood risks at the upstream villages.

Enhanced data availability: Improve the resolution and coverage of hydrometeorological data to enhance hydrological assessments for both floods and droughts. This includes investing in local data collection efforts and integrating advanced remote sensing technologies.

Update climate projections: Update and downscale the climate projections to match with the latest IPCC 6 recommendations and use it to do a comparative analysis of the current projections.

Adaptation/mitigation measures:

Water reservoirs: Construct and expand water reservoirs and elevated water storage facilities to ensure water availability for usage and consumption during dry seasons.

Rainwater harvesting: Promote rainwater harvesting systems to enhance water availability and manage water resources effectively.

Flood control and mitigation: Increase height of levees, construct small-scale dykes and weirs to retain water during rainy seasons and mitigate flood risks; Implement measures to protect riverbanks from erosion, including enhancing the resilience of riparian vegetation; and provide flood-tolerant crop seedlings, such as rice, to ensure agricultural resilience during flooding.

Infrastructure: Enhance road conditions and construct or improve bridges to ensure efficient evacuation and access during emergencies. Improve communication infrastructure to facilitate the reception of early warning messages and vital information from district and provincial levels.

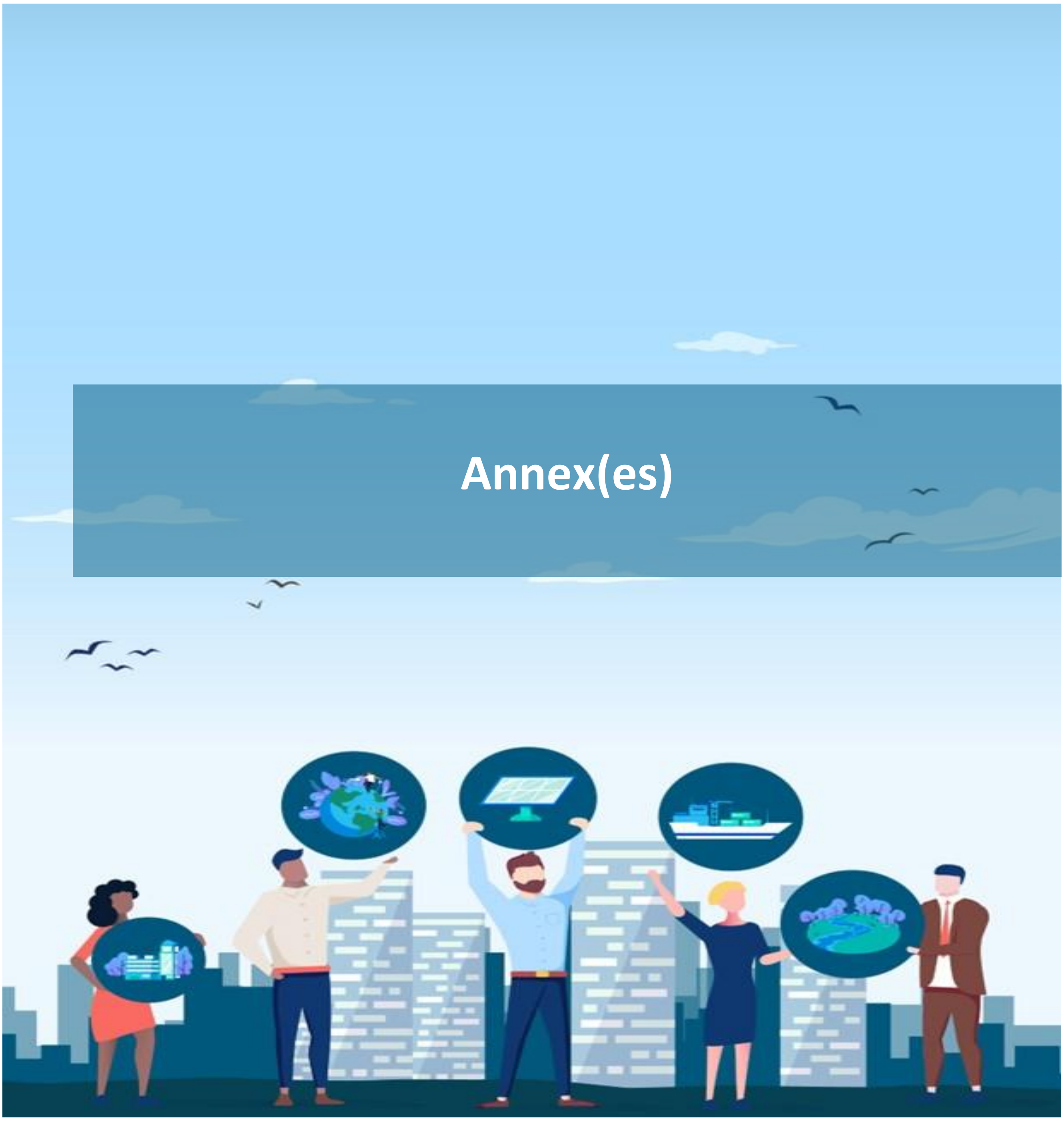
Agriculture: Provide seedlings of drought and flood-resistant crops to support agriculture in areas prone to these climate challenges. Enhance irrigation canals to regulate water levels and improve agricultural productivity.

Community-Centered adaptation: Develop community-based early warning systems tailored to each village's specific flood and drought risks. Include capacity-building initiatives to empower local communities in disaster preparedness and response.

Policy and planning integration: Advocate for policies that integrate climate resilience into local development plans and zoning regulations. Strengthen coordination between stakeholders, policymakers, and development organizations to prioritize climate change adaptation efforts in the region.

Economic impact mitigation: Develop strategies to mitigate the wide-ranging and long-term economic impacts of flooding, as also evidenced by the 2019 events. Implement effective post-disaster recovery and resilience-building efforts, including financial support mechanisms and infrastructure rehabilitation, to foster sustainable development in flood-prone reg

Annex(es)



Annex 1: Climate Scenarios

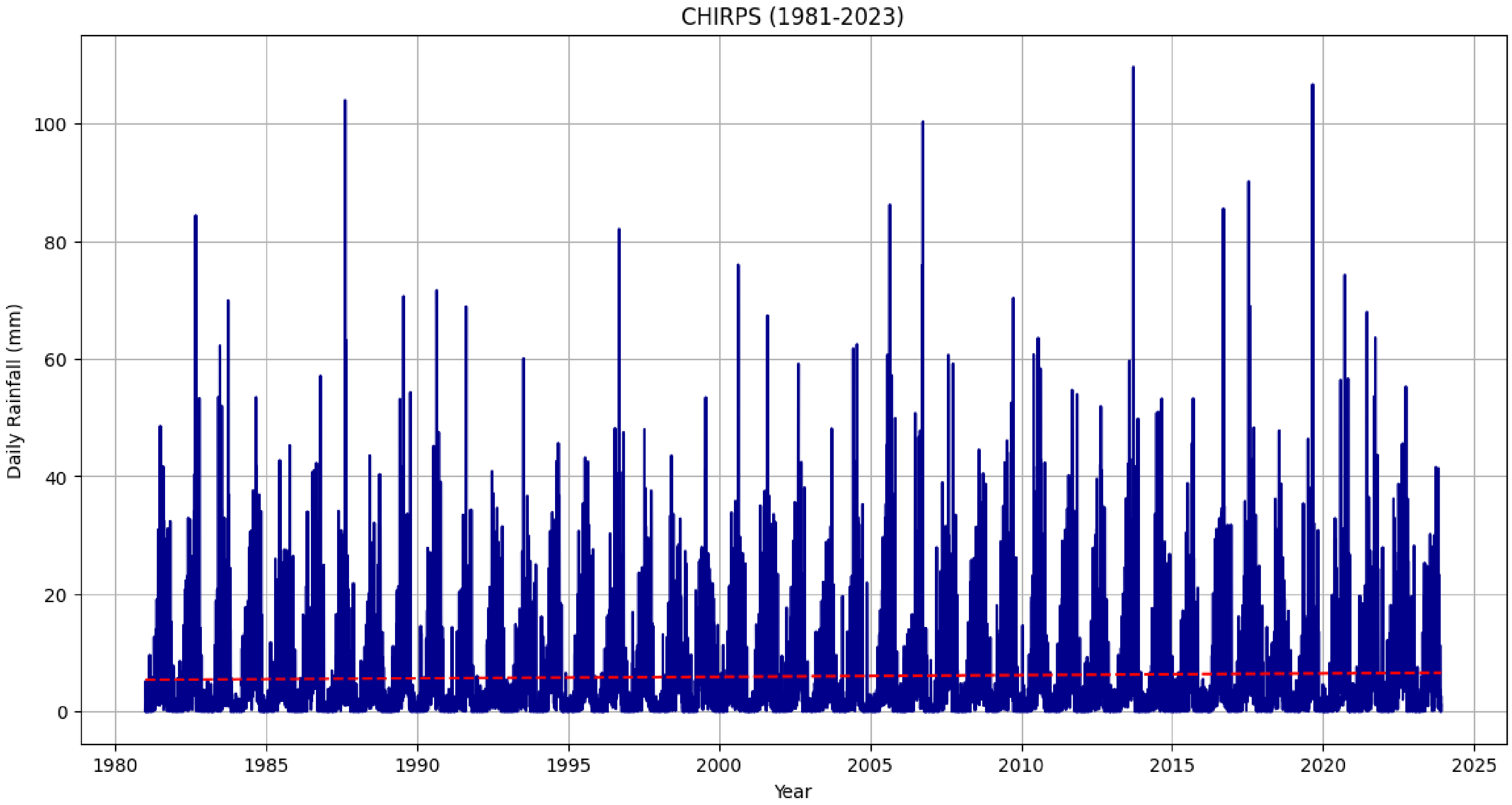


Figure 37 Temporal trend of historical rainfall (CHIRPS) - 1981-2023

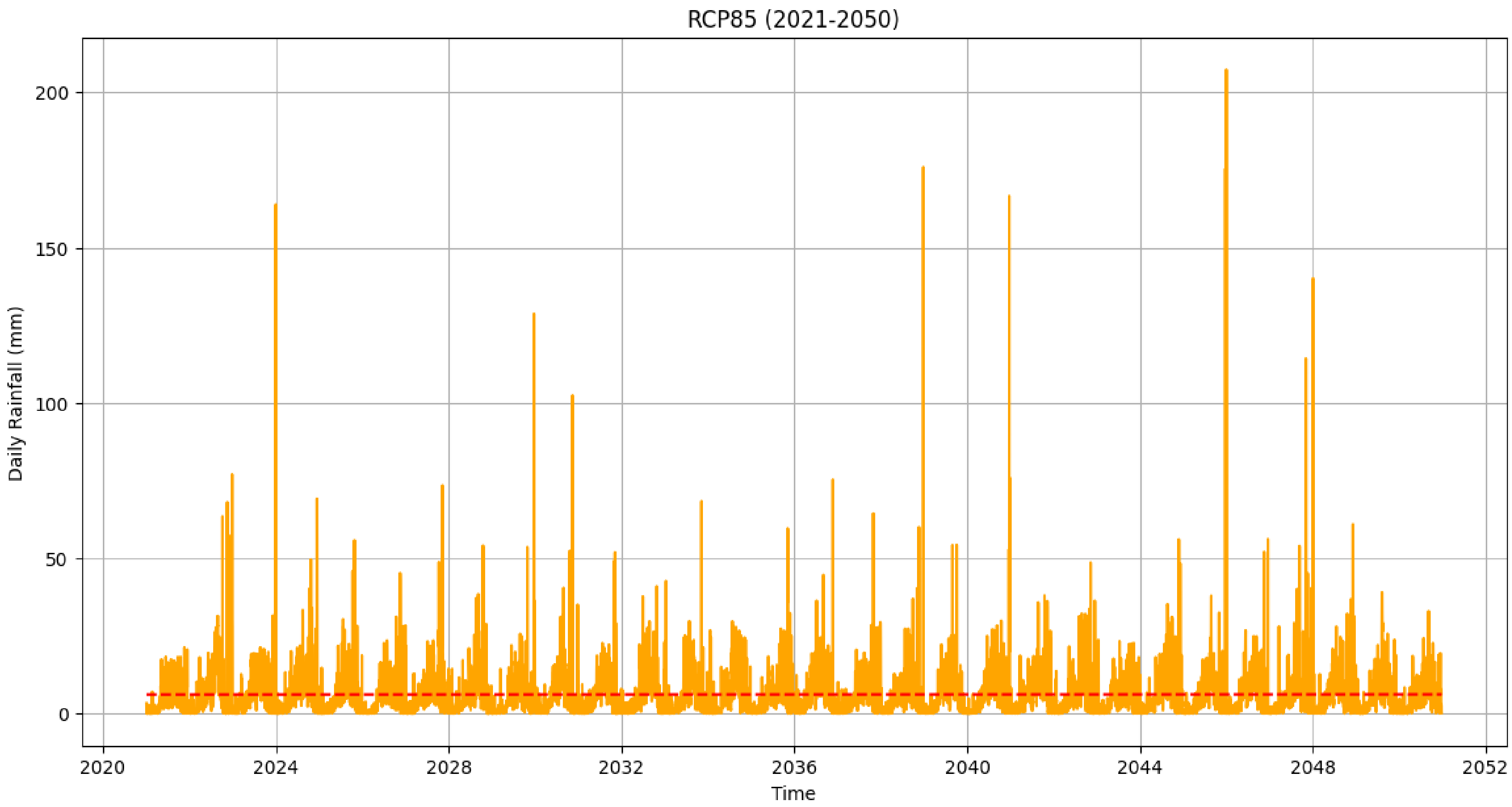


Figure 38 Temporal trend of projected reainfall (RCP85) - 2021-2050

Annex 2: Flood

Current Scenario

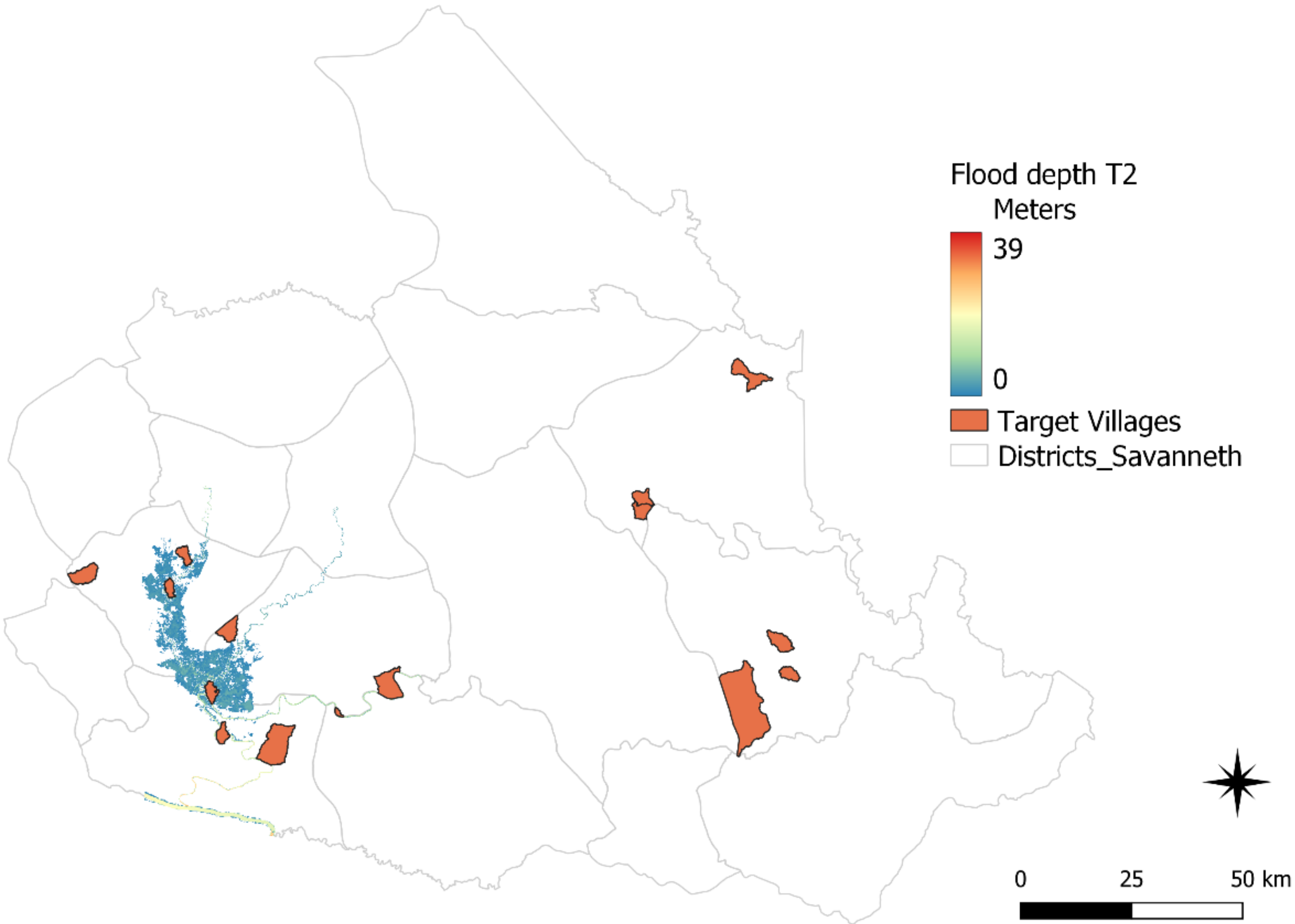


Figure 39 Flood depth and extent at 2 year (T2) return period (current scenario).

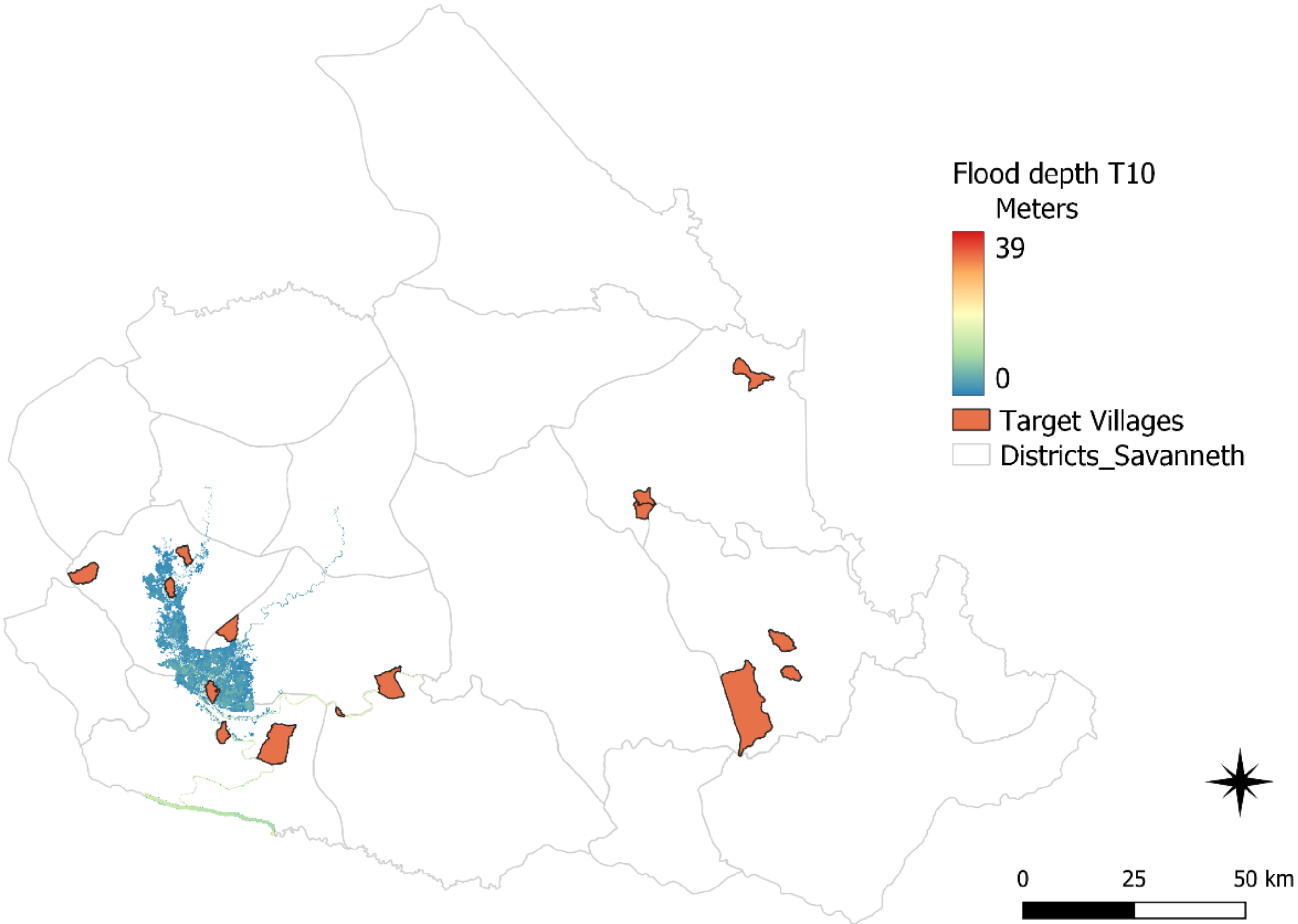


Figure 40 Flood depth and extent at 10 year (T10) return period (current scenario).

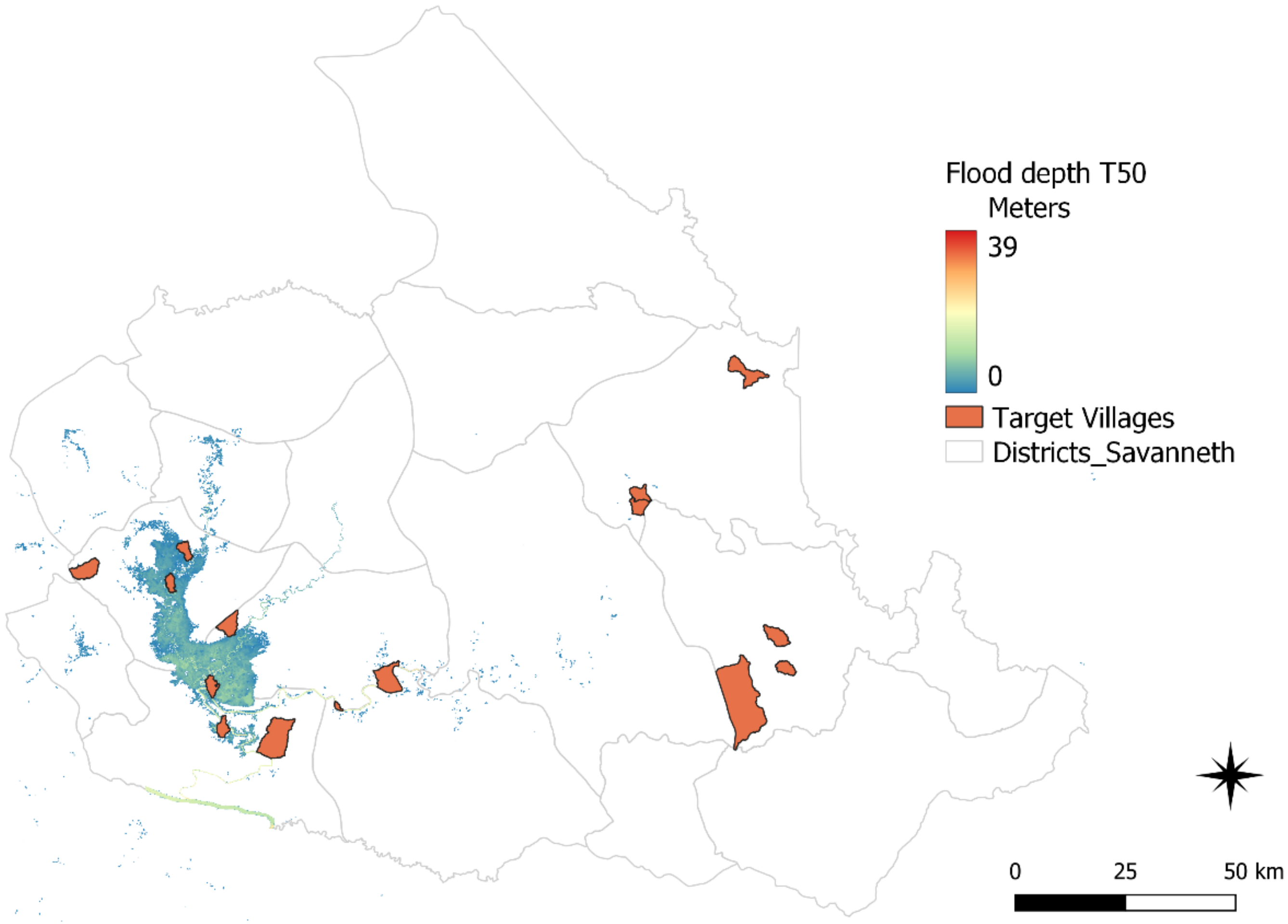


Figure 41 Flood depth and extent at 50 year (T50) return period (current scenario).

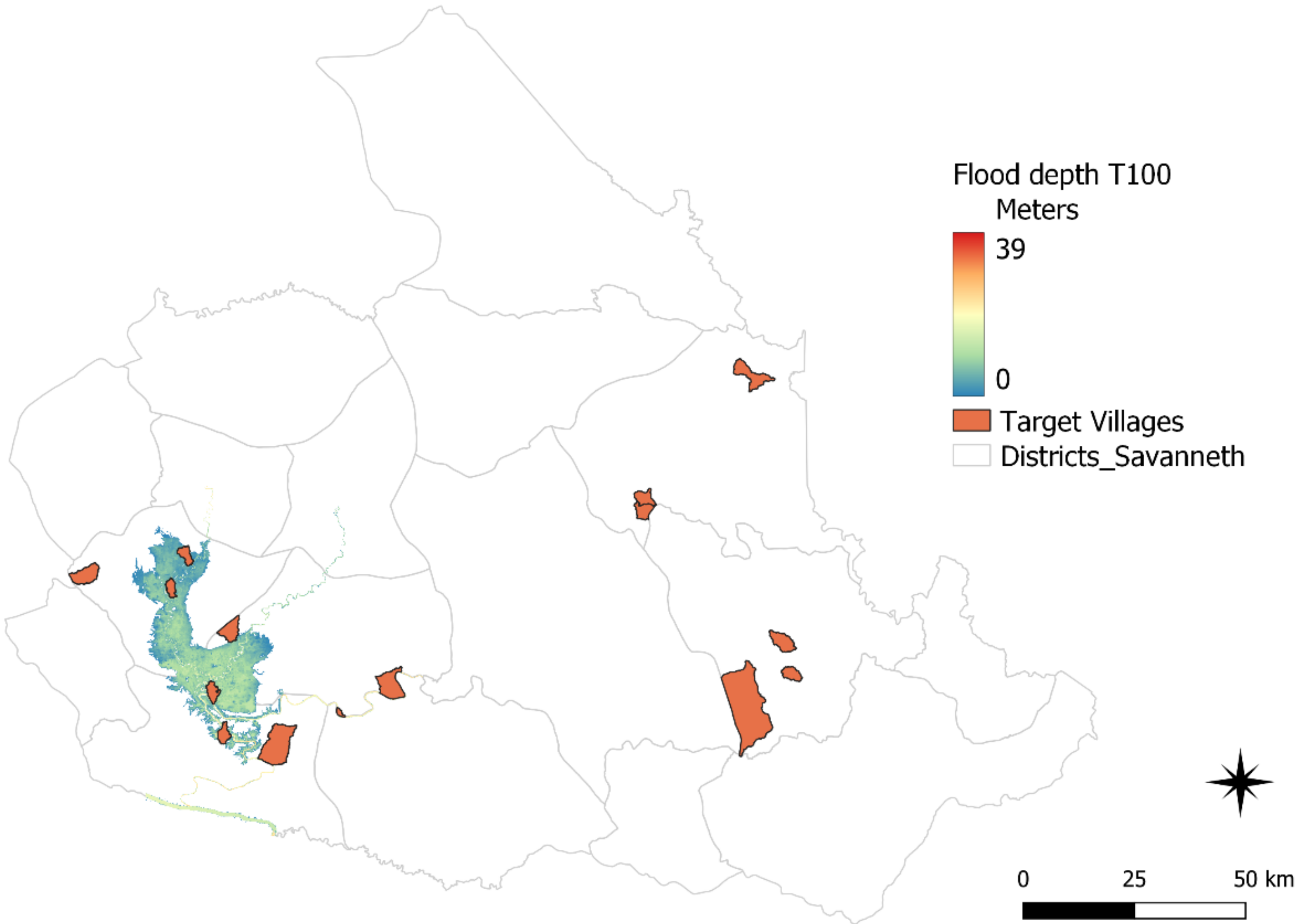


Figure 42 Flood depth and extent at 100 year (T100) return period (current scenario).

Future scenario

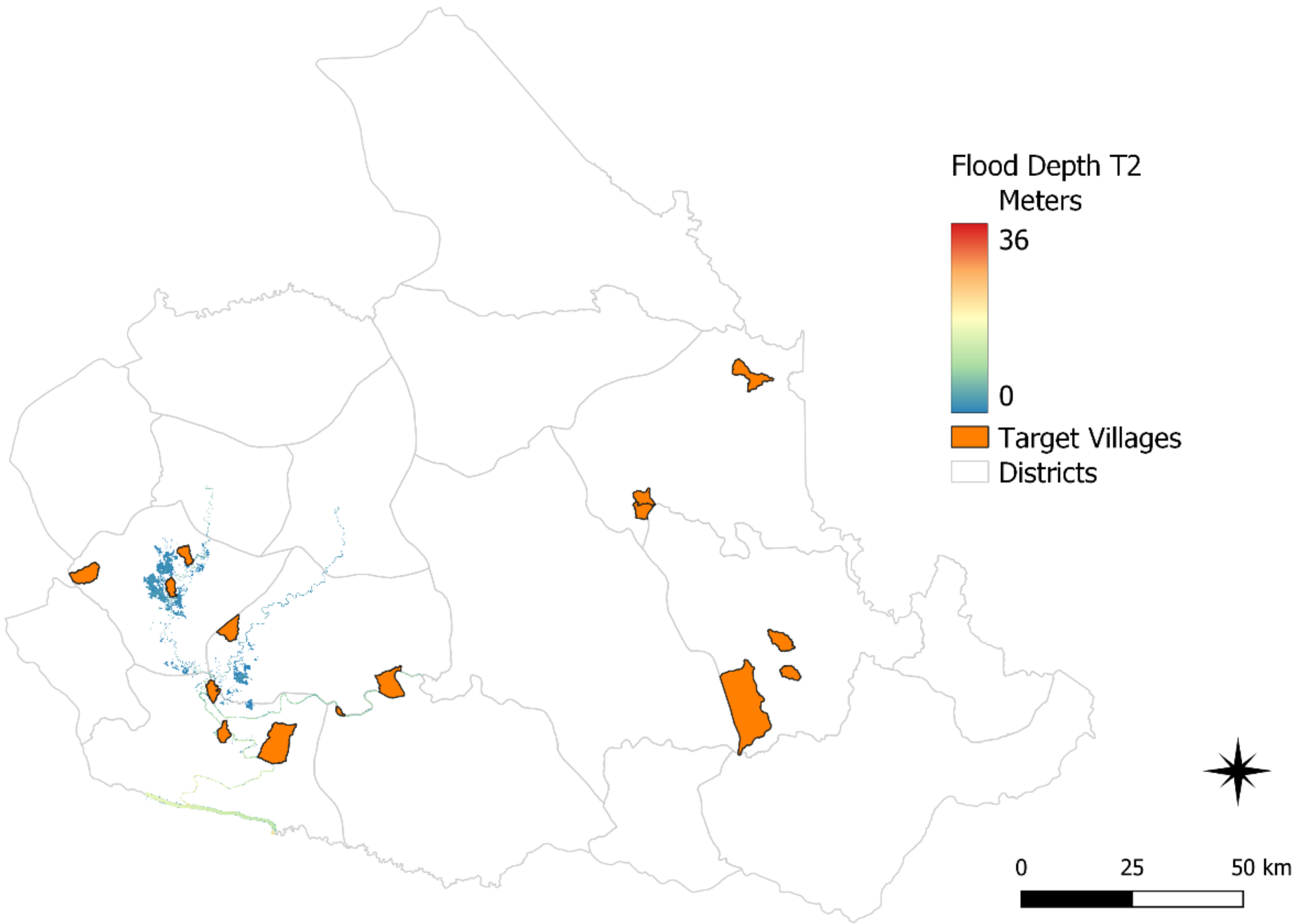


Figure 43 Flood depth and extent at 2 year (T2) return period (future scenario-RCP85).

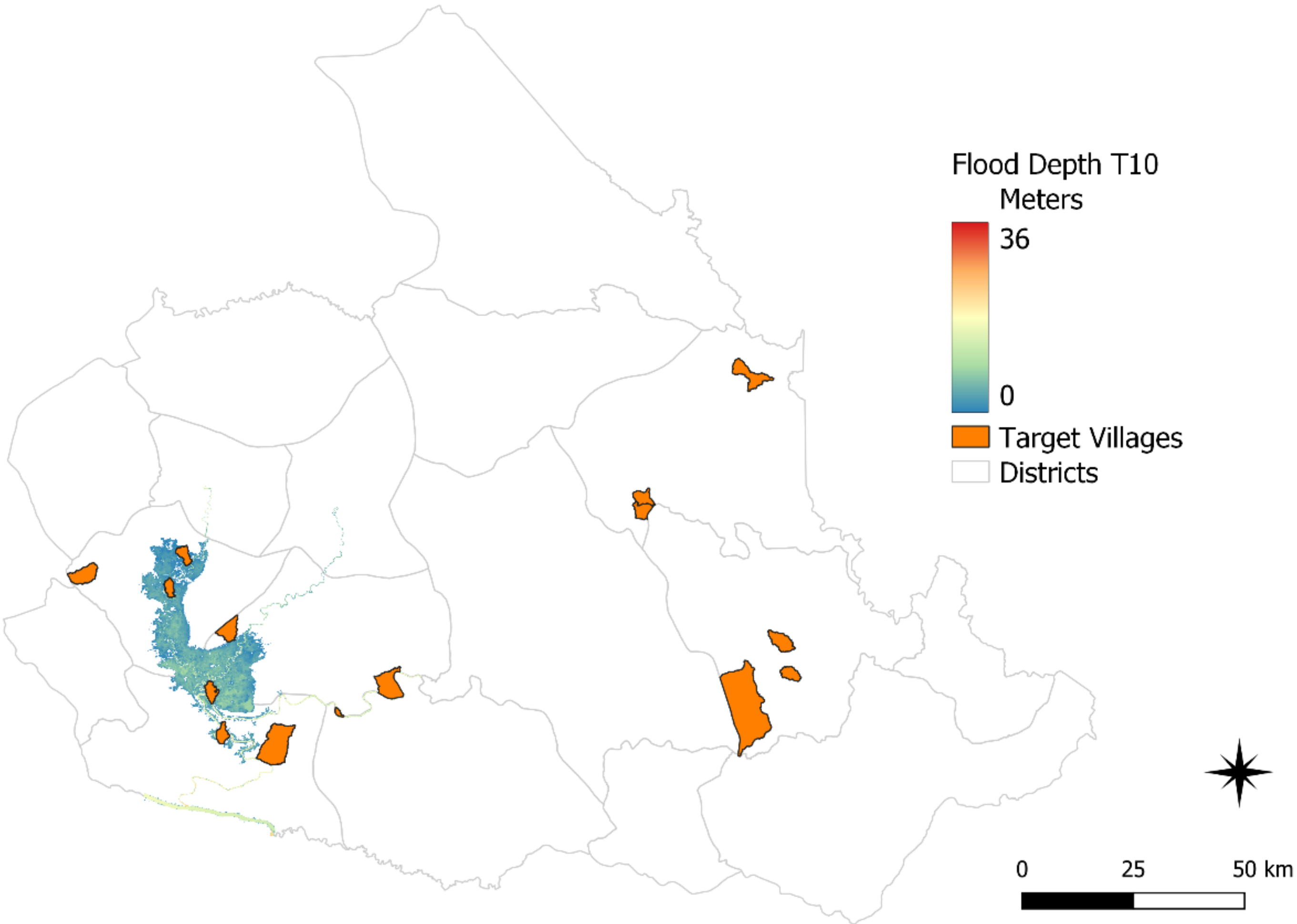


Figure 44 Flood depth and extent at 10 year (T10) return period (future scenario-RCP85).

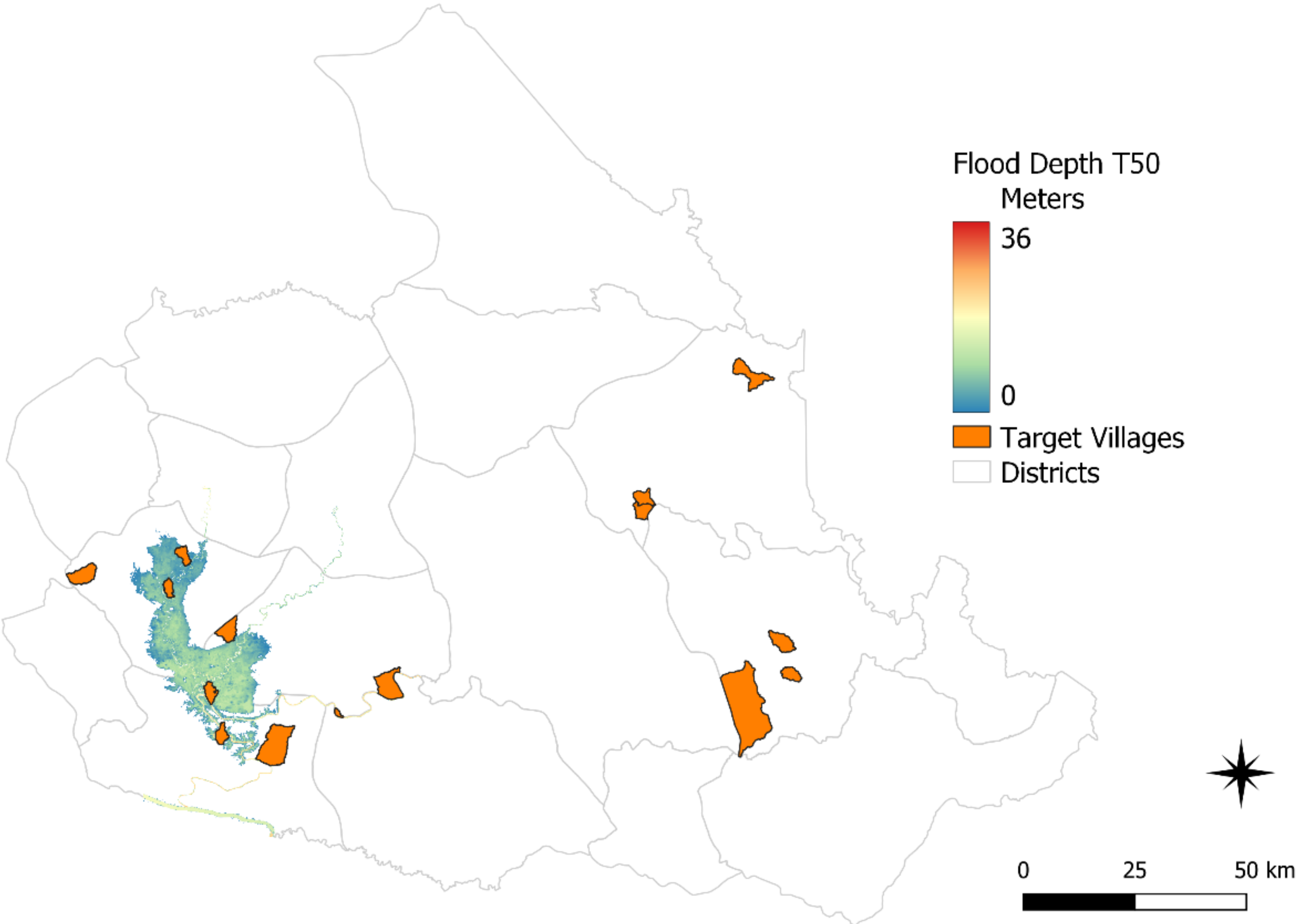


Figure 45 Flood depth and extent at 50 year (T50) return period (future scenario-RCP85)

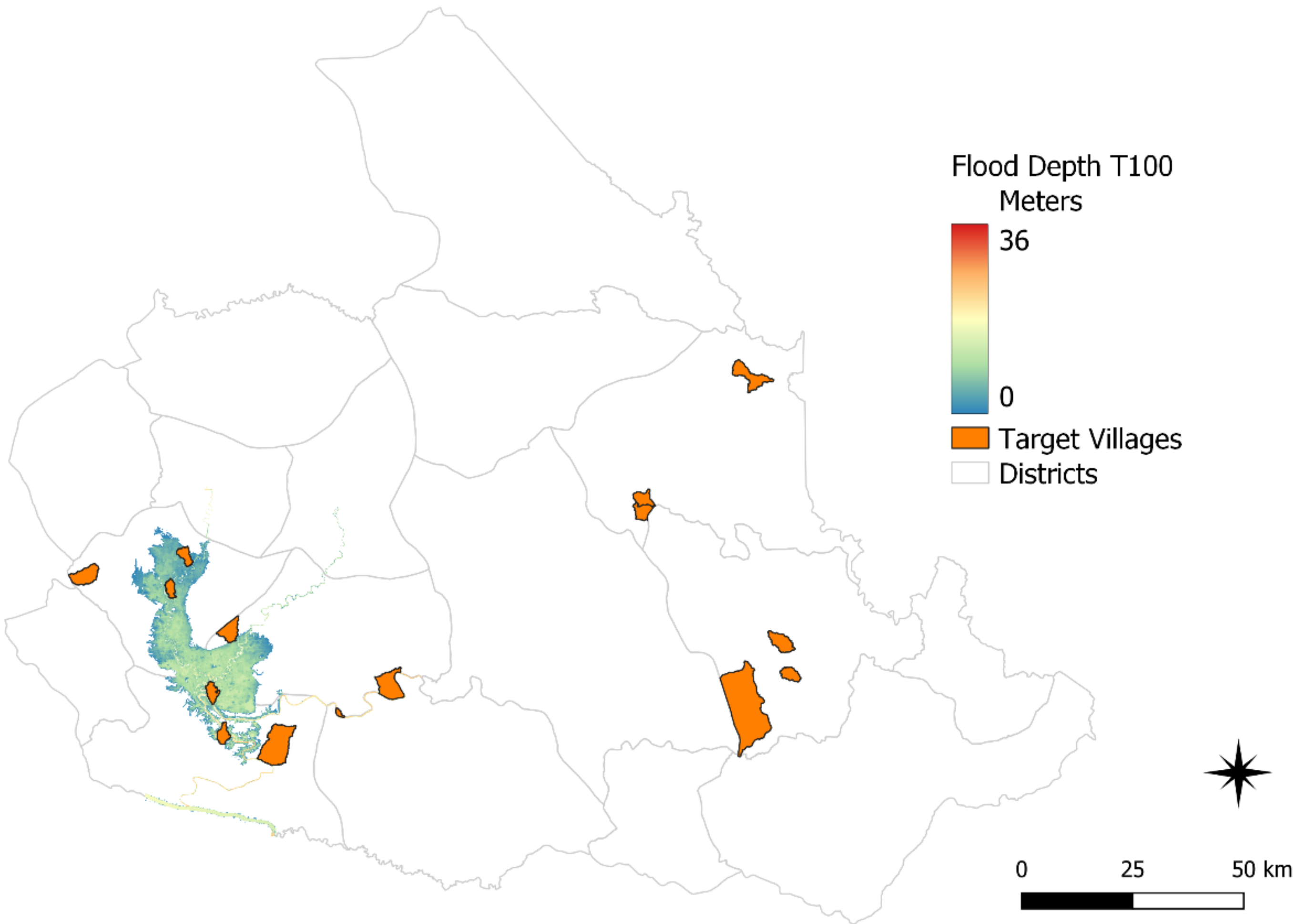


Figure 46 Flood depth and extent at 100 year (T100) return period (future scenario-RCP85).

Annex 3: Drought

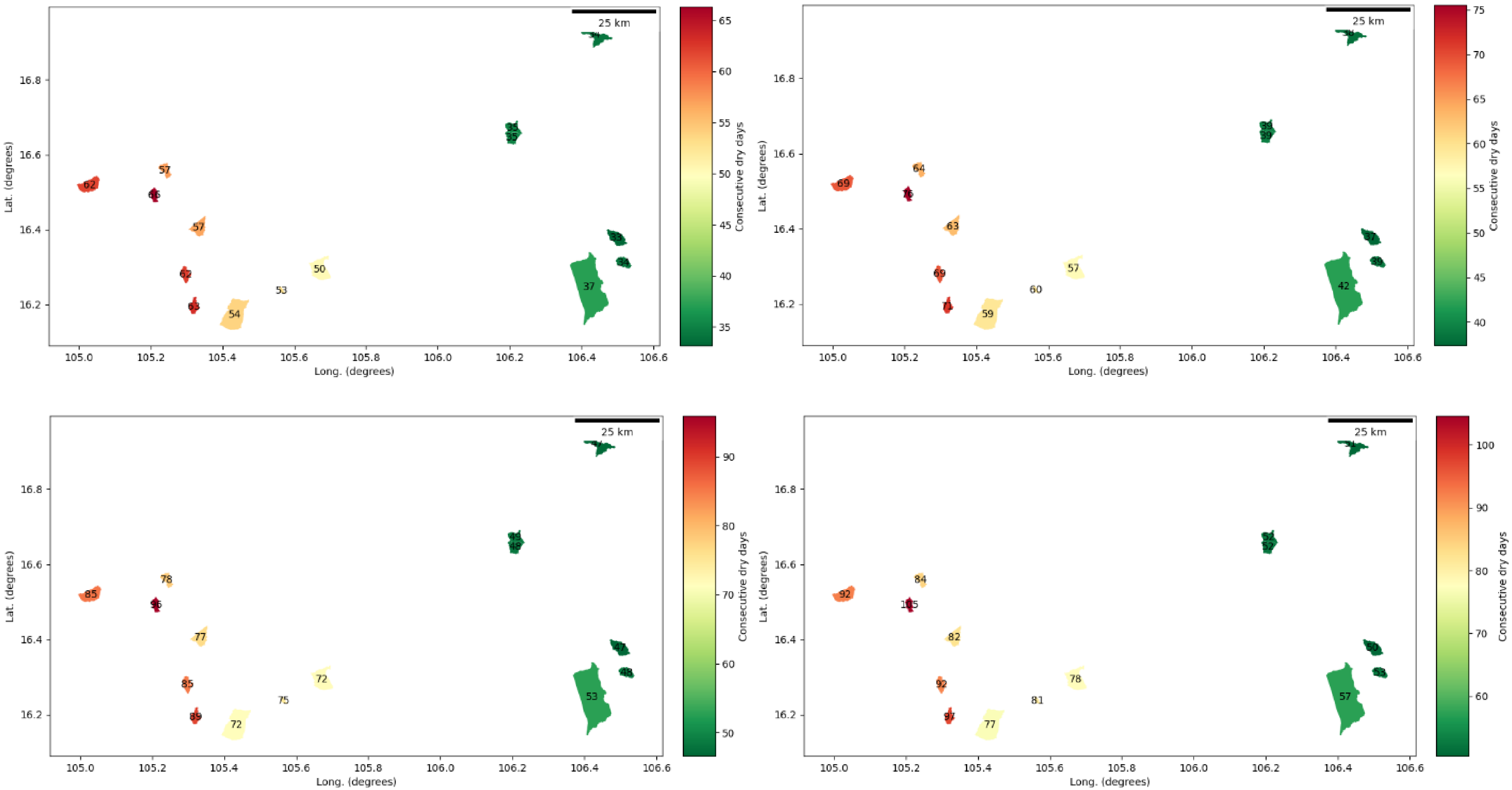


Figure 47 Current scenario: consecutive Dry Days (Yearly mean per village): Return level (days) of a 1/5 year (Left top), 1/10 year (right top), 1/50 year (Left bottom) a 1/100 year (Right bottom)

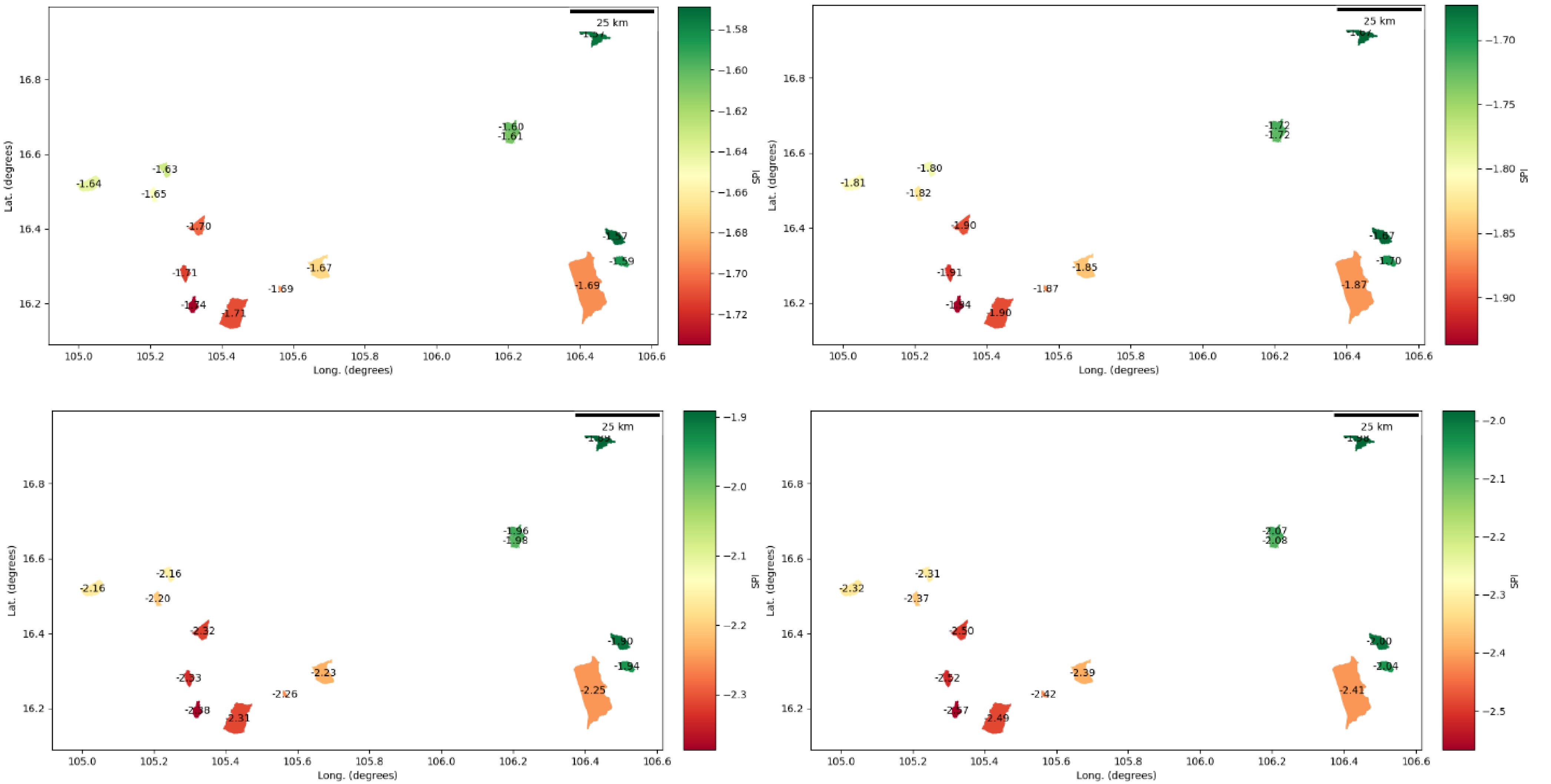


Figure 48 Current scenario: drought Hazard maps giving the mean SP per village for a 3 month moving average with return period 1/5 (Left top), return period 1/10 (Right top), return period 1/50 (Left Bottom), return period 1/100 (Right Bottom).

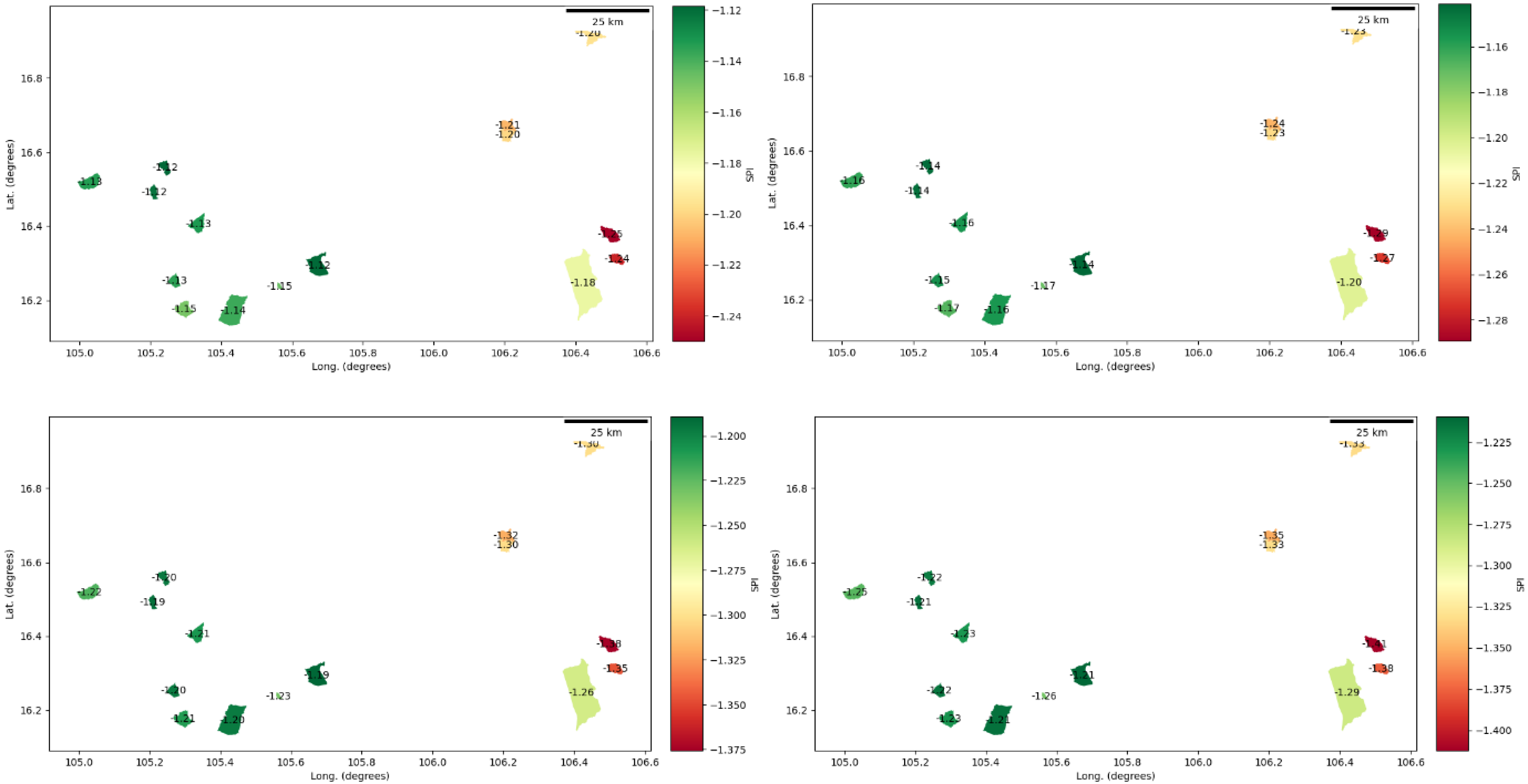


Figure 49 Future scenario: drought Hazard maps giving the mean SP per village for a 3 month moving average with return period 1/5 (Left top), return period 1/10 (Right top), return period 1/50 (Left Bottom), return period 1/100 (Right Bottom).

Annex 4: Asset mapping

Table 7 Crop fractions for Savannakhet based on the 2022 agricultural census.

Crop	**Fraction**
Lowland rainfed paddy	75.55%
Dry season paddy	11.07%
Vegetables	6.22%
Sugarcane	2.27%
Starchy Roots	1.91%
Total Maize	1.16%
Soybean	0.73%
Tobacco	0.32%
Upland rainfed paddy	0.26%
Peanut	0.22%
Cotton	0.22%
Mungbean	0.07%
Coffee	0.00%
Tea	0.00%
Total	**100.00%**

Annex 5: Exposure

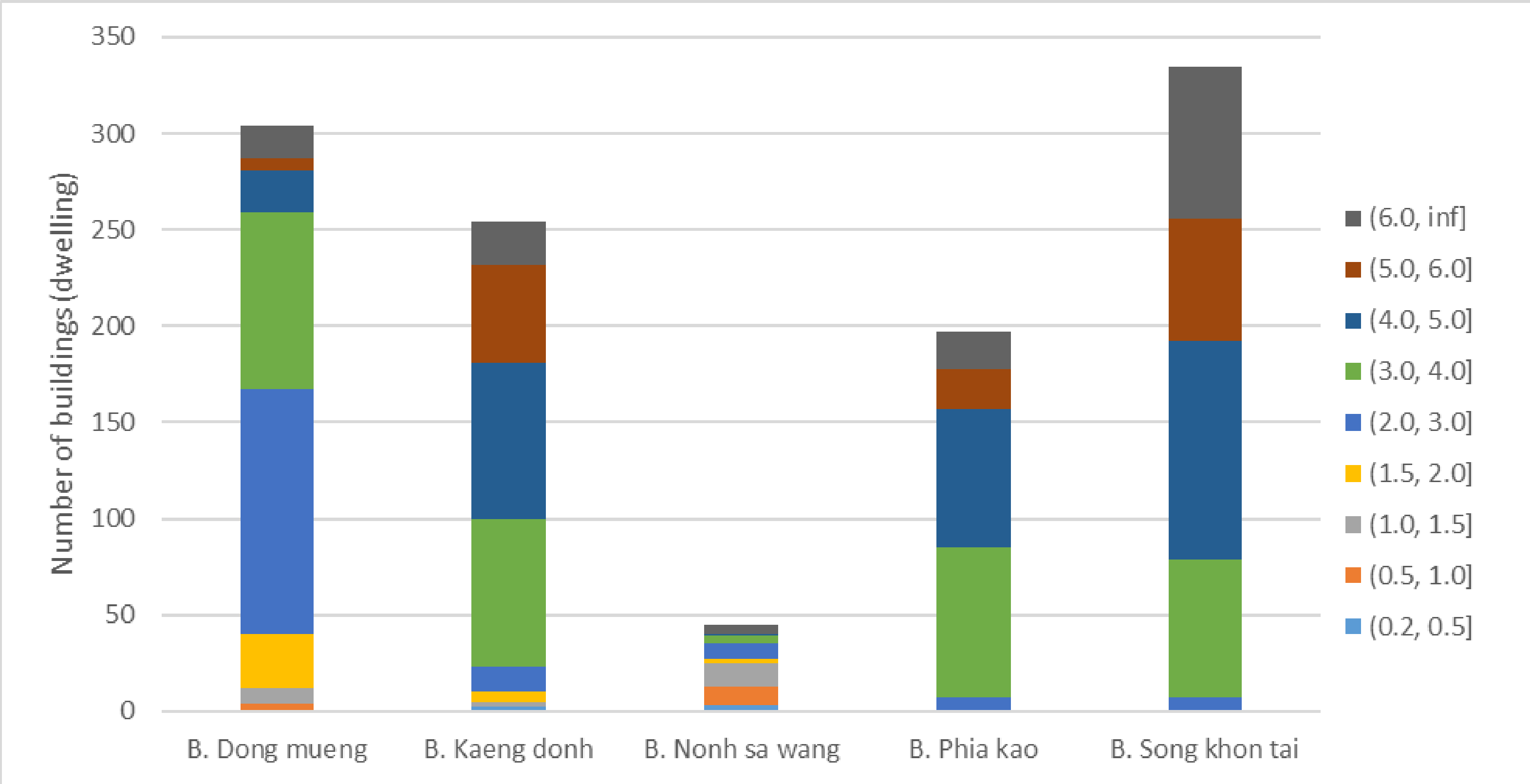


Figure 50 Number of dwellings exposed to flooding during a 1 in 100 year return period indicating the flood height they would be exposed to.

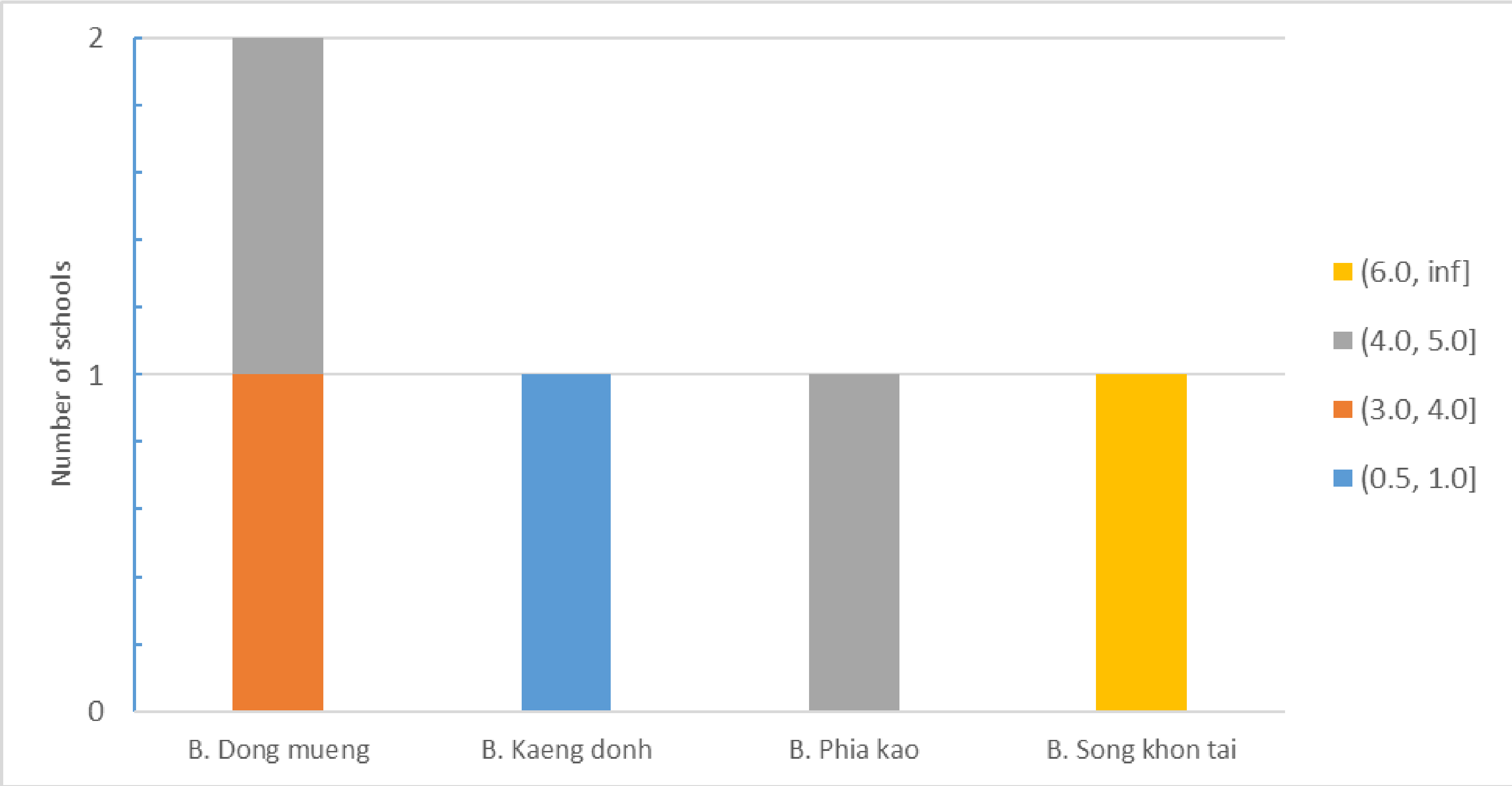


Figure 51 Number of schools exposed to a 1 in 100 year flood per village and indicating the flood height they would be exposed

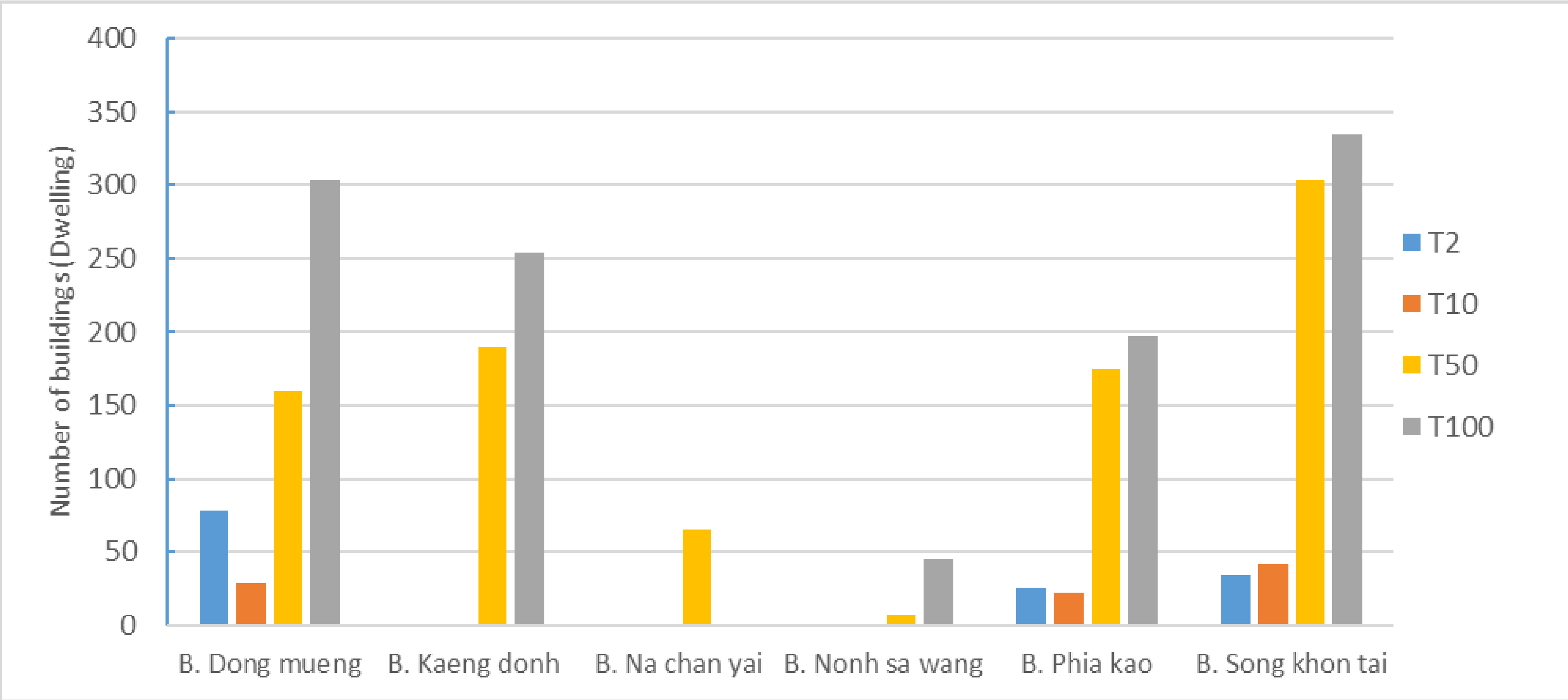


Figure 52 Overview of the exposed dwellings for the different flood hazard scenarios based on the different return periods

Annex 6: Flood impact and risk

1. Infrastructure

Table 8 Monetary values of assets based on sectoral sub-divisions

category	cost(LAK)	unit	SectorialSubdivision
Road_motorway	320,000	USD/km	Road_Asphalt
Road_primary	350,000	USD/km	Road_Concrete
Road_secondary	250,000	USD/km	Road_Bittument
Road_tertiary	140,000	USD/km	Road_earth
Dwelling	3,050,000	LAK/m2	Dwelling
CommunityCentre	4,740,000	LAK/m2	CommunityCentre
Courthouse	3,330,000	LAK/m2	Courthouse
Government	3,410,000	LAK/m2	Government
Townhall	9,820,000	LAK/m2	Townhall
Policestation	4,580,000	LAK/m2	Policestation
Marketplace	2,150,000	LAK/m2	Marketplace
Childcare	4,380,000	LAK/m2	Childcare
College	3,710,000	LAK/m2	College
Education_office	4,260,000	LAK/m2	Education_office
Preschool	3,990,000	LAK/m2	Preschool
School	3,710,000	LAK/m2	School
University	4,460,000	LAK/m2	University
Clinic	3,510,000	LAK/m2	Clinic
Hospital	4,730,000	LAK/m2	Hospital
Pharmacy	3,810,000	LAK/m2	Pharmacy
FireStation	4,610,000	LAK/m2	FireStation
Water_canal	860,000	LAK/km	Water_canal
Water_drain	620,000	LAK/m	Water_drain
Bridge	18,000	USD/meter long	Bridge

Table 9 Snap-shot of the data for Dong mueng village and the dwellings in the village (100 year return period).

uucne	Sectorial Subdivision	Variable	Value	Count	Area	Total cost (USD)
B. Dong mueng	Dwelling	Flood_bins	(0.2, 0.5]	1	40	5789
B. Dong mueng	Dwelling	Flood_bins	(0.5, 1.0]	3	216	30937
B. Dong mueng	Dwelling	Flood_bins	(1.0, 1.5]	8	427	61153
B. Dong mueng	Dwelling	Flood_bins	(1.5, 2.0]	28	2427	347974
B. Dong mueng	Dwelling	Flood_bins	(2.0, 3.0]	127	11404	1634786
B. Dong mueng	Dwelling	Flood_bins	(3.0, 4.0]	92	6679	957425
B. Dong mueng	Dwelling	Flood_bins	(4.0, 5.0]	22	1282	1837400
B. Dong mueng	Dwelling	Flood_bins	(5.0, 6.0]	6	745	106786
B. Dong mueng	Dwelling	Flood_bins	(6.0, inf]	17	1623	232643

Damage cost: current

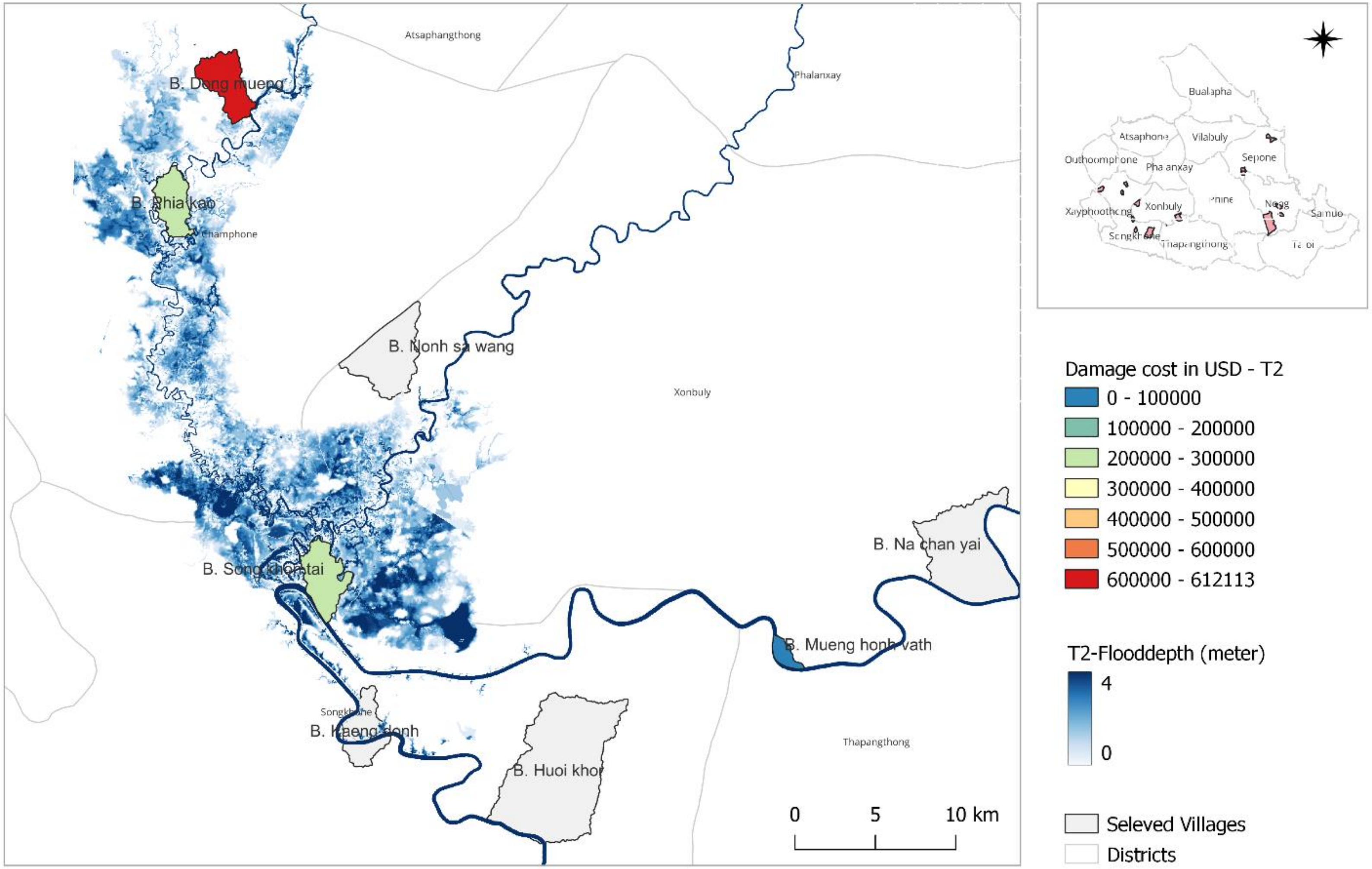


Figure 53 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 2 year event

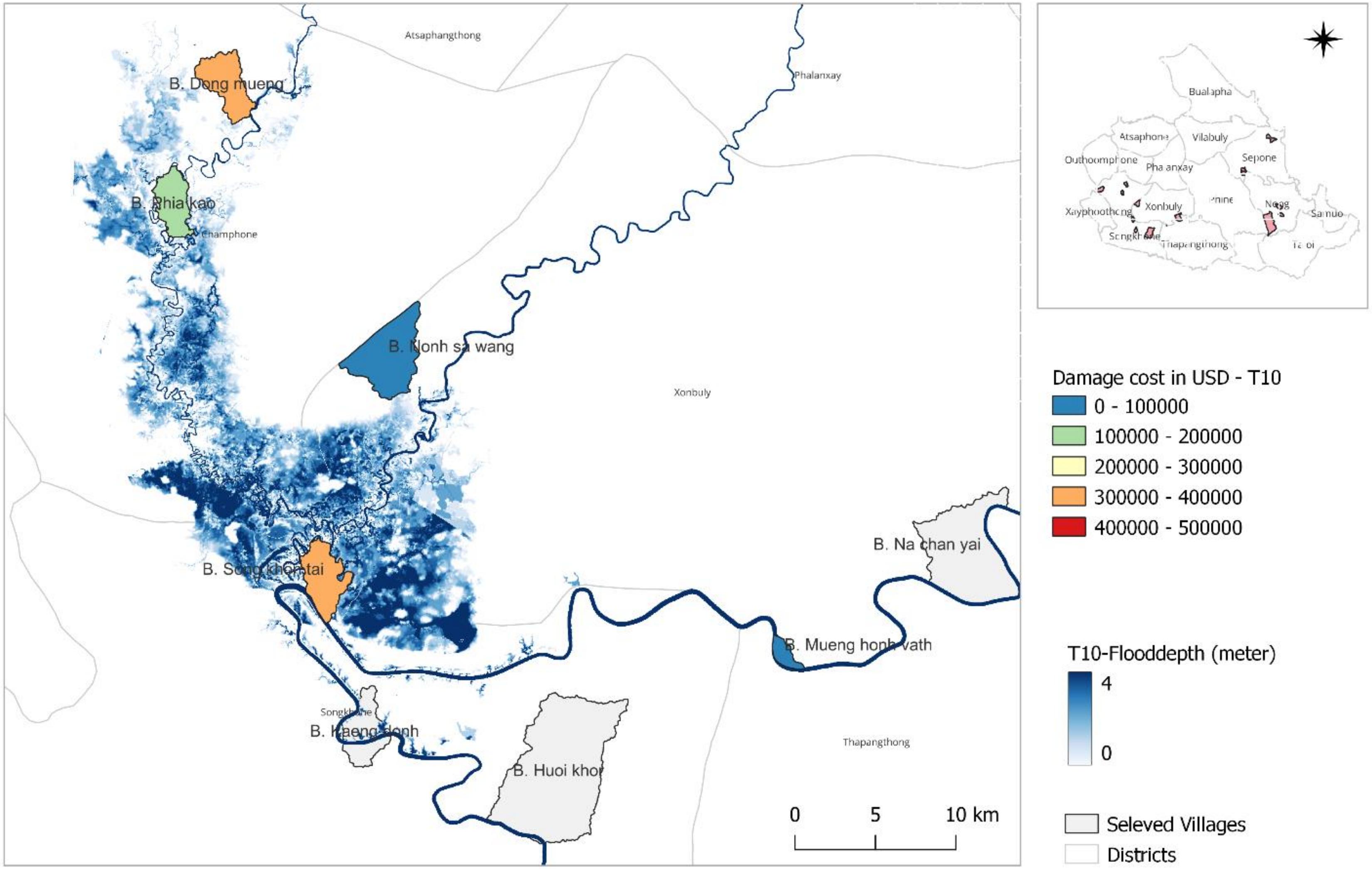


Figure 54 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 10 year event

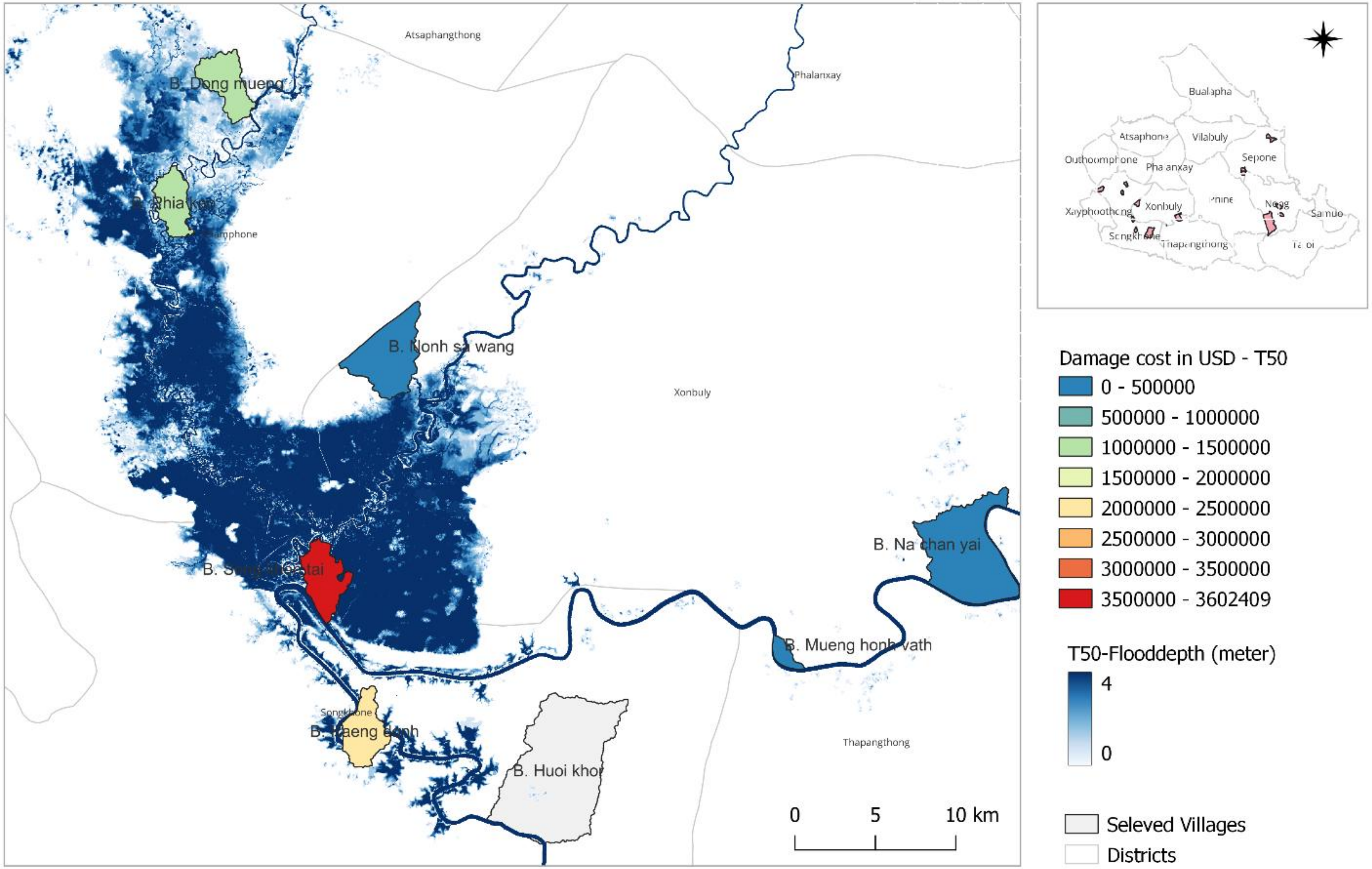


Figure 55 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 50 year event

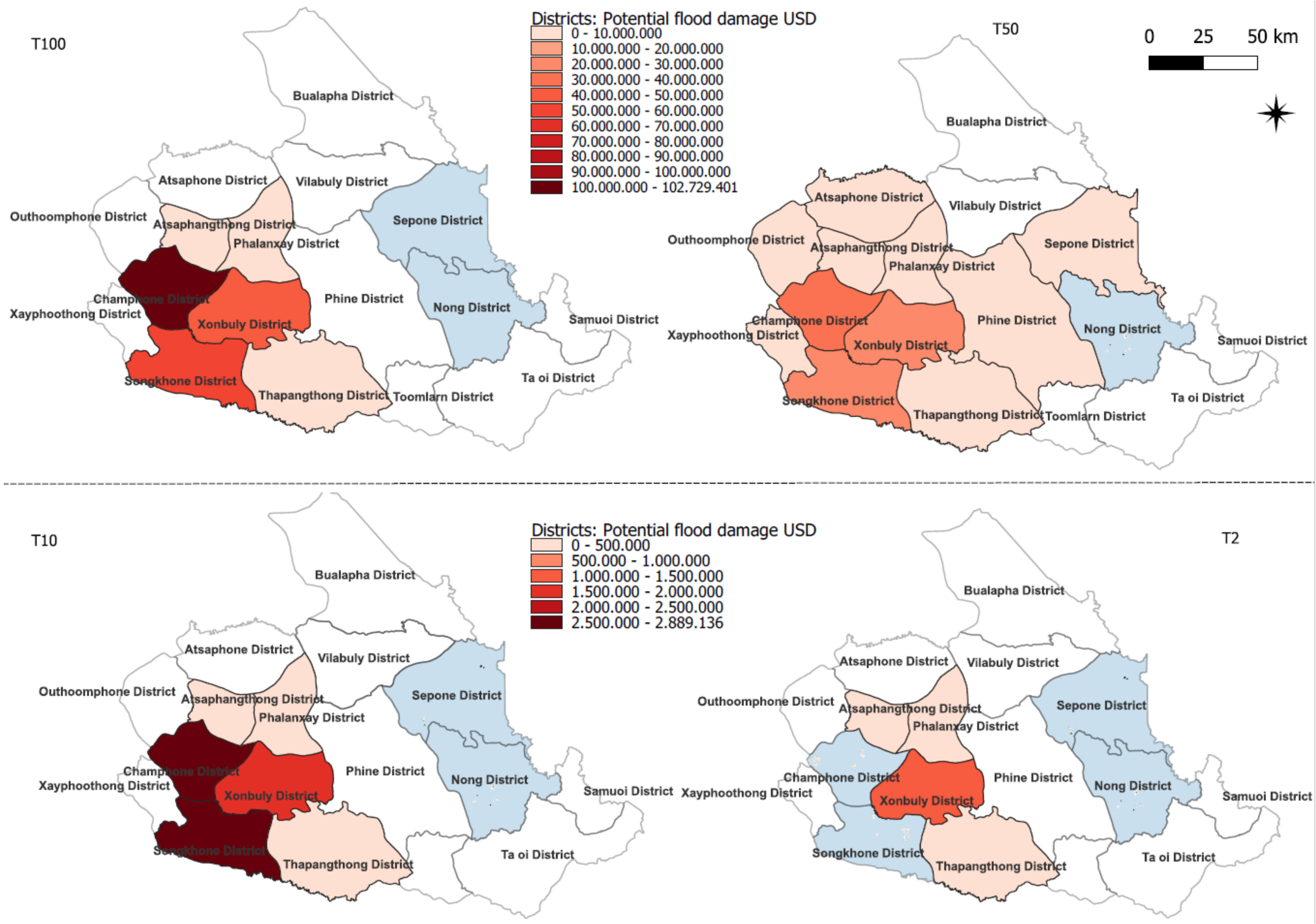


Figure 56: Flood damage in USD at district level

Damage cost: future

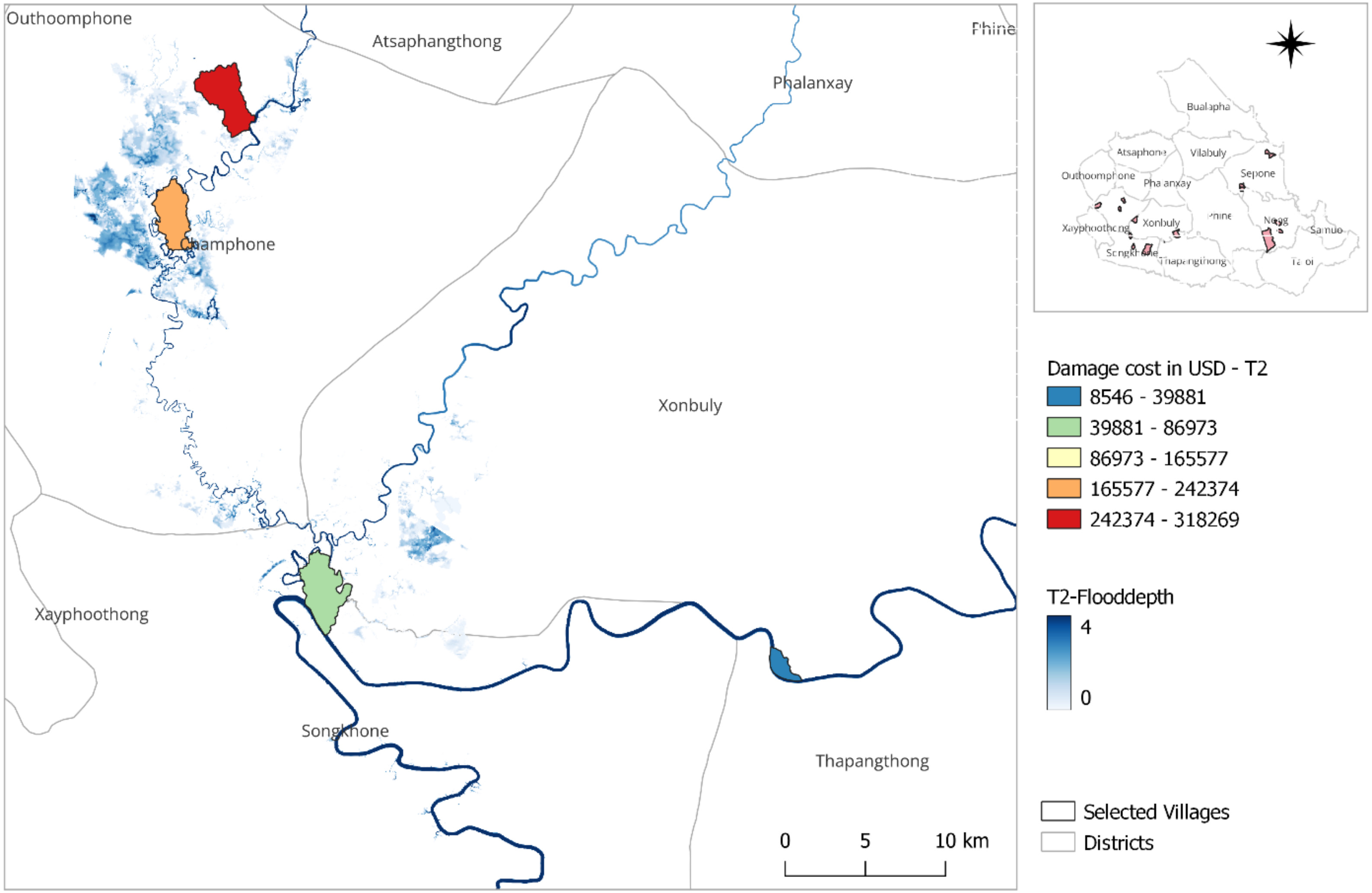


Figure 57 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 2 year event-future scenario

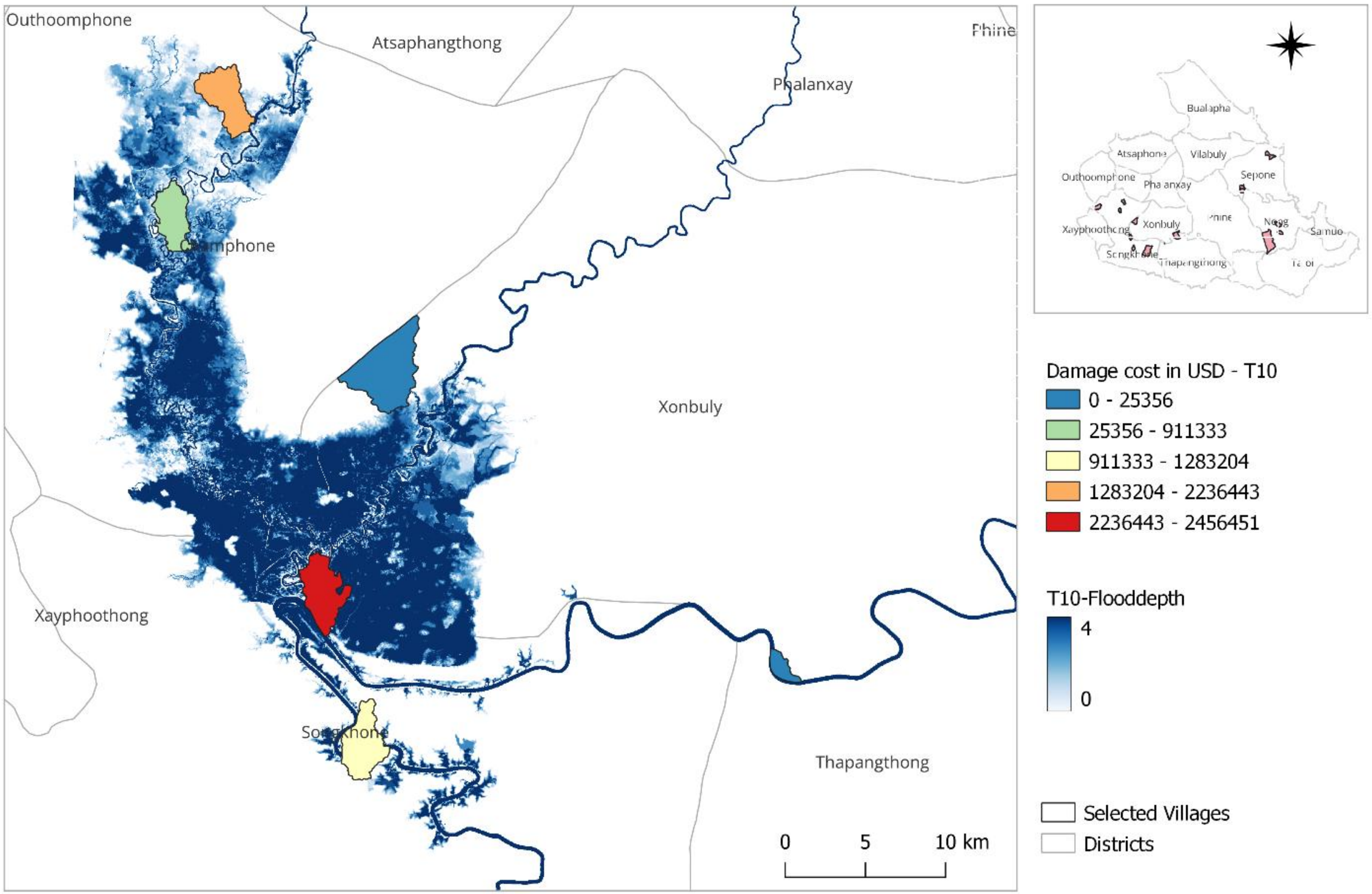


Figure 58 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 10 year event-future scenario

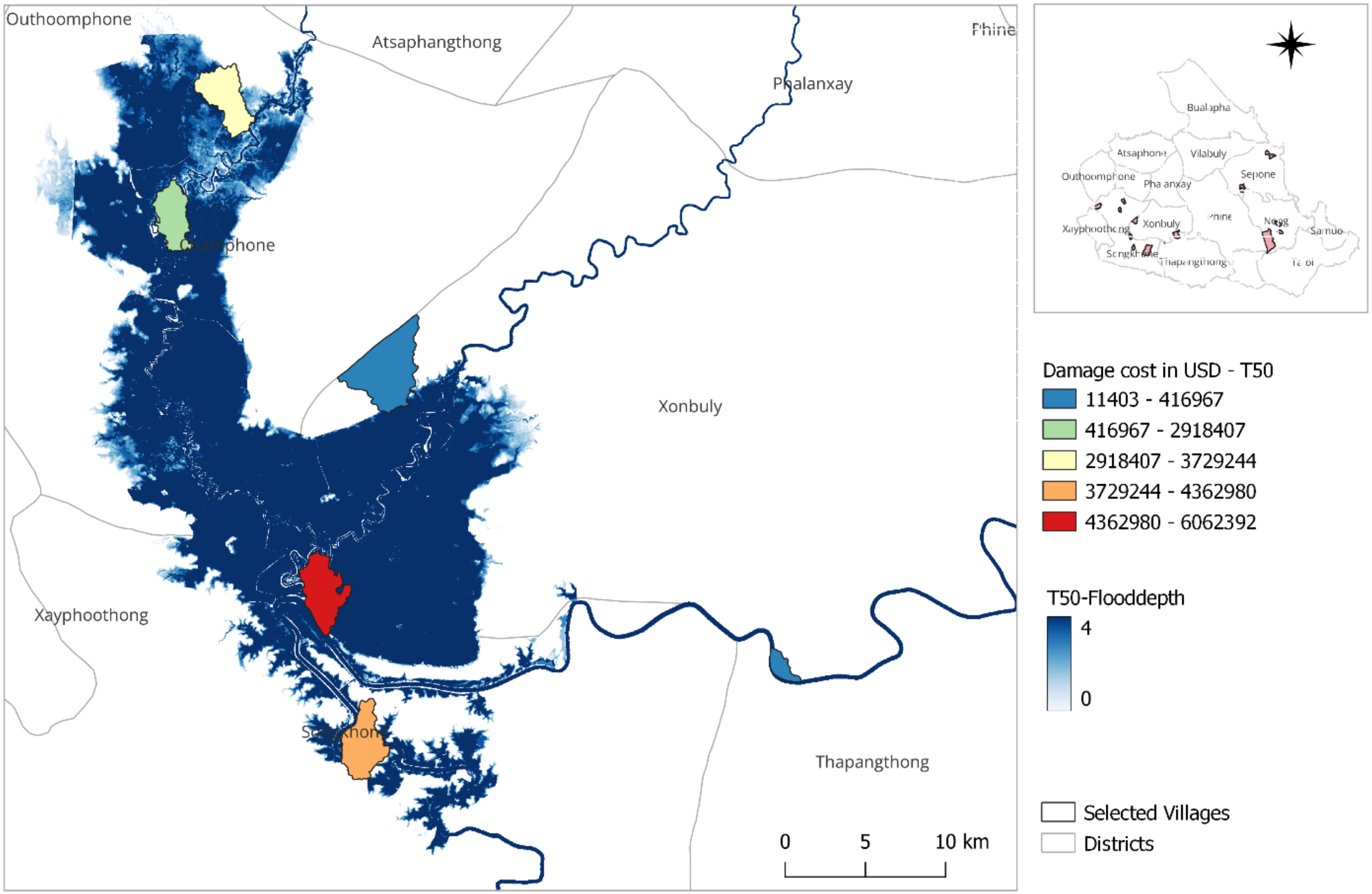


Figure 59 Impact map of the cost of flood damage in USD aggregated by village for a 1 in 50 year event-future scenario

2. Population - Casualties-current

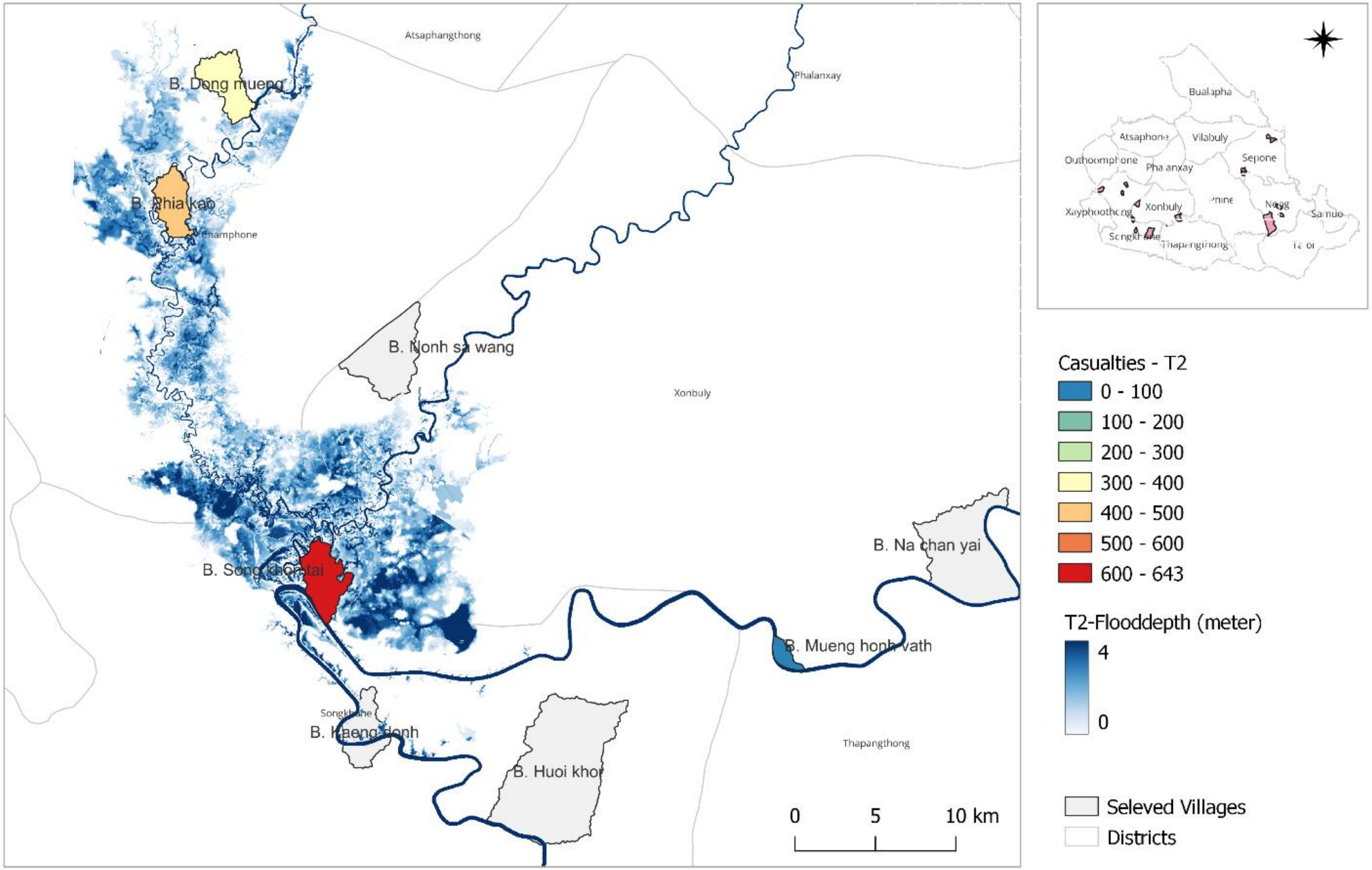


Figure 60 Potential casualties in villages due to flooding at 1 in 50 year return period for current scenario.

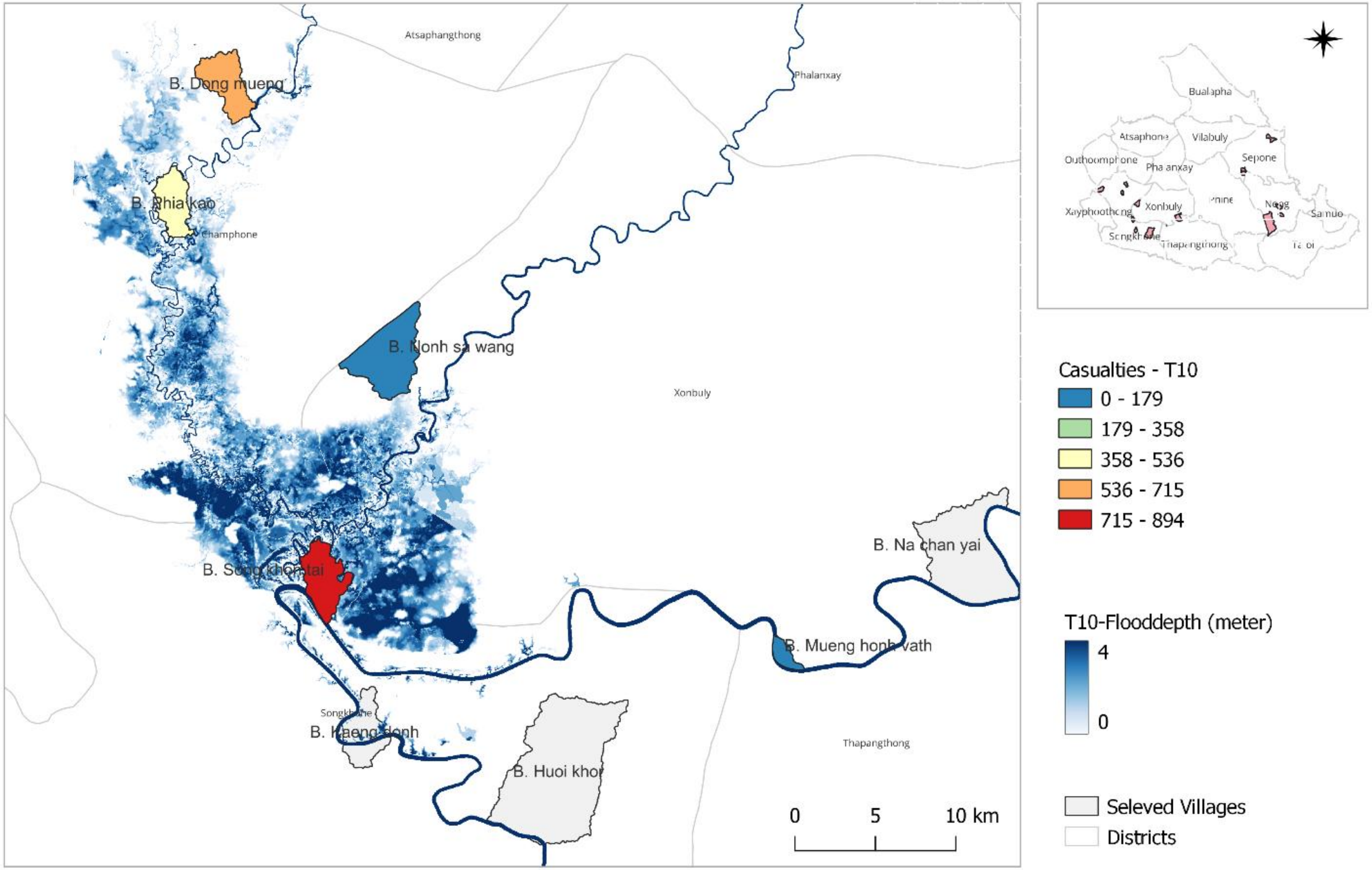


Figure 61 Potential casualties in villages due to flooding at 1 in 10 year return period for current scenario..

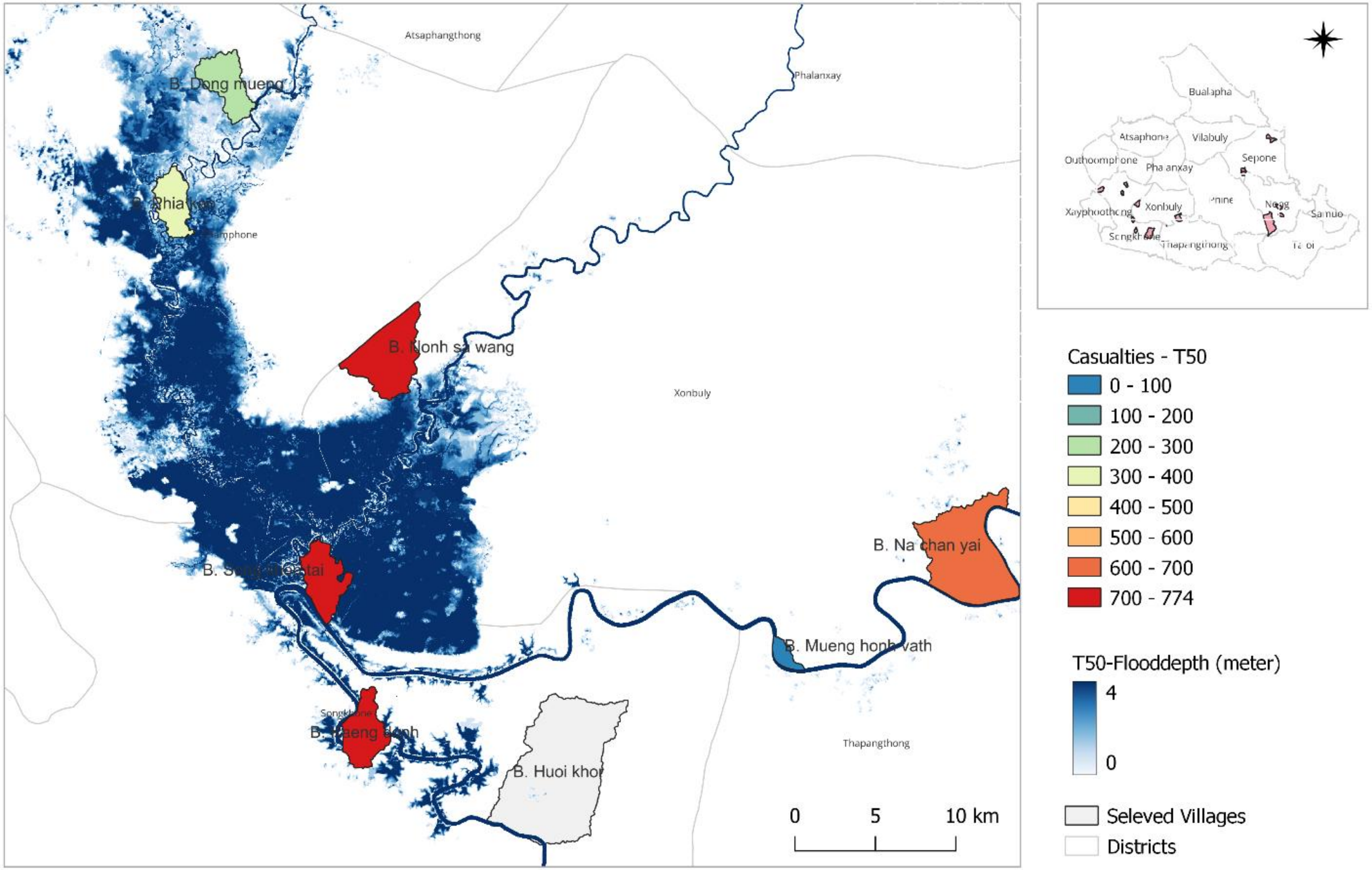


Figure 62 Potential casualties in villages due to flooding at 1 in 50 year return period for current scenario..

Casualties – future

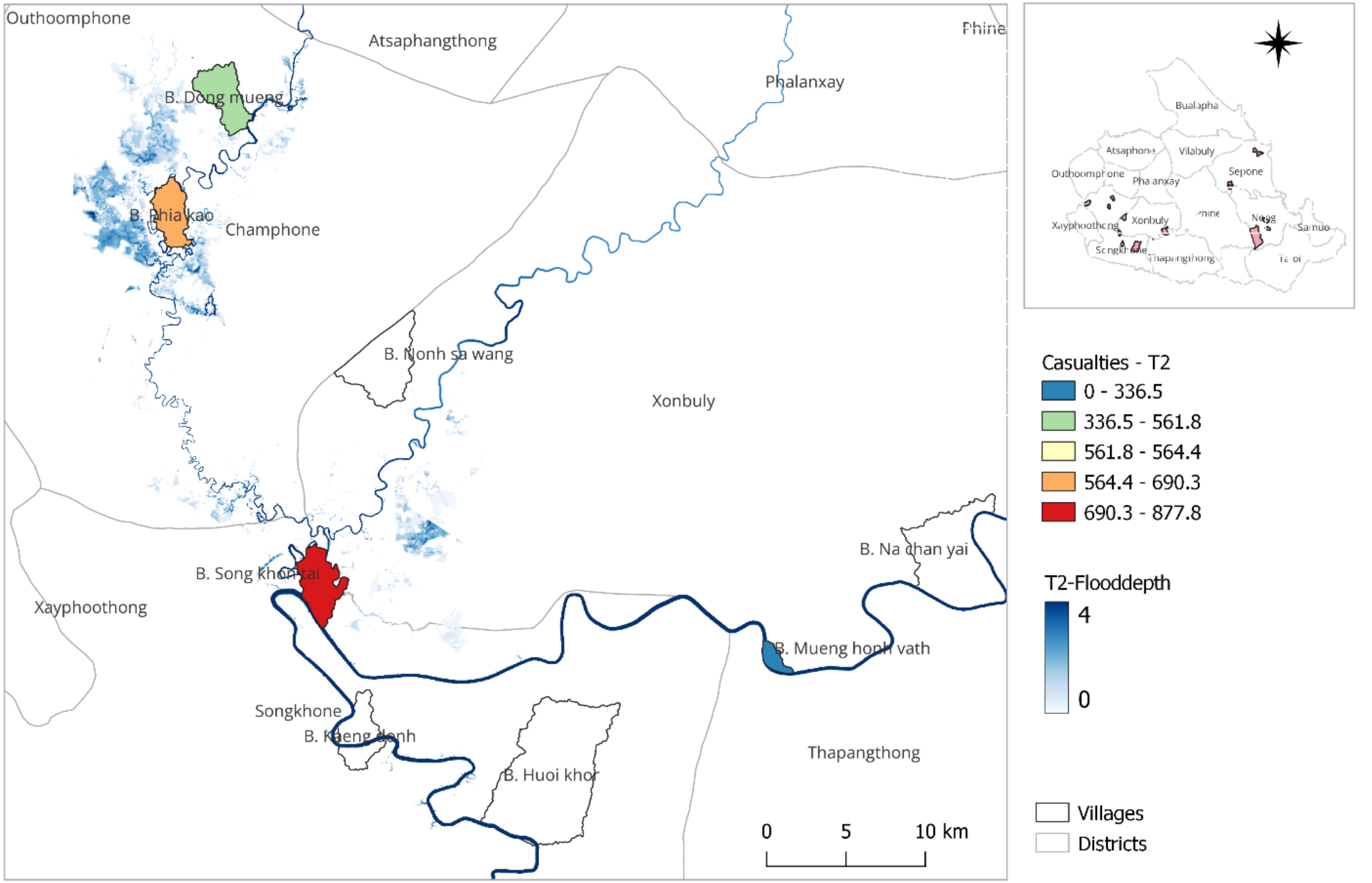


Figure 63 Potential casualties in villages due to flooding at 1 in 2 year return period for future scenario.

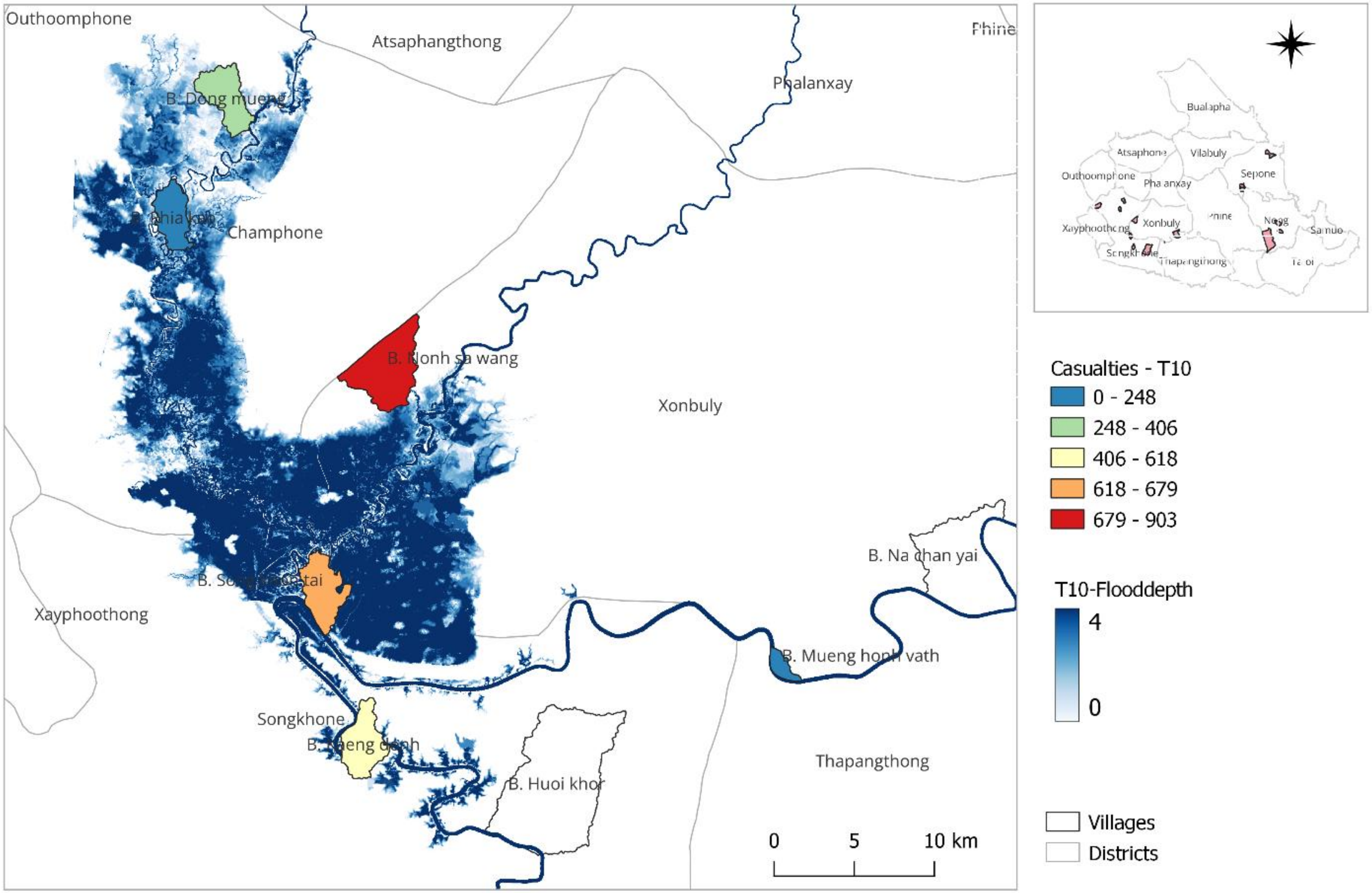


Figure 64 Potential casualties in villages due to flooding at 1 in 10 year return period for future scenario.

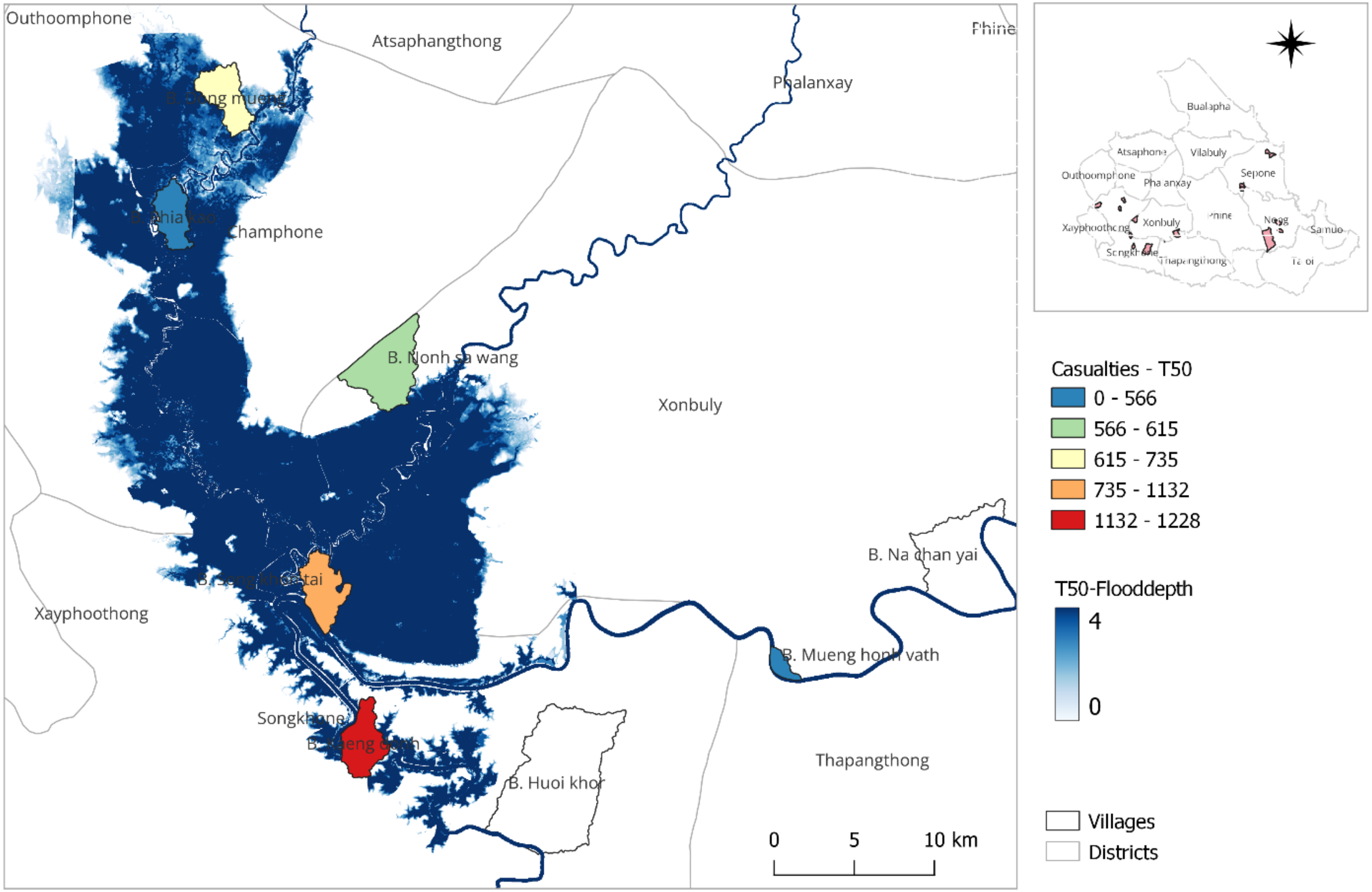


Figure 65 Potential casualties in villages due to flooding at 1 in 50 year return period for future scenario.

Riskscore: Current

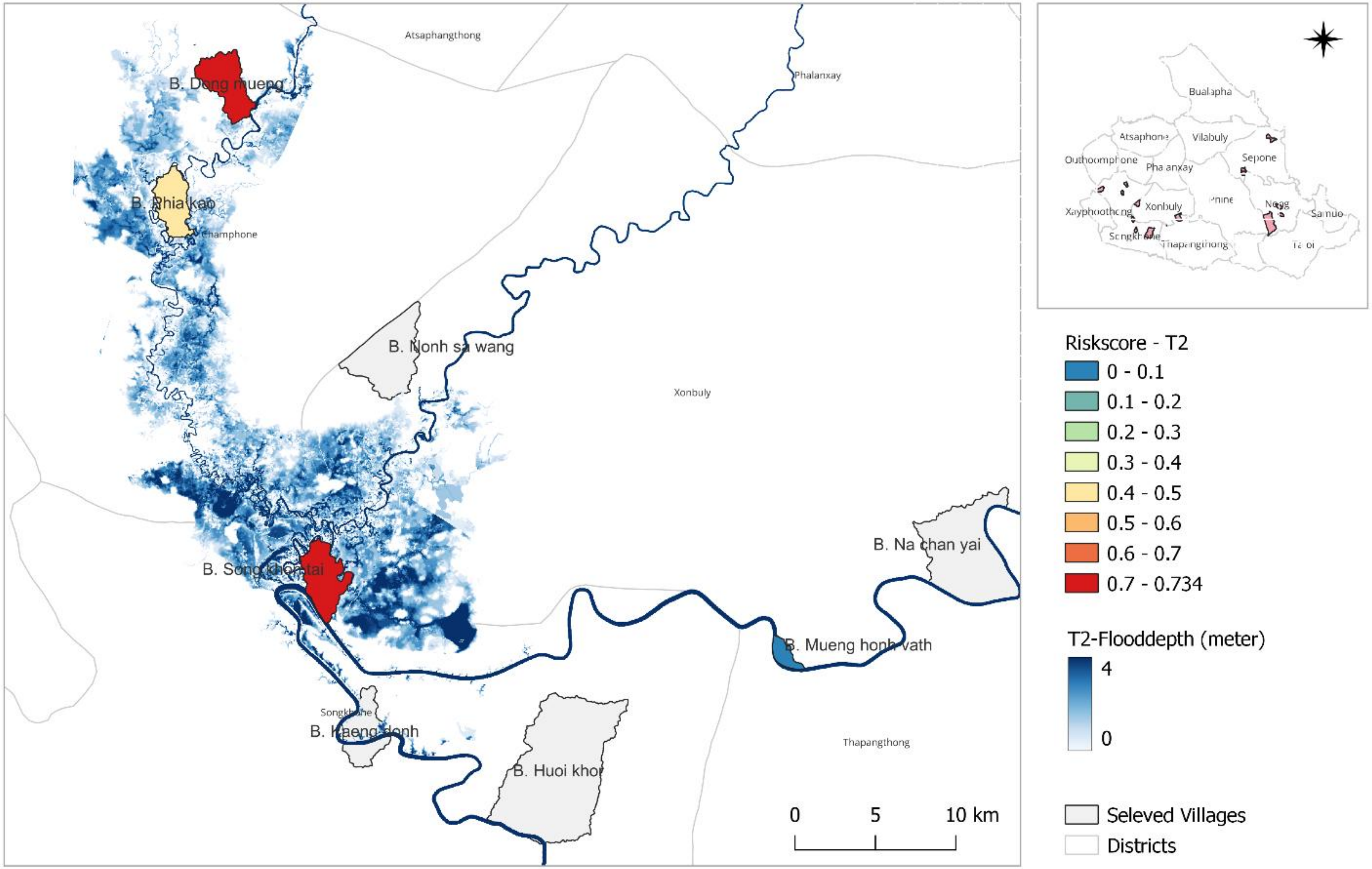


Figure 66 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 2 year flood event-current scenario

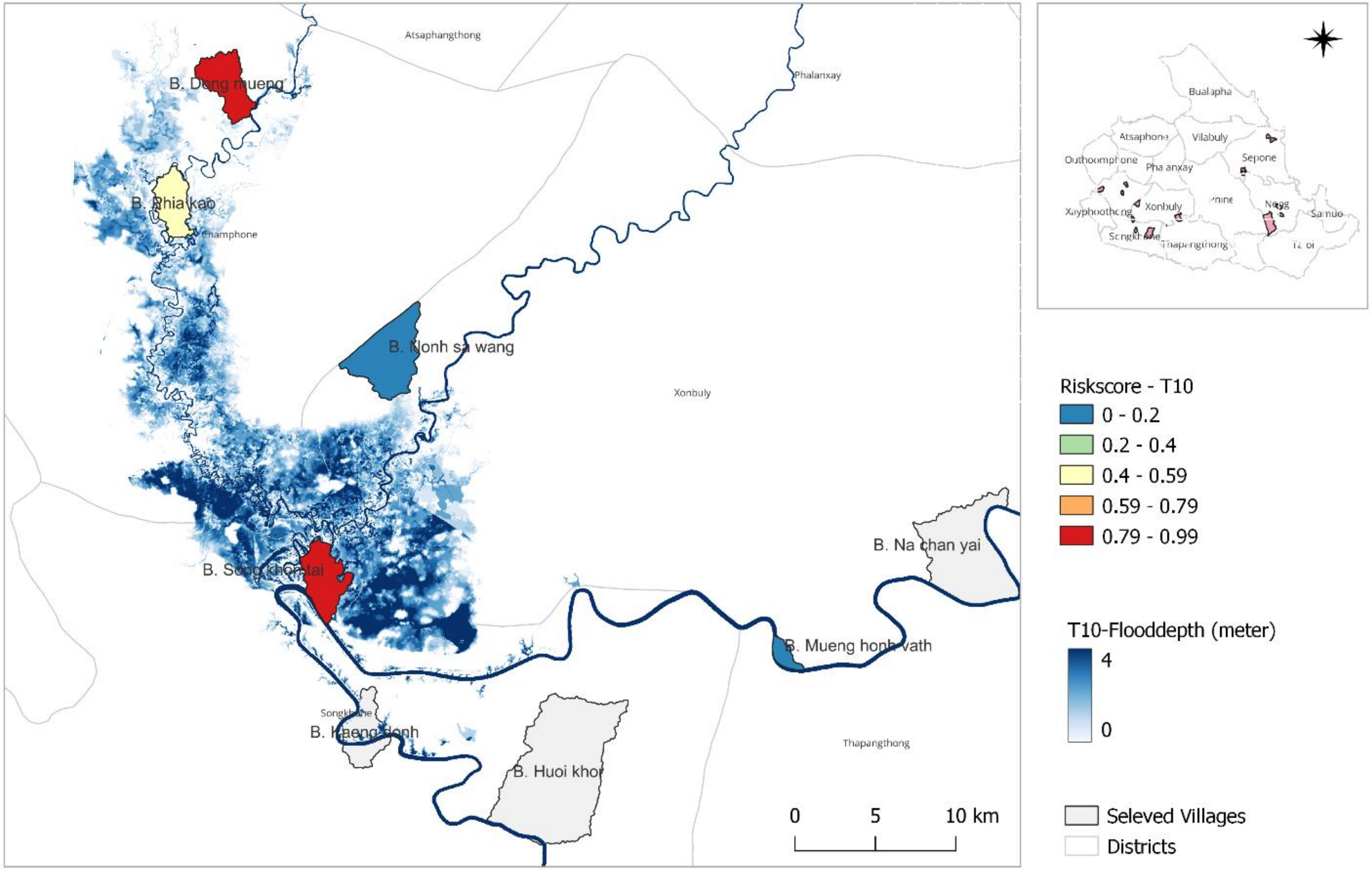


Figure 67 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 10 year flood event-current scenario

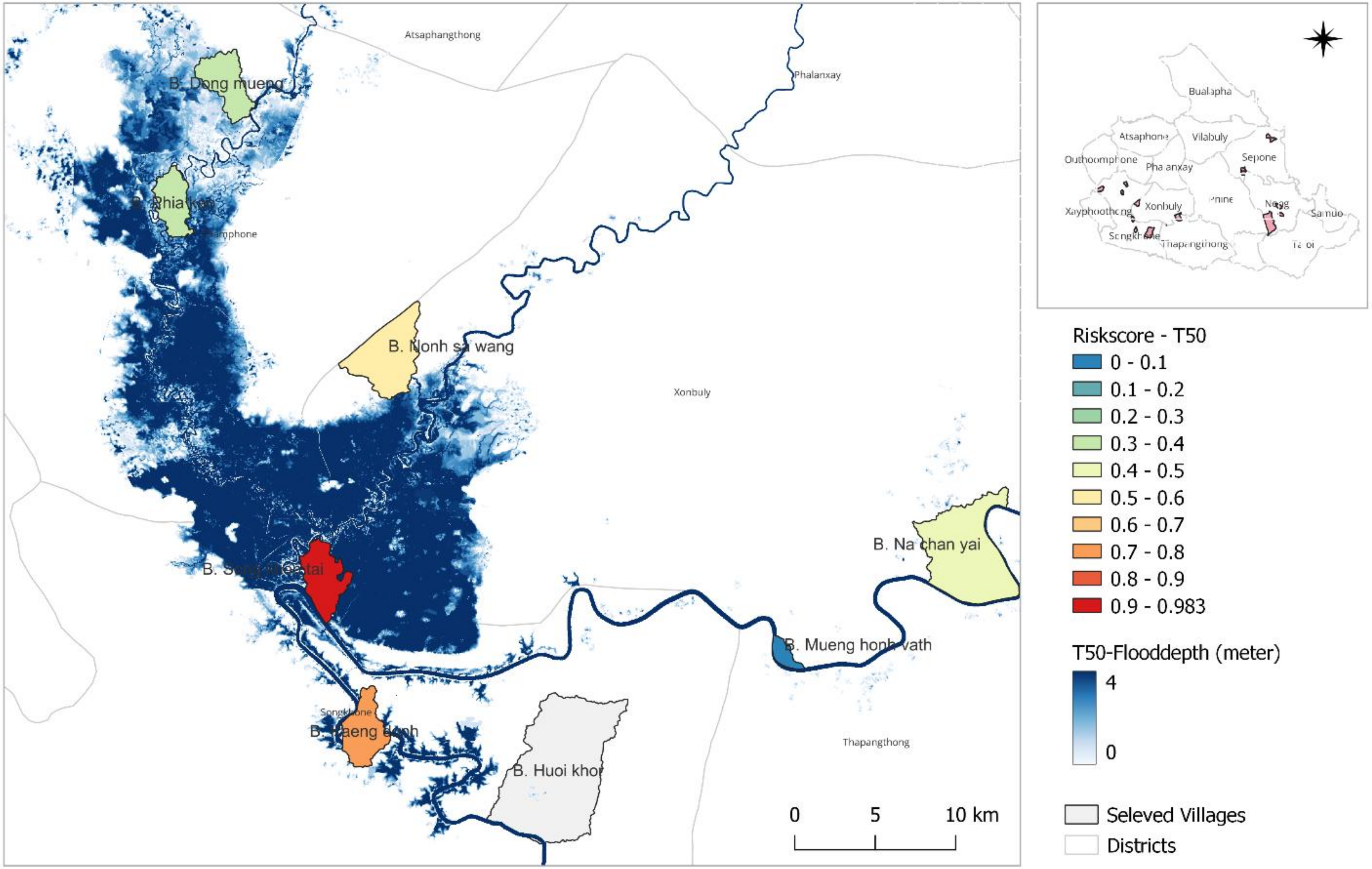


Figure 68 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 50 year flood event-current scenario

Future

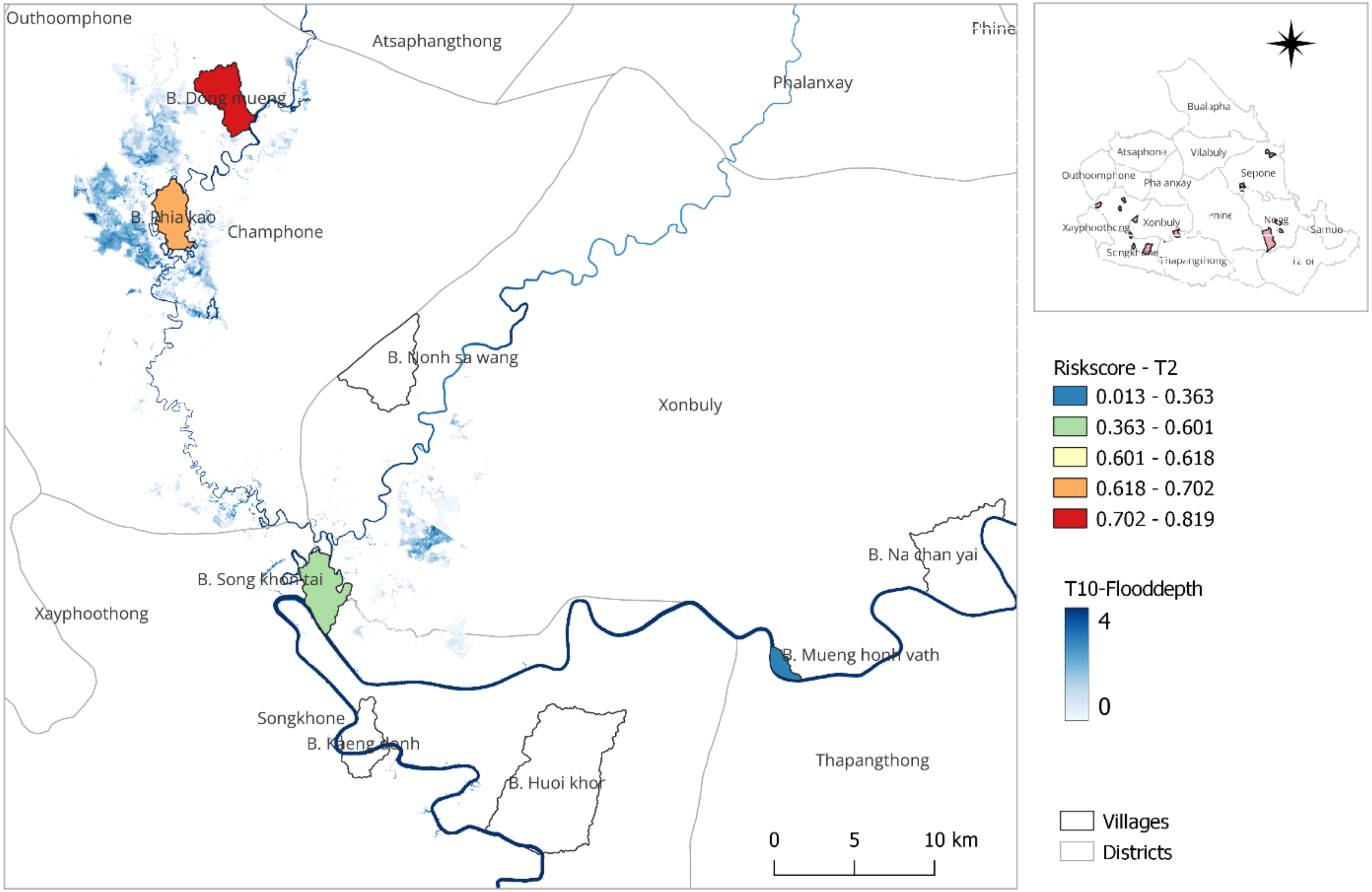


Figure 69 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 2 year flood event-future scenario.

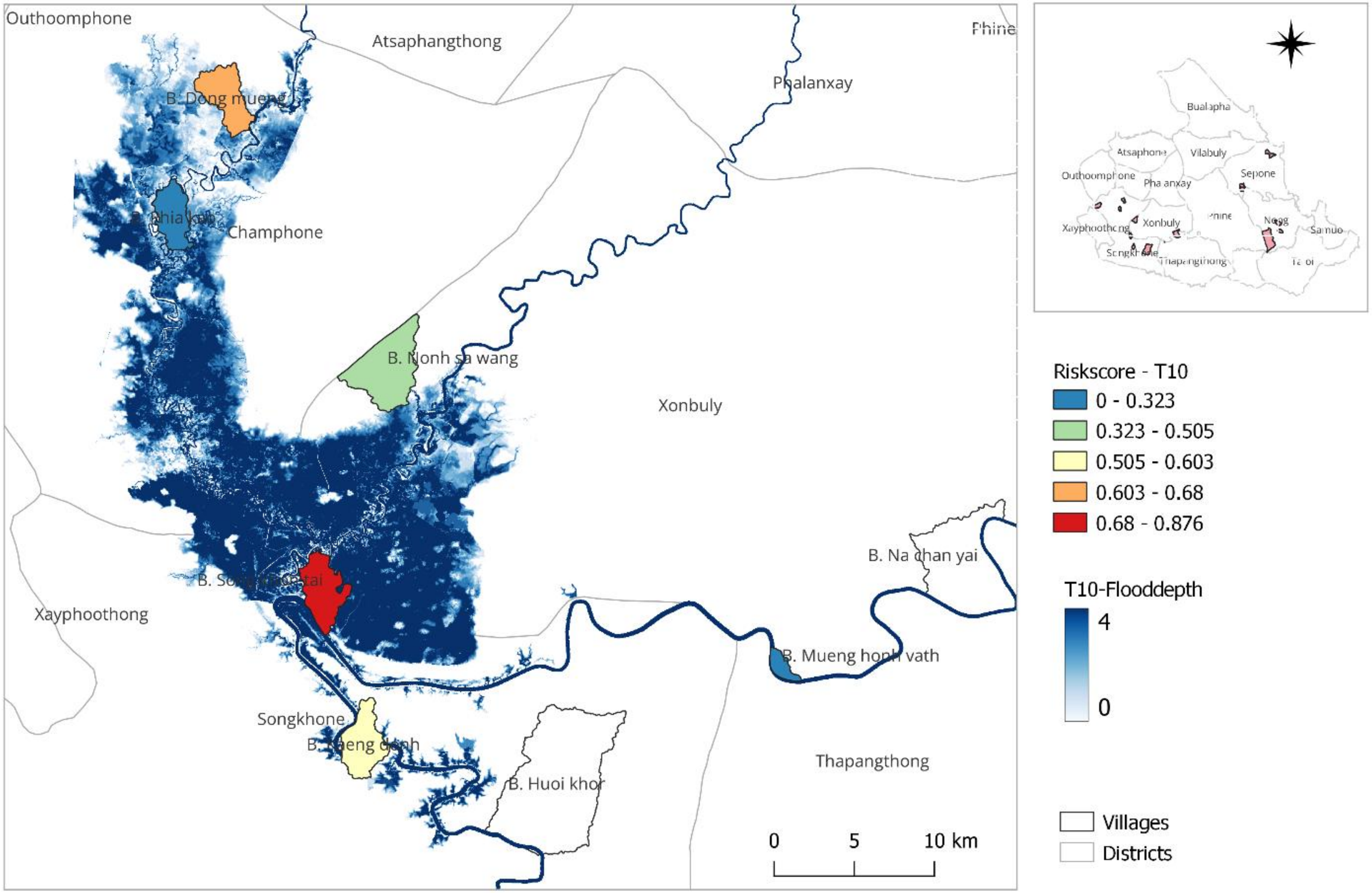


Figure 70 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 10 year flood event-future scenario.

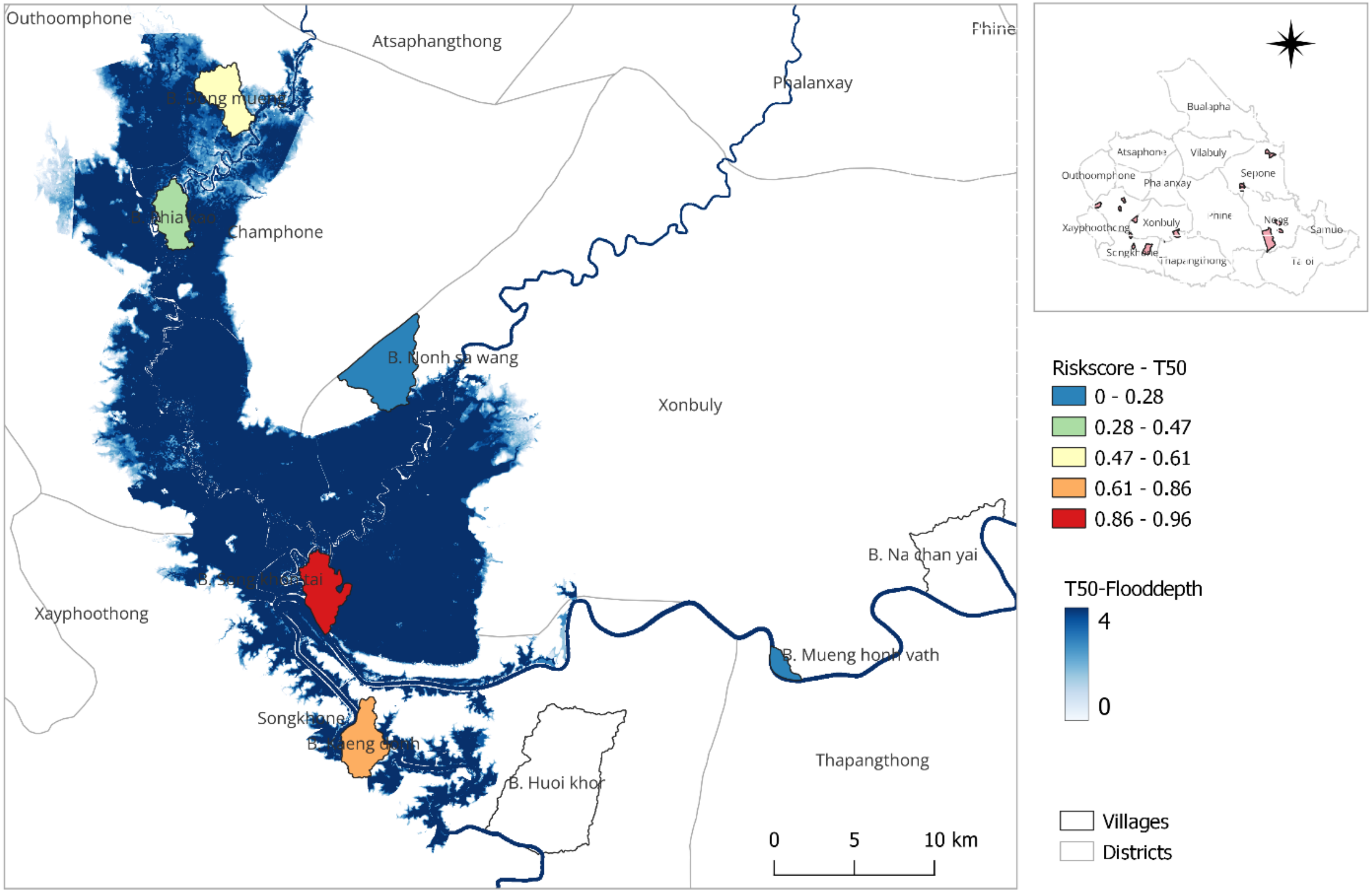


Figure 71 Flood risk score for the villages exposed to floods based on the flood modelling for a 1 in 50 year flood event-future scenario.

Agriculture

Table 10 Crop prices and average price per hectare

	LAK/Ha	USD	Fraction cultivated / ha	USD /ha
Lowland rainfed paddy	17130000	805.11	0.755	607.85
Dry season paddy	17130000	805.11	0.11	88.56
Upland rainfed paddy	17130000	805.11	0.0026	2.09
Total Maize	19630000	922.61	0.0116	10.70
Starchy Roots	17350000	815.45	0.0191	15.58
Peanut	6500000	305.5	0.0022	0.67
Soybean	6500000	305.5	0.0073	2.23
Vegetables	6500000	305.5	0.0622	19.00
Mungbean	6500000	305.5	0.0007	0.21
Tobacco	6500000	305.5	0.0032	0.98
Cotton	6500000	305.5	0.0022	0.67
Sugarcane	6500000	305.5	0.0227	6.93
Average price per HA				**755.49**

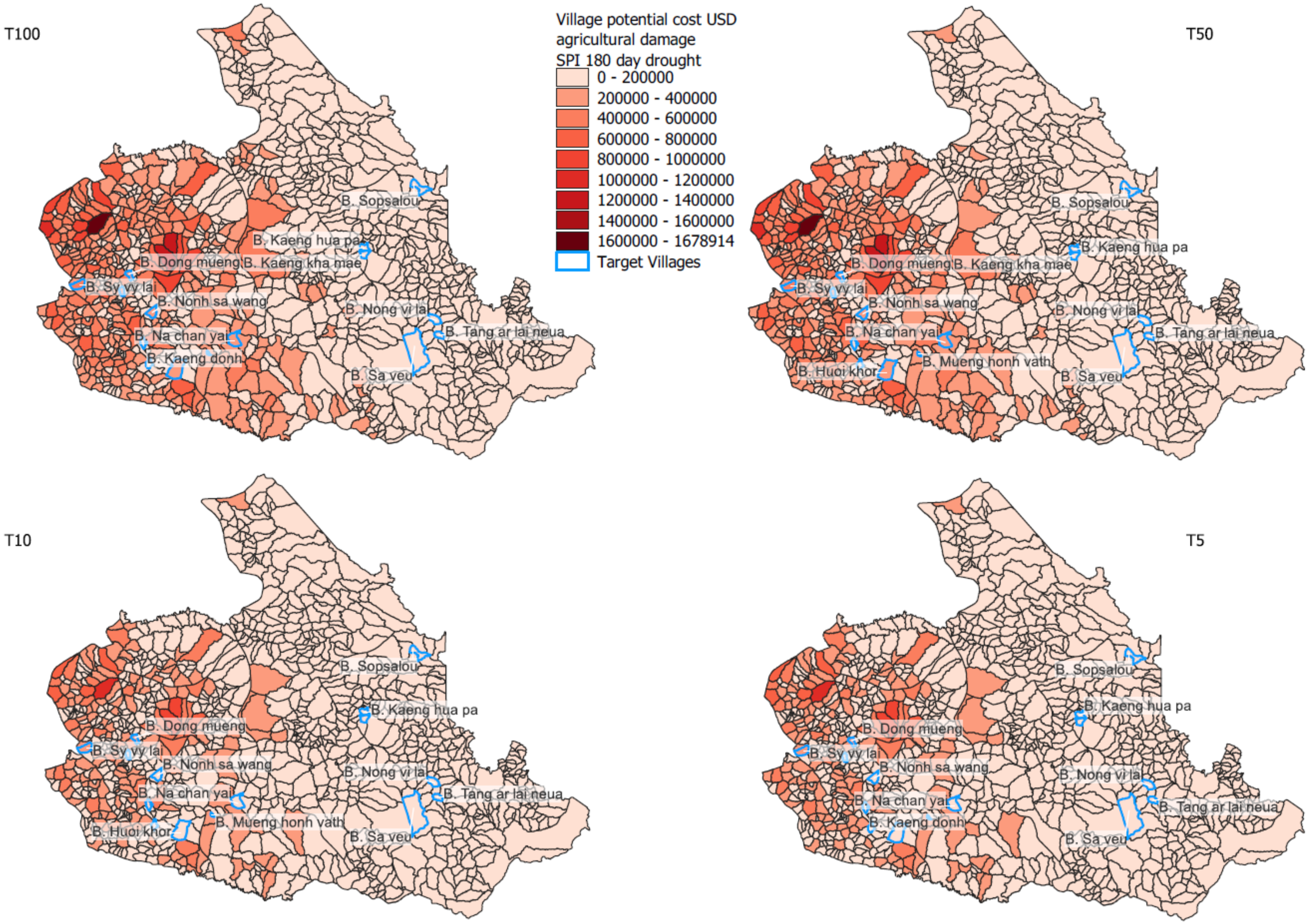


Figure 72 Potential cost for agricultural damage (USD) at village - SPI-180 days drough

IWRM-EbA Project

Project Management Unit

Department of Water and Resources (DWR)

Ministry of Agriculture and Environment (MAE)

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