FutureWater

FINAL REPORT

Climate risk assessment of key agricultural supply chains in the 3S and 4P Basins, Cambodia

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CLIENT UNDP Cambodia

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Executive summary

This study was commissioned under the project *Enhancing Integrated Water Management and Climate Resilience in Vulnerable Urban Areas of the Mekong River Basin*, funded by the Ministry of Environment of the Republic of Korea and implemented by UNDP. The report evaluates the impacts of climate change on water-related climate risks in the 3S and 4P Basins in Cambodia, with a focus on the production of the region's most important crops. Cashew, mango, banana and cassava are selected as cash crops with value chains of relatively high socio-economic importance and with large cropping areas. The reports explores in a spatial manner the main production areas of each of these crops, crop-specific climate hazards and critical thresholds values, and how they are projected to be affected by climate change over the next decades. Sources of information are a combination of policy reports and scientific literature, climate model outputs, GIS analyses, and stakeholder consultations. Government data of Community Vulnerability Index are consulted to assess the vulnerability component of risk. Results are mapped at district level and should ultimately inform the identification of adaptation strategies for enhancing climate resilience of agriculture in the 3S and 4P Basins.

In terms of overall climate change, the study finds that an average increase of temperature of around 1.5 °C should be expected around 2050, compared to a reference period of 1985 - 2014. Projections regarding changes in precipitation are more uncertain, but it is likely that overall wetter conditions should be anticipated in the 3S and 4P Basin. Climate hazards with the highest impact on agriculture in 3S and 4P Basins are expected to be heat, flash floods, and drought. In terms of relative changes to the current situation, especially heat stress is expected to increase drastically, making up an increasingly important part of the overall climate risk to agriculture in the region.

Taking into account crop-specific sensitivity to climate change, climate risks to cultivation of cashew, mango and banana are expected to increase over the next decades. Due to the regional socio-economic importance of these crops, it is crucial that effective adaptation options are identified and implemented in the regional agricultural sector. The district-level mapping presented in this study can guide the identification of priority areas for implementation of such measures. Despite the relatively small size of the study area, spatial variability can be observed when comparing expected severity of climate hazards at the district level. Projected increases in climate hazard severity are exacerbated by the low adaptive capacity and overall resilience of the basin population.

While cashew, mango and banana are all expected to be increasingly at risk, cassava is expected to continue to thrive in the 3S and 4P Basins, particularly due to its relatively high tolerance for hot conditions. Promoting cassava cultivation could therefore play an effective role in climate adaptation strategies. Identification of adaptation measures is beyond the scope of this study, and need to take into account the climate risks associated with the full supply chains of the selected crops. In general, efforts towards identification and prioritization of adaptation options should be strongly aligned with existing policies and strategies of the Cambodian Ministry of Agriculture, Forestry and Fisheries.

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1 Introduction

1.1 Background

The United Nations Development Programme (UNDP) is the UN's global development network, an organization advocating for change and connecting countries to knowledge, experience, and resources to help people build a better life. The UNDP Country Office in Cambodia works in partnership with the Royal Government of Cambodia, non-government organizations, civil society organizations, community-based organizations, multilateral aid agencies, bilateral donors, and private sector to support the progress towards the Sustainable Development Goals (SDGs).

In 2021, UNDP received funding from the Ministry of Environment of the Government of Republic of Korea for the project *Enhancing Integrated Water Management and Climate Resilience in Vulnerable Urban Areas of the Mekong River Basin*. The objective of the project is to strengthen the climate and disaster resilience of people and communities in vulnerable regions through improved risk and vulnerability assessment and advancing an integrated approach to water resources management.

To meet the above objective, the project is implementing a set of measures that span across three key Outputs:

1. Inclusive assessment of water-related climate risks completed in the priority river basins.
2. Enabling environment for gender-responsive climate risk-informed integrated water resources management developed.
3. Funding proposal for priority risk reduction measures developed.

Project activities are implemented with a focus on the two priority urban areas of Stung Treng and Kratie, within the 4P and 3S river basins in Cambodia.

As part of Output 1, to examine the way that water-related climate hazards are affecting livelihoods, markets, and supply chains, market-specific analyses need to be conducted to articulate risks and barriers. These should provide a comprehensive look at the climate-related risks that critical supply chains will be exposed to, encompassing components of production, storage, and logistics, among others. The climate risk assessment describes in this report addresses the production component of key agricultural value chains.

1.2 Objectives and Scope

The objective of this work is to fill the knowledge gap regarding the projected impacts of climate change on water-related climate risks in the 3S and 4P Basins, with a focus on the production of the most important cash crops in the region. More concretely, the scope of the study is comprised of the following:

1. Assessment of the likely climate change impacts on selected relevant hazards (e.g., flood, drought, extreme heat) that are expected to affect production of key crops, as well as flood severity and/or flood frequency.
2. Articulation of climate risks for each selected crop by integrating the above with additional information on exposure and vulnerability, based on insights from other project activities related to community vulnerability, as well as data from additional sources.

In this manner, the study should inform follow-up analyses of climate risks associated with the full supply chains, including post-harvesting aspects of storage and logistics, and associated vulnerability and overall socio-economic impacts. Moreover, the results of this study are expected to feed into the forthcoming funding proposal for priority risk reduction measures (Output 3), as well as multiple capacity building activities implemented under the project.

1.3 Reading Guide

This report describes the methodology and most important results of the assessment of climate risks to which the key agricultural supply chains in the 3S and 4P Basins are exposed, with a strong consideration of the context of on-going climate change. Chapter 2 provides a brief description of the study area as well as an in-depth exploration of regional changing climate patterns and trends. The methodology implemented for performing the climate risk assessment is elaborated in Chapter 3. Chapter 4, then, focuses on the selection of cash crops and climate hazards for which the assessment was performed. The main results of the climate risk assessment are presented in Chapter 5, and their implications (both within and beyond the project context) are discussed in Chapter 6. Finally, Chapter 7 lists the most important conclusions and recommendations to inform follow-up activities.

2 Study area

2.1 General Description

The study area is comprised of the portions of the 3S and 4P Basins that are located within the boundaries of Cambodia (Figure 1). Four provinces are covered by the two basins: Ratanak Kiri (entirely), Mondul Kiri (for the major part), as well as substantial parts of Stung Treng and Kratie Provinces. The main urban centers within this geographical scope are Stung Treng and Kratie, located respectively near the confluences of the Sekong (3S) and Prek Te (4P) rivers. In total, the area covered by the climate risk assessment amounts to 36,148 km^2. Exact population data are not available for the area within the catchment boundaries, but based on provincial estimates the total population of the 3S and 4P Basins is likely around 650,000 inhabitants[1].

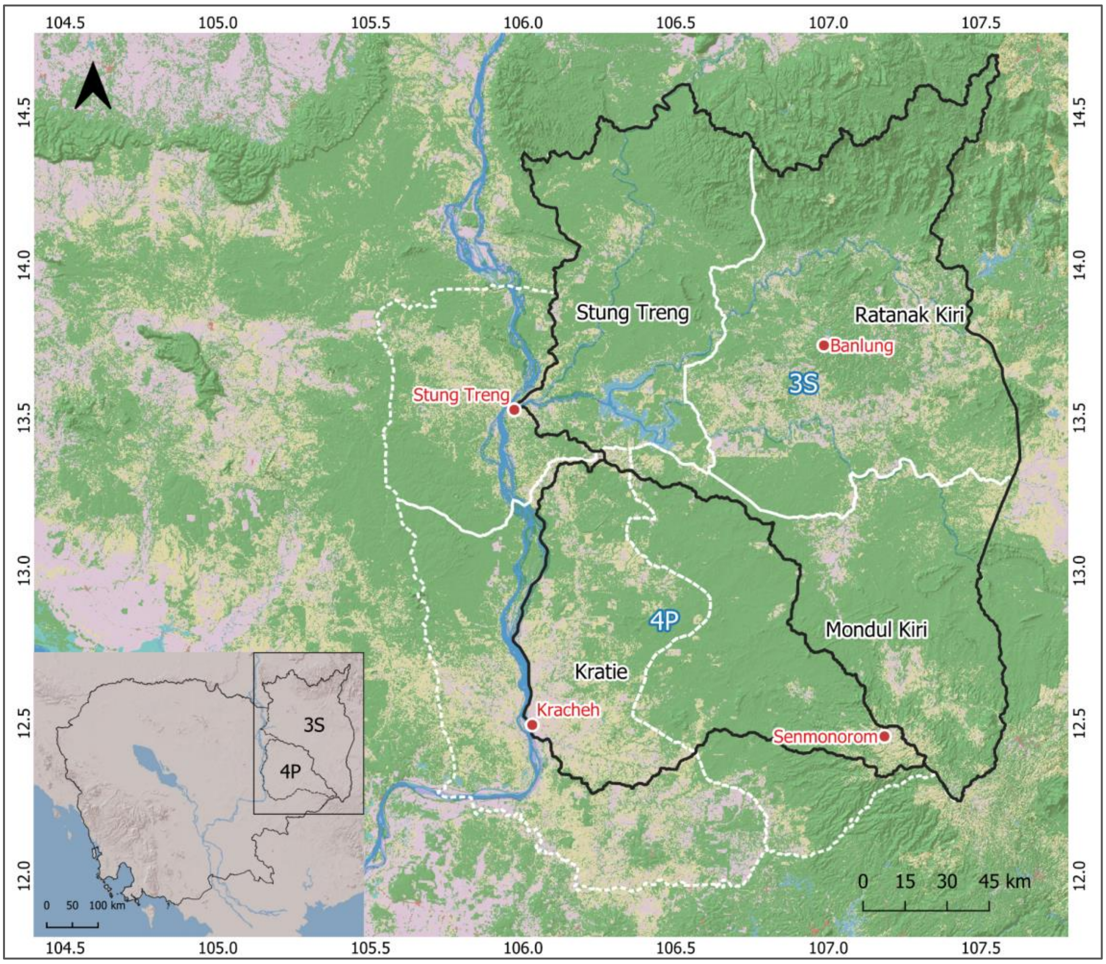

Figure 1. Basins 3S and 4P (black) and their location within the provinces Kratie, Stung Treng, Ratanak Kiri, and Mondul Kiri (white). The provincial capital cities are denoted in red.

The 3S Basin is composed of the catchments of the Sekong, Sesan and Srepok rivers. These three rivers are the three largest trans-boundary tributaries to the Mekong River. Only 19% of the Sekong basin is within Cambodia, with the vast majority located in Lao PDR. The Sesan and Srepok are approximately evenly divided between Cambodia and Vietnam (Constable, 2015). As can be seen in Figure 2, the northeastern part of the 3S basin is made up of relatively rugged terrain, with peaks of over

[1] General Population Cunsus of Cambodia (2019):
https://www.nis.gov.kh/nis/Census2019/Provisional%20Population%20Census%202019_English_FINAL.pdf

1,400 m. The flood plains of the three rivers get progressively wider downstream, and ultimately the full basin is drained by the Sekong river into the Mekong near Stung Treng town. The reservoir created by Lower Sesan-2 dam, commissioned in 2018, has become an important feature in the 3S Basin with a significant impact on the hydrology of the downstream part of the basin.

The 4P Basin is considerably smaller, with less pronounced elevation differences, and does not contain any transboundary catchments. From North to South, it is made up of the areas drained by Prek Preah, Prek Krieng, Prek Kampi and Prek Te rivers.

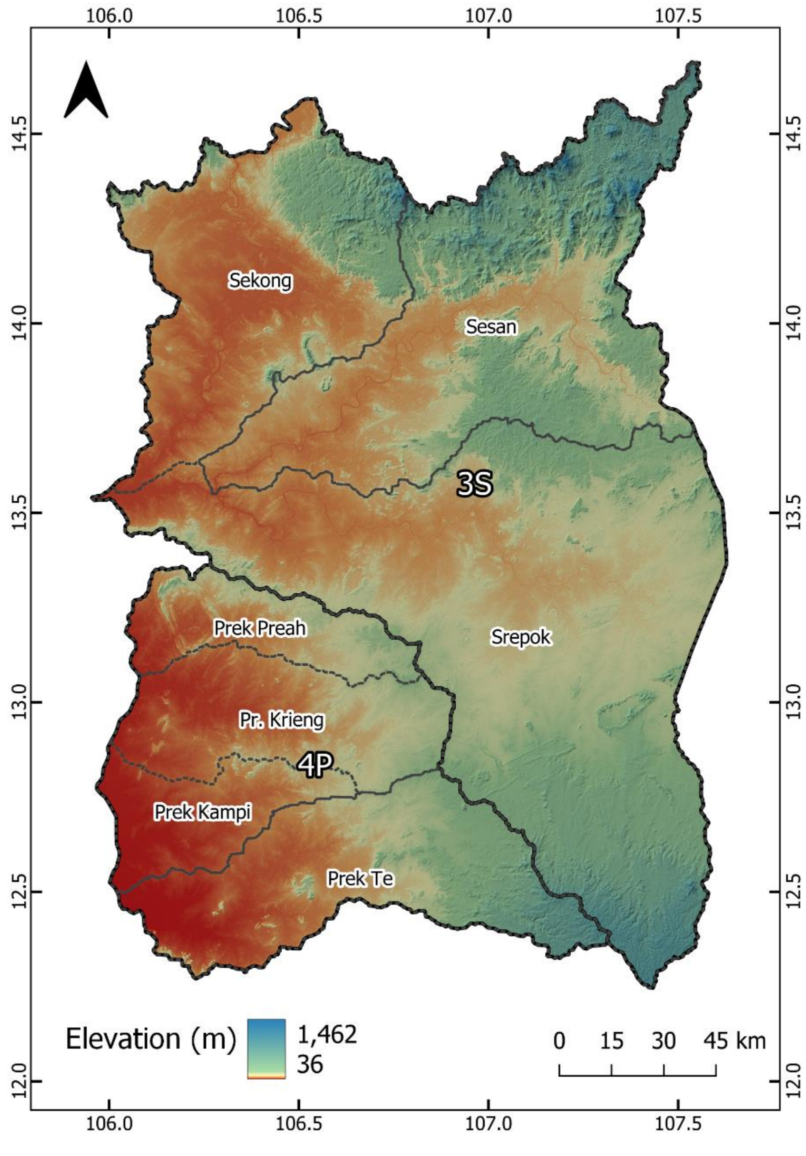

Figure 2. Digital Elevation Model (DEM) of basins 3S and 4P (data: SRTM)

Figure 3 presents a 3S & 4P excerpt of the land use / land cover map prepared by the Mekong River Commission (MRC) for the full Mekong Basin for the year 2020 (MRC TD, 2021). As shown on the map, areas in the upstream parts of the basins at higher elevations remain largely covered by forests. Plantations have expanded in recent years in several parts of the region, including particularly in Ratanak Kiri Province (Sesan Basin), the southeast of Srepok Basin, and in the north of Kratie Province (Prek Preah). Purposes of these plantations include cashew, rubber, and timber production. Agriculture occurs scattered around the lower-lying areas of the basins, and shifting cultivation is practiced locally at sloping areas. Although paddy rice is grown in several parts of the basins, most notably near Kratie in the downstream sections of Prek Kampi and Prek Te, paddy extents are relatively small when looking at the national scale (ASEAN and GIZ, 2015; Constable, 2015).

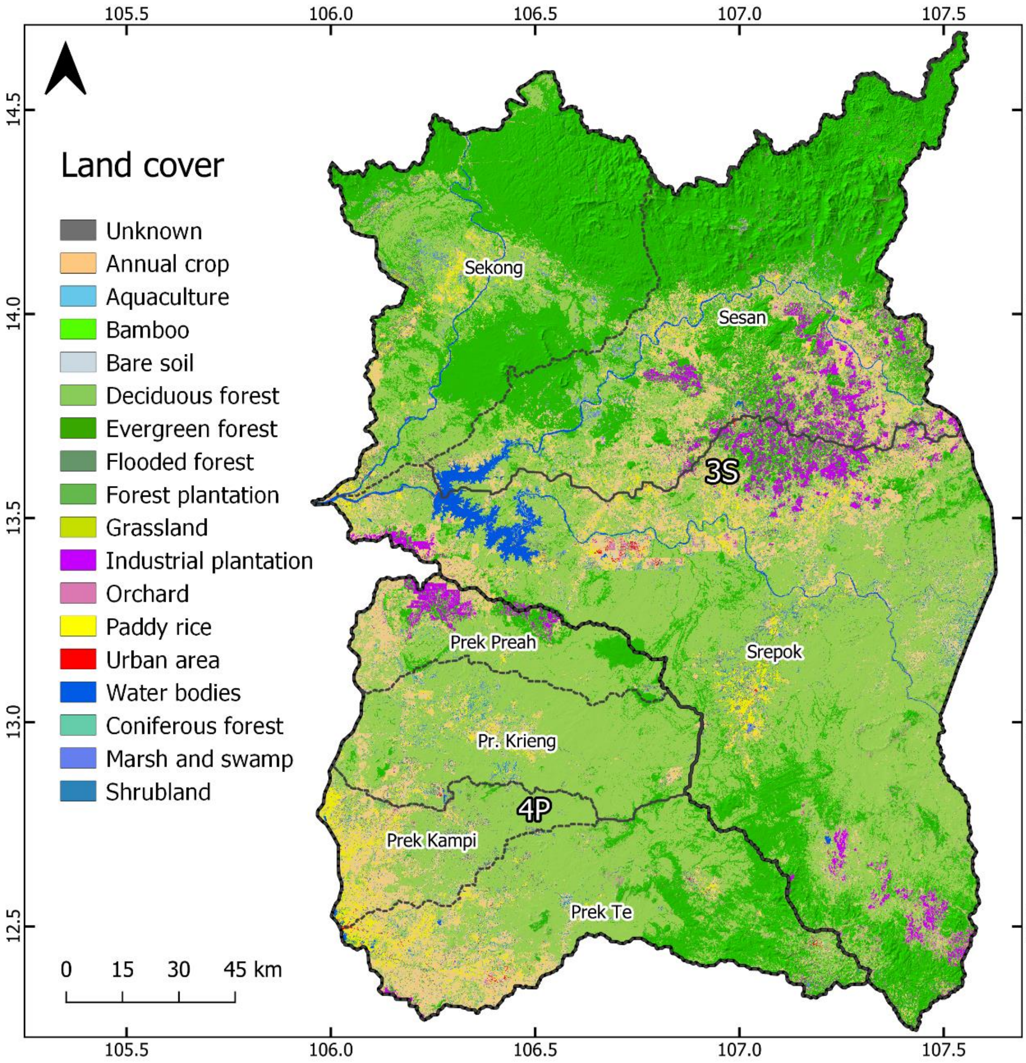

Figure 3. Land use / land cover map of basins 3S and 4P (data source: MRC 2021)

2.2 Climate Change in the 3S and 4P Basins

The below section describes the impacts of climate change on precipitation and temperature dynamics and trends in the 3S and 4P Basins, based on a thorough analysis of state-of-the-art data.

Projections of future climates are provided by GCMs (Global Circulation Models). An important source of the climate projections to date is the results from the Coupled Model Intercomparison Project Phase 6 (CMIP) activities. CMIP6 has led to a standard set of model simulations and a (more or less) uniform output. Since the downscaling and local adjustment of GCMs are needed, NASA has developed the so-called NEX-GDDP (NASA Earth Exchange Global Daily Downscaled Projections) (Thrasher et al., 2022). The dataset is provided to assist in conducting studies of climate change impacts at local to regional scales and to enhance public understanding of possible future global climate patterns at the spatial scale of individual towns, cities, and watersheds.

The NASA-NEX-GDDP consists of 35 GCM outputs for two Shared Socioeconomic Pathways (SSP-2 and SSP-5) for a historic period (1950 - 2014) and the future (2015 - 2100). The projections are analyzed using a set of indicators ranging from more direct ones (e.g., change in temperature) to more meaningful integrated and advanced indicators (e.g., monthly maximum consecutive 5-day precipitation). Because projections of future climate vary strongly per climate model, forming one important dimension of future climate uncertainty, it is key to consider this uncertainty by including an ensemble of climate models in the analysis.

2.2.1 Historic Climate Trends

The first step in developing a climate change assessment is to analyze historic observations of climate and to perform trend analyses. This can reveal whether trends in climate variables can already be observed based on historic data. Trends, or the absence of trends, do not imply that future changes will follow historic patterns. Any statistical trend analysis should be accompanied by an understanding of the underlying physical processes and future projections using GCMs.

Reanalysis of historical weather data provides a clear picture of past weather. Through a variety of methods of observations from various instruments (in situ, remote sensing, models) are assimilated onto a regularly spaced grid of data. Placing all instrument observations onto a regularly spaced grid makes comparing the actual observations with other gridded datasets easier. In addition to putting observations onto a grid, reanalysis also holds the gridding model constant keeping the historical record uninfluenced by artificial factors. Reanalysis helps ensure a level playing field for all instruments throughout the historical record.

To this end, the ERA5-land reanalysis product from the ECMWF was used to analyze historical trends in temperature and precipitation, and derived indicators, for the project area. This product is used as it provides a global, spatially gridded time series of several climate variables at resolutions of 9km and sub-daily (3hr) timescales. The dataset is fully operational (updated every month) and runs from 1981 to the near present. From this dataset, spatially averaged time series of precipitation and temperature are extracted for the project area at daily, weekly, and yearly timescales for the entire period that the dataset covers. This allows the analysis of annual and seasonal trends in historical climate alongside extremes.

<u>Spatiotemporal climate variability</u>

Cambodia is roughly bowl shaped, with a large relatively flat interior flanked by low mountain ranges. The northern border with Thailand is made up by the Dangrek mountain range, with a maximum elevation of around 600m; and in the west and southeast of the country are the Cardamom and Damrei ranges, with a maximum elevation of 1,813 m. The interior of the country is largely flat (ranging from 10-100m), with large areas made up by fertile alluvial floodplain, much of which has been converted to rice cultivation. This flat topography leads to a complicated hydrodynamic regime whereby flow directions between the Mekong Delta area and the Tonle Sap basin are reversed at different periods of the year.

The climate of Cambodia is monsoon-dominated, with a large proportion of rainfall occurring over a relatively short period of the year, generally between May and October. Total average annual rainfall is around 1500 mm, increasing with elevation and with highest total rainfall falling in the southeast and over the Cardamom mountain range in the west. Temperatures are generally high year-round, ranging from around 24-35°C, with January and April generally the coolest and hottest months respectively. The higher elevation and upstream basin 3S can generally be characterized by cooler temperatures and higher rainfall, while the lower-lying downstream basin 4P is characterized by higher temperatures and lower rainfall.

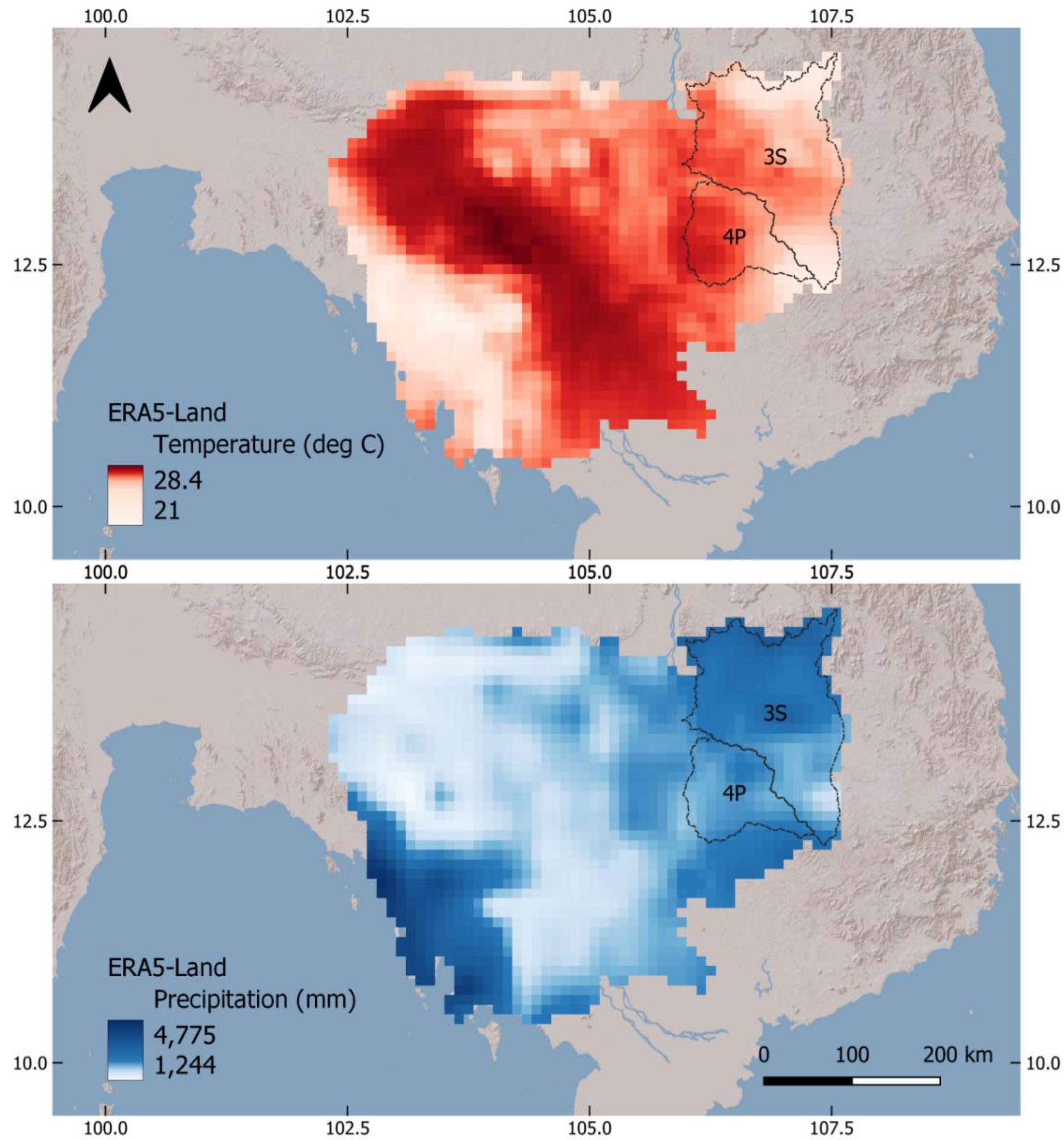

Figure 4. Mean annual Temperature (top) and precipitation (bottom) for 2017–2022 across Cambodia (source ERA5-Land)

<u>Temperature and precipitation trends</u>

Because the climatic trends between 3S and 4P basins do not differ significantly, the historic climate trends were analyzed and reported for the two basins combined. Historical temperature shows that the average annual temperature is around 26.3 °C for basins 3S and 4P. The average annual minimum and maximum temperatures range between 16.5 °C and 37.6 °C, so an interannual temperature variability of around 20 °C can be observed. Analysis of temperature data shows that the mean annual temperature has increased approximately by about 0.9 °C in 40 years in the period 1981 - 2020 (see Figure 5). This provides evidence that temperatures have increased in recent years, which may negatively impact agricultural production in the region.

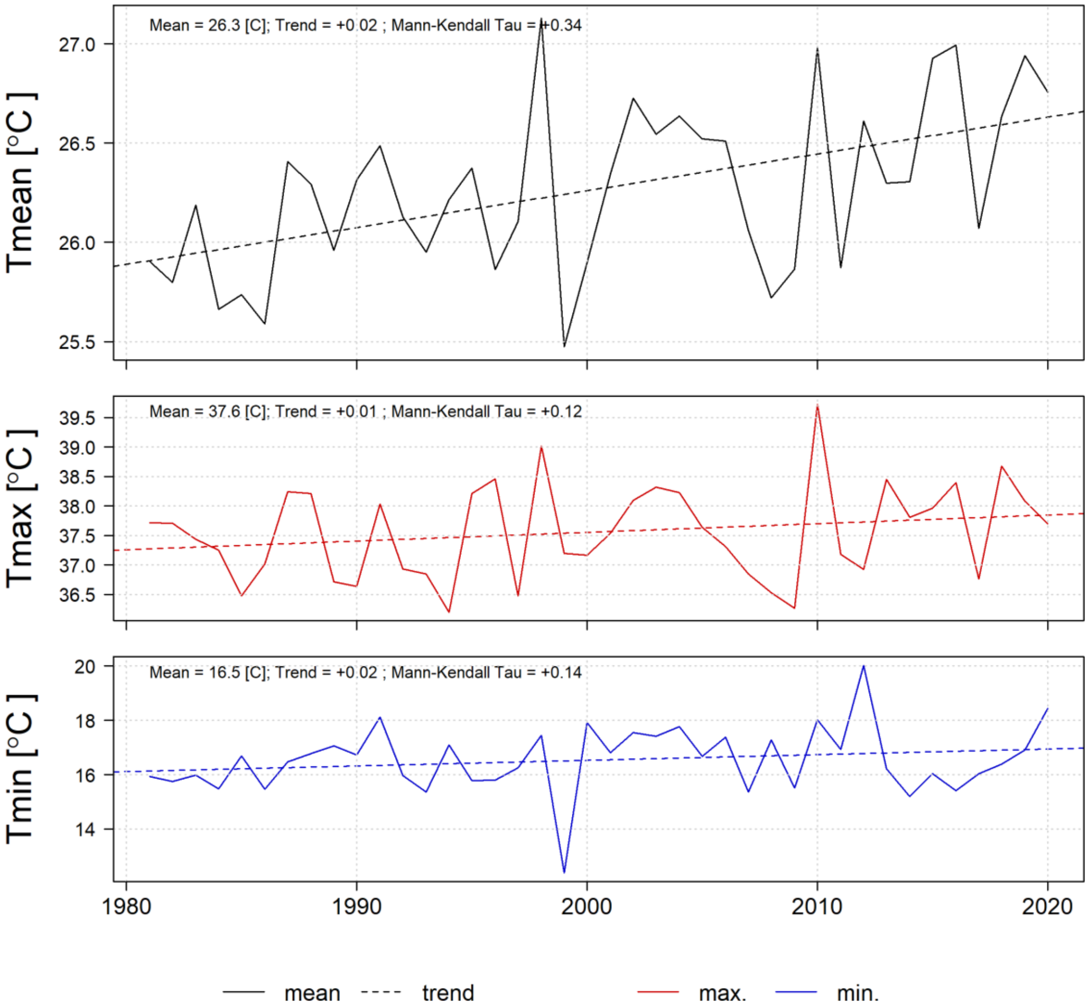

Figure 5. Average, maximum and minimum yearly temperatures from ERA5-Land dataset with trendline

Historical ERA5 precipitation patterns show that the annual precipitation for basins 3S and 4P ranged approximately between 1650 - 2400 mm in the period 1981 - 2020, with mean precipitation around 2000 mm. Moreover, analysis shows that precipitation has consistently decreased over the years at a rate of 2.75 mm per year. The 10-daily maximum cumulative precipitation for individual years, which is an indicator of extreme precipitation, indicates a weak increasing trend of 0.41 mm per year (see Figure 6). The Mann Kendall Tau value indicates the strength of the monotonic trend of increase or decrease in a time series, with a value of 1 indicating a strong significant trend and -1 indicating no trend.

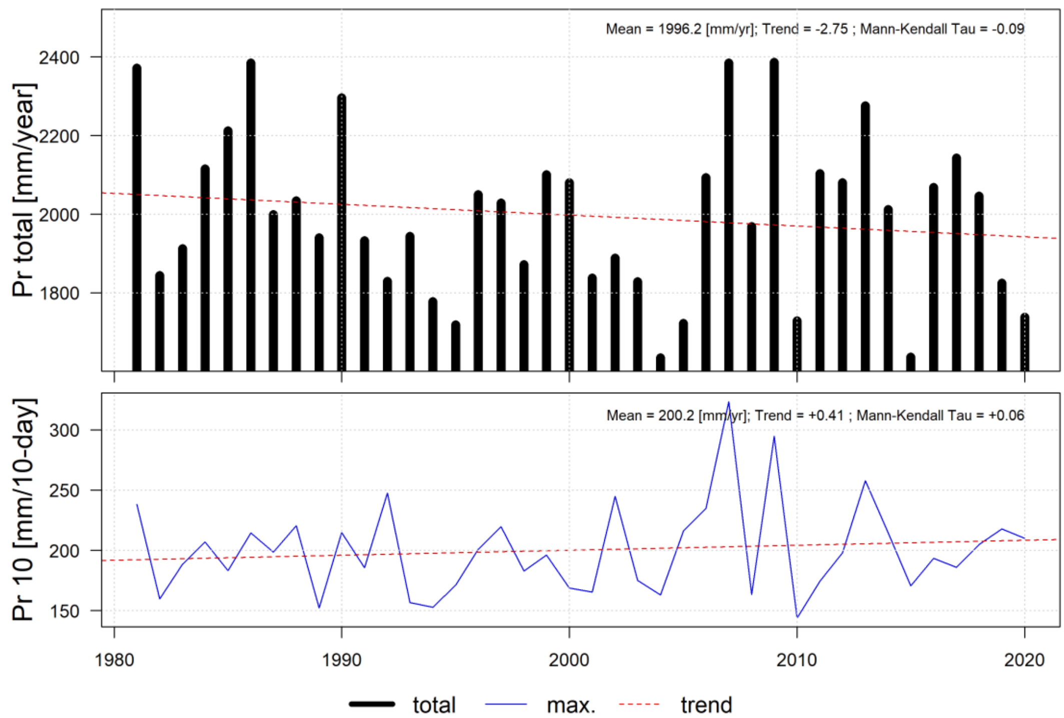

Figure 6. Total yearly and 10-day maximum cumulative precipitation with a trendline

<u>Seasonality</u>

A clear seasonality is evident, with high average monthly temperatures prevailing during March - May, with temperatures ranging around 30 °C. Cooler average monthly temperatures occur during December and January, with temperatures ranging around 24 °C (see Figure 7). Most of the rainfall occurs during the rainy season between May until October. The interannual variation is high, as almost no precipitation occurs during the dry season.

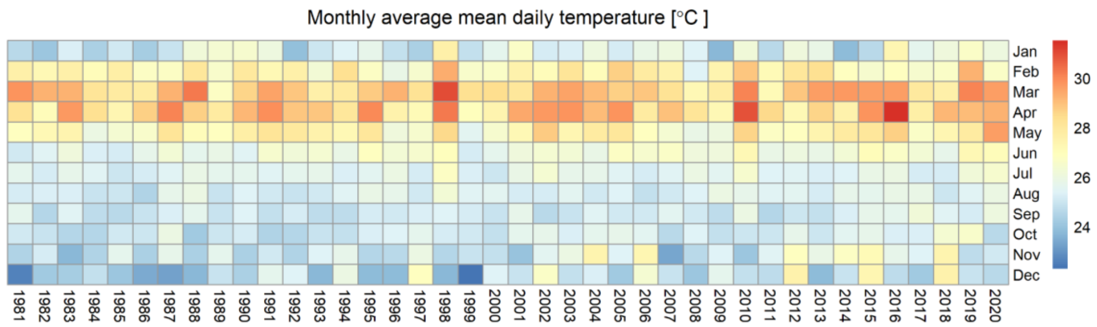

Figure 7. Seasonality in temperature from ERA5-Land dataset

Monthly total precipitation [mm]

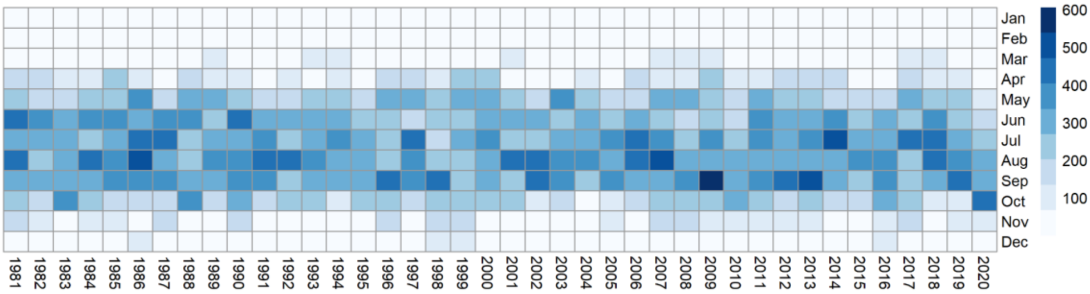

Figure 8. Seasonality of precipitation from ERA5-Land dataset

Summary table

Table 1. Summary table of precipitation and temperature means and trends (1950-2014)

Basin	Precipitation		Temperature	
	Mean (mm)	Trend (mm/yr)	Mean (°C)	Trend (°C/yr)
3S-4P	1996	-2.75	26.3	+0.02

2.2.2 Future Climate Projections

The NEX-GDDP-CMIP6 data were used to analyze future climate trends. This dataset contains extended sets of variables and is used to provide an analysis of trends in terms of temperature and precipitation, and derived climate change indicators. This product was used as it provides spatially gridded time series including temperature and precipitation derived from an ensemble of 35 General Circulation Models with global coverage. The data is available at downscaled resolutions of ~25 km and daily time series, covering “historical” (1950 - 2014) and “future” (2015 - 2100) periods and varying emissions scenarios. From this dataset, spatially averaged time series of precipitation and temperature are extracted for the 3S and 4P basins combined at daily, monthly, and yearly timescales for the entire period that the dataset covers. This allows for the analysis of annual and seasonal trends in the future for climatic means and extremes.

Two SSP scenarios (SSP2-4.5 and SSP5-8.5) were analyzed to provide a range of future climate projections. SSP2-4.5 represents a “stabilization scenario”, in which greenhouse gas emissions peak around 2040 and are then reduced. Although often used as ‘business as usual’, the SSP5-8.5 is above the business-as-usual emission scenarios and designed as a worst-case scenario. We included this scenario as an upper limit to the possible future climate. These scenarios were selected as they represent an envelope of likely climate changes and hence cover a plausible range of possible future changes in temperature and precipitation relating to project implementation.

Alongside the two SSP scenarios, projections were evaluated at the following time horizons (see Table 2). A 20-year window was selected as appropriate for deriving average climate changes, effectively considering interannual variations in temperature and precipitation, and robust comparison.

Table 2. Future climate time horizons

Horizon	Time span
Reference [2005]	1995 – 2014
Short-term [2030]	2020 – 2039

Horizon	Time span
Mid-term [2050]	2040 – 2059
Long-term [2070]	2060 – 2079

<u>Average trends in temperature and precipitation</u>

In terms of average climate trends, the climate model ensemble predicts a clear increase in annual mean temperature for the basins 3S and 4P in the future for all time horizons (see Figure 9). It is also clear that under the higher SSP5-8.5 scenario, a larger increase in temperature is expected compared to the SSP2-4.5 scenario). On the short-term [2030], changes in mean temperature around 0.6–0.7°C are predicted by the climate model ensemble, for the mid-term [2050] and long-term [2070] horizons, mean temperatures are projected to increase to around 1.2–1.6°C and 1.6–2.7°C (see Table 3).

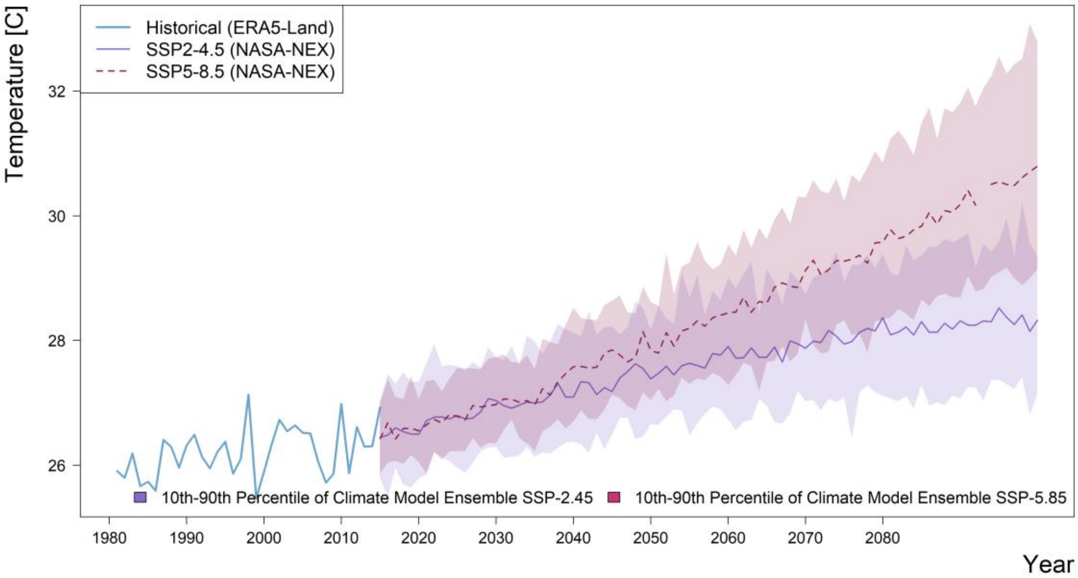

Figure 9. Time series of mean yearly ERA5-Land temperature for the historical period (1981–2020), and NASA NEX (per model bias-corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

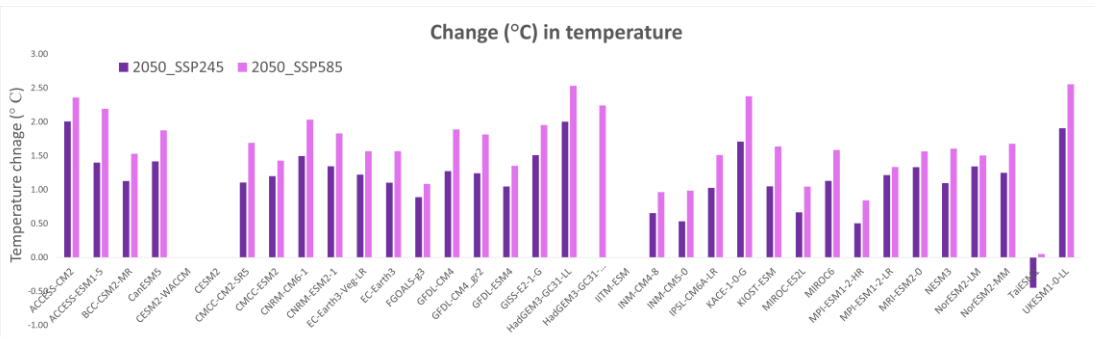

Figure 10. Change in annual mean temperature (°C) for the mid-term time horizon [2050] (w.r.t reference period 1981-2020) projected by the individual GCMs in NEX-GDDP-CMIP6 dataset.

The future trend for precipitation is less clear but, overall, the climate model ensemble projects a slight increase in mean annual precipitation till the end of the century. A large spread in model predictions is evident, with some models predicting (much) higher future increases in precipitation than others. For the short-term horizon [2030], changes in precipitation in the range of around 1 - 4% are projected by the climate model ensemble, for the mid-term [2050] and long-term horizons [2070], this increases to around

5 - 6% and 6 - 8%, with a larger spread in model projections and higher divergence between emissions pathways SSP2-4.5 and SSP5-8.5.

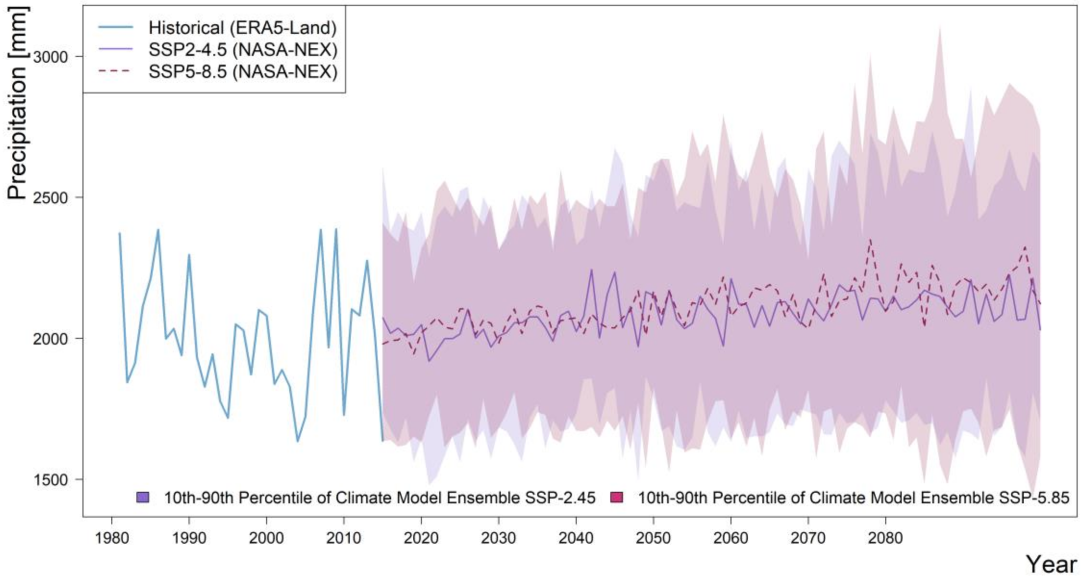

Figure 11. Time series of the yearly ERA5-Land precipitation for the historical period (1981 - 2020), and NASA NEX (per model bias-corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

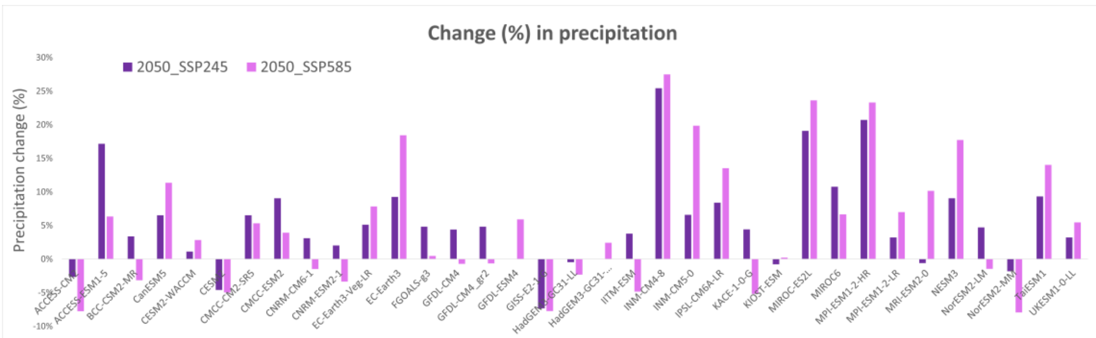

Figure 12. Change in mean annual precipitation (%) for the mid-term time horizon [2050] (w.r.t reference period 1981-2020) projected by the individual GCMs in NEX-GDDP-CMIP6 dataset.

<u>Seasonality</u>

In terms of seasonality, the climate model ensemble projects a general consistent increase in mean temperatures for all months (Figure 13). A greater increase in temperatures is predicted in the long-term future [2070] timescale and under the higher SSP5-8.5 scenario. The GCM ensemble results suggest an increase in precipitation during the months June until October, which are currently already characterized by high precipitation. This trend is more extreme under the SSP5-8.5 scenario compared to SSP2-4.5. So more extreme rainfall can be expected during the rainy season. During the dry season precipitation is projected to remain relatively stable in the future under both scenarios. So, the dry season is projected to remain dry and with higher predicted temperatures more extreme drought events may be expected.

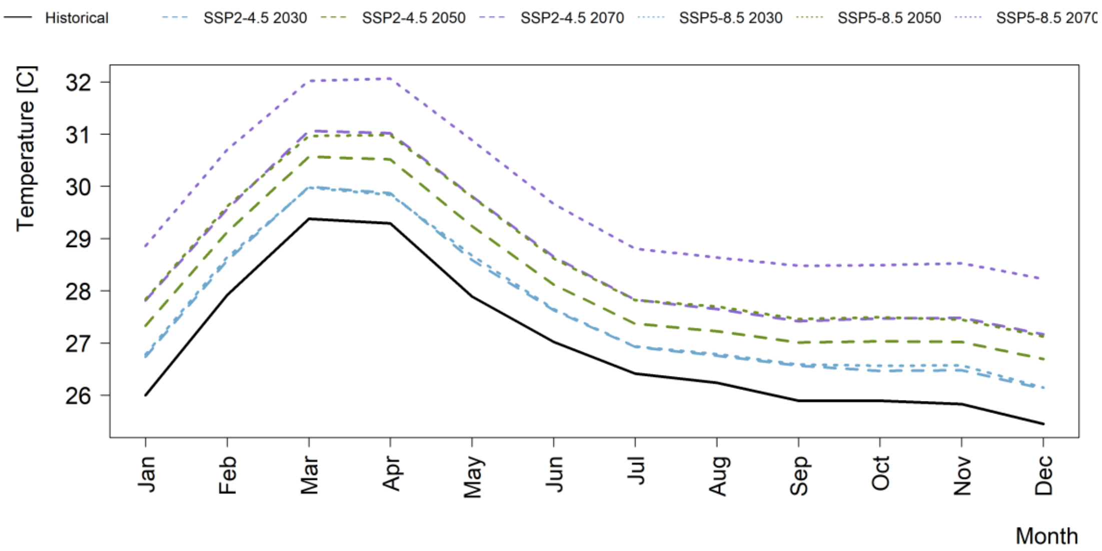

Figure 13. Average monthly temperature for historical (1995–2014) and future time horizons under the two SSP scenarios

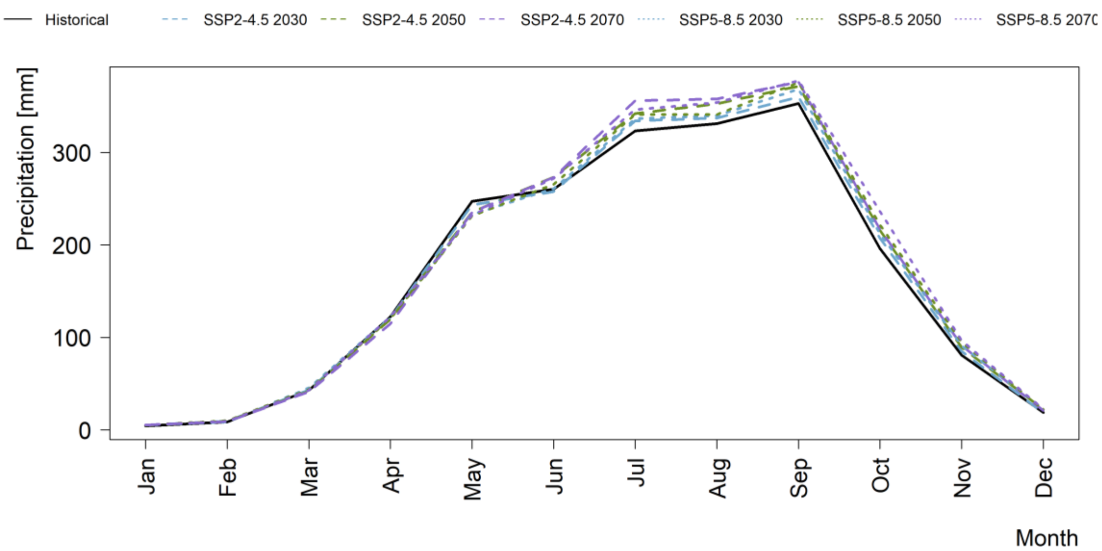

Figure 14. Average monthly precipitation for historical (1995–2014) and future time horizons under the two SSP scenarios.

Summary tables

The combination of 35 GCMs, two SSPs, and three time-horizons leads to a total of 210 (35 x 2 x 3) projections for the future. Table 3 and Table 4 show detailed results for all projections of changes in mean annual temperature and total annual precipitation. Delta values (% change for precipitation and °C for temperature) indicate the difference between historical and future time horizons for the two SSP scenarios. These tables show consistency between GCMs in terms of projecting a warmer future climate in the project area (especially for the longer-term horizon) but indicate the large uncertainty in the future precipitation.

The main statistics (median, 25th percentile, and 75th percentile) of the changes in precipitation and temperature, respectively. It also includes the number of GCMs that are showing a positive versus negative change for precipitation, and the number of GCMs that are predicting a change above 1.5ºC and 2.5ºC. In summary, all GCMs predict a hotter future, with most predictions lying between 1.5 and

2.5ºC. All climate models predict a hotter future. More than 50% of the models predicting an increase of more than 2.5ºC for the 2070 horizon under the most extreme scenario. There is a relatively clear consensus in precipitation predictions, with the majority of GCMs predicting a wetter future under both SSP scenarios. Considering the 75th percentile value of the projections as a benchmark for robust climate change adaptation, the statement can be made that wetter conditions should be anticipated in the future for both basins 3S and 4P.

Table 3. Summary table showing statistics regarding spread in CMIP6 ensemble predictions for future changes in mean temperature.

Scenarios	Average (°C)	25th Perc. (°C)	75th Perc. (°C)	GCMs >1.5°C	GCMs >2.5°C
2030_SSP245	+0.6	+0.5	+0.9	0	0
2050_SSP245	+1.2	+1.0	+1.4	5	0
2070_SSP245	+1.6	+1.6	+1.6	22	3
2030_SSP585	+0.7	+0.6	+0.6	0	0
2050_SSP585	+1.6	+1.6	+1.6	23	2
2070_SSP585	+2.7	+2.6	+2.6	31	19

Table 4. Summary table showing statistics regarding spread in CMIP6 ensemble predictions for future changes in mean annual precipitation.

Scenarios	Average (%)	25th Perc. (%)	75th Perc. (%)	GCMs Dryer	GCMs Wetter
2030_SSP245	1%	-3%	6%	11	23
2050_SSP245	6%	1%	9%	7	27
2070_SSP245	6%	-1%	12%	10	24
2030_SSP585	4%	-1%	7%	10	25
2050_SSP585	5%	-2%	11%	13	22
2070_SSP585	8%	-1%	14%	11	24

3 Methods

3.1 Conceptual Framework of Risk

This study addresses the climate-related risks that the production of key cash crops in the 3S and 4P Basins will be exposed to in the future. In line with the conceptual framework to define risk used by the Intergovernmental Panel on Climate Change (IPCC), risk was understood in this study as the potential to suffer severe loss of performance of a system, society, or community in a specific time horizon, determined conceptually as a function of hazard severity, exposure, and vulnerability (Figure 15). The different components of the risk framework are defined as follows:

- *Risk*: potential losses triggered by natural hazards over exposed elements
- *Hazard*: physical phenomena that can cause impact on people and property
- *Exposure*: location of people, properties, and activities in relation to hazards.
- *Vulnerability*: conditions determining degree of susceptibility to suffering impacts from a hazard. For climate-related hazards, Vulnerability integrates the concepts of Sensitivity and Adaptive Capacity.

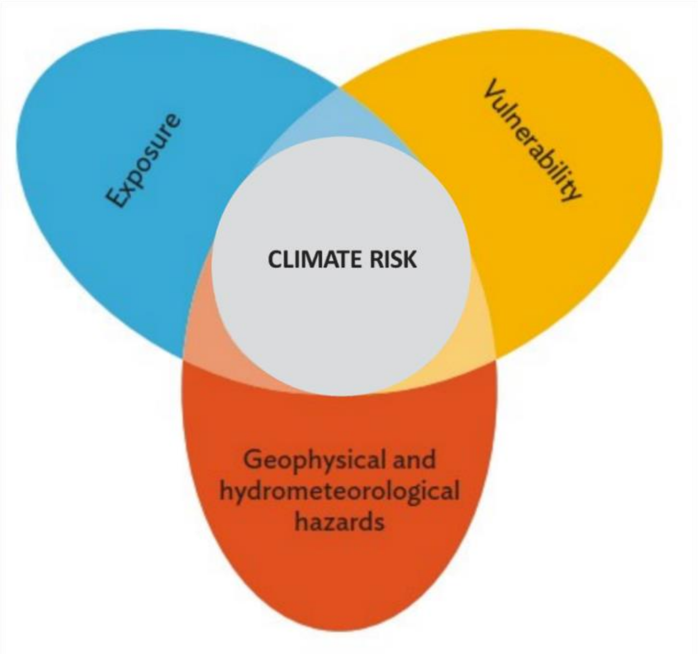

Figure 15. Climate risk (R) as a function of Hazard (H), Exposure (E), and Vulnerability (V) components

3.2 Methodological Steps

While Section 2.2 provides the general context of current and projected climate trends and patterns in the 3S and 4P Basins, the risk assessment focused on selected crops and climate hazards considered to be relevant to the production of these particular crops. Figure 16 provides a schematic overview of the different steps that were undertaken in completing the climate risk assessment.

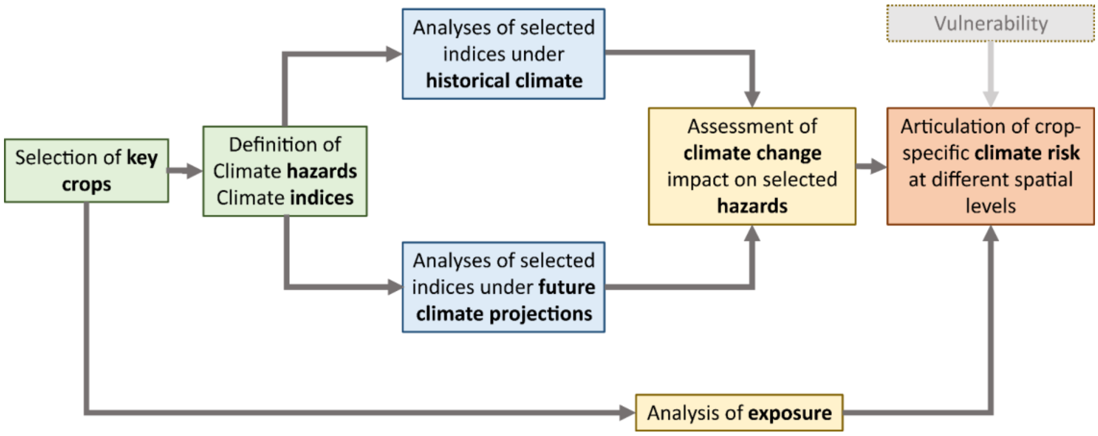

Figure 16. Flowchart of the approach to assess the impact of climate change on water-related climate hazards affecting crop production and urban flooding in the 3S and 4P River Basins

As a first step, the key agricultural value chains were selected. The focus was on cash crops, of which the value chain provides a source of income to a significant amount of people in the 3S and 4P Basins. The socio-economic importance of different crops in the basins was assessed based on two criteria: (i) the value of crop produced, and (ii) the number of agricultural holdings reporting cultivation of the crop. As economic data on agricultural production are typically collected on the provincial level, the selection of value chains was based on data for the four provinces overlapping with the basins (Figure 1).

Once the crops were known, a set of crop-specific relevant hazards were identified. Climate change impacts on environmental and socio-economic systems are commonly driven by (1) climate-related hazards: potentially harmful hydro-meteorological events (e.g., drought, heat waves, flash floods) of which the intensity and/or frequency increases, and (2) slow-onset long-term changes in temperature and precipitation, causing an overall change in the hydro-climatic and (agro-)ecological regimes, and can cause increased water scarcity and changes in the suitability, feasibility or performance of certain activities. A particular crop, for example, may be more productive under higher mean temperatures, or another crop may be less productive under lower mean precipitation). These long-term impacts on the overall system are essential for identifying adaptation investments and their potential lifetime.

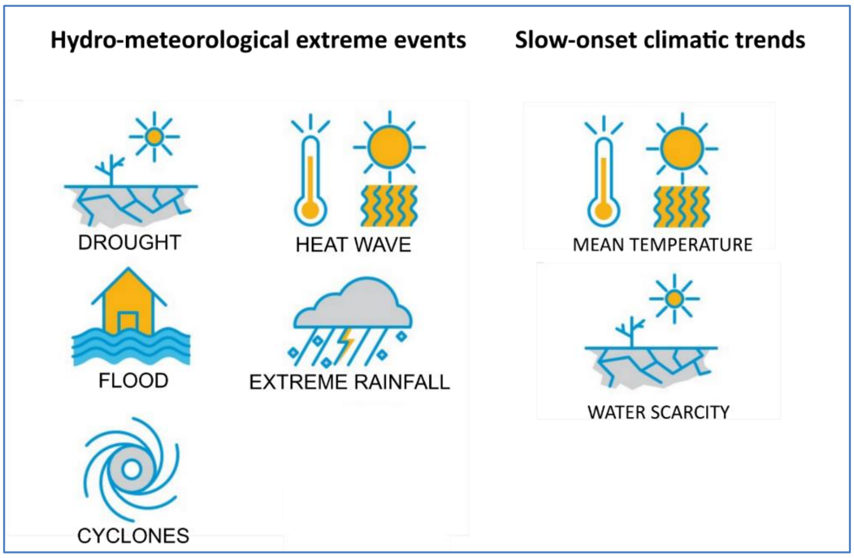

Figure 17. Examples climate-related hazards resulting from hydro-meteorological extreme events or due to slow-onset climatic trends.

An assessment of climate change impacts typically involves comparing a baseline situation with future scenarios in a specific future time slice (time horizon). It requires the construction of both baseline climate conditions and climate variability conditions, and their changes resulting from climate change. As the outputs of this study need to be specific to each value chain, it was essential to focus on a set of climate hazards that are particularly of importance to each of the selected crops. These hazards were determined based on a review of literature based on observations in Cambodia, the Mekong region, and globally.

After identification of the climate hazards, a Climate Index (CI) was associated with each of them (see Figure 18), representing the climate drivers affecting the historical period's baseline hazard rating. CI are products derived from essential climate variables, which summarize the past and projected climate change obtained from climate model data, reanalysis, and observations. They are used as a proxy to estimate the change in hazard rating compared to the baseline. The long-term (~30 years) average of a CI variable was defined as the normal and is used as a baseline value. The anomaly of a CI is the variation relative to the climatological normal during a particular reference period. As much as possible, critical thresholds for each CI were obtained from a literature review. This includes, for example, critical temperature or precipitation levels that are known to negatively affect the growth of the selected crops, and ultimately the quantity and/or quality of the yield.

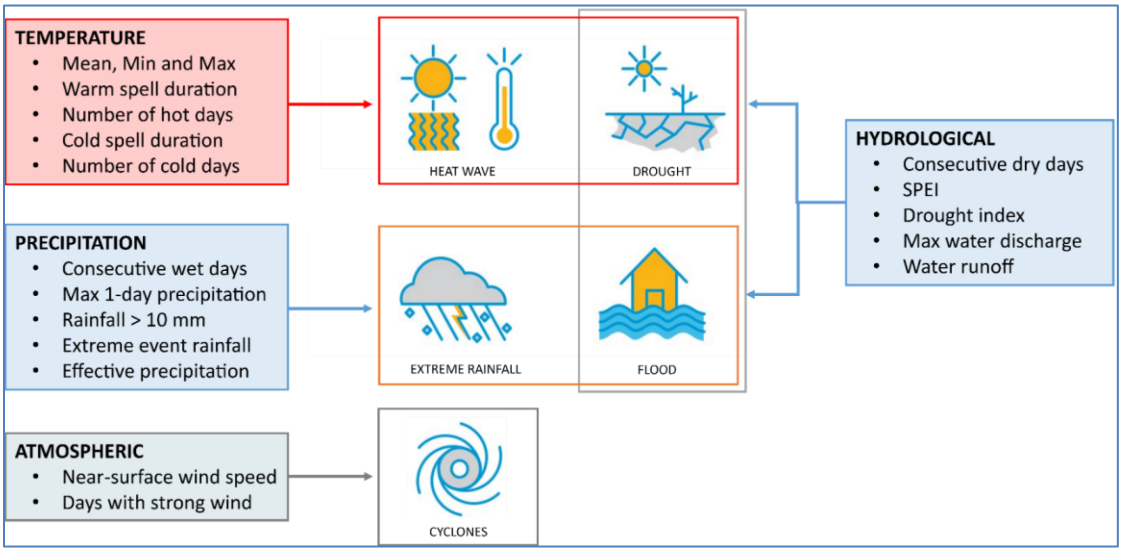

Figure 18. Climate Indices (CI) related to climate hazards (source: Amadio et al., 2022[1])

The occurrence and severity of the selected hazards was explored spatially for both a reference period and a future period (further elaborated in the next section). The difference between the reference and future conditions was assumed to represent the impact of climate change on the severity of the particular hazard.

3.3 Selection of Climate Model and Scenarios for Climate Risk Assessment

The NASA-NEX-GDDP consists of 35 GCM outputs for two SSPs (SSP2-4.5 and SSP5-8.5) for a historic period (1950 - 2014) and the future (2015 - 2100). For consistency with other climate change impact studies in the region, this study adopted the approach of choosing a particular GCM (in contrast to the ensemble method employed in section 2.2.2) to represent future changes in the climate. For the previous

[1] Amadio, M., Hunink, J.E. Fourniadis, Y., 2022. ADB Climate and Disaster Risk Screening and Assessment Tool – Methodology. TA-9414, ADB.

Coupled Model Intercomparison Project Phase (CMIP5) It was found by Kiem (2013) [1] and JBA (2014) [2] that three GCMs performed reasonably well in terms of a monsoon climate, representing each a different climate pathway for the region:

1. A '**drier overall**' lower bound of projected future impacts (GISS-E2-R-CC)
    a. Associated with an 8% decrease in annual basin wide rainfall under a medium emission, 2060 scenario.
    b. Associated with a 1.6 °C increase in annual temperature under a medium emission 2060 scenario.
2. A '**wetter overall**' upper bound of projected future impacts (GFDL-CM3)
    a. Associated with an 8% increase in annual basin-wide rainfall in a medium emission 2060 scenario.
    b. Associated with a 1.5 °C increase in annual temperature under a medium emission 2060 scenario.
3. An '**increased seasonality**' whereby a 'drier' dry season rainfall is combined with a 'wetter' wet season rainfall (IPSL-CM5A-MR).
    a. Associated with a 5% increase in annual basin-wide rainfall in a medium emission 2060 scenario. (-11% in the dry season and +8% in the wet season).
    b. Associated with a 1.5 °C increase in annual temperature under a high emission 2060 scenario.

As the CMIP6 GCM ensemble reinforces the notion that increased seasonality can be expected for the 4P and 3S River basins (see Section 2.2.2), this study selects the IPSL-CM6A-LR GCM to be representative of future changes of the climate. IPSL-CM6A-LR is the CMIP6 successor of the IPSL-CM5A-MR, which was shown by Boucher et al., 2020 to have increased skill compared to its CMIP5 predecessor.

Selected climate indices are evaluated for both SSP2-4.5 and SSP5-8.5 at the following time horizons:

- Reference period [2000] (1985 - 2014)
- Mid-term horizon [2050] (2036 - 2065)

A 30-year window was selected as appropriate for deriving average climate changes, effectively considering interannual variations in temperature and precipitation, and robust comparison.

3.4 Risk Assessment for Districts and catchments

The mapping of selected climate indices for the different scenarios and periods yields spatial layers at the native spatial resolution of the NEX-GDDP-CMIP6 dataset. These data were aggregated to different spatial units of interest: districts, provinces, and catchments (

Table 5). Results presented in this report focus on the district level, as the level of highest detail for which the outputs where calculated. Given the relatively course native spatial resolution of the climate model datasets, results were not disaggregated further to commune level. To allow for identification of districts with relatively high hazard severity, the area-averaged CI values were converted to three qualitative categories of risk: high, medium, and low risk.

[1] Kiem A (2013) Climate Change Adaptation planning in the Lower Mekong Basin - Review of Climate Scenario and downscaling approaches. Report for MRC CCAI

[2] JBA Consulting, 2014. Exploratory analysis of climate change factor ranges - Final Report, s.l.: GIZ/ MRC

Table 5. Level-2 administrative districts within basins 3S and 4P

Province	District	Basin
Kratie	Chetr Borei	4P
Kratie	Chhloung	4P
Kratie	Kracheh	4P
Kratie	Sambour	4P
Kratie	Snuol	4P
Mondul Kiri	Kaev Seima	4P
Mondul Kiri	Kaoh Nheaek	4P / 3S
Mondul Kiri	Ou Reang	4P / 3S
Mondul Kiri	Pech Chreada	4P / 3S
Mondul Kiri	Saen Monourom	4P / 3S
Ratanak Kiri	Andoung Meas	3S
Ratanak Kiri	Ban Lung	3S
Ratanak Kiri	Bar Kaev	3S
Ratanak Kiri	Koun Mom	3S
Ratanak Kiri	Lumphat	3S
Ratanak Kiri	Ou Chum	3S
Ratanak Kiri	Ou Ya Dav	3S
Ratanak Kiri	Ta Veaeng	3S
Ratanak Kiri	Veun Sai	3S
Stung Treng	Sesan	3S
Stung Treng	Siem Pang	3S
Stung Treng	Stueng Traeng	3S

Where possible based on availability of exposure data (cropped areas), categories of exposure were assigned to each of the spatial units in a similar manner. Data sources consulted in this step included crop-specific maps (where available), prioritized since they can be flexibly aggregated to different spatial units, and provincial-level government statistics. Combination of the classification of hazard severity and exposure yielded a categorical assessment of climate risk at the district, province, and basin levels.

As discussed in Section 3.1, a full risk assessment needs to include vulnerability. Two different data sources were consulted for looking into the vulnerability component of risk:

- The report describing the "Baseline and stocking exercise on climate risk, vulnerability and water resource management in the priority areas of 3Ss and 4Ps river basin", as prepared by GESC Consultants under the same project (GESC, 2023)
- The data portal of the Department of Climate Change (DCC) of the Ministry of Environment (MoE) of Cambodia, containing commune-level values for several climate-related vulnerability indices, based on Cambodia's Commune Database (CDB).

Insights obtained from these sources are discussed in Chapter 6 of this report and, as much as possible, connected to the results of the assessment of hazard and exposure.

3.5 Provincial Workshops and Bilateral Stakeholder Meetings

To ensure that the results of the study are recognized and accepted by provincial-level decision makers, two workshops were organized in June 2023 in Kratie and Stung Treng Provinces. These sessions were aimed at provincial-level government agencies with mandates related to disaster management, water resources, and/or agriculture (PCDM, PDoWRAM, PDAFF). The stakeholders were updated on the methodology and intermediate results of the study. At the core of the workshops, interactive discussions were held on the quality and relevance of the results, and the potential for uptake of the results in policy and decision making was discussed.

In addition, bilateral meetings with three important national-level stakeholders were organized in Phnom Penh: the Department of Climate Change (DCC) of the Ministry of Environment (MoE), the Ministry of Agriculture, Forests and Fisheries (MAFF), and the Cambodia country office of the UN Food and Agricultural Organization (FAO).

Feedback collected during the workshops and bilateral meetings was incorporated and is reflected in this report.

Figure 19. Impression of the workshop in Kratie (25-Jun-2023)

4 Selection of crops and hazards

4.1 Selection of Crops

Agriculture is one of the main sources of income for the communities living in the 3S and 4P River Basins. The agricultural potential of the area is high, and a range of high value cash crops are grown alongside subsistence rice paddies (Constable, 2015; MacQuarrie et al., 2013).

A first step in the selection of crops was the identification of three key agricultural value chains in the two river basins. The focus was on cash crops, of which the value chain provides a source of income to a significant amount of people. The 2020 Cambodia Agricultural Survey (CAS) was consulted to obtain data on the value of crop produced in the basins, and the number of agricultural holdings reporting cultivation of the crop (National Institute of Statistics, 2021). These data are available at the province level.

Table 6 presents the data on the value of crop production that is provided by the CAS 2020. Although several crops clearly represent a substantial economic value (particularly cashew and cassava), a full picture cannot be obtained as there are considerable data gaps for several crops. The initial selection of three crops was therefore strongly based on Figure 7, which for 15 crops presents the number and percentage of agricultural holdings that reported cultivation of each particular crop. Based on this overview, cashew, mango and banana were included as the three focus crops of the climate risk assessment.

Table 6. Value of crops produced in the provinces overlapping with 3S and 4P basins (CAS 2020)

Province	Description	Cassava	Banana	Mango	Cashew	Coconut	Black pepper	Rubber
Kratie	Average unit price of production sold (USD / kg)	$0.08	$0.33	$0.19	$0.74	$0.52	$1.79	$0.56
	Production sold (tonnes)	62,342			24,125			
	Value of production sold (USD)	$5,143,870			$17,932,918			
Mondul Kiri	Average unit price of production sold (USD / kg)	$0.08	$0.32		$0.92		$1.76	$0.50
	Production sold (tonnes)	57,772			2,500		3,870	9,876
	Value of production sold (USD)	**$4,752,567**			**$2,300,442**		**$6,810,478**	**$4,889,242**
Ratanak Kiri	Average unit price of production sold (USD / kg)	$0.13			$0.67			$0.64
	Production sold (tonnes)	126,713			37,071			
	Value of production sold (USD)	**$16,197,685**			**$24,689,108**			
Stung Treng	Average unit price of production sold (USD / kg)		$0.33		$1.01			
	Production sold (tonnes)				8,745			
	Value of production sold (USD)				**$8,802,963**			

During the provincial workshops (Section 3.5), participants emphasized the importance of also including cassava in the study. Therefore, ultimately the shortlist of selected crops was expanded to four: cashew, mango, banana, and cassava. Below sections discuss the most important climate hazards, defined climate indices, and available exposure data for each of these crops. Based on the available data, which were mostly available at the provincial level, it was not possible to establish clear differences between main crops in the 3S and 4P areas. One selection of four crops was therefore decided for the full study area.

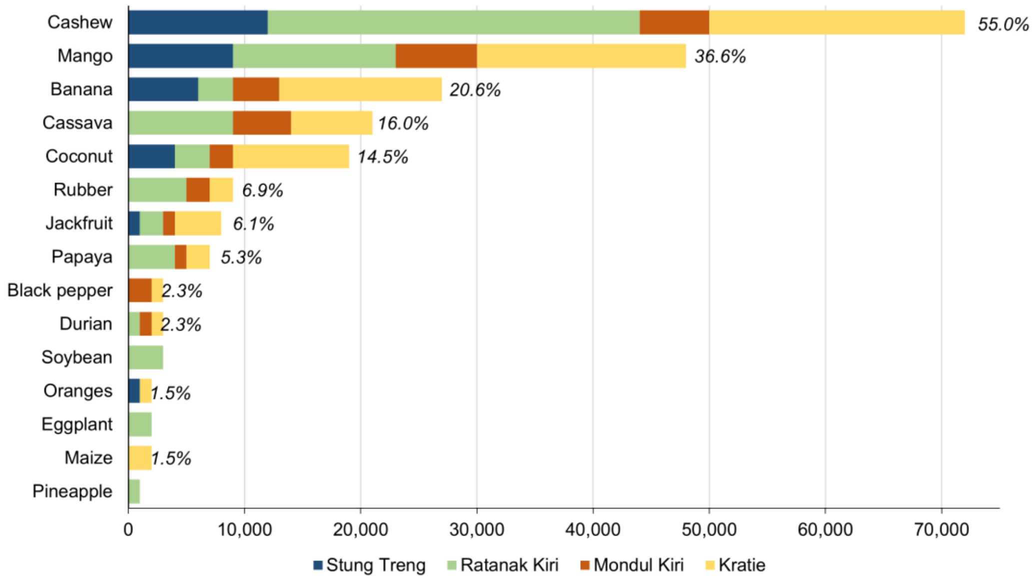

Figure 20. Ranking of crops according to the number of agricultural holdings (%) reporting on its production in the provinces overlapping with 3S and 4P basins (CIAS 2020)

Agricultural holding definition

An agricultural holding is defined as an economic unit of agricultural production under single management comprising all livestock kept and all land used wholly or partly for agricultural production purposes, without regard to title, legal form, or size. Single management may be exercised by an individual or household, jointly by two or more individuals or households, by a clan or tribe, or by a juridical person such as a corporation, cooperative, or government agency. The holding's land may consist of one or more parcels, located in one or more separate areas or in one or more territorial or administrative divisions, providing the parcels share the same production means, such as labour, farm buildings, machinery, or draught animals. The scope of agricultural activity includes the growing of perennial or non-perennial crops, plant propagation, animal production, or mixed farming. Other non-farm economic activities, such as fishery, forestry and aquaculture are considered diversification activities of the holding.

Source: FAO

The next sections discuss for each crop their main cultivated areas in the 3S and 4P Basins (exposure) and the typical factors that determine their climatic suitability (optimal growing conditions).

4.2 Cashew

4.2.1 Exposure

As can be seen in Figure 21, within the boundaries of the 3S and 4P basins, cashew is produced most in Ratanak Kiri Province, followed by Kratie Province. The map of Figure 21 was produced by a satellite-based supervised crop classification methodology, based on a range of vegetation and land use / land cover indices derived from optical and radar satellite imagery (Saah et al., 2020). The cashew production locations found in Figure 21 were corroborated by the Cambodia Inter-Censal Agriculture Survey (CIAS) of 2019, in which the county's agricultural holdings are surveyed and recorded. Figure 22 shows the CIAS map presenting the portion of surveyed agricultural holdings that report cashew production. As can be seen, cashew production is concentrated in the north-eastern provinces of Cambodia, with for example more than two thirds of Ratanak Kiri's holdings growing this crop (see also Table 7).

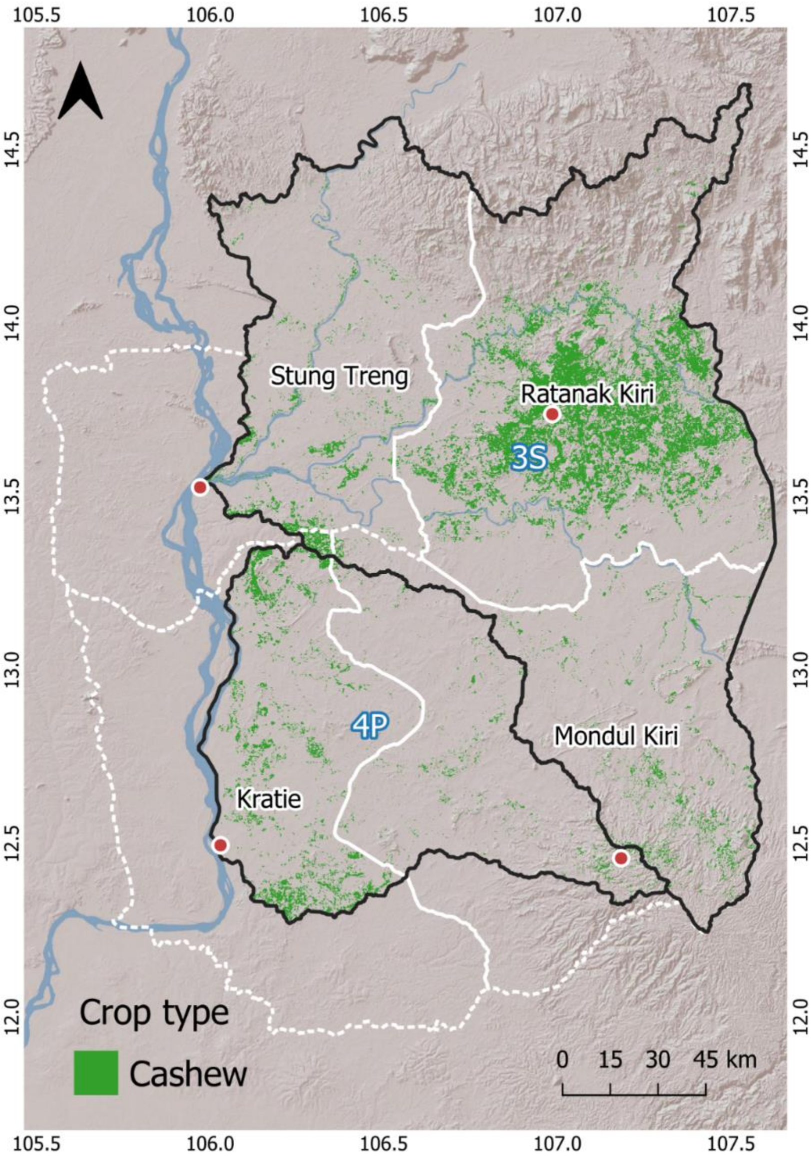

Figure 21. Cashew production in the 3S and 4P basins (data: SIG 2023)

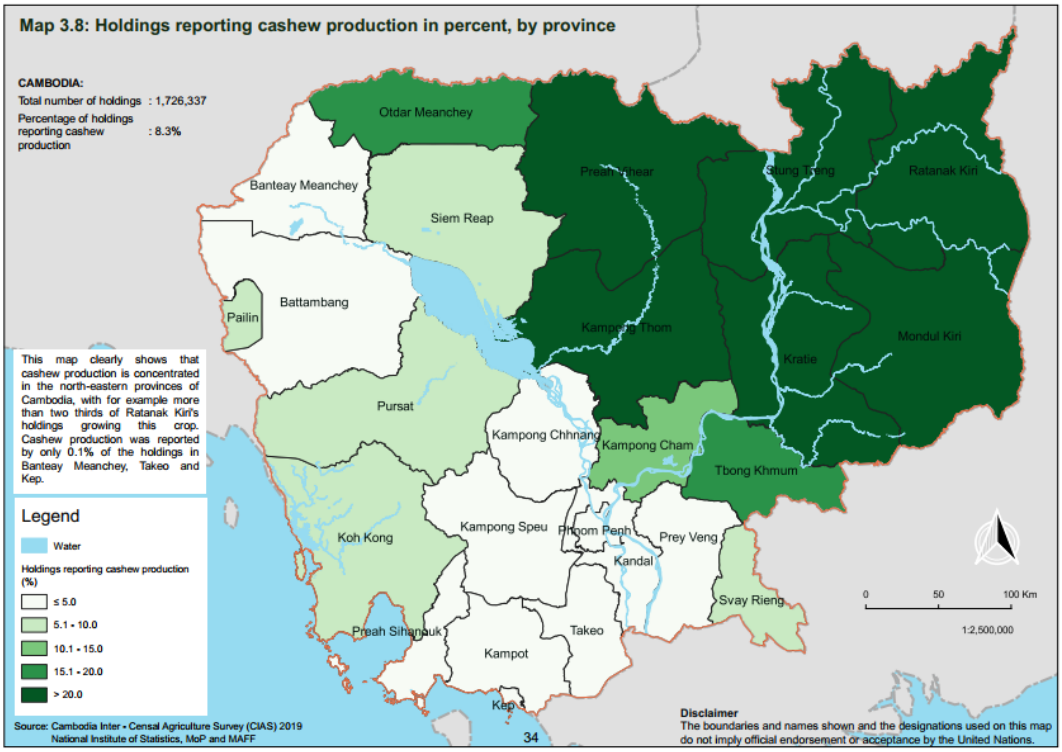

Figure 22: CIAS 2019 map of the portion of surveyed agricultural holdings that report cashew production (NIS and MAFF, 2020).

Table 7. Holdings reporting cashew production (CICAS, 2019).

Province	Reported cashew production (%)
Kratie	30.2
Mondul Kiri	38.0
Ratanak Kiri	67.7
Stung Treng	46.6

4.2.2 Climatic Suitability

Cashew is a tropical plant which can thrive under high and constant temperatures, but young plants are sensitive to frost. Areas where the temperatures range from 24 - 28°C with an annual precipitation of 1,000 - 2,250 mm are ideal for cashew growing. Temperatures above 34°C between the flowering and fruiting period could adversely affect the fruit setting and retention. Cashew needs a climate with a well-defined dry season of at least four months to produce the best yields. Coincidence of excessive rainfall and high relative humidity with flowering may result in flower/fruit drop and heavy incidence of fungal diseases. Cashew is not tolerant to saline soils and does not grow well in soils with poor drainage (Rupa et al., 2013).

To determine the current and future climatic suitability of cashew production in the S3 and 4P basins, the study by Grüter et al. (2022) offers the best insights. In this study, were the expected suitability of Coffee, Cashew and Avocado production due to climate change was modeled, the biophysical requirements of Cashew were collated from literature into four suitability classes, see Table 8 (S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N: Unsuitable). After reviewing the expected ranges of future climate variables for the S3 and 4P basins (see section 2.2.2 and Annex 1), it can be concluded that the climatic conditions are (and remain) in optimal ranges for cashew production, except for mean annual temperature. A mean annual temperature greater than 28 °C affects cashew production, it is the upper bound between the class highly suitable (S1) and moderately suitable (S2). Section 2.2.2 and annex 1 show that temperatures are expected to exceed this threshold in the future, likely affecting cashew yields and revenue generated from cashew production.

Table 8. Climatic threshold values determining suitability levels for cashew production (Grüter et al., 2022)

Climate	S1	S2	S3	N
Mean annual temperature (°C)	24 - 28	28 - 31 20 - 24	31 - 34 15 - 20	>34 <15
Mean minimum temperature of coldest month (°C)	>10	8-10	4 - 8	<4
Mean annual precipitation (mm)	1,000 - 2,250	2,250 - 3,200 800-1,000	3,200-4,500 500-800	>4,500 <500
Length of dry season (months)	0 - 4	4 - 5	5 - 6	>6
Mean relative humidity of driest month (%)	>30	25 - 30	20 - 25	<20

4.3 Mango

4.3.1 Exposure

Figure 23 shows the CIAS map presenting the portion of surveyed agricultural holdings that report mango production. As can be seen, mangos are produced in most Cambodian provinces. Of the four provinces that overlap with the 3S and 4P Basins, Stung Treng and Kratie have the highest percentage of holdings producing mango (about 27% and 18%, respectively), while Mondul Kiri and Ratanak Kiri have almost no agricultural holdings reporting mango production (see Table 9 for details).

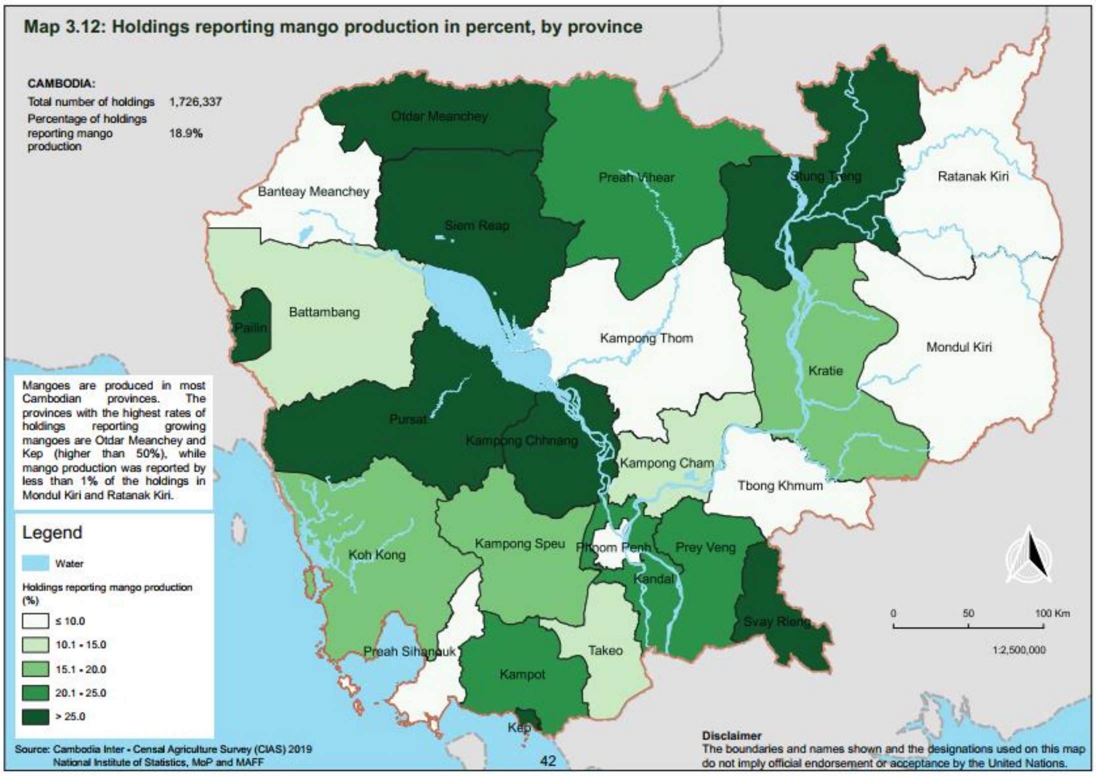

Figure 23. CIAS map presenting the portion of surveyed agricultural holdings that report mango production (NIS and MAFF, 2020).

Table 9. Holdings reporting mango production (CIAS 2019)

Province	Reported mango production (%)
Kratie	18.9
Mondul Kiri	0.5
Ratanak Kiri	0.9
Stung Treng	26.9

4.3.2 Climatic Suitability

Mango is a tropical fruit tree that thrives in tropical and subtropical climates. Mango trees require specific temperature ranges for optimal growth and fruit production. Extreme temperatures, whether too hot or too cold, can damage flowers and young fruit, reducing yield. Mango trees also require a specific amount of water, and changes in rainfall patterns can affect water availability for trees, which can also impact yield. Furthermore, climate change can also increase the risk of pest and disease infestations, which can further reduce mango yields.

Mango trees require a warm tropical climate to grow successfully. The ideal temperature range for mango tree development and fruit growth is 24 °C to 30 °C. Temperatures below 10 °C can cause damage to the tree and inhibit fruit development. Rainfall distribution over the year is more important than cumulated annual precipitation, especially to produce high-quality fruits. Mango trees need a distinct dry season and a wet season for optimal growth and fruit production. The lower limit for precipitation for commercial mango growing is around 750 mm. However, it is essential to have a well-defined dry period during the flowering and fruiting stages, as excessive unseasonal rainfall or prolonged waterlogging can adversely affect fruit development and increase the risk of diseases. Mango trees prefer high humidity, especially during flowering and fruit development. Relative humidity levels between 60% and 80% are favorable for mango cultivation (Normand et al., 2015).

Successful flower induction in mango is essential for fruit production (Luo et al., 2019). The flower induction process is driven by (relatively) cool temperatures that stimulate leaves to produce a signal that is transmitted to the shoot apex, resulting in flower production. Exposure to low daily minimum and maximum temperatures is required for initiated buds to achieve floral induction. Given that mango is adapted to tropical and sub-tropical conditions, floral induction is also limited by low temperatures. There is not a clear consensus among the literature as to what the upper and lower temperature boundaries are for inductive conditions, but it is reported that ideal flowering conditions for all cultivars are day temperatures below 32 °C and night temperatures below 18 °C. The upper temperature limit is to flowering is considered as more constraining; temperatures greater than 34 °C during the flowering are recognized to adversely impact flower induction and consequent fruit production (Liu et al., 2023).

Basing on literature review and climate data analysis (section 2.2 and Annex 1), the following climate hazards can be identified for the 3S and 4P river basins, under both current and future conditions:

- Heat stress (temperatures > 34 °C) during the mango tree flowering season. The flowering season runs from December until March for the most popular cultivars in Cambodia.
- Excessive unseasonal rains from December until March, leading to prolonged waterlogging, during the flowering and fruit development stages.

4.4 Banana

4.4.1 Exposure

Figure 24 shows the CIAS map presenting the portion of surveyed agricultural holdings that report banana production. As can be seen, bananas are produced in most Cambodian provinces. Of the four provinces that overlap with the 3S and 4P river basins, Stung Treng and Kratie have the highest percentage of holdings producing banana (about 21% and 28%, respectively), while Mondul Kiri and Ratanak Kiri far fewer agricultural holdings reporting banana production. In fact, with less than 1% reported, banana production is almost absent in Ratanak Kiri province (see Table 10 for details).

During the provincial workshops, it was reported that these data may not accurately reflect the economic importance of banana to the basin population; although relatively many people practice banana cultivation, these are often grown on small plots and do not always constitute a major source of income.

Table 10. Holdings reporting banana production (CIAS 2019)

Province	Reported banana production (%)
Kratie	27.7
Mondul Kiri	6.8
Ratanak Kiri	0.7
Stung Treng	20.9

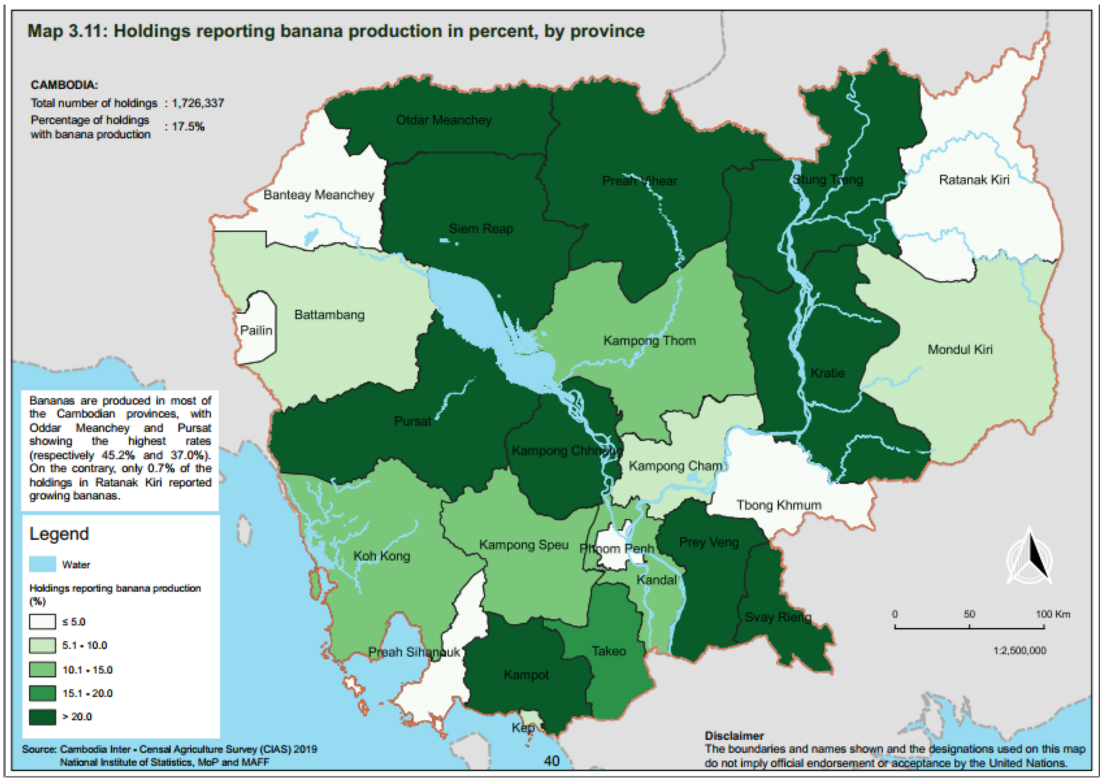

Figure 24: CIAS map presenting the portion of surveyed agricultural holdings that report banana production (NIS and MAFF, 2020).

4.4.2 Climatic suitability

Banana plants require specific temperature and moisture conditions for optimal growth and fruit production. Changes in temperature and rainfall patterns can affect the timing of growth stages, flowering, and fruit development, leading to lower yields and quality. Bananas are also susceptible to several pests and diseases, and climate change can increase the risk and severity of these problems, further reducing yields.

Bananas thrive in warm temperatures. The optimal temperature range for banana growth is between 23°C and 27 °C. Temperatures below 10°C or above 40°C are shown to negatively impact banana productivity (e.g., Abdoussalami et al., 2023a; Salvacion, 2020; Varma and Bebber, 2019). Bananas require a significant amount of water throughout their growing season. Adequate and well-distributed rainfall is crucial for optimal growth. The ideal rainfall range for banana production in Cambodia is between 1500 and 2500 millimeters per year. However, it's important to note that bananas can tolerate short periods of drought but will suffer if there is excessive waterlogging. Bananas prefer a humid climate. They grow best in areas with a relative humidity of around 75-85%. High humidity helps in leaf expansion and overall growth of the plant. Bananas require plenty of sunlight to grow and produce fruit. They typically need at least 6-8 hours of direct sunlight per day. Sufficient sunlight is crucial for photosynthesis, which provides the energy needed for banana plant growth. While bananas prefer a relatively calm environment, they can withstand moderate winds. However, strong winds can cause damage to the leaves, stems, and fruits (Salvacion, 2020).

Table 11. Recommended ranges of temperature and precipitation suitable for growing and producing bananas (source: Noleppa et al., 2021)

Author	Region	Variable	Minimum	Optimum	Maximum
Calberto et al. (2015)	Global	Temperature	13 °C	27 °C	38 °C

Author	Region	Variable	Minimum	Optimum	Maximum
FAO (2020c)	Global	Temperature	16 °C	27 °C	38 °C
Ikisan (2020)	Global	Temperature	10 °C	23 °C	40 °C
Turner and Lahav (1983)	Global	Temperature	10 °C	25 °C	37 °C
Varma and Bebber (2019a)	Global	Temperature	10 °C	27 °C	35 °C
Varma and Bebber (2019a)	LAC	Temperature	20 °C	27 °C	30 °C
Varma and Bebber (2019a)	Global	Precipitation	0 mm	1700 mm	8000 mm
Varma and Bebber (2019a)	LAC	Precipitation	85 mm	2650 mm	5300 mm

A comprehensive review of climate change and its effects on banana production is provided by (Noleppa et al., 2021). Collating from several sources (see Table 11), they summarized the following minimum, optimum and maximum values of temperature and precipitation for growing and producing bananas (Table 12).

Table 12. Minimum, optimum, and maximum temperature and precipitation for banana production

Variable	Minimum	Optimum	Maximum
Annual average temperature	15 °C	25 °C	35 °C
Annual average precipitation	40 mm	2100 mm	6650 mm

Basing on these thresholds and climate data analysis (section 2.2 and Annex 1), the following crop-specific climate hazard can be identified for banana production in the 3S and 4P river basins, under both current and future conditions:

- Heat stress, with average temperature temperatures > 35 °C throughout the year.

4.5 Cassava

4.5.1 Exposure

As can be seen in Figure 25, within the boundaries of the 3S and 4P basins, cassava is produced most in Ratanak Kiri Province, followed by Kratie Province. The map of Figure 25 is produced by a satellite-based supervised crop classification methodology, based on a range of vegetation and land use / land cover indices derived from optical and radar satellite imagery (Saah et al., 2020). The cassava production locations found in Figure 25 are not fully in agreement with CIAS 2019 data, as the latter reports the highest percentage of holdings producing cassava in Mondu Kiri (almost 28%), closely followed by Ratanak Kiri (over 27%). See Table 13 for details.

Table 13. Holdings reporting cassava production (CIAS 2020)

Province	Reported cassava production (%)
Kratie	17.3
Mondul Kiri	27.5
Ratanak Kiri	27.2
Stung Treng	10.8

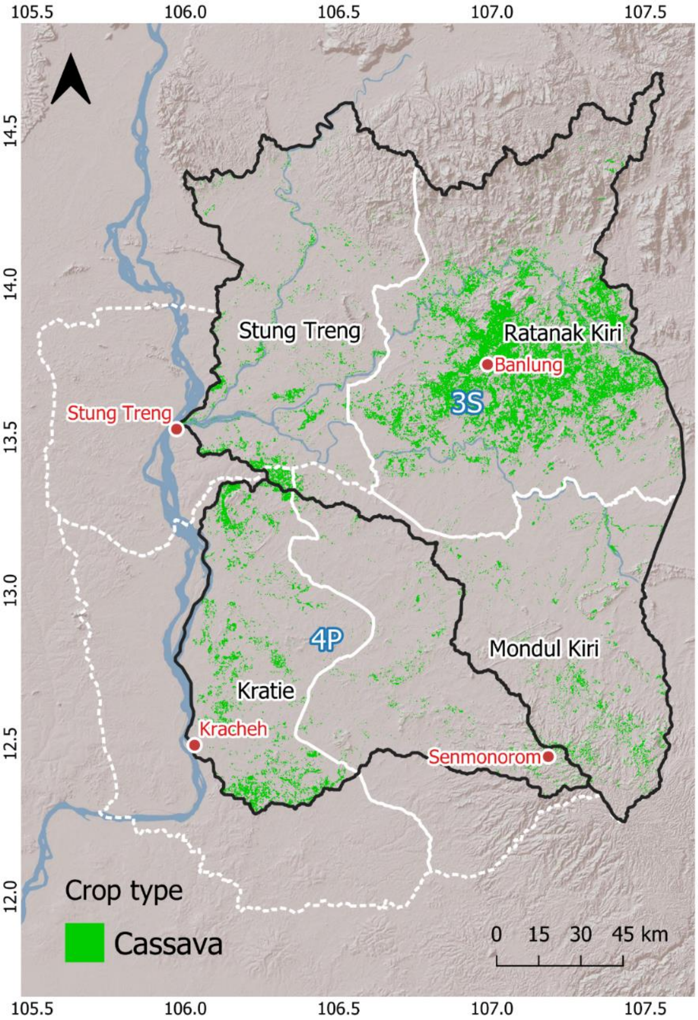

Figure 25. Cassava production in the 3S and 4P basins (data: SIG 2023)

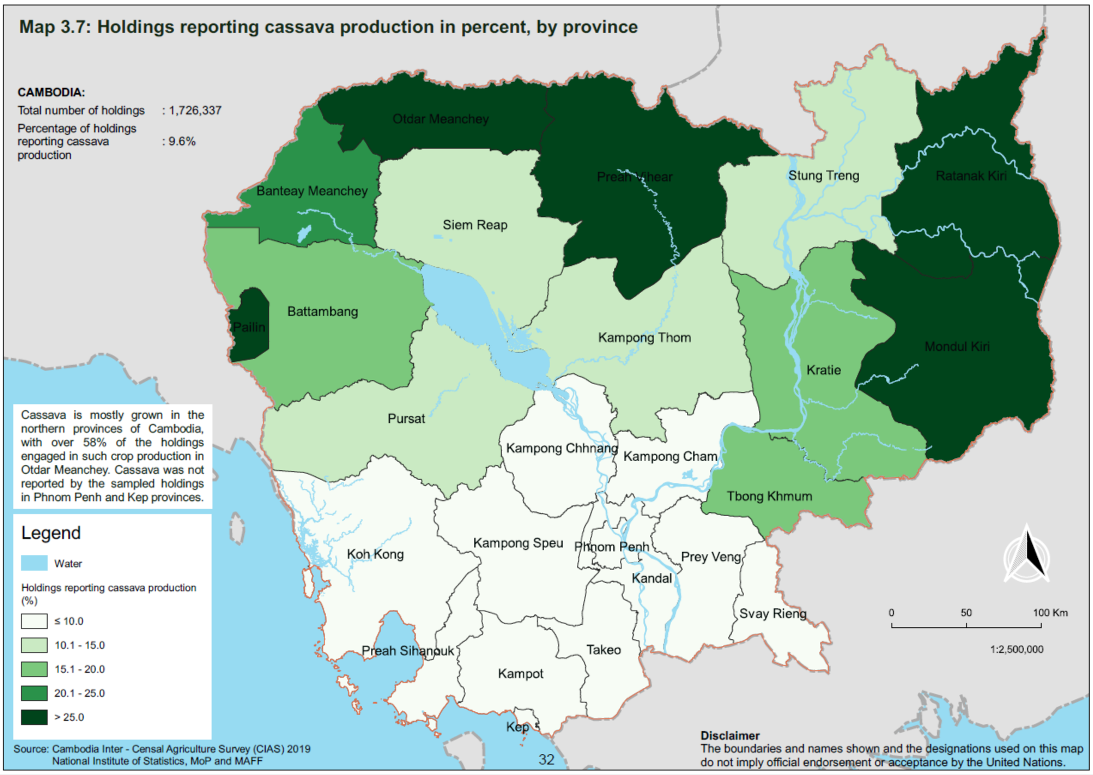

Figure 26. CIAS map presenting the portion of surveyed agricultural holdings that report cassava production.

4.5.2 Climatic suitability

Cassava is a major staple, bioenergy, and industrial crop in many parts of the developing world. In Southeast Asia, cassava is grown on over 4 M ha by nearly 8 M (small-scale) farming households, under climatic and biophysical conditions that often prove unsuitable for many other crops. Tolerance to environmental extremes such as drought or increased temperatures, sustained yields under (relatively) low soil fertility levels and an ability to grow on marginal lands make cassava particularly suitable for resource-poor smallholders in many parts of South-east (SE) Asia (Graziosi et al., 2016). Cambodia is the fourth largest cassava producer in Asia and the tenth largest globally. Over 12 million tonnes of fresh cassava root are harvested each year.

Literature review on the climatic requirements makes clear that climate change is not expected to threaten future production of cassava in Cambodia (Ceballos et al., 2011; Devi et al., 2022; Shrestha et al., 2018). On the contrary, production might in fact increase due to more favorable climatic conditions and increased photosynthetic stimulation by elevated atmospheric CO_2 levels in C3 plants such as cassava (Rosenthal and Ort, 2012b).

In general, cassava requires a warm humid climate. Temperature is important, as all growth stops at about 10 ºC. Typically, the crop is grown in areas that are frost free the year round. The highest root production can be expected in the tropical lowlands, below 150 m altitude, where temperatures average 25-27°C, but some varieties grow at altitudes of up to 1500 m. The plant produces best when rainfall is abundant, but it can be grown where annual rainfall is as low as 500 mm or where it is as high as 5,000 mm if there is good internal drainage. Cassava cannot withstand flooding or moist soil conditions over prolonged periods as the roots are particularly sensitive to waterlogging, causing rotting and loss of agricultural yields (Sutrisno et al., 2023)

Cassava can stand prolonged periods of drought in which most other food crops would perish. This makes it valuable in regions where annual rainfall is low or where seasonal distribution is irregular. In tropical climates the dry season has about the same effect on Cassava as low temperature has on deciduous perennials in other parts of the world. The period of dormancy lasts two to three months and growth resumes when the rains begin again. Cassava is a sun-loving crop and should be grown under open conditions. Yield is drastically reduced under shaded conditions e.g., when grown under coconut. Twelve hours daylength is reported to be optimum for cassava.

In their study on the adaptation of cassava to climate change, Ceballos et al., (2011) modeled the future global environmental suitability of cassava using the EcoCrop model by FAO. Basing themselves on literature review and expert judgement, they used the following minimum, optimum and maximum climatic conditions for cassava production (see Table 14).

Table 14. Climate suitability ranges for cassava

Climate variable	Minimum	Optimum	maximum
Growing season length	240	240	240
Temperature	0-15	22-32	45
Rainfall	300	800-2,200	2,800

Based on the climate suitability ranges provided in Table 14, it can be concluded that both the current and expected future climate conditions (see Annex 1) for basins 3S and 4P are (and remain) very suitable to produce cassava. But since cassava roots are particularly sensitive to waterlogging, flash flooding and prolonged inundation can be identified as a potential climate hazard.

5 Assessment of climate hazards

Based on the literature review presented in Chapter 4, Table 15 lists the climate hazards and associated (crop-specific) climate indices that were identified for the selected crops cashew, mango, and banana. This chapter assesses the climate hazards for each crop. Since drought and flash floods / inundation are hazards that are relevant to agriculture in general, they are assessed in separate sections.

As the climatic suitability of cassava in the 3S and 4P Basins is not expected to be affected by climate change (Section 4.5.2), the crop is excluded from Table 15. Rather, it is a crop that is often considered in light of adaptation strategies, as is further discussed in Section 6.2.

Table 15. Climate hazards for the selected crops and their associated (crop-specific) Climate Indices

Crop	Climate hazards	Climate indices
Cashew	Heat Drought Flash flood / inundation	*Mean annual T > 28 °C* *Δ Consecutive Dry Days (CDD)* *Δ Max 5-day rainfall (Rx5d)*
Mango	Heat during flowering season Damage by off-season rains Drought Flash flood / inundation	*No. of months Tmax > 34 °C in Dec - Mar* *Δ Max 1-day rainfall (Rx1d) in Dec - Mar* *Δ Consecutive Dry Days (CDD)* *Δ Max 5-day rainfall (Rx5d)*
Banana	Heat Drought Flash flood / inundation	*No. of months Tmax > 35 °C* *Δ Consecutive Dry Days (CDD)* *Δ Max 5-day rainfall (Rx5d)*

5.1 Drought

Drought is a climate hazard relevant to all crops produced in basins 3S and 4P and assessed in this study. The climate index associated with drought is consecutive dry days (CDD), which is defined as the annual maximum number of consecutive days with precipitation less than 0.1 mm. Figure 27 shows the number of annual consecutive dry days during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] future time horizon, as well as the percent change (%) for both SSPs with respect to the reference period. The data is aggregated to level-2 administrative districts in river basins 3S and 4P.

Historically, of the four provinces overlapping with the 3S and 4P basins, the low-lying and downstream Kratie province is the driest with about 54 maximum consecutive dry days per year. The higher elevation and upstream Ratanak Kiri province is the least dry of the four provinces, with around 40 CDD per year. Future projections show that all level-2 districts in 3S and 4P basins can expect moderate increases of drought hazard severity, especially in the districts that are currently somewhat less affected. Districts that are currently characterized by a relatively high drought severity will continue to experience these high levels, while districts with a current relatively low drought severity level are expected to experience higher drought severity levels. As a result, the differences in CDD will become smaller between the districts, moving closer to the combined 3S and 4P basin average increase of CDD of 48 days for both SSPs.

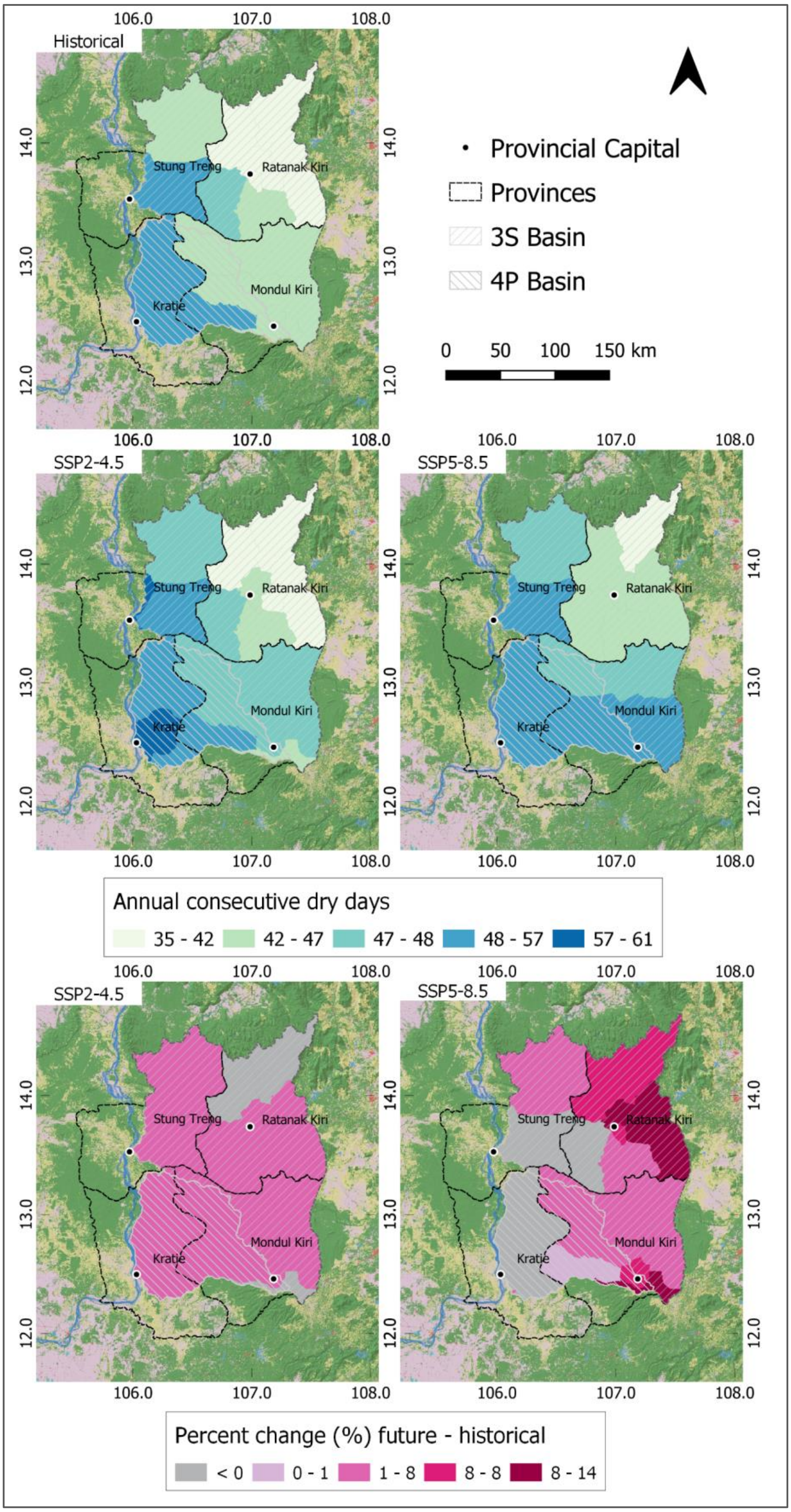

Figure 27. Number of annual consecutive dry days (CDD, in days) during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period.

Table 16. Percent change (%) number of annual consecutive dry days (CDD)

		CDD (days)	CDD change (%)		
Province	District	Historical	SSP2-4.5	SSP5-8.5	SSP Average
Kratie	Chetr Borei	54.0	4.8	-3.5	0.7
Kratie	Chhloung	53.8	5.7	0.7	3.2
Kratie	Kracheh	54.9	5.6	-1.0	2.3
Kratie	Sambour	53.9	5.0	-3.9	0.5
Kratie	Snuol	52.7	5.1	-3.7	0.7
Mondul Kiri	Kaev Seima	49.2	4.9	0.0	2.4
Mondul Kiri	Kaoh Nheaek	46.4	2.3	3.9	3.1
Mondul Kiri	Ou Reang	46.1	-0.9	8.4	3.8
Mondul Kiri	Pech Chreada	46.3	1.8	7.3	4.5
Mondul Kiri	Saen Monourom	45.9	1.7	7.6	4.6
Ratanak Kiri	Andoung Meas	39.4	1.5	11.5	6.5
Ratanak Kiri	Ban Lung	41.7	4.2	7.9	6.1
Ratanak Kiri	Bar Kaev	39.8	5.2	12.7	9.0
Ratanak Kiri	Koun Mom	46.6	1.8	-0.4	0.7
Ratanak Kiri	Lumphat	42.7	2.9	5.9	4.4
Ratanak Kiri	Ou Chum	41.3	4.5	8.8	6.6
Ratanak Kiri	Ou Ya Dav	39.5	1.0	13.6	7.3
Ratanak Kiri	Ta Veaeng	35.4	-2.4	8.3	3.0
Ratanak Kiri	Veun Sai	40.8	-0.2	8.0	3.9
Stung Treng	Sesan	51.9	3.3	-2.9	0.2
Stung Treng	Siem Pang	46.2	1.3	4.6	2.9
Stung Treng	Stueng Traeng	56.1	4.4	-2.9	0.8

5.2 Flash Flood / Inundation

Flash flood and/or inundation is a climate hazard relevant to all crops produced in basins 3S and 4P and assessed in this study. The climate index associated with flooding and inundation is Rx5day, which is defined as the annual maximum 5-day consecutive amount of precipitation (mm). Figure 28 shwos the maximum annual 5-day consecutive precipitation (mm) during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, as well as the percent change (%) for both SSPs with respect to the reference period. The data is aggregated to level-2 administrative districts in river basins 3S and 4P, see also Table 17

Historically, of the four provinces overlapping with the 3S and 4P basins, the higher elevation and upstream Ratanak Kiri province experiences the highest intensity 5-day rainfall events (and is likely more prone to flash flooding) with an average of 211 mm of consecutive 5-day precipitation across all districts. The two most mountainous districts in the northeast of Ratanak Kiri (Andoung Meas and Ta Veaeng) experience the most extreme rainfall events in 3S and 4P basins, with 234 and 242 mm of consecutive 5-day rainfall respectively.

Climate projections show that all level-2 districts in 3S and 4P basins can expect significantly more extreme rainfall events in the future, though the spatial patterns remain generally the same. On average, for both SSPs across all districts in the 3S and 4P basins, consecutive 5-day precipitation will increase by about 31 mm, which is a 17% increase with respect to current amounts.

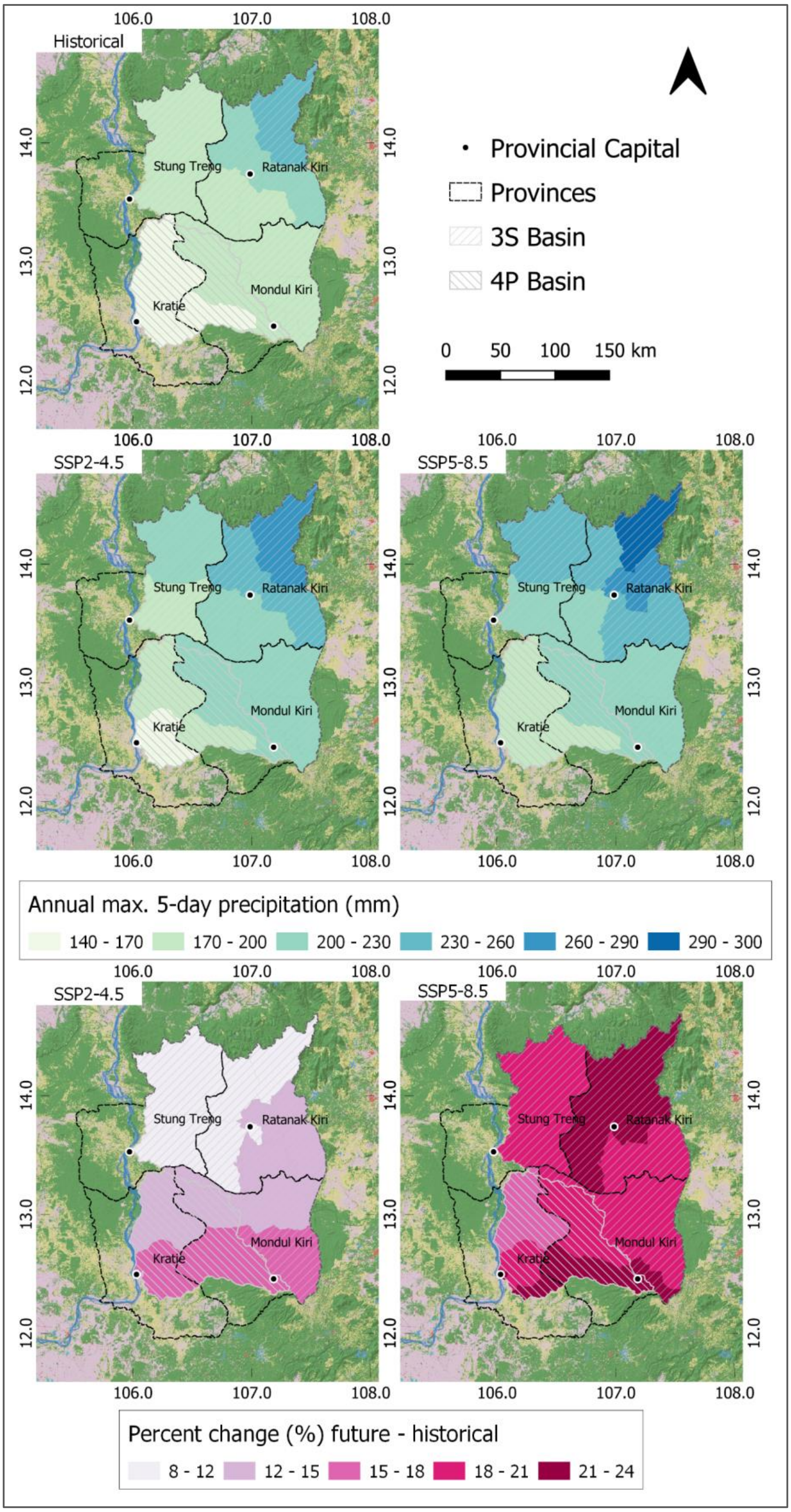

Figure 28.Maximum annual 5-day consecutive precipitation (Rx5day, in mm) during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period.

Table 17. Change (mm) in maximum annual 5-day consecutive precipitation

		Rx5d (mm)	Rx5d change (mm)		
Province	**District**	**Historical**	**SSP2-4.5**	**SSP5-8.5**	**SSP Average**
Kratie	Chetr Borei	146.7	21.7	29.1	25.4
Kratie	Chhloung	139.6	20.5	31.8	26.2
Kratie	Kracheh	142.3	20.5	29.2	24.8
Kratie	Sambour	154.4	18.0	26.9	22.5
Kratie	Snuol	143.7	22.1	32.4	27.3
Mondul Kiri	Kaev Seima	158.3	25.3	32.6	29.0
Mondul Kiri	Kaoh Nheaek	177.4	23.7	32.3	28.0
Mondul Kiri	Ou Reang	175.1	28.9	36.8	32.8
Mondul Kiri	Pech Chreada	179.4	29.3	36.0	32.7
Mondul Kiri	Saen Monourom	176.3	28.8	36.5	32.6
Ratanak Kiri	Andoung Meas	234.0	29.5	54.1	41.8
Ratanak Kiri	Ban Lung	202.8	22.3	44.7	33.5
Ratanak Kiri	Bar Kaev	213.6	24.8	47.6	36.2
Ratanak Kiri	Koun Mom	181.2	20.7	38.3	29.5
Ratanak Kiri	Lumphat	191.2	22.3	39.1	30.7
Ratanak Kiri	Ou Chum	213.3	24.7	49.3	37.0
Ratanak Kiri	Ou Ya Dav	214.5	27.9	43.8	35.9
Ratanak Kiri	Ta Veaeng	242.4	26.0	55.2	40.6
Ratanak Kiri	Veun Sai	210.8	23.5	45.1	34.3
Stung Treng	Sesan	173.4	19.1	35.3	27.2
Stung Treng	Siem Pang	193.5	20.3	37.6	29.0
Stung Treng	Stueng Traeng	172.6	17.4	32.4	24.9

5.3 Cashew

5.3.1 Heat > 28 °C

A mean annual temperature greater than 28 °C affects cashew production, it is the upper bound between the class highly suitable (S1) and moderately suitable (S2) (see Table 8, collated by (Grüter et al., 2022)). Figure 29 shows the probability (%) that mean annual temperature exceeds 28 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, as well as the percent change (%) of this cashew-specific heat stress indicator for both SSPs with respect to the reference period.

Historically, of the four provinces overlapping with the 3S and 4P basins, the eastern higher-elevation provinces Ratanak Kiri and Mondul kiri experience cooler temperatures compared to the lower-lying provinces Kratie and Stun Treng (see also Figure 4). These conditions are reflected in the probability of annual mean temperatures greater than 28°C, with lower probabilities for Ratanak Kiri and Mondul kiri (20-30%) compared to Kratie and Stun Treng (50-60%). Climate projections show a (very) high probability (%) that mean annual temperature will exceed 28 °C in the future for all level-2 districts, which will likely affect cashew production in the 3S and 4P basins. In fact, the average probability of annual mean T > 28 °C across all districts is greater than 90% for both SSPs, meaning that mean temperatures below 28 °C is expected to occur for less than one month per year in the future. For several districts in Kratie and Stung Treng provinces (i.e., Sesan, Chetr Borei, Chhloung, Kracheh, Sambour, Snuol and Stueng Traeng) annual mean temperatures are in fact not expected to go below 28 °C, so here conditions for cashew production are not expected to remain highly suitable (S1) in the future.

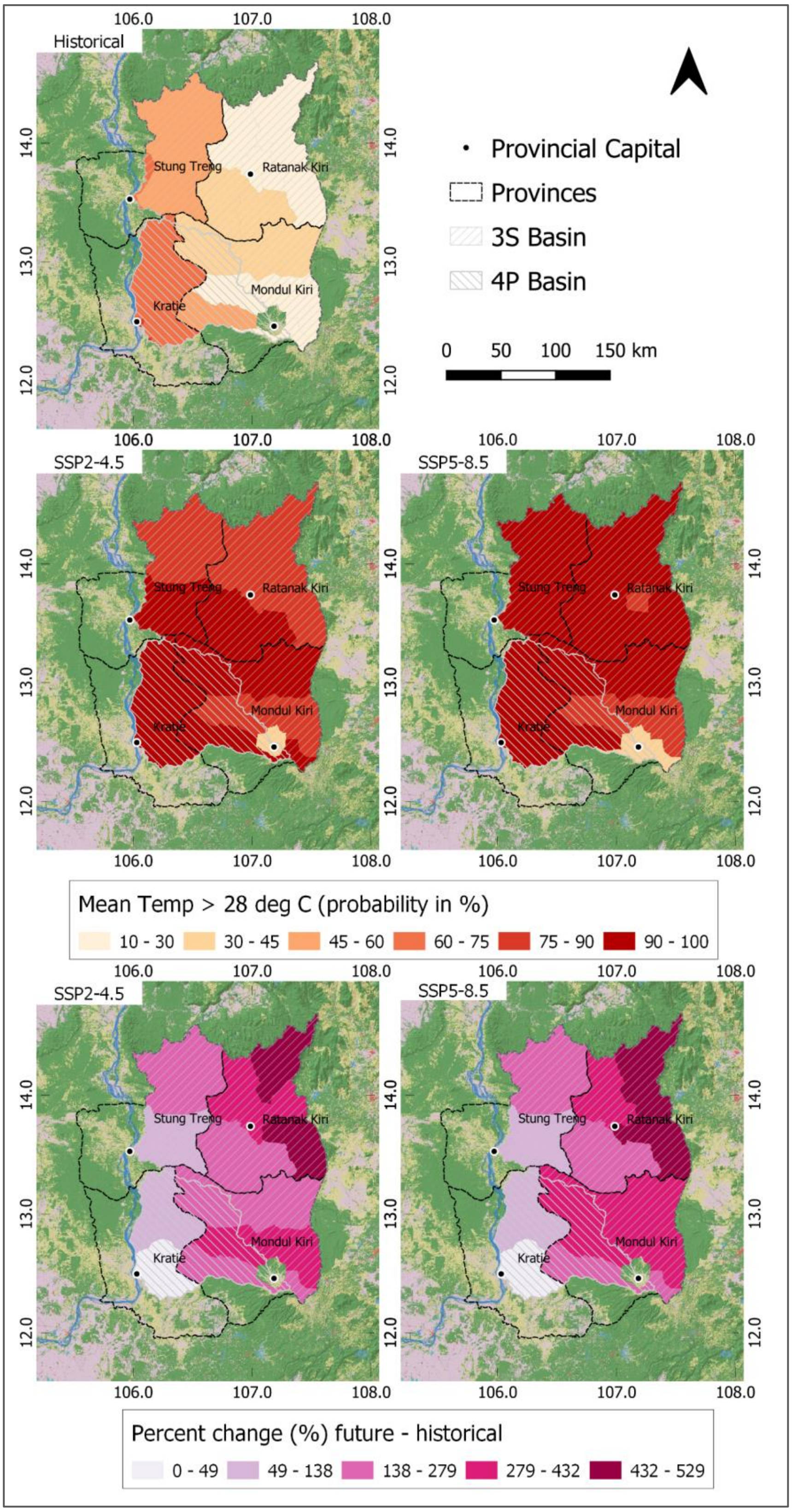

Figure 29. Probability (%) that mean annual temperature exceeds 28 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period.

5.3.2 Risk Table

Table 18 shows the climate-related risk that the production of cashew will be exposed to in the future, disaggregated to the level-2 districts within (and overlapping) with basin 3S and 4P. The considered climate hazards are heat stress (specified to climatic suitability of cashew), flash flooding, and drought. The hazards are classified into three classes (low-moderate-high) according to the expected relative changes to the hazard intensity in the future. The exposure component is determined according to the cashew production in each district, based on the dataset presented in Figure 21. Cashew production is highest the districts in Ratanak Kiri province, which are thus characterized by the highest exposure. Table 18 shows that the future climate risk for cashew production in basin 3S and 4P are expected to be highest for most districts in Ratanak Kiri province and for Sambour district in Kratie province.

Table 18. Climate hazard risk table for Cashew, differentiated to districts within basin 3S and 4P.

District	Province	Exposure	Expected changes in hazard intensity			Risk
			Heat	*Flash flood*	*Drought*	
Chetr Borei	Kratie	Moderate	High	Moderate	Low	**Moderate**
Chhloung	Kratie	Moderate	High	Moderate	Low	**Moderate**
Kracheh	Kratie	Low	High	Moderate	Low	**Low**
Sambour	Kratie	High	High	Moderate	Low	**High**
Snuol	Kratie	Moderate	High	Moderate	Low	**Moderate**
Kaev Seima	Mondul Kiri	Low	High	Moderate	Low	**Low**
Kaoh Nheaek	Mondul Kiri	Moderate	High	Moderate	Low	**Moderate**
Ou Reang	Mondul Kiri	Low	High	Moderate	Low	**Low**
Pech Chreada	Mondul Kiri	Moderate	High	Moderate	Low	**Moderate**
Saen Monourom	Mondul Kiri	Low	High	Moderate	Low	**Low**
Andoung Meas	Ratanak Kiri	High	High	High	Moderate	**High**
Ban Lung	Ratanak Kiri	High	High	Moderate	Moderate	**High**
Bar Kaev	Ratanak Kiri	High	High	High	Moderate	**High**
Koun Mom	Ratanak Kiri	High	High	Moderate	Low	**Moderate**
Lumphat	Ratanak Kiri	High	High	Moderate	Low	**Moderate**
Ou Chum	Ratanak Kiri	High	High	Moderate	Moderate	**High**
Ou Ya Dav	Ratanak Kiri	High	High	High	Moderate	**High**
Ta Veaeng	Ratanak Kiri	Moderate	High	High	Low	**High**
Veun Sai	Ratanak Kiri	Moderate	High	Moderate	Low	**Moderate**
Sesan	Stung Treng	Moderate	High	Moderate	Low	**Moderate**
Siem Pang	Stung Treng	Moderate	High	Moderate	Low	**Moderate**
Stueng Traeng	Stung Treng	Moderate	High	Moderate	Low	**Moderate**

5.4 Mango

5.4.1 Heat > 34 °C during flowering season

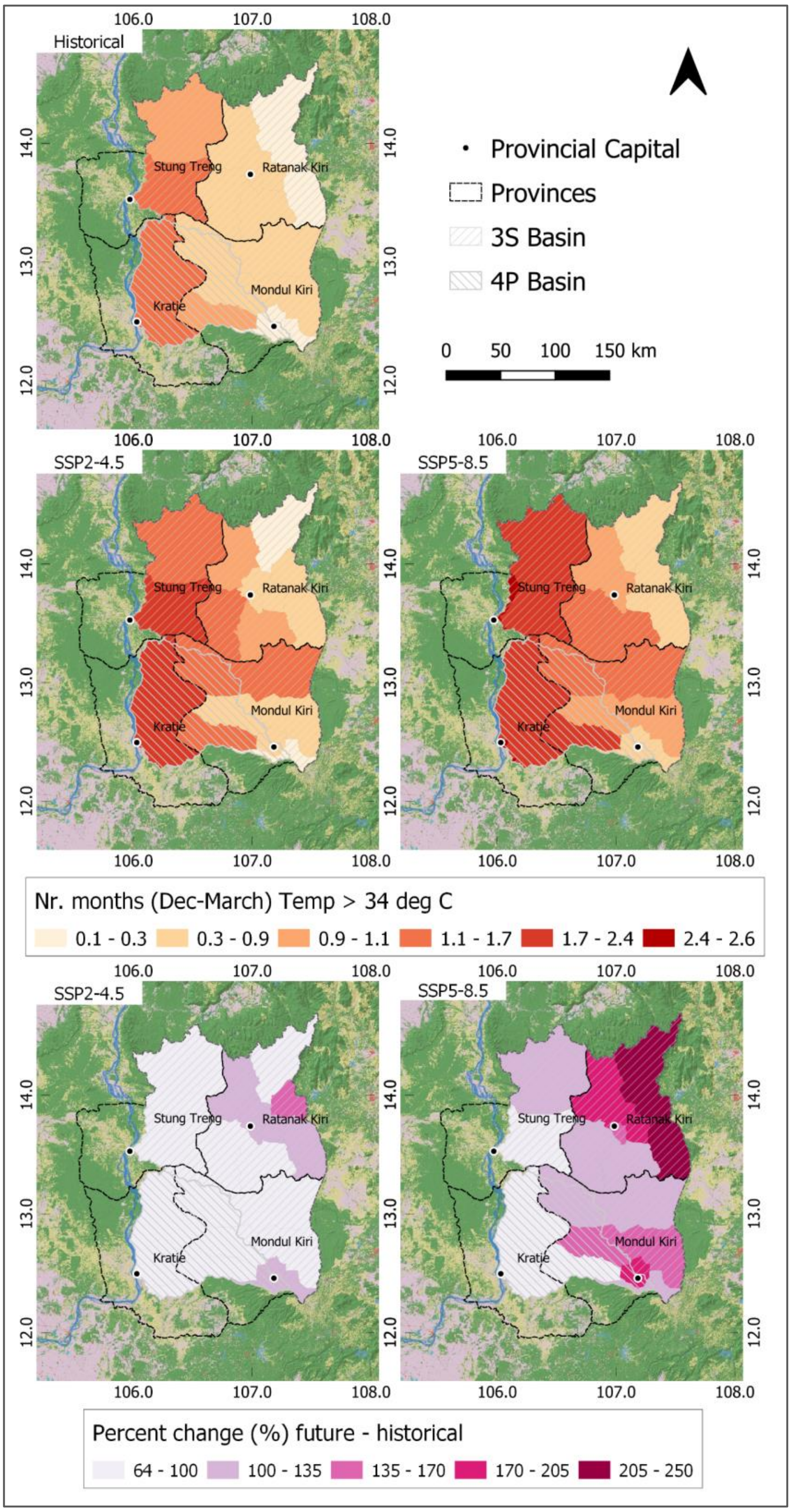

Figure 30. Number of months between December until March where the average maximum temperature exceeds 34 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period.

5.4.2 Damage by off-season rains

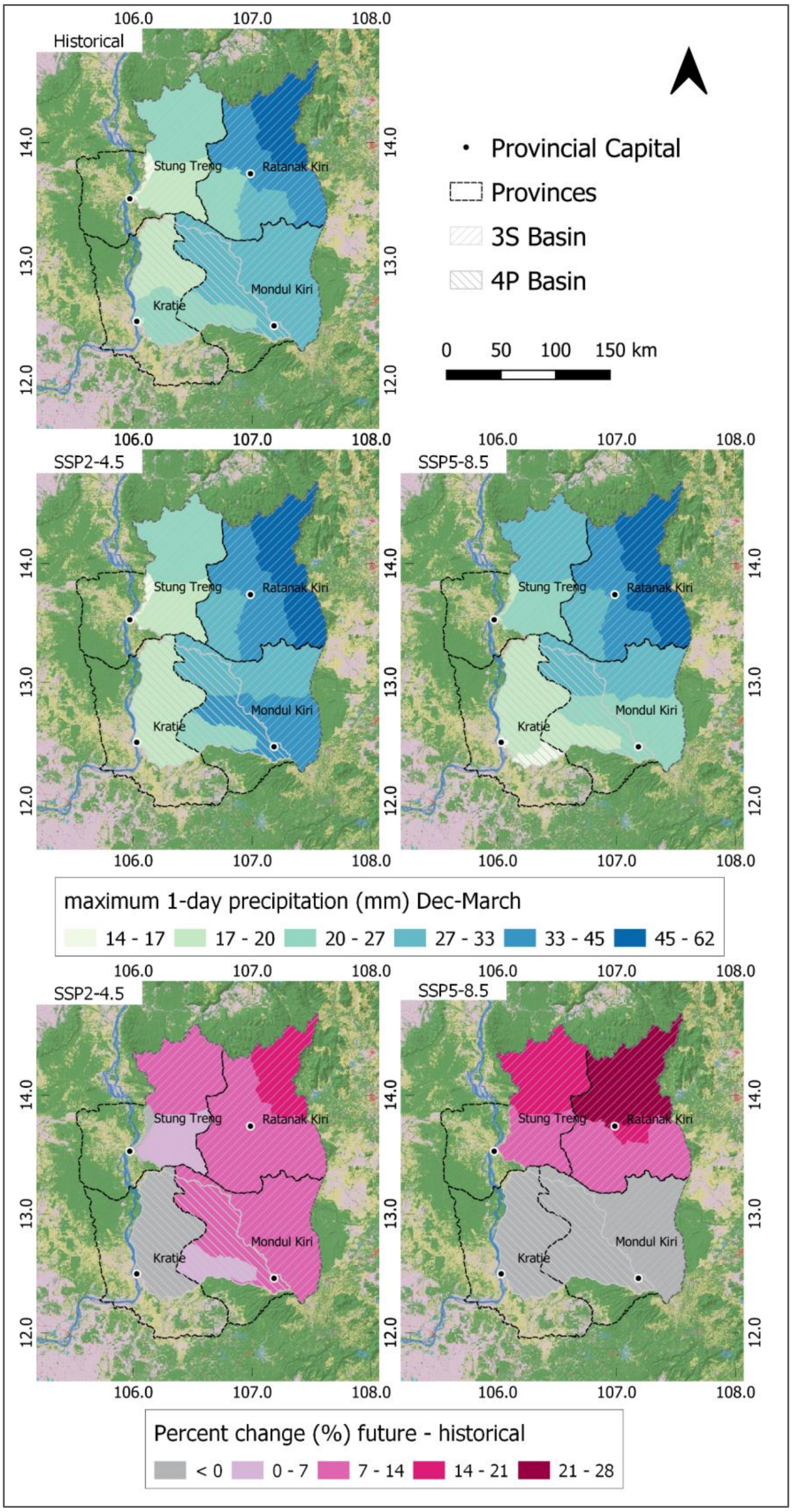

Figure 31. Maximum 1-day precipitation (mm) between December until March during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period

Mango production is affected by the following climate hazards can be identified for the 3S and 4P river basins, under both current and future conditions:

- Heat stress (with temperatures > 34 °C) during the mango tree flowering season. The flowering season runs from December until March for the most popular cultivars in Cambodia.
- Excessive unseasonal rains from December until March, leading to prolonged waterlogging, during the flowering and fruit development stages.

Figure 30 shows the number of months between December until March (averaged over a 30-year window) where the average maximum temperature exceeds 34 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, as well as the percent change (%) of this crop-specific indicator for both SSPs with respect to the reference period. Historically, the severity of heat stress that mango experiences during the flowering season is higher in Kratie and Stung Treng provinces compared to Mondul Kiri and Ratanak Kiri provinces. During the four month long flowering season, temperatures exceed 34 °C for about 1.2 months in Kratie and Stung Treng while these temperatures are only exceeded for about 15 days in Mondul Kiri and Ratanak Kiri. Climate projections show that in the future the number of months with temperatures greater than 34 °C is expected to increase by 1 month for Kratie and Stung Treng, to 2,2 months or more than 50% of the time during the flowering season. For Mondul Kiri and Ratanak Kiri province the number of months with these temperatures is expected to increase to 1 month, or 25% of the time during the flowering season. Districts in Ratanak Kiri (with current low heat stress conditions) are expected to experience the highest increase in heat stress severity in the future, where the number of months with temperatures greater than 34 °C is expected to more than double.

Figure 31 shows the maximum 1-day precipitation (mm) between December until March during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, as well as the percent change (%) of this crop-specific indicator for both SSPs with respect to the reference period. The more mountainous districts in Ratanak Kiri province (i.e., Ou Ya Dav, Andoung Meas, and Ta Veaeng) experience the highest intensity rainfall events during December until March, with max 1-day rainfall amounts of around 45-50 mm. In contrast, max 1-day rainfall in the lower-lying provinces Kratie and Stung Treng is around 15-25 mm in intensity, so districts within these provinces are exposed to rainfall events that are at least 50% less intense.

Climate projections show that in the future the maximum 1-day precipitation (mm) between December until March is expected to decrease for the southern provinces Kratie and Mondul Kiri, particularly under the SSP5-8.5 pathway. Max 1-day rainfall is expected to decrease by about 15-20%, which is likely to have a positive impact on mango production. In contrast, districts in the northern part of basin 3S are expected to experience a significant increase of around 20-25% in max 1-day rainfall between December until March. Such an increase in extreme rainfall may lead to increased risk of damage to mango flowers, with reduced mango production as result.

5.4.3 Risk Table

Table 19 shows the climate-related risk that the production of mango will be exposed to in the future, disaggregated to the level-2 districts within (and overlapping) with basin 3S and 4P. The considered climate hazards are heat stress (specified to climatic suitability of mango), extreme rainfall (rx1day), flash flooding (rx5day), and drought. The hazards are classified into three classes (low-moderate-high) according to the expected relative changes to the hazard intensity in the future. The exposure component is determined according to the mango production, based on the provincial level dataset presented in Figure 23. Mango production is highest in districts in Stung Treng (27%) and Kratie (19%) province, which are thus characterized by the highest exposure. Considering exposure and expected changes in climate hazard severity, Table 19 shows that the future climate risk for mango production in basin 3S and 4P are expected to be highest for districts in Stung Treng province. High exposure (high mango production) and significant increase in extreme rainfall event during the flowering season are deciding factors contributing to the high climate risk.

Table 19. Climate hazard risk table for Mango, differentiated to districts within basin 3S and 4P.

*no district level data

District	Province	Exposure*	Expected changes in hazard intensity: *Heat*	*Extreme rainfall*	*Flash flood*	*Drought*	Risk
Chetr Borei	Kratie		High	Low	Moderate	Low	**Moderate**
Chhloung	Kratie		High	Low	Moderate	Low	**Moderate**
Kracheh	Kratie	High	High	Low	Moderate	Low	**Moderate**
Sambour	Kratie		High	Low	Moderate	Low	**Moderate**
Snuol	Kratie		High	Low	Moderate	Low	**Moderate**
Kaev Seima	Mondul Kiri		High	Low	Moderate	Low	**Low**
Kaoh Nheaek	Mondul Kiri		High	Low	Moderate	Low	**Low**
Ou Reang	Mondul Kiri	Low	High	Low	Moderate	Low	**Low**
Pech Chreada	Mondul Kiri		High	Low	Moderate	Low	**Low**
Saen Monourom	Mondul Kiri		High	Low	Moderate	Low	**Low**
Andoung Meas	Ratanak Kiri		High	High	High	Moderate	**Moderate**
Ban Lung	Ratanak Kiri		High	High	Moderate	Moderate	**Moderate**
Bar Kaev	Ratanak Kiri		High	High	High	Moderate	**Moderate**
Koun Mom	Ratanak Kiri		High	Moderate	Moderate	Low	**Low**
Lumphat	Ratanak Kiri	Low	High	Moderate	Moderate	Low	**Low**
Ou Chum	Ratanak Kiri		High	High	Moderate	Moderate	**Moderate**
Ou Ya Dav	Ratanak Kiri		High	Moderate	High	Moderate	**Moderate**
Ta Veaeng	Ratanak Kiri		High	High	High	Low	**Moderate**
Veun Sai	Ratanak Kiri		High	High	Moderate	Low	**Low**
Sesan	Stung Treng		High	Moderate	Moderate	Low	**High**
Siem Pang	Stung Treng	High	High	High	Moderate	Low	**High**
Stueng Traeng	Stung Treng		High	Moderate	Moderate	Low	**High**

5.5 Banana

5.5.1 Heat > 35 °C

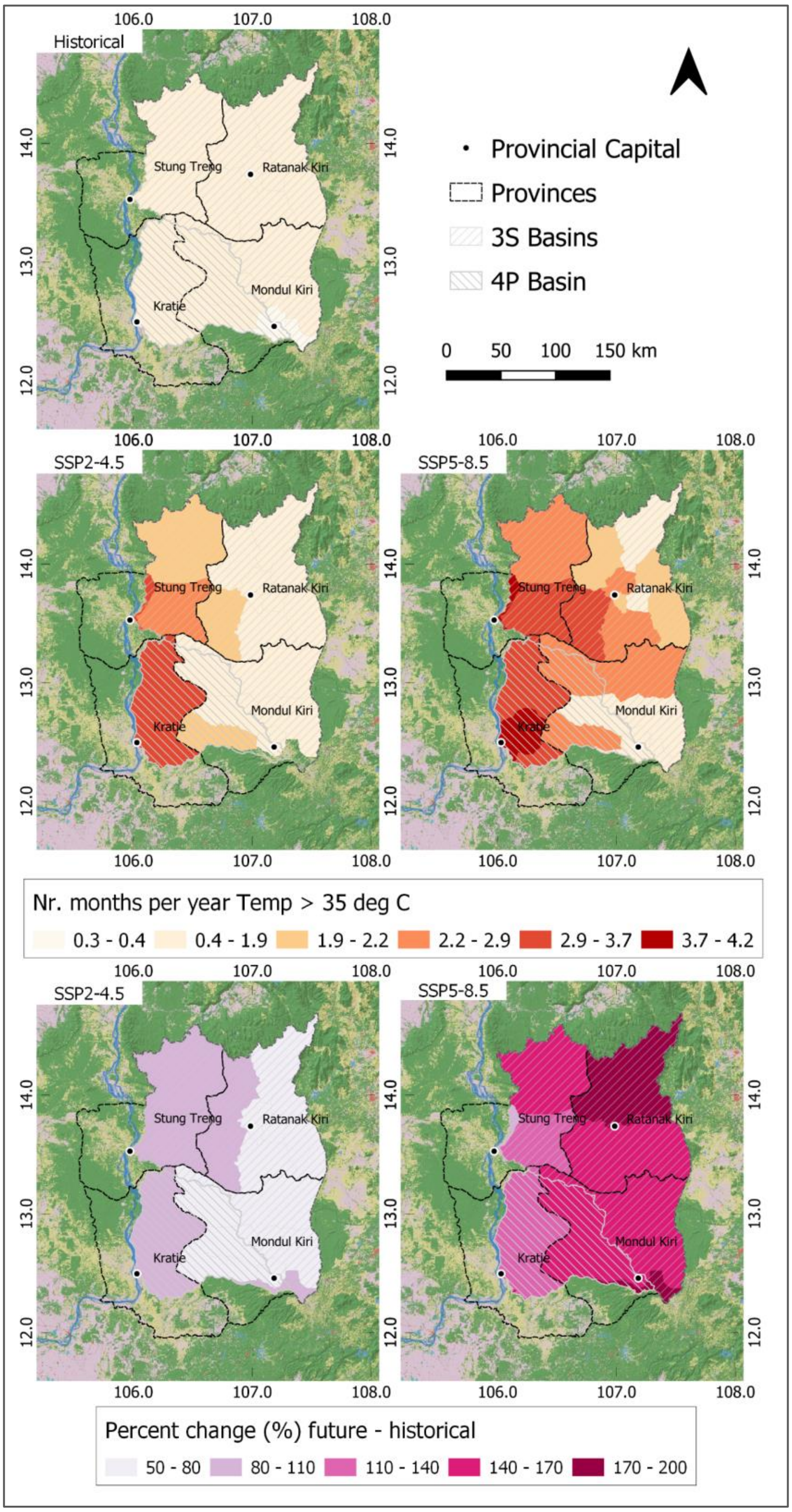

Figure 32: Number of months per year where the average maximum temperature exceeds 35 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, and the percent change (%) of this indicator for both SSPs with respect to the reference period.

Heat stress, with an average temperature > 35 °C throughout the year, affects banana production in basins 3S and 4P. Figure 32 shows the number of months per year where the average maximum temperature exceeds 35 °C during the reference period [2005] and for SSP2-4.5 and SSP5-8.5 at the mid-term [2050] time horizon, as well as the percent change (%) of this crop-specific indicator for both SSPs with respect to the reference period.

Currently, the banana-specific heat stress is relatively low (temperature > 35 °C occurs on average for 1 month per year) across all districts overlapping with the 3S and 4P basins, but the severity of heat hazard will significantly intensify in the future. In absolute terms, the future heat hazard for banana production is expected to be highest for districts in the low-lying provinces Stung Treng and Kratie. Temperatures greater than 35 °C are expected for 3-4 months per year in the future under both SSP pathways, likely affecting banana production. In relative terms, the greatest change in heat stress severity is expected for districts in the relatively cooler and higher elevation provinces Ratanak Kiri and Mondul Kiri. In districts in Ratanak Kiri (i.e., Ta Veaeng, Veun Sai, Ou Chum, Ou Reang, Andoung Meas) the number of months per year with temperatures greater than 35 °C are expected to more than double compared to current conditions. As a result, heat stress severity is expected to become moderate to high across all districts.

5.5.2 Risk Table

Table 20 shows the climate-related risk that the production of banana will be exposed to in the future, disaggregated to the level-2 districts within (and overlapping) with basin 3S and 4P. The considered climate hazards are heat stress (specified to climatic suitability of mango), flash flooding, and drought. The hazards are classified into three classes (low-moderate-high) according to the expected relative changes to the hazard intensity in the future. The exposure component is determined according to the banana production, based on the provincial level dataset presented in Figure 24. Banana production is highest in districts in Kratie (28%) and Stung Treng (21%) province, which are thus characterized by the highest exposure. Considering exposure and expected changes in climate hazard severity, Table 20 shows that the future climate risk for banana production in basin 3S and 4P are expected to be highest for districts in Kratie and Stung Treng province. High exposure (high banana production) and significant increase in heat stress conditions are deciding factors contributing to the high climate risk.

Table 20. Climate hazard risk table for Banana, differentiated to districts within basin 3S and 4P.

*no district level data

District	Province	Exposure*	Expected changes in hazard intensity			Risk
			Heat	*Flash flood*	*Drought*	
Chetr Borei	Kratie	High	High	Moderate	Low	**High**
Chhloung	Kratie		High	Moderate	Low	**High**
Kracheh	Kratie		High	Moderate	Low	**High**
Sambour	Kratie		High	Moderate	Low	**High**
Snuol	Kratie		High	Moderate	Low	**High**
Kaev Seima	Mondul Kiri	Moderate	High	Moderate	Low	**Moderate**
Kaoh Nheaek	Mondul Kiri		High	Moderate	Low	**Moderate**
Ou Reang	Mondul Kiri		High	Moderate	Low	**Moderate**
Pech Chreada	Mondul Kiri		High	Moderate	Low	**Moderate**
Saen Monourom	Mondul Kiri		High	Moderate	Low	**Moderate**
Andoung Meas	Ratanak Kiri	Low	High	High	Moderate	**Moderate**
Ban Lung	Ratanak Kiri		High	Moderate	Moderate	**Low**
Bar Kaev	Ratanak Kiri		High	High	Moderate	**Moderate**
Koun Mom	Ratanak Kiri		High	Moderate	Low	**Low**
Lumphat	Ratanak Kiri		High	Moderate	Low	**Low**
Ou Chum	Ratanak Kiri		High	Moderate	Moderate	**Low**
Ou Ya Dav	Ratanak Kiri		High	High	Moderate	**Moderate**
Ta Veaeng	Ratanak Kiri		Moderate	High	Low	**Low**
Veun Sai	Ratanak Kiri		High	Moderate	Low	**Low**
Sesan	Stung Treng	High	High	Moderate	Low	**High**
Siem Pang	Stung Treng		High	Moderate	Low	**High**
Stueng Traeng	Stung Treng		High	Moderate	Low	**High**

6 Implications

6.1 Vulnerability of the Basin Population

For obtaining a full picture of climate risk, it is important to consider vulnerability of the population of the 3S and 4P basins to the hazards evaluated in the previous chapter. An important component of vulnerability is the adaptive capacity of the population; i.e. the ability of an individual, household or community to develop resilience and adjust to the climate risks. This adaptive capacity is a function of access to financial, technical, educational, and community resources. Two different data sources were consulted for looking into the vulnerability component of risk:

- The report describing the “Baseline and stocking exercise on climate risk, vulnerability and water resource management in the priority areas of 3Ss and 4Ps river basin”, as prepared by GESC Consultants under the same project (GESC, 2023)
- The data portal of the Department of Climate Change (DCC) of the Ministry of Environment (MoE) of Cambodia, containing commune-level values for several climate-related vulnerability indices, based on Cambodia’s Commune Database (CDB).

Insights obtained from each of these resources are summarized below.

6.1.1 Survey Results from Baseline and Stocktaking Study

A field survey was conducted in 2022 among 10 communes in the 3S and 4P Basins, all located in Stung Treng and Kratie Provinces. Since these communes were selected based on their expected vulnerability to climate change impacts, the survey results may not be fully representative for the full basins. Still, the survey sheds light on trends and impacts of the most important hazards as perceived by the basin population, and their adaptive capacity to cope with these hazards.

The survey results confirm droughts, floods, and extreme rainfall as the major hazards occurring in the last 5 years, which is in line with the scope of this climate risk assessment. Moreover, increasing heat is observed by 76% of the respondents in the same periods.

In terms of adaptive capacity, the survey found that the majority of the households (>60%) consult weather forecasts for being aware of floods and drought episodes. The respondents were proposed a number of adaptation measures, with the question whether they (are able to) utilize or access these. Different types of measures were listed, including retaining water at the household level, making adjustments to their dwellings, practice alternative cropping techniques, access alternative water sources, etc. Strikingly, the survey results indicated that a vast majority of the respondents apparently do not practice any of these adaptation measures.

When asked about external assistance to cope with the challenges of adapting to climate change and mitigating disaster risk, respondents answered that communities in the study area receive primarily food aid (47%) and material support (36%), and to a lesser extent financial support (12%). Other types of support, including strikingly capacity development / training, are received by only a marginal part of the surveyed population.

Although the survey did not include communes from all four basin provinces and does not allow for any geographical differentiation within the basins, it does indicate that the adaptive capacity (and thus the overall climate resilience) of the population in the study area is relatively low.

6.1.2 Commune-level Vulnerability Indices

The DCC data portal allows for exploring community-level vulnerability data for the years 2014 - 2021. Vulnerability to droughts, floods and storms are included separately, as well as an overall Composite Vulneratbility Index (CVI), prepared following the methodology of Rai et al. (2015). The CVI is based on multiple data from Cambodia's Commune Database (CDB), and is an average of the values of individual vulnerability indices for all three hazards, including floods, drought and storms. The variables from the CDB that build these vulnerability indices were selected based on a significant correlation with observed (time lagged) losses and damages from these hazards. The indices are based on proxies of education, poverty, health, agriculture, business and environment, among others.

Figure 33 shows the CVI values at the district level for the most recent year of data (2021). Higher values indicate a higher vulnerability to climate hazards. Districts indicated with purple colors (the three highest classes in the legend) fall in the Quite Vulnerable and Highly Vulnerable classes as distinguished by Rai et al., (2015). Based on this map, it can be concluded that substantial parts of all four provinces should be considered vulnerable to climate change.

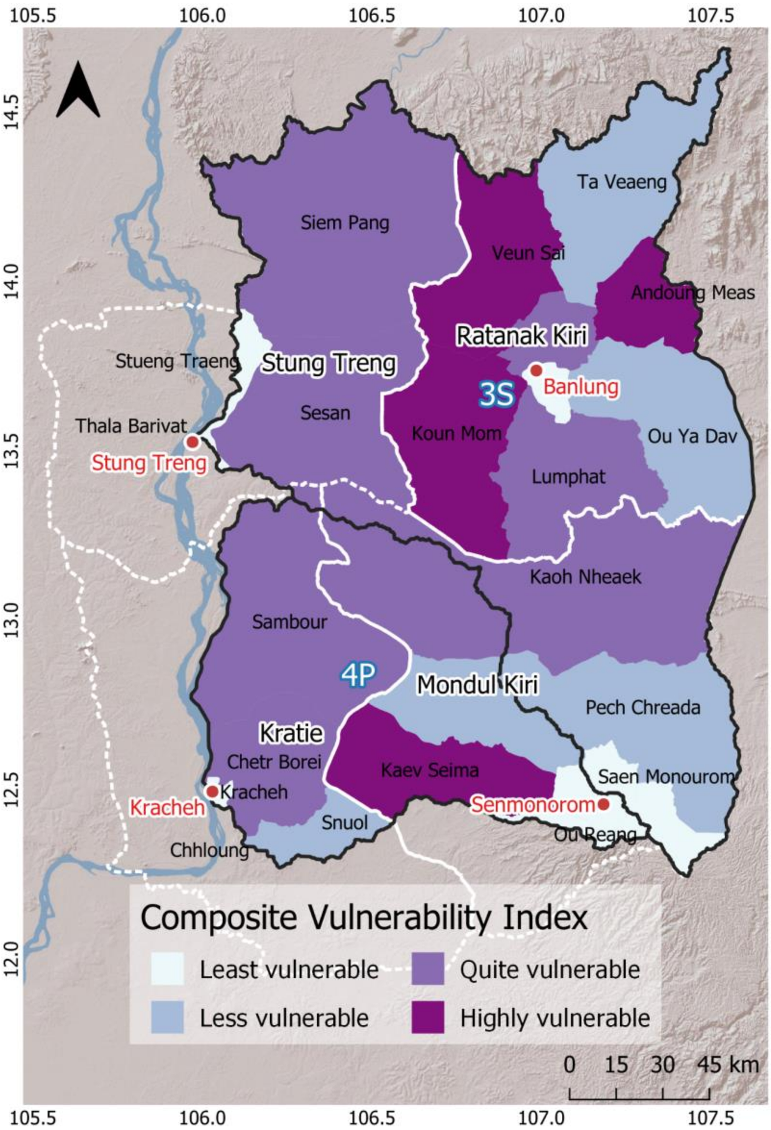

Figure 33. Composite Vulnerability Index in the 3S and 4P Basins in 2021, averaged at the district level (data source: *https://ncsd.moe.gov.kh/*)

Table 21. Composite Vulnerability Index (2021) disaggregated to districts in the 3S and 4P Basins

District	Province	VI score	VI category
Chetr Borei	Kratie	-0.28	Quite vulnerable
Chhloung	Kratie	-0.68	Less vulnerable
Kracheh	Kratie	-2.18	Least vulnerable
Sambour	Kratie	-0.20	Quite vulnerable
Snuol	Kratie	-1.10	Less vulnerable
Kaev Seima	Mondul Kiri	0.27	Highly vulnerable
Kaoh Nheaek	Mondul Kiri	-0.15	Quite vulnerable
Ou Reang	Mondul Kiri	-3.24	Least vulnerable
Pech Chreada	Mondul Kiri	-0.85	Less vulnerable
Saen Monourom	Mondul Kiri	-3.85	Least vulnerable
Andoung Meas	Ratanak Kiri	1.70	Highly vulnerable
Ban Lung	Ratanak Kiri	-1.96	Least vulnerable
Bar Kaev	Ratanak Kiri	-0.54	Less vulnerable
Koun Mom	Ratanak Kiri	0.49	Highly vulnerable
Lumphat	Ratanak Kiri	0.09	Quite vulnerable
Ou Chum	Ratanak Kiri	-0.16	Quite vulnerable
Ou Ya Dav	Ratanak Kiri	-0.66	Highly vulnerable
Ta Veaeng	Ratanak Kiri	-0.75	Less vulnerable
Veun Sai	Ratanak Kiri	1.76	Highly vulnerable
Sesan	Stung Treng	-0.35	Quite vulnerable
Siem Pang	Stung Treng	-0.11	Quite vulnerable
Stueng Traeng	Stung Treng	-1.73	Least vulnerable

6.2 Implications for adaptation strategies

In general, different type of adaptation strategies can be followed when trying to adjust to climate risks in agricultural systems. A brief review of relevant literature yielded the following overview (Aryal et al., 2020; FAO, 2013):

- Promote cultivation of diverse crops that are more resilient to climate change, such as drought-tolerant varieties or climate-smart crops that can withstand extreme weather events.
- Improve water management techniques by promoting the construction of small-scale irrigation systems, water harvesting structures, and efficient water use practices like drip irrigation to ensure crops have access to water during dry periods.
- Encourage the integration of trees and crops through agroforestry systems. Trees provide shade, improve soil fertility, and enhance water retention, thus reducing the vulnerability of crops to climate-related stresses
- Promote soil conservation practices such as contour plowing, terracing, and mulching to prevent soil erosion and improve soil health. This helps retain moisture in the soil and maintain its fertility.
- Provide training and support to farmers on improved agronomic practices, including proper timing of planting, appropriate fertilizer application, and pest and disease management, to optimize crop yields and minimize losses.
- Strengthen the availability and accessibility of weather information and early warning systems at the community level. This allows farmers to make informed decisions about planting, harvesting, and other agricultural activities based on climate forecasts.

- Improve access to credit and financial services for farmers to help them invest in climate-resilient technologies and practices. Introduce risk management tools such as crop insurance to protect farmers against climate-related losses.
- Encourage formation of farmer cooperatives and networks to facilitate collective action, knowledge exchange, and joint marketing of products. This strengthens resilience of farmers by enabling access to resources, share risks, and negotiate better prices.
- Enhance capacity-building on climate-smart agriculture, sustainable land management, and post-harvest practices. This empowers farmers with the knowledge and skills necessary to adapt to changing climatic conditions.

The above types of strategies were explored during with province-level stakeholders during the workshops in Kratie and Stung Treng, in light of their expected effectiveness and feasibility in the 3S and 4P Basins.

As discussed during the bilateral stakeholder meeting with MAFF, further activities towards selection and prioritization adaptation measures should strongly account for guidelines proposed by the MAFF. Among others, these revolve around practices that enhance agricultural diversification and agro-ecological practices, which should sustain and improve agricultural production in a sustainable manner. Table 22 lists adaptation options recommended for the Plateau and Mountain Ecozone of Cambodia in the Adaptation Technologies Guide published by MAFF and supported by Asian Development Bank (MAFF, 2019).

Table 22. Broad list of adaptation options in the Plateau and Mountain Ecozone of Cambodia, of which the 3S and 4P Basins are part. List is adapted from MAFF (2019)

Hazard	Adaptation options
Increased temperature	Altitude shift Change crops to heat tolerant species Shading
Drought	Small-scale water storage: (i) Household water ponds built (ii) Community ponds Drip irrigation Mulch/ permanent cover Alternative upland cropping systems Early maturing & drought tolerant varieties
Increased rainfall, storms and extreme events	Mulch/ permanent cover Shift cropping calendar SALT Build reservoir to store water Small-scale water storage: (i) Household water ponds, (ii) community water ponds
Floods (minor importance)	Shift cropping calendar Develop small-scale water storage: (i) household water ponds, (ii) community water ponds

Of the climate hazards discussed in detail in this climate risk assessment, the gradually increasing heat stress is arguably the one that is currently under-represented in adaptation strategies and media exposure (as opposed to e.g. floods and droughts, which are more “visible” hazards). Adaptation options such as reducing soil temperature by introducing cover crops may therefore be effective, as well as investigating the potential to shift cropping calendars. Although the latter may not seem intuitive for perennial crops, there are e.g. techniques for inducing off-season flowering (and thus fruit harvesting) in mango[1]. Crop diversification and expansion of heat tolerant species is another strategy that may be explored. For example, Cambodia's National Cassava Policy recognizes cassava as a crop that is particularly resilient to climate change, and positions it at the center of efforts to develop Cambodia's agro-industrial sector in a sustainable manner over next decades[2].

A full exploration of adaptation strategies is out of the scope of this report, and needs to be conducted in close collaboration with the relevant government stakeholders at national, provincial and district levels. Moreover, it is important to note that, while this report as well as the adaptation options highlighted here are limited to crop production, in fact climate risks can be relevant to the full agricultural value chain. Post-harvest management, processing infrastructure and energy use are examples of aspects that can also be affected by climate hazards, and made more resilient by appropriate adaptation options.

[1] See for example https://www.itfnet.org/v1/2014/12/cambodia-double-mango-harvest-draws-overseas-interest/
[2] https://www.undp.org/cambodia/press-releases/new-cassava-policy-transform-production-crucial-crop

7 Conclusions and recommendations

7.1 Conclusions

As part of this climate risk assessment, an overall analysis was performed to identify the expected impacts of climate change on average trends and seasonality of precipitation and temperature in the 3S and 4P Basins. All climate models included in the study project a hotter climate, where an average increase of temperature of around 1.5 ºC should be expected around 2050 (compared to a reference period of 1985 - 2014). Projections regarding changes in precipitation are more uncertain, but it seems likely that overall wetter conditions should be anticipated in the 3S and 4P Basin.

Taking the 2035 - 2065 period as the time horizon of interest, it is expected that climate hazards with the highest impact on agriculture in 3S and 4P Basins will be heat, flash floods, and drought. Impacts of climate change on e.g. annual precipitation and relative humidity are not expected to lead to major stresses on production of the key cash crops. In terms of relative changes to the current situation, especially heat stress is expected to increase drastically, making up an increasingly important part of the overall climate risk to agriculture in the region.

Despite the relatively small size of the study area, some spatial variability is visible when comparing expected severity of climate hazards at the district level. A moderate increase in the length of drought events is expected, where especially districts with a current relatively low drought severity level (e.g. in Ratanak Kiri Province) are expected to experience higher drought severity levels in the future. A similar phenomenon is visible for heat stress; although average temperatures are expected to increase across the basins, the relatively highest increase is expected in the districts that are currently the coolest. Extreme rainfall and flash floods, however, are expected to increase across the basins, with spatial patterns remaining approximately the same.

Key cash crops explicitly considered in this study are cashew, mango, banana and cassava, because of their economic value and the number of people depending on their value chains. Climate risks to cultivation of cashew, mango and banana are expected to increase over the next decades, which potentially significant impacts on the livelihoods of a major part of the 3S and 4P Basin population. It is, therefore, of critical importance that effective adaptation options are identified and implemented in the regional agricultural sector. Projected increases in climate hazard severity are exacerbated by the low adaptive capacity and overall resilience of the basin population.

While cashew, mango and banana are all expected to be increasingly at risk, cassava is expected to continue to thrive in the 3S and 4P Basins, particularly due to its relatively high tolerance for hot conditions. Promoting cassava cultivation could therefore play an effective role in climate adaptation strategies.

7.2 Recommendations

This climate risk assessment is intended to serve as a resource for informing follow-up activities, both within and beyond the scope of the project. The following recommendations can be made based on the results of this study:

- A follow-up climate risk assessment of the full value chains of the four selected key cash crops will support the development of a comprehensive adaptation strategy. IFAD has published guidelines for performing such an assessment of complete agricultural value chains (Vermeulen, 2015)

- Efforts towards identification and prioritization of adaptation options should be strongly aligned with existing policies and strategies of the Cambodian government, most notably MAFF;
- Identification and prioritization of adaptation options should take into consideration the main climate hazards evaluated in this study, with special attention to the potential impact of increasing heat stress on agriculture in the 3S and 4P Basins;
- Given their socio-economic importance to the basin population, it is recommended that future adaptation options focus on cashew, mango, and (to a lesser extent) banana. Cassava is a very important crop in the region, but due to its climate resilience could be part of a package of adaptation measures;
- It is advised for future piloting of adaptation measures to focus on districts identified in this study as expected to be subject to increasing climate risks;
- A full exploration of adaptation strategies is out of the scope of this report, and needs to be conducted in close collaboration with the relevant government stakeholders at national, provincial and district levels.

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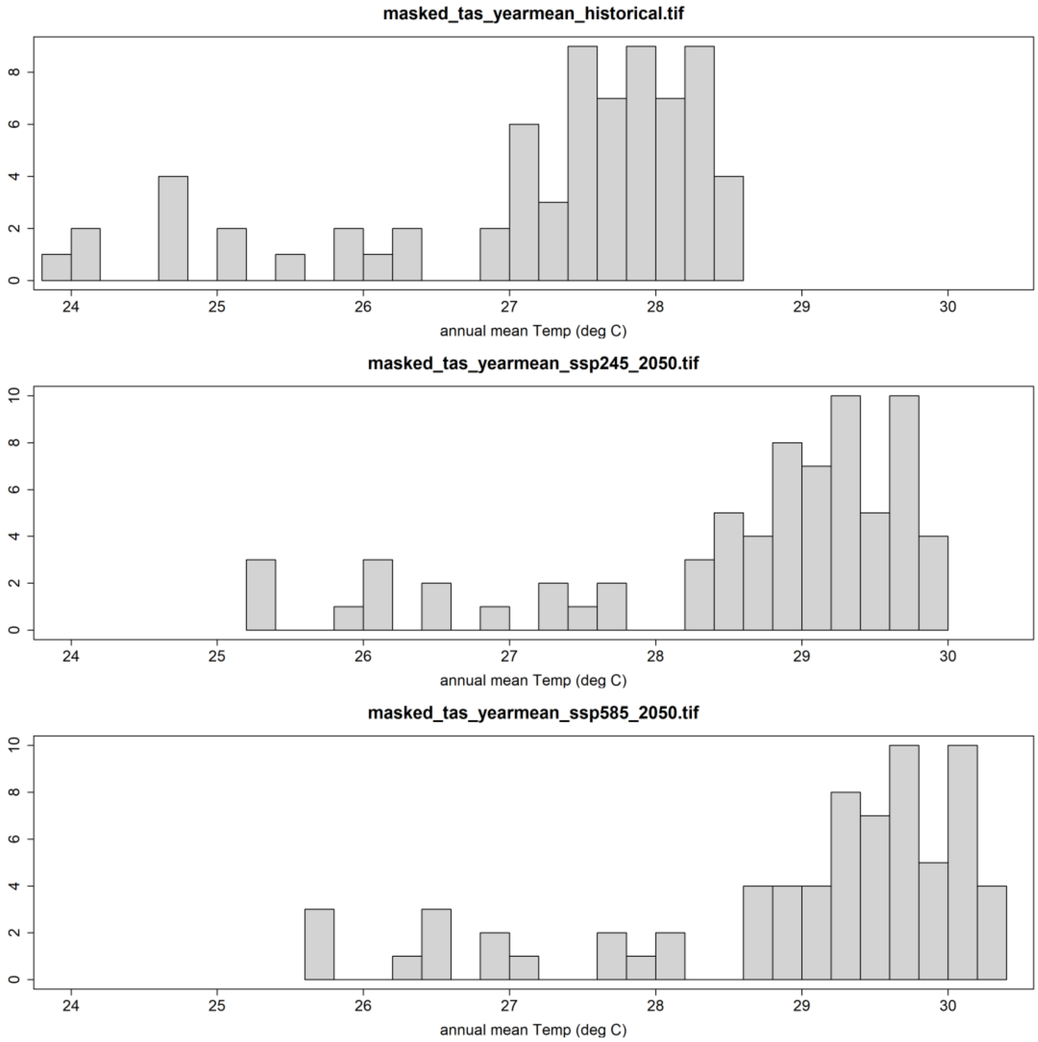
Annex 1: Exploratory CI Histograms

CI Histograms

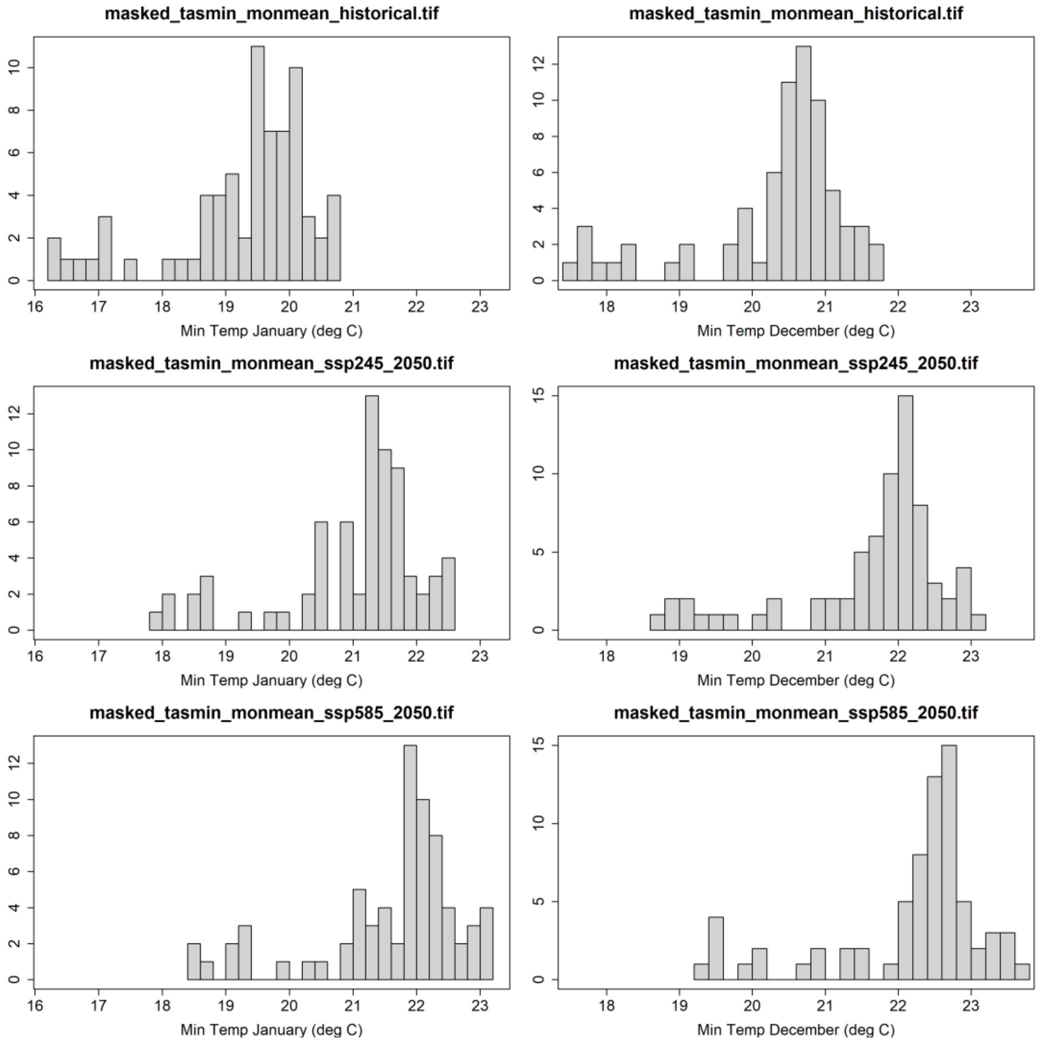
Crop-specific Climate Indicators

Climate Indicator	Cashew	Banana	Mango
Mean annual Tas (°C)	Y	N	N
Mean Tasmin (°C) coldest month (Dec-Jan)	Y	N	N
Mean Hurs (%) driest month (Jan-Feb)	Y	N	N
Monthly mean Tasmax (°C) Dec-March	N	N	Y
Monthly mean Pr mm) Dec-March	N	N	Y
Monthly mean CDD (days) Dec-March	N	N	Y
Mean annual Tasmax (°C)	N	Y	N
Mean annual Pr (mm)	N	Y	N
Monthly Mean Hurs (%)	N	Y	N
Mean Annual Rx5d (mm)			
Mean annual CDD (days)	N	Y	N

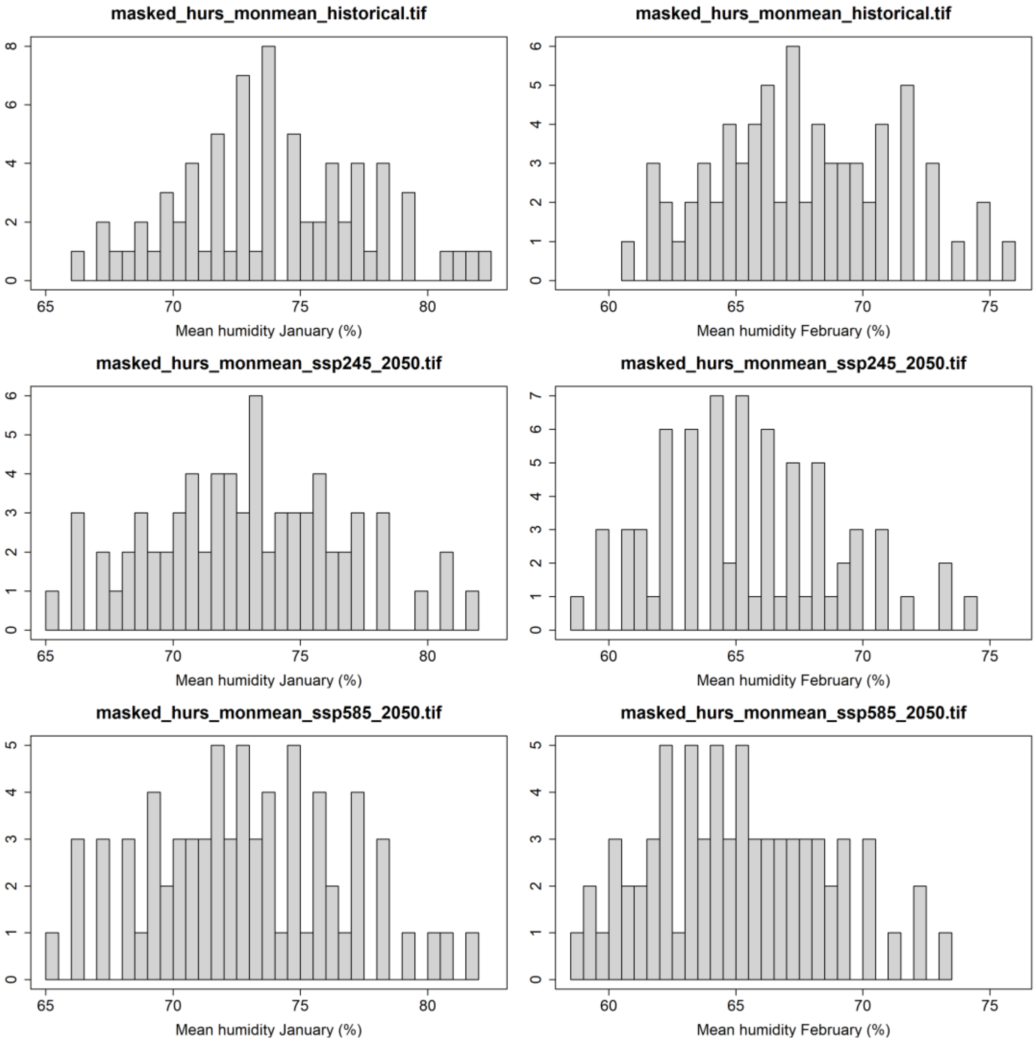
Mean annual Tas (°C)



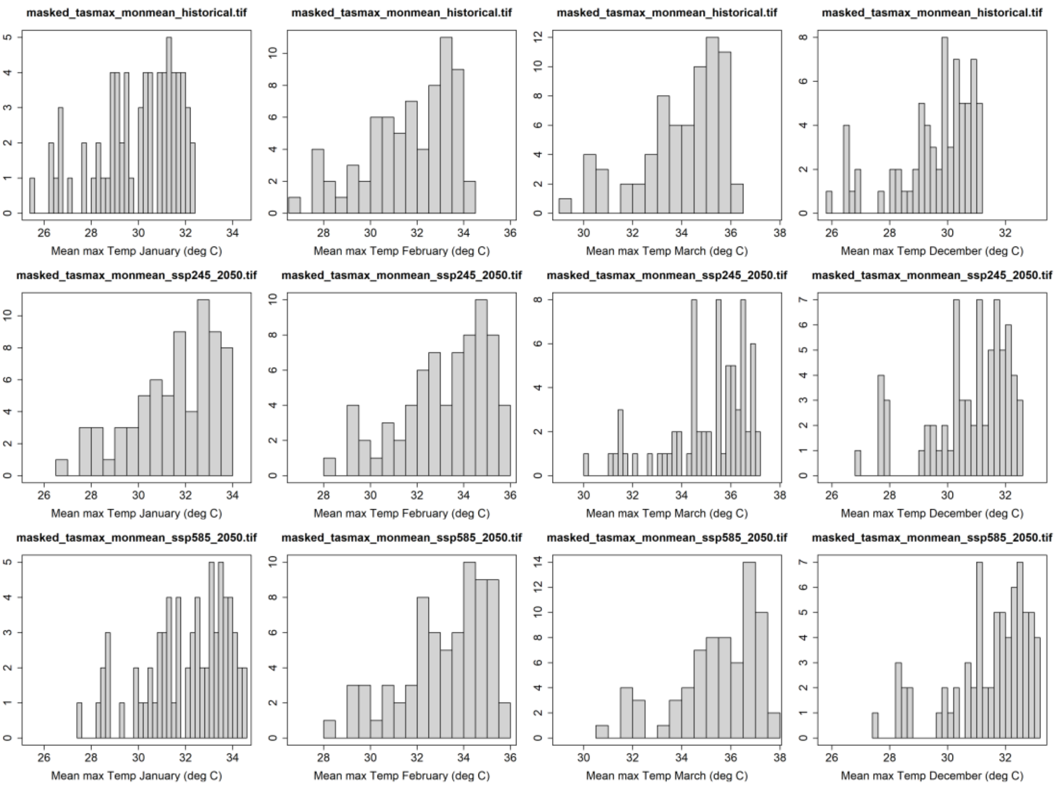
Mean Tasmin (°C) coldest months Dec-Jan



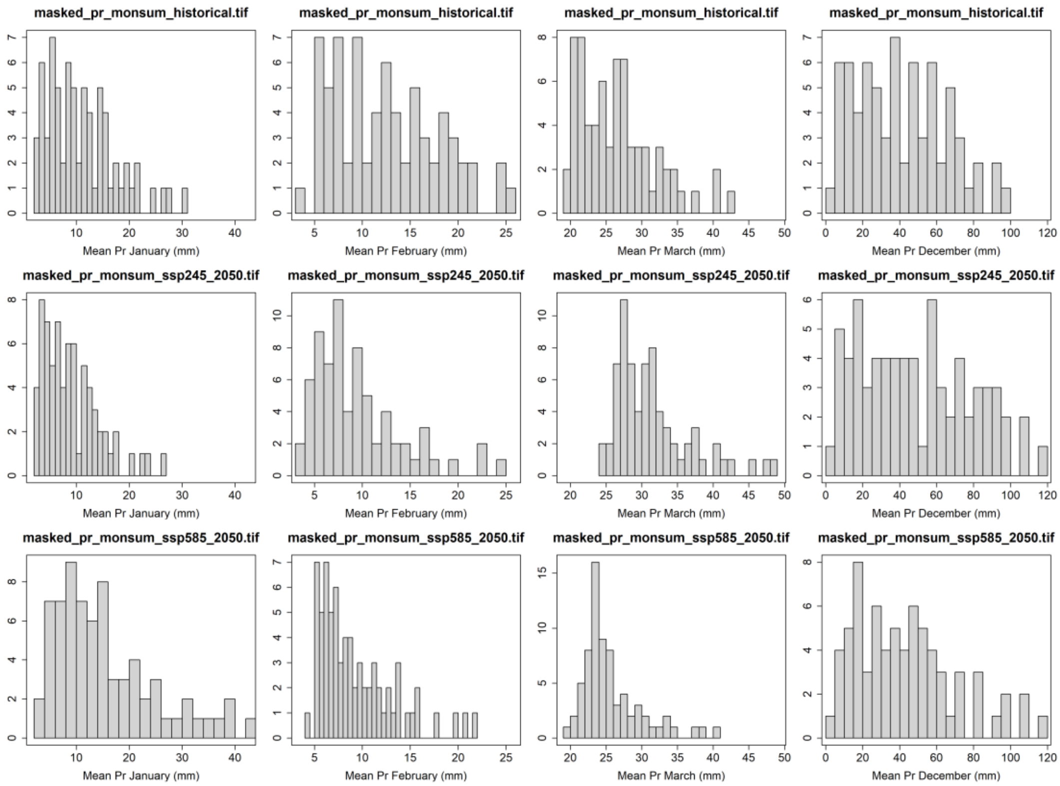
Mean Hurs (%) driest month (Jan-Feb)



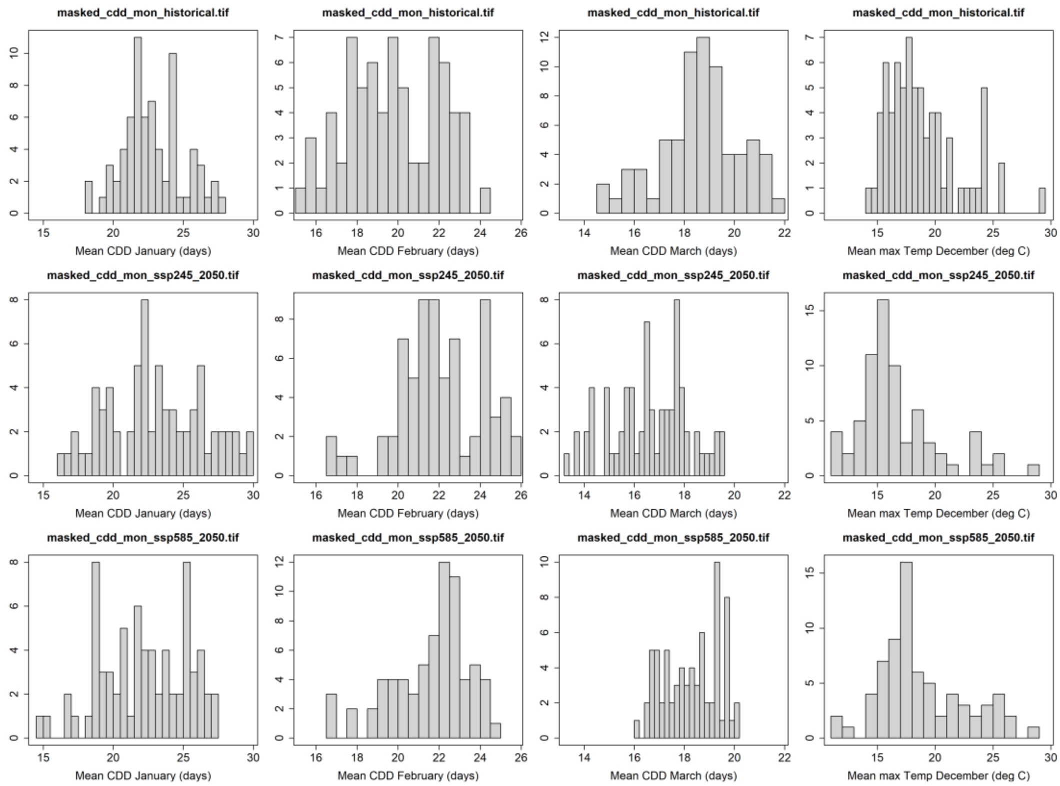
Monthly mean Tasmax (°C) Dec-March



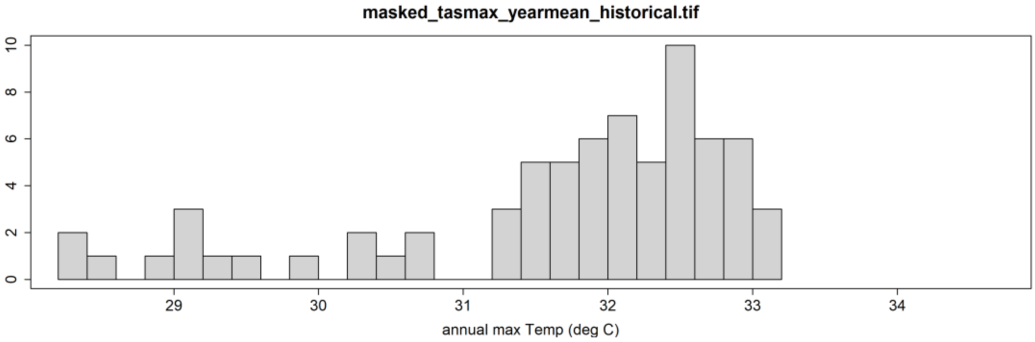
Monthly mean Pr (mm) Dec-March

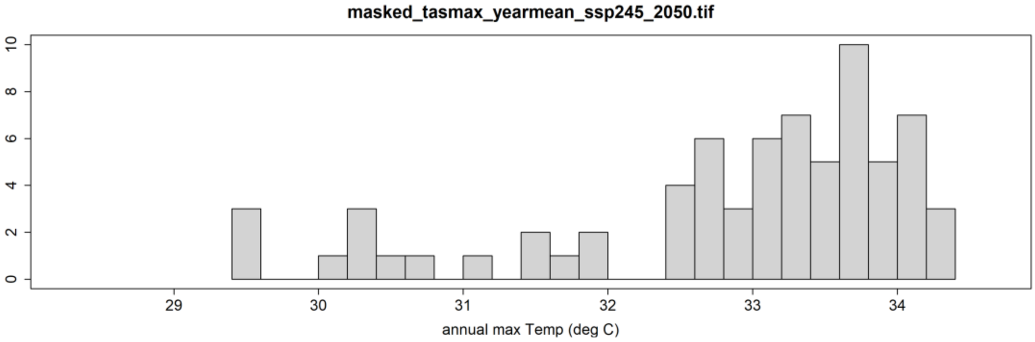


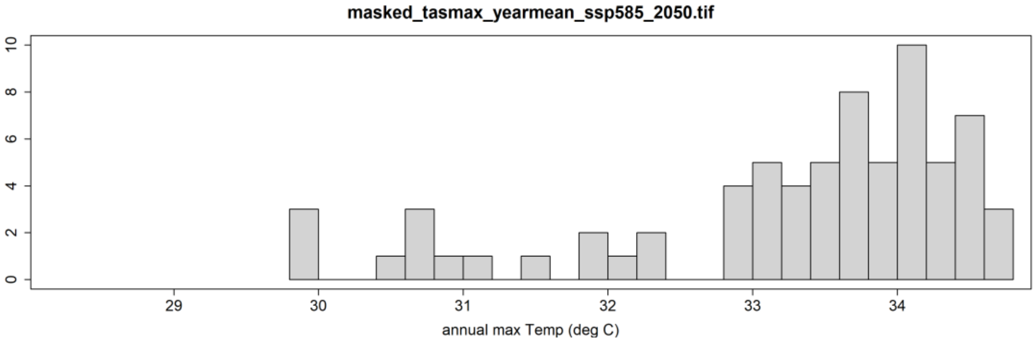
Monthly mean CDD (days) Dec-March



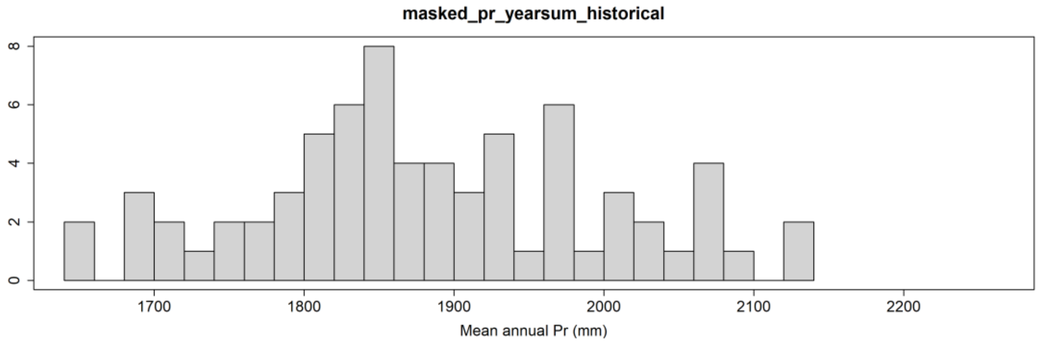
Mean annual Tasmax (°C)

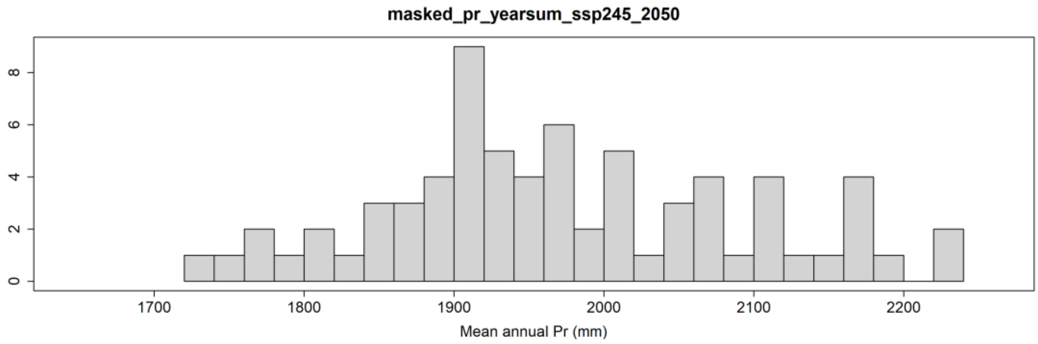


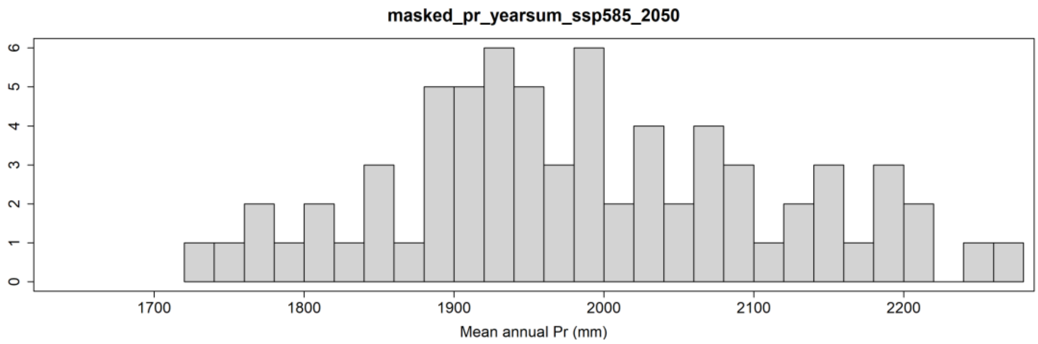




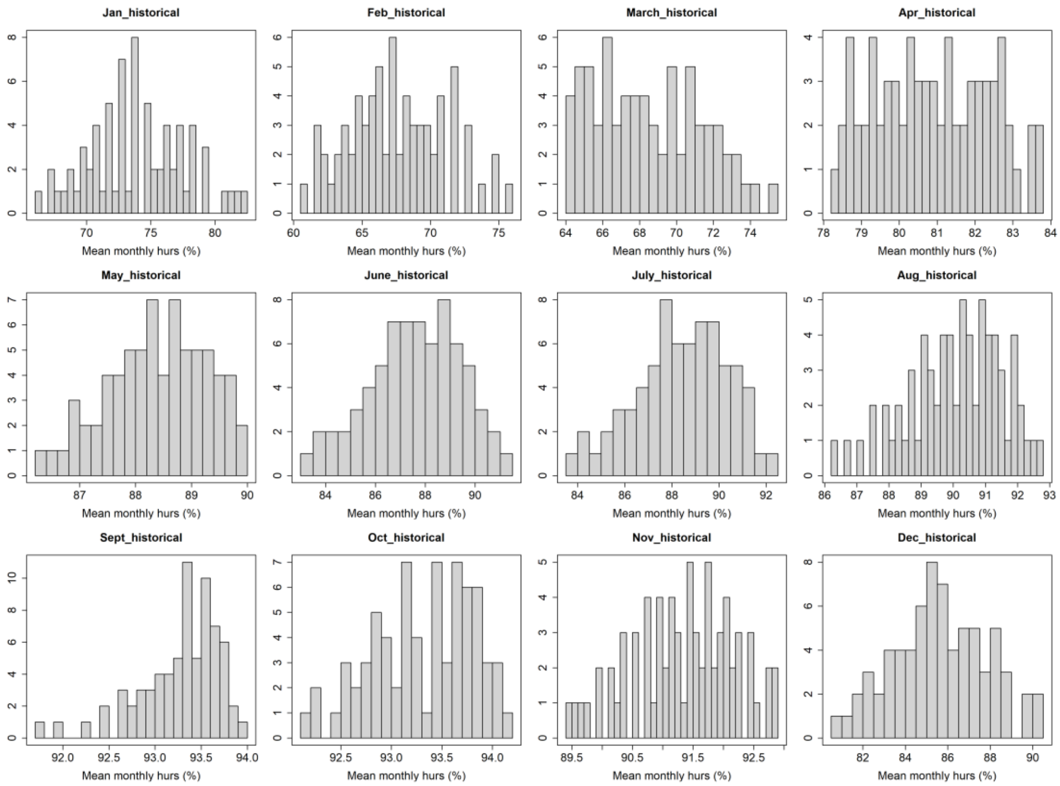
Mean annual Pr (mm)

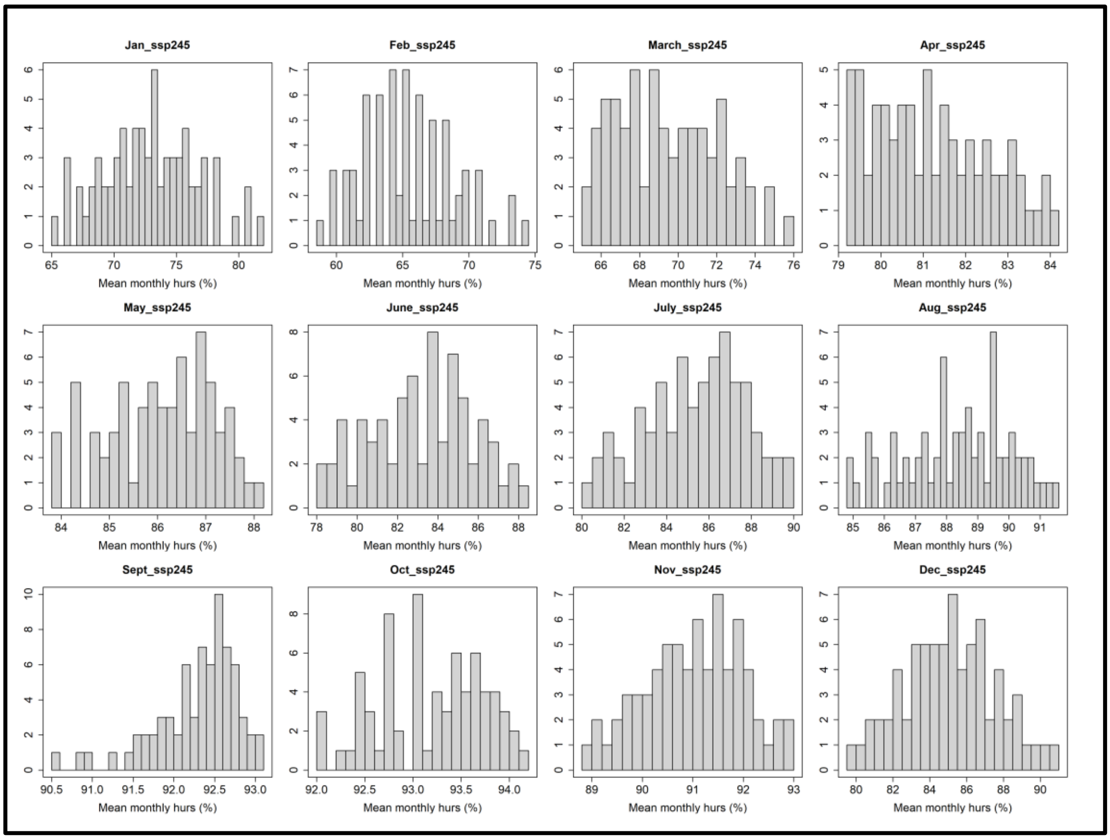


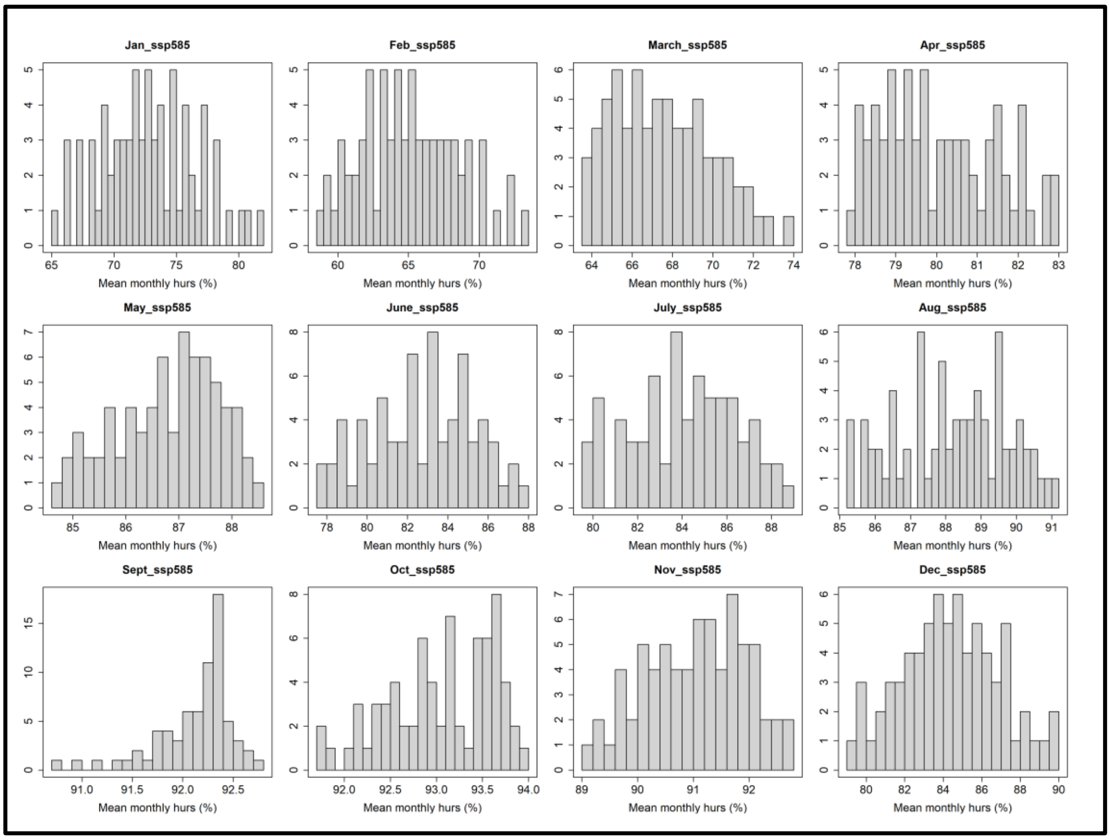




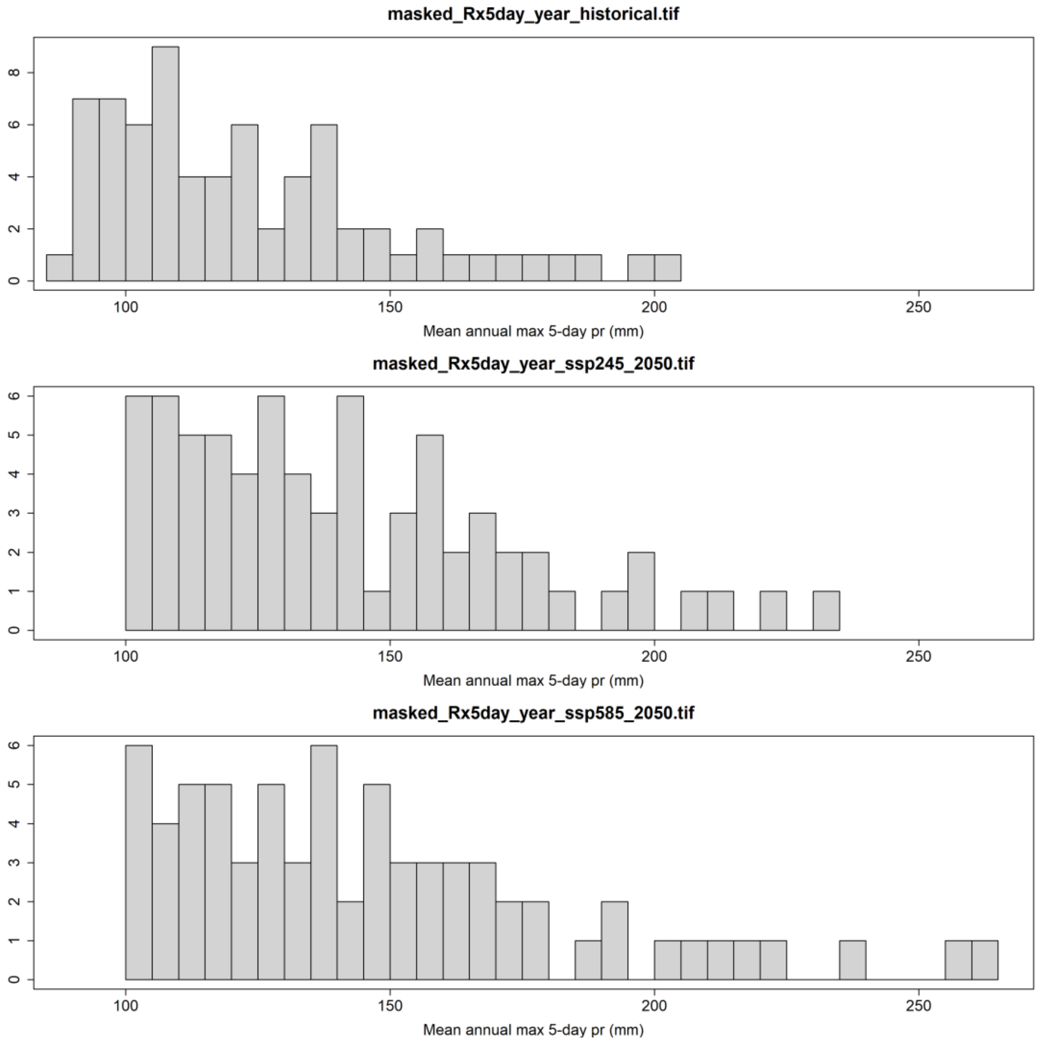
Monthly Mean Hurs (%)







Mean annual Rx5day (mm)


masked_Rx5day_year_historical.tif
Mean annual max 5-day pr (mm)
masked_Rx5day_year_ssp245_2050.tif
Mean annual max 5-day pr (mm)
masked_Rx5day_year_ssp585_2050.tif
Mean annual max 5-day pr (mm)

Mean annual CDD (days)