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Agronomic Conditions and Droughts in Lower Mekong River Basin: Integrating Innovative Digital and Space Applications for Disaster Risk Management

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Executive Summary

The assessment focuses on the agronomic conditions and droughts in Lao PDR, Cambodia, Thailand, and Viet Nam, a region in South-East Asia known for its diverse landscapes and climates. These countries are geographically interconnected, sharing borders and forming a significant portion of the Mekong River basin, a critical area for agriculture and ecosystems. The study highlights the region's vulnerability to climate change, as evidenced by the Climate Risk Index rankings, which place Thailand, Viet Nam, and Cambodia among the most at-risk nations globally. Lao PDR, while ranked lower, still faces considerable climate risks that necessitate ongoing adaptation efforts.

The frequency of drought events in these countries further underlines the urgent need for robust climate adaptation strategies. Thailand has been particularly hard-hit, with eleven drought events since 2001, while Cambodia and Viet Nam have each experienced four, and Lao PDR one. These droughts have posed significant challenges to agricultural productivity and underscore the importance of effective monitoring and mitigation strategies.

Traditional methods of evaluating agronomic conditions and droughts, which rely heavily on in situ observations of weather, climate, soil, and agricultural practices, have proven inadequate for monitoring widespread phenomena like drought. The sparse distribution of critical observations, particularly in regions with limited water resources, has made it difficult to assess the full impact of environmental changes. In recent years, however, integrated and innovative digital and space technologies have emerged as a valuable tool for disaster risk management and monitoring crops and assessing agricultural production on a larger scale.

This assessment, part of the Asia-Pacific Plan of Action on Space Applications for Sustainable Development (2018-2030), aims to leverage geospatial information derived from the integrated digital and space applications to provide a comprehensive analysis of agronomic conditions and droughts in the region. It addresses key questions about the geographic and climatic characteristics of the target countries, the historical impact of droughts, trends in agricultural production, land cover and land use composition, soil texture types, and the influence of temperature and rainfall on agricultural practices. By analyzing spatial patterns and temporal trends, the assessment offers valuable insights for policymakers and stakeholders, promoting informed decision-making and the development of sustainable agricultural practices in the target countries including Cambodia, Lao PDR, Thailand, and Viet Nam.

The assessment of agronomic conditions across Cambodia, Lao PDR, Thailand, and Viet Nam reveals significant regional agricultural transformations driven by climate change and evolving market demands. In Cambodia, a shift from rice to cassava, with production surging dramatically, reflects changing priorities and adaptation to climate impacts, underscored by increasing temperature and variable rainfall affecting crop yields. Lao PDR has similarly seen a rise in cassava production surpassing rice, with a reliance on rainfed agriculture and critical soil types like clay loam and loam, highlighting the need for adaptive water management amidst rising temperatures and fluctuating precipitation. Thailand’s stable rice production, alongside diversification into cassava and sugarcane, faces challenges from temperature increases and variable precipitation, necessitating improved irrigation and crop resilience. In Viet Nam, a rise in vegetable production and shifting crop priorities, alongside consistent temperature increases and changing rainfall patterns, underline the need for enhanced water management and adaptive strategies to mitigate climate change impacts on agriculture.

Cambodia

Over the past two decades, Cambodia's agricultural landscape has undergone significant changes. Rice, traditionally the dominant crop, has been overtaken by cassava in recent years, with cassava production surging from 0.14 million tons in 2001 to 17.7 million tons in 2022. Meanwhile, rice production has also increased substantially, from 4 million tons to 11.7 million tons. Other crops such as maize, sugarcane, and vegetables have seen steady growth. Traditional practices involve planting during the monsoon season and harvesting in the dry months, with crop yields heavily dependent on rainfall due to limited irrigation infrastructure. This shift in crop dominance and the gradual increase in the production of other crops reflect changing agricultural priorities and adaptation to evolving market demands.

Cambodia's land cover composition reveals a diverse vegetative landscape with significant areas of cropland and forest. Cropland covers 57,616 km², representing 31.82% of the total area, while tree cover is the largest land cover class, accounting for 46.81%. Cropland is predominantly rainfed, covering 73,736 km² (33.23%), with irrigated cropland making up a smaller proportion of 4.61%. The cropland is further classified into herbaceous and woody crops, totaling 69,192 km², with herbaceous crops occupying the majority. Soil texture analysis highlights loam as the most prevalent soil type, covering 97,844 km² or 53.45% of Cambodia's area. This soil type is particularly beneficial for agriculture due to its favorable moisture retention and drainage properties, supporting diverse crop cultivation across the country.

Cambodia has experienced a notable increase in average temperature, rising from 26.95°C to 27.89°C between 1991 and 2020, reflecting a warming trend consistent with global climate patterns. Analysis of temperature change rates between 2000-2010 and 2010-2020 shows a significant increase in warming across all months in the latter decade. Monthly temperature anomalies in 2023 compared to long-term averages reveal both cooler and warmer trends, with early months showing cooler temperatures that may delay crop planting and impact growth stages. Conversely, mid-year months and late-year periods exhibit warming anomalies, which could accelerate crop growth but also increase water requirements and stress. The rising temperatures demand adaptive agricultural strategies to manage the impacts of climate change on crop production and water resources.

Cambodia's rainfall patterns over the past three decades have shown complex trends with implications for agriculture. The period from 2000 to 2010 saw increases in rainfall during critical agricultural months like March, May, and August, generally benefiting crop growth. However, from 2010 to 2020, significant declines in March, April, and May raised concerns about water stress for crops. While the latter period of the crop growth cycle showed increased rainfall, these were outside the main growing season, potentially causing off-season flooding. The variability in rainfall during key months, including the rainy season and dry season, highlights the growing unpredictability of Cambodia's climate. This necessitates improved water management strategies and the development of climate-resilient crops to mitigate the adverse effects of changing rainfall patterns on agricultural productivity.

The greenness patterns (NDVI profiles) for Cambodia's croplands from 1991 to 2023 indicated a clear seasonal pattern of agricultural productivity, with low values during the dry season and peak values during the monsoon period. Recent years have shown increased variability in NDVI, indicating more pronounced fluctuations in cropland productivity. These variations are influenced by climatic factors such as changes in rainfall and temperature extremes, as well as human activities like shifts in agricultural practices and land use. The growing variability in NDVI reflects the impact of climate change on crop yields and agricultural stability, emphasizing the need for adaptive management practices to address the challenges posed by erratic weather patterns and ensure sustainable food production.

Lao People’s Democratic Republic (Lao PDR)

Agriculture is a cornerstone of Lao PDR’s economy, employing a significant portion of the population and accounting for a substantial share of the GDP. The agricultural sector is diverse, with a range of practices from traditional rice cultivation to the expansion of tree farming, including crops like mango, coconut, and banana. Over the past two decades, rice has been the predominant crop, but there has been a notable shift, with cassava surpassing rice in production volume by 2022. The increase in cassava production, from 7,010 tons in 2001 to 5.28 million tons in 2022, reflects changes in crop preferences and market demands. Conversely, maize production has declined significantly since 2016, indicating potential challenges or shifts in farming practices. The continuous rise in crop production overall, including sugarcane and vegetables, underscores a growing agricultural sector, although the changing crop rankings highlight the dynamic nature of agricultural priorities and practices in Lao PDR.

The distribution of land cover and land use in Lao PDR reveals a landscape heavily shaped by agriculture. Croplands constitute 10.50% of the total area, with a predominance of rainfed cropland, indicating a reliance on natural rainfall for farming. Irrigated cropland covers a smaller proportion, highlighting the limited scope of managed water resources. The absence of significant tree or shrub crops suggests a focus on annual crops rather than permanent orchards. The total agricultural land area is 22,510 km², with cropland specifically accounting for 15,740 km². Within this, temporary crops are more extensive than permanent ones, and areas equipped for irrigation are crucial for maintaining agricultural productivity. This distribution emphasizes the importance of both natural and managed water resources in supporting Lao PDR's agriculture.

Soil texture plays a critical role in agricultural productivity in Lao PDR. The most prevalent soil type is Clay Loam, covering 84.50% of the total area and 54.92% of cropland. This soil type is advantageous for agriculture due to its balanced properties, including good water retention and drainage, which support diverse crop growth. Loam, another beneficial soil type, covers 10.65% of the total area and 26.93% of cropland, providing excellent fertility and moisture retention. These soil characteristics are integral to sustaining agricultural practices and ensuring productive cropland, reflecting the suitability of Lao PDR's soil for a variety of crops.

Temperature trends in Lao PDR have also shown a significant increase over the past three decades. The average temperature rose from 22.55°C to 23.55°C between 1991 and 2020, reflecting a 1°C increase. This warming trend is consistent with global patterns of climate change and has implications for agriculture. Recent data shows consistent monthly temperature increases from 2010 to 2020, with the most substantial rises occurring in the warmer months. This trend suggests that increasing temperatures could stress crops, impact growth cycles, and necessitate adjustments in agricultural practices to mitigate the effects of rising temperatures on productivity.

Lao PDR has experienced notable fluctuations in monthly precipitation over the past two decades. Between 2000 and 2010, increases in rainfall during key agricultural months generally supported crop growth, although declines in some months posed challenges. The 2010-2020 period indicated shifts in precipitation patterns, with increased rainfall during off-season months raising concerns about potential flooding and its impacts on soil structure and planting schedules. These changes indicate the growing unpredictability of Lao PDR's climate, affecting traditional farming practices and highlighting the need for adaptive strategies such as improved water management and crop diversification to cope with the evolving precipitation patterns.

The greenness patterns (NDVI profiles) for Lao PDR's croplands from 1991 to 2023 reveal an evident annual agricultural cycle, with lower NDVI values at the start of the year and higher values during the growing season.

Recent years have shown increasing NDVI values during peak growing months, indicating potential improvements in agricultural productivity or management. However, notable anomalies in recent years, such as significant deviations from the long-term average, suggest that climate change and/or variability impacts, including extreme weather events, are affecting crop health and productivity. These evolving NDVI patterns highlight the need for ongoing monitoring and adaptation strategies to address the challenges posed by changing environmental conditions.

Thailand

Rice remains the staple food and primary agricultural export of Thailand, with the country consistently ranking as one of the world's largest rice exporters. Despite the adoption of high-yield rice varieties in the 1960s, Thailand's rice yields are lower compared to East Asia. The main rice-producing regions, such as the Chao Phraya Basin and the Khorat Plateau, continue to be central to Thailand's rice production. Over time, rice production has remained relatively stable, increasing from 29 million tons in 2001 to 34 million tons in 2022.

Thailand's agricultural sector has diversified significantly. Besides rice, the country now produces various crops to meet domestic and international market demands. The production of cassava and sugarcane has expanded, with cassava increasing from 18.3 million tons in 2001 to 34 million tons in 2022. Sugarcane production has also risen, reaching 92 million tons in 2022. The rise of palm oil and other cash crops like rubber and coffee reflects the sector's adaptation to market needs and profitability. Tobacco, once a key cash crop, has declined due to reduced demand.

Despite the diversification and commercialization, challenges persist in Thailand's agricultural sector, including low productivity and quality issues. The sector remains heavily dependent on smallholders and faces issues such as competition in global markets, trade protectionism, and insufficient natural resource utilization. Efforts are being made to shift towards organic and higher-value production, aligning with the Organic Agriculture Development Strategy (2017–2021), aiming to enhance organic agricultural productivity.

Thailand's cropland distribution shows notable patterns. Irrigated croplands are concentrated in the northern region, particularly around Nakhon Sawan and Bangkok, benefiting from managed water supplies that support intensive farming. Conversely, rainfed croplands are found predominantly in the eastern part of the country, which relies heavily on natural rainfall.

Tree crops are mainly located along the southern coasts, where climatic conditions favour their growth. Cropland constitutes 49.42% of Thailand's land area, with rainfed cropland being the most prevalent (31.54%). Other significant land cover types include forests (35.15%), shrubland (9.46%), and grassland.

Clay Loam and Loam are the dominant soil types in Thailand's croplands, covering approximately 33% of the area each. These soil types are known for their good water retention and drainage properties, supporting diverse crop cultivation. Silty Loam, which covers around 17% of cropland, is also valuable for its moisture retention capabilities.

Thailand has experienced a consistent increase in temperature rates from 2000 to 2020. Notably, the rate of temperature change has accelerated in the more recent decade, with significant increases in all months. For example, May saw a dramatic shift from -0.32°C to 0.66°C, indicating notable warming. The year 2023 continued this trend with generally warmer temperatures compared to previous decades.

The rise in temperatures poses challenges for agriculture, including heat stress on crops, altered growing seasons, and increased water demands. Adaptive measures such as adjusting planting schedules, adopting heat-resistant crop varieties, and improving irrigation practices are necessary to mitigate the effects of rising temperatures on agricultural productivity.

Over the past two decades, Thailand has seen significant changes in precipitation patterns. From 2000 to 2010, key agricultural months experienced increases in rainfall, which generally supported crop growth. However, from 2010 to 2020, critical months such as March, April, and May observed sharp declines in rainfall, leading to potential water stress for crops. Conversely, July and August saw increases in rainfall, which, while beneficial, also risked waterlogging and pest issues.

The variability in precipitation poses challenges for agriculture, including difficulties in relying on historical weather patterns for planting and harvesting. Improved water management systems, adaptive strategies such as shifting planting seasons, and the development of climate-resilient crop varieties are essential to cope with these changes.

The greenness patterns (NDVI profiles) from 1991 to 2020 show typical seasonal variations in cropland vegetation, with peaks in greenness during the monsoon season. In 2023, the NDVI anomalies revealed both positive and negative deviations from the long-term average, indicating unusual vegetation conditions. Positive anomalies in the early months were followed by a significant negative anomaly in April and mixed anomalies later in the year.

Variability in NDVI profiles reflects broader climatic and agricultural changes. Positive anomalies could be due to favourable weather or improved practices, while negative anomalies might result from adverse conditions. Adaptation strategies should focus on understanding these anomalies to improve crop management and enhance resilience against climate variability.

Viet Nam

Rice remains Viet Nam's dominant crop, with production increasing from 32 million tons in 2001 to 42.7 million tons in 2022. Over the last five years, vegetables have surged to become the second major crop, rising from 5.6 million tons in 2012 to 16 million tons in 2022. Sugarcane, previously the second major crop, has dropped to third place. Cassava production has also grown significantly, while maize production has been declining since 2015. The agricultural sector contributes 15.3% to GDP and employs around 40.3% of the labour force, though agriculture is no longer the dominant economic sector.

Viet Nam's land use is diverse, with cropland covering about 28.13% of the total land area. Of this, 14.85% is irrigated cropland, highlighting the significant role of irrigation in agricultural productivity. Rainfed cropland covers 11.60%, showing the importance of natural rainfall. Agricultural land constitutes 39.29% of the total land area, with cropland making up 37.24%. Temporary crops cover 21.55% of the land, and permanent crops account for 15.70%. Clay Loam is the predominant soil type, supporting a wide range of crops.

Temperature trends from 2000 to 2020 show a consistent increase in the rate of temperature change, with notable warming during critical agricultural months. For instance, May's temperature rose from 28.73°C in 2023 compared to historical averages. These increases pose challenges such as heat stress on crops, altered growing seasons, and reduced yields, necessitating adaptive farming practices and resilient crop varieties.

Rainfall patterns have shifted significantly between 2000-2010 and 2010-2020. While the early 2000s saw increases in rainfall during key months like March, May, and June, the 2010s experienced declines in March, April, and May, leading to potential water stress for crops. Increased rainfall during the monsoon season and off-season months could result in waterlogging and pest issues. These changes highlight the need for adaptive strategies such as improved water management and shifting planting seasons.

The greenness patterns (NDVI profiles) for Viet Nam reveal a typical seasonal pattern with lower values early in the year, peaking in mid-year months, and declining towards the end of the year. Anomalies for 2023 show significant deviations, including a substantial positive anomaly in March and a negative anomaly in April. These fluctuations could be driven by climate variability, changes in agricultural practices, or external factors like pests. The data suggest an overall increase in NDVI values and variability, indicating productivity improvements but also highlighting vulnerabilities to climate change impacts.

Introduction

Space and geospatial information applications are important tools that can support work towards several SDGs in Asia and the Pacific, and yet despite significant progress in this region, space applications and geospatial information continue to be underutilized to fully benefit the most vulnerable, primarily because of the lack of capacity in terms of human, scientific, technological, organizational and institutional resources.

Integrating geospatial information can build greater resilience and significantly improve the productivity of agriculture, which is an important commodity for the economies of many member States and the livelihoods of millions in Asia-Pacific. Earth observation provides the opportunity to monitor large-scale vegetation, water quality, natural resources, and other conditions important for agriculture on a near-real-time basis. Through the integration of satellite data and data collected on the ground at the local level, crop production can be improved by optimizing the use of water and fertilizers, predicting the extent of crops, and orienting development policies towards sustainable practices. To ensure food security, effective monitoring of crops is necessary based on accurate, reliable and timely availability of information for making informed decisions. The space-derived information and land-based observations provide that opportunity for generating regular updates on crop production statistics that serve as inputs to achieve sustainable agriculture.

ESCAP has been implementing a pilot project to strengthen the capacity of the Lower Mekong River basin countries to identify suitable climate-resilient agricultural practices in rice crop production through enhanced access to digital early warning monitoring information for climatic shocks, transboundary water issues and geo-referenced agricultural production forecasts. This assessment will contribute to the implementation of the Asia-Pacific Plan of Action on Space Applications for Sustainable Development (2018-2030) and will strengthen food security and livelihoods of vulnerable rice-growing countries at the national and provincial levels against climatic and other natural disasters by improving access to digital early warning monitoring information for climatic shocks, addressing transboundary water issues and establishing geo-referenced production forecasts using the cloud-based crop monitoring system.

Over the years, evaluating crop production on a large scale has depended on in situ observations of various factors such as weather, climate, soil, and agricultural practices. However, monitoring phenomena like drought, which has significant environmental impacts, has been challenging due to its widespread nature, making it difficult to monitor using conventional systems. One of the main limitations of these methods is the sparse distribution of in situ observations in certain regions, particularly regarding critical factors like precipitation and soil moisture, which are essential for areas with limited or inconsistent water resources. In the last two decades, satellite data has emerged as a valuable tool for monitoring crops and assessing agricultural production. Building on the successes of previous modelling efforts, this assessment aims to extend this approach to include two additional major crops in Cambodia, Lao PDR, Thailand, and Viet Nam in South-East Asia. This assessment is part of the Asia-Pacific Plan of Action on Space Applications for Sustainable Development (2018-2030) and aims to utilize space applications and geospatial information for effective crop management in the region.

This assessment aims to provide a comprehensive analysis of the agronomic conditions in Lao PDR, Cambodia, Thailand, and Viet Nam. It seeks to address several key questions, including: What are the geographic and climatic characteristics of the target countries, and how do these factors influence agricultural practices and outcomes? What is the historical context of droughts in these countries, and how have they impacted agriculture over time? What are the trends in agricultural production, and how have they evolved in response to changing environmental conditions? What is the composition of land cover and land use types in these countries, and what proportion of the land is dedicated to cropland and agriculture? What are the prevailing soil texture types in the croplands, and how do these affect agricultural productivity? What are the trends in temperature and rainfall, and how have they influenced agricultural practices and crop yields? What are the trends and patterns of anomalies in the green biomass of croplands, and what do these anomalies reveal about the health and productivity of the agricultural landscape? To assess spatial patterns and temporal trends in these agronomic conditions, this evaluation utilizes a combination of global and regional datasets, along with estimates, to map and monitor key indicators. The findings are derived from desktop analysis of regional and global assessments, supported by spatial overlay analysis of specific indicators pertinent to the target countries. This approach ensures a thorough understanding of the factors affecting agriculture in the region, providing valuable insights for policymakers and stakeholders.

Chapter 1: Overview of Agronomic Conditions and Droughts in the Region

1.1. Importance of agronomic assessments and drought monitoring

Agriculture, a key driver of economic growth for many nations, meets the fundamental needs of humankind: food and fibre (Awokuse and Xie, 2015). Assessing agronomic conditions is essential for ensuring food security, optimizing crop yields, promoting sustainable agriculture, protecting the environment, and developing climate adaptation policies and plans. This assessment helps detect unfavorable environmental changes early, thereby reducing crop losses and environmental impact. Accurate agronomic evaluations also enhance economic benefits through cost-effective resource use and better market planning. Moreover, sustainable practices like soil and water conservation protect the environment and support long-term agricultural productivity. Consistent crop production and quality assurance contribute to food security, while data-driven insights inform policymakers and help manage agricultural risks. Regular and detailed assessments of agronomic conditions are vital for enhancing productivity, sustainability, and economic viability in agriculture. Identifying potential problems early allows for preventive measures to safeguard yields.

Precise monitoring of agronomic conditions, especially in diverse landscapes, simplifies macro-level decision-making. Accurate analysis of these conditions can boost crop production. Developing appropriate indicators for agricultural condition assessments helps advise policymakers (such as government departments) and farmers about current scenarios and upcoming challenges.

Integrating geospatial information can significantly improve agricultural productivity and resilience, which are crucial for the economies of many member states and the livelihoods of millions in the Asia-Pacific region. Earth observation enables near-real-time monitoring of large-scale vegetation, water quality, natural resources, and other critical agricultural conditions. By combining satellite data with ground-based data, crop production can be optimized through better use of water and fertilizers, accurate crop extent predictions, and policies oriented towards sustainable practices. Effective crop monitoring, based on accurate, reliable, and timely information, is necessary to ensure food security and make informed decisions. Space-derived information and land-based observations provide the opportunity to generate regular updates on crop production statistics, supporting sustainable agriculture.

The evaluation of sustainable agriculture canopies provides crucial insights into the agronomic characteristics of crops. Monitoring the agroecosystem reveals significant seasonal patterns within the agricultural production system. These variables are highly variable in spatial and temporal aspects, necessitating the use of remote sensing technology in agronomic research to identify crops, soil, climate, and environmental variations (Sishodia et al., 2020).

Periods of persistent abnormally dry weather, known as droughts, can cause serious agricultural, ecological, or hydrological imbalances and have severe environmental, social, and economic effects. The impacts of droughts depend on the degree of moisture deficiency, duration, and size of the affected area. Droughts significantly impact agricultural and agro-pastoral areas due to their substantial dependency on rainfall. Agricultural drought monitoring is crucial for maintaining global food security.

Remote sensing can effectively monitor agronomic conditions through various means, including reflective remote sensing for vegetation conditions, thermal remote sensing for environmental conditions, microwave remote sensing for soil moisture, and thermal and reflective remote sensing for environmental stress (Abbas et al., 2014). Earth Observation and geospatial data sets are widely used for vegetation health monitoring and have become a powerful tool for drought detection at the global level. Indices developed using remote sensing data, such as the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI) are employed to detect and monitor agricultural droughts.

1.2. Objectives of the assessment

A significant focus of the assessment is the composition of land cover and land use types, with particular attention to the proportion of land dedicated to cropland and agriculture. It also examines the prevailing soil texture types in these croplands and how they affect agricultural productivity. Additionally, the assessment analyzes trends in temperature and rainfall and their influence on agricultural practices and crop yields.

The evaluation utilizes a combination of global and regional datasets, along with remote sensing indices such as the Normalized Difference Vegetation Index (NDVI), to assess spatial and temporal patterns in green biomass and other key agronomic variables. This approach allows for the identification of water stress levels in crops and provides a comprehensive understanding of agronomic conditions across the target countries.

Ultimately, the findings of this assessment are intended to offer valuable insights for policymakers, farmers, and stakeholders, helping them make informed decisions regarding crop management, resource allocation, and climate adaptation strategies. By promoting sustainable agricultural practices through data-driven insights, the report aims to enhance productivity, resilience, and environmental protection, contributing to agricultural sustainability and food security in the region.

1.3. Description of the geospatial data sources and collection methods

This study will use a variety of data sources (Table 1), with Google Earth Engine (GEE) serving as the primary hub for data processing. GEE, a cloud computing platform for planetary-scale data analysis, ensures that the workflow is transparent, reproducible, flexible, adaptable, and accessible. Climate variables, including rainfall, temperature, and potential evaporation, will be primarily sourced from ERA-5. Assessments of crop vegetation and drought conditions using the NDVI products. Additionally, soil conditions and land cover will be analyzed using soil datasets, crop masks from ESA's 10m WorldCover map, and irrigated and rainfed cropland data from the GLC_FCS30D Global 30-meter Land Cover Change Datasets.

The composition and spatial distribution of land cover and land use were assessed using several datasets. These included ESA's WorldCover map for 2022 (Zanaga et al., 2022), with a 10-meter spatial resolution, and the GLCFCS30D Global 30-meter Land Cover Change Dataset (1985-2022) (Liu et al., 2023). The GLC_FCS30D dataset represents a significant advancement in global land-cover monitoring, offering detailed insights into land-cover dynamics over a 30-meter resolution spanning from 1985 to 2022. This dataset provided four categories of cropland: rainfed cropland, irrigated cropland, herbaceous cover cropland, and tree or shrub cropland (orchard). In contrast, the ESA WorldCover map provided a single cropland category, but it missed tree crops or orchards in many parts, which is probably included in the Tree Cover class. To ensure consistency among the datasets, we also analyzed two datasets provided by the FAO, including Land Cover and Land Use (FAOSTAT, 2024b). The FAO's Land Cover information is compiled from publicly available Global Land Cover (GLC) maps: The European Space Agency (ESA) Climate Change Initiative (CCI) annual land cover maps (1992–2020), produced by the Université Catholique de Louvain (UCL)-Geomatics and now part of the European Copernicus Program. The FAOSTAT Land Use domain contains data on forty-four categories of land use, irrigation, agricultural practices, and five indicators relevant to monitoring agriculture, forestry, and fisheries activities at national, regional, and global levels. This data is available by country and year, with global coverage and annual updates.

The corresponding changes in vegetation greenness, which indicates crop biomass, were assessed using time series data on the Normalized Difference Vegetation Index (NDVI). The NDVI measures the "greenness" of ground cover and serves as a proxy to indicate the density and health of vegetation. NDVI values range from +1 to -1, with high positive values corresponding to dense and healthy vegetation, while low or negative values indicate poor vegetation conditions or sparse vegetative cover (Bayarjargal et al., 2006; Cohen et al., 2018; Tucker et al., 1983)

The deviations in NDVI were analyzed using anomalies in NDVI maps, graphs, and tables, along with the time series values of NDVI. NDVI anomalies represent the variation of current monthly values compared to the long-term average (Tucker and Sellers, 1986). A positive anomaly (e.g., +5%) signifies enhanced vegetation conditions relative to the average, while a negative anomaly (e.g., -5%) indicates poorer vegetation conditions (Anyamba et al., 2010). The data for this analysis was accessed through the Food and Agriculture Organization's (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS) (FAO-GIEWS, 2024). GIEWS monitors the condition of major food crops at both country and global levels to assess production prospects. To support this analysis and supplement ground-based information, GIEWS utilizes remote sensing data, which provides valuable insights into water availability and vegetation health during cropping seasons. GIEWS relies on vegetation indicators derived from monthly vegetation data captured by the METOP-Advanced Very High-Resolution Radiometer (AVHRR) sensor at a 1 km resolution (for data from 2007 onwards). For data from 1984 to 2006, NDVI values were derived from the National Oceanic and Atmospheric Administration (NOAA)-AVHRR dataset at a 16 km resolution. Precipitation estimates for African countries (except Cabo Verde and Mauritius) are sourced from NOAA's Famine Early Warning Systems Network (FEWSNet), while data for other countries is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Table 1 *Description of geospatial data used in the study and its sources*

No	Indicator	Dataset	Resolution	Image Collection
1	Precipitation	ERA5-Land	11 km	ECMWF/ERA5_LAND/MONTHLY_AGGR
2	Temperature	ERA5-Land	11 km	ECMWF/ERA5_LAND/MONTHLY_AGGR
3	Soil Texture	OpenLandMap Soil Texture Class (USDA System)	250 m	OpenLandMap/SOL/SOL_TEXTURE-CLASS_USDA-TT_M/v02
4	NDVI	METOP-AVHRR	1 km	(FAO-GIEWS, 2024)
5	Crop Cover Mask	ESA's WorldCover	10 m	ESA/WorldCover/v200
6	Cropland: Rainfed/Irrigated	GLCFCS30D	30 m	projects/sat-io/open-datasets/GLC-FCS30D/annual
7	Land Cover and Land Use Data	FAO STAT	--	https://www.fao.org/faostat/en/

ERA5-Land, an enhanced reanalysis dataset with ~11 km resolution, offers a consistent view of land variables over several decades by replaying the land component of ERA5 (https://climatedataguide.ucar.edu/climate-data/era5-atmospheric-reanalysis). Reanalysis combines model data with global observations to create a complete and consistent dataset. This study will use monthly aggregates of rainfall, air temperature, and potential evaporation from the ERA5-Land Monthly Aggregated - ECMWF Climate Reanalysis ("ECMWF/ERA5_LAND/MONTHLY_AGGR") in the GEE. The analysis of temperature rainfall changes was conducted using ERA5 temperature data, which was processed in the GEE, followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term temperature averages (2001-2020) with the recorded temperatures for 2023 and producing various visualizations to enhance the understanding of these patterns.

The crop cover mask was created using the European Space Agency (ESA) WorldCover 10 m products (https://worldcover2021.esa.int/), which offer global land cover maps for 2020 and 2021 at a 10 m resolution, derived from Sentinel-1 and Sentinel-2 data (https://esa-worldcover.org/en). The water cropland will be extracted from the WorldCover maps utilizing the GEE image collections

"ESA/WorldCover/v200" and "ESA/WorldCover/v100".

The USDA soil texture classification system offers 12 soil texture classes for six soil depths (0, 10, 30, 60, 100, and 200 cm) at a 250 m resolution. These classes are derived from predicted soil texture fractions using the soil texture package in R (Hengl, 2018). This product is available in the GEE collection (OpenLandMap/SOL/SOL_TEXTURE-CLASS_USDA-TT_M/v02).

1.4. Overview of the analytical methods used for assessing agronomic conditions and droughts

The fundamental concept behind assessing agronomic conditions is to comprehend the prevailing spatial patterns of indicators and their temporal variation. To delineate spatial patterns, mean images spanning the last 20 years will be constructed, followed by an evaluation of deviations from this mean to assess changes in conditions. Given the dynamic nature of crop growth cycles, which can vary spatially and temporally, the analysis will be conducted at a monthly time step. This entails providing average spatial patterns every month and calculating deviations from the mean on the monthly scale. For static variables, only spatial patterns will be analyzed, whereas for dynamic variables—encompassing both climate and crop vegetation health indicators—temporal analysis in terms of deviations from the mean will be performed.

The Red and Near Infra-Red (NIR) surface reflectance wavebands are used to derive the Normalized Difference Vegetation Index (NDVI), a common vegetation health monitoring index (Tucker and Sellers, 1986). NDVI is based on the absorption of visible light by chlorophyll for photosynthesis and strong reflectance in the NIR region due to leaf cell structure. When vegetation is stressed, red light absorption decreases due to disturbed photosynthesis, and NIR reflectance decreases due to cell structure damage, reducing NDVI values. NDVI values range from -1 to +1, with values above 0 generally representing healthy vegetation and values below 0 indicating non-vegetated or stressed areas. NDVI is an early and effective indicator of plant stress, correlating highly with green biomass and vegetation productivity (Pettorelli et al., 2005).

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

where, ρ_{nir} and ρ_{red} represents the reflectance in NIR and Red spectral channels, respectively.

Maximum vegetation growth occurs during years with optimal weather conditions, which enhance soil nutrient uptake and efficient use of ecosystem resources. In contrast, unfavourable weather, particularly dry and hot conditions, suppresses vegetation growth and nutrient uptake, as observed in drought years. By analyzing NDVI over several years, obtaining the long-term averages and then the anomalies of the NDVI for the recent years were calculated.

The resulting image values, ranging from -100% to 100%, were classified into seven categories of vegetation stress, as recommended by several studies (Bento et al., 2018; Bhuiyan et al., 2006; Kogan et al., 2012; Kogan, 1997; Monteleone et al., 2020; Zeng et al., 2023).

An anomaly represents the deviation of a climatic variable, such as temperature, rainfall, or NDVI (Normalized Difference Vegetation Index), from its long-term average. The formula for calculating climatic anomalies is as follows:

Anomaly = X – X’

Where:

X = actual value of the average for any climatic variable

X’ = long-term average for that climatic variable

Anomalies help identify significant deviations from the norm, making it easier to detect patterns such as warming trends, drought conditions, or shifts in environmental behaviour. For temperature anomalies, a negative value indicates a decrease in temperature from the long-term average, while a positive value signals an increase. Similarly, for rainfall anomalies, a negative value points to a deficit, suggesting drier-than-usual conditions, whereas a positive value indicates an excess, signifying wetter-than-usual conditions. NDVI anomalies follow a similar pattern, with negative values indicating reduced vegetation health or coverage and positive values suggesting increased vegetation vigour.

1.5. Brief geographical, climatic, and agricultural overview of the targeted countries

Lao PDR, Thailand, Cambodia, and Viet Nam are located in South-East Asia, a region characterized by diverse landscapes and climates. Lao PDR, a landlocked country, is surrounded by China to the north, Viet Nam to the east, Cambodia to the southeast, Thailand to the west, and Myanmar to the northwest. Thailand, situated to the west of Lao PDR, shares borders with Myanmar, Lao PDR, Cambodia, and Malaysia to the south. Cambodia lies to the south of Lao PDR and shares borders with Thailand to the northwest and Viet Nam to the east. Viet Nam stretches along the eastern edge of the region, with its coastline bordering the South China Sea and sharing land borders with China to the north, Lao PDR to the northwest, and Cambodia to the southwest. These countries together form a significant portion of the Mekong River basin, which plays a crucial role in the region's agriculture and ecosystems.

Figure 1 *Study area map of the target countries*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

1.5.1. Cambodia

1.5.1.1. Geography

The Kingdom of Cambodia is located on the China-Indochina Peninsula, sharing borders with Thailand, Lao PDR, and Viet Nam. It is a member of the ASEAN (Association of South-East Asian Nations). Predominantly a land of plains and major rivers, Cambodia occupies a strategic position on significant overland and river trade routes connecting China with India and South-East Asia (Britannica, 2024). The country's landscape features a low-lying central alluvial plain encircled by uplands and low mountains, encompassing the Tonle Sap (Great Lake) and the upper reaches of the Mekong River delta. Transitional plains, sparsely forested and rising to about 200 meters above sea level, extend from this central region. The maximum dimensions of Cambodia are approximately 450 km from north to south and 580 km from east to west (Chandler & Overton, 2024).

1.5.1.2. Agriculture of Cambodia

Cambodia's agricultural landscape is rapidly transforming, especially in the cashew sector. Despite challenges such as lagging infrastructure, technology, and limited financial and human capital, agriculture remains vital to the national economy contributing significantly to GDP and employing most of the workforce. The sector benefits from a large labour force, significant market potential, and abundant resources including rice, soybeans, corn, cassava, and cashew nuts. Approximately 85% of the population is engaged in agriculture, covering around 6.7 million hectares of arable land. Rice is the major crop, principal food, and key export commodity, grown extensively around the Mekong and Tonle Sap regions, particularly in Bătdâmbâng, Kâmpóng Cham, Takêv, and Prey Vêng provinces. Traditional agriculture patterns involve planting in July or August and harvesting from November to January, with crop size and quality largely dependent on rainfall due to limited irrigation. Other important crops include cassava, corn, sugarcane, soybeans, and coconuts, while principal fruit crops are bananas, oranges, and mangoes, supplemented by other tropical fruits like breadfruits, mangosteens, and papayas. Agricultural exports constitute a significant portion of total export value, and the government prioritizes improving agricultural production and investment conditions. Cambodia, a lower middle-income country, exemplifies the interaction between agricultural production, regional road construction, and the agricultural eco-environment. The stable political climate, open policies, and rich natural resources make it an attractive investment destination in ASEAN. The country's soil is generally sandy and nutrient-poor, except for the fertile red-soil areas in the east suitable for commercial crops like rubber and cotton. Annual Mekong River floods deposit alluvial sediment that enriches the central plain and naturally irrigates rice fields. Cambodia ranks among the top five for cultivated area and top three in global cashew production, with significant cultivation in Kampong Thom, Kratie, and Ratanak Kiri provinces. Cashews thrive on well-drained sandy loam soil and can grow on marginal soils with minimal rainfall (1000mm annually). The estimated cashew cultivation area is 580,117 hectares and is expected to grow with many young plantations (Chaya et al., 2024; Fitzpatrick, 2019; Teck et al., 2023; Weng et al., 2023).

Over the past two decades (2001-2022), rice was the major crop in Cambodia (Figure 1 a), followed by cassava. Maize, sugarcane, and vegetables held the third, fourth, and fifth positions (Figure 1 a), respectively. However, in the last five years (2018-2022), cassava has surpassed rice as the top production crop (Figure 1 b). The rankings of the other three crops remained unchanged. Since 2014, cassava production has consistently surpassed that of rice (Figure 1 c). Overall, rice production increased from 4 million tons to 11.7 million tons, while cassava production surged from 0.14 million tons in 2001 to 17.7 million tons in 2022. The production and cultivated area of sugarcane, maize, and vegetables have also gradually increased over the past two decades (Figure 1 d) (FAOSTAT, 2024a).

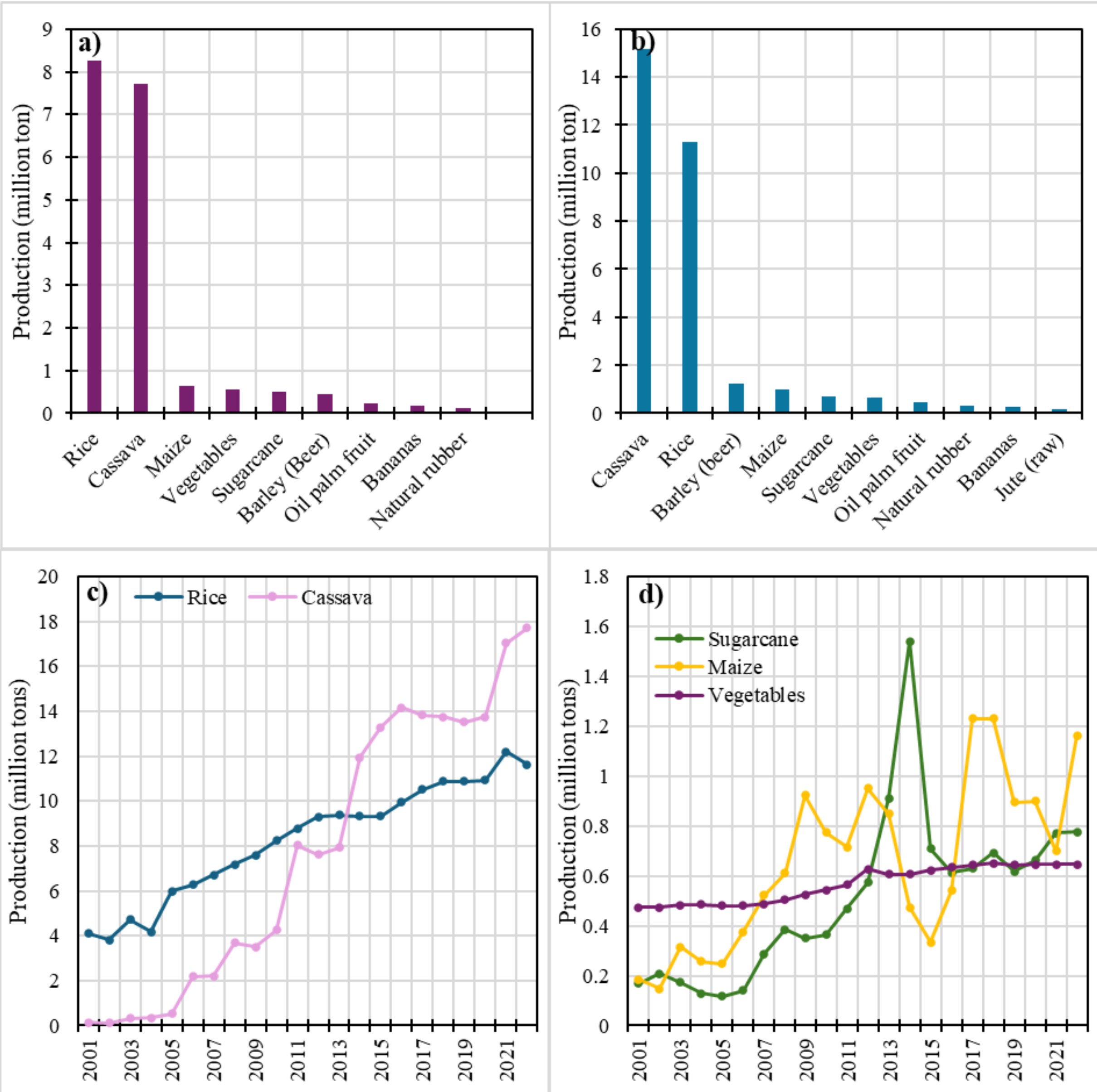

Figure 1 *Crop production statistics of Cambodia: a) average production of major crops from 2001 to 2022, b) average production of major crops from 2018 to 2022, c) annual production of the major primary crop from 2001 to 2022, d) average production of the major secondary crops from 2001 – 2022. Source: (FAOSTAT, 2024a)*

1.5.1.3. Climate of Cambodia

Cambodia's climate is also shaped by monsoon winds, creating two primary seasons. From mid-

May to early October, the southwest monsoon brings heavy rains and high humidity. From early November to mid-March, the northeast monsoon brings drier, lighter winds with variable cloudiness, infrequent precipitation, and lower humidity. The transitional periods between these seasons feature changing weather patterns. Temperatures remain high year-round, ranging from about 28°C in January, the coolest month, to around 35°C in April. Annual precipitation varies significantly across the country, with over 5,000 mm falling on the seaward slopes of the southwestern highlands, while the central lowland region receives about 1,270–1,400 mm. Approximately three-fourths of the annual rainfall occurs during the southwest monsoon (Britannica, 2024; CRCP:Cambodia, 2021).

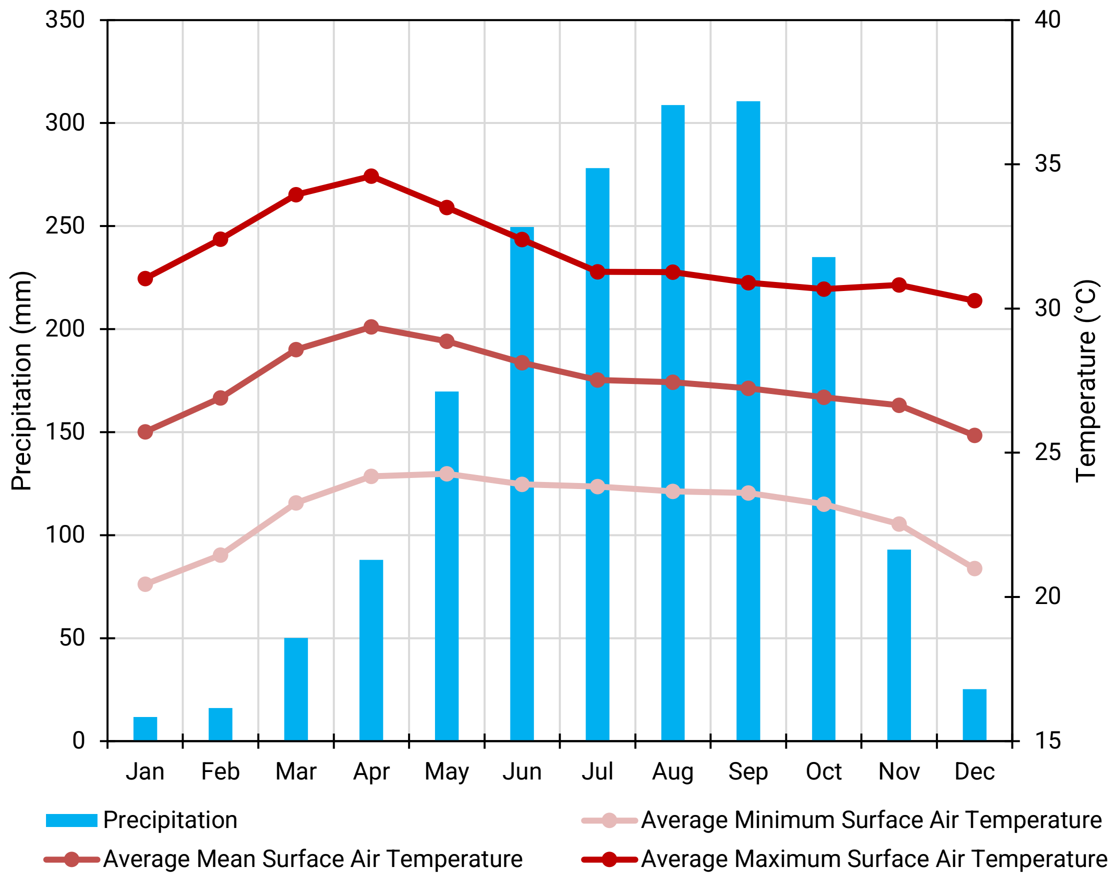

Figure 2 *Monthly climatology of average surface air temperature (mean, maximum, and minimum) and precipitation in Cambodia from 1991 to 2022. Source: (WorldBank, 2024a).*

1.5.2. Lao People's Democratic Republic (Lao PDR)

1.5.2.1. Geography

Located in South-East Asia at the heart of the Indochina Peninsula, The Lao People's Democratic Republic (PDR) is landlocked country bordered by China and Myanmar (Burma) to the north, Thailand to the west, Viet Nam to the east, and Cambodia to the south. Positioned between latitudes 14 to 23 degrees North and longitudes 100 to 108 degrees East, it ranks as the 84th largest country globally, covering an area comparable to the size of Britain. The country's geography is predominantly characterized by mountainous terrain and dense forests, interspersed with plains and plateaus. The Mekong River, a significant natural boundary, runs along much of the western and southern borders, shared with Thailand and Cambodia. Elevations in Lao PDR range from the lowest point at the Mekong River (70 meters) to the highest point at Phu Bia (2,818 meters). Approximately 6% of the land is suitable for agriculture, with most arable land located along the fertile Mekong River basin (Britannica, 2024; Factsanddetails, n.d.; Laostourism, 2024).

1.5.2.2. Agriculture of Lao People's Democratic Republic

The Lao People's Democratic Republic (PDR) is heavily dependent on agriculture, which accounts for half of its GDP and involves around three-fourths of its population in farming activities. Agricultural production in Lao PDR is primarily driven by low-productivity smallholders, most of whom live in poverty (World Bank, 2021), with 97% of farmers owning their land. Sticky rice production is predominant, occupying about 93% of the rice cultivation area and mainly serving home consumption (NationsEncyclopedia, 2024). Shifting cultivation, a widespread agricultural practice in Lao PDR, involves clearing land, farming it briefly, and then leaving it fallow to restore soil fertility. Due to Lao PDR' mountainous terrain and challenges in developing irrigation systems, establishing permanent agricultural land is difficult. Consequently, much of the population relies on shifting cultivation, particularly for rice. This practice covers a significantly larger area than permanent agriculture, with slash-and-burn activities notably increasing between 2015 and 2020 (Chen et al., 2023). Tree farming is widespread, featuring crops such as mango, coconut, and banana. Additionally, 8% of farmers participate in aquaculture, and 71% are involved in fishing. Major crops include rice, vegetables, beans, sugarcane, starchy roots, and tobacco, with significant growth in vegetable and bean production since 1990. Cash crops consist of mung beans, soybeans, peanuts, tobacco, cotton, sugarcane, coffee, and tea. Despite agriculture's domestic importance, its role in foreign trade is minimal. Agriculture accounts for over one-fifth of Lao PDR's exports. Between 2018 and 2021, these exports grew by approximately 23 percent annually, with an average yearly value of USD 982 million. Improved agricultural performance and increased regional exports have shown their potential to reduce poverty. Consequently, poverty rates dropped significantly from 24.6 percent to 18.3 percent between 2013 and 2019, driven by rising incomes from agricultural exports (World Bank, 2021). The completion of a China-supported railway project under the Belt and Road Initiative is expected to improve Lao PDR' connectivity and economic outlook. Looking ahead, Lao PDR aspires to become a leading organic agricultural producer and exporter, with strong potential for increased foreign market demand for its agricultural products (World Bank, 2021). Shifting cultivation is a major land use in Lao PDR and a significant driver of both forest disturbance and regrowth (Chen et al., 2023).

Over the past two decades (2001-2022), rice was the major crop in Lao PDR (Figure 3a), followed by edible roots and cassava. Vegetables, sugarcane, and maize held the fourth, fifth, and sixth positions, respectively (Figure 3a). Overall, the production of all these crops increased, and the ranking of major crops remained unchanged over the past five years (2018-2022), except for maize, which is now placed seventh, with bananas moving to the sixth position (Figure 3b). The rankings of the other three crops remained unchanged. Over the last two years, cassava production has consistently surpassed that of rice and was ranked first in 2022 (Figure 3c). Overall, rice production increased from 2.5 million tons to 3.6 million tons, while cassava production surged from 7,010 tons in 2001 to 5.28 million tons in 2022 (Figure 3c). The production and cultivated area of sugarcane and vegetables have also gradually increased over the past two decades (Figure 3d) However, maize production has significantly decreased since 2016 (Figure 3d). (FAOSTAT, 2024a).

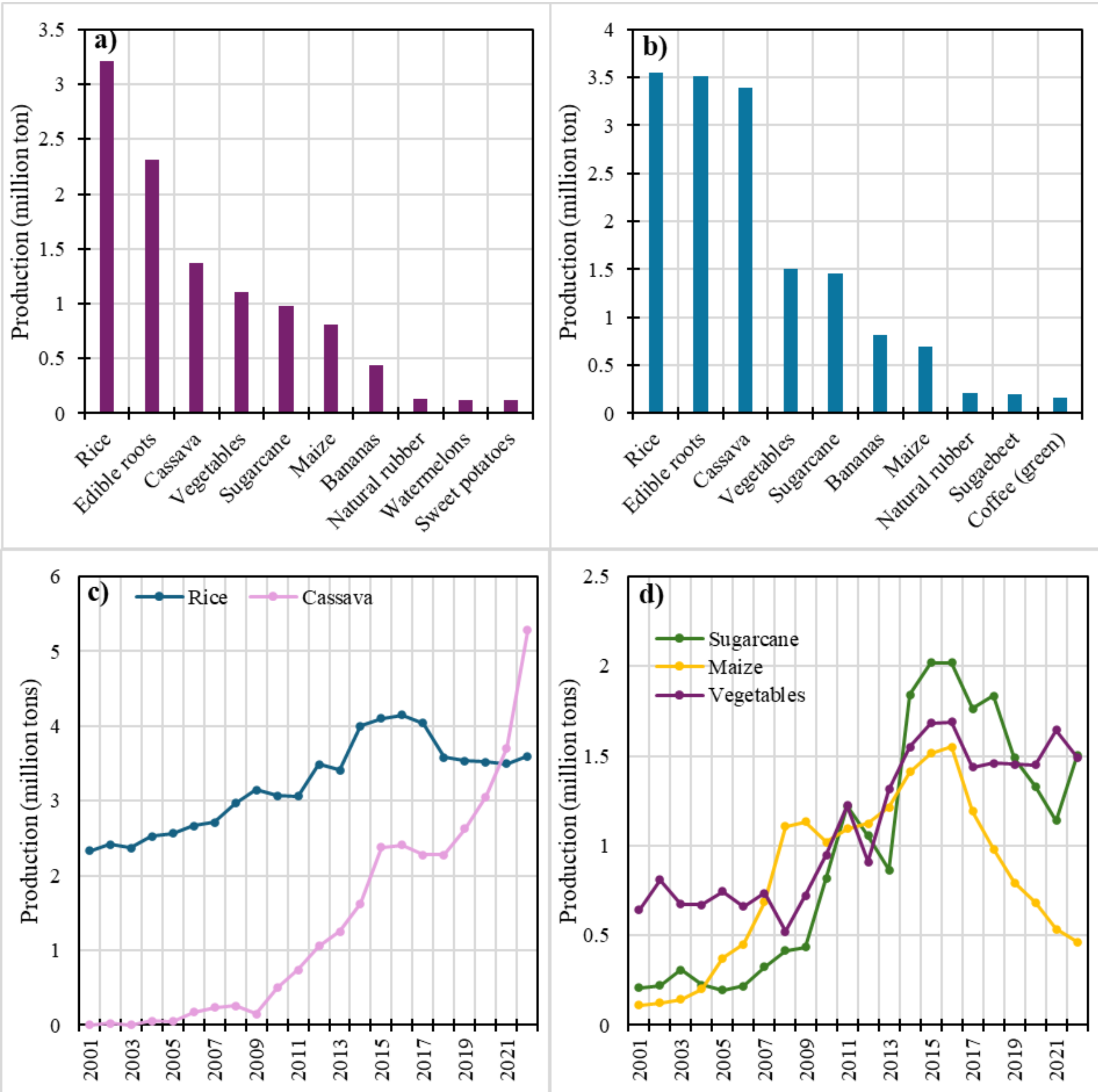

Figure 3 Crop production statistics of Lao PDR: a) average production of major crops from 2001 to 2022, b) average production of major crops from 2018 to 2022, c) annual production of the major primary crop from 2001 to 2022, d) average production of the major secondary crops from 2001 – 2022. Source: (FAOSTAT, 2024a). Sugarbeet is representing Raw cane or beet sugar (centrifugal only)

1.5.2.3. Climate of Lao People's Democratic Republic

Located just below the Tropic of Cancer, Lao PDR experiences a tropical savanna climate characterized by three main seasons: hot, cool, and wet monsoon. Lao PDR experiences two distinct seasons throughout the year. From late May to October, the country faces heavy tropical rains, while from December to April, it experiences high temperatures with minimal rainfall. These seasons are bridged by short periods of spring and autumn. The country is influenced by monsoons, with about 90% of its annual rainfall occurring during the wet season from May to October (Cramb, 2020). The dry season spans from November to April. Despite the relatively high average precipitation, there are periods of inadequate rainfall, especially for rice cultivation, leading to significant yield declines. These droughts are often regional, sparing production in other parts of the country. During this dry period, the slashing and burning practices associated with shifting cultivation are typically carried out (CRCP:Lao-PDR, 2021; Li et al., 2014).

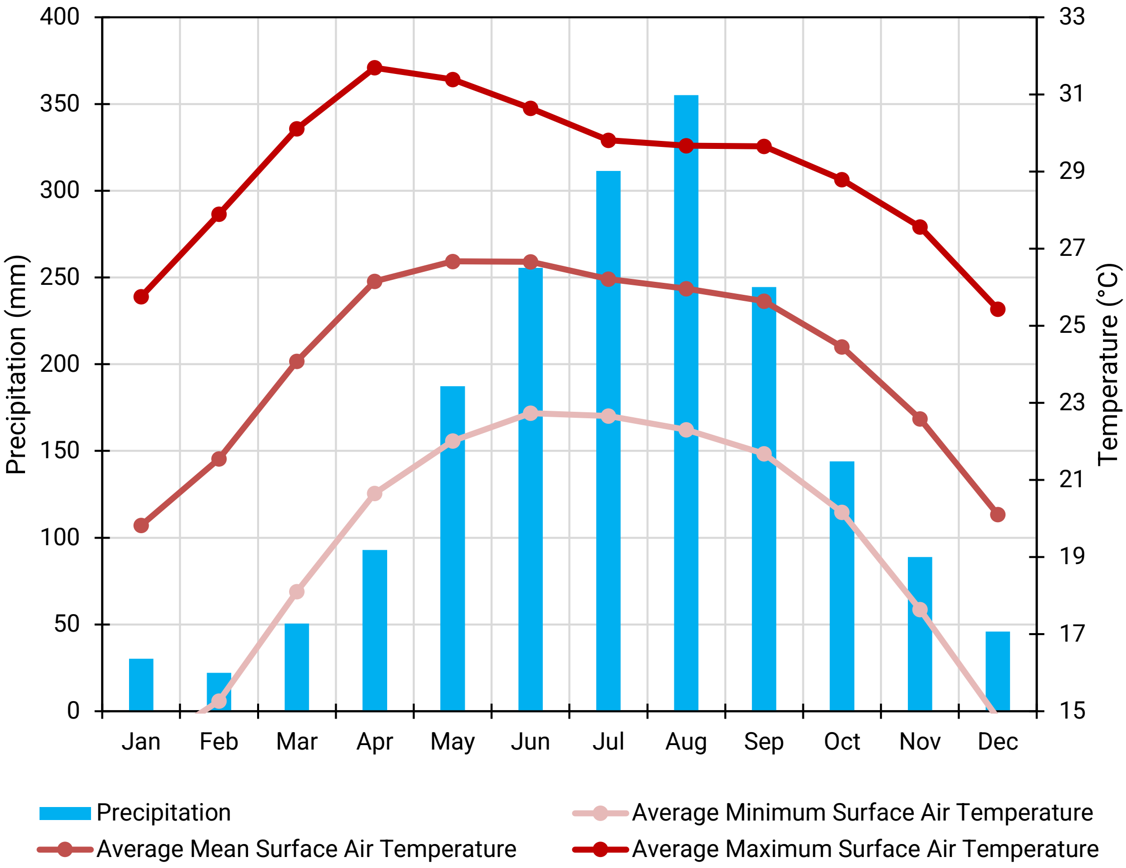

Figure 4 Monthly climatology of average surface air temperature (mean, maximum, and minimum) and precipitation in Lao PDR from 1991 to 2022. Source: (WorldBank, 2024a)

1.5.3. Thailand

1.5.3.1. Geography

Thailand, officially known as the Kingdom of Thailand, is centrally located in mainland South-East Asia and entirely within the tropics, featuring diverse ecosystems such as the hilly, forested northern frontier, the fertile central plains, the expansive northeastern plateau, and the rugged coasts of the narrow southern peninsula. The country's landscapes include low mountains, fertile alluvial plains with rice paddies, and sandy beaches influenced by the Asian monsoons. Peaks average around 1600 meters, with Mount Inthanon reaching 2585 metres near Chiang Mai. Thailand is divided into five distinct regions: the folded mountains in the north and west, the Khorat Plateau in the northeast, the Chao Phraya River basin in the centre, the maritime corner in the southeast, and the peninsular portion in the southwest. The northernmost border with Myanmar features high mountains extending to the southern border with Malaysia. The central plain, dominated by the Chao Phraya River, is crucial for agriculture, while the Khorat Plateau drains into the Mekong River bordering Lao PDR. The Chao Phraya and Mekong River systems support Thailand’s agricultural economy, facilitating wet-rice cultivation and transportation. The southern region is characterized by mangrove swamps, extensive coastlines, and numerous islands, notably Phuket (Britannica, 2024; Factsanddetails, n.d.; WorldBank, 2024b).

1.5.3.2. Agriculture of Thailand

Agriculture has been integral to Thailand since ancient times. Although its share in the Gross Domestic Product (GDP) has gradually declined to just six percent, the sector still employs about one-third of the labour force and accounts for one-third of total export revenue. Additionally, agriculture is the second-largest source of greenhouse gas emissions in Thailand, with rice cultivation being the primary source of methane emissions. Employment in agriculture has decreased from 62 percent in 1992 to 30 percent in 2022. Thailand is a leading global exporter of tapioca products, rubber, canned tuna, and canned pineapple. The agriculture and food sector contributes 10-15 percent to the gross national income and employs around 42 percent of the working population, generating a similar percentage of national exports. Key food crops include rice, cassava, maize, and banana, with 13-26 percent of the food energy consumed in Thailand coming from non-native crops. The country houses 68,495 crop varieties compared to over 700,000 in international collections. Durian is a significant fruit crop due to Thailand's optimal climate and soil conditions. Rice remains the main staple and primary agricultural export, with Thailand being one of the world’s largest rice exporters for decades. However, despite adopting high-yield rice varieties in the 1960s, yields are lower compared to East Asia due to less efficient labour inputs. The Chao Phraya basin and the Khorat Plateau are the main commercial rice-producing areas. Agricultural production has diversified to meet both domestic and international market demands, producing crops like cassava, maize, kenaf, longans, mangoes, pineapples, durians, cashews, vegetables, and flowers. Cash crops such as rubber, coffee, sugarcane, and various fruits are predominantly produced on large agribusiness-owned holdings, while tobacco, once a key cash crop, has seen a significant decline due to reduced demand. Among the four major sub-sectors—crop production, livestock, fishery, and forestry—crop production is the most important, accounting for 75 percent of total revenue. Challenges in agricultural development in Thailand include the agricultural production structure, competition in the world market and trade protectionism, low productivity, low quality of products, and insufficient utilization of natural resources. The agricultural sector, mainly supported by smallholders, remains the livelihood basis for most of the population. About 38 percent of Thailand's total land area (51.3 million hectares) is used for agricultural activities, with 60 percent as paddy fields, 22.8 percent under field crops, and 9.4 percent occupied by fruit and other perennial crops. The planted area has increased significantly over the last two decades, producing most of the growth in agricultural production during this period. Agricultural development policies in Thailand face challenges such as narrowed farming areas, a significant rural labour force moving to urban areas, and farmers not benefiting from government policies. Despite increased commercialization and diversification, agricultural productivity remains below regional averages. Thailand is shifting towards organic and higher-value production, aligning with the government's objectives under the Organic Agriculture Development Strategy, 2017–2021, to increase organic agricultural productivity and develop Thailand's organic sector (Chomchalow, 1993; FAO, 2024, 2018; ITA, 2024; Ngoc, 2020; Rueangrit et al., 2020; WorldBank, 2024b).

Thailand's agricultural landscape is diverse and distinct from that of its neighbouring countries Figure 5. Sugarcane has consistently been the top crop in Thailand since 2001, with its production increasing from 49.2 million tons in 2001 to 92 million tons in 2022. In 2018 and 2019, production exceeded 130 million tons. There has been little change in the relative rankings of crop production over the past two decades, except that palm oil has replaced mango/guava/mangosteen in the tenth place. Overall, rice production has remained relatively stable, increasing from 29 million tons to 34 million tons, while cassava production has grown from 18.3 million tons in 2001 to 34 million tons in 2022. Oil palm fruit, which ranks fourth in Thailand after sugarcane, rice, and cassava, has gradually increased from 4 million tons to 19 million tons (FAOSTAT, 2024a).

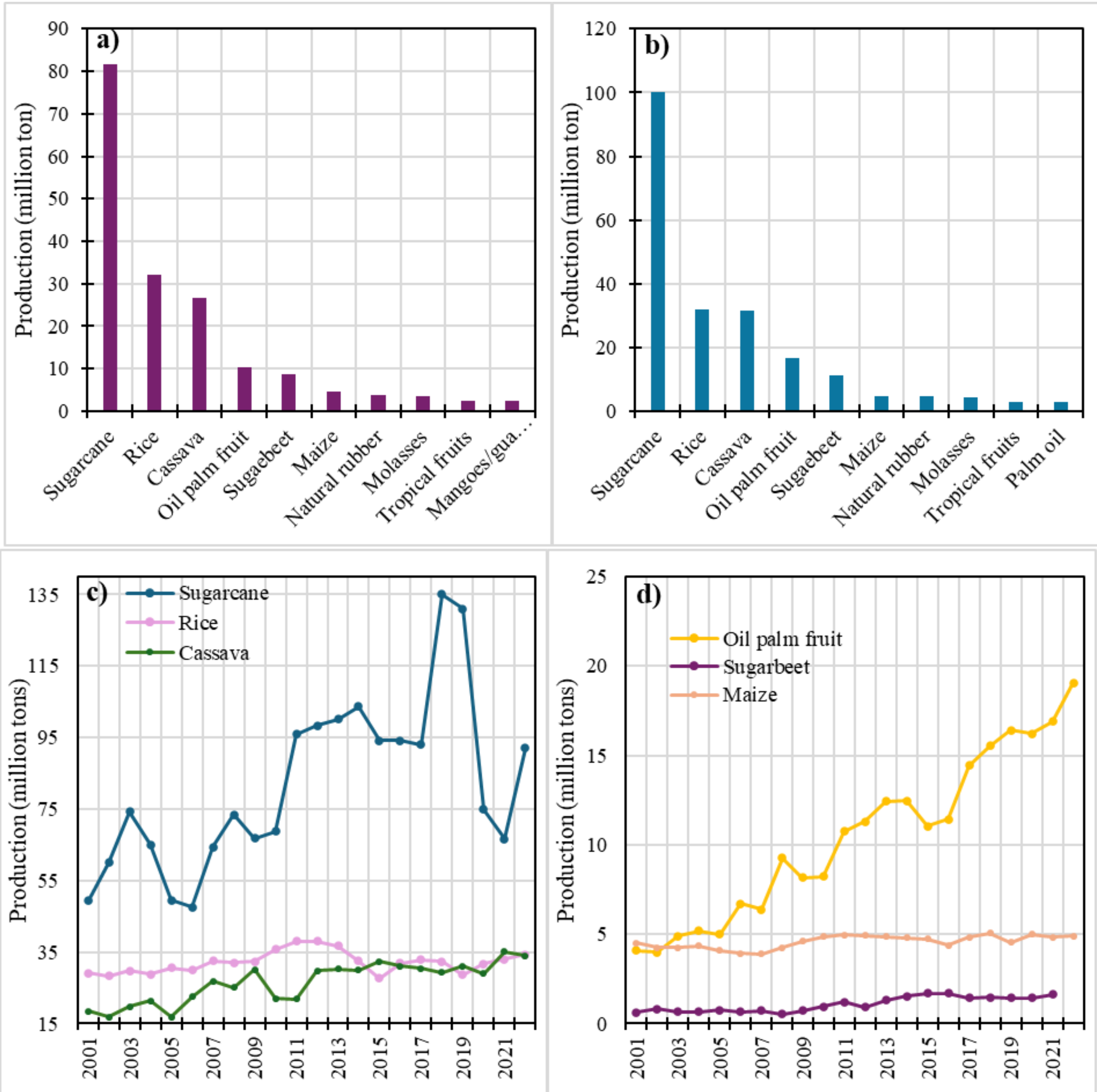

Figure 5 *Crop production statistics of Thailand: a) average production of major crops from 2001 to 2022, b) average production of major crops from 2018 to 2022, c) annual production of the major primary crop from 2001 to 2022, d) average production of the major secondary crops from 2001 – 2022. Source: (FAOSTAT, 2024a). Sugar beet is representing Raw cane or beet sugar (centrifugal only)*

1.5.3.3. Climate of Thailand

Thailand's climate is characterized by a tropical monsoon pattern, significantly influenced by seasonal monsoon winds. The southwest monsoon, commencing in May, brings warm, moist air from the Indian Ocean, resulting in substantial rainfall, particularly in mountainous regions. This effect is intensified by the Inter-Tropical Convergence Zone (ITCZ) from May to October and by tropical cyclones, which further increase rainfall. Conversely, the northeast monsoon, beginning in October, brings cold, dry air from the anticyclone in China over most parts of Thailand, especially the northern and northeastern regions at higher latitudes. The mean annual rainfall in Thailand varies from 1,200 to 4,500 mm, with lower totals on the leeward side and higher totals on the windward side. Average temperatures are 26.3°C in the north and 27.5°C in the southern and coastal areas. Nationwide, temperatures remain relatively steady throughout the year, averaging between 25 and 29°C. The greatest temperature fluctuations occur in the north, where frost can occasionally occur in December at higher elevations, while maritime influences moderate the climate in the south. In March and April, stagnant air creates a distinct hot-and-dry intermonomer period. During the northeast monsoon, the cooler, drier air produces frequent morning fogs in the north and northeast, which typically dissipate by midday. Humidity is extremely high during the rainy season, contributing to the overall tropical monsoon climate (Britannica, 2024; CRCP:Thailand, 2021; FAO, 2024; WorldBank, 2024a).

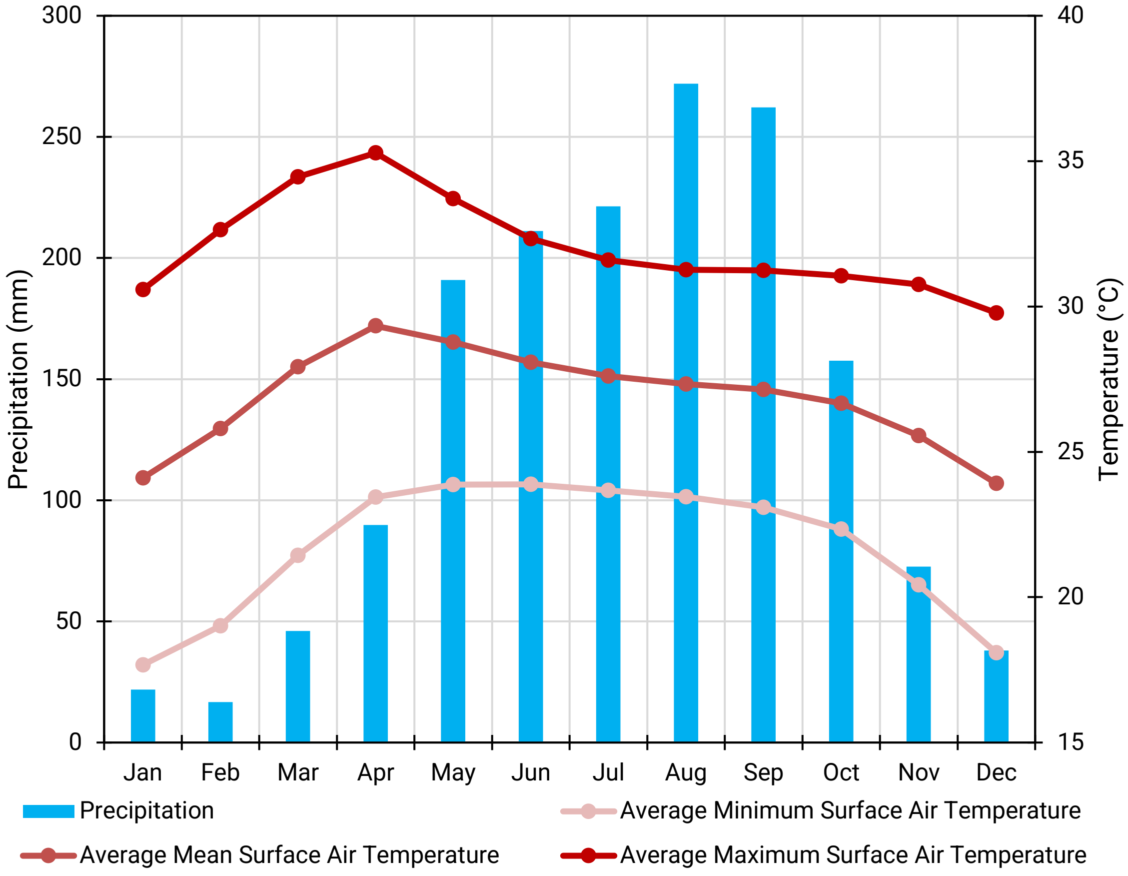

Figure 6 *Monthly climatology of average surface air temperature (mean, maximum, and minimum) and precipitation in Thailand from 1991 to 2022. Source: (WorldBank, 2024a)*

1.5.4. Viet Nam

1.5.4.1. Geography

Viet Nam, officially known as the Socialist Republic of Viet Nam, spans approximately 1,650 km from north to south and is about 50 km wide at its narrowest point. Bordered by China to the north, the South China Sea to the east and south, the Gulf of Thailand to the southwest, and Cambodia and Lao PDR to the west, Viet Nam's land borders total 4,550 km. The country forms an S-shaped strip from 23°23' to 8°27' north latitude. Viet Nam's topography is diverse, including hills, mountains, deltas, coastlines, and a continental shelf, shaped by a monsoon, humid climate. The terrain descends from northwest to southeast, influencing river flows. Key physiographic features include the Annamese Cordillera and the extensive alluvial deltas of the Red River in the north and the Mekong River in the south, connected by a narrow coastal plain. Three-quarters of Viet Nam's territory consists of low mountains and hilly regions, with elevations below 1,000 meters making up 85% of the area. Only 1% is above 2,000 meters, including Fansipan, the highest peak in Indochina at 3,143 meters. Mountain ranges are highest in the west and northwest, lowering towards the coastal lowlands. South of Hai Van Pass, the terrain simplifies with limestone mountains transitioning to granite and the Central Highlands plateau behind the Truong Son Range (Britannica, 2024; Factsanddetails, n.d.; WorldBank, 2024b).

1.5.4.2. Agriculture overview of Viet Nam

The relative contribution of agriculture, forestry, and fishing to Viet Nam's economy has declined due to the rapid growth of the industry and service sectors. As of 2017, the agricultural sector contributed 15.3% to the gross domestic product (GDP) but employed around 40.3% of the labour force. While agriculture is no longer the dominant economic sector, it still employs more than half of the population, despite manufacturing accounting for only 8% of all employment. Rice is the most important crop, grown primarily in the Red and Mekong River deltas. Other significant food crops include sugarcane, cassava (manioc), corn (maize), sweet potatoes, and nuts. Agriculture in Viet Nam remains highly labour-intensive, with much ploughing still done by water buffalo. The Mekong delta and southern terrace regions are home to many banana, coconut, and citrus plantations. Coffee and tea are cultivated in the central highlands, and rubber production, once disrupted by war, has been restored in these regions as well. Dragon fruit has become a valuable product for the Vietnamese economy, especially in the poorest areas of the Mekong Delta, contributing to sustainable development amid global climate change challenges like saline intrusion and drought. In Lao PDR, most agricultural land is dedicated to paddy rice production, with a growing proportion allocated to maize. Rice remains a staple for household food security, and studies suggest potential benefits of climate change on the net primary productivity of rice plants (Britannica, 2024; CRCP:Vietnam, 2021; Factsanddetails, n.d.; Luu et al., 2021).

Rice is the most dominant crop in Viet Nam (Figure 7), with production gradually increasing from 32 million tons in 2001 to 42.7 million tons in 2022. Sugarcane, previously the second major crop, dropped to third place in the last five years (2018-2022). In contrast, vegetable production has surged significantly, rising from 5.6 million tons in 2012 to 16 million tons in 2022, making it the second major crop in Viet Nam in the last five years (2018-2022). However, from 2001 to 2022, vegetables are ranked third (Figure 7). Cassava, the fourth major crop, increased from 3.5 million tons to 10.6 million tons. Conversely, maize production increased gradually until 2015 but has been declining since then (FAOSTAT, 2024a).

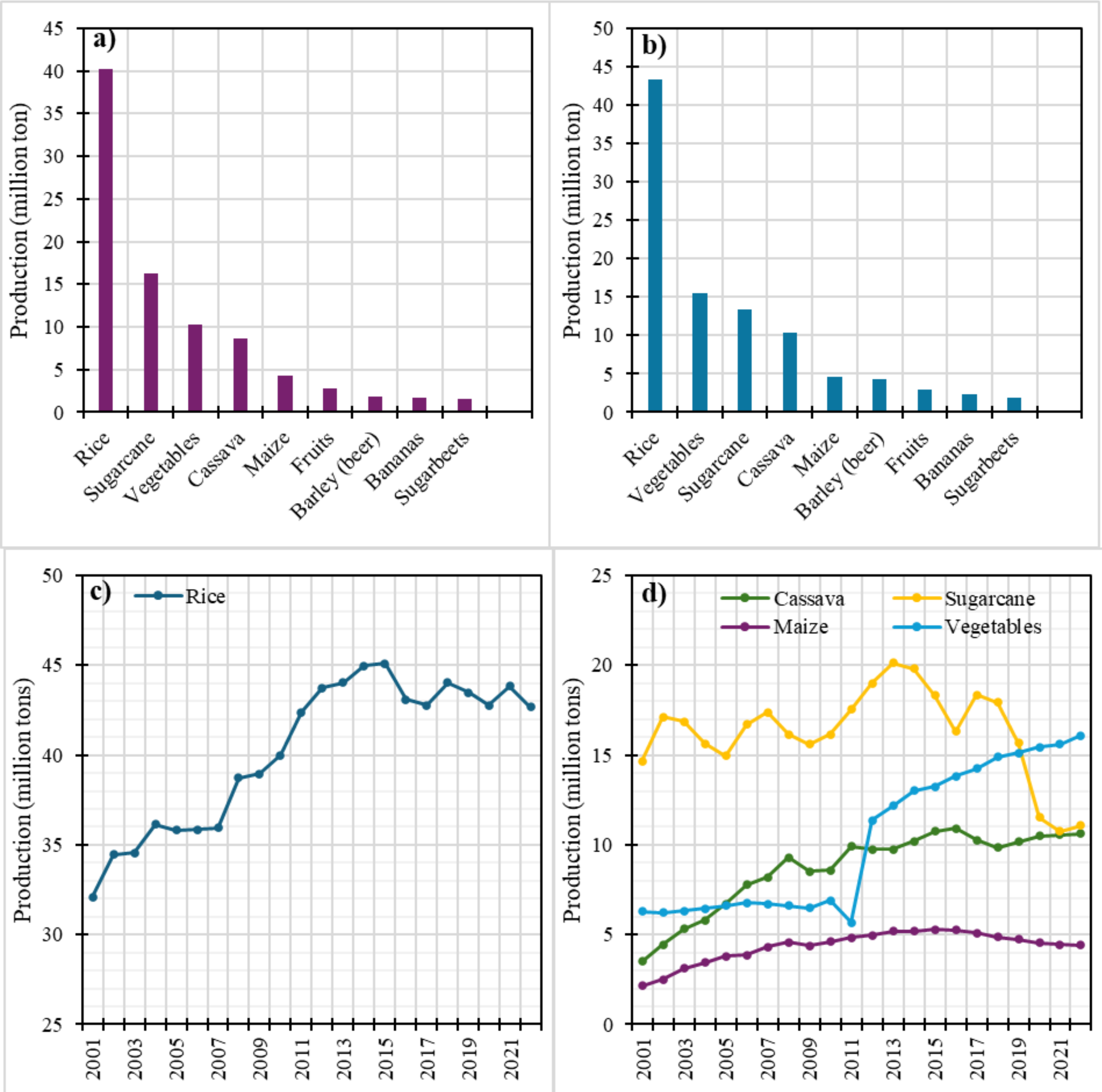

Figure 7 Crop production statistics of Viet Nam: a) average production of major crops from 2001 to 2022, b) average production of major crops from 2018 to 2022, c) annual production of the major primary crop from 2001 to 2022, d) average production of the major secondary crops from 2001 – 2022. Source: (FAOSTAT, 2024a). Sugarbeet is representing Raw cane or beet sugar (centrifugal only)

1.5.4.3. Climate of Viet Nam

Viet Nam, a South-East Asian nation with an extensive coastline, experiences a diverse but generally warm climate that includes both temperate and tropical regions. The entire country is influenced by the annual monsoon, which significantly impacts its climate cycles. The rainy seasons align with monsoon circulations, bringing heavy rainfall to the north and south from May to October, and the central regions from September to January. In northern Viet Nam, average temperatures range from 22°C to 27.5°C in summer and from 15°C to 20°C in winter. The southern regions experience a narrower temperature range, with 28°C to 29°C in summer and 26°C to 27°C in winter. Northern Viet Nam's winter season lasts from November to April, with a persistent drizzle from early February to late March, sometimes considered a transitional period. The summer season, from April or May to October, is characterized by heat, heavy rainfall, and occasional typhoons. In central and southern Viet Nam, the southwest monsoon from June to November brings rains and typhoons to the eastern slopes of the mountains and lowland plains. The period from December to April is drier, influenced by the northeast monsoon winds, and in the south, by high temperatures. Viet Nam's climate is also impacted by the El Niño Southern Oscillation (ENSO), which affects monsoonal circulation and drives complex shifts in rainfall and temperature patterns at a sub-national level. El Niño influences sea levels, drought incidence, and even disease patterns. The northern part of Viet Nam lies at the edge of the tropical climatic zone (Britannica, 2024; CRCP:Vietnam, 2021; Factsanddetails, n.d.; WorldBank, 2024a).

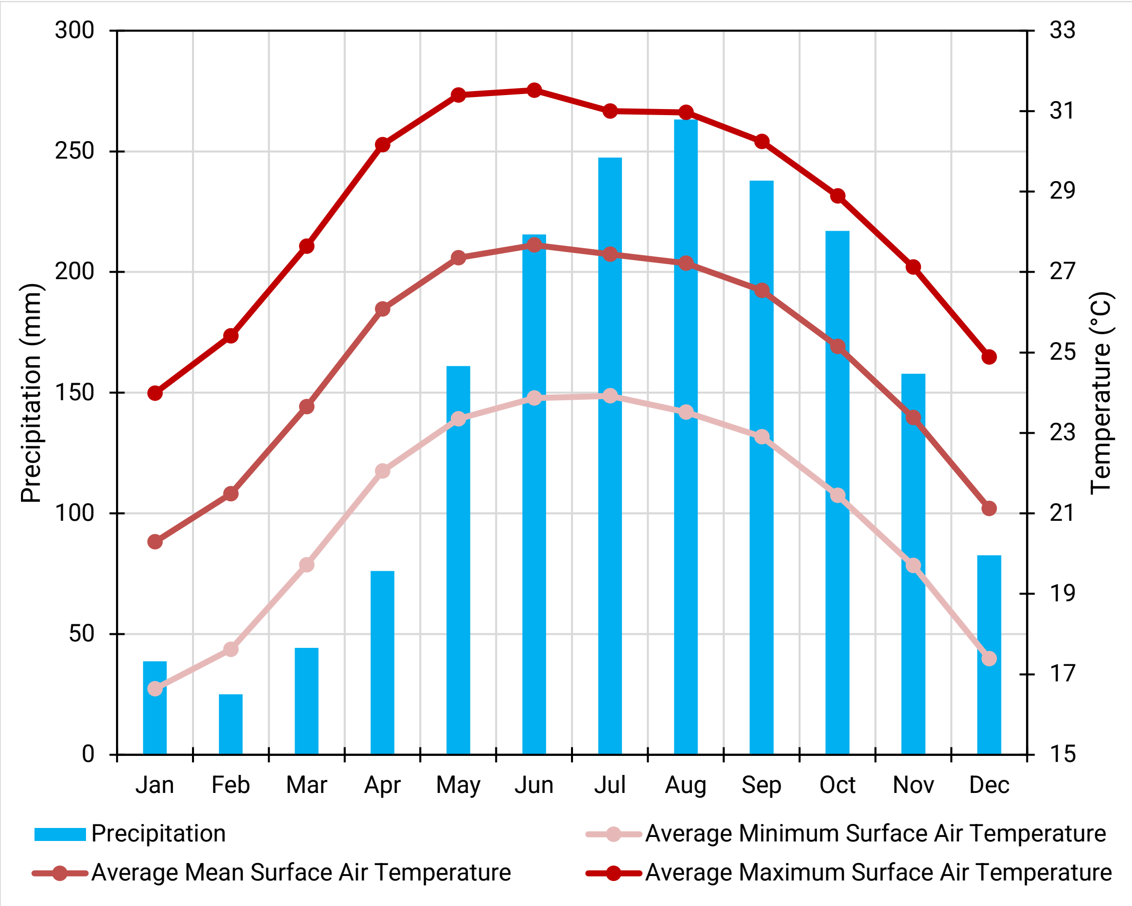

Figure 8 *Monthly climatology of average surface air temperature (mean, maximum, and minimum) and precipitation in Viet Nam from 1991 to 2022. Source: (WorldBank, 2024a)*

1.6. Historical context of agronomic challenges and drought in the region

The Climate Risk Index rankings (Table 2) highlight the varying levels of vulnerability to climate change among South-East Asian countries, with significant implications for their socio-economic stability and environmental sustainability. Thailand ranked 9th globally and 5th in the Asia-Pacific region (ESCAP), stands as one of the most at-risk nations, indicating severe susceptibility to climate-related disasters. Viet Nam follows closely, positioned 13th globally and 7th in ESCAP, reflecting considerable climate risks. Cambodia shares the same global rank of 14 but is placed slightly lower in the ESCAP ranking at 8th, still pointing to substantial climate vulnerabilities. In contrast, Lao PDR, ranked 52nd globally and 20th in ESCAP, faces relatively lower climate risks, yet its position within the region underscores the need for continued vigilance and adaptation efforts.

Since 2001, these countries have experienced multiple drought events (Table 2, Table 6): Cambodia has faced four droughts, Viet Nam also endured four droughts, and Lao PDR experienced one drought event. Thailand has been particularly hard-hit, facing eleven drought events. These rankings and the frequency of drought events underscore the pressing need for these countries to implement robust climate adaptation and mitigation strategies to safeguard their populations and economies (EM-DAT, 2024).

***Table 2** Climate Risk Index Ranking of the target countries in the world and ESCAP region (source: (Eckstein et al., 2021), and the number of significant droughts since 2001 (source: (EM-DAT, 2024).*

Country	Climate Risk Index	Global Rank	Rank in ESCAP	Drought frequency since 2011
Thailand	*30*	*9*	*5*	*11*
Viet Nam	*36*	*13*	*7*	*4*
Cambodia	*36*	*14*	*8*	*4*
Lao PDR	*61*	*52*	*20*	*1*

1.6.1. Droughts in Cambodia

In Cambodia, drought events have been recorded intermittently over the years, with four significant occurrences since 2001 (Table 6). The longest drought lasted from January to July 2002, affecting 650,000 people and causing damages worth $38,000. Other notable droughts include one in September 2001 that lasted a month and affected 300,000 people, and a heat wave in April 2005 that also lasted a month and affected 600,000 people. In May 2016, a water shortage crisis affected 2.5 million people in the country (EM-DAT, 2024).

Between 1971 and 2020, Cambodia's average mean temperature increased by 0.29°C per decade, with the most significant changes in the northern provinces and during winter. Average minimum temperatures rose by 0.29°C per decade, while maximum temperatures increased by 0.32°C per decade, with Ratanak Kiri province experiencing the highest increase at 0.33°C per decade. Over the same period, Cambodia saw significant seasonal precipitation variations, with central and eastern provinces experiencing notable decreases, particularly in Kampong Thom and Ratanak

Kiri, which saw the largest decreases per decade (−44.71 mm and −43.44 mm, respectively), especially during the summer wet monsoon months (CRCP:Cambodia, 2021; TWBG, 2023)

Drought incidents are expected to increase in intensity and frequency, influenced by ENSO, with nearly the entire country facing high exposure to agricultural losses. The annual median probability of severe meteorological drought in Cambodia is around 4%, with provinces in the southern plains severely affected every five or six years. Severe droughts in 1995, 1996, and 2002 affected approximately 2.5 million people, while droughts in 2004 and 2005 impacted 30% of the country's agricultural land, resulting in a 14% drop in rice yields. Another severe drought in 2015-2016 affected 2.5 million people across 18 provinces. As only 20% of Cambodia's rice fields have irrigation, poorer farmers relying on rainfed cropping systems are particularly vulnerable to more frequent and intense droughts or longer dry seasons (CRCP:Cambodia, 2021; TWBG, 2023).

Table 3 *A brief history of major drought events in Cambodia since 2001. Source:(EM-DAT, 2024)*

No	Location	Cause	Duration	No. Affected	Total Damage ('000 US$)
1	*Kampong Cham, Kampong Chhnang, Kampong Speu, Kampong Thom, Kampot, Kandal, Kep, Koh Kong, Kratie, Phnom Penh, Preah Sihanouk, Prey Veng, Pursat, Svay Rieng, Takeo provinces*		*09.2001 -2001*	*300000*	
2	*Takeo, Kampot, Kampong Speu, Kampong Chhnang, Kandal, Prey Veng, Phnom Penh, Otdar Meanchey, Banteay Meanchey, Pursat, Battambang provinces*		*01.2002 – 07.2002*	*650000*	*38000*
3	*Kampong Speu province*	*Heat wave*	*04.2005 – 04.2005*	*600000*	
4	*Banteay Meanchey, Battambang, Pursat, Kampong Speu provinces*	*Water shortage*	*05.2016 – 05.2016*	*2500000*	

1.6.2. Droughts in Lao People's Democratic Republic

Over the past two decades, only one significant drought event occurred in Lao PDR, in July 2019 (EM-DAT, 2024). Climate change could influence food production through direct and indirect effects on crop growth processes, including changes in carbon dioxide levels, precipitation patterns, and temperatures. Temperatures near Vientiane have increased by an estimated 1.03°C between 1900-1917 and 2000-2017, with a notable acceleration since the 21st century, while precipitation patterns have shifted towards more intense periods, influenced by the South-East Asian climate and ENSO. Lao PDR faces an annual median probability of severe meteorological drought of around 4%, with two primary types of droughts—meteorological and hydrological—affecting the region. Projections suggest an increased likelihood of drought in the future, potentially influenced by climate change's impact on monsoon and ENSO patterns, although further research is needed to clarify these effects (CCKP, 2024a; CRCP:Lao-PDR, 2021).

1.6.3. Droughts in Thailand

Thailand's vulnerability to climate change is exacerbated by its extensive coastline, reliance on agriculture in rural communities, and densely populated urban areas located in flood-prone plains. The GermanWatch Global Climate Risk Index 2021 ranked Thailand 9th globally for long-term climate risk. The country has faced severe climate impacts, including floods, droughts, extreme weather events, sea level rise, and high temperatures. These events have had devastating effects on agriculture, destroying rice and other crops, and increasing water stress for farmers in drought-prone areas (CRCP:Thailand, 2021; FAO, 2024).

Temperature increases have been observed across Thailand since the mid-20th century, with significant rises in minimum temperatures and the number of warm nights reported from 1961-1998. From 1970-2006, daily maximum, mean, and minimum temperatures increased at rates of 0.12-0.59°C, 0.10-0.40°C, and 0.11-0.55°C per decade, respectively. Studies observe an increase in annual precipitation in Thailand, primarily due to higher wet season rainfall. Precipitation variability over the 20th century was driven by the El Niño Southern Oscillation, with strong El Niño years correlating with moderate and severe droughts. A 2016 study found that while precipitation events have become less frequent, they have intensified. Temperatures in Thailand are projected to increase by 3.8°C by the 2080s, approximately 0.5°C less than the global average, and by 1.1°C under the RCP2.6 emissions pathway, similar to the projected global average. While there is considerable uncertainty regarding local long-term future precipitation trends, some global trends are evident. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, supported by evidence from different regions of Asia (CCKP, 2024a; CRCP:Thailand, 2021; Lacombe et al., 2012; Manton et al., 2001; Saengsawang et al., 2017; Westra et al., 2014).

Thailand has experienced a total of eleven drought events since 2001 (Table 6). The longest drought lasted from January 2015 to January 2017, affecting 3.3 million people. Another significant event occurred from April to August 2012, impacting 12 million people and causing $1,200 in total damages. Additionally, a severe El Niño-induced drought from February to December 2020 affected 5 million people and resulted in $2,300 in total damage. The country's worst drought in 20 years happened in 2010, leading to record-low water levels in the Mekong River. In 2011, severe flooding affected over a million people, and in 2015-16, one of the worst droughts in decades caused critically low water reservoir levels nationwide (EM-DAT, 2024).

Climate change is exacerbating these challenges, increasing production risks for the agricultural sector and intensifying issues such as water scarcity, pollution, and soil degradation. Floods and droughts in Thailand are rising, particularly affecting the Northeastern and Southern regions. The government has responded to these challenges with policies such as The Strategic Plan on Climate Change (2008-2012) and the Climate Change Master Plan (2012-2050) to mitigate the negative effects of erratic weather conditions (CRCP:Thailand, 2021; FAO, 2024).

Table 4 *A brief history of major drought events in Thailand since 2001. Source:(EM-DAT, 2024)*

No	Location	Cause	Duration	No. Affected	Total Damage ('000 US$)
1	*Nakhon Sawan, Udon Thani, Khon Kaen, Satun, Phrae, Loei, Kalasin, Sukhothai, Nakhon Ratchasima provinces*	*El Nino*	*02.2020 – 2020*	*5000000*	*2300*
2	*Ang Thong, Bangkok, Buriram, Chachoengsao, Chainat, Chaiyaphum, Chanthaburi, Chiang Mai, Chiang Rai,*		*01.2005 – 03.2005*		*420000*

	Chonburi, Chumphon, Kalasin, Kampaeng Phet, Kanchanaburi, Khon Kaen, Krabi, Lampang, Lamphun, Loei, Lopburi, Mae Hong Son, Maha Sarakham, Mukdahan, Nakhon Nayok, Nakhon Pathom, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nakhon Si Thammarat, Nan Narathiwat, Nong Khai, Nonthaburi, Pathum Thani, Pattani, Phangnga, Phatthalung, Phayao, Phetchabun, Phetchaburi, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Phuket, Prachuap Khilikhan, Ranong, Ratchaburi, Rayong, Roi Et, Sakon Nakhon, Samut Prakarn, Samut Sakhon, Samut Songkham, Saraburi, Satun, Si Saket, Singburi, Songkhla, Sukhothai, Suphanburi, Surat Thani, Surin, Tak, Trad, Trang, Uthai Thani, Uttaradit, Yala, Yasothon, Amnat Charoen, Nong Bua Lamphu, Phachinburi, Sa Kaeo, Ubon Ratchathani, Udon Thani provinces				
3	*Ang Thong, Chainat, Chaiyaphum, Chiang Rai, Kalasin, Kampaeng Phet, Khon Kaen, Lampang, Loei, Lopburi, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nan, Nong Bua Lamphu, Nong Khai, Phayao, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Sakon Nakhon, Saraburi, Singburi, Sukhothai, Suphanburi, Udon Thani, Uthai Thani, Uttaradit provinces*		*04.2008 – 2008*	*10000000*	
4	*Ang Thong, Chainat, Chaiyaphum, Chiang Rai, Kalasin, Kampaeng Phet, Khon Kaen, Lampang, Loei, Lopburi, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nan, Nong Bua Lamphu, Nong Khai, Phayao, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Sakon Nakhon, Saraburi, Singburi, Sukhothai, Suphanburi, Udon Thani, Uthai Thani, Uttaradit provinces*		*03.2010 – 03.2011*	*6482602*	
5	*Chians Rai, Nan, Phrae, Loei, Nong Khai, Ubon Ratchathani, Mukdahan, Sakon Nakhon, Si Saket, Surin, Chaiyaphum, Amnat Charoen, Kalasin, Nakhon Ratchasima, Buriram, Yasothon provinces (North); Sukhothai, Phetchabun, Phichit provinces (Central); Prachuap Khilikhan, Phetchaburi, Kanchanaburi provinces (West)*		*06.2011 – 2011*		
6	*Lampang, Kamphaeng Phet, Nan, Phayao, Chiang Mai, Sukhothai (Northern provinces); Nong Khai, Si Sa Ket, Khon Kaen, Maha Sarakham, Udon Thani, Chaiyaphum (NorthEast provinces); Phetchaburi, Kanchanaburi, Prachuap Khiri Khan, Chon Buri, Nakhon Nayok, Suphan*		*04.2012 – 08.2012*	*12000000*	*1200*

	Buri, Chanthaburi, Chachoengsao, Trat, Phuket provinces. 17 are in the North, 19 in the Northeast, 5 in the central region, 6 in the East and 1 in the South.				
7	*Ang Thong, Bangkok, Buriram, Chachoengsao, Chainat, Chaiyaphum, Chanthaburi, Chiang Mai, Chiang Rai, Chonburi, Chumphon, Kalasin, Kampaeng Phet, Kanchanaburi, Khon Kaen, Krabi, Lampang, Lamphun, Loei, Lopburi, Mae Hong Son, Maha Sarakham, Mukdahan, Nakhon Nayok, Nakhon Pathom, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nakhon Si Thammarat, Nan Narathiwat, Nong Khai, Nonthaburi, Pathum Thani, Pattani, Phangnga, Phatthalung, Phayao, Phetchabun, Phetchaburi, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Phuket, Prachuap Khilikhan, Ranong, Ratchaburi, Rayong, Roi Et, Sakon Nakhon, Samut Prakarn, Samut Sakhon, Samut Songkham, Saraburi, Satun, Si Saket, Singburi, Songkhla, Sukhothai, Suphanburi, Surat Thani, Surin, Tak, Trad, Trang, Uthai Thani, Uttaradit, Yala, Yasothon, Amnat Charoen, Nong Bua Lamphu, Phachinburi, Sa Kaeo, Ubon Ratchathani, Udon Thani provinces*	*Dry conditions*	*03.2014 – 03.2014*		
8	*42 provinces. 28 provinces in the North and Northeast*		*01.2015 – 01.2017*		*3300000*
	North, Northeastern, Central Plains		*07.2019 – 02.2020*		

1.6.4. Droughts in Viet Nam

Viet Nam has faced several significant drought events, with four major droughts since 2001, impacting millions and causing extensive damage. (Table 6). In May 2002, a drought affected 1.3 million people and caused $200,000 in damages. Another drought in May 2005 affected 410,000 people and resulted in $42,120 in damages. The most severe drought occurred between December 2015 and May 2017, driven by a lack of rainfall and El Niño, affecting 1.75 million people and causing $6.75 million in damages. The most recent drought, from July 2019 to February 2020, affected 685,558 people (EM-DAT, 2024).

Since 1960, mean annual temperatures in Viet Nam have increased by 0.5°C–0.7°C, with the fastest increases in southern Viet Nam and the Central Highlands. From 1971 to 2010, the warming rate was 0.26°C per decade, nearly twice the global average. Winter months have seen more warming than summer months, with a significant increase in the frequency of hot days and nights and a decrease in cold days and nights. While national mean rainfall has not changed significantly since 1960, central regions have seen increased rainfall, and northern and southern regions have seen decreases. El Niño continues to influence precipitation trends. Projections indicate an average temperature increase of 3.4°C by 2080–2100 under the highest emission pathway, with more frequent and prolonged droughts expected. Modelling by the Viet Nam Ministry of Natural Resources and Environment suggests annual precipitation increases of 10% to 20% by 2045–2065 across all mainland regions, although other precipitation projections show no significant changes. Analysis suggests that these changes will affect all regions of Viet Nam, with droughts projected to occur more frequently and last longer (CCKP, 2024a; CRCP:Vietnam, 2021; Katzfey et al., 2014; MONRE, 2016).

Table 5 *A brief history of major drought events in the target Viet Nam since 2001. Source:(EM-DAT, 2024)*

No	Location	Cause	Duration	No. Affected	Total Damage ('000 US$)
1	*An Giang, Kien Giang, Long An provinces*		*05.2002 – 2002*	*1300000*	*200000*
2	*Ben Tre province*		*05.2005 – 2005*	*410000*	*42120*
3	*An Giang, Ba Ria-Vung Tau, Ben Tre, Binh Dinh, Binh Duong, Binh Phuoc, Binh Thuan, Can Tho city, Dak Lak, Dak Nong, Dong Nai, Dong Thap, Gia Lai, Hau Giang, Ho Chi Minh City, Khanh Hoa, Kon Tum, Lam Dong, Long An, Ninh Thuan, Phu Yen, Quang Nam, Quang Ngai, Soc Trang, Tay Ninh, Tien Giang, Tra Vinh, Vinh Long provinces*	*Lack of rainfall, El NIno*	*12.2015 – 05.2017*	*1750000*	*6750000*
4	*Long An, Tien Giang, Ben Tre, Dong Thap, Vinh Long, Tra Vinh, Soc Trang, An Giang, Kien Giang, Hau Giang, Bac Lieu, Ca Mau, Can Tho city*		*07.2019 – 02.2020*	*685558*	

***Table 6** A brief history of major drought events in the target countries since 2001. Source:(EM-DAT, 2024)*

Country	Location	Cause	Duration	No. Affected	Total Damage ('000 US$)
Cambodia	*Kampong Cham, Kampong Chhnang, Kampong Speu, Kampong Thom, Kampot, Kandal, Kep, Koh Kong, Kratie, Phnom Penh, Preah Sihanouk, Prey Veng, Pursat, Svay Rieng, Takeo provinces*		*09.2001 -2001*	*300000*	
Cambodia	*Takeo, Kampot, Kampong Speu, Kampong Chhnang, Kandal, Prey Veng, Phnom Penh, Otdar Meanchey, Banteay Meanchey, Pursat, Battambang provinces*		*01.2002 – 07.2002*	*650000*	*38000*
Cambodia	*Kampong Speu province*	*Heat wave*	*04.2005 – 04.2005*	*600000*	
Cambodia	*Banteay Meanchey, Battambang, Pursat, Kampong Speu provinces*	*Water shortage*	*05.2016 – 05.2016*	*2500000*	
Lao PDR			*07.2019 – 07.2019*		
Thailand	*Nakhon Sawan, Udon Thani, Khon Kaen, Satun, Phrae, Loei, Kalasin, Sukhothai, Nakhon Ratchasima provinces*	*El Nino*	*02.2020 – 2020*	*5000000*	*2300*
Thailand	*Ang Thong, Bangkok, Buriram, Chachoengsao, Chainat, Chaiyaphum, Chanthaburi, Chiang Mai, Chiang Rai, Chonburi, Chumphon, Kalasin, Kampaeng Phet, Kanchanaburi, Khon Kaen, Krabi, Lampang, Lamphun, Loei, Lopburi, Mae Hong Son, Maha Sarakham, Mukdahan, Nakhon Nayok, Nakhon Pathom, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nakhon Si Thammarat, Nan Narathiwat, Nong Khai, Nonthaburi, Pathum Thani, Pattani, Phangnga, Phatthalung, Phayao, Phetchabun, Phetchaburi, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Phuket, Prachuap Khilikhan, Ranong, Ratchaburi, Rayong, Roi Et, Sakon Nakhon, Samut Prakarn, Samut Sakhon, Samut Songkham, Saraburi, Satun, Si Saket, Singburi, Songkhla, Sukhothai, Suphanburi, Surat Thani, Surin, Tak, Trad, Trang, Uthai Thani, Uttaradit, Yala, Yasothon, Amnat Charoen, Nong Bua Lamphu, Phachinburi, Sa Kaeo, Ubon Ratchathani, Udon Thani provinces*		*01.2005 – 03.2005*		*420000*
Thailand	*Ang Thong, Chainat, Chaiyaphum, Chiang Rai, Kalasin, Kampaeng Phet, Khon Kaen, Lampang, Loei, Lopburi, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nan, Nong Bua Lamphu, Nong Khai, Phayao, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Sakon Nakhon, Saraburi, Singburi, Sukhothai, Suphanburi, Udon Thani, Uthai Thani, Uttaradit provinces*		*04.2008 – 2008*	*10000000*	
Thailand	*Ang Thong, Chainat, Chaiyaphum, Chiang Rai, Kalasin, Kampaeng Phet, Khon Kaen, Lampang, Loei, Lopburi, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nan, Nong Bua Lamphu, Nong Khai, Phayao, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Sakon Nakhon, Saraburi, Singburi, Sukhothai, Suphanburi, Udon Thani, Uthai Thani, Uttaradit provinces*		*03.2010 – 03.2011*	*6482602*	
Thailan	*Chians Rai, Nan, Phrae, Loei, Nong Khai, Ubon Ratchathani,*		*06.201*		

d	*Mukdahan, Sakon Nakhon, Si Saket, Surin, Chaiyaphum, Amnat Charoen, Kalasin, Nakhon Ratchasima, Buriram, Yasothon provinces (North); Sukhothai, Phetchabun, Phichit provinces (Central); Prachuap Khilikhan, Phetchaburi, Kanchanaburi provinces (West)*		*1 – 2011*		
Thailand	*Lampang, Kamphaeng Phet, Nan, Phayao, Chiang Mai, Sukhothai (Northern provinces); Nong Khai, Si Sa Ket, Khon Kaen, Maha Sarakham, Udon Thani, Chaiyaphum (NorthEast provinces); Phetchaburi, Kanchanaburi, Prachuap Khiri Khan, Chon Buri, Nakhon Nayok, Suphan Buri, Chanthaburi, Chachoengsao, Trat, Phuket provinces. 17 are in the North, 19 in the Northeast, 5 in the central region, 6 in the East and 1 in the South.*		*04.2012 – 08.2012*	*12000000*	*1200*
Thailand	*Ang Thong, Bangkok, Buriram, Chachoengsao, Chainat, Chaiyaphum, Chanthaburi, Chiang Mai, Chiang Rai, Chonburi, Chumphon, Kalasin, Kampaeng Phet, Kanchanaburi, Khon Kaen, Krabi, Lampang, Lamphun, Loei, Lopburi, Mae Hong Son, Maha Sarakham, Mukdahan, Nakhon Nayok, Nakhon Pathom, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan, Nakhon Si Thammarat, Nan Narathiwat, Nong Khai, Nonthaburi, Pathum Thani, Pattani, Phangnga, Phatthalung, Phayao, Phetchabun, Phetchaburi, Phichit, Phitsanulok, Phra Nakhon Si Ayudhya, Phrae, Phuket, Prachuap Khilikhan, Ranong, Ratchaburi, Rayong, Roi Et, Sakon Nakhon, Samut Prakarn, Samut Sakhon, Samut Songkham, Saraburi, Satun, Si Saket, Singburi, Songkhla, Sukhothai, Suphanburi, Surat Thani, Surin, Tak, Trad, Trang, Uthai Thani, Uttaradit, Yala, Yasothon, Amnat Charoen, Nong Bua Lamphu, Phachinburi, Sa Kaeo, Ubon Ratchathani, Udon Thani provinces*	*Dry conditions*	*03.2014 – 03.2014*		
Thailand	*42 provinces. 28 provinces in the North and Northeast*		*01.2015 – 01.2017*		*3300000*
Thailand	*North, Northeastern, Central Plains*		*07.2019 – 02.2020*		
Viet Nam	*An Giang, Kien Giang, Long An provinces*		*05.2002 – 2002*	*1300000*	*200000*
Viet Nam	*Ben Tre province*		*05.2005 – 2005*	*410000*	*42120*
Viet Nam	*An Giang, Ba Ria-Vung Tau, Ben Tre, Binh Dinh, Binh Duong, Binh Phuoc, Binh Thuan, Can Tho city, Dak Lak, Dak Nong, Dong Nai, Dong Thap, Gia Lai, Hau Giang, Ho Chi Minh City, Khanh Hoa, Kon Tum, Lam Dong, Long An, Ninh Thuan, Phu Yen, Quang Nam, Quang Ngai, Soc Trang, Tay Ninh, Tien Giang, Tra Vinh, Vinh Long provinces*	*Lack of rainfall, El NIno*	*12.2015 – 05.2017*	*1750000*	*6750000*
Viet Nam	*Long An, Tien Giang, Ben Tre, Dong Thap, Vinh Long, Tra Vinh, Soc Trang, An Giang, Kien Giang, Hau Giang, Bac Lieu, Ca Mau, Can Tho city*		*07.2019 – 02.2020*	*685558*	

Chapter 2: Agronomic Conditions and Droughts in Cambodia

2.1. Geospatial data overview

This study utilized various data sources (Table 1) with Google Earth Engine (GEE) as the primary hub for data processing. GEE, a cloud computing platform for planetary-scale data analysis, ensures the flexibility and adaptability of the workflow. Please refer to section 1.3 for an overview of the geospatial data used in this study. For the specific analysis of agronomic conditions and droughts in Cambodia, all datasets were processed at the national scale to derive country-specific information. Additionally, regional-level maps and information are included to provide spatially exclusive perspectives, considering the regional context, particularly the neighboring countries.

2.2. Agronomic Conditions in Cambodia

The agronomic conditions in Cambodia were assessed through an in-depth analysis of land cover and land use composition, with a particular emphasis on cropland. This assessment utilized various land cover and land use datasets. Additionally, the distribution and patterns of soil texture across the country were examined. Long-term trends and patterns in precipitation, temperature and NDVI were evaluated. These indices provided insights into the health and viability of croplands under different environmental stresses.

2.2.1. Land cover land use composition and cropland in Cambodia

The composition and spatial distribution of land cover and land use in Cambodia and the surrounding region were assessed using several datasets. These included ESA's WorldCover map for 2022, with a 10-meter spatial resolution, and the GLCFCS30D Global 30-meter Land Cover Change Dataset (1985-2022). The GLC_FCS30D dataset represents a significant advancement in global land-cover monitoring, offering detailed insights into land-cover dynamics over a 30-meter resolution spanning from 1985 to 2022. This dataset provided four categories of cropland: rainfed cropland, irrigated cropland, herbaceous cover cropland, and tree or shrub cropland (orchard). In contrast, the ESA WorldCover map provided a single cropland category, but it missed tree crops or orchards in many parts, which is probably included in the Tree Cover class. To ensure consistency among the datasets, we also analyzed two datasets provided by the FAO (FAOSTAT, 2024b), including Land Cover and Land Use. The FAO's Land Cover information is compiled from publicly available Global Land Cover (GLC) maps: The European Space Agency (ESA) Climate Change Initiative (CCI) annual land cover maps (1992–2020), produced by the Université Catholique de Louvain (UCL)-Geomatics and now part of the European Copernicus Program. The FAOSTAT Land Use domain contains data on forty-four categories of land use, irrigation, agricultural practices, and five indicators relevant to monitoring agriculture, forestry, and fisheries activities at national, regional, and global levels. This data is available by country and year, with global coverage and annual updates.

The land cover composition in Cambodia (Table 7, Figure 9, Figure 10), highlights a diverse vegetative landscape with a significant presence of cropland and forest. Cropland is diagonally distributed from the northwest to the centre and southeast of Cambodia, effectively dividing the forest into two patches: one in the northeast and the other in the southeast along the coast. According to ESA WorldCover, cropland covers 57,616 km² (31.82% of the area), while the largest land cover class in Cambodia is tree cover, accounting for 46.81% of the total area. Other land cover types include smaller proportions of shrubland, built-up areas, bare or sparse vegetation, water bodies, mangroves, and moss or lichen.

The more detailed breakdown indicates that the rainfed cropland is the most prevalent, covering 73,736 km² (33.23% of the total area), indicating a significant reliance on natural rainfall for agriculture. Irrigated cropland constitutes 4.61%, with these areas primarily distributed along the southeast of Cambodia into the Gulf of Thailand. Most cropland is concentrated around the centre of Cambodia. Herbaceous cover cropland and tree or shrub cropland (orchards) are present in much smaller areas.

From the FAO Land Cover dataset (CCI LC), cropland is categorized under herbaceous crops and woody crops, totalling 69,192 km². Herbaceous crops cover 62,881 km² (34.45%), while woody crops contribute 7,311 km² (4.01%). This classification indicates a substantial presence of both annual and perennial crops across the landscape (Table 8).

In the FAO Land Use dataset, cropland is part of the broader agricultural land category. it covers 46,148 km² (26.14%), and it is further divided into temporary crops (41,022 km² or 23.24%) and permanent crops (4,947 km² or 2.80%). The data also shows that land equipped for irrigation covers 2,700 km² (1.53%), highlighting a significant portion of cropland with managed water resources (Table 8).

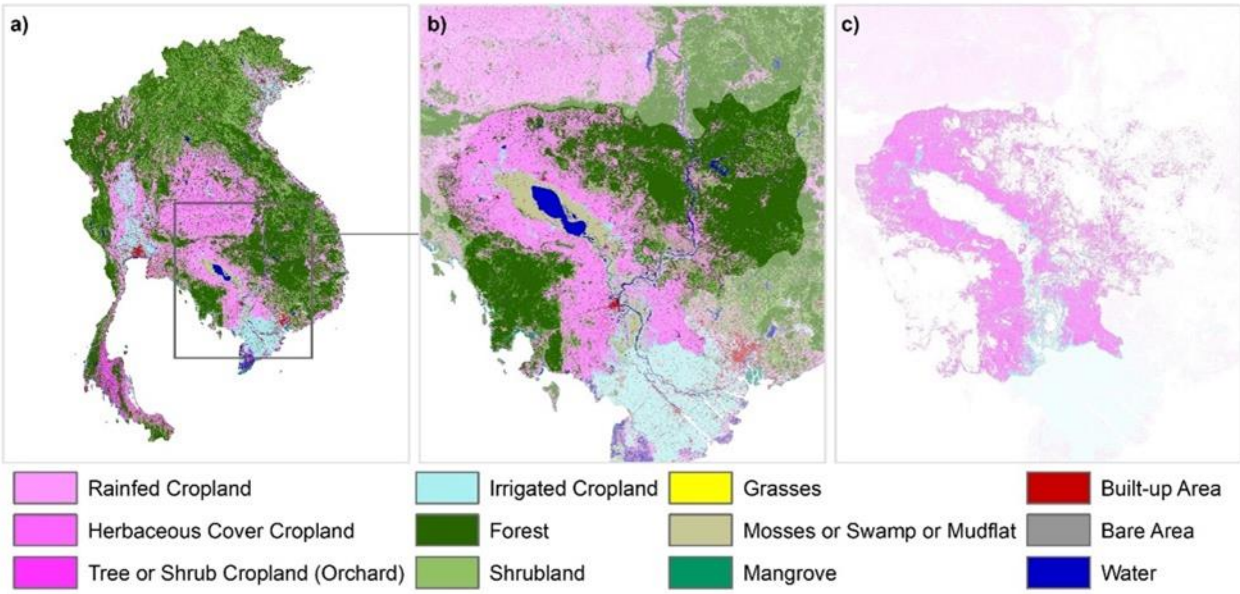

Figure 9 *The cropland and land cover land use composition of Cambodia using the GLCFCS30D: a) Overview and location of Cambodia in the region; b) Spatial distribution of land cover/land use patterns across Cambodia; c) Distribution of cropland areas within Cambodia. Data source: (Liu et al., 2023)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

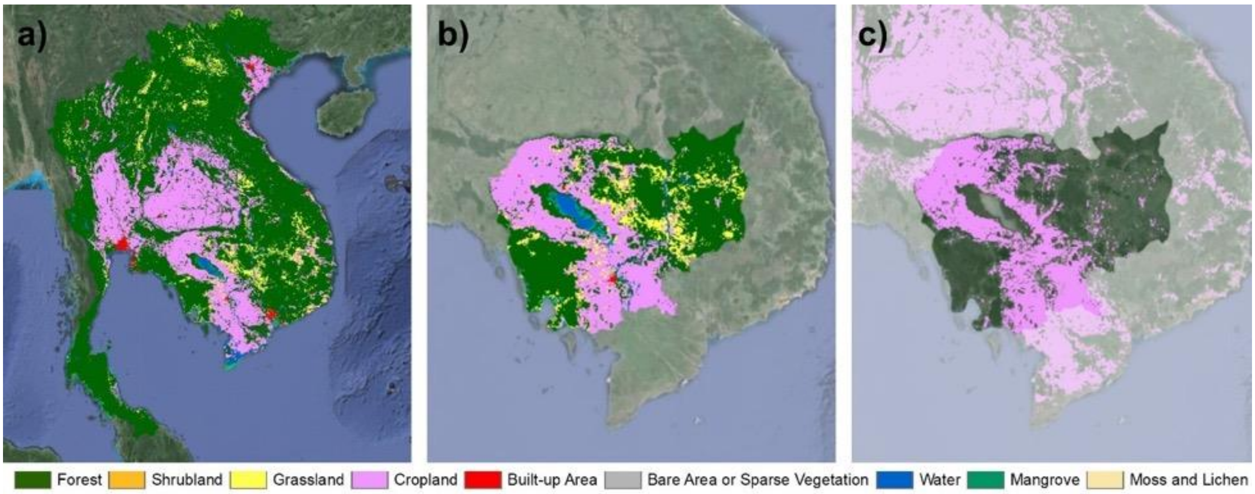

Figure 10 *The cropland and land cover land use composition of Cambodia using the ESA's WorldCover Map: a) Overview and location of Cambodia in the region; b) Spatial distribution of land cover/land use patterns across Cambodia; c) Distribution of cropland areas within Cambodia. Data Source: (Zanaga et al., 2022)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 7 Dis*tribution of vegetated land cover land use classes in Cambodia from ESA's WorldCover and the distribution of cropland and its sub-classes from GLCFCS.*

ESA - World Cover			GLCFCS		
LCLU Classes	**Area (Km2)**	**%**	**Cropland Classes**	**Area**	**%**
Tree cover	*84759*	*46.81*	**Cropland**	*73736*	*39.41*
Shrubland	*586*	*0.32*	**Rainfed Cropland**	*62172*	*33.23*
Grassland	*24885*	*13.74*	**Herbaceous Cover Cropland**	*2932*	*1.57*
Cropland	*57616*	*31.82*	**Tree or Shrub Cropland (Orchard)**	*8*	*0.00*
Built-up Area	*1333*	*0.74*	**Irrigated Cropland**	*8623*	*4.61*
Bare or Sparse vegetation	*2810*	*1.55*	**Forest**	*82792*	*44.25*
Water	*8501*	*4.70*	**Shrubland**	*12917*	*6.90*
Mangroves	*569*	*0.31*	**Grassland**	*1*	*0.00*
Moss and lichen	*420*	*0.22*	**Mangrove**	*508*	*0.27*

__Table 8__ Distribution of land cover land use classes in Cambodia from the FAO's Land Cover (CCI LC) and the FAO's Land Use map (FAOSTAT, 2024b).

FOA - Land Cover - CCI LC			FAO - Land Use		
LCLU Class Name	**Area**	**%**	**LCLU Class Name**	**Area**	**%**
Artificial surfaces	*312*	*0.17*	**Agricultural land**	*61148*	*34.64*
Herbaceous crops	*62881*	*34.45*	**Cropland**	*46148*	*26.14*
Woody crops	*7311*	*4.01*	**Temporary crops**	*41022*	*23.24*
Grassland	*12680*	*6.95*	**Permanent crops**	*4947*	*2.80*
Tree-covered areas	*71142*	*38.98*	**Temporary meadows and pastures**	*13*	*0.01*
Mangroves	*429*	*0.24*	**Temporary fallow**	*166*	*0.09*
Shrub-covered areas	*16805*	*9.21*	**Permanent meadows and pastures**	*15000*	*8.50*
Shrubs and/or herbaceous vegetation	*6597*	*3.61*	**Land area equipped for irrigation**	*2700*	*1.53*
Sparsely natural vegetated areas	*4*	*0.00*	**Agriculture area actually irrigated**		*0.00*
Terrestrial barren land	*22*	*0.01*	**Arable land**	*41201*	*23.34*
Inland water bodies	*4344*	*2.38*	*Forest land*	*77570*	*43.94*
			Naturally regenerating forest	*71291*	*40.39*
			Planted Forest	*6279*	*3.56*
			Other land	*37802*	*21.42*

2.2.2. Composition of Soil Texture in Cambodia

To understand the general soil texture composition across Cambodia and the cropland of Cambodia, the USDA's soil texture layer at 10 cm depth was used. The datasets consisted of 12 soil texture classes for six soil depths (0, 10, 30, 60, 100, and 200 cm) at a 250 m resolution,. derived from predicted soil texture fractions using the soil texture package in R (Hengl, 2018).

The dataset, masked over Cambodia and the cropland areas, reveals that the landscape primarily consists of two soil texture types (Figure 11, Table 9). Clay loam (ClLo) is prevalent in the middle of the country, particularly around the Tonlé Sap Lake, where much of the cropland is concentrated. Loam (Lo) is the most dominant soil texture type across the country, covering areas predominantly characterized by forest. However, a significant portion of the cropland also occupies loam soil, indicating its suitability for agricultural activities. This distribution highlights the strategic utilization of clay loam and loam soils in Cambodia's agricultural landscape, optimizing the natural properties of these soils for effective and sustainable farming practices (Figure 11, Table 9).

The distribution of soil texture classes in Cambodia, including a focus on cropland areas, reveals significant insights into the agricultural landscape (Table 9). At a 10 cm depth, loam (Lo) emerges as the most prevalent soil texture class across Cambodia, covering 97,844 km² or 53.45% of the total area. This prevalence is even more pronounced in cropland areas, where loam covers 39,131 km², accounting for 46.83% of the cropland soil texture. The high proportion of loam in cropland areas is advantageous for agriculture due to its balanced properties of moisture retention and drainage, making it ideal for various crops.

Clay loam (ClLo) is the second most dominant soil texture, encompassing 69,331 km² or 37.87% of Cambodia's total area (Table 9). Within cropland areas, clay loam covers 33,594 km², constituting 40.20% of the soil texture. The substantial presence of clay loam in croplands suggests a preference for soils that offer good nutrient retention and moderate water permeability, which are beneficial for sustained agricultural productivity.

Silty loam (SiLo), though less extensive, still represents a notable portion of the soil texture, covering 10,956 km² or 5.98% of Cambodia's total area (Table 9). In cropland areas, silty loam accounts for 7,396 km² or 8.85%. This texture provides fertile soil with high moisture-holding capacity, supporting crop growth in specific regions.

Other soil textures, such as clay (Cl), silty clay (SiCl), sandy clay (SaCl), and silt (Si), have minimal representation. Clay covers 3,319 km² or 1.81% of the total area, and its presence in cropland areas is slightly higher at 2,408 km² or 2.88%. Silty clay and sandy clay are almost negligible in both total and cropland areas, while silt covers 1,603 km² or 0.88% of the total area and 1,030 km² or 1.23% of cropland areas (Table 9).

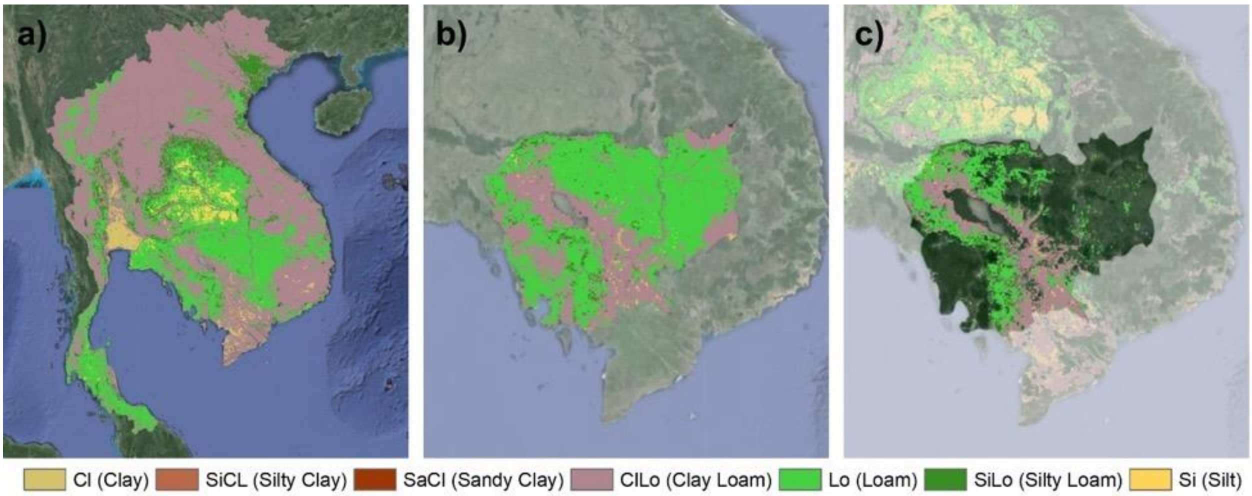

Figure 11 *The soil texture composition (at 10 cm depth) of Cambodia using the USDA's soil texture data: a) Overview and location of Cambodia in the region; b) Spatial distribution of soil texture patterns across Cambodia; c) Distribution of soil texture masked over the cropland areas.*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 9 *Distribution of the soil texture classes (at 10 cm depth) in Cambodia and masked over the cropland*

Soil Texture Class	Cambodia		Cambodia - Cropland	
	Area	(%)	Area	(%)
Cl (Clay)	3319	1.81	2408	2.88
SiCl (Silty Clay)	1	0.00	1	0.00
SaCl (Sandy Clay)	11	0.01	0	0.00
ClLo (Clay Loam)	69331	37.87	33594	40.20
Lo (Loam)	97844	53.45	39131	46.83
SiLo (Silty Loam)	10956	5.98	7396	8.85
Si (Silt)	1603	0.88	1030	1.23

2.2.3. Trends of Air Temperature in Cambodia

The analysis of temperature changes in Cambodia was conducted using ERA5 temperature data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term temperature averages (2001-2020) with the recorded temperatures for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average temperatures and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average temperatures, the monthly temperatures for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of temperature changes, violin plots and box plots were used. Violin plots illustrated the distribution of temperatures, showing the density and probability of different temperature ranges over time. Box plots offered a clear visualization of the temperature distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the temperature changes in Cambodia, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of temperature trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual trend of temperature in Cambodia shows that the average temperature has increased from 26.95°C to 27.89°C between 1991 and 2020. This reflects an increase of 0.94°C for nearly three decades. This highlights the significant warming trend experienced in Cambodia, consistent with global patterns of rising temperatures due to climate change.

The comparative analysis of monthly temperature change rates between two decades, 2000-2010 and 2010-2020. There is a consistent increase in the rate of temperature change across all months in the more recent decade (2010-2020) compared to the earlier one (2000-2010). In January, the change rate increased from 0.07 to 0.30. February saw a shift from a slight decrease of -0.05 to a positive 0.20. March, which had a significant decrease of -0.30 in the 2000s, experienced a substantial increase to 0.29 in the 2010s. Similarly, April's change rate quadrupled from 0.10 to 0.46. May recorded a dramatic shift from -0.18 to 0.61, indicating a notable warming trend. June also transitioned from a slight decrease of -0.09 to an increase of 0.33. July's temperature change rate rose from -0.02 to 0.31, and August followed a similar pattern, changing from -0.10 to 0.38. September and October observed modest increases from 0.01 to 0.39 and from 0.00 to 0.42, respectively. November, which initially had a slight decrease of -0.09, showed the highest increase among all months to 0.76. December's change rate increased from 0.31 to 0.57. These trends indicate a significant and widespread increase in the rate of temperature change over the past decade, reflecting accelerated warming.

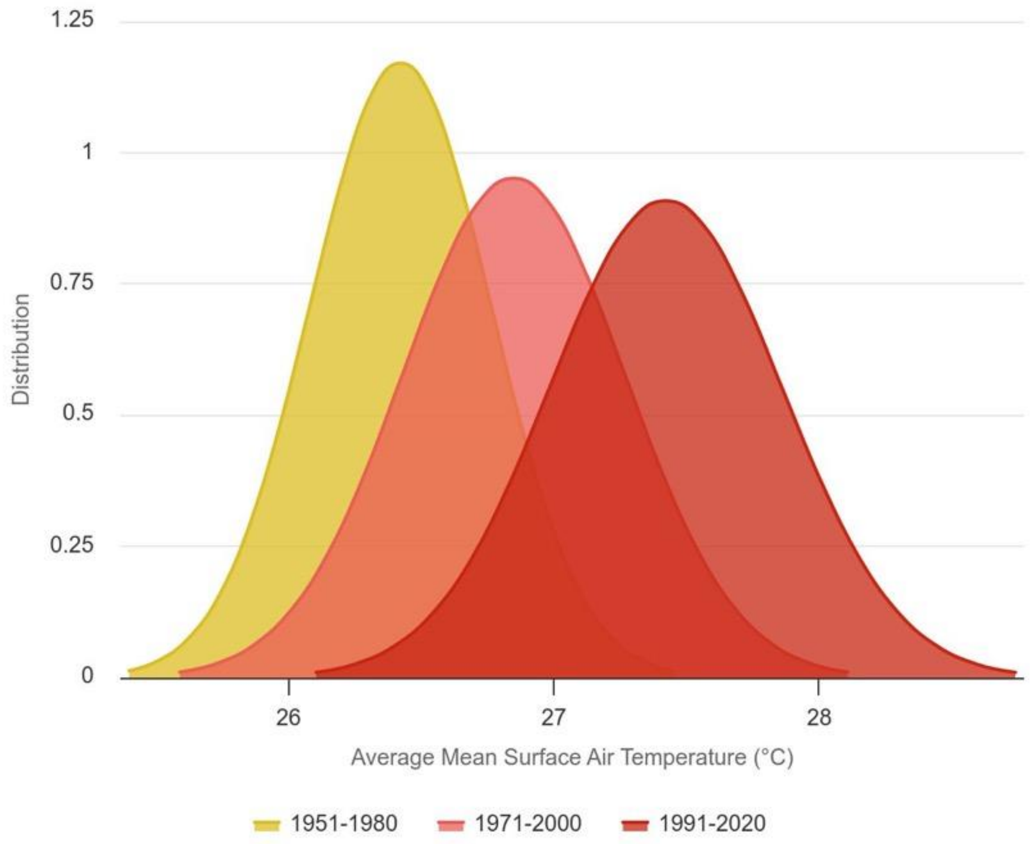

Figure 12 *Change in distribution of average mean surface air temperature in Cambodia from 1991-2020 (CCKP, 2024b)*

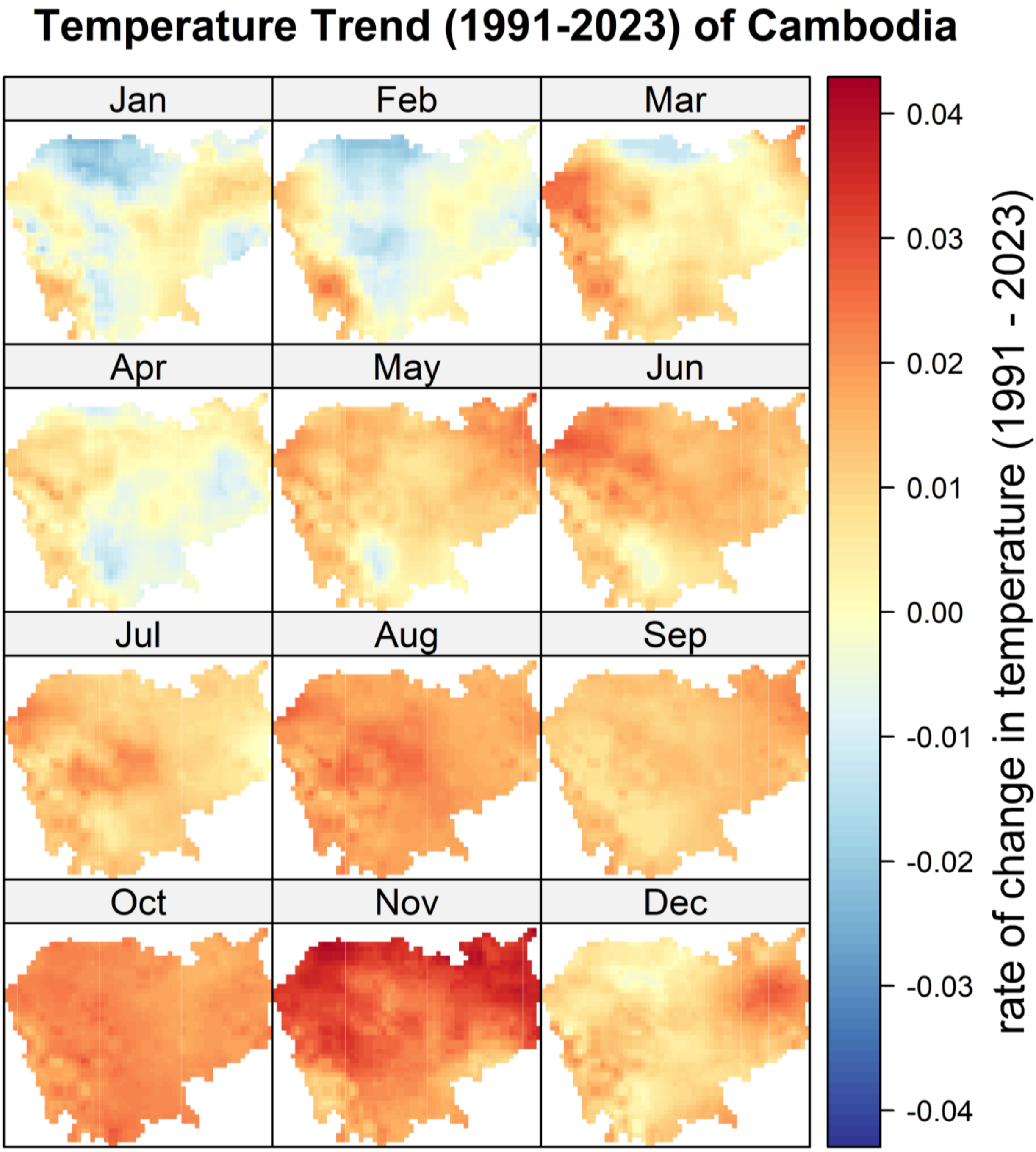

Figure 13 *Spatial patterns of temperature trends in Cambodia, indicating the rate of change in temperatures from 1991 to 2023*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Over the years, there has been a noticeable variation in temperatures across different months A clear trend of increasing temperatures over the years is observed, with significant implications for croplands in Cambodia.

From May to October, which are critical months for agriculture, there have been notable increases in temperature. May temperatures have risen from an average of 26.00°C in 1999 to 29.68°C in 2020, reflecting a significant warming trend during the planting season for rice. June temperatures have increased from 25.70°C in 1999 to 27.83°C in 2019, impacting early crop growth stages. July and August have also seen rising temperatures, with July increasing from 25.70°C in 2000 to 27.36°C in 2019, and August from 25.70°C in 2000 to 27.38°C in 1998. September temperatures have risen from 25.34°C in 2022 to 26.69°C in 2017, crucial for crop maturation.

October has shown an increase from 24.80°C in 1992 to 26.55°C in 2019, affecting the harvest period.

Currently, the temperatures during these critical agricultural months continue to trend upward. In 2023, May's average temperature was 28.73°C, June was 27.16°C, July was 26.64°C, August was 27.02°C, September was 26.11°C, and October was 26.17°C. These increases pose challenges for agricultural productivity, potentially leading to heat stress on crops, altered growing seasons, and reduced yields.

The consistent rise in temperatures emphasizes the need for adaptive farming practices and resilient crop varieties to mitigate the adverse effects of climate change on Cambodia's croplands. These fluctuations and significant changes in critical agricultural months underline the importance of adapting farming practices to cope with the rising temperatures and the broader impacts of climate change on Cambodia's cropland productivity. The year 2023 shows generally warmer temperatures compared to the early 1990s, aligning with the global trend of rising temperatures.

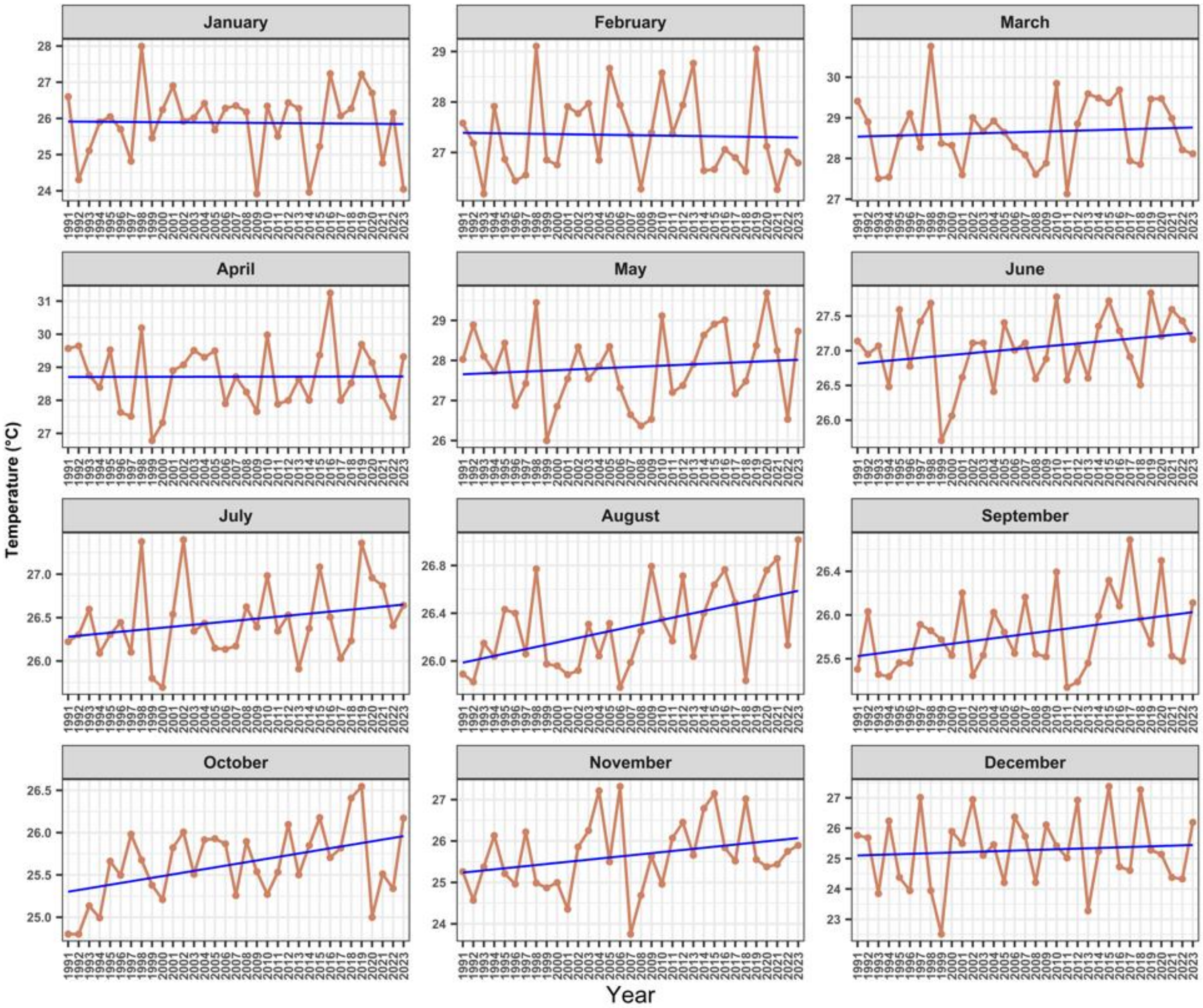

Figure 14 Spatially aggregated mean monthly temperature time series line plots with trend lines, depicting the variation of mean monthly temperatures over time in Cambodia.

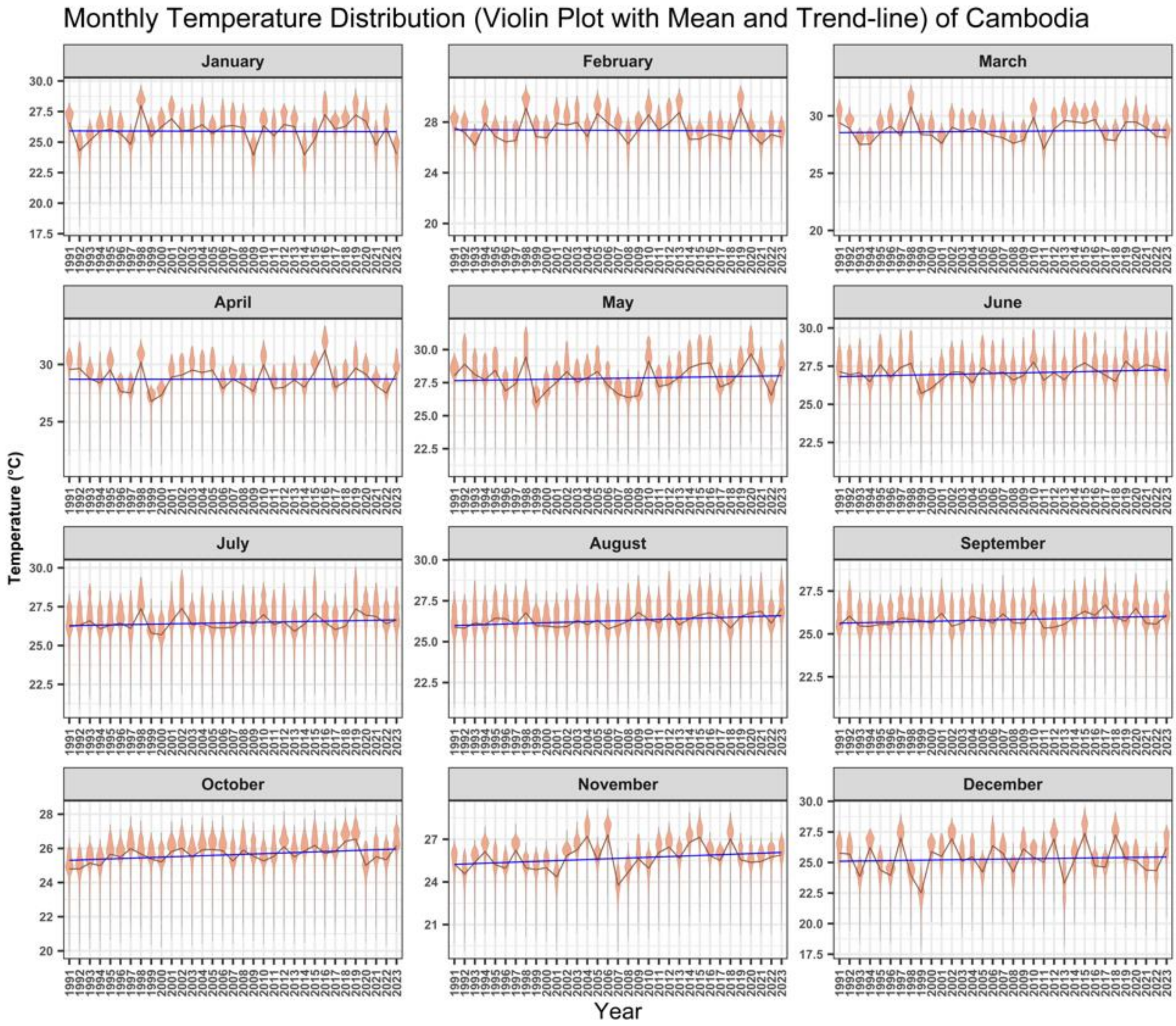

Figure 15 *Distribution of mean monthly temperature time series and violin plots in Cambodia, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly temperatures*

Table 10 Spatially aggregated mean monthly air temperature (°C) in Cambodia from 1991 to 2023, derived from ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	*26.60*	*27.58*	*29.41*	*29.57*	*28.03*	*27.14*	*26.22*	*25.89*	*25.50*	*24.80*	*25.26*	*25.77*
1992	*24.31*	*27.18*	*28.90*	*29.65*	*28.89*	*26.95*	*26.30*	*25.82*	*26.03*	*24.80*	*24.57*	*25.68*
1993	*25.11*	*26.18*	*27.51*	*28.76*	*28.11*	*27.07*	*26.60*	*26.15*	*25.46*	*25.13*	*25.38*	*23.85*
1994	*25.90*	*27.91*	*27.54*	*28.39*	*27.72*	*26.48*	*26.09*	*26.04*	*25.44*	*24.99*	*26.13*	*26.24*
1995	*26.05*	*26.87*	*28.54*	*29.53*	*28.43*	*27.59*	*26.30*	*26.43*	*25.56*	*25.66*	*25.21*	*24.38*
1996	*25.70*	*26.44*	*29.10*	*27.64*	*26.87*	*26.78*	*26.44*	*26.40*	*25.56*	*25.50*	*24.96*	*23.94*
1997	*24.82*	*26.55*	*28.27*	*27.52*	*27.42*	*27.42*	*26.10*	*26.06*	*25.91*	*25.98*	*26.22*	*27.01*
1998	*27.99*	*29.10*	*30.76*	*30.19*	*29.44*	*27.69*	*27.38*	*26.77*	*25.86*	*25.68*	*24.99*	*23.94*
1999	*25.46*	*26.85*	*28.37*	*26.78*	*26.00*	*25.70*	*25.80*	*25.97*	*25.77*	*25.38*	*24.87*	*22.51*
2000	*26.24*	*26.75*	*28.32*	*27.32*	*26.85*	*26.06*	*25.70*	*25.96*	*25.63*	*25.21*	*25.00*	*25.90*
2001	*26.90*	*27.91*	*27.60*	*28.90*	*27.54*	*26.62*	*26.54*	*25.89*	*26.20*	*25.82*	*24.35*	*25.49*
2002	*25.93*	*27.77*	*29.01*	*29.07*	*28.34*	*27.11*	*27.40*	*25.92*	*25.44*	*26.01*	*25.86*	*26.94*
2003	*26.02*	*27.97*	*28.67*	*29.51*	*27.54*	*27.11*	*26.34*	*26.31*	*25.63*	*25.51*	*26.25*	*25.11*
2004	*26.41*	*26.85*	*28.92*	*29.30*	*27.86*	*26.41*	*26.43*	*26.04*	*26.03*	*25.92*	*27.21*	*25.46*
2005	*25.68*	*28.67*	*28.64*	*29.50*	*28.35*	*27.40*	*26.15*	*26.31*	*25.84*	*25.93*	*25.50*	*24.21*
2006	*26.28*	*27.94*	*28.28*	*27.90*	*27.31*	*27.01*	*26.13*	*25.78*	*25.65*	*25.87*	*27.32*	*26.37*
2007	*26.35*	*27.35*	*28.09*	*28.71*	*26.64*	*27.11*	*26.17*	*25.99*	*26.16*	*25.26*	*23.75*	*25.73*
2008	*26.18*	*26.28*	*27.61*	*28.25*	*26.37*	*26.60*	*26.62*	*26.25*	*25.64*	*25.90*	*24.69*	*24.21*
2009	*23.92*	*27.39*	*27.89*	*27.66*	*26.53*	*26.88*	*26.39*	*26.79*	*25.62*	*25.54*	*25.63*	*26.11*
2010	*26.34*	*28.58*	*29.84*	*29.98*	*29.12*	*27.77*	*26.98*	*26.35*	*26.39*	*25.27*	*24.96*	*25.42*
2011	*25.51*	*27.37*	*27.13*	*27.89*	*27.20*	*26.58*	*26.34*	*26.17*	*25.34*	*25.53*	*26.07*	*25.02*
2012	*26.43*	*27.94*	*28.85*	*28.00*	*27.37*	*27.07*	*26.53*	*26.71*	*25.39*	*26.10*	*26.45*	*26.92*
2013	*26.28*	*28.77*	*29.59*	*28.65*	*27.91*	*26.60*	*25.91*	*26.04*	*25.56*	*25.50*	*25.66*	*23.28*
2014	*23.96*	*26.64*	*29.49*	*28.00*	*28.63*	*27.35*	*26.37*	*26.40*	*25.99*	*25.85*	*26.78*	*25.24*
2015	*25.23*	*26.67*	*29.37*	*29.37*	*28.91*	*27.72*	*27.08*	*26.64*	*26.32*	*26.18*	*27.15*	*27.37*
2016	*27.24*	*27.06*	*29.69*	*31.25*	*29.01*	*27.29*	*26.50*	*26.77*	*26.08*	*25.70*	*25.84*	*24.73*
2017	*26.07*	*26.90*	*27.94*	*28.00*	*27.17*	*26.91*	*26.03*	*26.49*	*26.69*	*25.82*	*25.52*	*24.61*
2018	*26.27*	*26.63*	*27.85*	*28.52*	*27.48*	*26.51*	*26.23*	*25.84*	*25.97*	*26.41*	*27.02*	*27.27*
2019	*27.22*	*29.05*	*29.46*	*29.69*	*28.37*	*27.83*	*27.36*	*26.54*	*25.74*	*26.55*	*25.55*	*25.28*
2020	*26.70*	*27.12*	*29.47*	*29.14*	*29.68*	*27.21*	*26.96*	*26.76*	*26.50*	*25.00*	*25.38*	*25.14*
2021	*24.76*	*26.27*	*28.99*	*28.13*	*28.24*	*27.59*	*26.87*	*26.86*	*25.62*	*25.51*	*25.44*	*24.38*
2022	*26.15*	*27.01*	*28.21*	*27.50*	*26.53*	*27.43*	*26.41*	*26.13*	*25.58*	*25.34*	*25.75*	*24.33*
2023	*24.05*	*26.79*	*28.11*	*29.32*	*28.73*	*27.16*	*26.64*	*27.02*	*26.11*	*26.17*	*25.89*	*26.19*

A comparison of monthly average temperatures between two periods—the long-term average from 2001 to 2020 and the recorded temperatures for the year 2023—was assessed for Cambodia. This analysis also included temperature anomalies for each month, indicating deviations from the long-term average.

In January 2023, the average temperature was 23.695°C, which is 2.001°C cooler than the long-term average of 25.696°C. February continued this trend with cooler temperatures, showing an anomaly of -0.748°C, resulting in an average temperature of 26.443°C compared to the long-term average of 27.192°C. Similarly, March was 0.555°C cooler than the long-term average of 28.320°C, recording a temperature of 27.765°C. These cooler temperatures early in the year could delay the planting season and slow down the initial growth stages of crops, potentially reducing yields.

In contrast, April observed a slight increase in temperature. The average for April 2023 was 28.968°C, which is

0.455°C warmer than the long-term average of 28.513°C. May experienced a more significant increase, with an anomaly of +0.863°C, leading to an average temperature of 28.380°C compared to the long-term average of 27.517°C. Both June and July had temperatures slightly above the long-term averages, with June being 0.108°C warmer and July 0.116°C warmer than their respective long-term averages. These increases in temperature during the mid-year could accelerate crop growth, but also increase water requirements and the risk of heat stress, potentially impacting crop health and productivity.

August observed a more pronounced warming, with a temperature of 26.666°C, resulting in an anomaly of +0.718°C over the long-term average of 25.949°C. September, October, and November also experienced slight temperature increases, with anomalies of +0.203°C, +0.390°C, and +0.046°C, respectively. The average temperatures in these months were marginally above their long-term averages. Warmer temperatures in these months could lead to an extended growing season but also heighten the risk of drought and pest infestations, which could adversely affect crop yields.

December concluded the year with a temperature of 25.842°C, which was 0.696°C warmer than the long-term average of 25.146°C. Warmer winters can impact certain crops that require cooler temperatures for vernalization, potentially affecting flowering and fruiting stages.

Overall, the data reveals that 2023 in Cambodia had a mix of cooler and warmer months compared to the long-term averages, with most months showing slight warming anomalies, particularly in the latter half of the year. This trend of increasing temperatures, especially during crucial growing months, has significant implications for cropland in Cambodia. Warmer temperatures can lead to changes in growing seasons, increased water demand, and greater stress on crops. These factors necessitate adaptive measures such as altering planting schedules, implementing water management strategies, and adopting heat-resistant crop varieties to sustain agricultural productivity and food security in the face of changing climatic conditions.

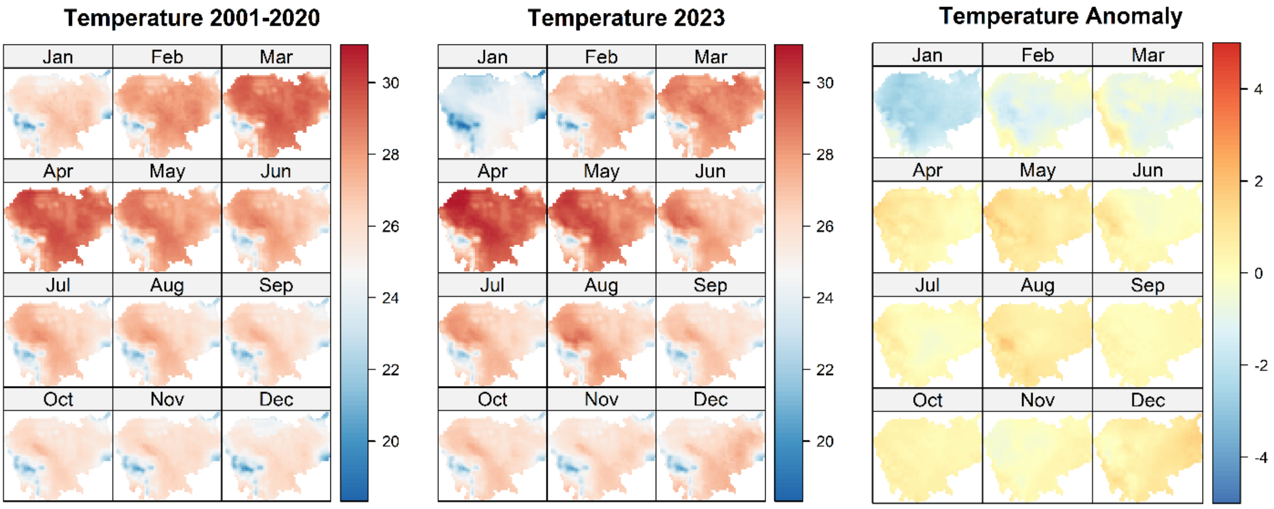

Figure 16 *Spatial distribution of temperatures in Cambodia, displaying long-term monthly average temperatures, monthly average temperatures for 2023, and anomaly maps showing the difference between the 2023 temperatures and the long-term averages*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

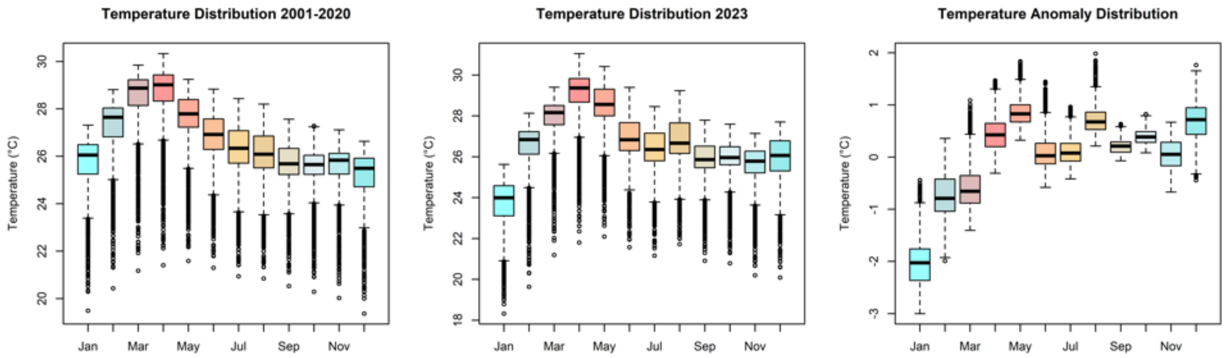

Figure 17 *Boxplot visualization of the mean monthly temperatures in Cambodia, comparing the long-term monthly averages, the monthly temperatures recorded in 2023, and the corresponding temperature anomalies*

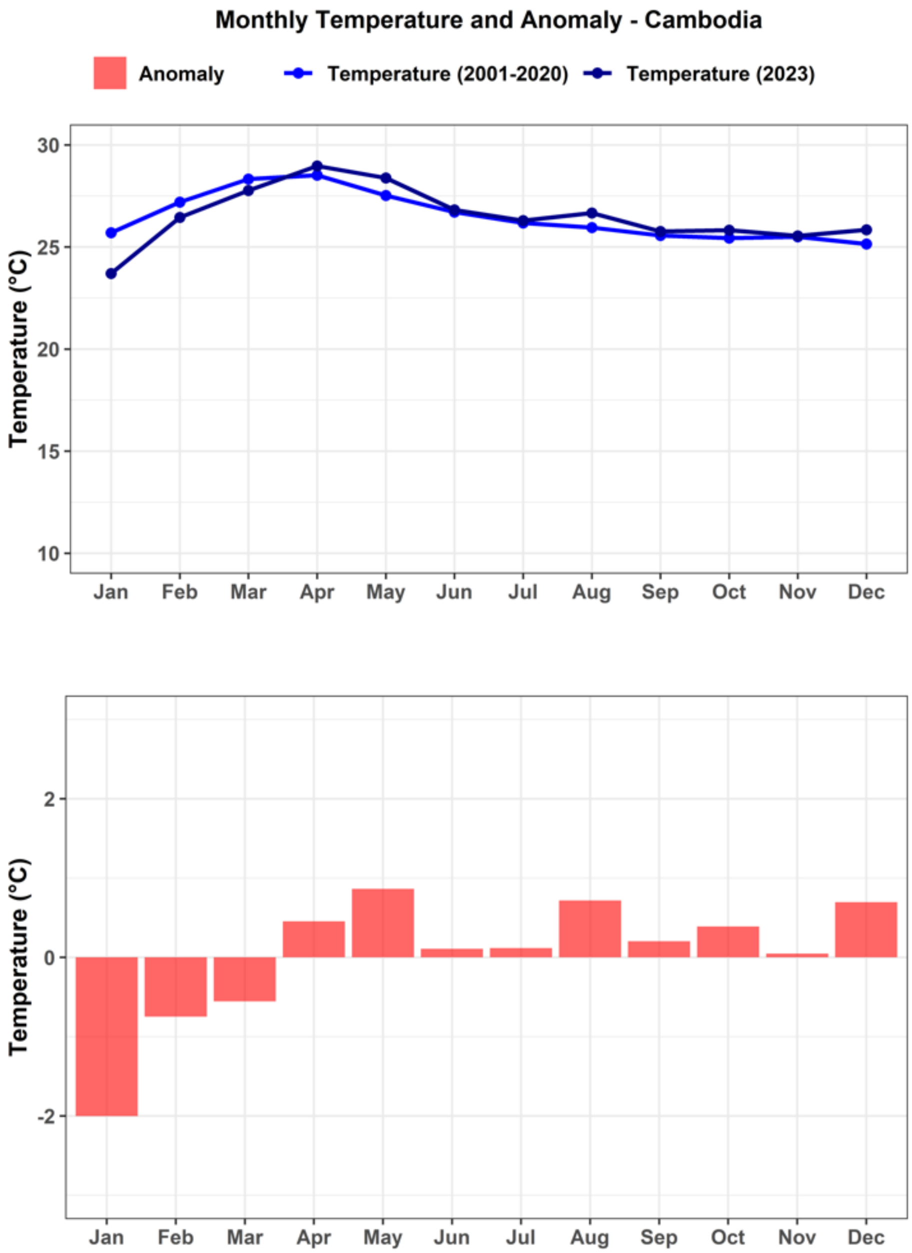

Figure 18 *Spatially aggregated monthly temperature series in Cambodia, showing the long-term averages, the temperatures recorded in 2023, and the anomalies.*

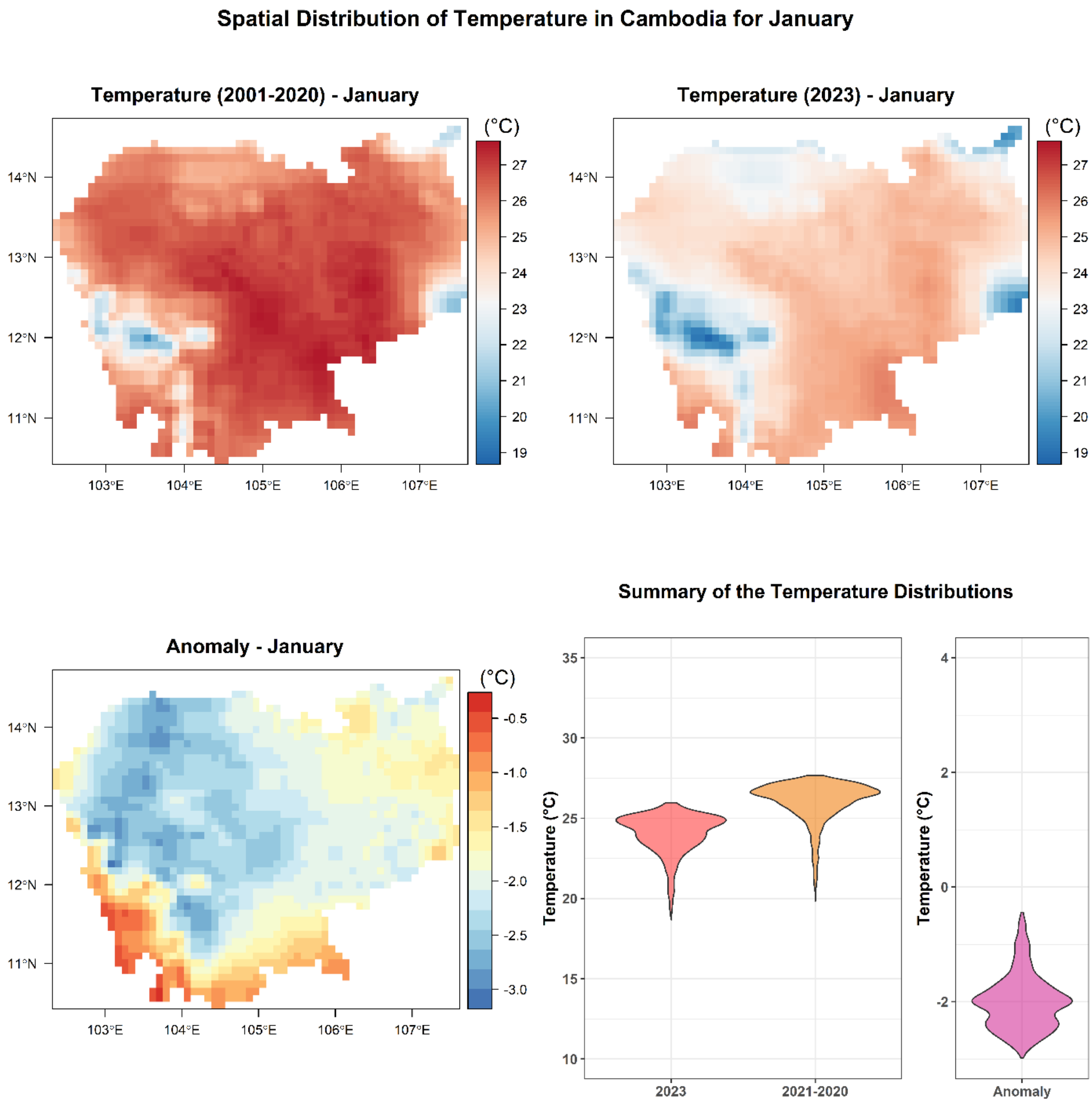

Figure 19 *Maps and violin plots illustrate the spatial distribution of January temperatures in Cambodia. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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Spatial Distribution of Temperature in Cambodia for May

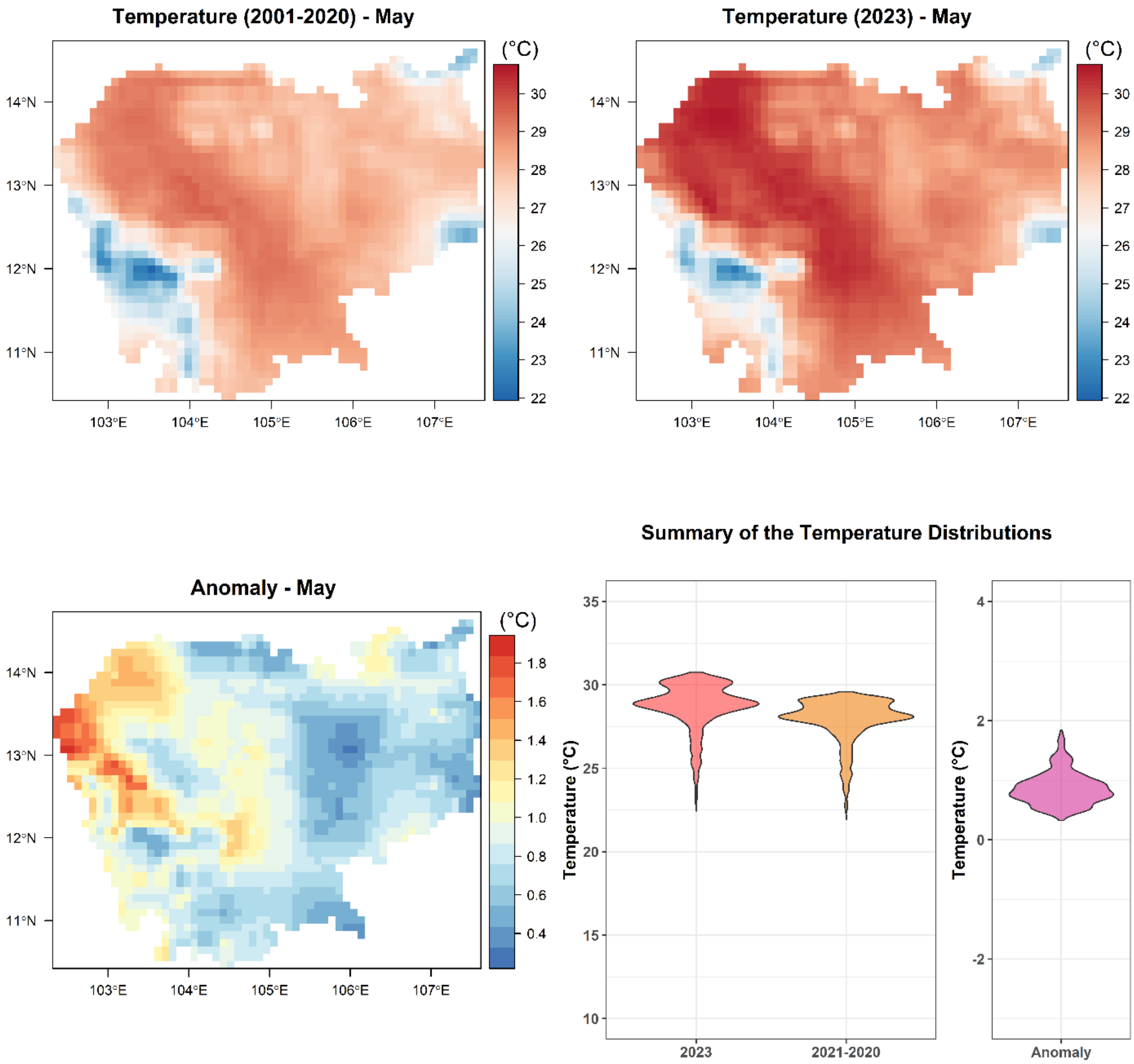

Figure 20 *Maps and violin plots illustrating the spatial distribution of May temperatures in Cambodia. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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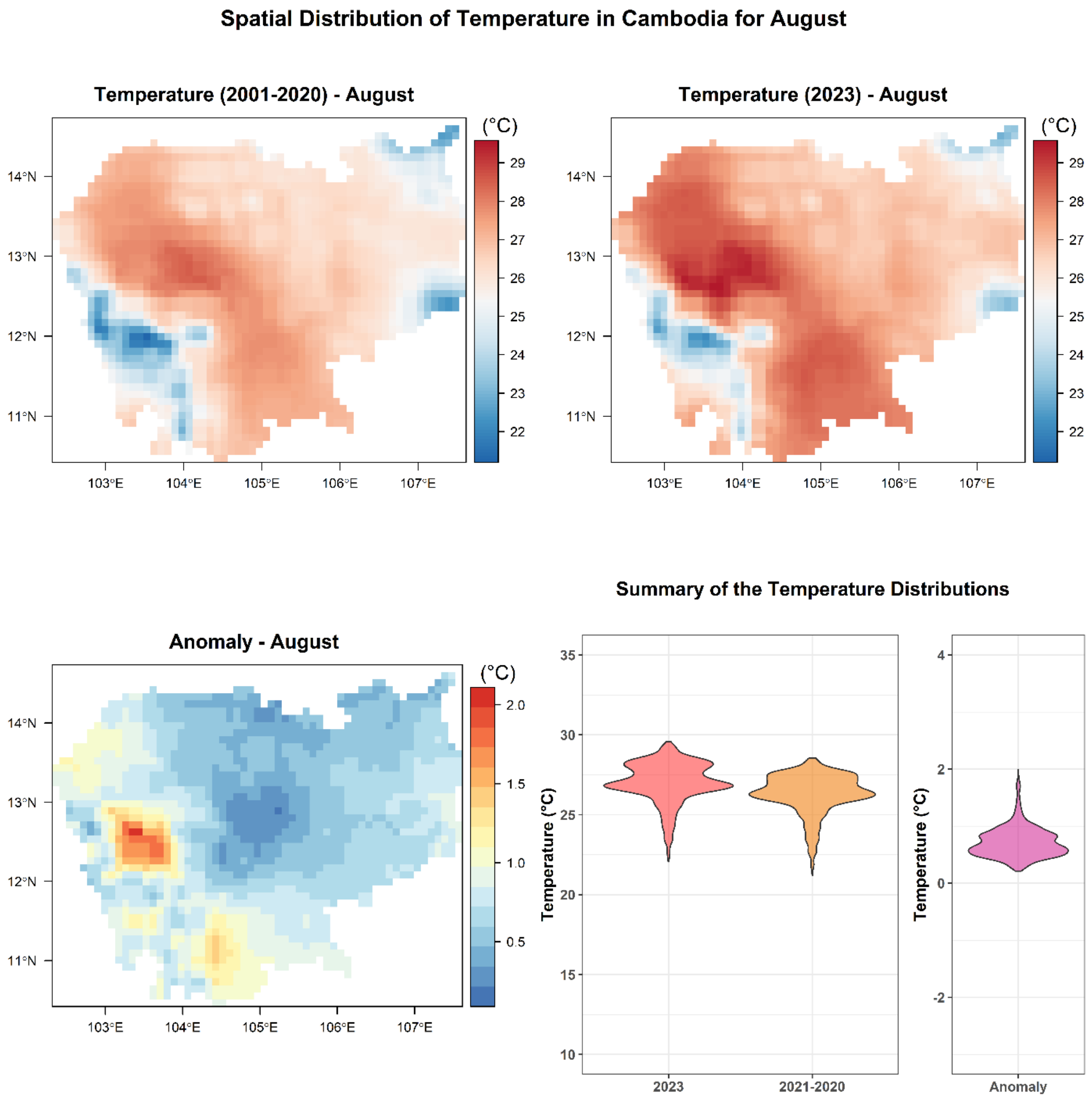

Figure 21 *Maps and violin plots illustrate the spatial distribution of August temperatures in Cambodia. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

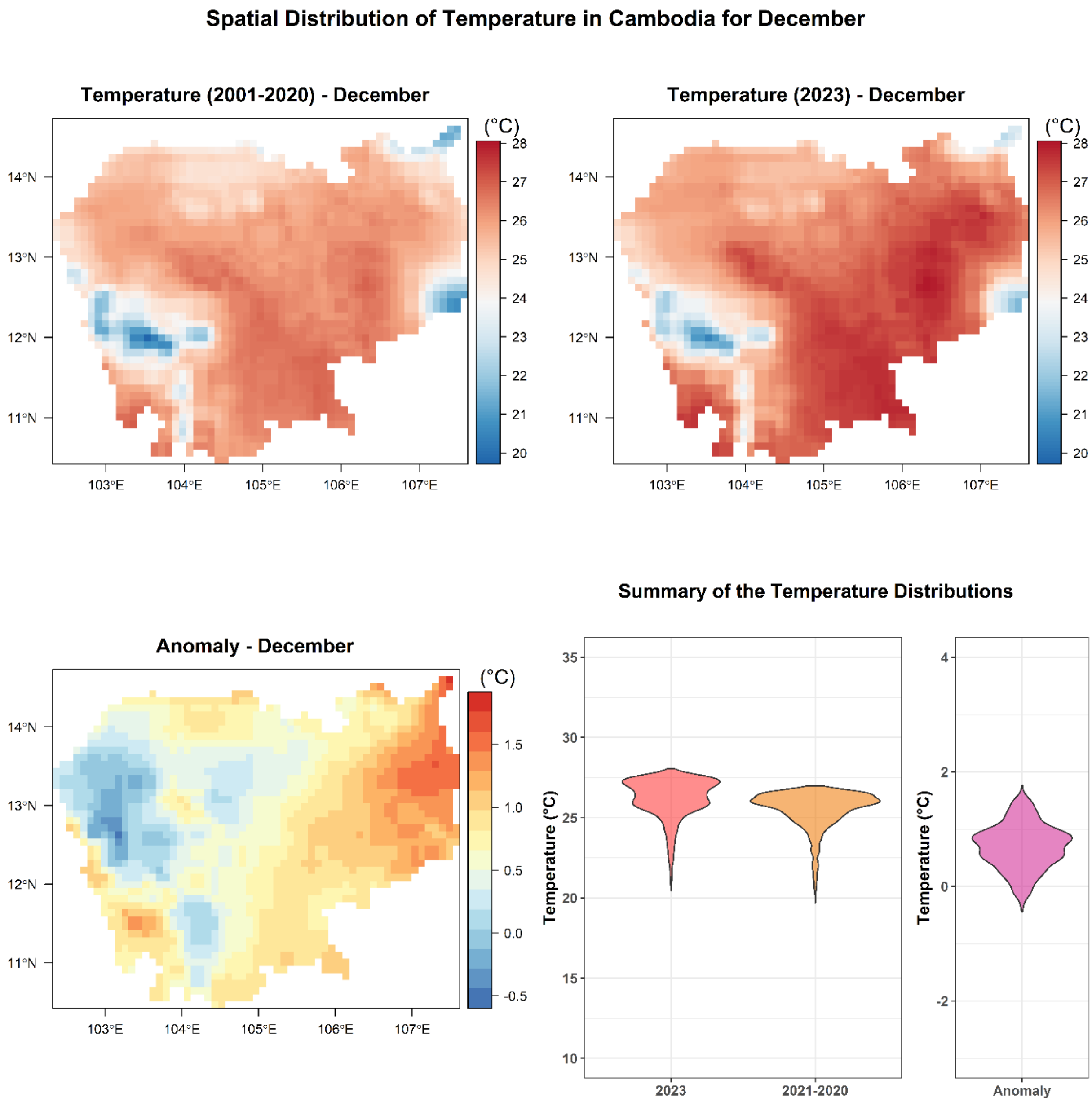

Figure 22 Maps and violin plots illustrate the spatial distribution of December temperatures in Cambodia. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 11 Monthly averages of long-term temperatures (°C), 2023 monthly averages (°C), and temperature anomalies (°C) in Cambodia

Month	Temperature (2001-2020)	Temperature (2023)	Anomaly
Jan	25.696	23.695	-2.001
Feb	27.192	26.443	-0.748
Mar	28.320	27.765	-0.555
Apr	28.513	28.968	0.455
May	27.517	28.380	0.863
Jun	26.705	26.812	0.108
Jul	26.174	26.290	0.116
Aug	25.949	26.666	0.718
Sep	25.559	25.762	0.203
Oct	25.432	25.822	0.390
Nov	25.496	25.543	0.046
Dec	25.146	25.842	0.696

2.2.4. Trends of Rainfall in Cambodia

The analysis of rainfall changes in Cambodia was conducted using ERA5 rainfall data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term rainfall averages (2001-2020) with the recorded rainfall for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average rainfalls and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average rainfalls, the monthly rainfalls for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of rainfall changes, violin plots and box plots were used. Violin plots illustrated the distribution of rainfalls, showing the density and probability of different rainfall ranges over time. Box plots offered a clear visualization of the rainfall distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the rainfall changes in Cambodia, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of rainfall trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual rainfall trend in Cambodia indicates an increase in average rainfall from 1,770 mm to 1,802 mm between 1991 and 2020, reflecting a rise of 32 mm over nearly three decades. The average rainfall during this period was 1,785 mm. Additionally, the peak of rainfall distribution has shifted towards lower values compared to the distribution from 1971 to 2000, highlighting a slight reduction in rainfall over the past three decades.

Over the past two decades, Cambodia has experienced significant changes in its monthly precipitation trends, which could have profound effects on its agricultural landscape. From 2000 to 2010, key agricultural months like March, May, and August saw increases in average monthly rainfall, with rises of 17.68 mm, 11.87 mm, and 19.11 mm, respectively, generally benefiting crop growth. However, the following decade, from 2010 to 2020, marked a concerning shift, with critical months such as March, April, and May experiencing sharp declines in rainfall by -12.12 mm, -20.80 mm, and -19.41 mm. These reductions during essential growing periods could lead to severe water stress for crops, potentially lowering yields and increasing the likelihood of crop failures. While some months in 2010-2020, like January, July, and December, saw increases in rainfall, these changes fall outside the main growing season, raising concerns about their limited agricultural benefit and the potential for off-season flooding. The shifting precipitation patterns highlight the growing unpredictability of Cambodia's climate, underscoring the urgent need for adaptive strategies to safeguard agricultural productivity, food security, and the livelihoods of millions dependent on farming.

The shifting precipitation patterns, characterized by reduced rainfall during key agricultural months and increased rainfall during off-season months, highlight the growing unpredictability of Cambodia's climate. These changes could disrupt traditional farming practices, making it increasingly difficult for farmers to rely on historical weather patterns for determining planting and harvesting schedules. The need for adaptive strategies is becoming more urgent, as farmers may need to shift planting seasons, adopt drought-resistant crop varieties, and rely more heavily on irrigation to cope with reduced rainfall during crucial months. Additionally, improved water management systems will be essential to mitigate the negative impacts of increased rainfall during the off-season, such as flooding and soil erosion.

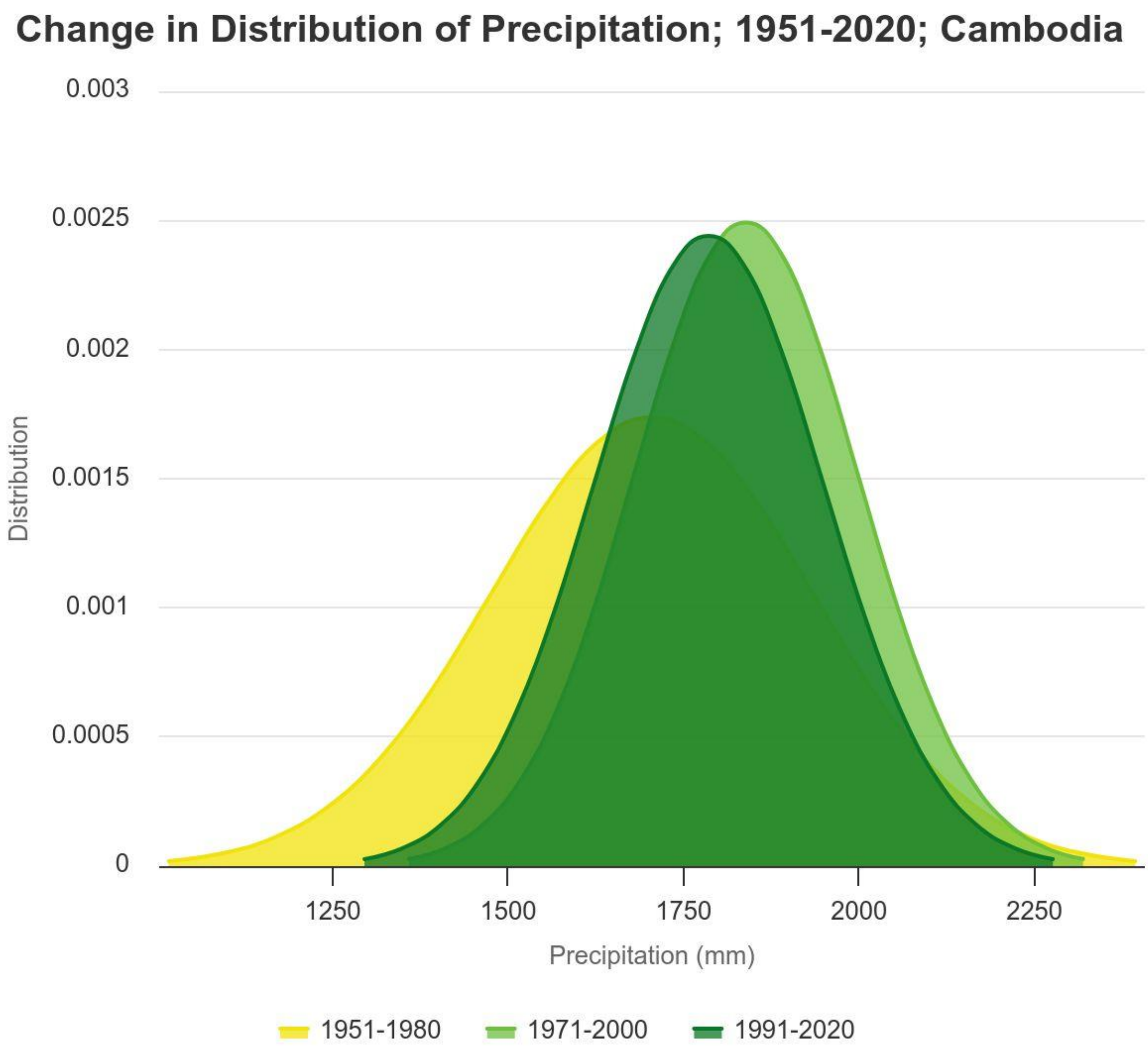

Figure 23 *Change in distribution of average rainfall in Cambodia for 1951 – 1980, 1971 – 2000, and 1991-2020 (CCKP, 2024b)*

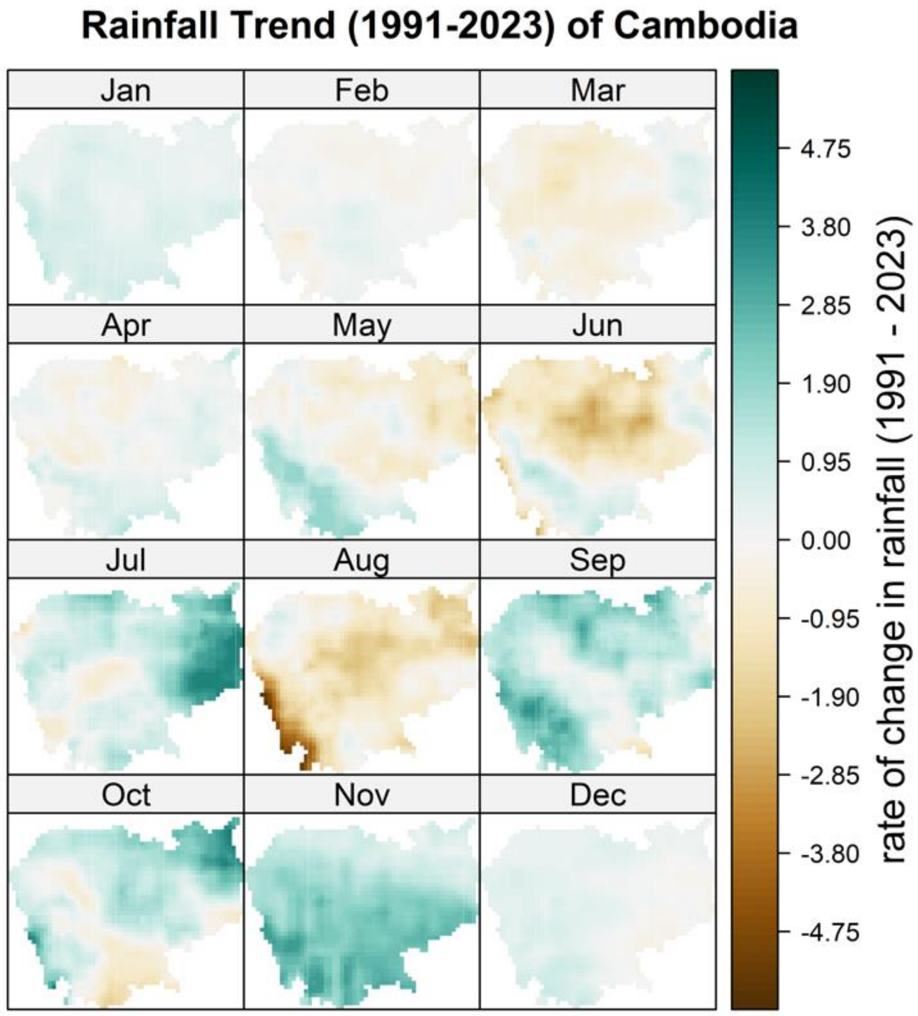

Figure 24 *Spatial patterns of rainfall trends in Cambodia, indicating the rate of change in rainfalls from 1991 to 2023*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Cambodia's rainfall data over the past three decades reveals complex trends that have profound implications for the country’s agriculture, particularly in its rice-growing regions. These trends exhibit both increases and decreases in monthly rainfall across different years, which could potentially affect crop production cycles, water management, and overall food security.

From May to October, a period crucial for the rice planting, growing, and harvesting cycles, the data shows significant variability. For instance, May’s rainfall has increased substantially, rising from 180.31 mm in 1991 to a peak of 286.36 mm in 2022. This notable increase suggests that May has become wetter over time, which could impact the timing of planting. Excessive rainfall during this early stage can lead to waterlogging, which is detrimental to young rice plants. June has also experienced erratic rainfall, with figures peaking at 264.30 mm in 1994 and dropping to a low of 135.26 mm in 2021. Such variability can affect early crop growth stages, potentially leading to either insufficient water for crops or excessive moisture that can cause diseases and reduce yields.

In July and August, there has been a general upward trend in rainfall. July's rainfall reached 339.44 mm in 2023, while August saw a high of 343.78 mm in 2006. While increased rainfall can ensure a sufficient water supply, it also brings challenges such as an increased risk of flooding, which can damage crops and reduce productivity. September, which is crucial for crop maturation, shows a broad range in rainfall, from 421.76 mm in 2009 to a significantly lower 213.58 mm in 2017. These fluctuations can result in unpredictable harvests, with excessive rainfall potentially delaying harvests and leading to crop losses, while insufficient rainfall might lead to poor grain development. October, as the harvest period, also exhibits variability, with rainfall ranging from 253.73 mm in 1991 to a peak of 321.63 mm in 2021. Increased rainfall during harvest can lead to post-maturation damage.

The dry season months, particularly January, February, and March, have also shown significant fluctuations. January's rainfall has increased dramatically from 4.28 mm in 1991 to 71.72 mm in 2023. This rise in what is traditionally a dry month could disrupt water storage and management practices essential for the dry season and potentially lead to waterlogged fields unprepared for early planting. February and March display high variability, with March experiencing a notable drop in rainfall from 156.39 mm in 2001 to just 16.19 mm in 2023. Such sharp declines during a period typically used for preparing fields can severely impact agricultural planning and readiness for the upcoming growing season.

The observed rainfall trends highlight a growing unpredictability in Cambodia’s climate, posing several challenges for agriculture. The increased rainfall in traditionally dry months necessitates better water management systems to capture and store water efficiently for use during drier periods. Additionally, the rising rainfall during monsoon months increases the risk of flooding and waterlogging, which can damage crops, particularly rice, which is sensitive to both drought and excessive moisture. The variability in rainfall patterns complicates crop planning and may require shifts in the planting and harvesting calendar to align with changing rainfall patterns. There is also an urgent need for the development of climate-resilient crop varieties that can withstand both excessive rainfall and potential droughts, ensuring stable yields despite the changing climate.

In conclusion, the rainfall data from Cambodia reflects both increasing and decreasing trends across different months, with significant impacts on the country’s agriculture. These changes underscore the need for adaptive strategies in water management, crop planning, and the development of resilient agricultural systems to cope with the ongoing challenges posed by climate change.

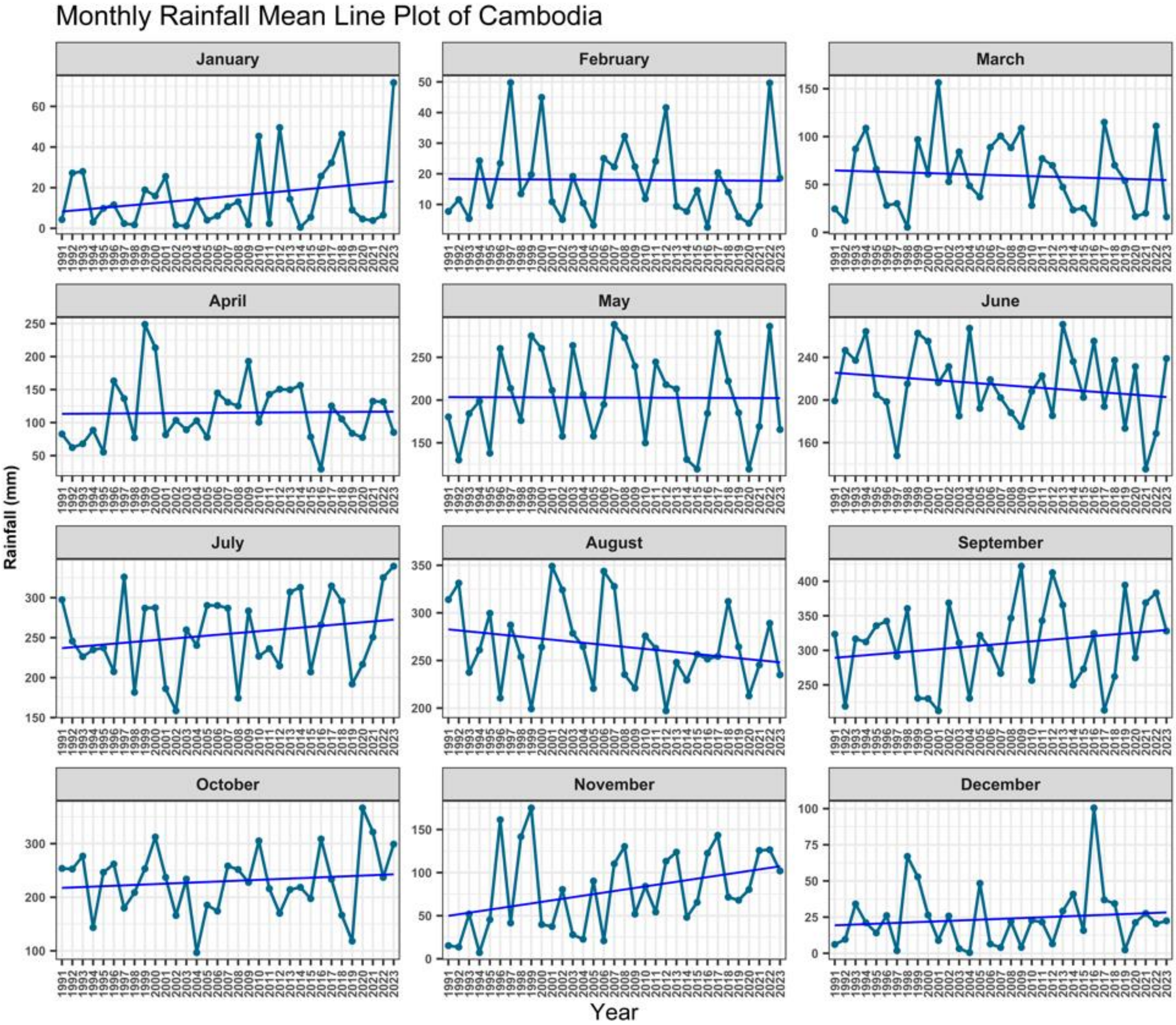

***Figure 25** Spatially aggregated mean monthly rainfall time series line plots with trend lines, depicting the variation of mean monthly rainfalls over time in Cambodia.*

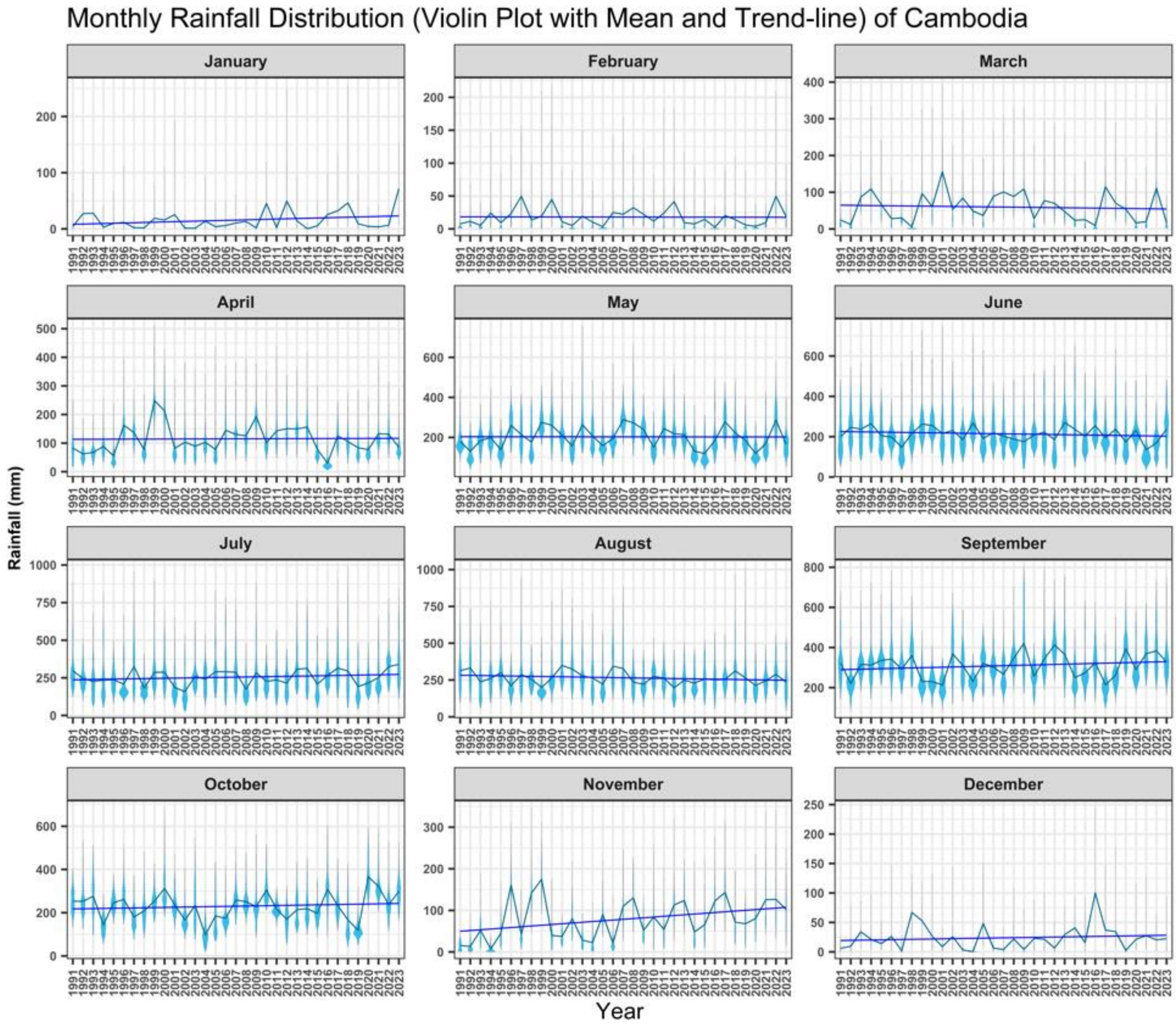

__Figure 26__ Distribution of mean monthly rainfall time series and violin plots in Cambodia, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly rainfalls

Table 12 Spatially aggregated mean monthly air rainfall (mm) in Cambodia from 1991 to 2023, derived from ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	*4.28*	*7.72*	*24.53*	*82.62*	*180.31*	*199.16*	*297.46*	*313.92*	*323.36*	*253.73*	*15.25*	*6.13*
1992	*27.18*	*11.56*	*12.27*	*62.15*	*129.97*	*246.56*	*245.65*	*331.32*	*219.27*	*252.65*	*13.61*	*9.65*
1993	*27.94*	*5.38*	*87.12*	*67.85*	*184.13*	*237.15*	*226.15*	*237.46*	*316.62*	*276.72*	*51.98*	*34.13*
1994	*3.02*	*24.24*	*108.83*	*88.37*	*198.59*	*264.30*	*234.83*	*261.04*	*312.25*	*143.47*	*7.14*	*21.17*
1995	*9.81*	*9.53*	*66.04*	*55.27*	*137.81*	*205.05*	*237.17*	*299.59*	*335.57*	*246.52*	*45.42*	*14.10*
1996	*11.55*	*23.43*	*28.20*	*163.04*	*260.29*	*198.38*	*207.51*	*210.49*	*342.30*	*261.82*	*161.34*	*26.11*
1997	*2.32*	*49.76*	*30.10*	*136.32*	*213.64*	*147.73*	*325.88*	*287.28*	*291.39*	*179.77*	*41.54*	*1.85*
1998	*1.70*	*13.45*	*5.35*	*77.00*	*176.01*	*215.23*	*181.58*	*254.04*	*360.60*	*208.75*	*141.76*	*66.96*
1999	*18.90*	*19.71*	*96.87*	*248.79*	*275.06*	*262.56*	*287.01*	*199.14*	*230.69*	*253.16*	*175.03*	*52.85*
2000	*15.89*	*44.94*	*60.76*	*213.24*	*260.29*	*255.09*	*287.50*	*264.07*	*230.18*	*312.31*	*39.78*	*26.44*
2001	*25.51*	*10.87*	*156.39*	*81.51*	*211.37*	*216.28*	*186.11*	*349.07*	*212.54*	*237.14*	*37.50*	*8.88*
2002	*1.54*	*5.08*	*52.94*	*103.45*	*157.62*	*231.36*	*158.45*	*324.13*	*368.71*	*165.98*	*80.38*	*25.80*
2003	*1.07*	*19.18*	*84.12*	*89.12*	*263.73*	*185.08*	*259.79*	*278.61*	*310.73*	*233.81*	*28.00*	*3.29*
2004	*13.68*	*10.41*	*48.57*	*102.82*	*206.71*	*267.29*	*240.38*	*264.54*	*230.56*	*96.64*	*22.68*	*0.48*
2005	*4.03*	*3.20*	*36.98*	*77.80*	*157.85*	*192.11*	*290.34*	*220.63*	*321.80*	*185.32*	*90.22*	*48.37*
2006	*6.08*	*25.02*	*88.80*	*144.81*	*194.87*	*219.07*	*290.23*	*343.78*	*301.93*	*174.19*	*20.90*	*6.50*
2007	*10.67*	*22.27*	*100.74*	*130.85*	*288.47*	*202.12*	*286.89*	*327.77*	*266.68*	*258.31*	*110.16*	*4.04*
2008	*13.08*	*32.26*	*88.35*	*125.08*	*272.93*	*188.06*	*174.34*	*235.22*	*346.69*	*251.65*	*130.33*	*21.92*
2009	*1.80*	*22.30*	*108.62*	*192.91*	*239.54*	*175.07*	*283.46*	*220.97*	*421.76*	*227.79*	*51.86*	*4.12*
2010	*45.37*	*11.85*	*28.16*	*100.54*	*149.97*	*208.06*	*226.75*	*275.89*	*256.45*	*305.16*	*84.09*	*22.82*
2011	*2.29*	*24.07*	*77.13*	*142.63*	*244.52*	*222.64*	*236.28*	*262.92*	*343.07*	*216.13*	*54.32*	*21.56*
2012	*49.55*	*41.62*	*69.85*	*150.56*	*218.07*	*185.25*	*214.57*	*197.11*	*412.39*	*169.95*	*113.18*	*6.54*
2013	*14.35*	*9.41*	*47.33*	*149.80*	*213.03*	*270.87*	*307.23*	*248.02*	*365.71*	*214.12*	*123.77*	*29.22*
2014	*0.49*	*7.73*	*23.47*	*156.46*	*130.52*	*236.11*	*312.97*	*229.27*	*249.87*	*218.58*	*48.09*	*40.89*
2015	*5.48*	*14.56*	*25.26*	*78.23*	*119.34*	*202.44*	*207.12*	*256.44*	*273.07*	*197.30*	*65.56*	*15.75*
2016	*25.64*	*2.55*	*9.19*	*29.56*	*184.51*	*255.21*	*266.14*	*251.45*	*324.65*	*308.70*	*122.44*	*100.42*
2017	*32.22*	*20.39*	*115.03*	*125.31*	*278.17*	*193.88*	*314.78*	*254.35*	*213.58*	*233.47*	*143.34*	*36.92*
2018	*46.3*	*14.0*	*70.14*	*105.4*	*222.1*	*237.2*	*295.6*	*312.0*	*262.0*	*166.6*	*71.59*	*34.37*

	6	*4*		*0*	*5*	*4*	*4*	*6*	*6*	*8*		
2019	*8.99*	*5.97*	*53.93*	*83.66*	*185.07*	*173.39*	*192.00*	*264.40*	*394.37*	*118.21*	*67.92*	*2.37*
2020	*4.56*	*3.84*	*16.46*	*77.51*	*119.33*	*231.31*	*216.57*	*212.79*	*289.38*	*366.52*	*80.29*	*21.28*
2021	*3.79*	*9.52*	*20.04*	*132.31*	*169.05*	*135.26*	*250.56*	*245.33*	*368.88*	*321.63*	*125.67*	*27.59*
2022	*6.47*	*49.63*	*111.03*	*131.43*	*286.36*	*168.69*	*325.14*	*289.11*	*383.21*	*236.93*	*126.52*	*20.48*
2023	*71.72*	*18.59*	*16.19*	*85.14*	*165.49*	*238.85*	*339.44*	*234.99*	*328.01*	*298.98*	*102.00*	*22.43*

A comparison of monthly average rainfalls between two periods—the long-term average from 2001 to 2020 and the recorded rainfalls for the year 2023—was assessed for Cambodia. This analysis also included rainfall anomalies for each month, indicating deviations from the long-term average.

Cambodia's rainfall data for 2023 indicates significant deviations from long-term averages, with notable implications for agriculture.

In January 2023, the average rainfall observed was 71.719 mm, representing a substantial increase of 56.081 mm over the long-term average of 15.639 mm. February also experienced an increase, with an average of 18.595 mm, which is 3.264 mm above the long-term average of 15.331 mm. Conversely, March observed a decrease in rainfall, with 16.186 mm, 48.887 mm below the long-term average of 65.073 mm. Such reduced rainfall could delay planting and impede the initial stages of crop growth, potentially affecting yields.

April recorded 85.144 mm of rainfall, which is 27.257 mm below the long-term average of 112.401 mm. May observed a decrease as well, with 165.490 mm, which is 37.399 mm less than the long-term average of 202.888 mm. These reductions could influence crop growth stages and overall productivity. In contrast, June and July had above-average rainfalls, with June recording 238.849 mm (24.207 mm above the long-term average of 214.642 mm) and July 339.438 mm (91.436 mm above the long-term average of 248.002 mm). Increased rainfall during these months could enhance crop growth but also elevate water requirements and the risk of heat stress, potentially impacting crop health and productivity.

August observed a decrease, with 234.993 mm, which is 31.479 mm below the long-term average of 266.472 mm. September experienced an increase, with 328.010 mm, 19.710 mm above the long-term average of 308.300 mm. October also saw increased rainfall, measuring 298.976 mm, 81.693 mm above the long-term average of 217.283 mm. November recorded 102.003 mm, which is 24.672 mm above the long-term average of 77.331 mm. December had a slight decrease with 22.433 mm, 0.344 mm below the long-term average of 22.777 mm.

The seasonal variations in rainfall throughout 2023 reveal complex dynamics impacting Cambodia's croplands. The pronounced increases in rainfall during the mid-year months of June and July, coupled with notable variations in the latter part of the year, reflect a shifting climate pattern that could influence growing conditions. The reduced rainfall early in the year could delay planting and slow crop establishment, while increased mid-year rainfall may boost crop growth but require adjustments to water management practices. The variations observed in late summer and autumn, with both increases and decreases in rainfall, could affect crop maturation and harvesting. Overall, these fluctuations necessitate adaptive agricultural strategies, including revising planting schedules, enhancing irrigation efficiency, and selecting crop varieties that can withstand variable moisture conditions to sustain agricultural productivity and mitigate the impacts of climate change on Cambodia's croplands.

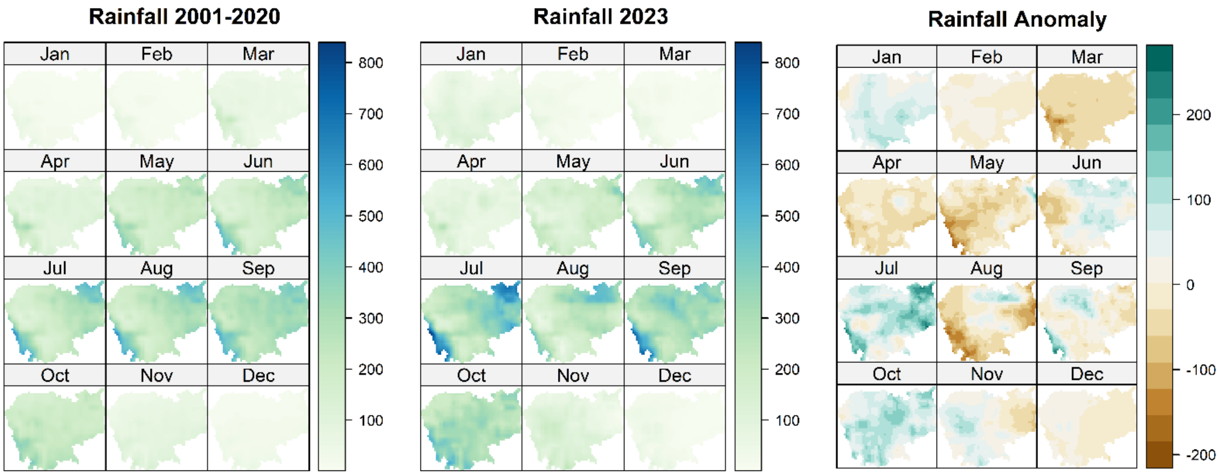

Figure 27 *Spatial distribution of rainfalls in Cambodia, displaying long-term monthly average rainfalls, monthly average rainfalls for 2023, and anomaly maps showing the difference between the 2023 rainfalls and the long-term averages*

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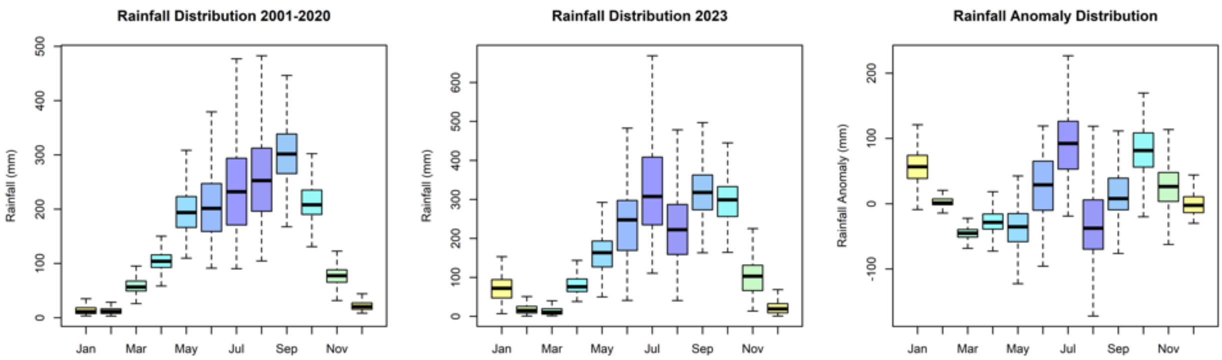

Figure 28 *Boxplot visualization of the mean monthly rainfalls in Cambodia, comparing the long-term monthly averages, the monthly rainfalls recorded in 2023, and the corresponding rainfall anomalies*

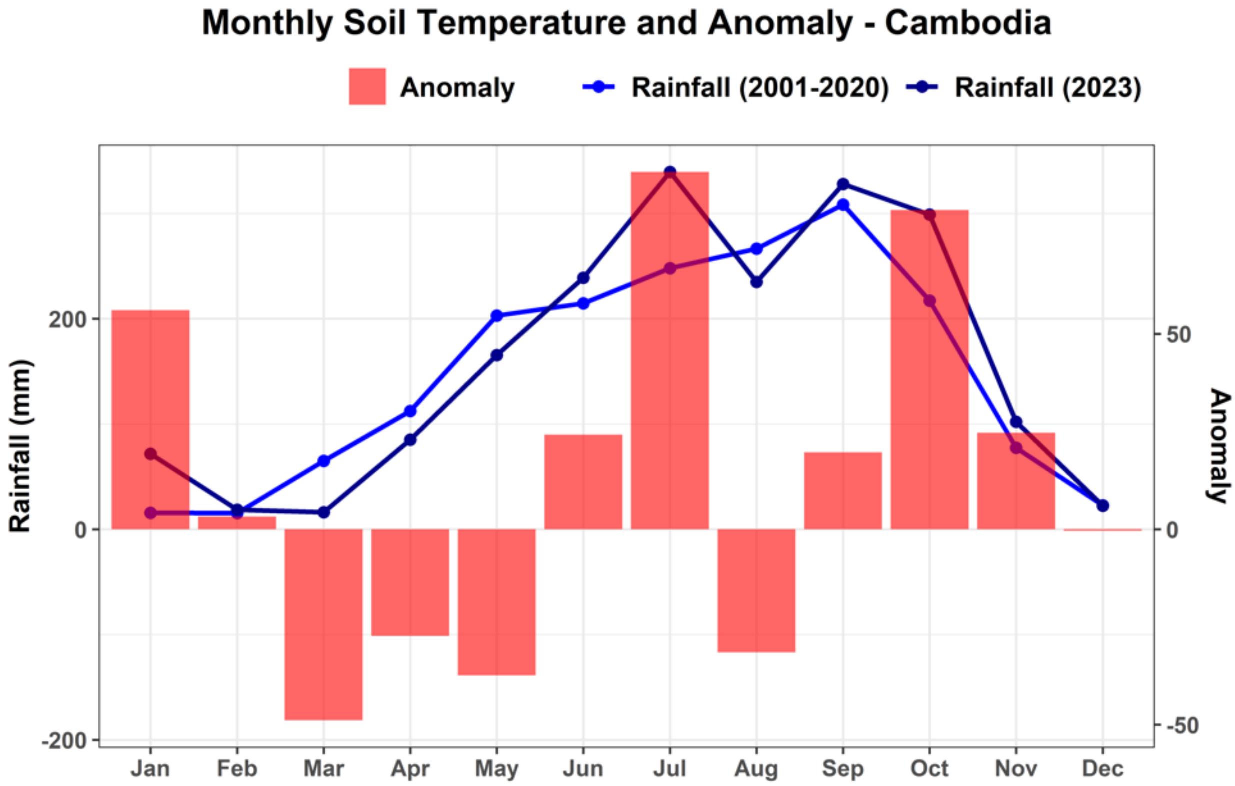

Figure 29 *Spatially aggregated monthly rainfall series in Cambodia, showing the long-term averages, the rainfalls recorded in 2023, and the anomalies.*

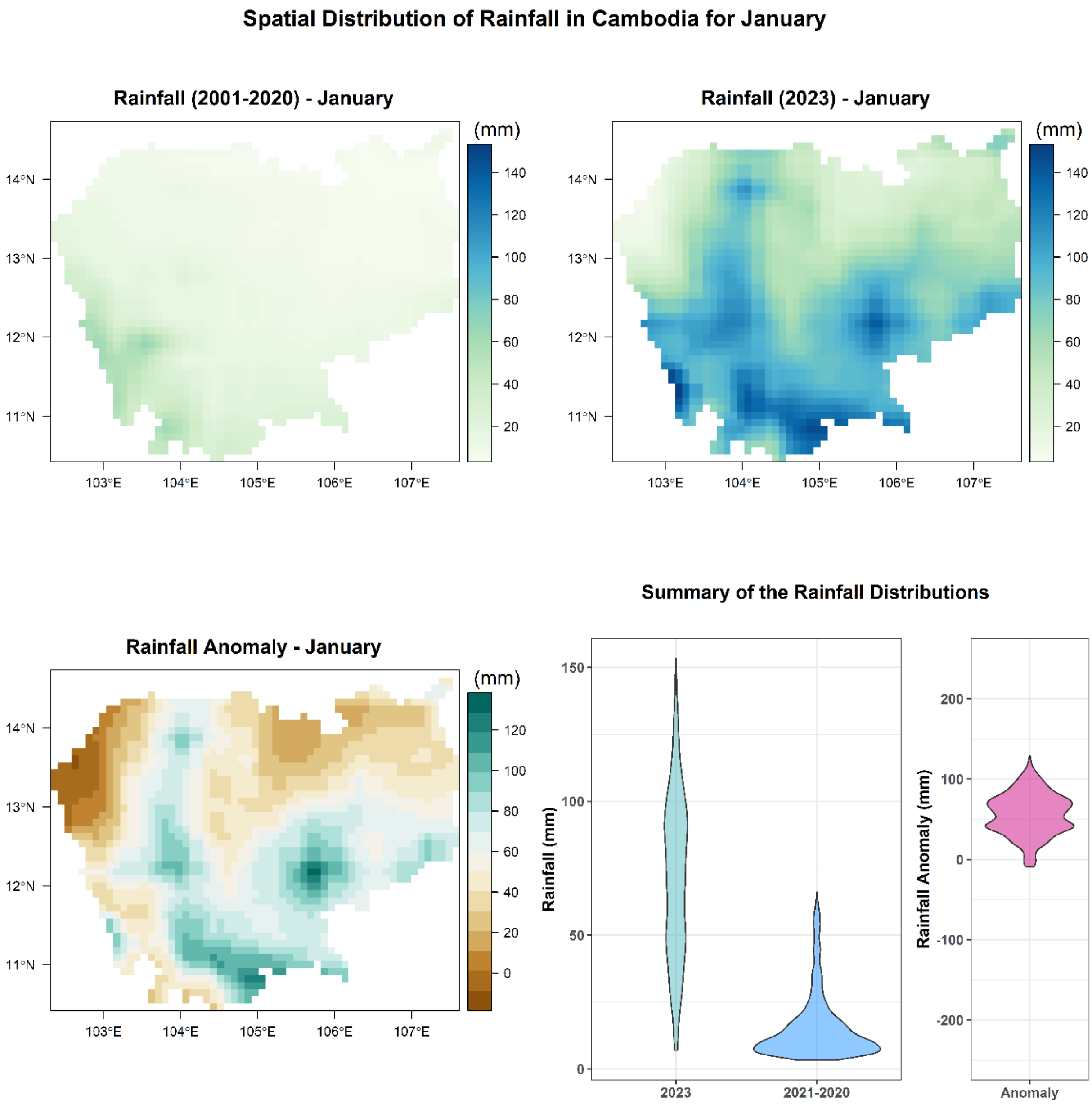

Figure 30 *Maps and violin plots illustrate the spatial distribution of January rainfalls in Cambodia. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data*

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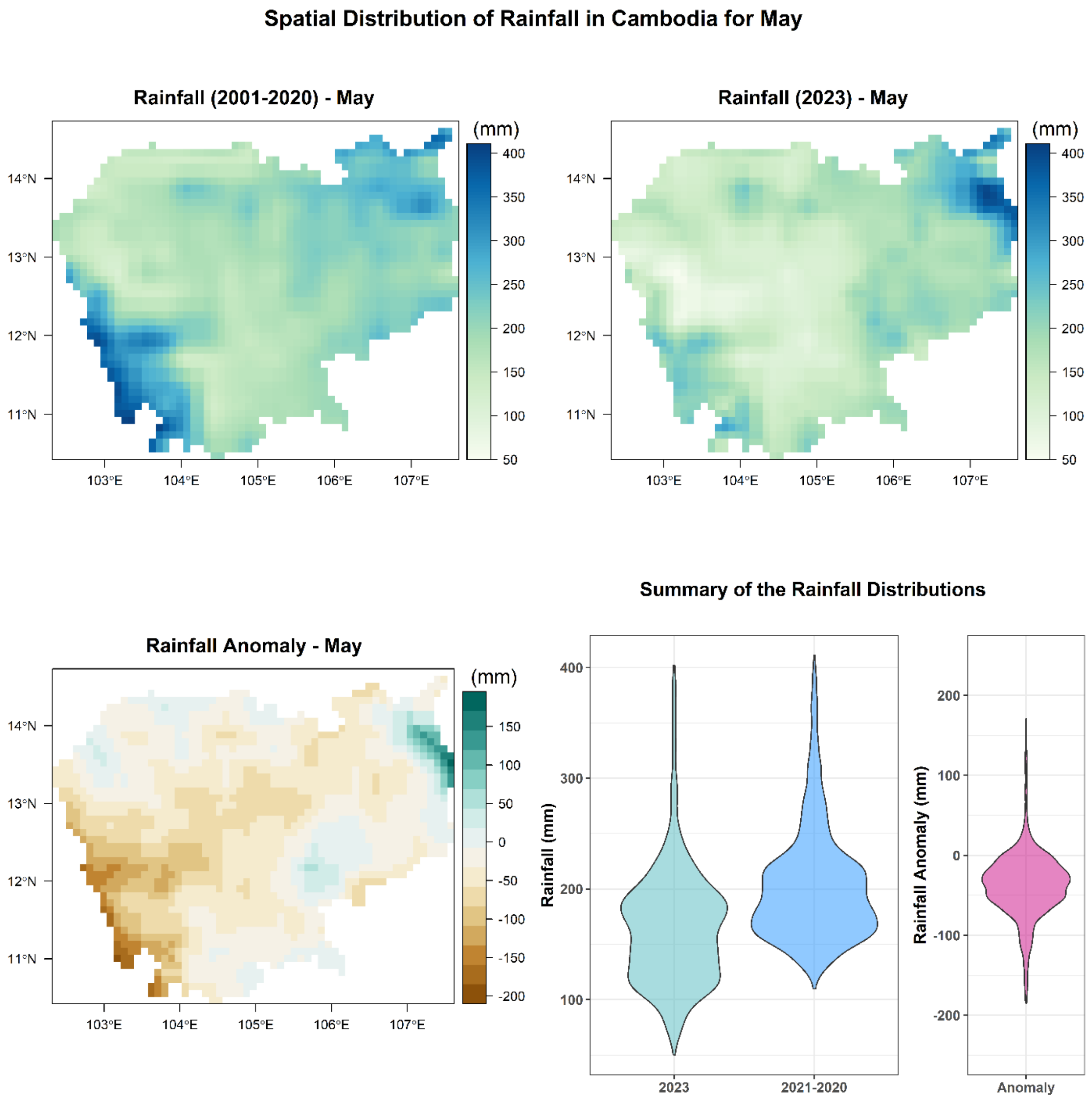

Figure 31 *Maps and violin plots illustrate the spatial distribution of May rainfalls in Cambodia. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data*

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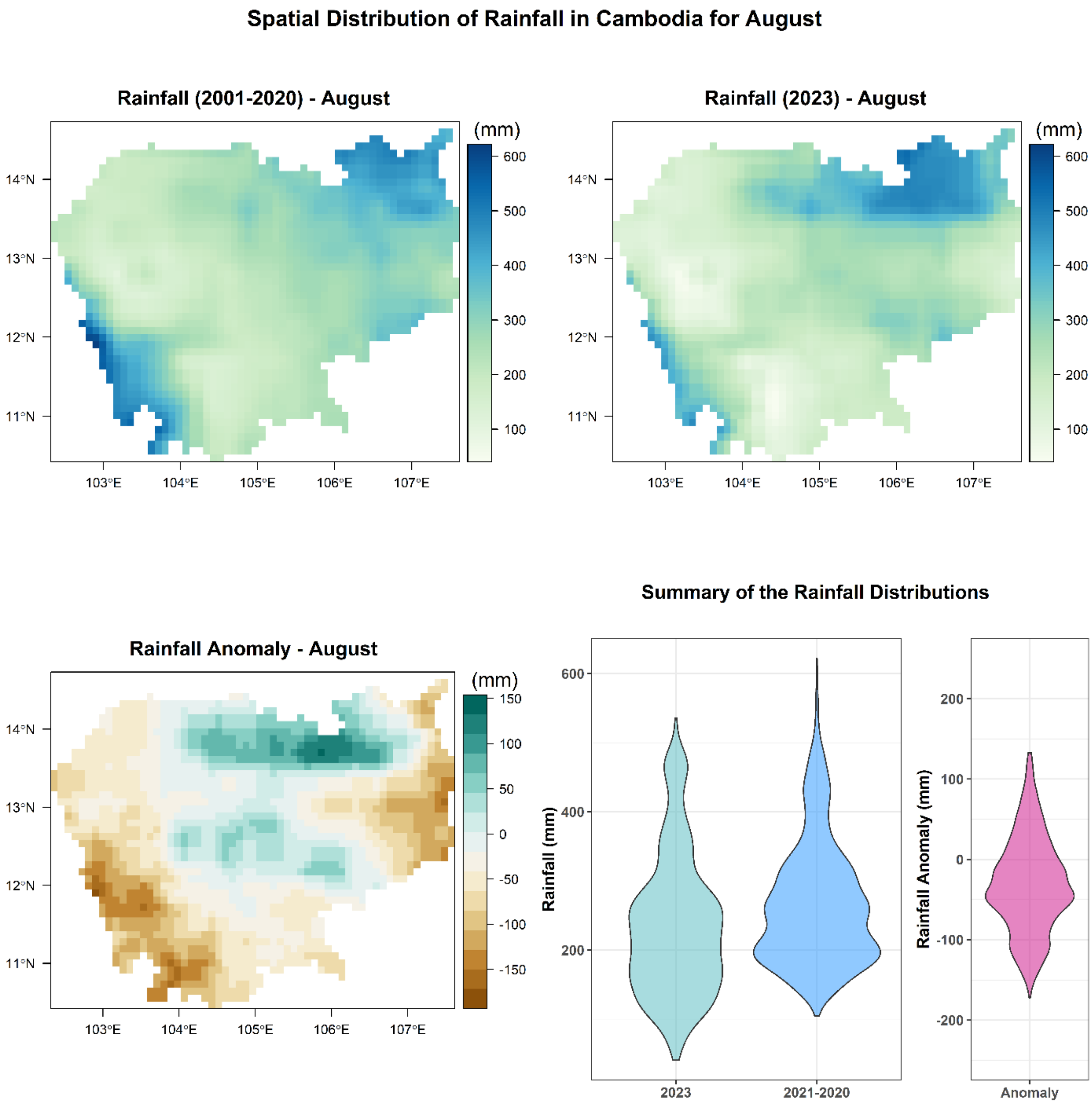

__Figure 32__ Maps and violin plots illustrate the spatial distribution of August rainfalls in Cambodia. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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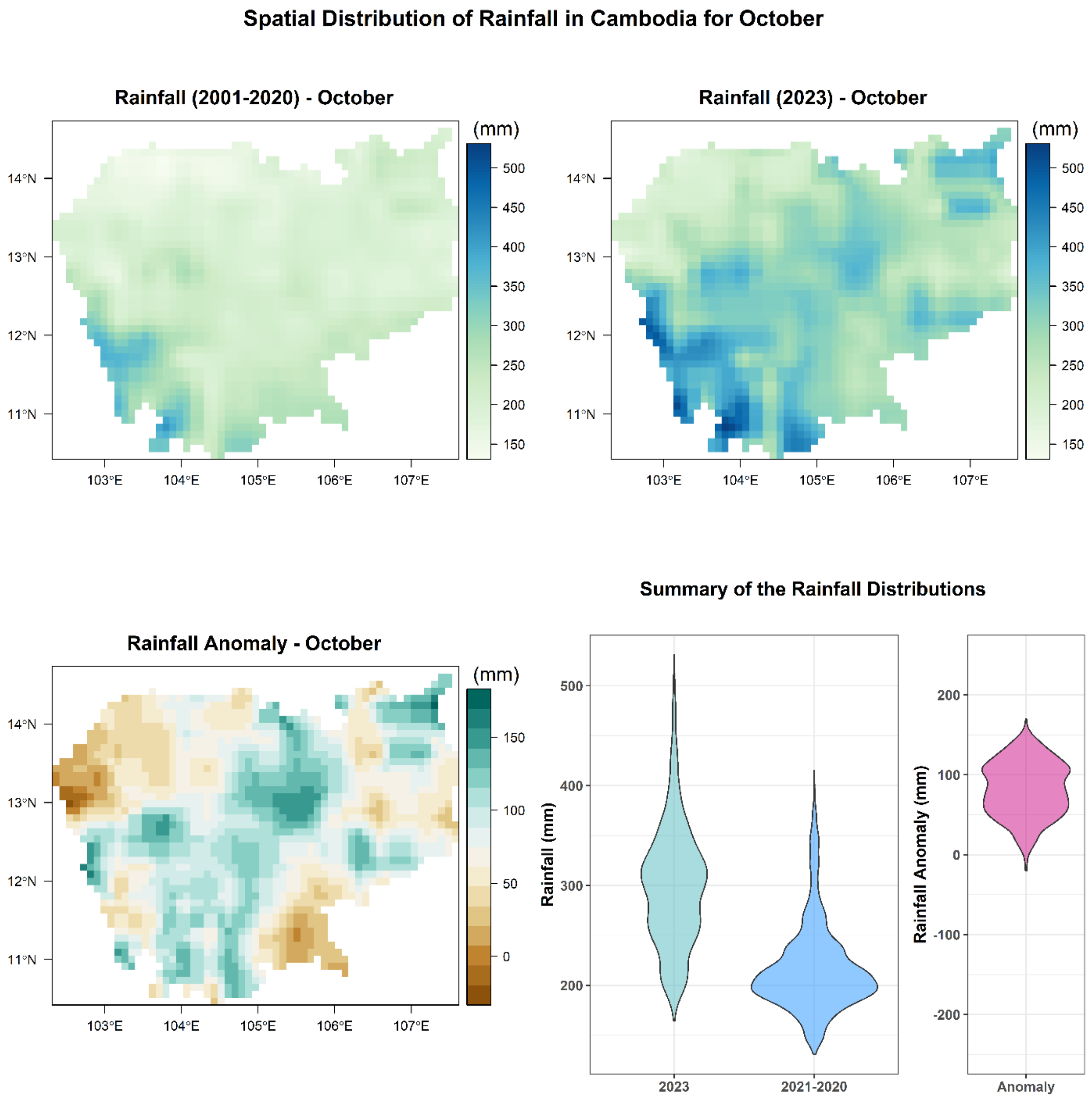

__Figure 33__ Maps and violin plots illustrate the spatial distribution of October rainfalls in Cambodia. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 13 *Monthly averages of long-term rainfalls (mm), 2023 monthly averages (mm), and rainfall anomalies (mm) in Cambodia*

Month	Rainfall (2001-2020)	Rainfall (2023)	Anomaly
Jan	*15.639*	*71.719*	*56.081*
Feb	*15.331*	*18.595*	*3.264*
Mar	*65.073*	*16.186*	*-48.887*
Apr	*112.401*	*85.144*	*-27.257*
May	*202.888*	*165.490*	*-37.399*
Jun	*214.642*	*238.849*	*24.207*
Jul	*248.002*	*339.438*	*91.436*
Aug	*266.472*	*234.993*	*-31.479*
Sep	*308.300*	*328.010*	*19.710*
Oct	*217.283*	*298.976*	*81.693*
Nov	*77.331*	*102.003*	*24.672*
Dec	*22.777*	*22.433*	*-0.344*

2.2.5. Trends of NDVI in Cambodia

To analyze the cascading impacts of changing conditions, such as variations in temperature and rainfall, the corresponding changes in vegetation greenness, which indicates crop biomass, were assessed using time series data on the Normalized Difference Vegetation Index (NDVI). The NDVI measures the "greenness" of ground cover and serves as a proxy to indicate the density and health of vegetation. NDVI values range from +1 to -1, with high positive values corresponding to dense and healthy vegetation, while low or negative values indicate poor vegetation conditions or sparse vegetative cover (Cohen et al., 2018) (Bayarjargal et al., 2006; Tucker et al., 1983).

The deviations in NDVI were analyzed using anomalies in NDVI maps, graphs, and tables, along with the time series values of NDVI. NDVI anomalies represent the variation of current dekadal (10-day period) values compared to the long-term average (Tucker and Sellers, 1986). A positive anomaly (e.g., +5%) signifies enhanced vegetation conditions relative to the average, while a negative anomaly (e.g., -5%) indicates poorer vegetation conditions (Anyamba et al., 2010).

The data for this analysis was accessed through the Food and Agriculture Organization's (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS) (FAO-GIEWS, 2024). GIEWS monitors the condition of major food crops at both country and global levels to assess production prospects. To support this analysis and supplement ground-based information, GIEWS utilizes remote sensing data, which provides valuable insights into water availability and vegetation health during cropping seasons. In addition to rainfall estimates and NDVI, GIEWS relies on vegetation indicators derived from 10-day (dekadal) vegetation data captured by the METOP-Advanced Very High-Resolution Radiometer (AVHRR) sensor at a 1 km resolution (for data from 2007 onwards). For data from 1984 to 2006, NDVI values are derived from the National Oceanic and Atmospheric Administration (NOAA)-AVHRR dataset at a 16 km resolution. Precipitation estimates for African countries (except Cabo Verde and Mauritius) are sourced from NOAA's Famine Early Warning Systems Network (FEWSNet), while data for other countries is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

In this assessment, monthly maps of NDVI anomalies were obtained for the years 2022, 2023, and up to July 2024. Time series statistics were generated at the sub-national level and then integrated at the country level to indicate the monthly variation in NDVI profiles over crop areas and the corresponding anomalies.

The long-term NDVI profiles in Cambodia's cropland areas, from 1991 to 2023, demonstrate a clear seasonal pattern in agricultural productivity throughout the year. The NDVI values typically start low in the early months (January to March), corresponding to the dry season when croplands have limited vegetation cover due to reduced water availability. As the monsoon season begins in April, NDVI values rise, peaking between July and September when the croplands experience the most vigorous growth due to abundant rainfall. After the monsoon season ends, the NDVI gradually declines from October onwards, indicating the end of the growing season and the approach of the dry season.

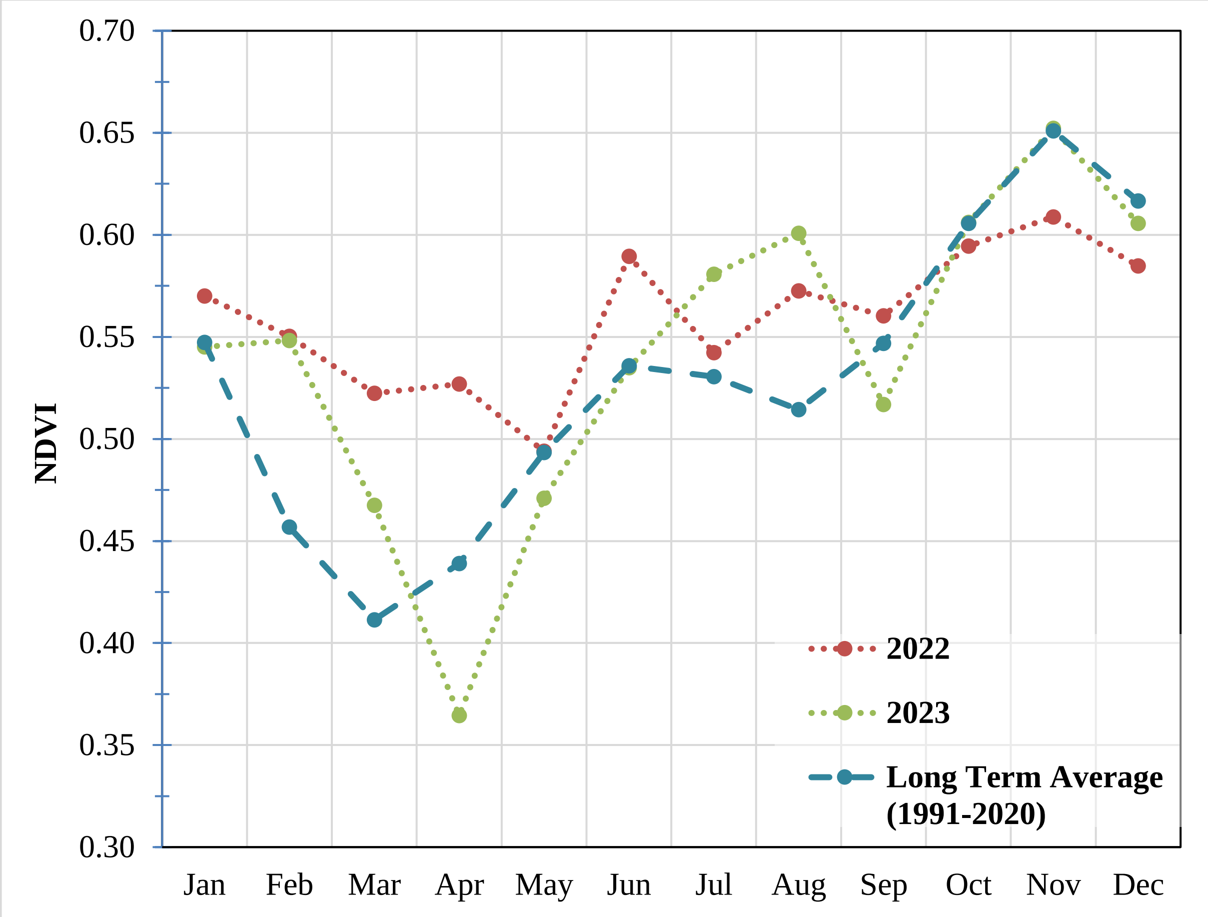

Figure 34 Spatially aggregated mean monthly NDV profiles in Cambodia from 1991 to 2023 showing monthly averages, long-term averages (1991-2020), and anomalies for 2022-23 over the crop area (FAO-GIEWS, 2024)

In 2023, the NDVI profiles for croplands showed significant monthly anomalies. Early in the year, the NDVI was close to the long-term average, but March, April, and September saw substantial declines, indicating that these months may have faced unfavourable conditions like delayed rainfall or drought, affecting crop growth. Conversely, July and August had higher-than-average NDVI values, suggesting that these months benefited from favourable growing conditions, possibly due to well-timed and sufficient rainfall. The mixed NDVI anomalies throughout 2023 reflect variability in cropland conditions, impacting agricultural productivity.

In contrast, 2022 exhibited significant positive anomalies in the early months, particularly in February and March, where NDVI values were notably higher than the long-term average. This suggests that croplands may have experienced unusually favourable growing conditions, such as early rainfall or better-than-average soil moisture. However, from October to December, NDVI values showed negative anomalies, implying that the positive trends in the early year were not sustained, potentially due to adverse weather conditions or other stress factors affecting crop health.

The observed NDVI anomalies in croplands can be attributed to various factors, including climatic variations such as shifts in rainfall patterns, temperature extremes, or droughts. Human activities, like changes in agricultural practices, land use, or irrigation, may also influence these changes. These anomalies have significant implications for agriculture, as variations in cropland productivity directly affect crop yields, food security, and the livelihoods of farmers in the region.

Over the period from 1991 to 2023, the NDVI profiles for croplands show increasing variability, particularly in recent years. Earlier decades exhibited more stable NDVI values with fewer extreme anomalies, while recent years have seen more pronounced fluctuations. This trend may reflect the growing impact of climate change, leading to more erratic weather patterns and increased uncertainty in agricultural productivity. The evolving NDVI profiles underscore the need for adaptive strategies in agricultural management to mitigate the adverse impacts of these changes and ensure sustainable food production.

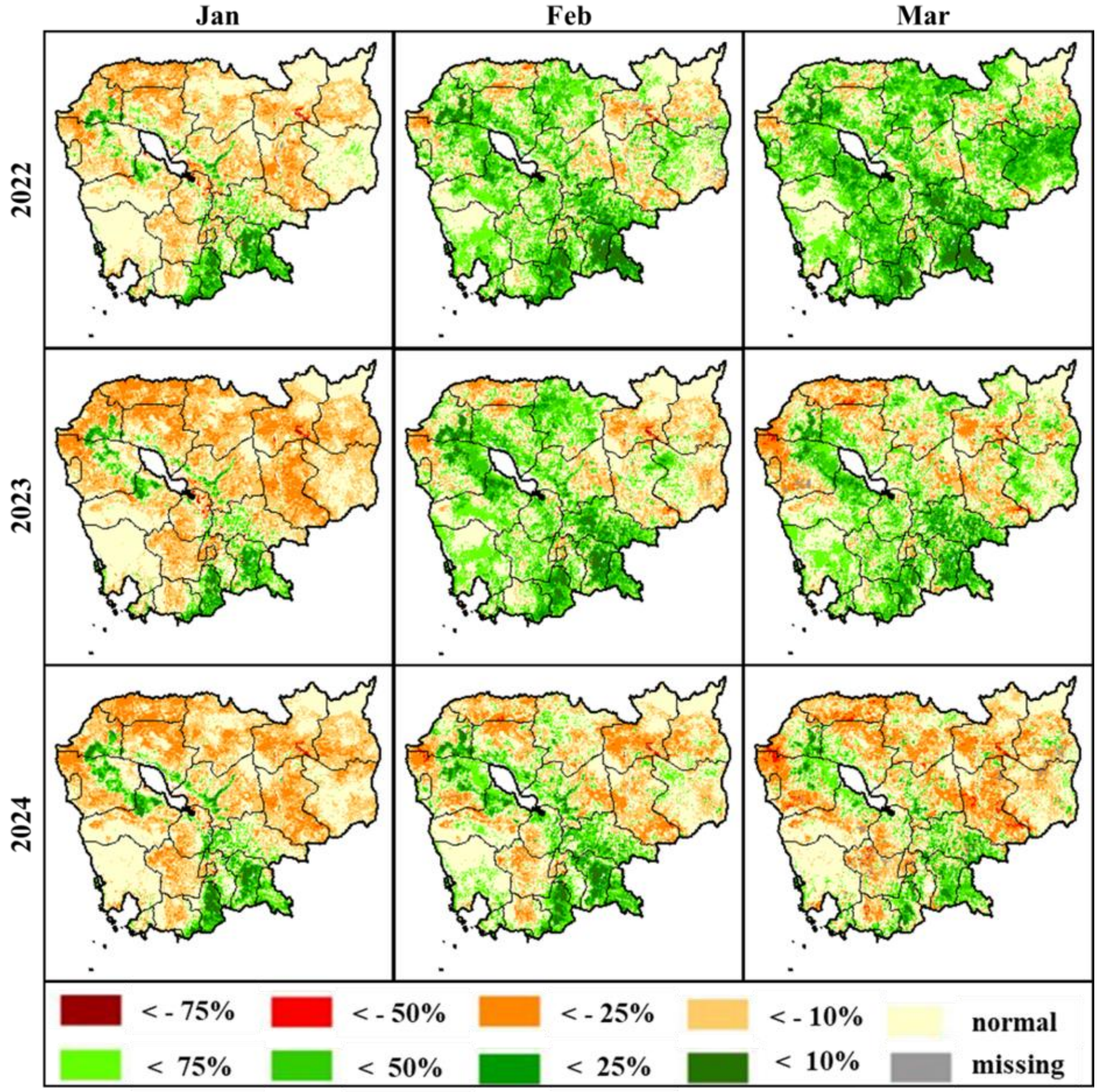

Figure 35 *Monthly NDVI anomaly maps of Cambodia for 2022-24 (January, February, and March) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

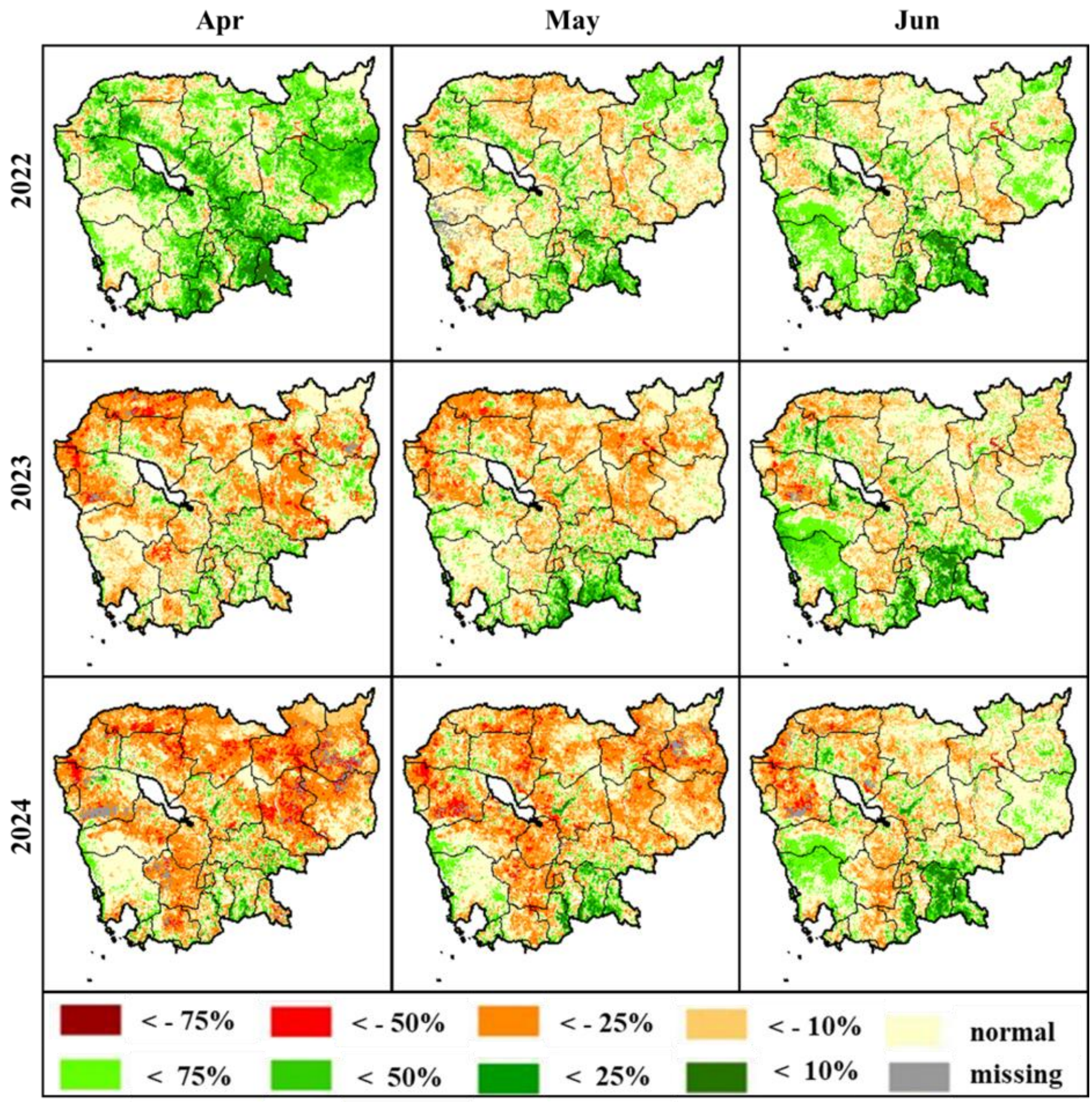

Figure 36 *Monthly NDVI anomaly maps of Cambodia for 2022-24 (April, May, and Jun) (FAO-GIEWS, 2024)*

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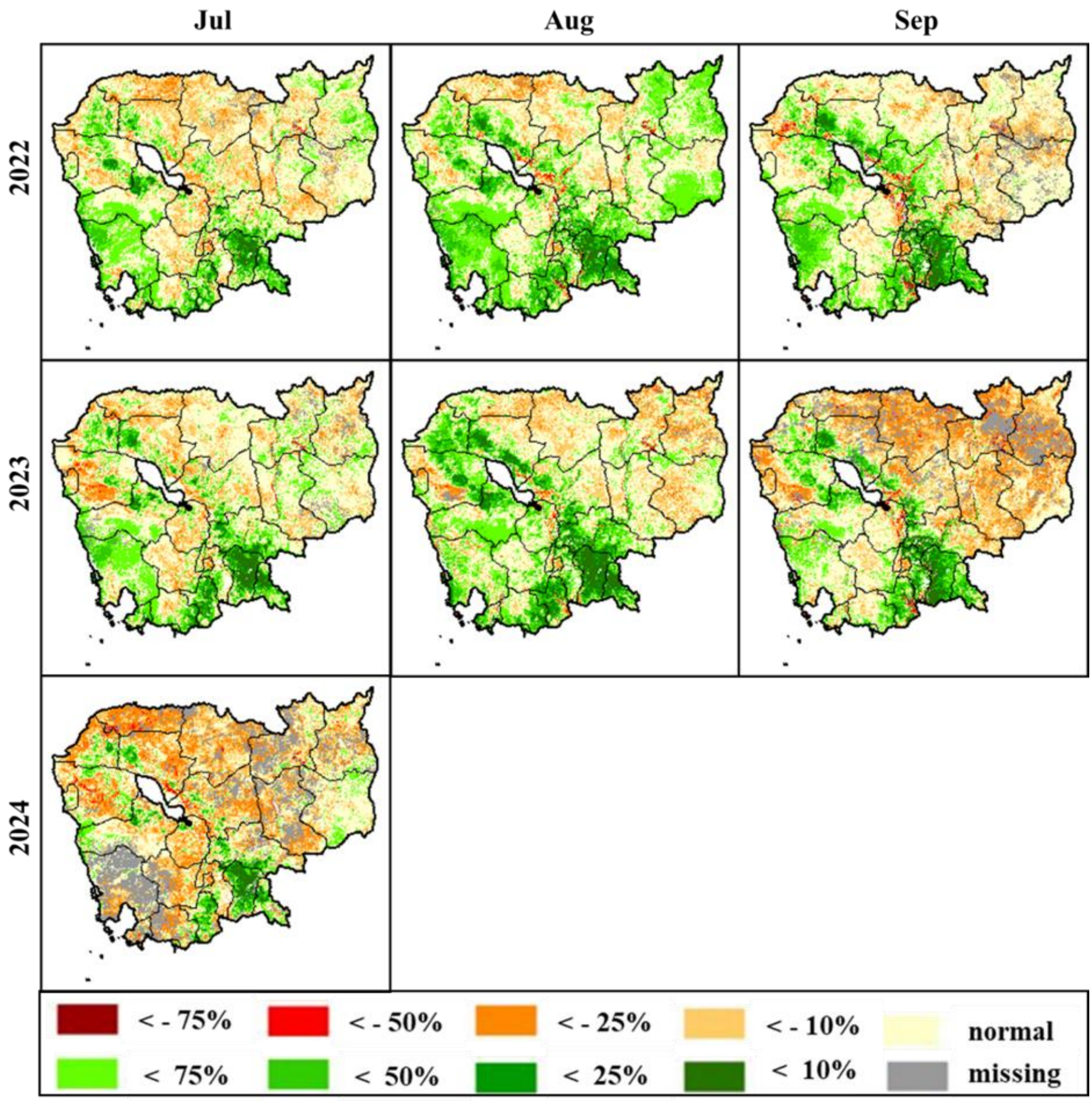

Figure 37 *Monthly NDVI anomaly maps of Cambodia for 2022-24 (July, August, and September) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

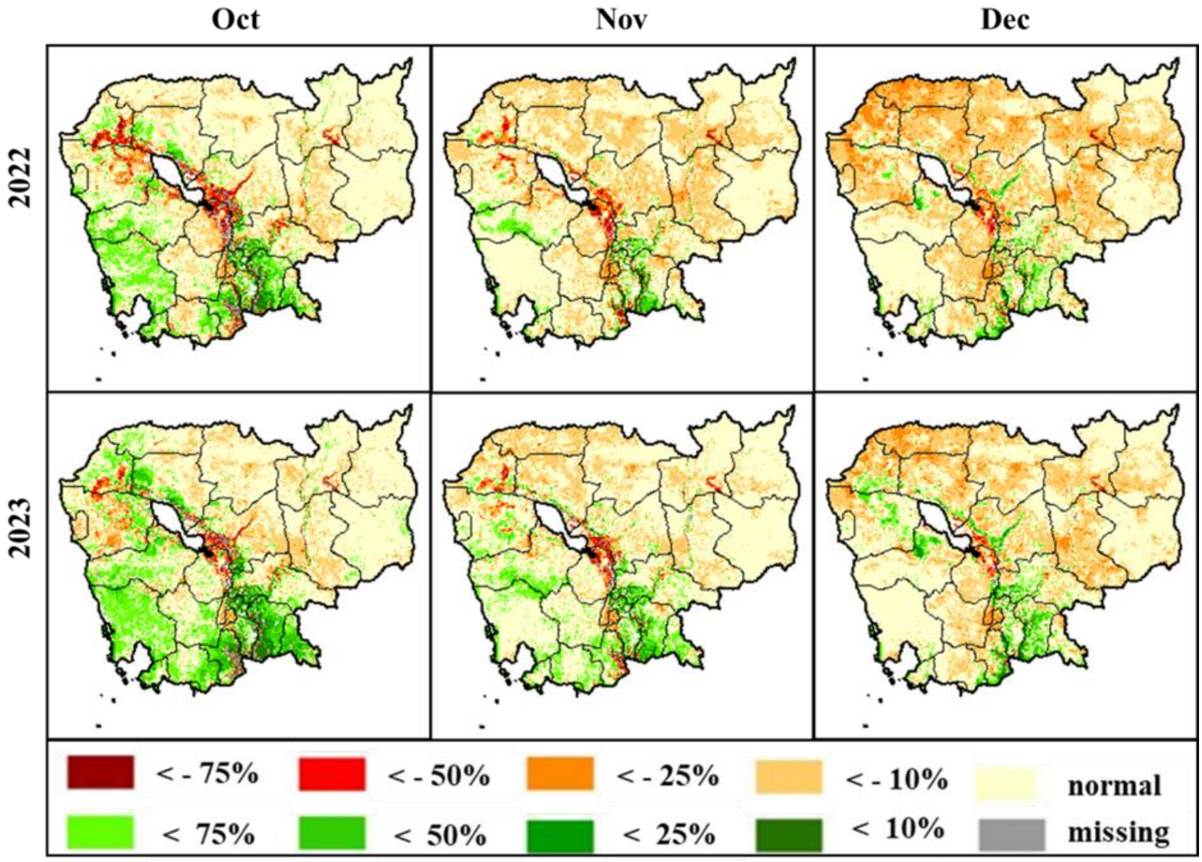

Figure 38 *Monthly NDVI anomaly maps of Cambodia for 2022-23 (October, November, and December) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

***Table 14** Spatially aggregated mean monthly NDV profiles in Cambodia from 1991 to 2023, long-term average (1991-2020), and the anomalies for 2021-23 over the crop area (FAO-GIEWS, 2024)*

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0.618	0.493	0.443	0.438	0.500	0.535	0.490	0.367	0.361	0.487	0.591	0.521
1992	0.512	0.458	0.361	0.359	0.428	0.488	0.512	0.396	0.544	0.553	0.620	0.563
1993	0.494	0.419	0.424	0.476	0.502	0.519	0.511	0.498	0.469	0.610	0.620	0.555
1994	0.442	0.334	0.394	0.463	0.412	0.365	0.362	0.403	0.456	0.521	0.585	0.571
1995	0.539	0.465	0.437	0.425	0.515	0.595	0.566	0.443	0.508	0.606	0.650	0.645
1996	0.547	0.512	0.435	0.467	0.551	0.611	0.534	0.540	0.553	0.553	0.609	0.656
1997	0.549	0.522	0.520	0.529	0.557	0.522	0.449	0.505	0.578	0.669	0.748	0.664
1998	0.542	0.501	0.401	0.417	0.475	0.580	0.659	0.605	0.585	0.643	0.604	0.605
1999	0.590	0.462	0.472	0.523	0.513	0.596	0.503	0.555	0.671	0.596	0.583	0.536
2000	0.513	0.417	0.360	0.413	0.452	0.492	0.433	0.370	0.353	0.393	0.437	0.425
2001	0.571	0.524	0.436	0.507	0.531	0.521	0.529	0.473	0.570	0.563	0.648	0.681
2002	0.586	0.474	0.399	0.390	0.485	0.545	0.566	0.443	0.490	0.598	0.686	0.700
2003	0.627	0.459	0.444	0.465	0.483	0.567	0.577	0.545	0.528	0.600	0.694	0.667
2004	0.537	0.447	0.390	0.388	0.460	0.516	0.504	0.455	0.528	0.616	0.689	0.640
2005	0.473	0.376	0.319	0.367	0.415	0.488	0.488	0.474	0.534	0.567	0.637	0.613
2006	0.584	0.463	0.380	0.446	0.498	0.506	0.450	0.477	0.524	0.645	0.657	0.613
2007	0.568	0.433	0.388	0.373	0.487	0.508	0.487	0.508	0.541	0.615	0.645	0.625
2008	0.550	0.451	0.425	0.462	0.525	0.549	0.557	0.539	0.561	0.638	0.664	0.640
2009	0.548	0.467	0.479	0.530	0.553	0.572	0.552	0.566	0.597	0.631	0.685	0.611
2010	0.526	0.461	0.394	0.407	0.478	0.546	0.566	0.549	0.600	0.649	0.684	0.631
2011	0.552	0.433	0.418	0.430	0.525	0.560	0.557	0.568	0.565	0.630	0.670	0.613
2012	0.542	0.500	0.468	0.484	0.521	0.520	0.554	0.547	0.541	0.624	0.673	0.653
2013	0.523	0.438	0.380	0.437	0.534	0.571	0.552	0.575	0.577	0.636	0.684	0.597
2014	0.532	0.432	0.397	0.433	0.526	0.534	0.539	0.583	0.618	0.665	0.707	0.670
2015	0.557	0.431	0.371	0.394	0.475	0.526	0.541	0.607	0.622	0.695	0.728	0.675
2016	0.568	0.440	0.368	0.350	0.395	0.502	0.581	0.599	0.590	0.631	0.700	0.643
2017	0.604	0.525	0.455	0.539	0.551	0.583	0.556	0.573	0.600	0.666	0.655	0.644
2018	0.570	0.487	0.442	0.454	0.535	0.571	0.556	0.547	0.593	0.652	0.644	0.609
2019	0.543	0.438	0.372	0.413	0.488	0.549	0.575	0.522	0.522	0.653	0.677	0.628
2020	0.513	0.441	0.369	0.393	0.433	0.539	0.612	0.595	0.627	0.562	0.654	0.601
2021	0.544	0.468	0.425	0.415	0.489	0.594	0.578	0.566	0.565	0.579	0.605	0.584
2022	0.570	0.550	0.522	0.527	0.494	0.589	0.542	0.573	0.560	0.594	0.609	0.585
2023	0.545	0.548	0.468	0.364	0.471	0.535	0.581	0.601	0.517	0.606	0.652	0.606
2024	0.544	0.490	0.412	0.385	0.408	0.528	0.505	0.594				
Long Term Average (1991-2020)	0.547	0.457	0.411	0.439	0.493	0.536	0.531	0.514	0.547	0.606	0.651	0.617
Anomaly 2023	-0.40	20.01	13.64	-16.98	-4.52	-0.19	9.43	16.81	-5.48	0.08	0.18	-1.77
Anomaly 2022	4.15	20.45	26.96	20.00	0.13	9.99	2.20	11.33	2.47	-1.84	-6.47	-5.16
Anomaly 2021	-0.67	2.53	3.26	-5.53	-0.91	10.83	8.97	9.96	3.32	-4.46	-7.12	-5.35

Chapter 3: Agronomic Conditions and Droughts in Lao People's Democratic Republic (Lao PDR)

3.1. Geospatial data overview

This study utilized various data sources (Table 1) with Google Earth Engine (GEE) as the primary hub for data processing. GEE, a cloud computing platform for planetary-scale data analysis, ensures the flexibility and adaptability of the workflow. Please refer to the section 1.3 for an overview of the geospatial data used in this study. For the specific analysis of agronomic conditions and droughts in Lao PDR, all datasets were processed at the national scale to derive country-specific information. Additionally, regional-level maps and information are included to provide spatially exclusive perspectives, considering the regional context, particularly the neighbouring countries.

3.2. Agronomic Conditions in Lao People's Democratic Republic (Lao PDR)

The agronomic conditions in Lao PDR were assessed through an in-depth analysis of land cover and land use composition, with a particular emphasis on cropland. This assessment utilized various land cover and land use datasets. Additionally, the distribution and patterns of soil texture across the country were examined. Long-term trends and patterns in precipitation, temperature and NDVI were evaluated. These indices provided insights into the health and viability of croplands under different environmental stresses.

3.2.1.Land cover land use composition and cropland in Lao People's Democratic Republic (Lao PDR)

The composition and spatial distribution of land cover and land use in Lao PDR and the surrounding region were assessed using several datasets. These included ESA's WorldCover map for 2022, with a 10-meter spatial resolution, and the GLCFCS30D Global 30-meter Land Cover Change Dataset (1985-2022). The GLC_FCS30D dataset represents a significant advancement in global land-cover monitoring, offering detailed insights into land-cover dynamics over a 30-meter resolution spanning from 1985 to 2022. This dataset provided four categories of cropland: rainfed cropland, irrigated cropland, herbaceous cover cropland, and tree or shrub cropland (orchard). In contrast, the ESA WorldCover map provided a single cropland category, but it missed tree crops or orchards in many parts, which is probably included in the Tree Cover class. To ensure consistency among the datasets, we also analyzed two datasets provided by the FAO (FAOSTAT, 2024b), including Land Cover and Land Use. The FAO's Land Cover information is compiled from publicly available Global Land Cover (GLC) maps: The European Space Agency (ESA) Climate Change Initiative (CCI) annual land cover maps (1992–2020), produced by the Université Catholique de Louvain (UCL)-Geomatics and now part of the European Copernicus Program. The FAOSTAT Land Use domain contains data on forty-four categories of land use, irrigation, agricultural practices, and five indicators relevant to monitoring agriculture, forestry, and fisheries activities at national, regional, and global levels. This data is available by country and year, with global coverage and annual updates.

The spatial distribution of cropland in Lao PDR (Figure 39, Figure 40) primarily aligns with the larger cropland patches found across neighbouring Cambodia and Thailand. These significant cropland areas are mostly concentrated along the western border of Lao PDR. Smaller cropland patches are dispersed throughout the country, creating a mosaic of agricultural areas. Most of these croplands are rainfed, relying on natural rainfall rather than irrigation systems. This pattern highlights the regional agricultural practices and the reliance on rainfed farming in Lao PDR, similar to its neighbouring countries.

The distribution of vegetated land cover and land use classes in Lao PDR provides valuable insights into the landscape composition, and distribution of cropland (Table 15, Table 16). The croplands in Lao PDR cover 10.50% of the total area. Rainfed cropland is the most prevalent, covering 22,307 km² or 9.16% of the total area, indicating a significant reliance on natural rainfall for agriculture. Irrigated cropland constitutes 1,657 km² or 0.68%, highlighting areas with managed water supply. Herbaceous cover cropland is present but occupies a smaller area of 1,594 km² or 0.65%. Notably, there is no significant presence of tree or shrub cropland (orchards) in the dataset (Table 15).

In comparison, the ESA WorldCover dataset reports that cropland covers 16,995 km² or 7.45% of the total area, slightly lower than the figure reported by GLCFCS. This discrepancy highlights the importance of using multiple datasets to get a comprehensive view of land cover (Table 15).

Tree cover/forest cover is the dominant land cover class according to both datasets. Other land cover types, including shrubland, built-up areas, bare or sparse vegetation, and water bodies, make up the remaining proportions, each constituting less than 2% of the total area (Table 15, Table 16).

While tree cover and forest areas dominate Lao PDR' landscape, croplands play a crucial role, particularly in rainfed agriculture. The detailed sub-classification of croplands provides valuable insights into the agricultural practices and land use, which are essential for planning and sustainable development in Lao PDR.

The distribution of cropland in Lao PDR, as derived from the FAO’s Land Cover (CCI LC) and FAO’s Land Use map (FAOSTAT, 2024b), highlights the importance of agricultural land in the country's landscape (Table 16). Agricultural land in Lao PDR covers 22,510 km², which is 9.75% of the total area. Within this category, cropland specifically accounts for 15,740 km² or 6.82% of the total area. Temporary crops, which are seasonal or annual, cover 10,700 km² or 4.64%, while permanent crops, such as fruit trees and other perennials, occupy 3,500 km² or 1.52%. Additionally, temporary fallow lands, which are left unplanted for a season to restore soil fertility, account for 1,540 km² or 0.67%. Areas equipped for irrigation cover 4,410 km² or 1.91%, showing the importance of managed water supply in agriculture. The same extent is also classified as the actual irrigated area, emphasizing the significance of irrigation in Lao PDR. Arable land, which is ready for crop production, covers 12,240 km² or 5.30%.

The FAO Land Cover (CCI LC) dataset indicates that herbaceous crops cover 29,094 km² or 12.56% of the total area. This category includes various non-woody crops. Woody crops, which encompass orchards and other perennial plants, cover 3,090 km² or 1.33%.

Apart from cropland, the landscape of Lao PDR is predominantly covered by forests and shrublands. Forest land, according to the FAO’s Land Use dataset, covers 165,265 km² or 71.61% of the total area. This includes naturally regenerating forests (147,202 km² or 63.78%) and planted forests (18,064 km² or 7.83%). In comparison, the FAO Land Cover (CCI LC) dataset reports that tree-covered areas occupy 108,142 km² or 46.69%. Additionally, shrub-covered areas make up 72,505 km² or 31.30%, indicating a significant presence of woody and herbaceous shrubs. Grassland areas are also substantial, covering 15,306 km² or 6.61% (Table 16).

These datasets collectively illustrate that while forests and tree-covered areas dominate the landscape in Lao PDR, croplands play a crucial role in the country's land use. The detailed classification provided by the FAO datasets offers valuable insights into the agricultural practices and land use patterns, which are essential for planning and sustainable development in Lao PDR.

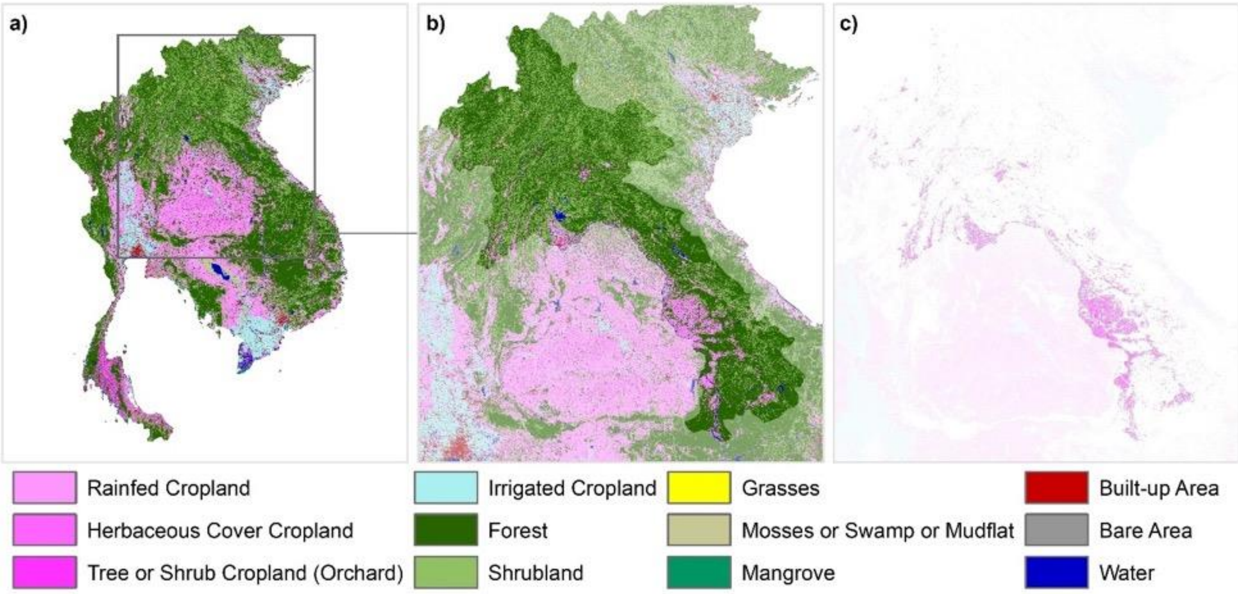

Figure 39 *The cropland and land cover land use composition of Lao PDR using the GLCFCS30D: a) Overview and location of Lao PDR in the region; b) Spatial distribution of land cover/land use patterns across Loas; c) Distribution of cropland areas within Lao PDR. Data source: (Liu et al., 2023)*

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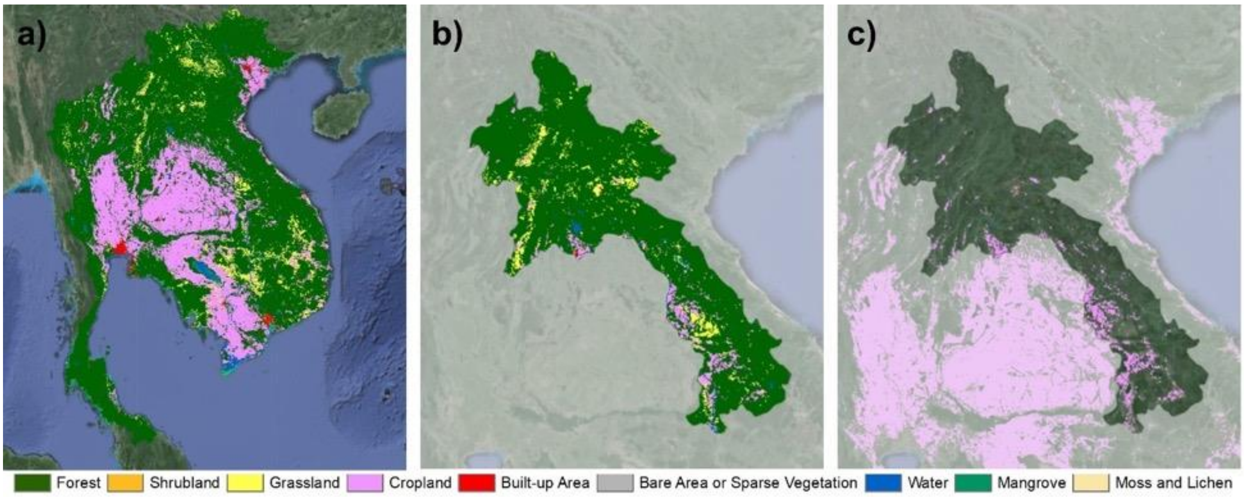

Figure 40 *The cropland and land cover land use composition of Lao PDR using the ESA's WorldCover Map: a) Overview and location of Loas in the region; b) Spatial distribution of land cover/land use patterns across Loas; c) Distribution of cropland areas within Lao PDR. Data Source: (Zanaga et al., 2022)*

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Table 15 *Distribution of vegetated land cover land use classes in Lao PDR from ESA's WorldCover and the distribution of cropland and its sub-classes from GLCFCS.*

ESA - World Cover			GLCFCS		
LCLU Classes	**Area (Km2)**	**%**	**Cropland Classes**	**Area**	**%**
Tree cover	*177880*	*77.98*	**Cropland**	*25558*	*10.50*
Shrubland	*717*	*0.31*	**Rainfed Cropland**	*22307*	*9.16*
Grassland	*27575*	*12.09*	**Herbaceous Cover Cropland**	*1594*	*0.65*
Cropland	*16995*	*7.45*	**Tree or Shrub Cropland (Orchard)**	*0*	*0.00*
Built-up Area	*638*	*0.28*	**Irrigated Cropland**	*1657*	*0.68*
Bare or Sparse vegetation	*1896*	*0.83*	**Forest**	*147944*	*60.77*
Water	*2412*	*1.06*	**Shrubland**	*65459*	*26.89*
Mangroves	*0*	*0.00*	**Grassland**	*516*	*0.21*
Moss and lichen	*0*	*0.00*	**Mangrove**	*0*	*0.00*

Table 16 *Distribution of land cover land use classes in Lao PDR from the FAO's Land Cover (CCI LC) and the FAO's Land Use map (FAOSTAT, 2024b).*

FOA - Land Cover - CCI LC			FAO - Land Use		
LCLU Class Name	**Area**	**%**	**LCLU Class Name**	**Area**	**%**
Artificial surfaces	*144*	*0.06*	**Agricultural land**	*22510*	*9.75*
Herbaceous crops	*29094*	*12.56*	**Cropland**	*15740*	*6.82*
Woody crops	*3090*	*1.33*	**Temporary crops**	*10700*	*4.64*
Grassland	*15306*	*6.61*	**Permanent crops**	*3500*	*1.52*
Tree-covered areas	*108142*	*46.69*	**Temporary meadows and pastures**	*0*	*0.00*
Mangroves	*0*	*0.00*	**Temporary fallow**	*1540*	*0.67*
Shrub-covered areas	*72505*	*31.30*	**Permanent meadows and pastures**	*6770*	*2.93*
Shrubs and/or herbaceous vegetation	*1067*	*0.46*	**Land area equipped for irrigation**	*4410*	*1.91*
Sparsely natural vegetated areas	*0*	*0.00*	**Agricultural area actually irrigated**	*4410*	*1.91*
Terrestrial barren land	*0*	*0.00*	**Arable land**	*12240*	*5.30*
Inland water bodies	*2267*	*0.98*	**Forest land**	*165265*	*71.61*
			Naturally regenerating forest	*147202*	*63.78*
			Planted Forest	*18064*	*7.83*
			Other land	*43025*	*18.64*

3.2.2. Composition of Soil Texture in Lao People's Democratic Republic (Lao PDR)

To understand the general soil texture composition across Lao PDR and the cropland of Lao PDR, the USDA's soil texture layer at 10 cm depth was used. The datasets consisted of 12 soil texture classes for six soil depths (0, 10, 30, 60, 100, and 200 cm) at a 250 m resolution, derived from predicted soil texture fractions using the soil texture package in R (Hengl, 2018).

The landscape of the Lao PDR is primarily consists of two soil texture types (Figure 11, Table 9). Clay loam (ClLo) is prevalent in the middle of the country, where much of the cropland is concentrated. Loam (Lo) is the most dominant soil texture type across the country, covering areas predominantly characterized by forest. However, a significant portion of the cropland also occupies loam soil, indicating its suitability for agricultural activities. This distribution highlights the strategic utilization of clay loam and loam soils in Lao PDR's agricultural landscape, optimizing the natural properties of these soils for effective and sustainable farming practices (Figure 11, Table 9).

The characteristics of the soil texture distribution (Figure 41) in Lao PDR closely follow the regional settings around the clustered cropland patches, mirroring the cropland pattern itself. The soil texture distribution reveals significant insights into the agricultural landscape, particularly concerning cropland areas. The predominant soil texture class in Lao PDR is Clay Loam, covering 204,044 km² or 84.50% of the total area. This dominance is also evident in cropland areas, where Clay Loam constitutes 16,623 km² or 54.92% of the cropland. Clay Loam's balanced properties, including good water retention and drainage, make it highly suitable for a variety of crops, underlining its importance in supporting Lao PDR' agriculture

Loam is the second most prevalent soil type in both the overall landscape and cropland areas. It covers 25,715 km² or 10.65% of the total area and 8,150 km² or 26.93% of cropland areas. Loam is considered ideal for agriculture due to its rich composition of sand, silt, and clay, providing excellent fertility and moisture retention. This soil type's significant presence in cropland areas highlights its crucial role in agricultural productivity Silty Loam, another important soil type, covers 10,735 km² or 4.45% of the total landscape and 4,868 km² or 16.08% of cropland areas. Known for its high nutrient content and good water-holding capacity, Silty Loam supports various agricultural activities, making it a valuable asset for crop cultivation in Lao PDR

Clay and Silt soils are less prevalent but still notable. Clay covers 330 km² or 0.14% of the overall landscape and 31 km² or 0.10% of cropland areas. Although challenging due to its dense nature and high water retention, Clay can be managed effectively for certain crops. Silt covers 634 km² or 0.26% of the landscape and 593 km² or 1.96% of cropland areas, offering fertile ground but requiring careful management to prevent erosion

Sandy Clay and Silty Clay are minimal in Lao PDR. Sandy Clay covers only 6 km² or 0.00% of the total area and 1 km² or 0.00% of cropland areas, indicating its limited agricultural significance. There is no presence of Silty Clay in the overall landscape or cropland areas

The overall picture of soil texture in Lao PDR shows a landscape dominated by Clay Loam and Loam soils, which are ideal for agriculture due to their balanced properties and fertility. These soil types are particularly prevalent in cropland areas, supporting the country's agricultural activities. Silty Loam also plays a significant role, contributing to the nutrient-rich environment necessary for crop growth. The presence of Clay and Silt soils highlights areas that may require more intensive management practices. The minimal presence of Sandy

Clay and the absence of Silty Clay suggest limited areas with these specific soil characteristics, focusing agricultural efforts on the more fertile and balanced soil types (Table 17).

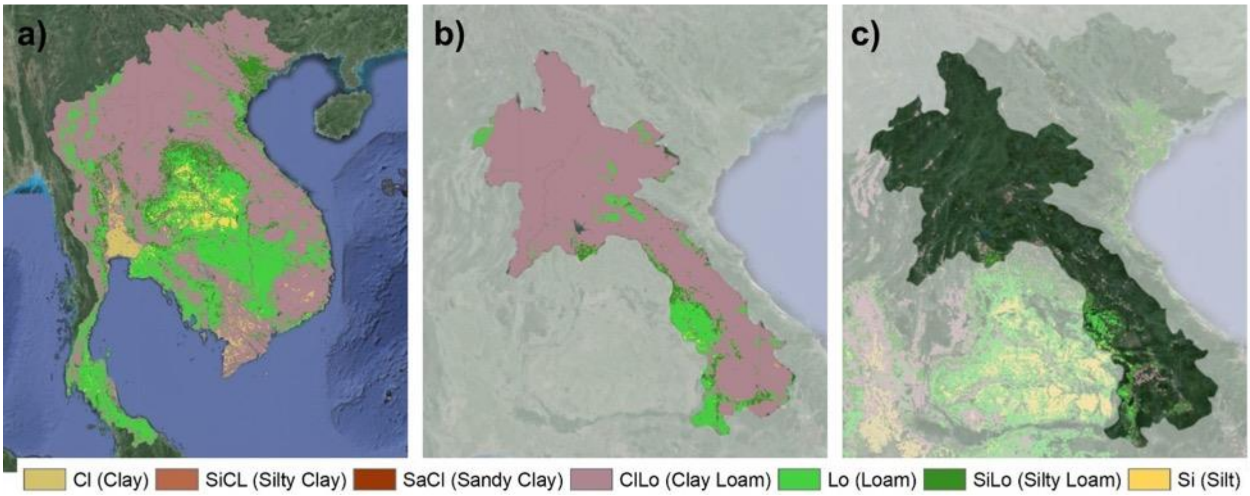

Figure 41 *The soil texture composition (at 10 cm depth) of Lao PDR using the USDA's soil texture data: a) Overview and location of Lao PDR in the region; b) Spatial distribution of soil texture patterns across Lao PDR; c) Distribution of soil texture masked over the cropland areas.*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 17 *Distribution of the soil texture classes (at 10 cm depth) in Lao PDR and masked over the cropland*

Soil Texture Class	Lao PDR		Lao PDR - Cropland	
	Area	(%)	Area	(%)
Cl (Clay)	*330*	*0.14*	*31*	*0.10*
SiCl (Silty Clay)	*0*	*0.00*	*0*	*0.00*
SaCl (Sandy Clay)	*6*	*0.00*	*1*	*0.00*
ClLo (Clay Loam)	*204044*	*84.50*	*16623*	*54.92*
Lo (Loam)	*25715*	*10.65*	*8150*	*26.93*
SiLo (Silty Loam)	*10735*	*4.45*	*4868*	*16.08*
Si (Silt)	*634*	*0.26*	*593*	*1.96*

3.2.3. Trends of Air Temperature in Lao People's Democratic Republic (Lao PDR)

The analysis of temperature changes in Lao PDR was conducted using ERA5 temperature data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term temperature averages (2001-2020) with the recorded temperatures for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average temperatures and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average temperatures, the monthly temperatures for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of temperature changes, violin plots and box plots were used. Violin plots illustrated the distribution of temperatures, showing the density and probability of different temperature ranges over time. Box plots offered a clear visualization of the temperature distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the temperature changes in Cambodia, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of temperature trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual trend of temperature in Loas shows that the average temperature has increased from 22.55°C to 23.55°C between 1991 and 2020. This reflects an increase of 1°C for nearly three decades. This highlights the significant warming trend experienced in Lao PDR, consistent with global patterns of rising temperatures due to climate change.

In the decade from 2010 to 2020, January observed a slight increase in temperature with a value of 0.09°C, while February and March also experienced increases of 0.10°C and 0.13°C, respectively. April showed a significant temperature rise, recording a value of 0.48°C. May exhibited the most substantial increase with a value of 0.77°C, followed by June at 0.55°C. July and August also showed increases of 0.32°C and 0.37°C, respectively. September, October, November, and December continued this trend with values of 0.62°C, 0.34°C, 0.97°C, and 0.42°C, respectively. These figures indicate a consistent upward trend in temperatures affecting cropland during this decade.

Conversely, the decade from 2000 to 2010 presented more variable trends. January and February showed slight changes, with values of -0.04°C and 0.04°C, respectively. March experienced a decrease in temperature with a value of -0.14°C, while April saw a modest increase at 0.10°C. May and June recorded decreases of -0.22°C and -0.11°C, respectively. July had a slight decrease with a value of -0.05°C, while August showed a very minimal increase at 0.03°C. September and October had minor changes with values of -0.02°C and 0.05°C, respectively. November exhibited a notable decrease at -0.36°C, while December showed a moderate increase at 0.26°C. This decade's data indicates less consistent warming trends and more variability in temperature changes affecting cropland.

Overall, the comparison highlights a marked shift towards increasing temperatures in the more recent decade (2010-2020). This consistent rise in temperatures could have significant implications for agriculture and cropland management in Lao PDR, necessitating adjustments and strategies to mitigate the impacts of climate change on agricultural productivity.

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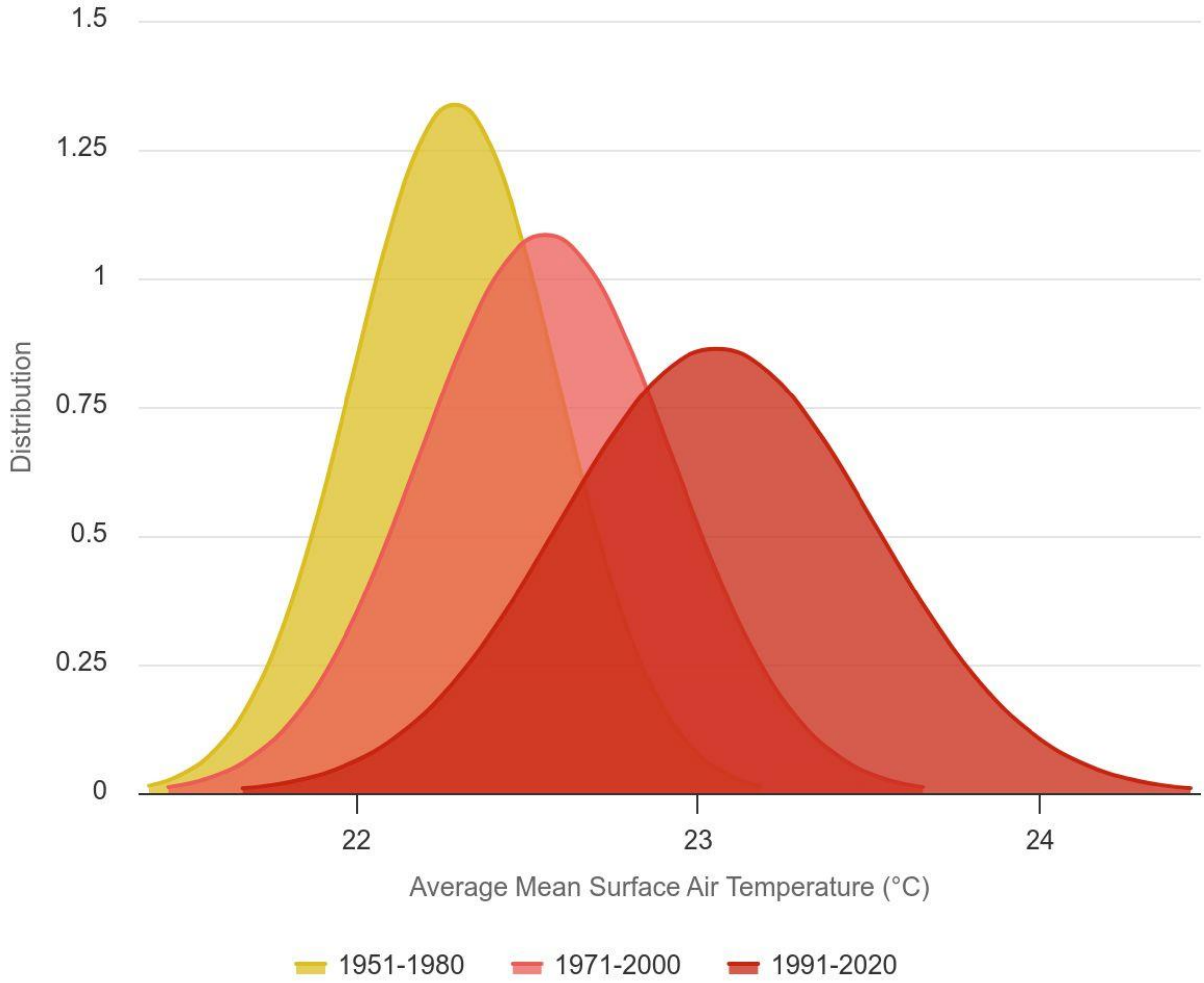

Figure 42 *Change in distribution of average mean surface air temperature in Lao PDR from 1991-2020 (CCKP, 2024b)*

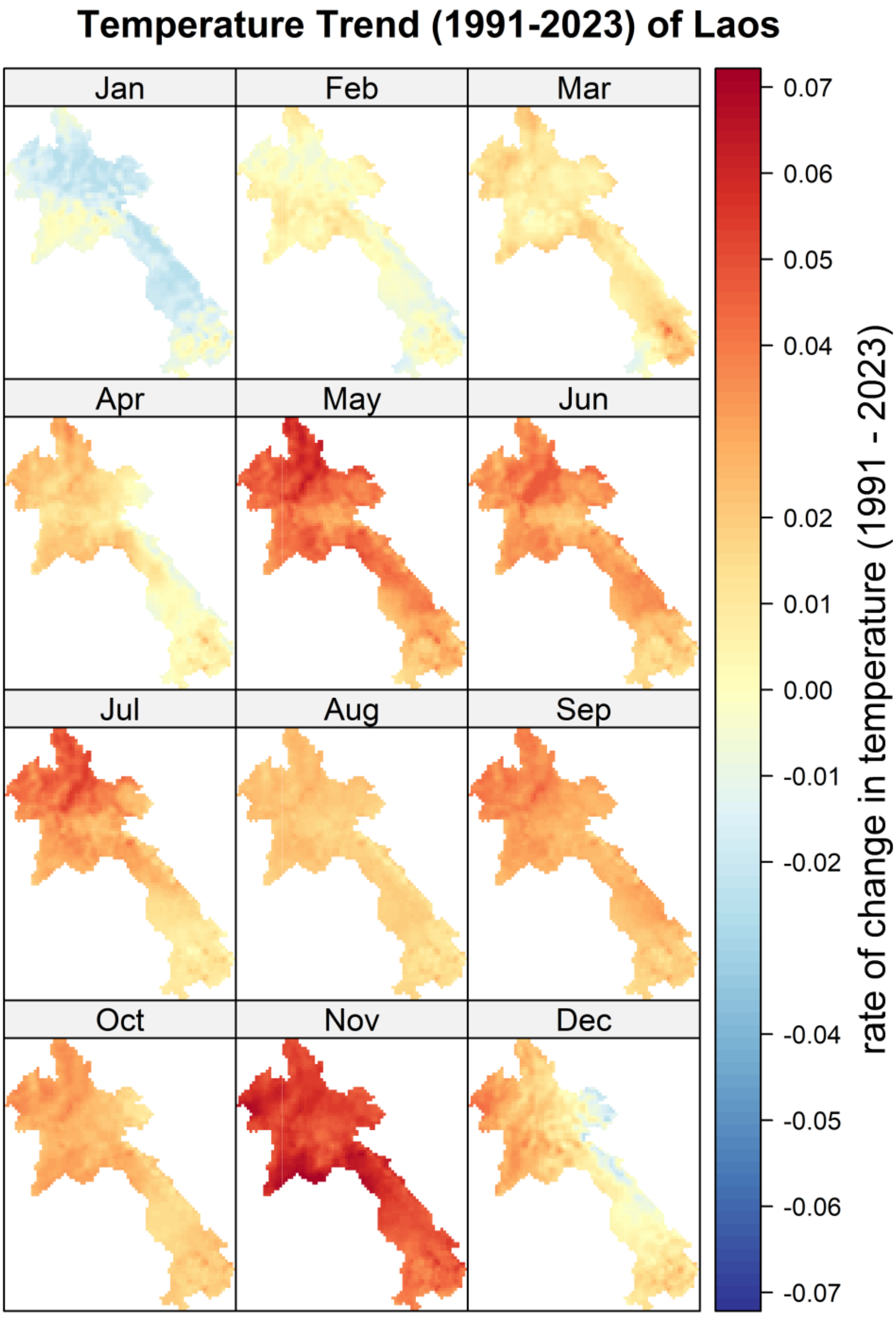

Figure 43 *Spatial patterns of temperature trends in Lao PDR, indicating the rate of change in temperatures from 1991 to 2023*

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Over the years, there has been a noticeable variation in monthly temperatures. A clear trend of increasing temperatures over the years is observed, with significant implications for croplands in Lao PDR.

From 1991 to 2000, temperatures in Lao PDR showed variability with no clear long-term trend. For example, in January, temperatures fluctuated between a low of 16.74°C in 1992 and a high of 20.97°C in 1998. Similarly, in April, temperatures ranged from 22.83°C in 1996 to 26.23°C in 1992. These variations reflect the natural interannual variability in climate.

The decade from 2000 to 2010 began to show a more consistent pattern of warming. January temperatures generally increased from 19.08°C in 2000 to 20.08°C in 2001 and 18.88°C in 2005, indicating a warming trend. April temperatures also exhibited an upward trend, from 23.91°C in 2000 to 25.81°C in 2001 and peaking at 25.32°C in 2003. Notably, May temperatures increased from 23.21°C in 2000 to 25.31°C in 2005. This decade's data points to a gradual warming trend that could affect cropland productivity and seasonal planting cycles.

In the most recent decade from 2010 to 2020, the warming trend became more pronounced. For instance, January temperatures in 2010 were 19.71°C, increasing to 20.61°C in 2020. April temperatures in 2010 were 26.04°C, peaking at 27.21°C in 2016. May also showed a significant increase, from 25.95°C in 2010 to 26.77°C in 2020. These consistent increases in temperature can have several impacts on cropland, including altered growing seasons, increased evaporation rates, and potential heat stress on crops.

The year 2023 continued to reflect the warming trend, with January temperatures at 17.48°C and April temperatures reaching 26.97°C. May temperatures were recorded at 26.38°C, indicating that the trend of rising temperatures persisted. These changes are significant as they can affect crop yields, water requirements, and the overall health of agricultural systems in Lao PDR.

The temperature trends in the two decades highlight a clear and consistent warming trend in Lao PDR, which has significant implications for cropland. The increasing temperatures can lead to shifts in growing seasons, increased water demand, and greater vulnerability to heat stress, all of which necessitate adaptive measures to sustain agricultural productivity and food security in the region.

The consistent rise in temperatures emphasizes the need for adaptive farming practices and resilient crop varieties to mitigate the adverse effects of climate change on the country's croplands. These fluctuations and significant changes in critical agricultural months underline the importance of adapting farming practices to cope with the rising temperatures and the broader impacts of climate change on cropland productivity. The year 2023 shows generally warmer temperatures compared to the early 1990s, aligning with the global trend of rising temperatures.

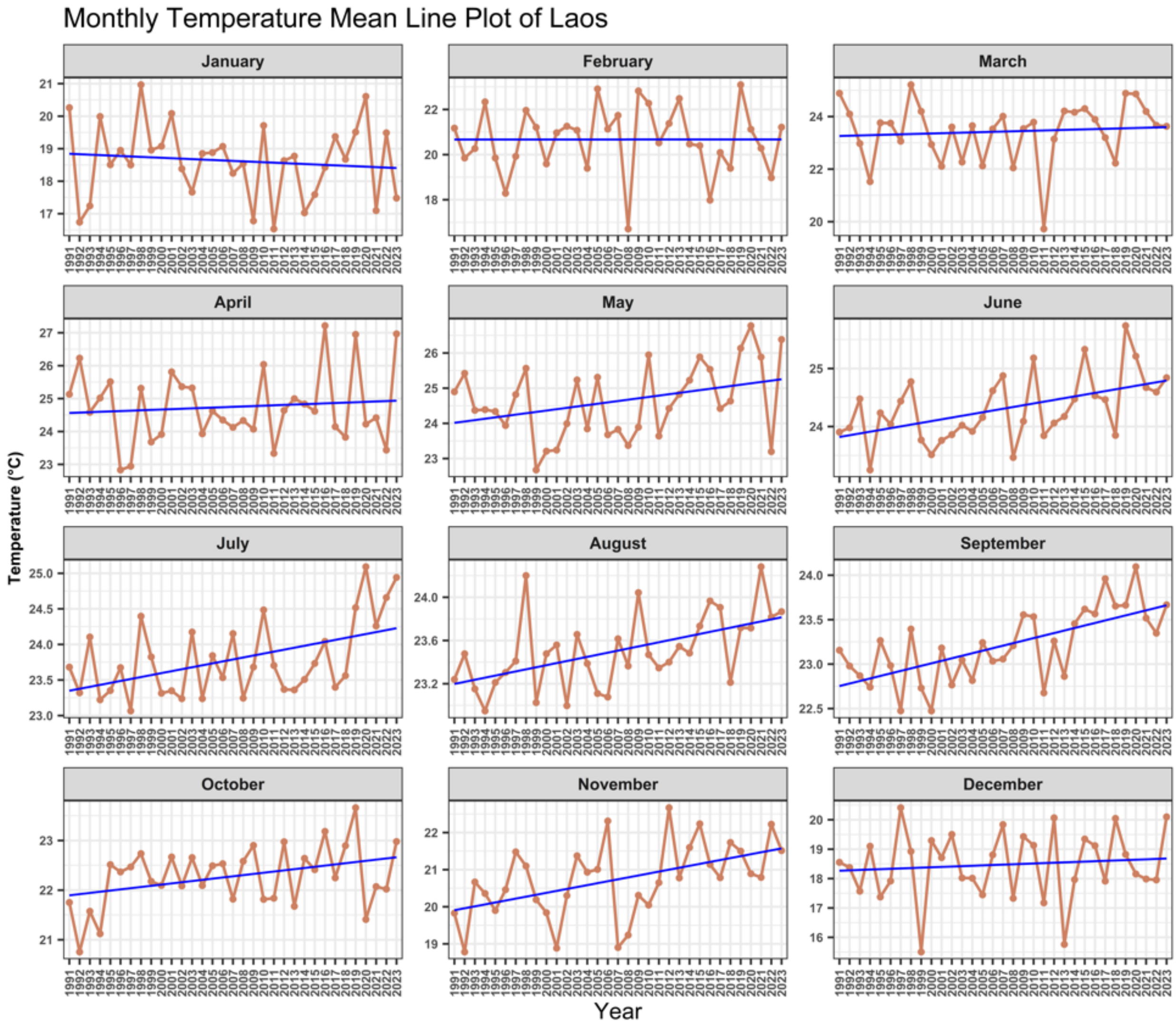

Figure 44 Spatially aggregated mean monthly temperature time series line plots with trend lines, depicting the variation of mean monthly temperatures over time in Lao PDR

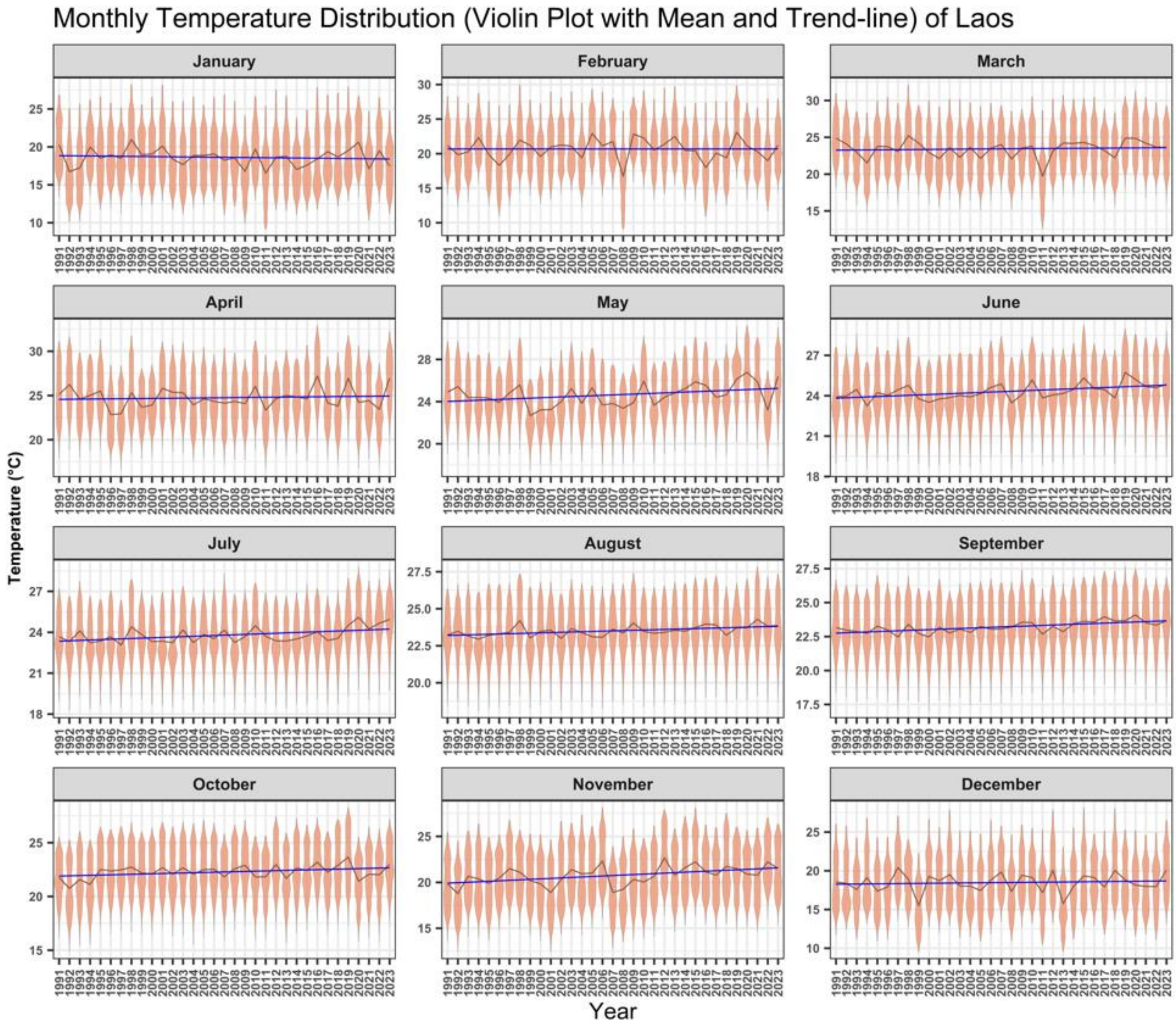

Figure 45 *Distribution of mean monthly temperature time series and violin plots in Lao PDR, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly temperatures*

Table 18 Spatially aggregated mean monthly air temperature (°C) of Lao PDR from 1991 to 2023 derived, from the ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	20.26	21.17	24.89	25.13	24.90	23.90	23.68	23.24	23.16	21.75	19.83	18.55
1992	16.74	19.85	24.10	26.23	25.42	23.98	23.32	23.48	22.98	20.75	18.78	18.38
1993	17.24	20.27	22.98	24.58	24.37	24.48	24.10	23.15	22.87	21.57	20.67	17.57
1994	19.99	22.33	21.52	25.02	24.39	23.25	23.22	22.95	22.74	21.12	20.36	19.10
1995	18.51	19.85	23.76	25.51	24.34	24.23	23.35	23.21	23.26	22.51	19.90	17.37
1996	18.95	18.29	23.75	22.83	23.94	24.04	23.67	23.30	22.98	22.37	20.46	17.92
1997	18.50	19.92	23.06	22.94	24.82	24.44	23.06	23.41	22.47	22.47	21.48	20.41
1998	20.97	21.96	25.21	25.31	25.56	24.77	24.40	24.20	23.39	22.74	21.10	18.92
1999	18.95	21.21	24.20	23.68	22.68	23.77	23.82	23.03	22.73	22.18	20.19	15.50
2000	19.08	19.59	22.94	23.91	23.21	23.51	23.31	23.48	22.47	22.10	19.84	19.29
2001	20.08	20.97	22.11	25.81	23.24	23.76	23.35	23.56	23.18	22.67	18.88	18.71
2002	18.38	21.26	23.60	25.36	23.99	23.86	23.24	23.00	22.77	22.09	20.30	19.50
2003	17.66	21.08	22.27	25.32	25.23	24.02	24.17	23.66	23.05	22.66	21.37	18.02
2004	18.85	19.40	23.65	23.93	23.84	23.92	23.24	23.39	22.82	22.09	20.93	18.01
2005	18.88	22.91	22.12	24.62	25.31	24.16	23.84	23.11	23.24	22.49	21.01	17.45
2006	19.07	21.13	23.53	24.35	23.68	24.62	23.53	23.08	23.03	22.53	22.31	18.81
2007	18.24	21.74	24.01	24.13	23.83	24.88	24.15	23.62	23.06	21.82	18.90	19.84
2008	18.54	16.71	22.05	24.33	23.37	23.47	23.24	23.36	23.21	22.58	19.24	17.33
2009	16.78	22.82	23.54	24.07	23.89	24.09	23.68	24.04	23.56	22.90	20.31	19.43
2010	19.71	22.27	23.79	26.04	25.95	25.18	24.48	23.47	23.53	21.81	20.05	19.13
2011	16.53	20.52	19.72	23.33	23.64	23.84	23.70	23.35	22.68	21.84	20.65	17.17
2012	18.63	21.38	23.14	24.64	24.42	24.06	23.37	23.40	23.26	22.97	22.67	20.07
2013	18.77	22.48	24.21	25.00	24.83	24.17	23.36	23.54	22.86	21.67	20.78	15.76
2014	17.03	20.47	24.16	24.83	25.22	24.47	23.51	23.48	23.46	22.64	21.60	17.97
2015	17.59	20.40	24.30	24.62	25.89	25.33	23.73	23.73	23.62	22.41	22.24	19.34
2016	18.43	17.98	23.89	27.21	25.54	24.53	24.04	23.97	23.57	23.18	21.14	19.12
2017	19.37	20.09	23.20	24.15	24.42	24.46	23.40	23.91	23.96	22.25	20.78	17.91
2018	18.67	19.40	22.23	23.83	24.63	23.85	23.56	23.21	23.65	22.89	21.73	20.05
2019	19.51	23.10	24.88	26.95	26.13	25.74	24.52	23.72	23.66	23.66	21.50	18.82
2020	20.61	21.12	24.86	24.23	26.77	25.21	25.09	23.72	24.10	21.41	20.89	18.16
2021	17.10	20.28	24.20	24.42	25.88	24.67	24.26	24.28	23.52	22.07	20.79	17.99
2022	19.49	18.97	23.67	23.44	23.20	24.59	24.66	23.82	23.35	22.02	22.22	17.96
2023	17.48	21.22	23.63	26.97	26.38	24.84	24.94	23.87	23.67	22.98	21.51	20.10

A comparison of monthly average temperatures between two periods—the long-term average from 2001 to 2020 and the recorded temperatures for the year 2023—was assessed for Lao PDR. This analysis also included temperature anomalies for each month, indicating deviations from the long-term average.

In January 2023, the average temperature was 17.128°C, which is 1.089°C cooler than the long-term average of 18.217°C. In contrast, February experienced a slight increase in temperature, showing an anomaly of +0.355°C, resulting in an average temperature of 20.866°C compared to the long-term average of 20.511°C. March followed this warming trend, being 0.367°C warmer than the long-term average of 22.913°C, recording a temperature of 23.281°C. These cooler temperatures in January could delay the planting season and slow down the initial growth stages of crops, potentially reducing yields. However, the warming in February and March could mitigate some of these effects, helping to accelerate crop growth.

April observed a significant increase in temperature. The average for April 2023 was 26.617°C, which is 2.129°C warmer than the long-term average of 24.488°C. May experienced a similar trend, with an anomaly of +1.691°C, leading to an average temperature of 26.033°C compared to the long-term average of 24.342°C. Both June and July had temperatures above the long-term averages, with June being 0.461°C warmer and July 1.180°C warmer than their respective long-term averages. These increases in temperature during the mid-year could accelerate crop growth, but also increase water requirements and the risk of heat stress, potentially impacting crop health and productivity.

August observed a moderate warming, with a temperature of 23.517°C, resulting in an anomaly of +0.352°C over the long-term average of 23.165°C. September, October, and November also experienced temperature increases, with anomalies of +0.354°C, +0.550°C, and +0.649°C, respectively. The average temperatures in these months were above their long-term averages. Warmer temperatures in these months could lead to an extended growing season but also heighten the risk of drought and pest infestations, which could adversely affect crop yields.

December concluded the year with a temperature of 19.748°C, which was 1.569°C warmer than the long-term average of 18.180°C. Warmer winters can impact certain crops that require cooler temperatures for vernalization, potentially affecting flowering and fruiting stages.

Overall, the data reveals that 2023 in Lao PDR had a mix of cooler and warmer months compared to the long-term averages, with most months showing warming anomalies, particularly in the latter half of the year. This trend of increasing temperatures, especially during crucial growing months, has significant implications for cropland in Lao PDR. Warmer temperatures can lead to changes in growing seasons, increased water demand, and greater stress on crops. These factors necessitate adaptive measures such as altering planting schedules, implementing water management strategies, and adopting heat-resistant crop varieties to sustain agricultural productivity and food security in the face of changing climatic conditions.

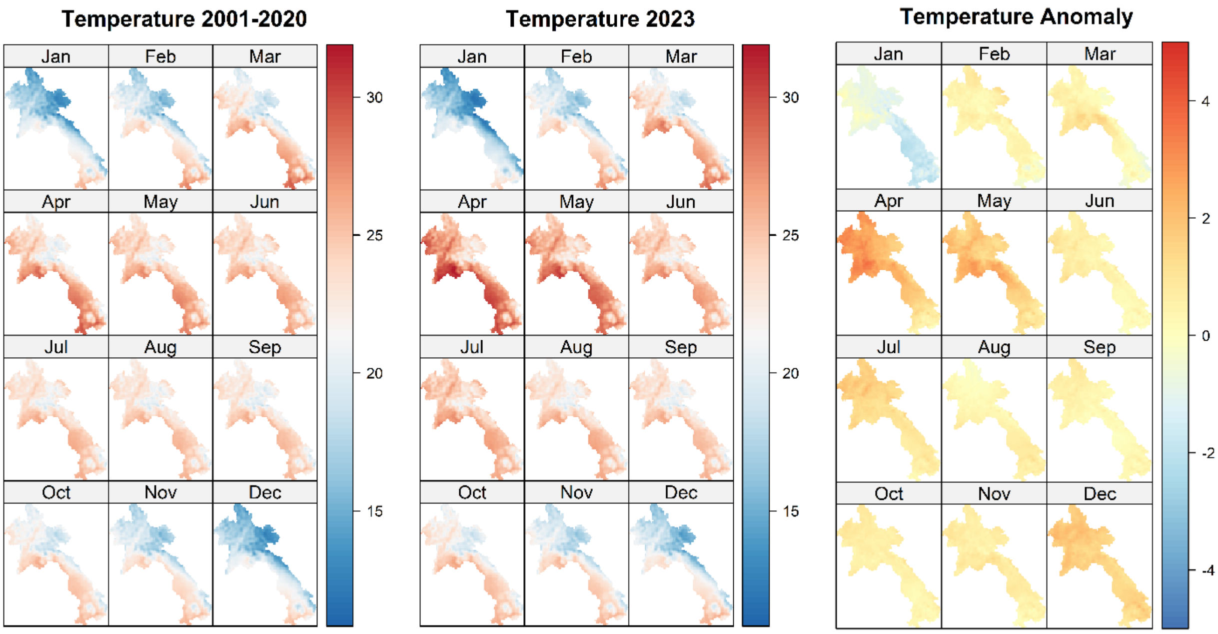

Figure 46 *Spatial distribution of temperatures in Lao PDR, displaying long-term monthly average temperatures, monthly average temperatures for 2023, and anomaly maps showing the difference between the 2023 temperatures and the long-term averages*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

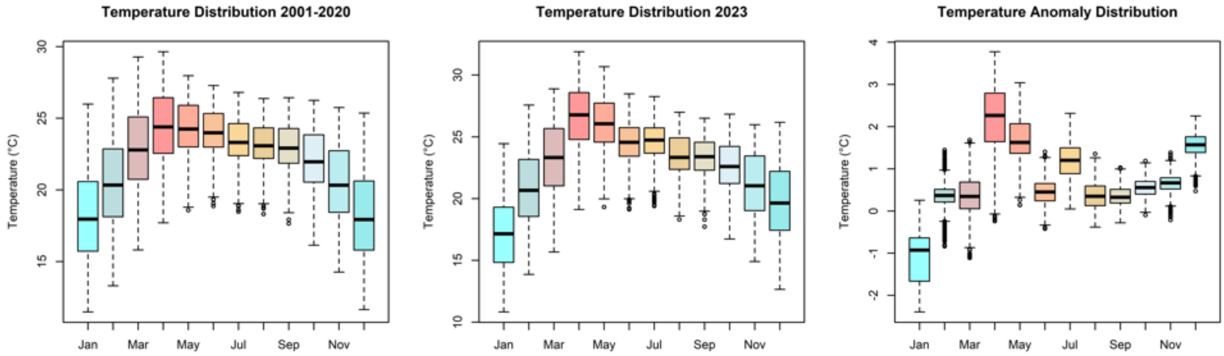

Figure 47 *Boxplot visualization of the mean monthly temperatures in Lao PDR, comparing the long-term monthly averages, the monthly temperatures recorded in 2023, and the corresponding temperature anomalies*

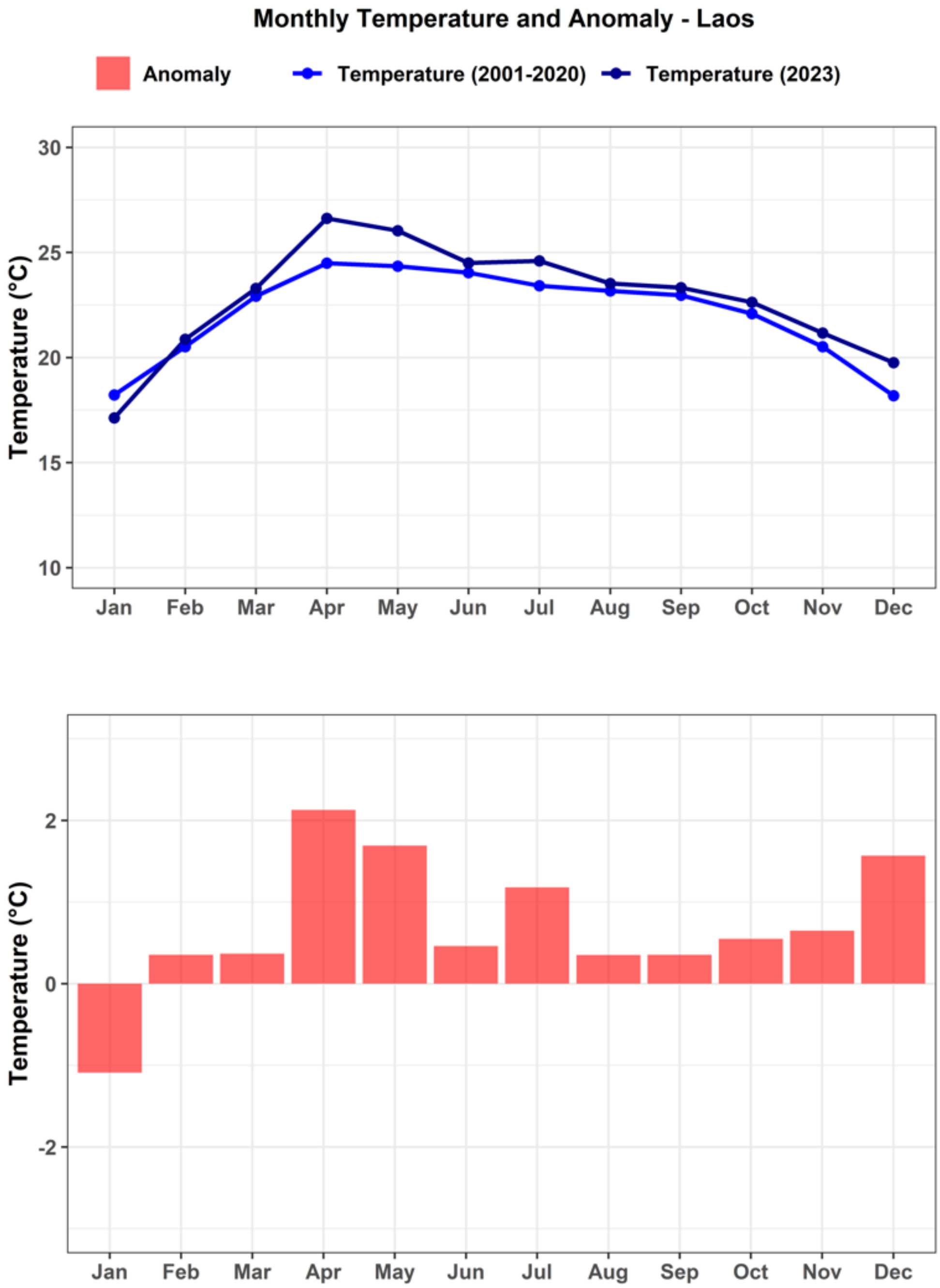

Figure 48 *Spatially aggregated monthly temperature series in Lao PDR, showing the long-term averages, the temperatures recorded in 2023, and the anomalies*

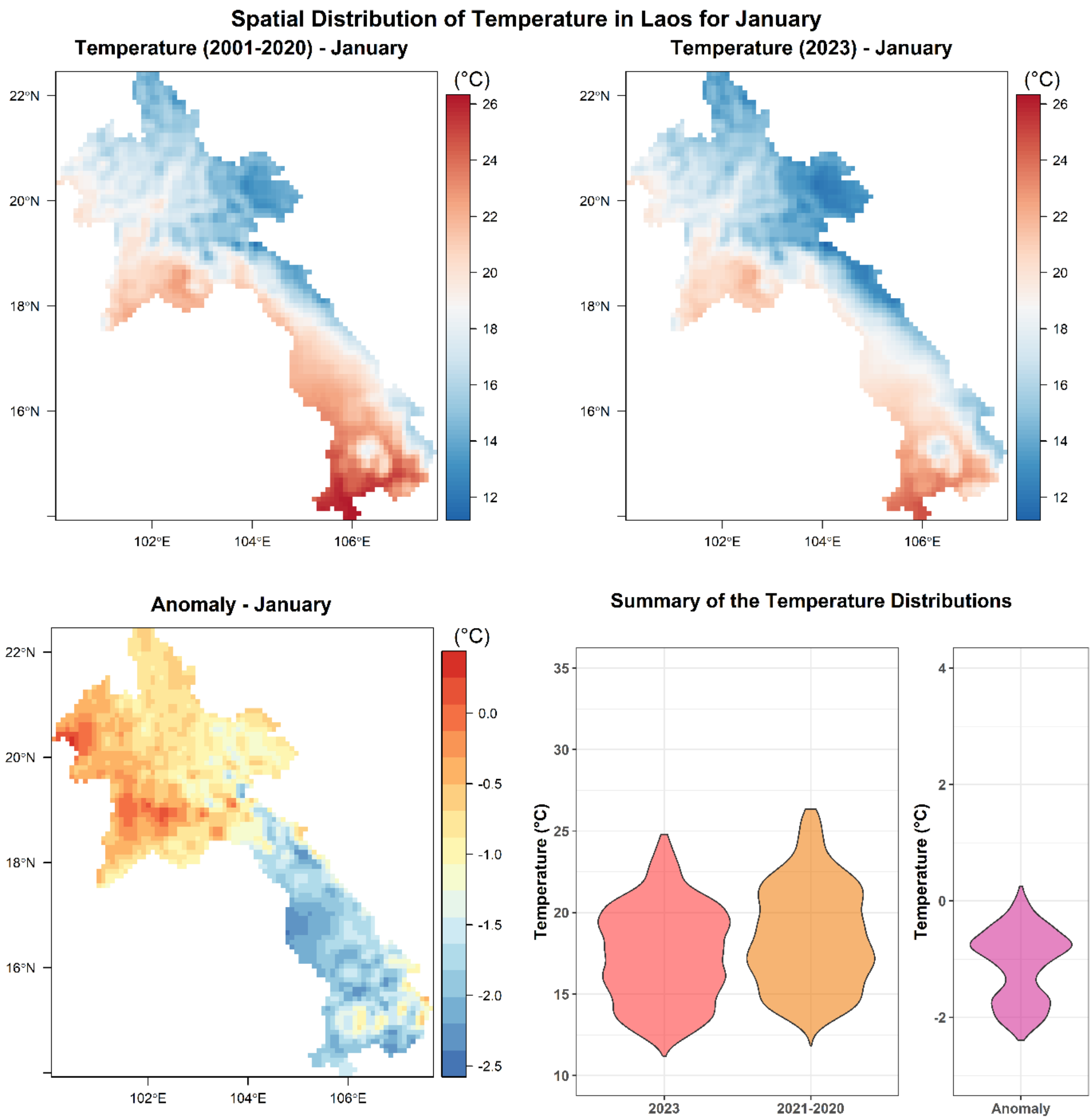

Figure 49 Maps and violin plots illustrate the spatial distribution of January temperatures in Lao PDR. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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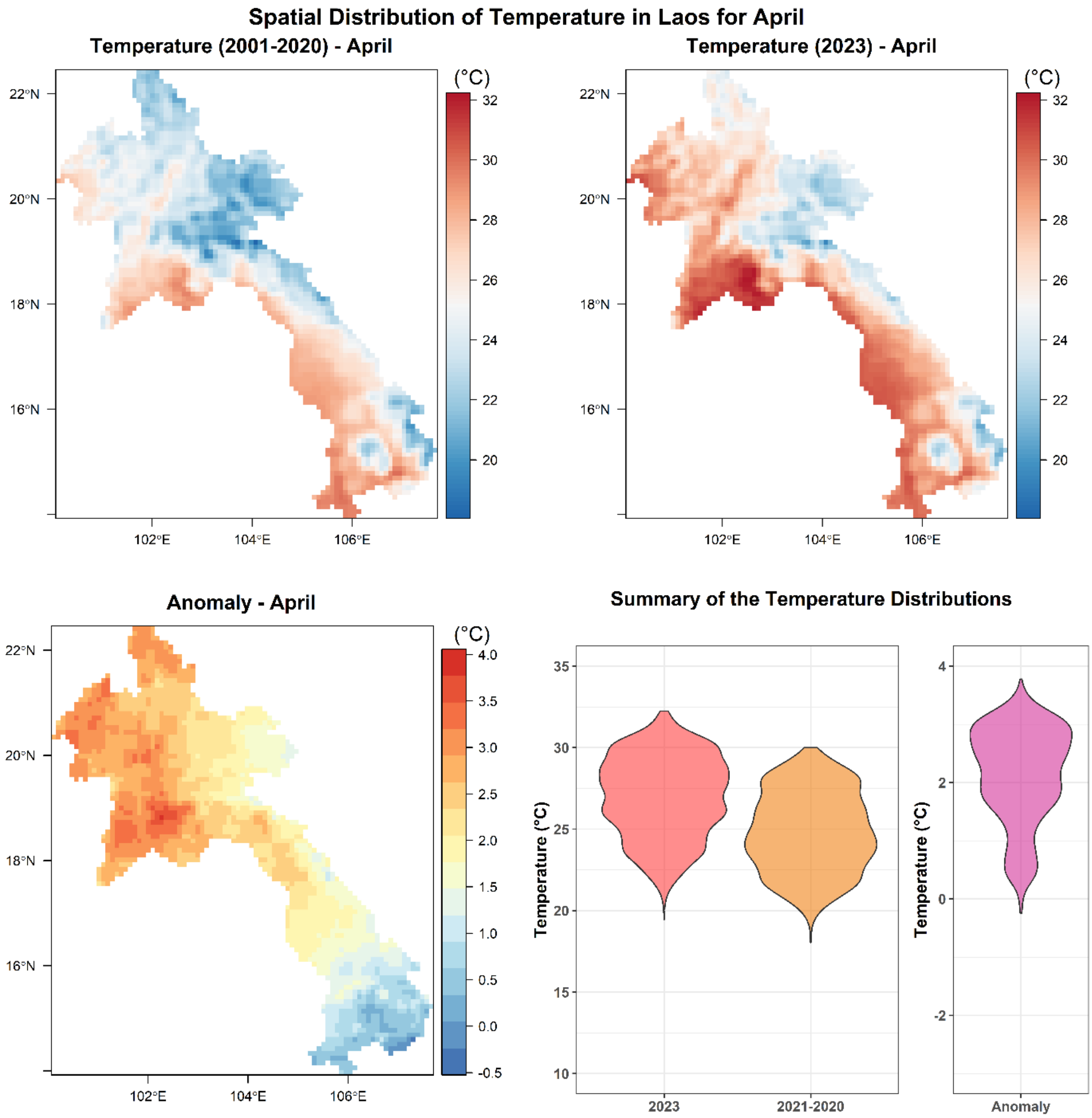

Figure 50 *Maps and violin plots illustrate the spatial distribution of April temperatures in Lao PDR. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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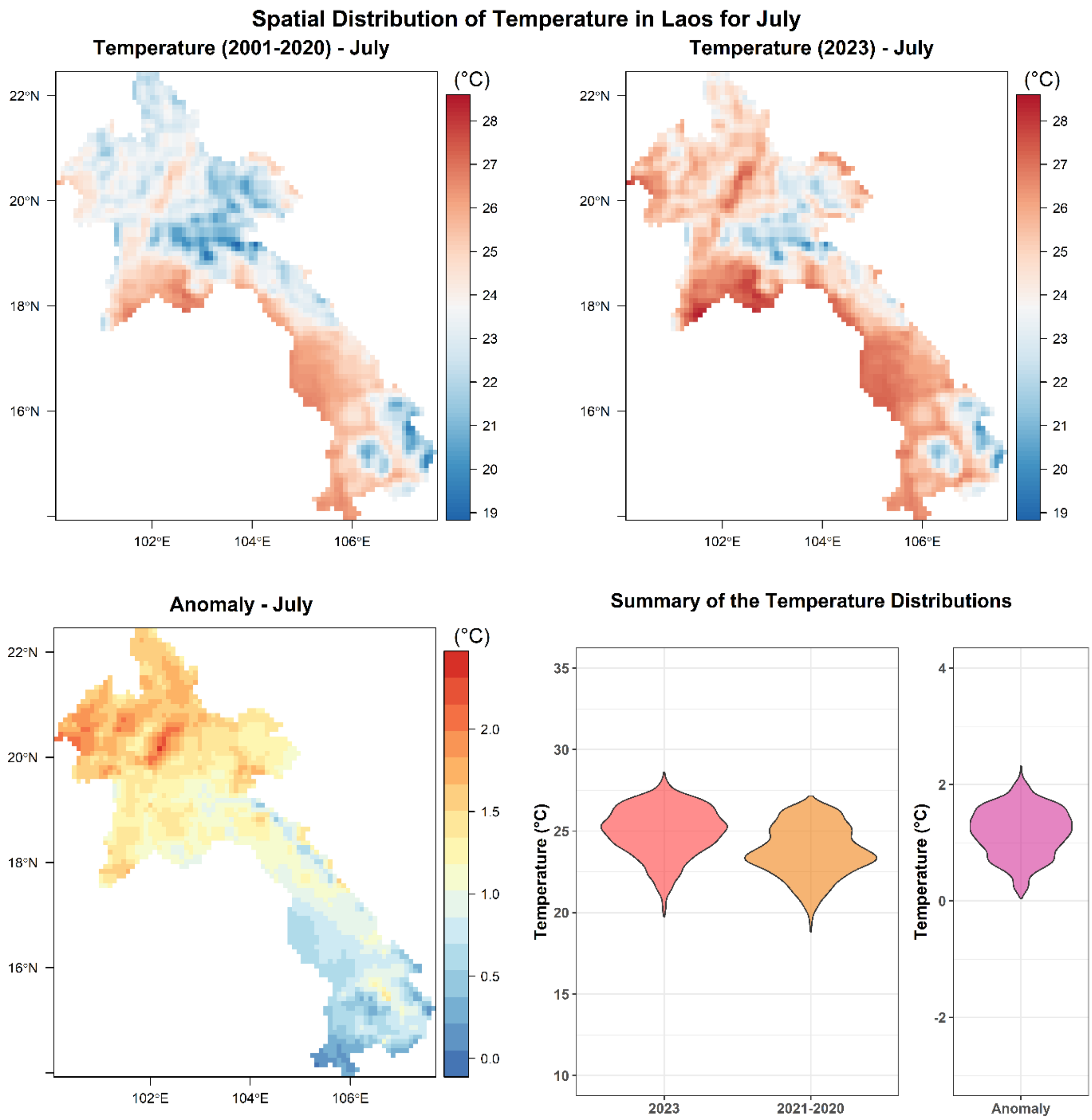

Figure 51 *Maps and violin plots illustrate the spatial distribution of August temperatures in Lao PDR. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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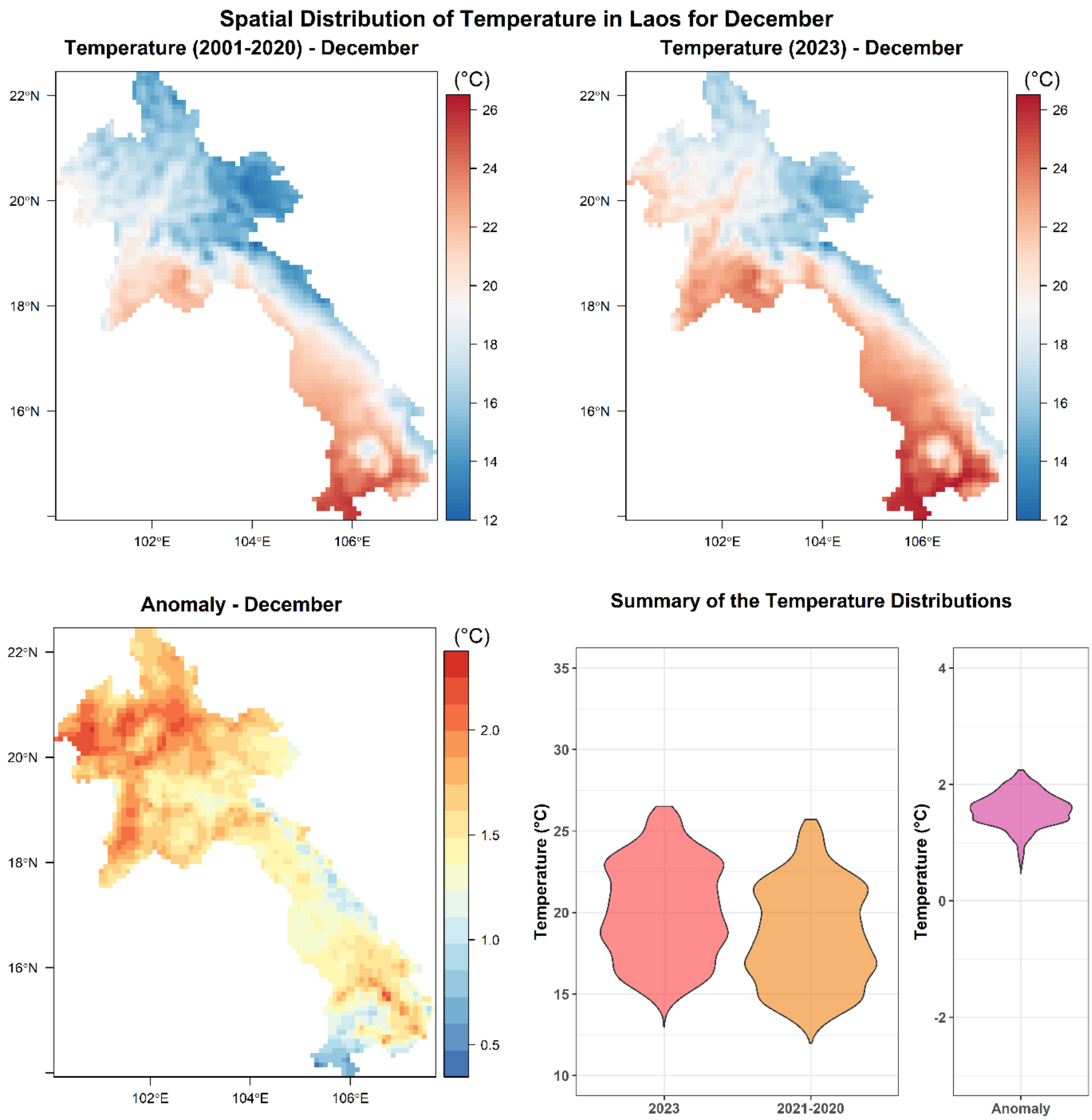

Figure 52 Maps and violin plots illustrate the spatial distribution of December temperatures in Lao PDR. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

__Table 19__ Monthly averages of long-term temperatures (°C), 2023 monthly averages (°C), and temperature anomalies (°C) in Lao PDR

Month	Temperature (2001-2020)	Temperature (2023)	Anomaly
Jan	*18.217*	*17.128*	*-1.089*
Feb	*20.511*	*20.866*	*0.355*
Mar	*22.913*	*23.281*	*0.367*
Apr	*24.488*	*26.617*	*2.129*
May	*24.342*	*26.033*	*1.691*
Jun	*24.031*	*24.491*	*0.461*
Jul	*23.411*	*24.591*	*1.180*
Aug	*23.165*	*23.517*	*0.352*
Sep	*22.962*	*23.317*	*0.354*
Oct	*22.079*	*22.629*	*0.550*
Nov	*20.514*	*21.163*	*0.649*
Dec	*18.180*	*19.748*	*1.569*

3.2.4. Trends of Rainfall in Lao People's Democratic Republic (Lao PDR)

The analysis of rainfall changes in Lao PDR was conducted using ERA5 rainfall data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term rainfall averages (2001-2020) with the recorded rainfall for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average rainfalls and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average rainfalls, the monthly rainfalls for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of rainfall changes, violin plots and box plots were used. Violin plots illustrated the distribution of rainfalls, showing the density and probability of different rainfall ranges over time. Box plots offered a clear visualization of the rainfall distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the rainfall changes in Lao PDR, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of rainfall trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual rainfall trend in Lao PDR indicates a decrease in average rainfall from 1986 mm to 1921 mm between 1991 and 2020, reflecting a decline of 25 mm over nearly three decades. The average rainfall during this period was 1953 mm. Additionally, the peak of rainfall distribution has shifted towards lower values compared to the distribution from 1971 to 2000, highlighting a significant reduction in rainfall over the past three decades.

Over the past two decades, Lao PDR has experienced significant fluctuations in its monthly precipitation trends, which could have profound effects on its agricultural landscape. Between 2000 and 2010, key agricultural months like March, May, and August observed increases in average monthly rainfall, with rises of 5.99 mm, 18.82 mm, and 9.04 mm, respectively. These increases generally benefited crop growth, providing ample water during critical growing periods. However, April and June showed declines in rainfall by -8.17 mm and -3.08 mm, respectively, which could have caused some challenges during these months.

The following decade, from 2010 to 2020, marked a concerning shift. Critical months such as March, April, and May experienced sharp declines in rainfall by -11.08 mm, -17.15 mm, and -39.12 mm, respectively. These reductions during essential growing periods could lead to severe water stress for crops, potentially lowering yields and increasing the likelihood of crop failures. Conversely, July and August saw increases in rainfall, with rises of 30.16 mm and 26.06 mm, respectively. While these increases during the monsoon season might seem beneficial, they could also pose challenges such as waterlogging and increased pest infestations, which could negatively impact crop health and productivity.

The shifting precipitation patterns are further highlighted by the changes observed during the off-season months.

For instance, January, which saw a decrease of -2.04 mm in the 2000-2010 decade, experienced an increase of 15.39 mm in the 2010-2020 period. Similarly, December's rainfall trend shifted from a decrease of -3.03 mm to an increase of 11.02 mm over the same period. These off-season increases raise concerns about their limited agricultural benefit and the potential for off-season flooding, which could disrupt soil structure and prepare unfavourable conditions for the following planting season.

These shifting precipitation patterns, characterized by reduced rainfall during key agricultural months and increased rainfall during off-season months, underscore the growing unpredictability of Lao PDR's climate. These changes could disrupt traditional farming practices, making it increasingly difficult for farmers to rely on historical weather patterns for determining planting and harvesting schedules. As a result, adaptive strategies are becoming more urgent, including shifting planting seasons, adopting drought-resistant crop varieties, and relying more heavily on irrigation to cope with reduced rainfall during crucial months. Additionally, improved water management systems will be essential to mitigate the negative impacts of increased rainfall during the off-season, such as flooding and soil erosion.

The trends observed over these two decades highlight the need for a strategic approach to agriculture in Lao PDR. Farmers and policymakers must work together to develop adaptive strategies that can mitigate the impacts of these changing precipitation patterns, ensuring sustainable agricultural productivity and food security in the face of an increasingly unpredictable climate.

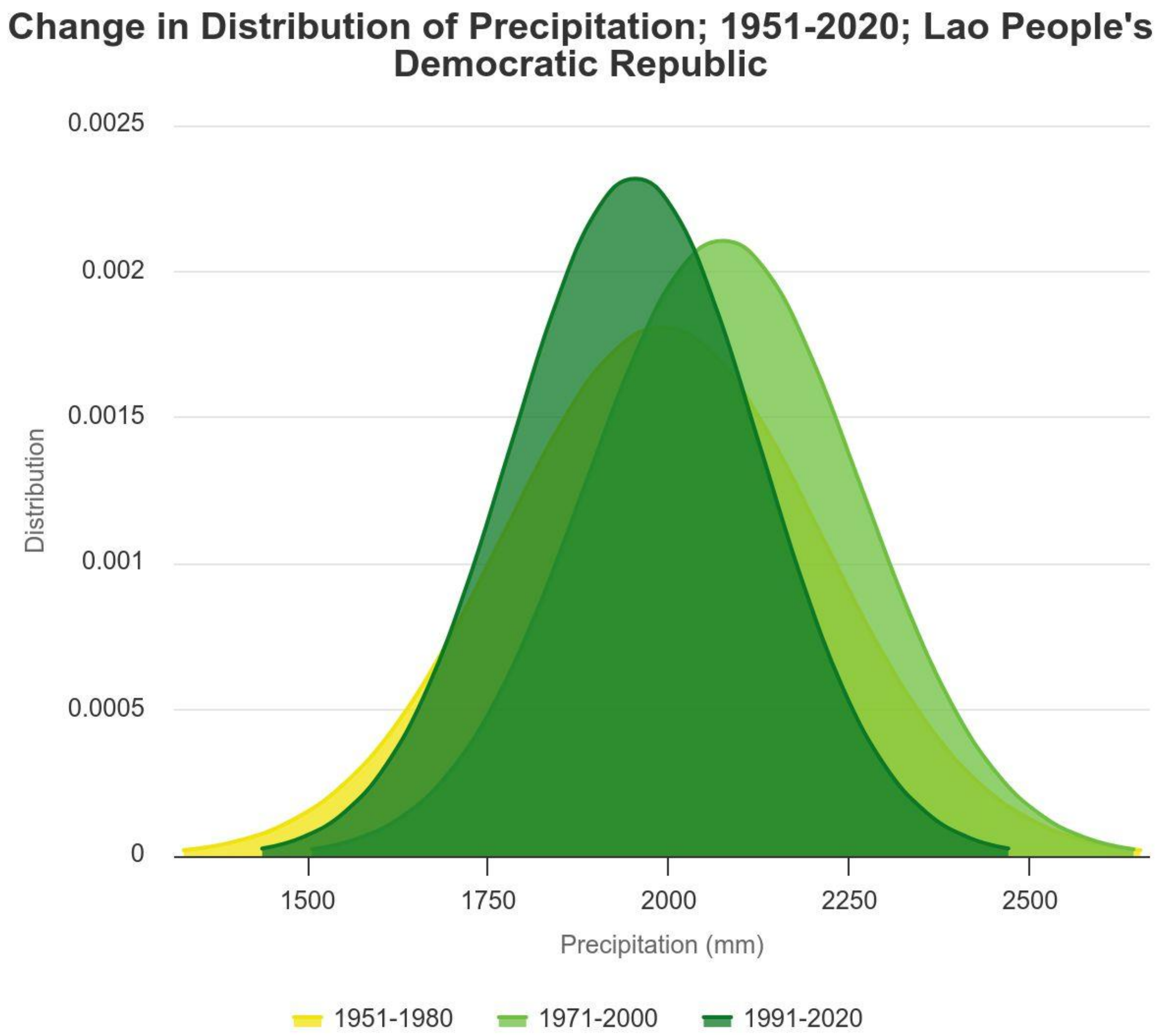

Figure 53 *Change in distribution of average rainfall in Lao PDR for 1951 – 1980, 1971 – 2000, and 1991-2020 (CCKP, 2024b)*

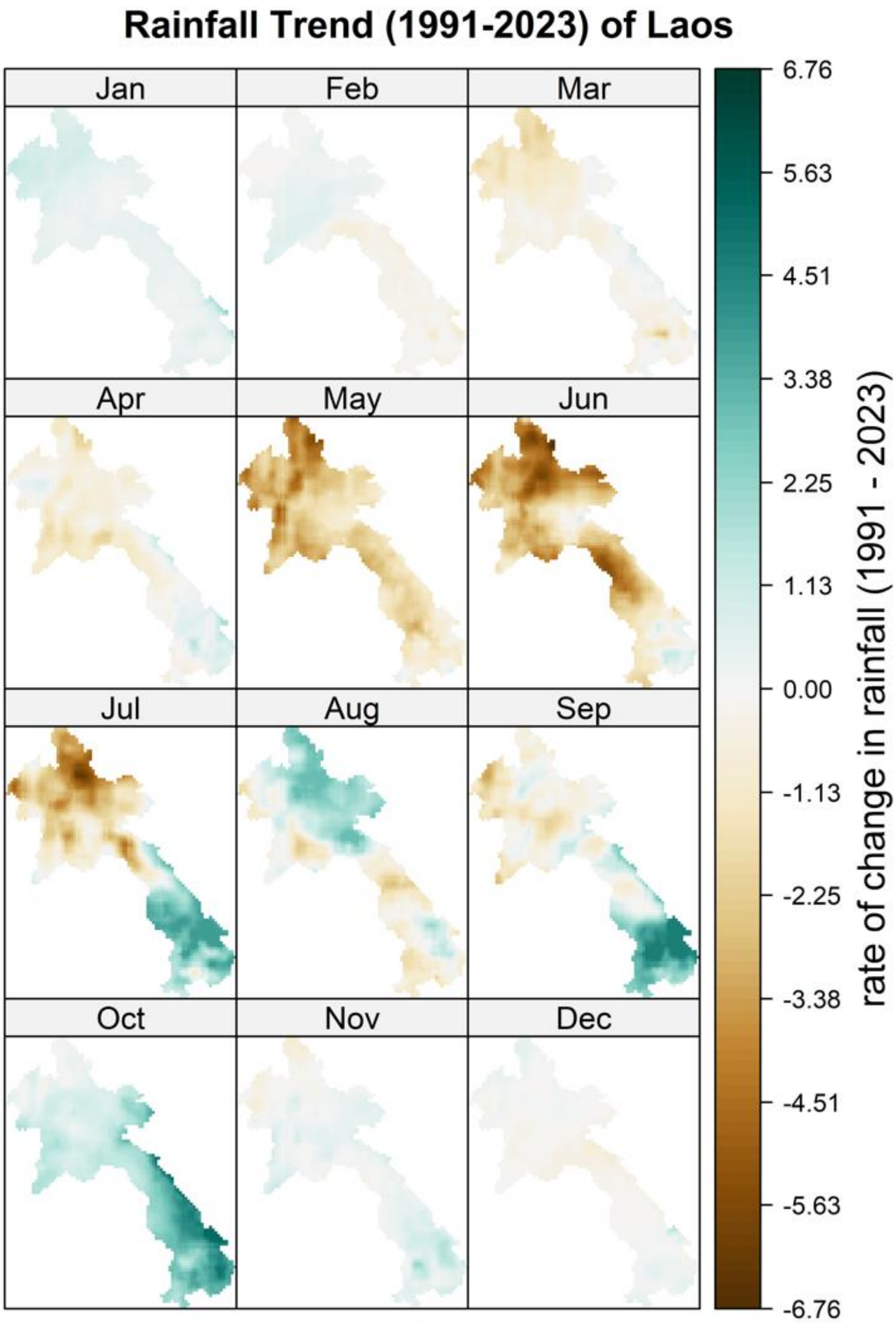

Figure 54 *Spatial patterns of rainfall trends in Lao PDR, indicating the rate of change in rainfalls from 1991 to 2023*

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Over the past three decades, Lao PDR has experienced notable shifts in monthly rainfall trends, which carry significant implications for its agricultural practices, particularly in the rice-growing regions. These trends, characterized by both increases and decreases in rainfall, are likely to influence crop production cycles, water management strategies, and overall food security.

The wet season, which is critical for rice planting, growing, and harvesting, has shown substantial variability in rainfall. In May, rainfall has increased from 184.89 mm in 1991 to 308.63 mm in 2022. This increase could lead to waterlogging during the early stages of rice planting, potentially harming young plants. Similarly, June's rainfall peaked at 435.65 mm in 1994 but dropped significantly to 185.32 mm in 2020. Such fluctuations can affect early crop growth, leading to either water stress or excessive moisture, both of which can reduce yields.

July and August have generally seen an upward trend in rainfall, with July reaching 601.07 mm in 2018 and August peaking at 503.84 mm in the same year. While this ensures ample water supply, it also increases the risk of flooding, which can damage crops and reduce productivity. In September, rainfall has varied widely, from 421.76 mm in 2009 to 208.11 mm in 2018. Such variability can result in unpredictable harvests, with excessive rainfall delaying harvests and insufficient rainfall leading to poor grain development. October, which is crucial for harvesting, has also shown variability, with rainfall ranging from 253.73 mm in 1991 to 292.26 mm in 2020. Increased rainfall during this period can lead to post-maturation damage.

The dry season months have also exhibited significant fluctuations, which could disrupt traditional water management practices and agricultural planning. In January, rainfall has risen dramatically from 12.69 mm in 1991 to 71.72 mm in 2023. This increase in what is traditionally a dry month could complicate water storage efforts and preparation for the planting season. February and March have shown high variability, with March, in particular, seeing a sharp decline from 156.39 mm in 2001 to just 21.01 mm in 2023. Such changes can severely impact the timing and effectiveness of field preparation for the upcoming growing season.

The observed rainfall trends indicate growing unpredictability in Lao PDR's climate, posing several challenges for agriculture. The increased rainfall during traditionally dry months necessitates improved water management systems to capture and store water for use during drier periods. Conversely, the rising rainfall during the monsoon months heightens the risk of flooding and waterlogging, which can damage sensitive crops like rice. To cope with these challenges, farmers may need to adjust planting and harvesting calendars, adopt climate-resilient crop varieties that can withstand both excessive rainfall and potential droughts and enhance irrigation systems. Developing adaptive strategies in water management and crop planning will be essential to maintaining agricultural productivity and food security in the face of these changing climatic conditions.

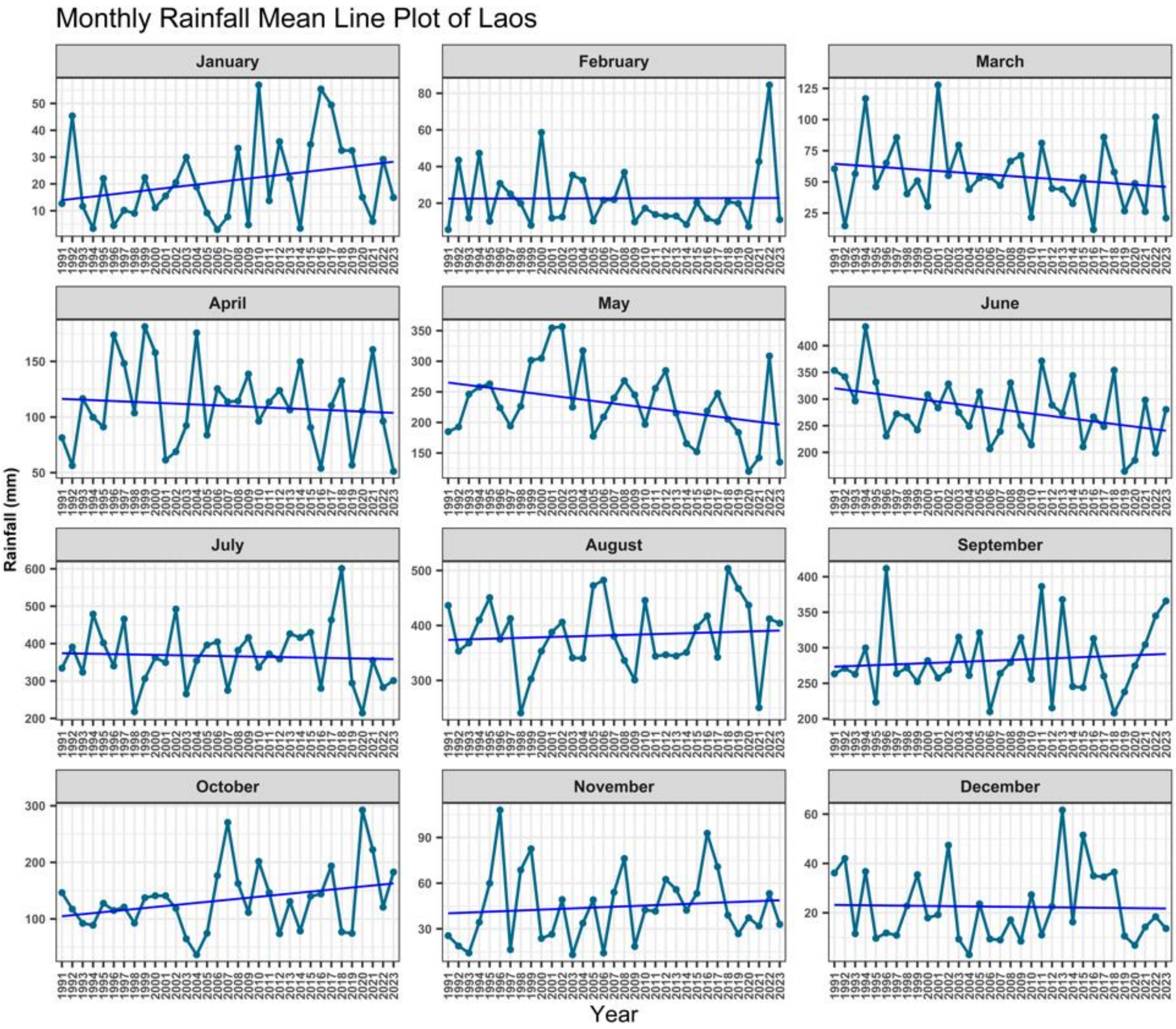

Figure 55 Spatially aggregated mean monthly rainfall time series line plots with trend lines, depicting the variation of mean monthly rainfalls over time in Lao PDR.

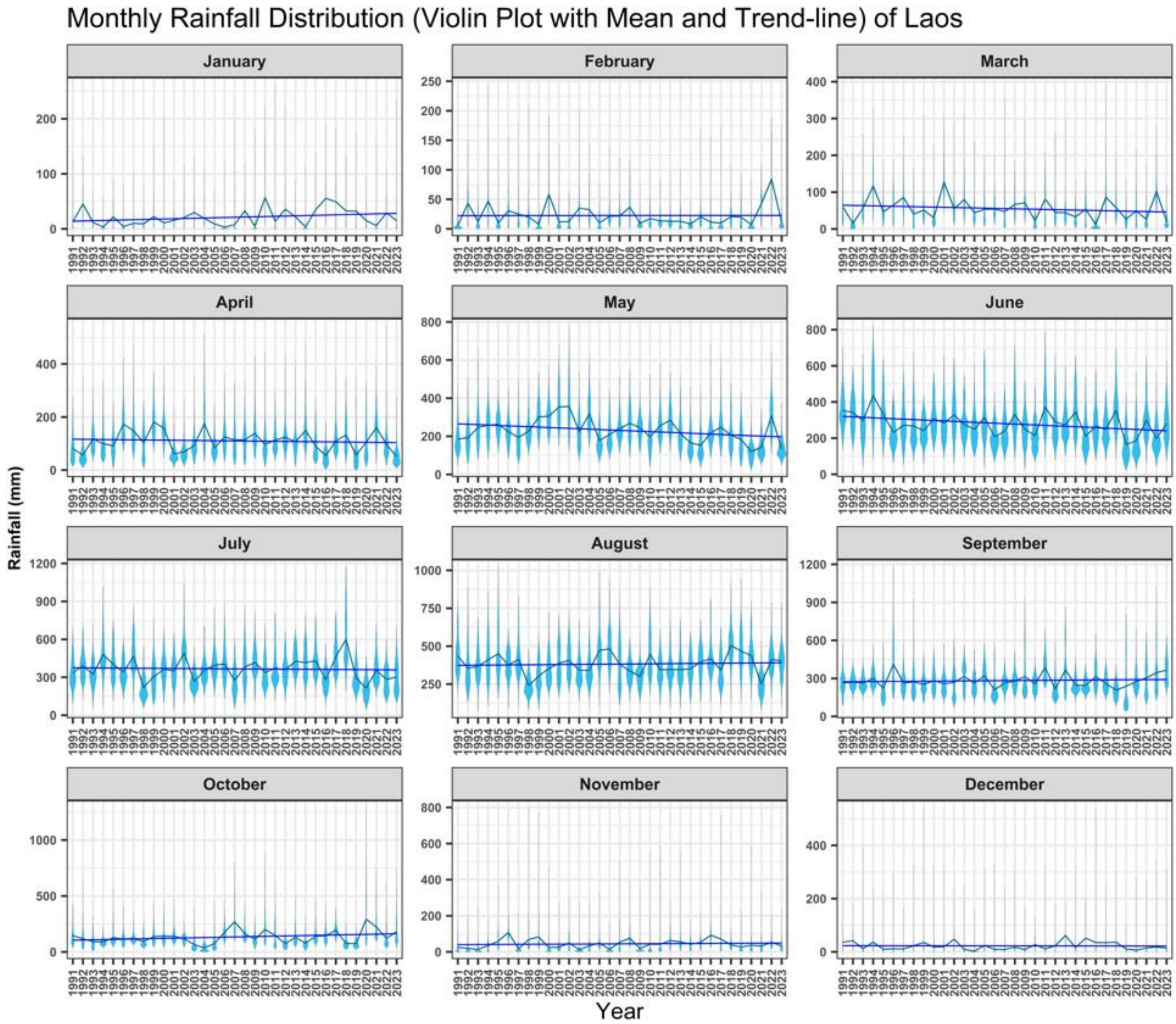

__Figure 56__ Distribution of mean monthly rainfall time series and violin plots in Lao PDR, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly rainfalls

Table 20 Spatially aggregated mean monthly rainfall (mm) in Lao PDR from 1991 to 2023, derived from ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	12.687	5.582	60.498	81.352	184.890	353.723	334.503	436.424	263.226	146.323	25.520	36.151
1992	45.367	43.509	14.753	56.376	192.617	341.768	390.816	353.304	271.151	117.315	18.750	42.024
1993	11.655	11.869	56.529	116.628	246.083	296.296	323.496	368.085	262.639	92.207	14.214	11.519
1994	3.386	47.256	116.808	99.814	257.739	435.653	478.863	410.115	299.802	88.913	34.395	36.744
1995	22.038	10.130	46.098	91.115	262.986	331.740	401.972	450.660	223.347	127.510	59.904	9.673
1996	4.457	30.767	65.101	173.805	223.976	230.664	340.353	375.000	411.744	114.964	107.980	11.842
1997	10.146	25.040	85.565	148.101	194.106	272.007	465.793	412.532	263.645	120.898	16.380	10.858
1998	9.033	19.850	40.381	103.628	226.354	266.783	217.988	240.635	271.744	92.534	68.684	22.780
1999	22.369	7.951	50.849	181.230	301.527	242.041	306.284	302.548	252.297	137.361	82.537	35.414
2000	11.091	58.577	30.391	157.916	304.815	308.252	362.651	353.262	281.937	140.999	23.720	17.933
2001	15.507	11.932	127.765	61.379	354.527	283.411	349.371	387.700	257.418	140.939	26.441	19.194
2002	20.563	12.484	55.107	68.883	356.517	328.435	492.181	406.077	268.934	118.594	49.210	47.381
2003	29.913	35.332	79.499	92.349	224.964	274.944	265.514	341.056	314.962	64.807	13.019	9.320
2004	18.845	32.507	43.970	175.623	317.427	248.958	354.489	340.185	261.078	36.699	33.736	2.990
2005	9.157	10.311	53.242	83.814	177.457	313.300	396.318	472.544	321.299	74.510	49.066	23.609
2006	2.965	21.593	54.030	125.425	208.825	206.475	404.618	482.433	209.831	176.455	14.126	9.392
2007	7.757	21.924	47.150	113.772	239.816	239.109	275.025	380.328	263.926	270.449	54.007	8.965
2008	33.296	36.843	66.631	114.436	268.217	330.404	382.163	336.336	279.198	162.624	76.211	17.115
2009	4.740	9.770	71.124	138.635	244.975	250.147	416.235	300.878	314.220	111.555	18.462	8.474
2010	56.906	17.302	21.501	96.270	196.743	213.970	336.440	445.609	255.843	201.574	42.456	27.307
2011	13.750	13.774	81.093	113.465	255.694	371.419	372.650	344.031	386.367	146.505	41.593	10.979
2012	35.782	12.891	44.722	123.890	284.757	288.633	358.997	346.625	215.353	73.808	62.480	22.563
2013	22.033	12.970	43.999	106.405	214.896	273.543	426.152	344.382	367.783	130.698	55.815	61.615
2014	3.451	8.341	32.584	149.809	165.423	344.029	416.226	351.083	245.379	78.650	42.219	16.269
2015	34.735	20.424	53.619	90.579	152.106	210.342	430.059	397.132	244.025	139.985	53.305	51.459
2016	55.359	11.635	11.731	53.937	218.655	266.579	280.354	417.314	312.932	144.105	92.755	34.966
2017	49.416	9.891	85.945	110.227	247.468	248.389	463.491	342.235	260.156	193.621	70.769	34.577
2018	32.464	20.869	57.807	132.543	205.232	354.040	601.070	503.842	208.114	76.935	38.985	36.494
2019	32.413	19.795	26.692	56.833	183.631	164.512	294.511	467.123	237.837	74.402	26.745	10.591
2020	15.033	7.278	48.749	105.389	120.047	185.322	214.513	436.880	274.545	292.261	37.236	6.776
2021	5.997	42.69	26.189	160.70	142.19	298.13	355.14	250.44	304.48	222.25	31.878	14.224

		4		*9*	*4*	*3*	*7*	*0*	*0*	*1*		
2022	*29.161*	*84.506*	*102.053*	*96.281*	*308.635*	*198.649*	*282.998*	*412.138*	*344.859*	*120.778*	*53.186*	*18.392*
2023	*14.915*	*11.048*	*21.007*	*51.221*	*135.022*	*280.358*	*301.126*	*403.969*	*365.814*	*182.737*	*32.969*	*13.616*

A comparison of monthly average rainfall between two periods—the long-term average from 2001 to 2020 and the recorded rainfall for the year 2023—was conducted for Lao PDR, with an emphasis on analyzing rainfall anomalies that indicate deviations from the long-term average.

In January 2023, Lao PDR experienced a decrease in rainfall, recording 14.915 mm, which is 9.790 mm below the long-term average of 24.704 mm. February followed a similar trend with a decrease to 11.048 mm, 6.345 mm less than the long-term average of 17.393 mm. March saw a more substantial decline, with rainfall dropping to 21.007 mm, 34.341 mm below the average of 55.348 mm. These early-year reductions could delay the planting season, impacting the initial stages of crop growth and potentially reducing yields.

April recorded 51.221 mm of rainfall, 54.462 mm below the long-term average of 105.683 mm, and May saw a significant decrease to 135.022 mm, 96.847 mm less than the average of 231.869 mm. Such reductions during critical growth stages could hinder crop development and overall productivity.

In contrast, June and August experienced above-average rainfall. June recorded 280.358 mm, 10.560 mm above the long-term average of 269.798 mm, and August saw 403.969 mm, 11.780 mm more than the average of 392.190 mm. While increased rainfall during these months can support crop growth, it also raises concerns about water management and the risk of waterlogging or heat stress.

July, however, recorded a significant decrease in rainfall, with 301.126 mm, 75.393 mm below the long-term average of 376.519 mm. This drop could strain crops during a critical growth period, potentially affecting overall yields. September showed a notable increase, recording 365.814 mm, 90.854 mm above the long-term average of 274.960 mm. This increase could benefit late-season crops but also pose risks such as flooding.

October recorded 182.737 mm, 47.278 mm above the long-term average of 135.459 mm, while November experienced a decrease to 32.969 mm, 11.963 mm below the average of 44.932 mm. December saw a slight reduction, with 13.616 mm, 9.386 mm below the long-term average of 23.002 mm.

The rainfall patterns observed in 2023 indicate complex dynamics that significantly impact Lao PDR's agricultural sector. The early-year reductions in rainfall could delay planting and slow crop establishment, while the mid-year increases require adaptive water management to prevent excessive moisture-related stress. The variations in late summer and autumn could affect crop maturation and harvesting, necessitating adjustments in agricultural practices.

Overall, these fluctuations highlight the need for adaptive agricultural strategies, including revising planting schedules, enhancing irrigation efficiency, and selecting crop varieties that can withstand variable moisture conditions to sustain agricultural productivity and mitigate the impacts of climate change on Lao PDR's croplands.

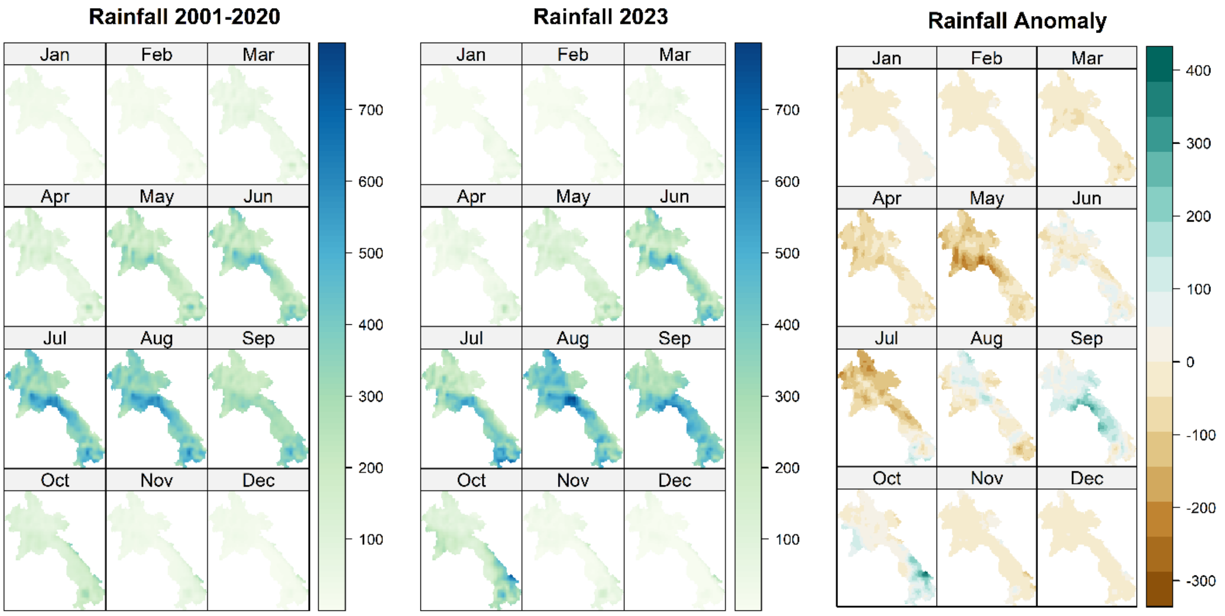

Figure 57 *Spatial distribution of rainfalls in Lao PDR, displaying long-term monthly average rainfalls, monthly average rainfalls for 2023, and anomaly maps showing the difference between the 2023 rainfalls and the long-term averages*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

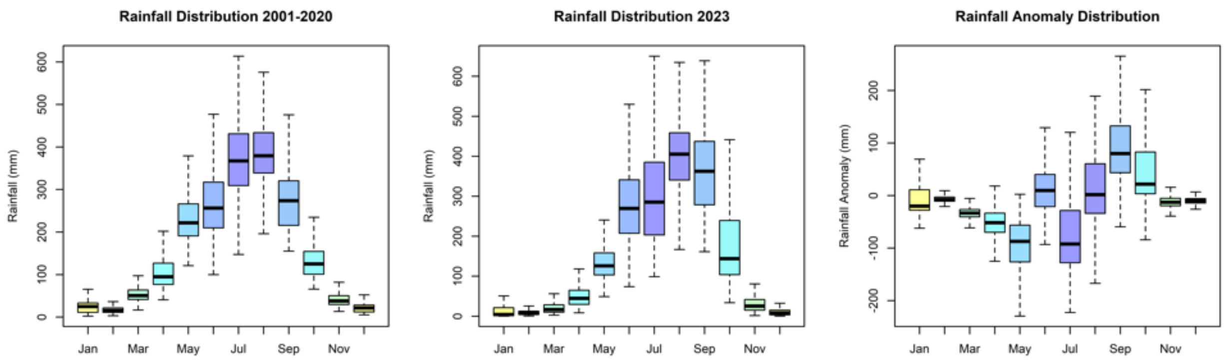

Figure 58 *Boxplot visualization of the mean monthly rainfalls in Lao PDR, comparing the long-term monthly averages, the monthly rainfalls recorded in 2023, and the corresponding rainfall anomalies*

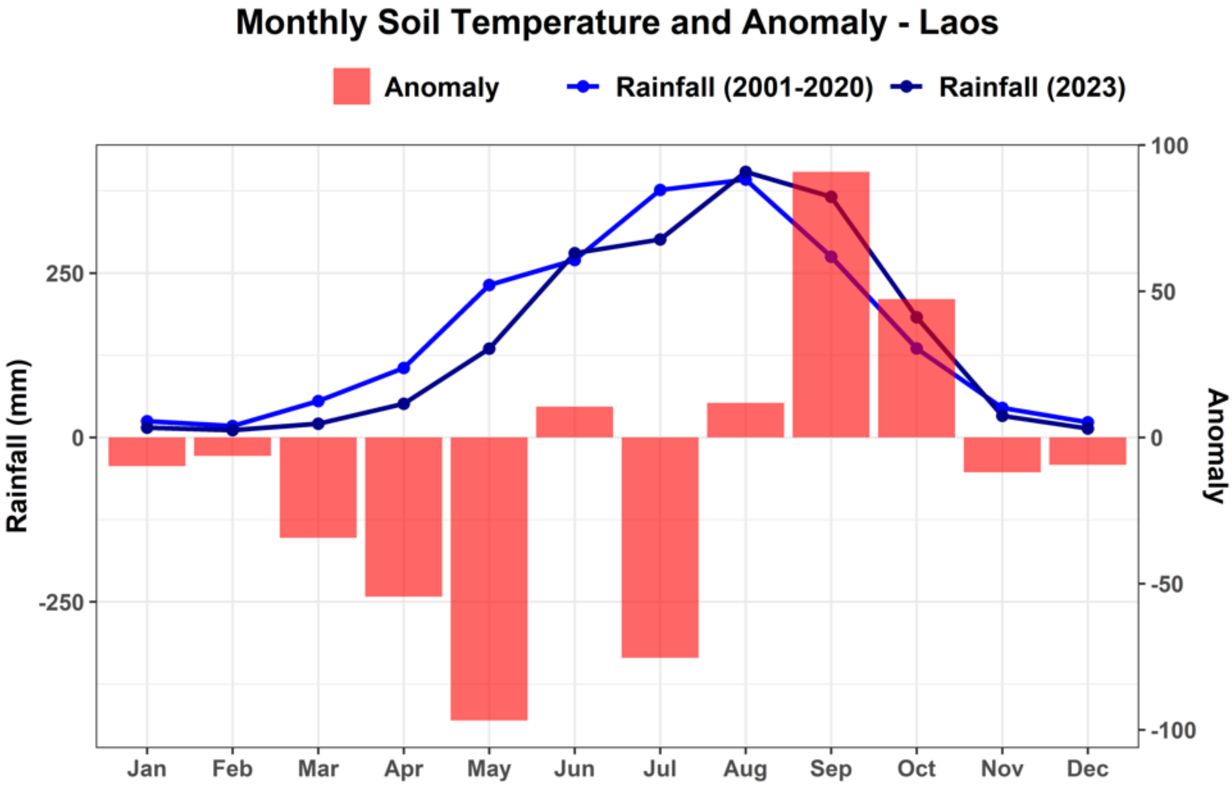

Figure 59 *Spatially aggregated monthly rainfall series in Lao PDR, showing the long-term averages, the rainfalls recorded in 2023, and the anomalies.*

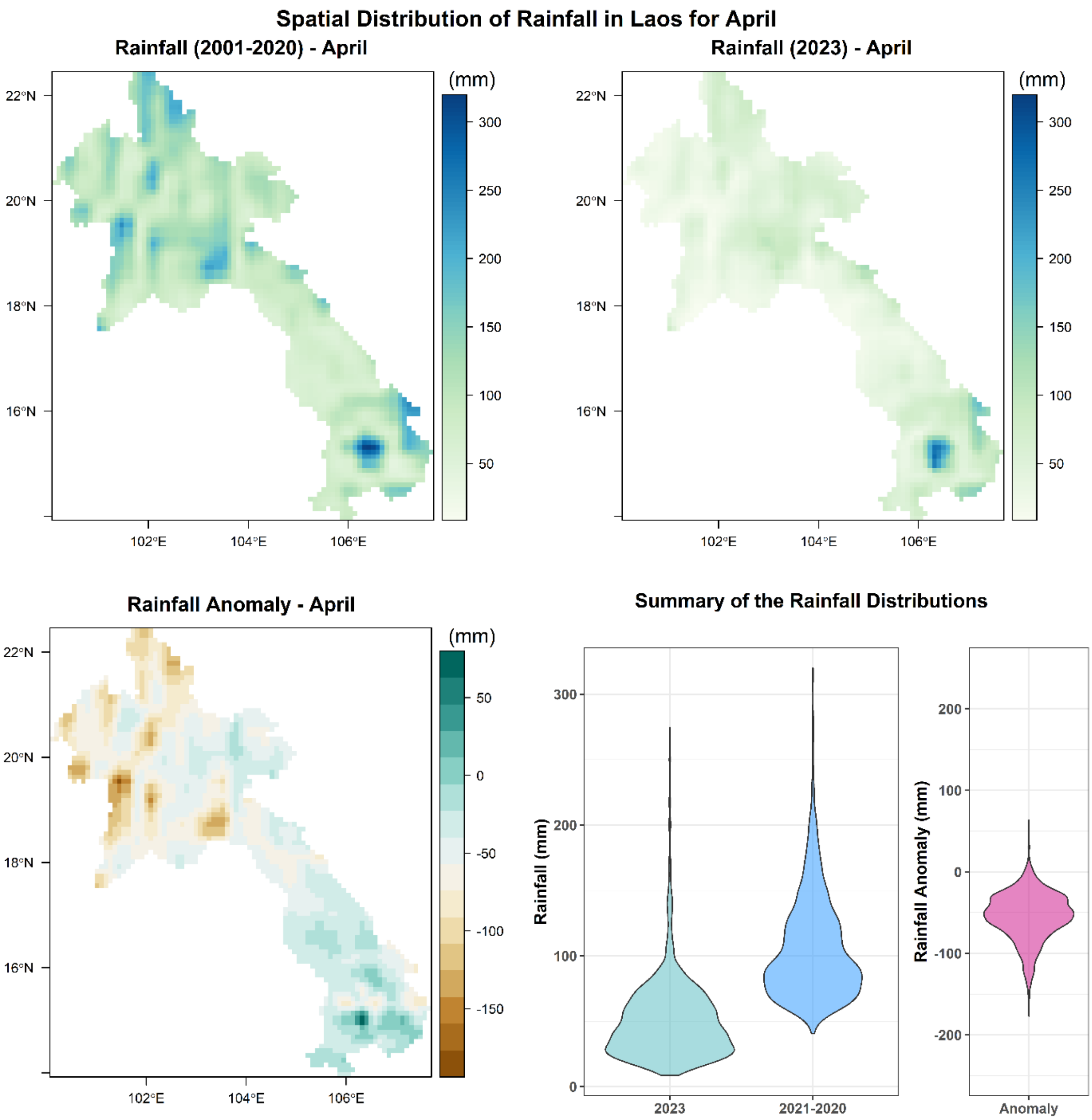

Figure 60 *Maps and violin plots illustrating the spatial distribution of April rainfalls in Lao PDR. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data*

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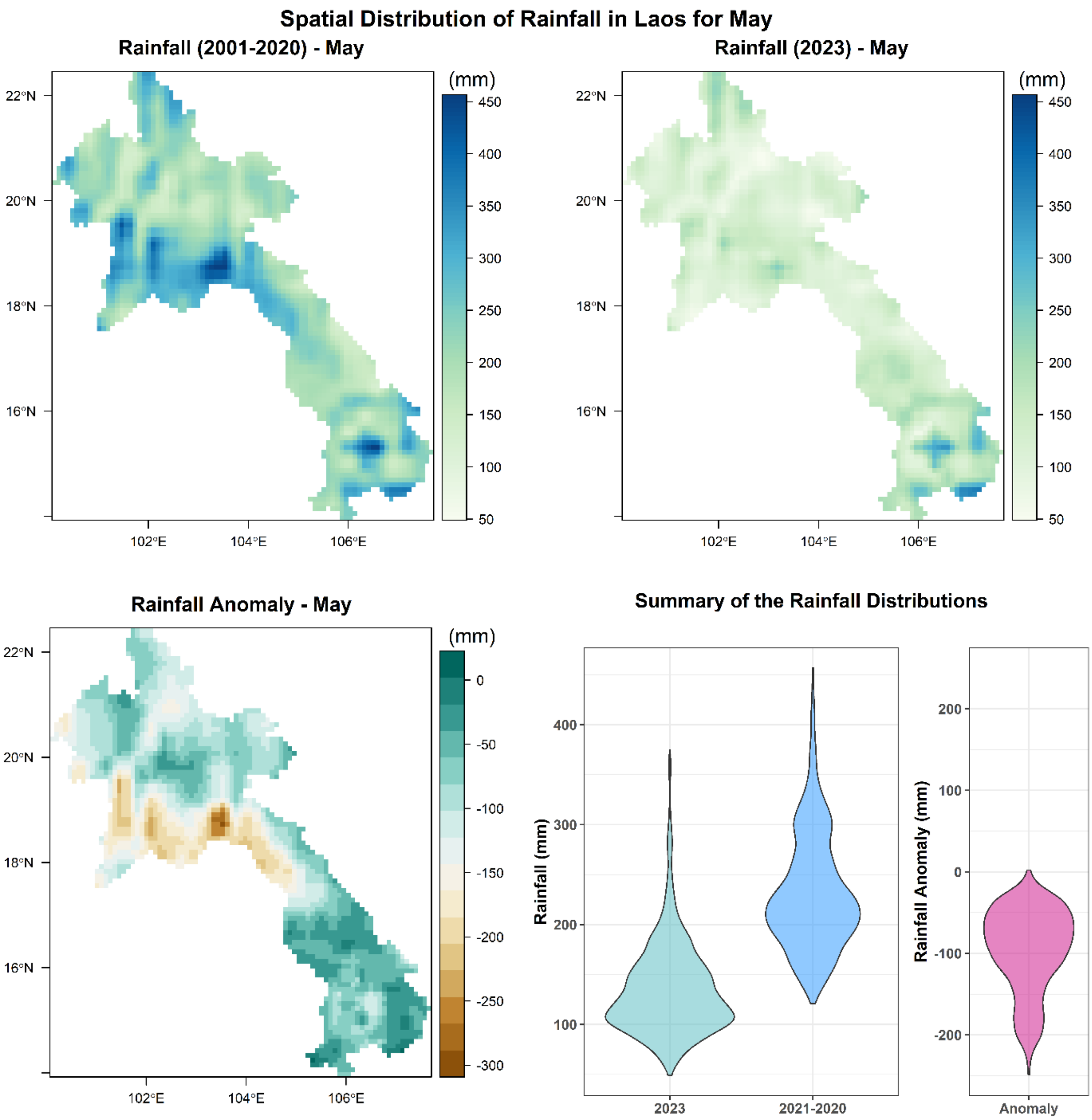

Figure 61 Maps and violin plots illustrating the spatial distribution of May rainfalls in Lao PDR. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

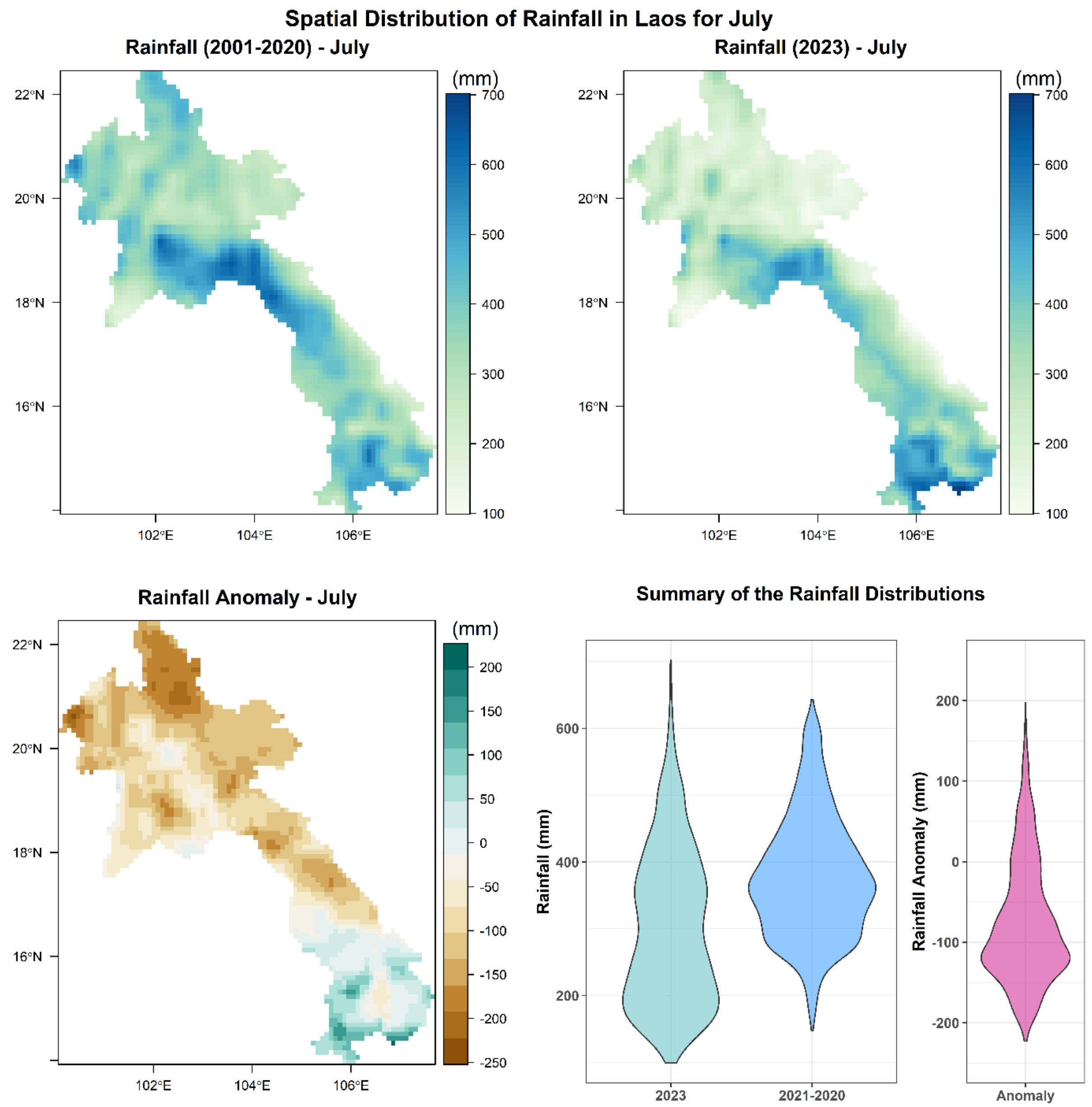

__Figure 62__ Maps and violin plots illustrate the spatial distribution of July rainfalls in Lao PDR. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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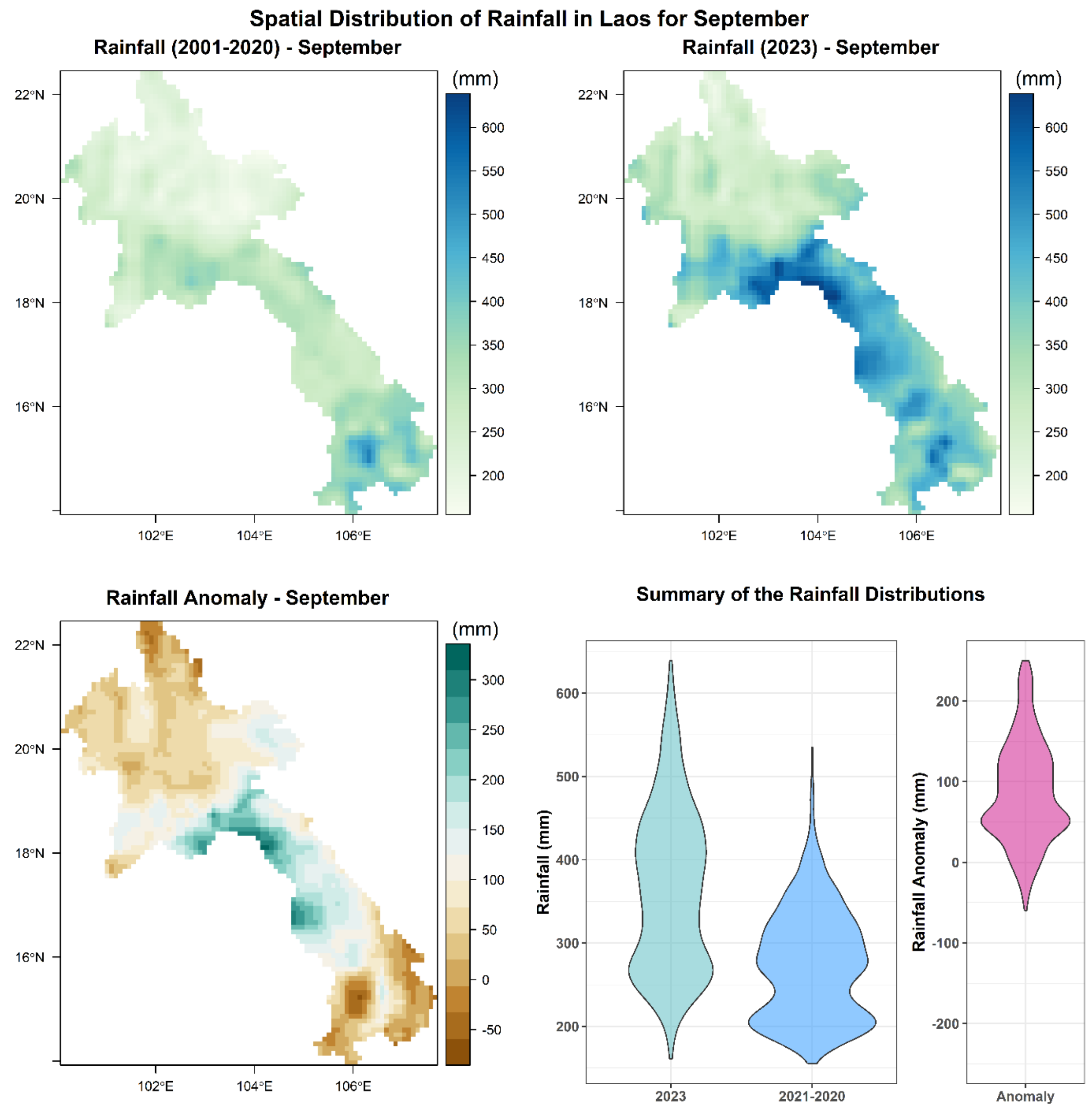

__Figure 63__ Maps and violin plots illustrate the spatial distribution of September rainfalls in Lao PDR. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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Table 21 *Monthly averages of long-term rainfalls (mm), 2023 monthly averages (mm), and rainfall anomalies (mm) in Lao PDR*

Month	Rainfall (2001-2020)	Rainfall (2023)	Anomaly
Jan	*24.704*	*14.915*	*-9.790*
Feb	*17.393*	*11.048*	*-6.345*
Mar	*55.348*	*21.007*	*-34.341*
Apr	*105.683*	*51.221*	*-54.462*
May	*231.869*	*135.022*	*-96.847*
Jun	*269.798*	*280.358*	*10.560*
Jul	*376.519*	*301.126*	*-75.393*
Aug	*392.190*	*403.969*	*11.780*
Sep	*274.960*	*365.814*	*90.854*
Oct	*135.459*	*182.737*	*47.278*
Nov	*44.932*	*32.969*	*-11.963*
Dec	*23.002*	*13.616*	*-9.386*

3.2.5. Trends of NDVI in Lao People’s Democratic Republic (Lao PDR)

To analyze the cascading impacts of changing conditions, such as variations in temperature and rainfall, the corresponding changes in vegetation greenness, which indicates crop biomass, were assessed using time series data on the Normalized Difference Vegetation Index (NDVI). The NDVI measures the "greenness" of ground cover and serves as a proxy to indicate the density and health of vegetation. NDVI values range from +1 to -1, with high positive values corresponding to dense and healthy vegetation, while low or negative values indicate poor vegetation conditions or sparse vegetative cover (Cohen et al., 2018) (Bayarjargal et al., 2006; Tucker et al., 1983).

The deviations in NDVI were analyzed using anomalies in NDVI maps, graphs, and tables, along with the time series values of NDVI. NDVI anomalies represent the variation of current dekadal (10-day period) values compared to the long-term average (Tucker and Sellers, 1986). A positive anomaly (e.g., +5%) signifies enhanced vegetation conditions relative to the average, while a negative anomaly (e.g., -5%) indicates poorer vegetation conditions (Anyamba et al., 2010).

The data for this analysis was accessed through the Food and Agriculture Organization's (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS) (FAO-GIEWS, 2024). GIEWS monitors the condition of major food crops at both country and global levels to assess production prospects. To support this analysis and supplement ground-based information, GIEWS utilizes remote sensing data, which provides valuable insights into water availability and vegetation health during cropping seasons. In addition to rainfall estimates and NDVI, GIEWS relies on vegetation indicators derived from 10-day (dekadal) vegetation data captured by the METOP-Advanced Very High-Resolution Radiometer (AVHRR) sensor at a 1 km resolution (for data from 2007 onwards). For data from 1984 to 2006, NDVI values are derived from the National Oceanic and Atmospheric Administration (NOAA)-AVHRR dataset at a 16 km resolution. Precipitation estimates for African countries (except Cabo Verde and Mauritius) are sourced from NOAA's Famine Early Warning Systems Network (FEWSNet), while data for other countries is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

In this assessment, monthly maps of NDVI anomalies were obtained for the years 2022, 2023, and up to July 2024. Time series statistics were generated at the sub-national level and then integrated at the country level to indicate the monthly variation in NDVI profiles over crop areas and the corresponding anomalies.

The long-term temporal NDVI profiles for croplands in Lao PDR from 1991 to 2020 reveal a pattern consistent with the annual agricultural cycle. NDVI values are typically lower at the beginning of the year (January to March) as crops are either harvested or in the early stages of growth. As the year progresses into the rainy season (April to October), the NDVI values increase, reflecting the growth and greening of crops. The peak values are usually observed between September and November, corresponding to the maturity of crops before harvest. After this peak, NDVI values gradually decline as crops are harvested or enter the dry season.

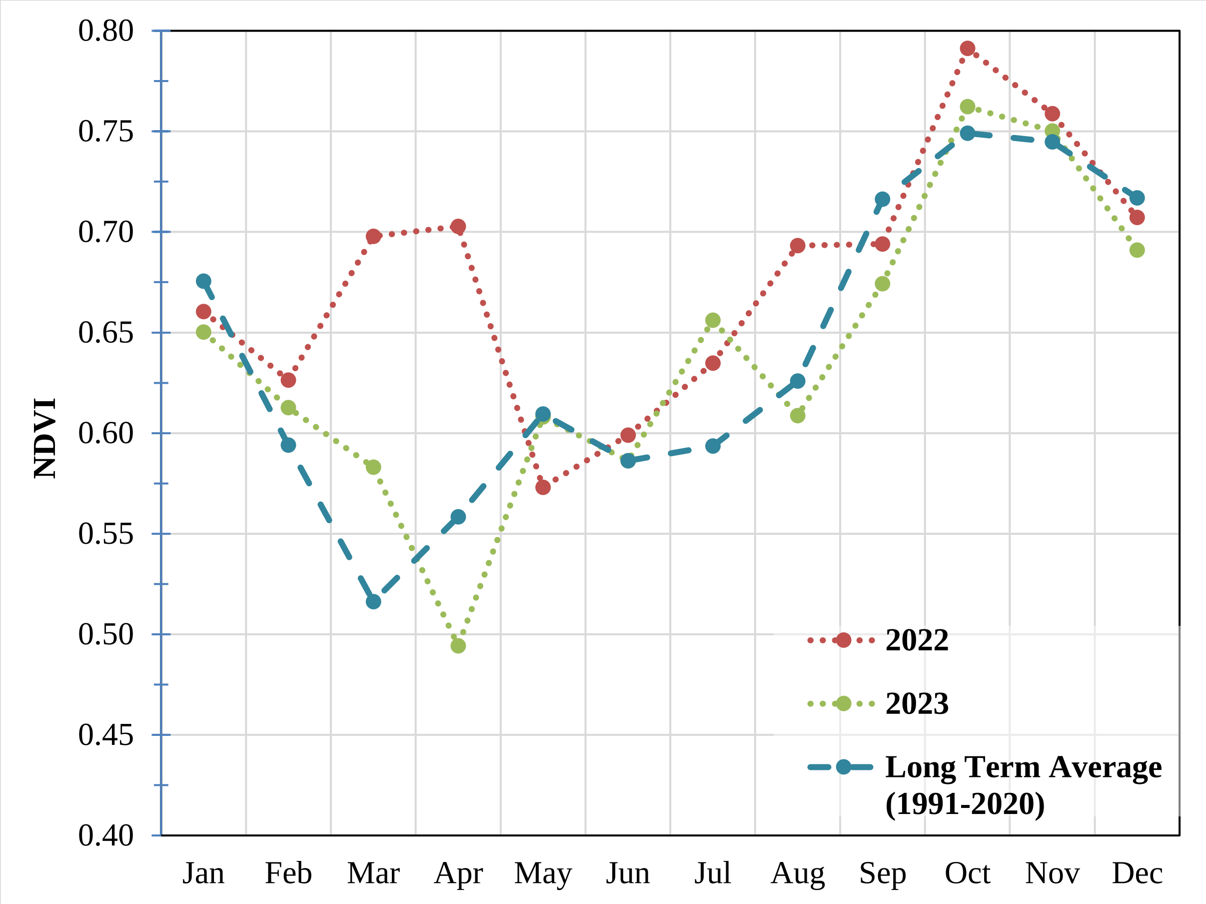

Figure 64 *Spatially aggregated mean monthly NDV profiles in Lao PDR from 1991 to 2023 showing monthly averages, long-term average (1991-2020), and anomalies for 2022-23 over the crop area (FAO-GIEWS, 2024)*

In 2023, notable monthly NDVI anomalies were observed, with deviations from the long-term average. For example, March saw a positive anomaly of 12.94%, indicating better-than-average vegetation health, likely due to favourable climatic conditions. However, April experienced a significant negative anomaly of -11.47%, suggesting a delay or disruption in crop growth, possibly due to unseasonal weather patterns or water stress. The anomalies varied across the months, with June showing a slight positive anomaly, while August and September had negative anomalies of -2.75% and -5.87%, respectively, indicating below-average vegetation health during these months. The year ended with slightly positive anomalies in October and November but returned to a negative anomaly in December.

The NDVI anomalies in 2022 present a different pattern compared to 2023. Early in the year, positive anomalies were observed, particularly in February (5.43%) and March (35.15%), indicating early and robust crop growth. April continued this trend with a high positive anomaly of 25.87%. However, May experienced a negative anomaly of -5.97%, likely due to environmental stressors such as a dry spell or pest outbreak. The latter half of the year showed mixed results, with significant positive anomalies in July (6.95%) and August (10.76%), suggesting good mid-season crop conditions, but with some negative anomalies in September (-3.12%) and November (-1.36%).

The anomalies observed in 2022 and 2023 are likely driven by a combination of climatic factors, including variability in rainfall, temperature extremes, and possibly the occurrence of extreme weather events such as droughts or floods. In 2023, the significant negative anomaly in April might be attributed to a late onset of the rainy season or a sudden temperature increase, affecting early crop growth. On the other hand, the positive anomalies in March and early 2022 could be linked to favourable growing conditions, such as adequate rainfall and moderate temperatures. Human factors, including changes in agricultural practices, land use changes, or irrigation patterns, could also influence these anomalies. The impacts of these anomalies could include reduced crop yields during months with negative NDVI anomalies or potentially higher yields during periods with positive anomalies.

Over the decades from 1991 to 2023, the NDVI profiles for croplands in Lao PDR have shown gradual changes, likely reflecting both climatic shifts and changes in agricultural practices. The early years (1991-2000) show more variability, with some years having lower NDVI values, particularly during the dry season. As we move into the 21st century, there is a trend toward higher NDVI values during peak growing months, which could indicate improved agricultural productivity or better management practices. However, recent years have also seen more pronounced anomalies, possibly due to the increasing impact of climate change, such as more frequent extreme weather events affecting crop health and productivity. This evolving pattern highlights the need for continuous monitoring and adaptation strategies to sustain agricultural productivity in the face of changing environmental conditions.

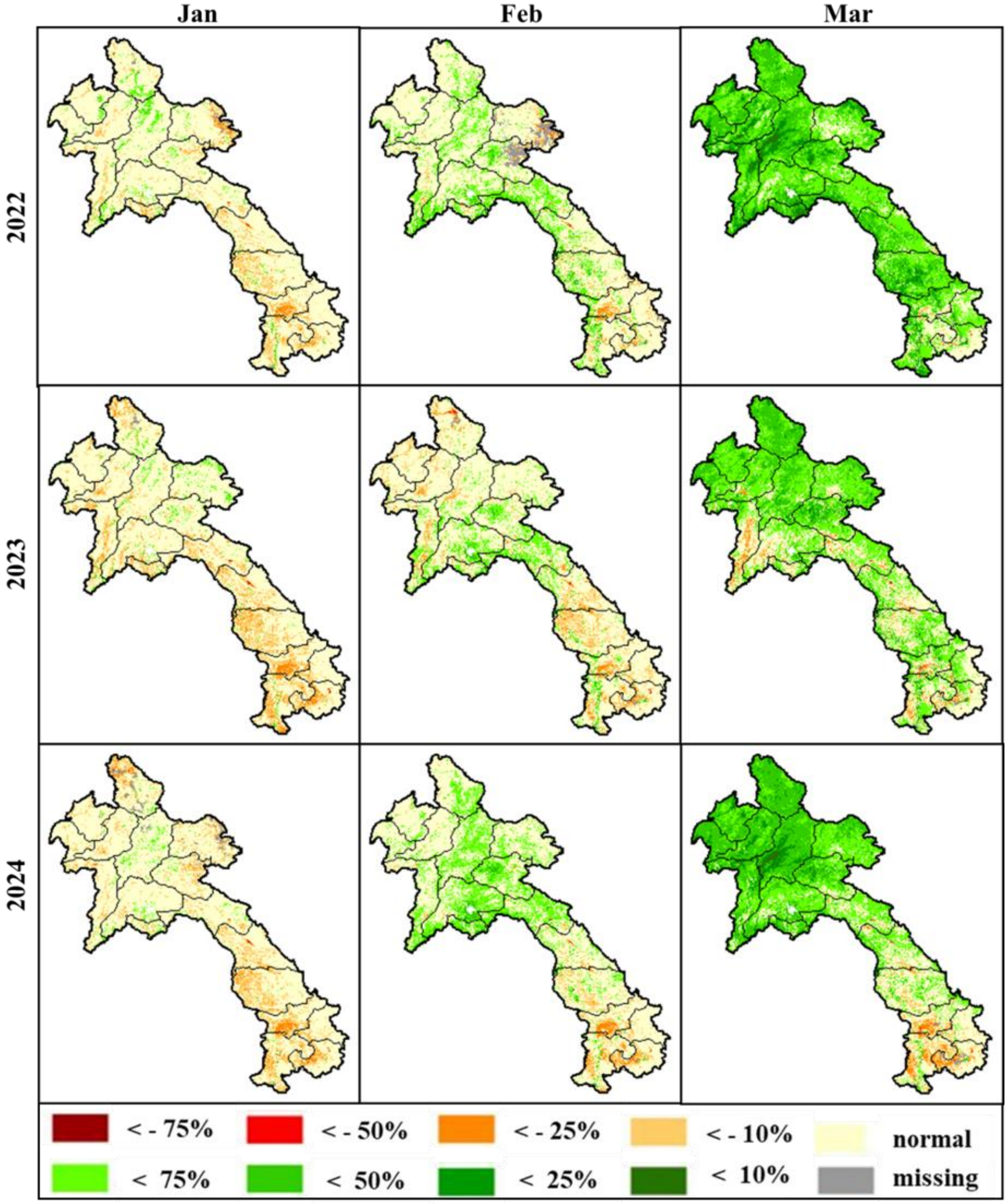

***Figure 65** Monthly NDVI anomaly maps of Lao PDR for 2022-24 (January, February, and March) (FAO-GIEWS, 2024)*

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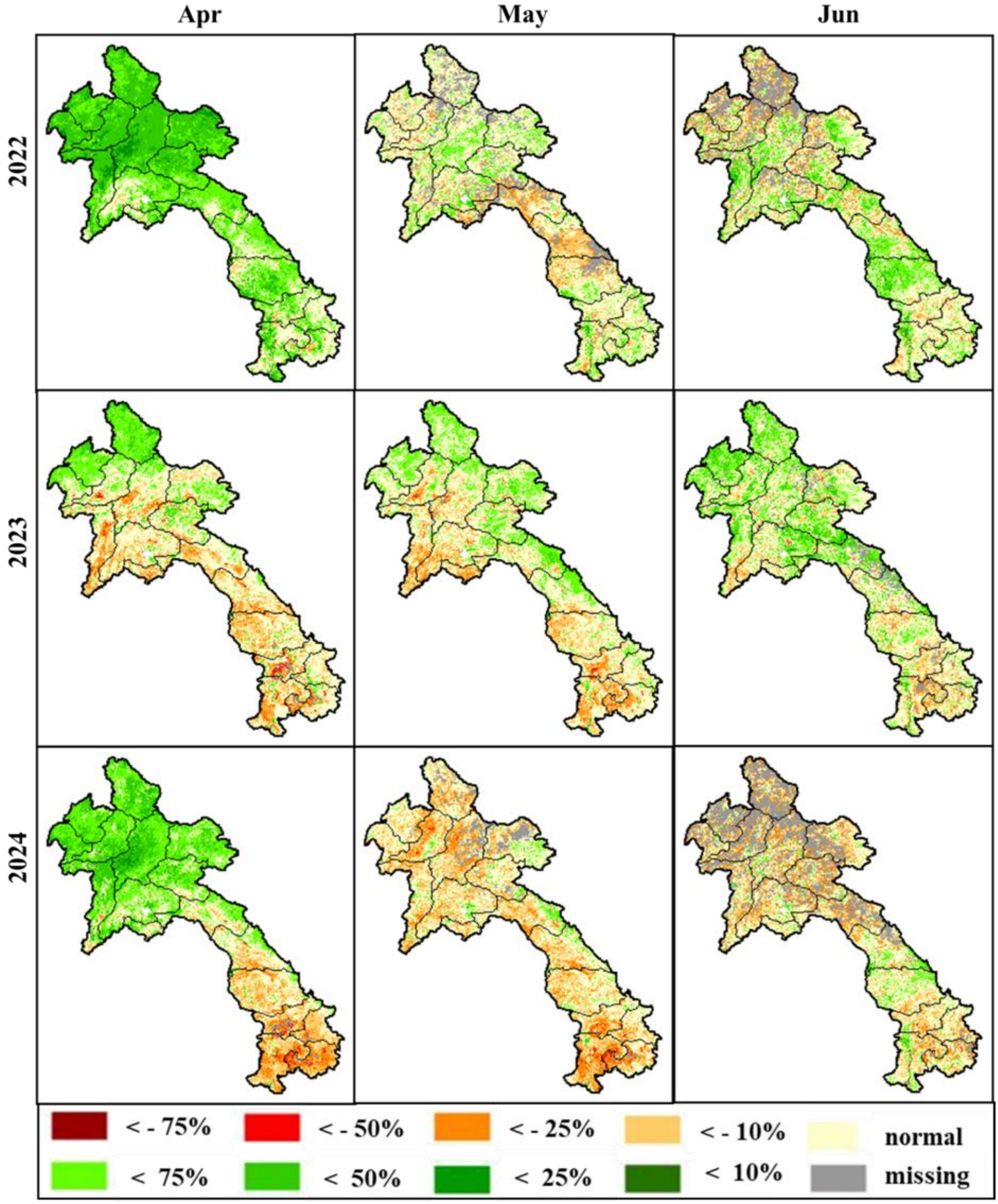

__Figure 66__ Monthly NDVI anomaly maps of Lao PDR for 2022-24 (April, May, and Jun) (FAO-GIEWS, 2024)

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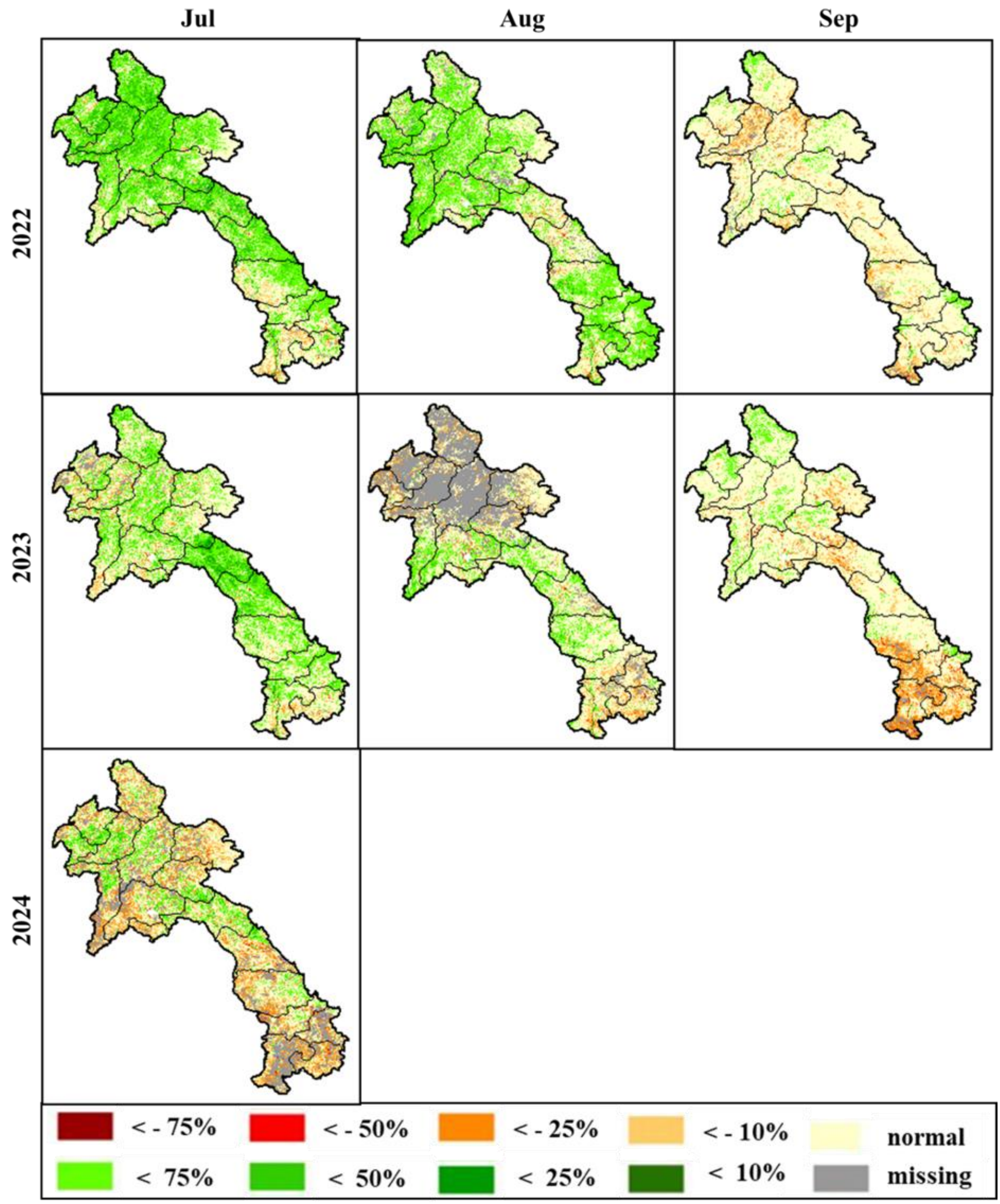

Figure 67 *Monthly NDVI anomaly maps of Lao PDR for 2022-24 (July, August, and September) (FAO-GIEWS, 2024)*

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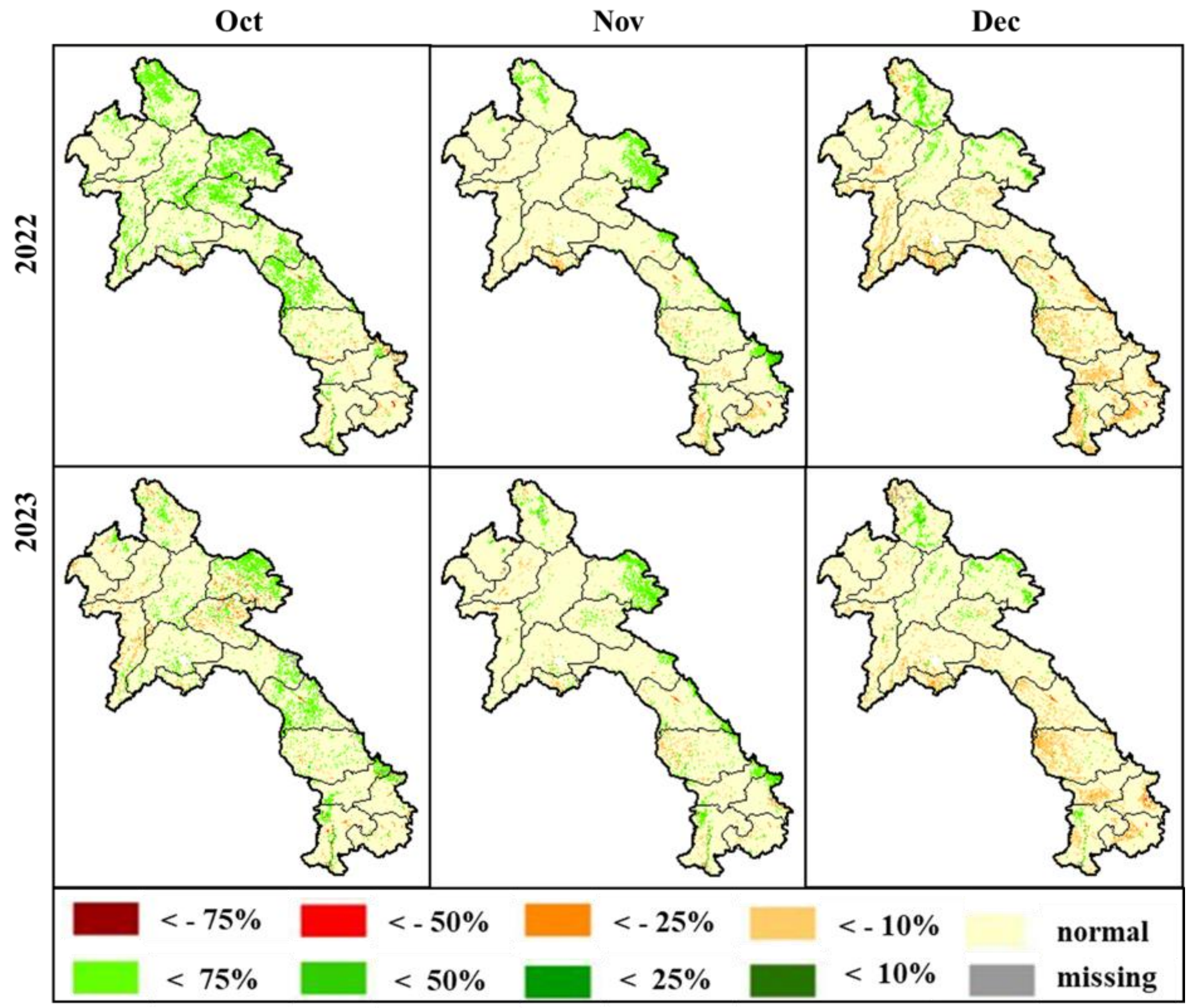

Figure 68 *Monthly NDVI anomaly maps of Lao PDR for 2022-24 (October, November, and December) (FAO-GIEWS, 2024)*

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Table 22 *Spatially aggregated mean monthly NDV profiles in Lao PDR from 1991 to 2023, long-term average (1991-2020), and the anomalies for 2021-23 over the crop area (FAO-GIEWS, 2024)*

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	*0.70*	*0.58*	*0.49*	*0.55*	*0.65*	*0.54*	*0.57*	*0.54*	*0.67*	*0.67*	*0.65*	*0.64*
1992	*0.60*	*0.56*	*0.42*	*0.45*	*0.54*	*0.52*	*0.68*	*0.66*	*0.72*	*0.70*	*0.68*	*0.68*
1993	*0.63*	*0.51*	*0.46*	*0.54*	*0.66*	*0.66*	*0.61*	*0.64*	*0.73*	*0.74*	*0.66*	*0.59*
1994	*0.47*	*0.43*	*0.50*	*0.56*	*0.53*	*0.51*	*0.48*	*0.55*	*0.65*	*0.66*	*0.67*	*0.67*
1995	*0.68*	*0.62*	*0.57*	*0.57*	*0.59*	*0.63*	*0.64*	*0.63*	*0.78*	*0.79*	*0.78*	*0.76*
1996	*0.70*	*0.64*	*0.53*	*0.60*	*0.69*	*0.65*	*0.55*	*0.71*	*0.77*	*0.77*	*0.76*	*0.73*
1997	*0.70*	*0.62*	*0.58*	*0.64*	*0.65*	*0.47*	*0.47*	*0.68*	*0.80*	*0.80*	*0.80*	*0.76*
1998	*0.67*	*0.54*	*0.54*	*0.62*	*0.63*	*0.55*	*0.73*	*0.70*	*0.79*	*0.80*	*0.73*	*0.70*
1999	*0.61*	*0.51*	*0.49*	*0.57*	*0.59*	*0.62*	*0.60*	*0.72*	*0.76*	*0.69*	*0.74*	*0.71*
2000	*0.69*	*0.57*	*0.49*	*0.54*	*0.62*	*0.63*	*0.58*	*0.58*	*0.54*	*0.63*	*0.55*	*0.54*
2001	*0.71*	*0.61*	*0.52*	*0.60*	*0.61*	*0.59*	*0.54*	*0.65*	*0.75*	*0.75*	*0.79*	*0.75*
2002	*0.71*	*0.64*	*0.51*	*0.57*	*0.60*	*0.54*	*0.39*	*0.50*	*0.69*	*0.76*	*0.73*	*0.72*
2003	*0.70*	*0.67*	*0.62*	*0.59*	*0.59*	*0.53*	*0.63*	*0.53*	*0.67*	*0.75*	*0.76*	*0.74*
2004	*0.65*	*0.56*	*0.48*	*0.58*	*0.58*	*0.55*	*0.49*	*0.42*	*0.63*	*0.71*	*0.73*	*0.71*
2005	*0.63*	*0.53*	*0.50*	*0.55*	*0.55*	*0.51*	*0.63*	*0.50*	*0.78*	*0.74*	*0.75*	*0.75*
2006	*0.73*	*0.62*	*0.51*	*0.58*	*0.62*	*0.59*	*0.52*	*0.60*	*0.69*	*0.77*	*0.74*	*0.72*
2007	*0.69*	*0.57*	*0.45*	*0.46*	*0.60*	*0.56*	*0.61*	*0.63*	*0.71*	*0.76*	*0.76*	*0.74*
2008	*0.70*	*0.61*	*0.54*	*0.59*	*0.63*	*0.59*	*0.59*	*0.63*	*0.70*	*0.76*	*0.77*	*0.76*
2009	*0.70*	*0.61*	*0.56*	*0.60*	*0.62*	*0.61*	*0.63*	*0.73*	*0.77*	*0.75*	*0.78*	*0.72*
2010	*0.69*	*0.61*	*0.49*	*0.50*	*0.60*	*0.63*	*0.65*	*0.67*	*0.74*	*0.76*	*0.76*	*0.73*
2011	*0.69*	*0.62*	*0.56*	*0.57*	*0.57*	*0.58*	*0.66*	*0.67*	*0.67*	*0.75*	*0.77*	*0.72*
2012	*0.69*	*0.61*	*0.53*	*0.59*	*0.61*	*0.57*	*0.60*	*0.65*	*0.74*	*0.77*	*0.76*	*0.74*
2013	*0.67*	*0.63*	*0.53*	*0.52*	*0.63*	*0.66*	*0.61*	*0.66*	*0.73*	*0.78*	*0.77*	*0.72*
2014	*0.69*	*0.61*	*0.51*	*0.53*	*0.63*	*0.59*	*0.58*	*0.65*	*0.73*	*0.78*	*0.76*	*0.74*
2015	*0.71*	*0.59*	*0.51*	*0.58*	*0.62*	*0.64*	*0.65*	*0.66*	*0.70*	*0.78*	*0.80*	*0.75*
2016	*0.70*	*0.63*	*0.49*	*0.50*	*0.57*	*0.64*	*0.68*	*0.70*	*0.73*	*0.78*	*0.80*	*0.77*
2017	*0.73*	*0.66*	*0.57*	*0.62*	*0.64*	*0.61*	*0.60*	*0.68*	*0.74*	*0.78*	*0.77*	*0.75*
2018	*0.72*	*0.64*	*0.58*	*0.60*	*0.65*	*0.62*	*0.58*	*0.59*	*0.71*	*0.78*	*0.76*	*0.73*
2019	*0.67*	*0.62*	*0.50*	*0.50*	*0.57*	*0.60*	*0.61*	*0.58*	*0.72*	*0.80*	*0.75*	*0.73*
2020	*0.65*	*0.56*	*0.45*	*0.47*	*0.63*	*0.60*	*0.65*	*0.63*	*0.67*	*0.71*	*0.80*	*0.76*
2021	*0.66*	*0.64*	*0.50*	*0.55*	*0.66*	*0.61*	*0.58*	*0.65*	*0.74*	*0.75*	*0.73*	*0.72*
2022	*0.66*	*0.63*	*0.70*	*0.70*	*0.57*	*0.60*	*0.63*	*0.69*	*0.69*	*0.79*	*0.76*	*0.71*
2023	*0.65*	*0.61*	*0.58*	*0.49*	*0.61*	*0.59*	*0.66*	*0.61*	*0.67*	*0.76*	*0.75*	*0.69*
2024	*0.63*	*0.64*	*0.64*	*0.59*	*0.52*	*0.54*	*0.58*	*0.62*				
Long Term Average (1991-2020)	0.676	0.594	0.516	0.558	0.610	0.586	0.594	0.626	0.716	0.749	0.745	0.717
Anomaly 2023	-3.75	3.15	12.94	-11.47	-0.24	0.02	10.54	-2.75	-5.87	1.75	0.72	-3.62
Anomaly 2022	-2.24	5.43	35.15	25.87	-5.97	2.19	6.95	10.76	-3.12	5.62	1.87	-1.36
Anomaly 2021	-2.27	7.72	-2.45	-1.24	8.91	3.59	-2.13	3.99	3.98	-0.35	-2.45	0.57

Chapter 4: Agronomic Conditions and Droughts in Thailand

4.1. Geospatial data overview

This study utilized various data sources (Table 1) with Google Earth Engine (GEE) as the primary hub for data processing. GEE, a cloud computing platform for planetary-scale data analysis, ensures the flexibility and adaptability of the workflow. Please refer to the section 1.3 an overview of the geospatial data used in this study. For the specific analysis of agronomic conditions and droughts in Thailand, all datasets were processed at the national scale to derive country-specific information. Additionally, regional-level maps and information are included to provide spatially exclusive perspectives, considering the regional context, particularly the neighboring countries.

4.2. Agronomic Conditions in Thailand

The agronomic conditions in Thailand were assessed through an in-depth analysis of land cover and land use composition, with a particular emphasis on cropland. This assessment utilized various land cover and land use datasets. Additionally, the distribution and patterns of soil texture across the country were examined. Long-term trends and patterns in precipitation, temperature and NDVI were evaluated. These indices provided insights into the health and viability of croplands under different environmental stresses.

4.2.1. Land cover land use composition and cropland in Thailand

The composition and spatial distribution of land cover and land use in Thailand and the surrounding region were assessed using several datasets. These included ESA's WorldCover map for 2022, with a 10-meter spatial resolution, and the GLCFCS30D Global 30-meter Land Cover Change Dataset (1985-2022). The GLC_FCS30D dataset represents a significant advancement in global land-cover monitoring, offering detailed insights into land cover dynamics over a 30-meter resolution spanning from 1985 to 2022. This dataset provided four categories of cropland: rainfed cropland, irrigated cropland, herbaceous cover cropland, and tree or shrub cropland (orchard). In contrast, the ESA WorldCover map provided a single cropland category, but it missed tree crops or orchards in many parts, which is probably included in the Tree Cover class. To ensure consistency among the datasets, we also analyzed two datasets provided by the FAO (FAOSTAT, 2024b), including Land Cover and Land Use. The FAO's Land Cover information is compiled from publicly available Global Land Cover (GLC) maps: The European Space Agency (ESA) Climate Change Initiative (CCI) annual land cover maps (1992–2020), produced by the Université Catholique de Louvain (UCL)-Geomatics and now part of the European Copernicus Program. The FAOSTAT Land Use domain contains data on forty-four categories of land use, irrigation, agricultural practices, and five indicators relevant to monitoring agriculture, forestry, and fisheries activities at national, regional, and global levels. This data is available by country and year, with global coverage and annual updates.

The diverse vegetation distribution in Thailand, as depicted by the land cover land use maps highlights the country's rich and varied landscape. The distribution of cropland in Thailand shows distinct patterns across different regions of the country, highlighting variations in agricultural practices and land use. Irrigated croplands are prominently found stretching from the northern region around Nakhon Sawan to Bangkok, primarily along the Chao Phraya River. This area benefits from managed water supplies, making it suitable for intensive farming. In contrast, rainfed croplands are concentrated in the eastern part of Thailand, extending from Bangkok and forming a substantial agricultural patch that reaches neighboring countries. This distribution underscores the significant reliance on natural rainfall for agriculture in this region.

Tree crops are predominantly located along the southern coasts of Thailand, where the climatic conditions are favorable for such cultivation. This distribution is less accurately represented in the ESA WorldCover map, where tree crops are classified under the broader tree cover category. While this classification captures the general presence of tree crops, it does not distinguish between different types of croplands as effectively as the GLCFCS dataset.

The (Figure 70) dataset shows a more precise categorization of croplands in Thailand, distinguishing between irrigated and rainfed croplands. This dataset effectively identifies three categories of croplands—rainfed, herbaceous cover, and tree or shrub croplands—allowing for a clearer understanding of agricultural practices and land use. By accurately differentiating between these categories, the GLCFCS dataset offers valuable insights into the distribution and types of cropland, complementing the information provided by ESA's WorldCover map (Figure 71). Cropland comprises 49.42% of the total area, within this cropland category, rainfed cropland is the most prevalent, representing 31.54% of the total area. This highlights the substantial reliance on natural rainfall for agricultural production. Herbaceous cover cropland accounts for 6.32%, while tree or shrub cropland (orchards) makes up 2.05%. Irrigated cropland constitutes 9.51%, indicating areas with managed water supply to support agriculture. The other land cover types, with forests covering 35.15% of the total area, followed by shrubland at 9.46%. Grassland, mangrove, and other minor categories are also present but in smaller proportions (Table 23).

In comparison, the ESA WorldCover dataset reports a lower estimate for cropland, at 33.55% of the total area (Figure 71). This discrepancy can be attributed to the classification of tree crops within the tree cover category, which accounts for 53.80% of the total area. Other land cover classes reported by ESA WorldCover include shrubland, grassland, built-up areas, bare or sparse vegetation, water bodies, mangroves, and moss or lichen, each occupying smaller proportions of the landscape (Table 23).

The analysis illustrates that while tree cover and forests dominate Thailand's landscape, croplands play a crucial role, particularly rainfed agriculture. The detailed sub-classification of croplands provides valuable insights into the agricultural practices and land use, essential for sustainable planning.

According to the FAOSTAT (FAOSTAT, 2024b), a comprehensive overview of Thailand's land cover (Table 24) shows that herbaceous crops occupy a substantial area, accounting for 43% of the total land cover. This category likely includes a significant portion of cropland, particularly annual crops and other herbaceous vegetation. Tree-covered areas make up 22.07% of the land, reflecting the extensive forested regions in the country. Other notable categories include grassland (7.90%) and shrub-covered areas (9.90%).

A more detailed breakdown of land use practices, emphasizing agricultural activities. According to this dataset, agricultural land constitutes 46% of Thailand's total land area, with cropland alone covering 44.43%. This high percentage of cropland indicates the country's significant agricultural output and land dedicated to farming activities.

Temporary crops, such as annual crops, cover 26.14% of the land, while permanent crops, like orchards and plantations, account for 10.86%. This distribution highlights the mix of crop types and the emphasis on both short-term and long-term agricultural production (Table 24).

The land equipped for irrigation covers 12.56% of the land. However, it is noted that there is no specific data on the actual area of agriculture that is currently irrigated. This suggests a significant portion of Thailand’s cropland benefits from irrigation infrastructure, crucial for maintaining agricultural productivity, particularly in areas where natural rainfall may be insufficient.

In summary, the statistics reveal that cropland plays a central role in Thailand's land use, with significant areas dedicated to both temporary and permanent crops. The dataset highlights the extensive use of herbaceous crops, with a substantial portion of agricultural land equipped for irrigation, underscoring the importance of both rainfed and irrigated agriculture in the country.

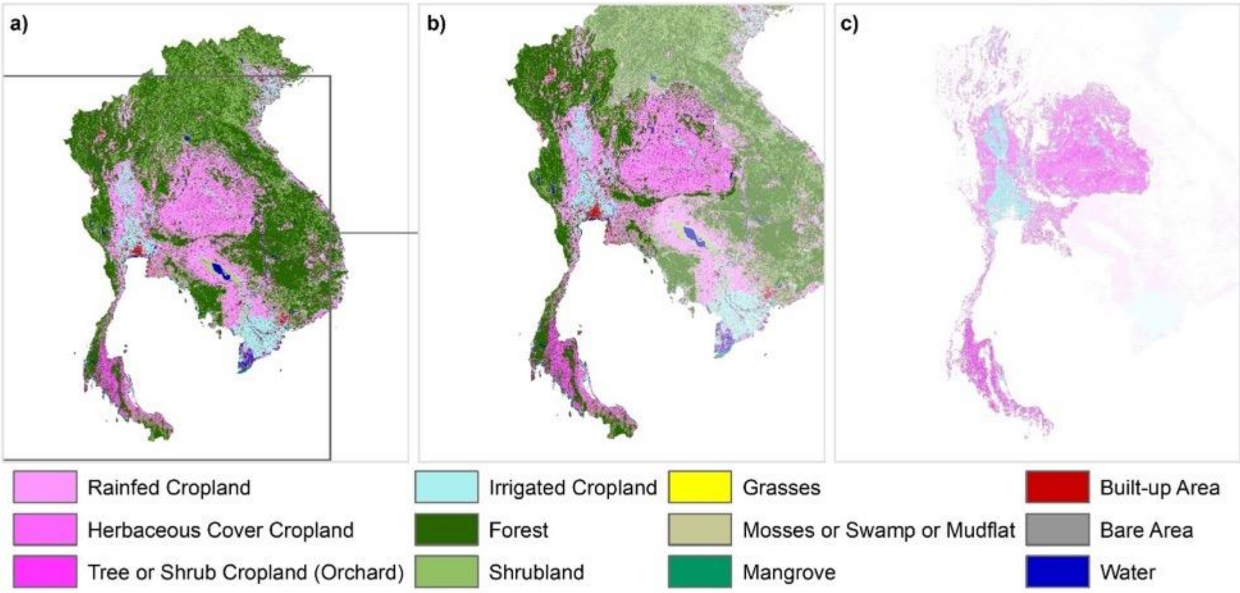

Figure 69 *The cropland and land cover land use composition of Thailand using the GLCFCS30D: a) Overview and location of Thailand in the region; b) Spatial distribution of land cover/land use patterns across Thailand; c) Distribution of cropland areas within Thailand. Data source: (Liu et al., 2023)*

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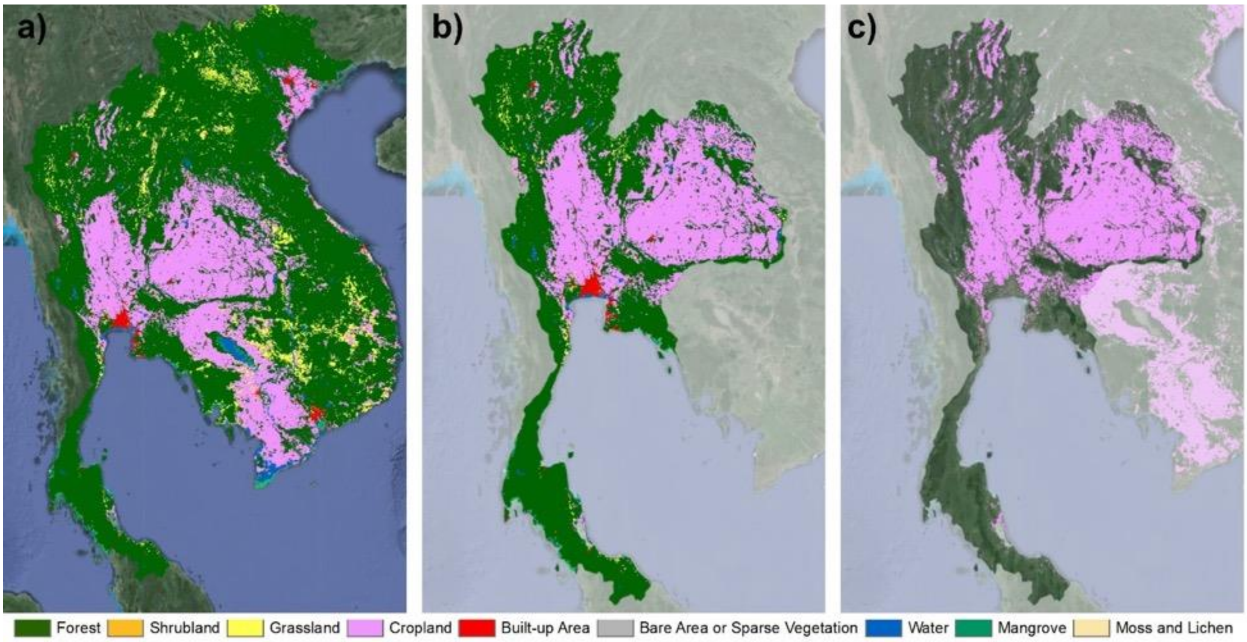

Figure 70 *The cropland and land cover land use composition of Thailand using the ESA's WorldCover Map: a) Overview and location of Thailand in the region; b) Spatial distribution of land cover/land use patterns across Thailand; c) Distribution of cropland areas within Thailand. Data Source: (Zanaga et al., 2022)*

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Table 23 *Distribution of vegetated land cover land use classes in Thailand from ESA's WorldCover and the distribution of cropland and its sub-classes from GLCFCS.*

ESA - World Cover			GLCFCS		
LCLU Classes	**Area (Km2)**	**%**	**Cropland Classes**	**Area**	**%**
Tree cover	277908	53.80	Cropland	263125	49.42
Shrubland	1965	0.38	Rainfed Cropland	167931	31.54
Grassland	28869	5.59	Herbaceous Cover Cropland	33639	6.32
Cropland	173327	33.55	Tree or Shrub Cropland (Orchard)	10940	2.05
Built-up Area	11300	2.19	Irrigated Cropland	50615	9.51
Bare or Sparse vegetation	10014	1.94	Forest	187156	35.15
Water	8539	1.65	Shrubland	50351	9.46
Mangroves	2531	0.49	Grassland	154	0.03
Moss and lichen	2119	0.41	Mangrove	2283	0.43

Table 24 *Distribution of land cover land use classes in Thailand from the FAO's Land Cover (CCI LC) and the FAO's Land Use map (FAOSTAT, 2024b).*

FOA - Land Cover - CCI LC			FAO - Land Use		
LCLU Class Name	**Area**	**%**	**LCLU Class Name**	**Area**	**%**
Artificial surfaces	3818	0.74	Agricultural land	235000	46.00
Herbaceous crops	222893	43.00	Cropland	227000	44.43
Woody crops	72132	13.91	Temporary crops	133549	26.14
Grassland	40928	7.90	Permanent crops	55500	10.86
Tree-covered areas	114396	22.07	Temporary meadows and pastures	35421	6.93
Mangroves	3602	0.69	Temporary fallow	2530	0.50
Shrub-covered areas	51298	9.90	Permanent meadows and pastures	8000	1.57
Shrubs and/or herbaceous vegetation	145	0.03	Land area equipped for irrigation	64150	12.56
Sparsely natural vegetated areas	317	0.06	Agricultural area actually irrigated		0.00
Terrestrial barren land	1	0.00	Arable land	171500	33.57
Inland water bodies	8857	1.71	Forest land	198010	38.76
			Naturally regenerating forest	163300	31.96
			Planted Forest	34710	6.79
			Other land	77520	15.17

4.2.2. Composition of Soil Texture in Thailand

To understand the general soil texture composition across Thailand and the cropland of Cambodia, the USDA's soil texture layer at 10 cm depth was used. The datasets consisted of 12 soil texture classes for six soil depths (0, 10, 30, 60, 100, and 200 cm) at a 250 m resolution, derived from predicted soil texture fractions using the soil texture package in R (Hengl, 2018).

In Thailand, the distribution of soil textures within cropland areas provides crucial insights into agricultural practices and soil suitability (Figure 71, Table 25). The landscape is predominantly characterized by Clay Loam and Silt, which play significant roles in agricultural productivity. Clay Loam, covering nearly 49% of the total land area, is the most prevalent soil texture. Its balanced mix of clay, silt, and sand ensures excellent water retention and drainage, making it highly suitable for various crops. This soil type supports the country's extensive agricultural activities by providing the necessary conditions for crop growth. Loam is another major soil type, accounting for approximately 30% of the landscape. Its well-balanced properties further enhance its suitability for agriculture, supporting a diverse range of crops and contributing to Thailand's overall agricultural productivity. In cropland areas, Clay Loam and Loam are particularly prominent, reflecting their suitability for both irrigated and rainfed agriculture (Figure 71, Table 25). Silt, covering about 6% of the cropland area, is also important but requires careful management due to its erosion potential. Other soil textures such as Silty Clay and Sandy Clay are less common in cropland areas, indicating their limited use for extensive agriculture. Overall, the distribution of soil textures highlights the dominance of Clay Loam and Loam in supporting Thailand's agricultural sector, underlining their critical role in the country's agricultural practices.

The dominant soil texture class within croplands is Clay Loam, covering approximately 33% of these areas. Clay Loam's balanced properties of good water retention and drainage make it particularly suitable for a diverse range of crops, supporting significant agricultural productivity. Loam is also a major soil type in croplands, accounting for about 33% of the cropland area. Its well-balanced nature complements agricultural activities, making it a versatile choice for various crops. Silty Loam, covering around 17% of cropland, is valuable for its ability to retain moisture, which is beneficial in certain farming contexts where water management is crucial (Figure 71, Table 25).

Silt and Clay are less prominent in cropland areas, with Silt covering approximately 11% and Clay around 6%. While Silt can be useful in specific conditions, its tendency to erode requires effective management practices. Clay, though less common, still plays a role in some cropland areas due to its capacity to retain nutrients and moisture. The presence of Silty Clay and Sandy Clay in croplands is minimal. This reflects their limited suitability for extensive agricultural use compared to other soil types. Overall, the distribution of soil textures within cropland highlights the predominance of Clay Loam and Loam, underscoring their importance in supporting Thailand's agricultural sector. This distribution aligns with the broader landscape patterns but shows a more concentrated use of these soils in cropland, emphasizing their critical role in the country's agricultural productivity.

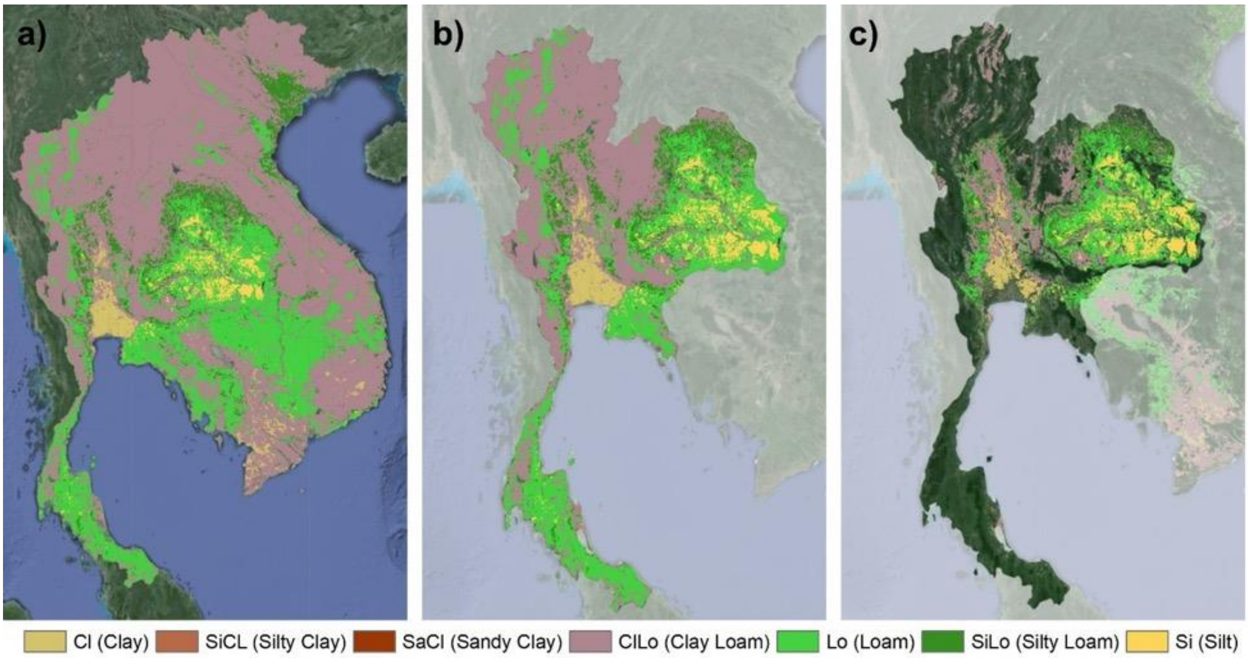

Figure 71 *The soil texture composition (at 10 cm depth) of Thailand using the USDA's soil texture data: a) Overview and location of Thailand in the region; b) Spatial distribution of soil texture patterns across Thailand; c) Distribution of soil texture masked over the cropland areas.*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 25 *Distribution of the soil texture classes (at 10 cm depth) in Thailand and masked over the cropland*

Soil Texture Class	Thailand		Thailand - Cropland	
	Area	(%)	Area	(%)
Cl (Clay)	19561	3.73	15355	5.71
SiCl (Silty Clay)	151	0.03	95	0.04
SaCl (Sandy Clay)	110	0.02	4	0.00
ClLo (Clay Loam)	256153	48.81	88281	32.83
Lo (Loam)	157546	30.02	89802	33.40
SiLo (Silty Loam)	59288	11.30	45564	16.95
Si (Silt)	31945	6.09	29765	11.07

4.2.3. Trends of Air Temperature in Thailand

The analysis of temperature changes in Thailand was conducted using ERA5 temperature data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term temperature averages (2001-2020) with the recorded temperatures for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average temperatures and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average temperatures, the monthly temperatures for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of temperature changes, violin plots and box plots were used. Violin plots illustrated the distribution of temperatures, showing the density and probability of different temperature ranges over time. Box plots offered a clear visualization of the temperature distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the temperature changes in Cambodia, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of temperature trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual trend of temperature in Cambodia shows that the average temperature has increased from 26.03°C to 226.74°C between 1991 and 2020. This reflects an increase of 0.71°C for nearly three decades. This highlights the significant warming trend experienced in Cambodia, consistent with global patterns of rising temperatures due to climate change.

The comparative analysis of monthly temperature change rates between two decades, 2000-2010 and 2010-2020, reveals a consistent increase in the rate of temperature change across all months in the more recent decade (2010-2020) compared to the earlier one (2000-2010).

In January, the change rate increased from 0.00 to 0.12. February saw a modest increase from 0.00 to 0.02. March, which experienced a significant decrease of -0.12 in the 2000s, recorded a positive change rate of 0.07 in the 2010s. April's change rate saw a five-fold increase from 0.06 to 0.31. May recorded a dramatic shift from -0.32 to 0.66, indicating a notable warming trend. June transitioned from a slight decrease of -0.14 to an increase of 0.30. July's temperature change rate rose from 0.00 to 0.11, while August experienced a slight increase from 0.09 to 0.10. September and October observed significant increases from 0.02 to 0.32 and from 0.08 to 0.23, respectively. November, which initially had a decrease of -0.21, showed the highest increase among all months, reaching 0.73. December's change rate increased from 0.25 to 0.48.

These trends indicate a significant and widespread increase in the rate of temperature change over the past decade, reflecting accelerated warming.

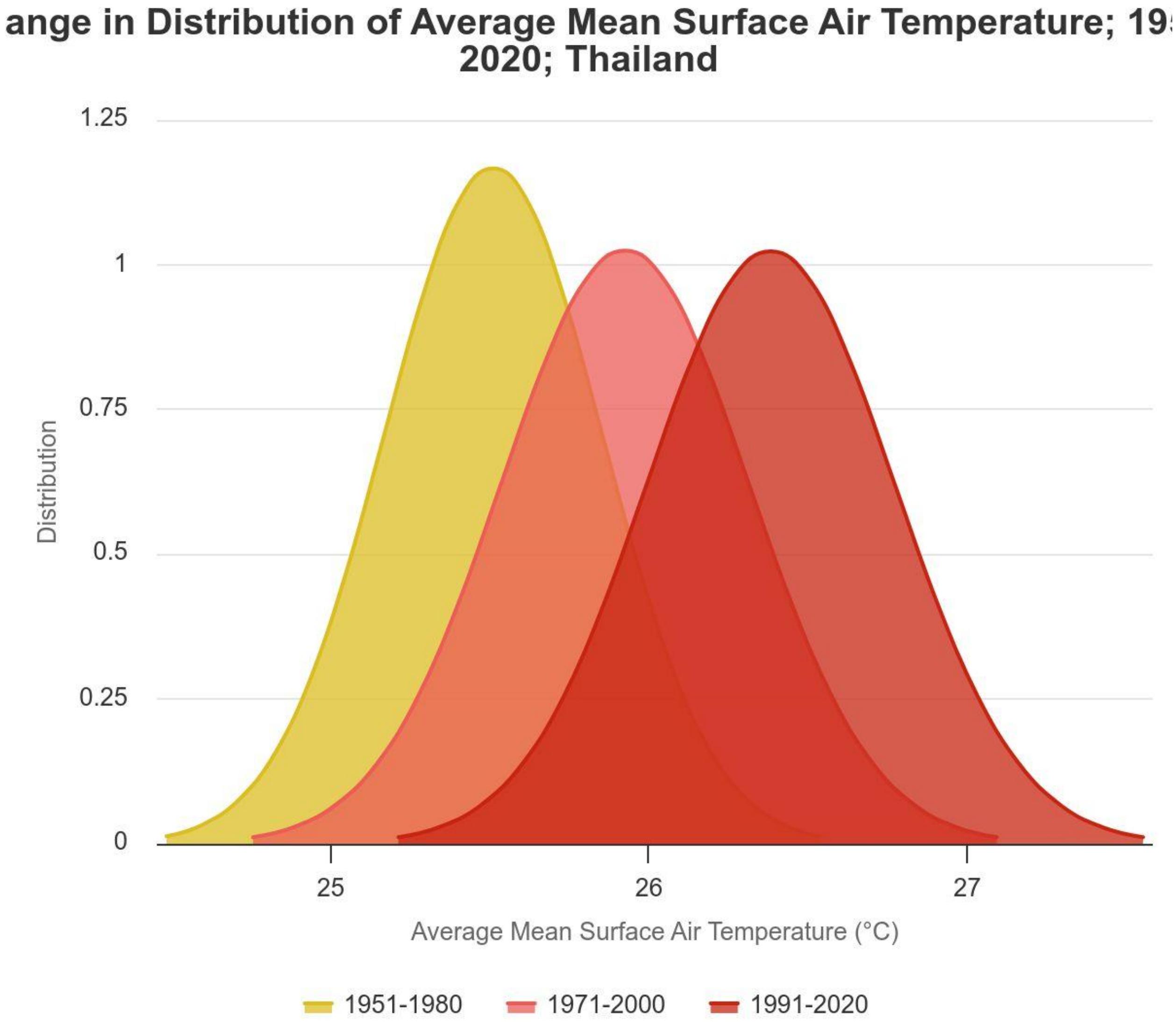

Figure 72 *Change in distribution of average mean surface air temperature in Thailand from 1991-2020 (CCKP, 2024b)*

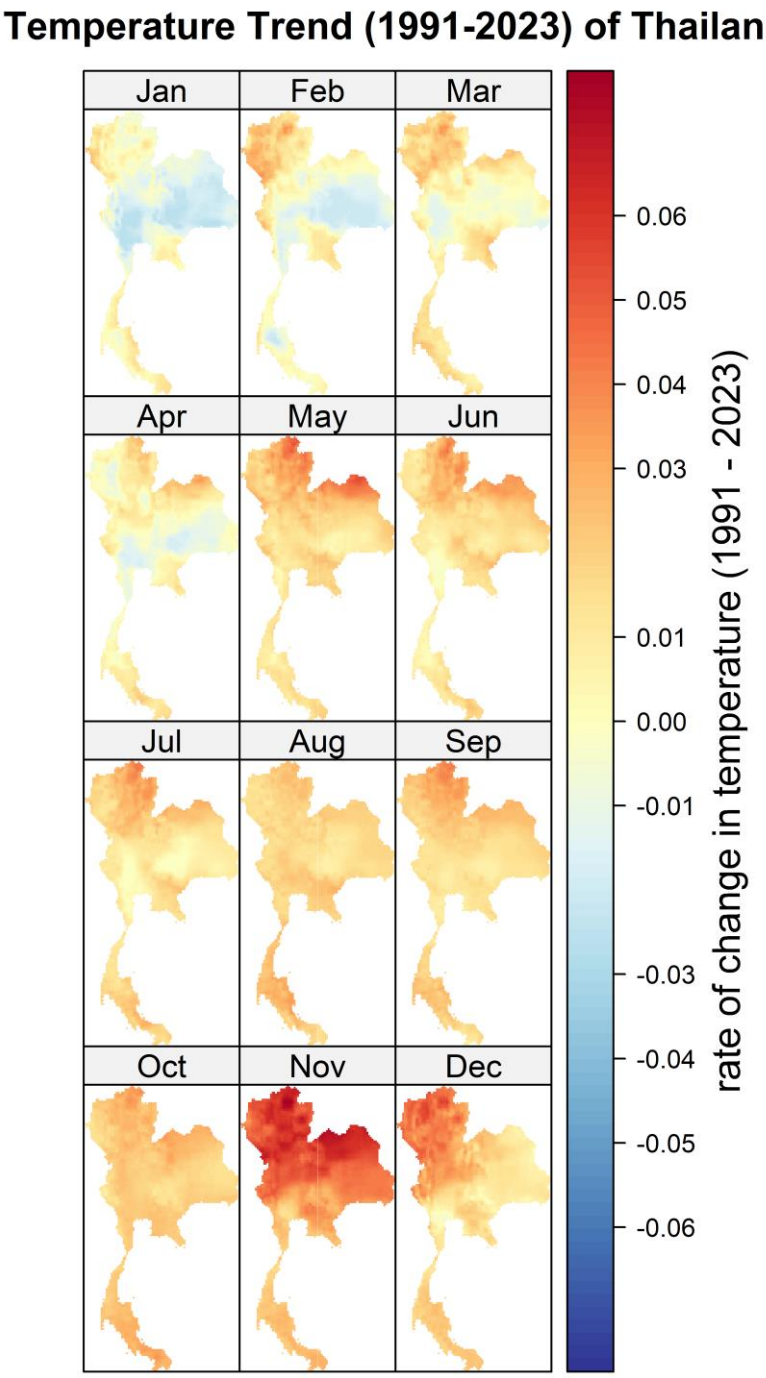

Figure 73 Spatial patterns of temperature trends in Thailand, indicating the rate of change in temperatures from 1991 to 2023

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Over the years, there has been a noticeable variation in temperatures across different months A clear trend of increasing temperatures over the years is observed, with significant implications for croplands in Thailand.

From May to October, which are critical months for agriculture, there have been notable increases in temperature. May temperatures have risen from an average of 26.00°C in 1999 to 29.68°C in 2020, reflecting a significant warming trend during the planting season for rice. June temperatures have increased from 25.70°C in 1999 to 27.83°C in 2019, impacting early crop growth stages. July and August have also seen rising temperatures, with

July increasing from 25.70°C in 2000 to 27.36°C in 2019, and August from 25.70°C in 2000 to 27.38°C in 1998. September temperatures have risen from 25.34°C in 2022 to 26.69°C in 2017, crucial for crop maturation. October has shown an increase from 24.80°C in 1992 to 26.55°C in 2019, affecting the harvest period.

Currently, the temperatures during these critical agricultural months continue to trend upward. In 2023, May's average temperature was 28.73°C, June was 27.16°C, July was 26.64°C, August was 27.02°C, September was 26.11°C, and October was 26.17°C. These increases pose challenges for agricultural productivity, potentially leading to heat stress on crops, altered growing seasons, and reduced yields.

The consistent rise in temperatures emphasizes the need for adaptive farming practices and resilient crop varieties to mitigate the adverse effects of climate change on Cambodia's croplands. These fluctuations and significant changes in critical agricultural months underline the importance of adapting farming practices to cope with the rising temperatures and the broader impacts of climate change on Cambodia's cropland productivity. The year 2023 shows generally warmer temperatures compared to the early 1990s, aligning with the global trend of rising temperatures.

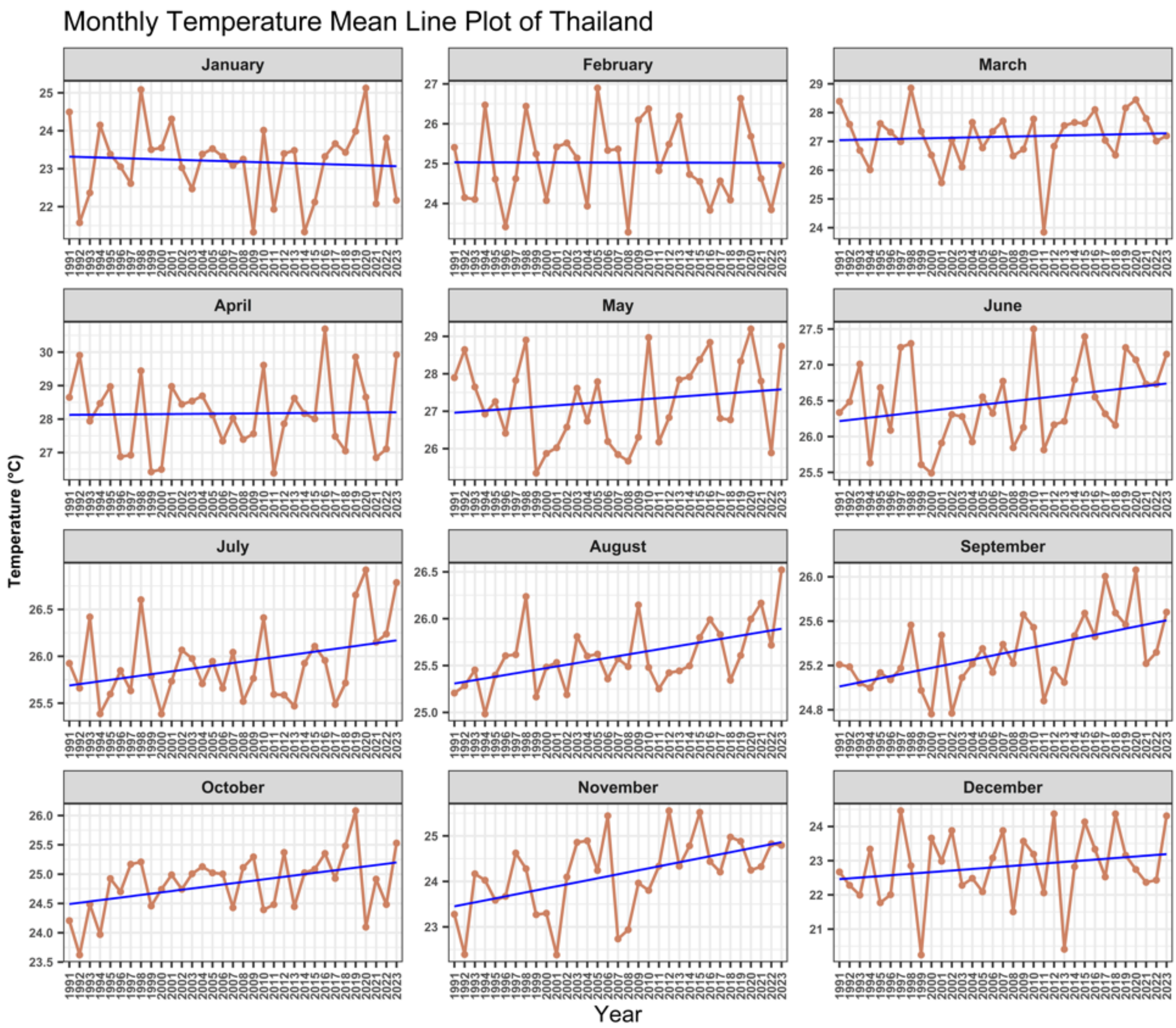

Figure 74 *Spatially aggregated mean monthly temperature time series line plots with trend lines, depicting the variation of mean monthly temperatures over time in Thailand*

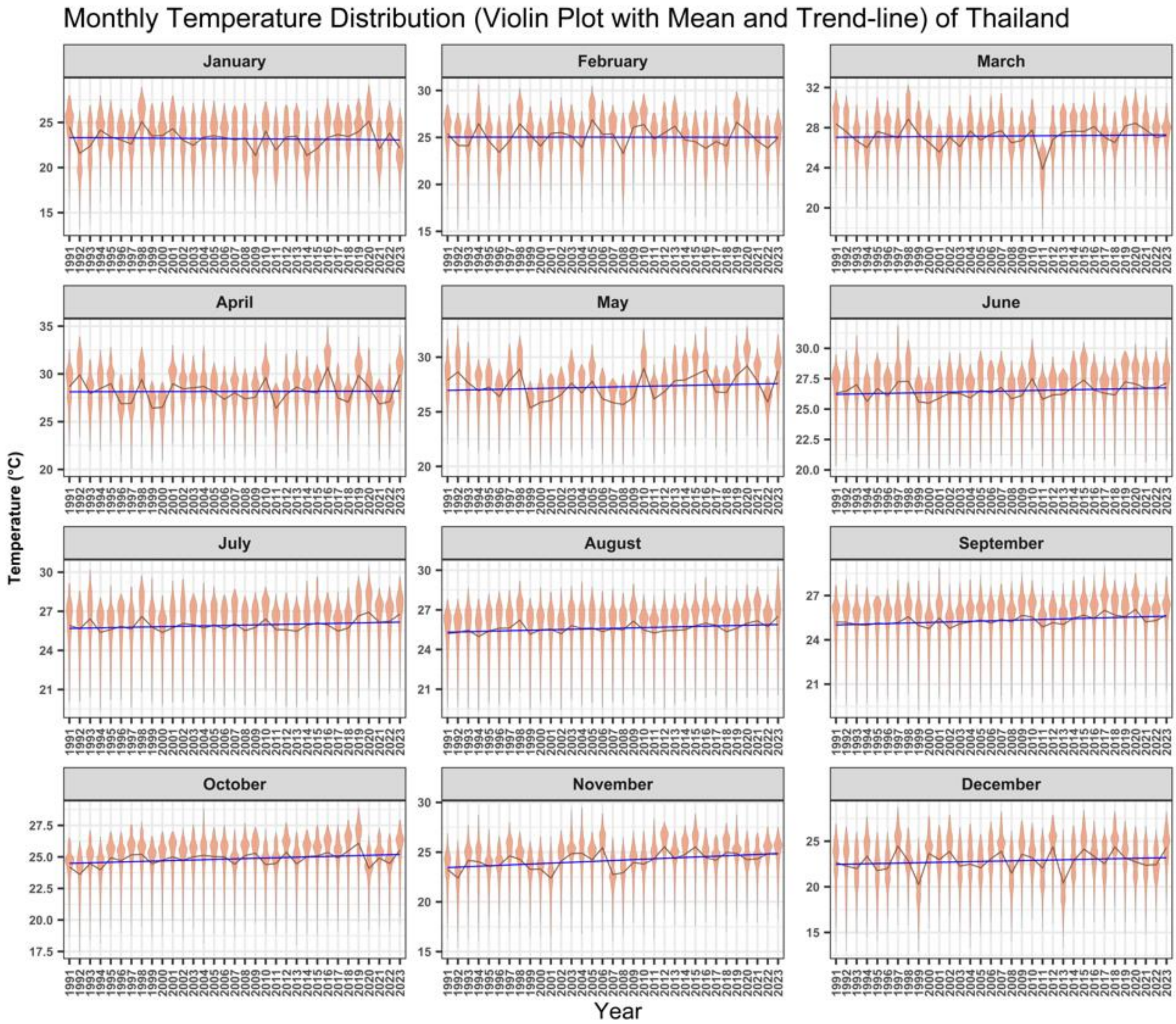

Figure 75 *Distribution of mean monthly temperature time series and violin plots in Thailand, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly temperatures*

Table 26 Spatially aggregated mean monthly air temperature (°C) of Thailand from 1991 to 2023 derived, from the ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	24.49	25.41	28.39	28.65	27.90	26.33	25.92	25.21	25.21	24.21	23.28	22.67
1992	21.58	24.15	27.59	29.91	28.64	26.48	25.66	25.29	25.19	23.62	22.39	22.28
1993	22.36	24.10	26.69	27.94	27.65	27.01	26.42	25.45	25.04	24.49	24.17	21.99
1994	24.15	26.47	26.01	28.47	26.92	25.63	25.39	24.98	25.00	23.97	24.03	23.34
1995	23.38	24.61	27.62	28.97	27.26	26.68	25.60	25.40	25.14	24.92	23.59	21.77
1996	23.05	23.42	27.32	26.88	26.41	26.09	25.85	25.60	25.07	24.70	23.67	22.01
1997	22.61	24.62	26.99	26.92	27.82	27.24	25.63	25.62	25.18	25.17	24.62	24.46
1998	25.08	26.44	28.85	29.44	28.90	27.30	26.60	26.24	25.57	25.21	24.28	22.85
1999	23.50	25.24	27.35	26.42	25.35	25.61	25.79	25.16	24.97	24.46	23.27	20.25
2000	23.55	24.07	26.52	26.50	25.87	25.49	25.38	25.48	24.76	24.74	23.30	23.66
2001	24.31	25.42	25.56	28.98	26.02	25.91	25.73	25.53	25.47	24.99	22.38	22.98
2002	23.03	25.52	27.06	28.44	26.58	26.31	26.07	25.19	24.77	24.74	24.10	23.88
2003	22.47	25.14	26.11	28.54	27.61	26.28	25.98	25.81	25.09	25.01	24.86	22.28
2004	23.38	23.94	27.66	28.69	26.74	25.93	25.71	25.60	25.21	25.13	24.89	22.48
2005	23.53	26.90	26.77	28.12	27.79	26.55	25.95	25.62	25.35	25.02	24.24	22.09
2006	23.32	25.33	27.34	27.34	26.19	26.32	25.66	25.36	25.14	25.00	25.44	23.08
2007	23.09	25.37	27.71	28.03	25.84	26.77	26.04	25.57	25.39	24.43	22.74	23.88
2008	23.25	23.28	26.49	27.39	25.67	25.84	25.52	25.49	25.22	25.11	22.94	21.51
2009	21.33	26.09	26.73	27.56	26.30	26.13	25.76	26.15	25.66	25.29	23.96	23.57
2010	24.01	26.37	27.78	29.61	28.97	27.50	26.41	25.48	25.54	24.39	23.80	23.19
2011	21.93	24.82	23.84	26.39	26.18	25.81	25.59	25.25	24.88	24.48	24.33	22.06
2012	23.40	25.49	26.83	27.86	26.83	26.16	25.59	25.42	25.16	25.37	25.55	24.37
2013	23.48	26.19	27.55	28.62	27.84	26.21	25.47	25.44	25.05	24.45	24.34	20.41
2014	21.33	24.73	27.66	28.16	27.92	26.79	25.93	25.50	25.47	25.02	24.78	22.82
2015	22.12	24.55	27.62	28.01	28.38	27.40	26.11	25.80	25.67	25.08	25.52	24.13
2016	23.32	23.83	28.10	30.69	28.84	26.55	25.96	25.99	25.46	25.35	24.44	23.33
2017	23.66	24.56	27.04	27.48	26.81	26.32	25.49	25.83	26.00	24.93	24.21	22.52
2018	23.43	24.09	26.52	27.05	26.77	26.16	25.72	25.34	25.67	25.48	24.97	24.37
2019	23.98	26.63	28.16	29.86	28.33	27.24	26.65	25.61	25.57	26.08	24.88	23.16
2020	25.13	25.68	28.45	28.65	29.20	27.07	26.92	26.00	26.06	24.10	24.25	22.74
2021	22.08	24.63	27.79	26.85	27.80	26.73	26.15	26.17	25.22	24.91	24.33	22.37
2022	23.81	23.84	27.01	27.11	25.89	26.73	26.24	25.72	25.32	24.48	24.83	22.43
2023	22.17	24.95	27.19	29.92	28.74	27.15	26.79	26.52	25.68	25.53	24.79	24.31

A comparison of monthly average temperatures between two periods—the long-term average from 2001 to 2020 and the recorded temperatures for the year 2023—was assessed for Thailand. This analysis also included temperature anomalies for each month, indicating deviations from the long-term average.

In January 2023, the average temperature was 21.817°C, which is 1.009°C cooler than the long-term average of 22.825°C. February continued this trend with cooler temperatures, showing an anomaly of -0.244°C, resulting in an average temperature of 24.603°C compared to the long-term average of 24.847°C. These cooler temperatures early in the year could delay the planting season and slow down the initial growth stages of crops, potentially reducing yields.

In March, temperatures slightly increased, with an anomaly of +0.144°C, recording an average temperature of 26.843°C compared to the long-term average of 26.699°C. April observed a more significant increase in temperature, with an average of 29.570°C, which is 1.646°C warmer than the long-term average of 27.924°C. May experienced a similarly pronounced increase, with an anomaly of +1.496°C, leading to an average temperature of 28.387°C compared to the long-term average of 26.890°C. Both June and July had temperatures above the long-term averages, with June being 0.685°C warmer and July 0.875°C warmer than their respective long-term averages. These increases in temperature during the mid-year could accelerate crop growth, but also increase water requirements and the risk of heat stress, potentially impacting crop health and productivity.

August observed a continued warming trend, with a temperature of 26.171°C, resulting in an anomaly of +0.922°C over the long-term average of 25.249°C. September, October, and November also experienced temperature increases, with anomalies of +0.289°C, +0.557°C, and +0.462°C, respectively. The average temperatures in these months were above their long-term averages. Warmer temperatures in these months could lead to an extended growing season but also heighten the risk of drought and pest infestations, which could adversely affect crop yields.

December concluded the year with a temperature of 23.958°C, which was 1.365°C warmer than the long-term average of 22.593°C. Warmer winters can impact certain crops that require cooler temperatures for vernalization, potentially affecting flowering and fruiting stages.

Overall, the data reveals that 2023 in Thailand had a mix of cooler and warmer months compared to the long-term averages, with most months showing warming anomalies, particularly in the latter half of the year. This trend of increasing temperatures, especially during crucial growing months, has significant implications for cropland in Thailand. Warmer temperatures can lead to changes in growing seasons, increased water demand, and greater stress on crops. These factors necessitate adaptive measures such as altering planting schedules, implementing water management strategies, and adopting heat-resistant crop varieties to sustain agricultural productivity and food security in the face of changing climatic conditions.

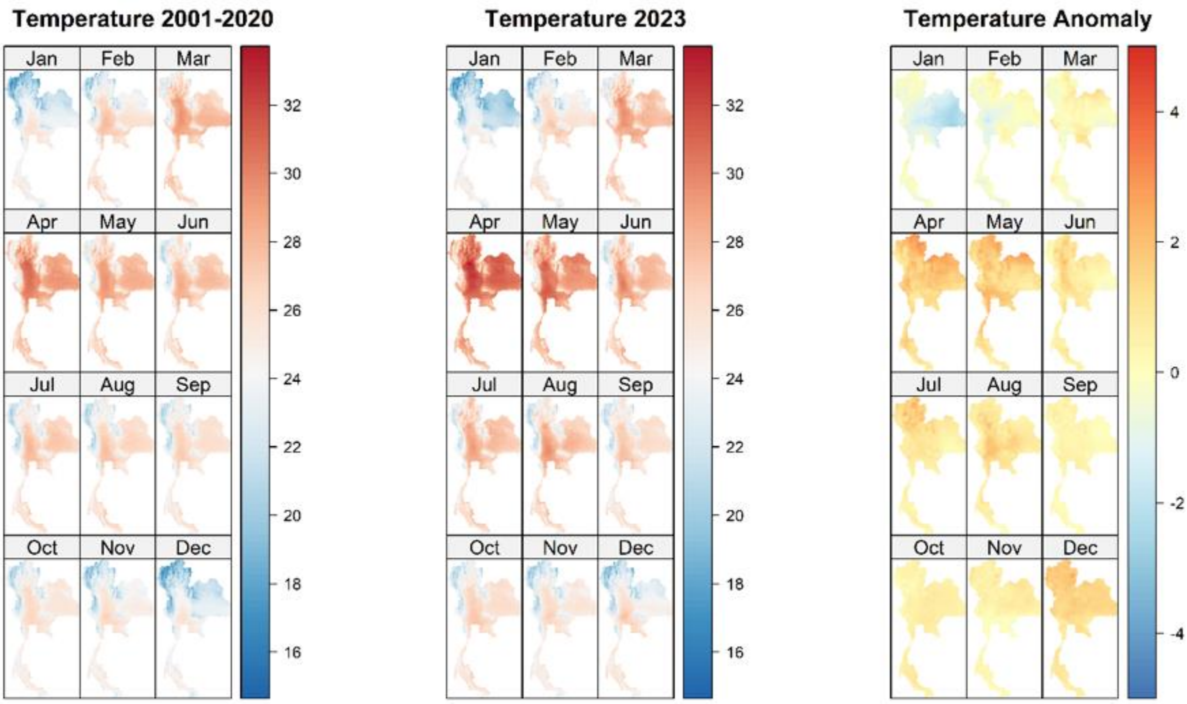

Figure 76 *Spatial distribution of temperatures in Thailand, displaying long-term monthly average temperatures, monthly average temperatures for 2023, and anomaly maps showing the difference between the 2023 temperatures and the long-term averages*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

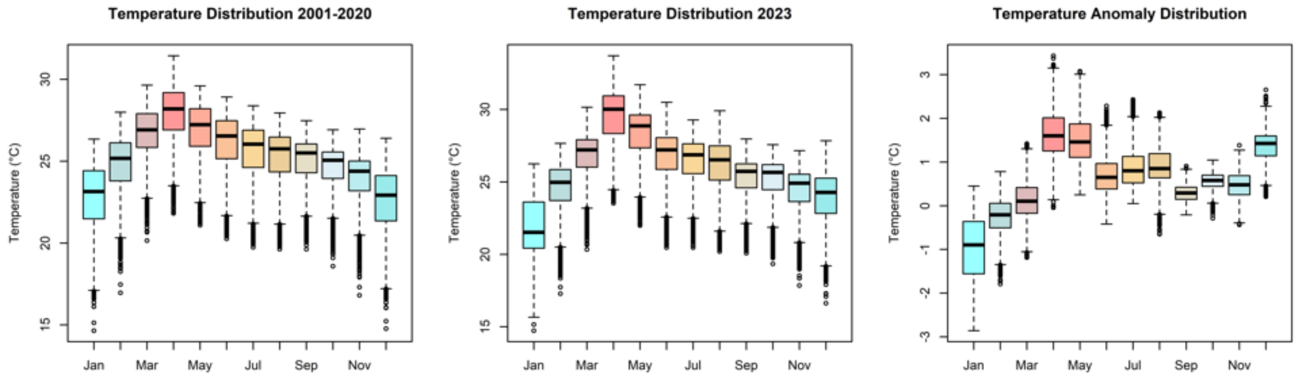

Figure 77 *Boxplot visualization of the mean monthly temperatures in Thailand, comparing the long-term monthly averages, the monthly temperatures recorded in 2023, and the corresponding temperature anomalies*

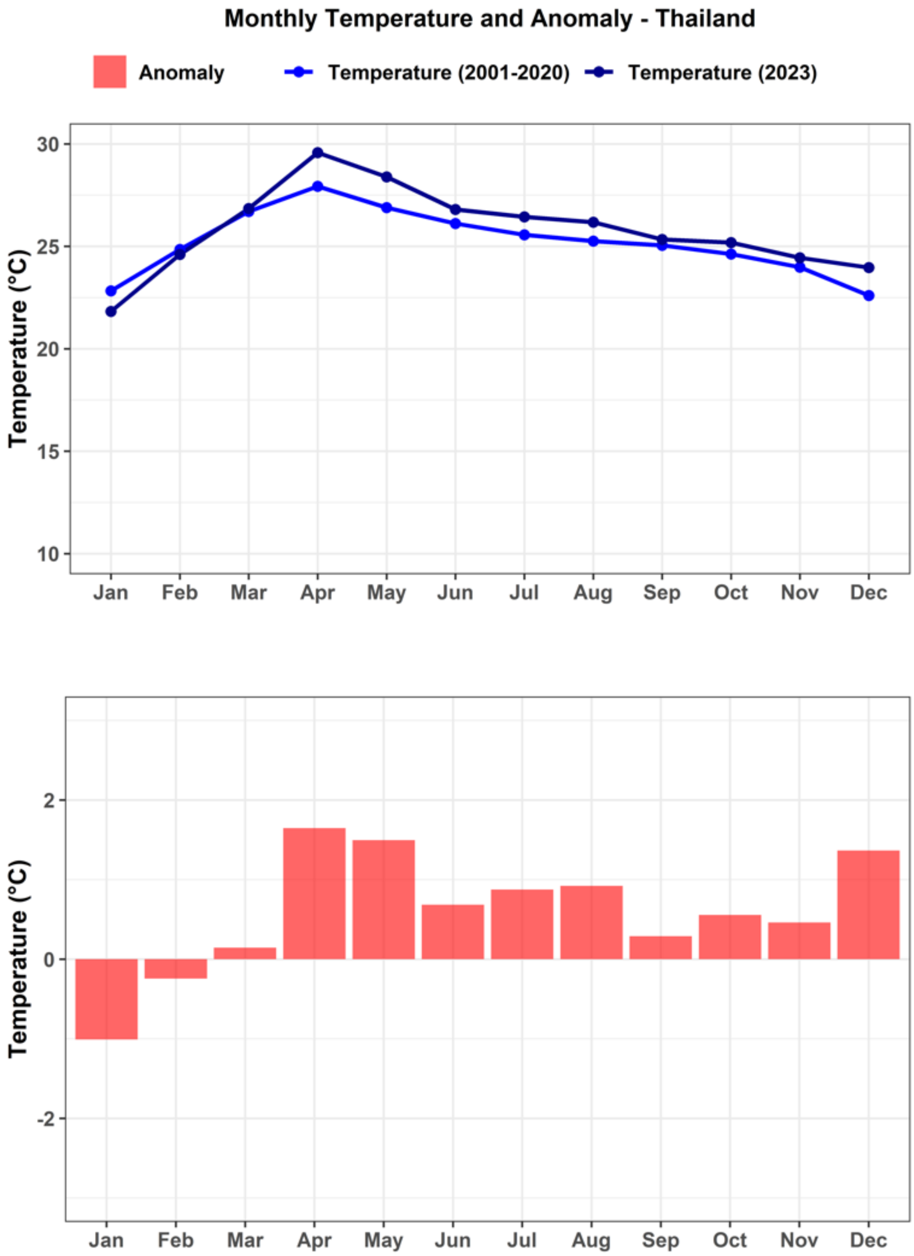

Figure 78 *Spatially aggregated monthly temperature series in Thailand, showing the long-term averages, the temperatures recorded in 2023, and the anomalies.*

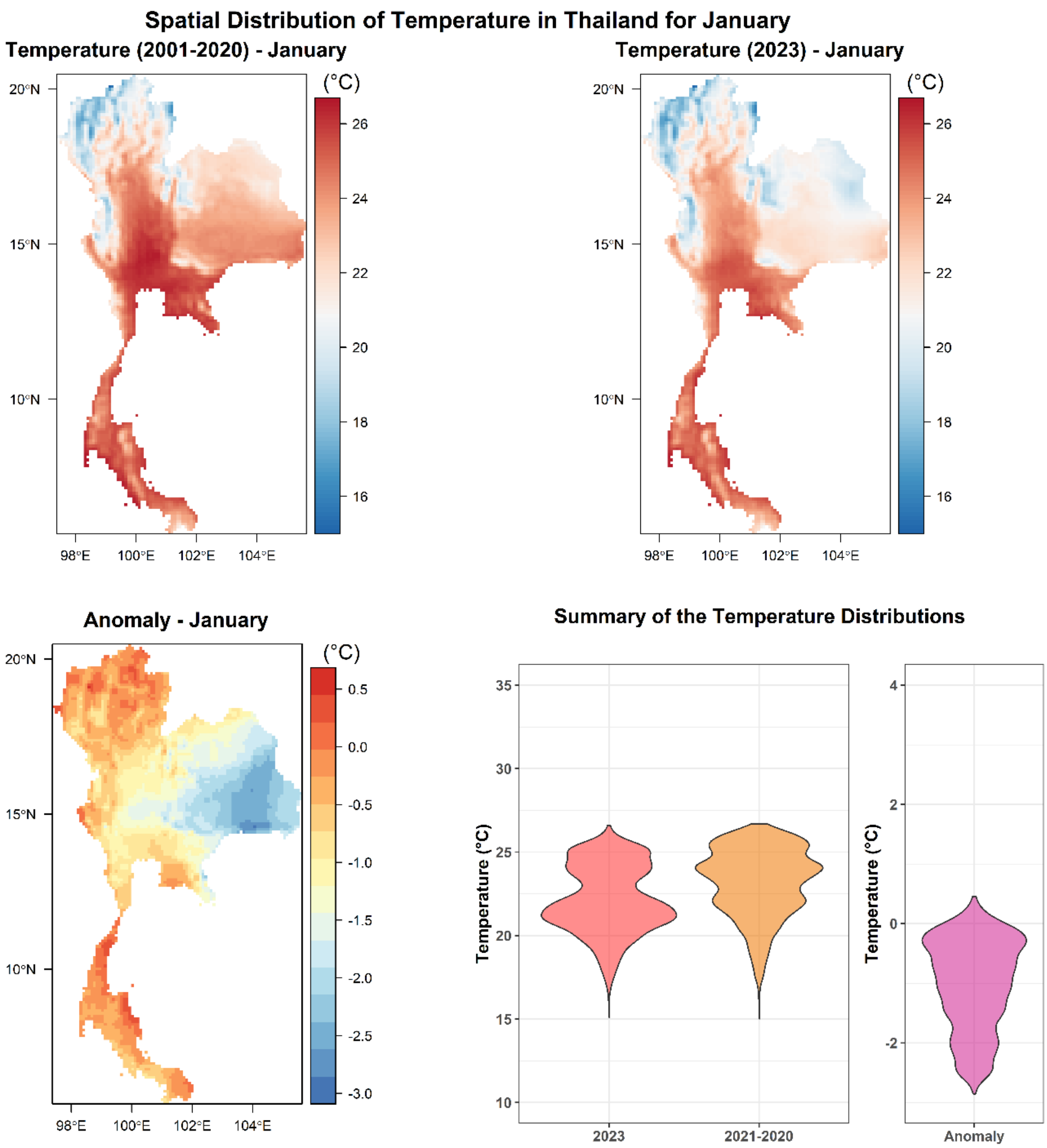

Figure 79 Maps and violin plots illustrate the spatial distribution of January temperatures in Thailand. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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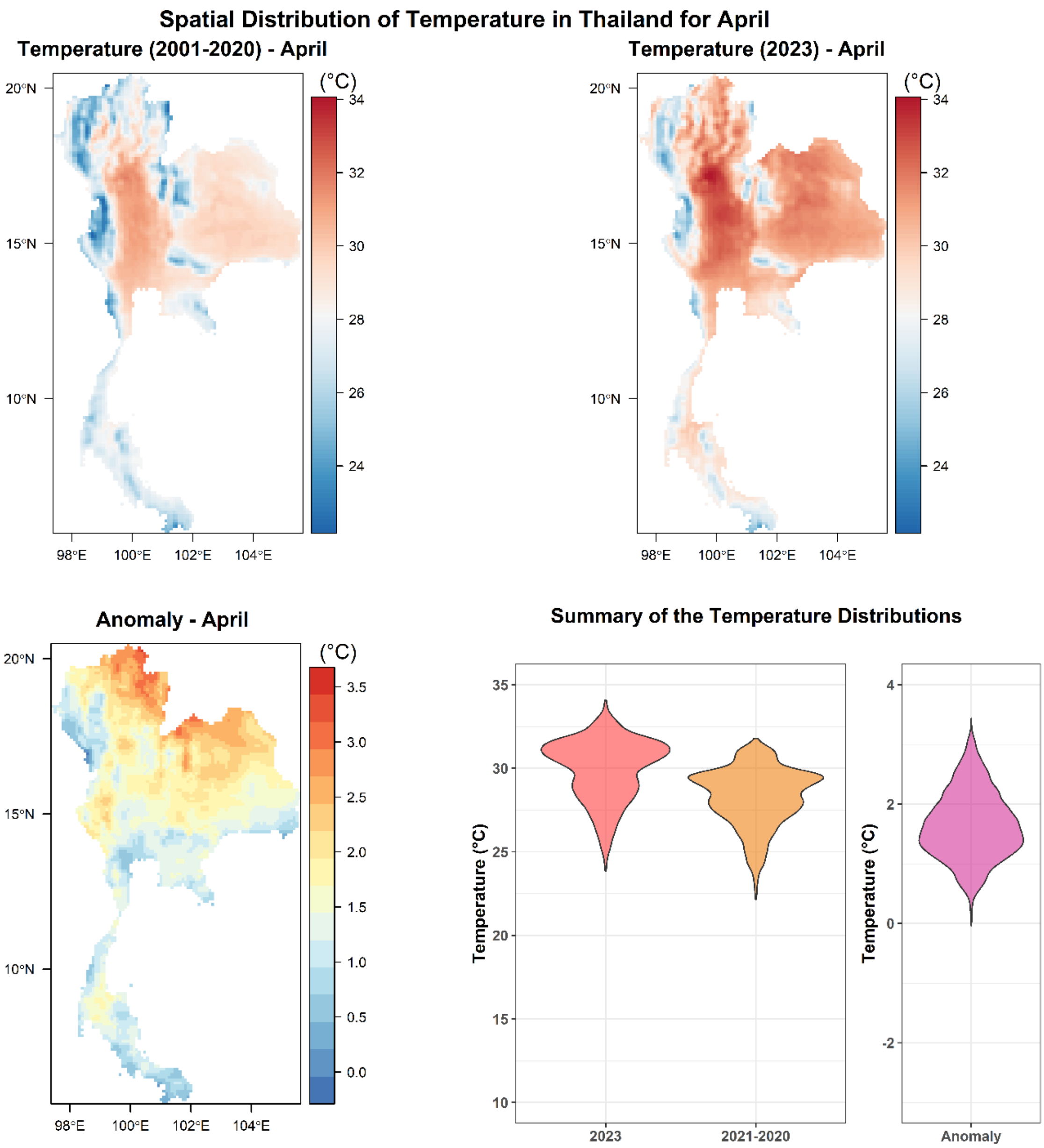

Figure 80 Maps and violin plots illustrate the spatial distribution of May temperatures in Thailand. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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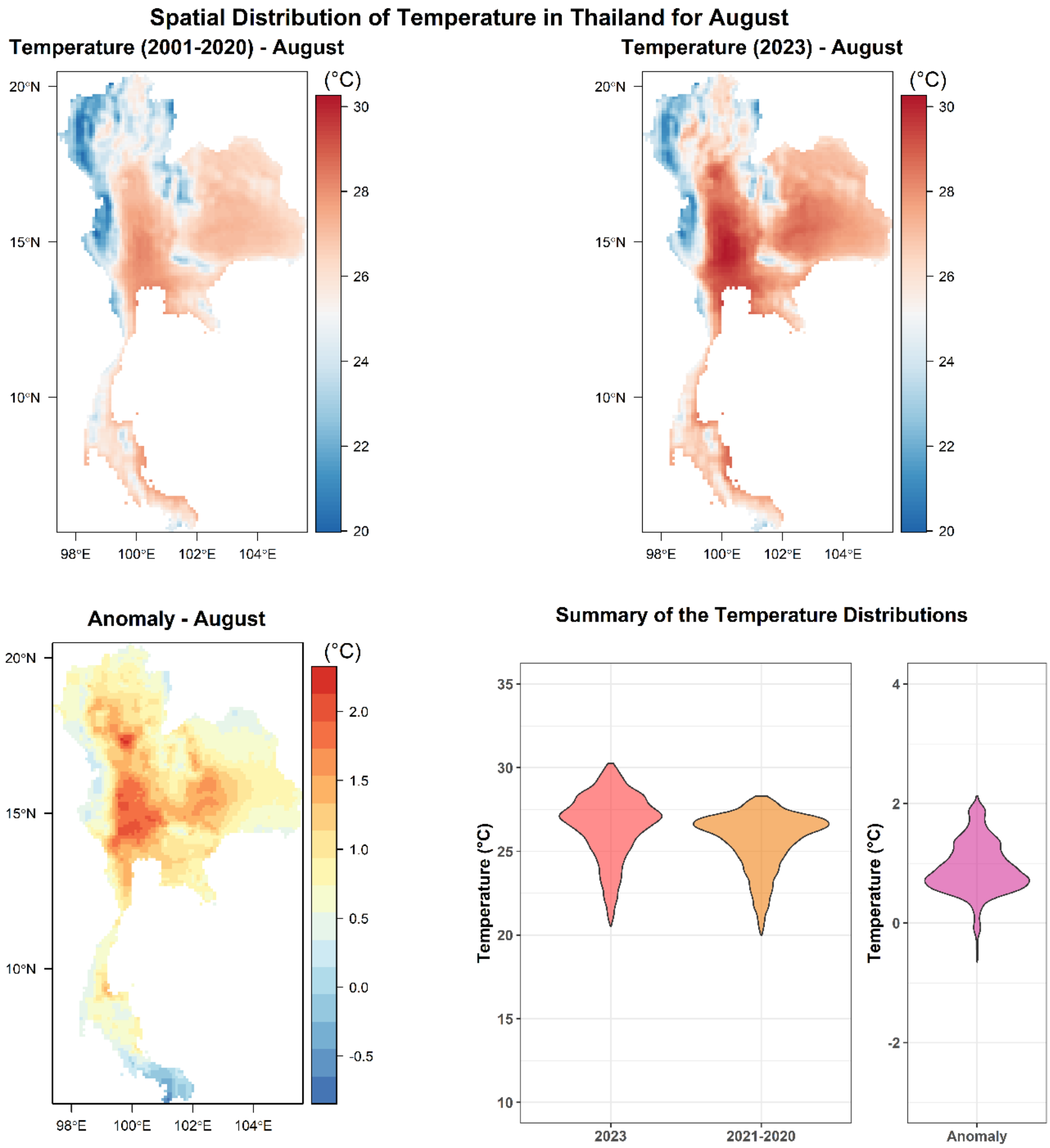

Figure 81 Maps and violin plots illustrate the spatial distribution of August temperatures in Thailand. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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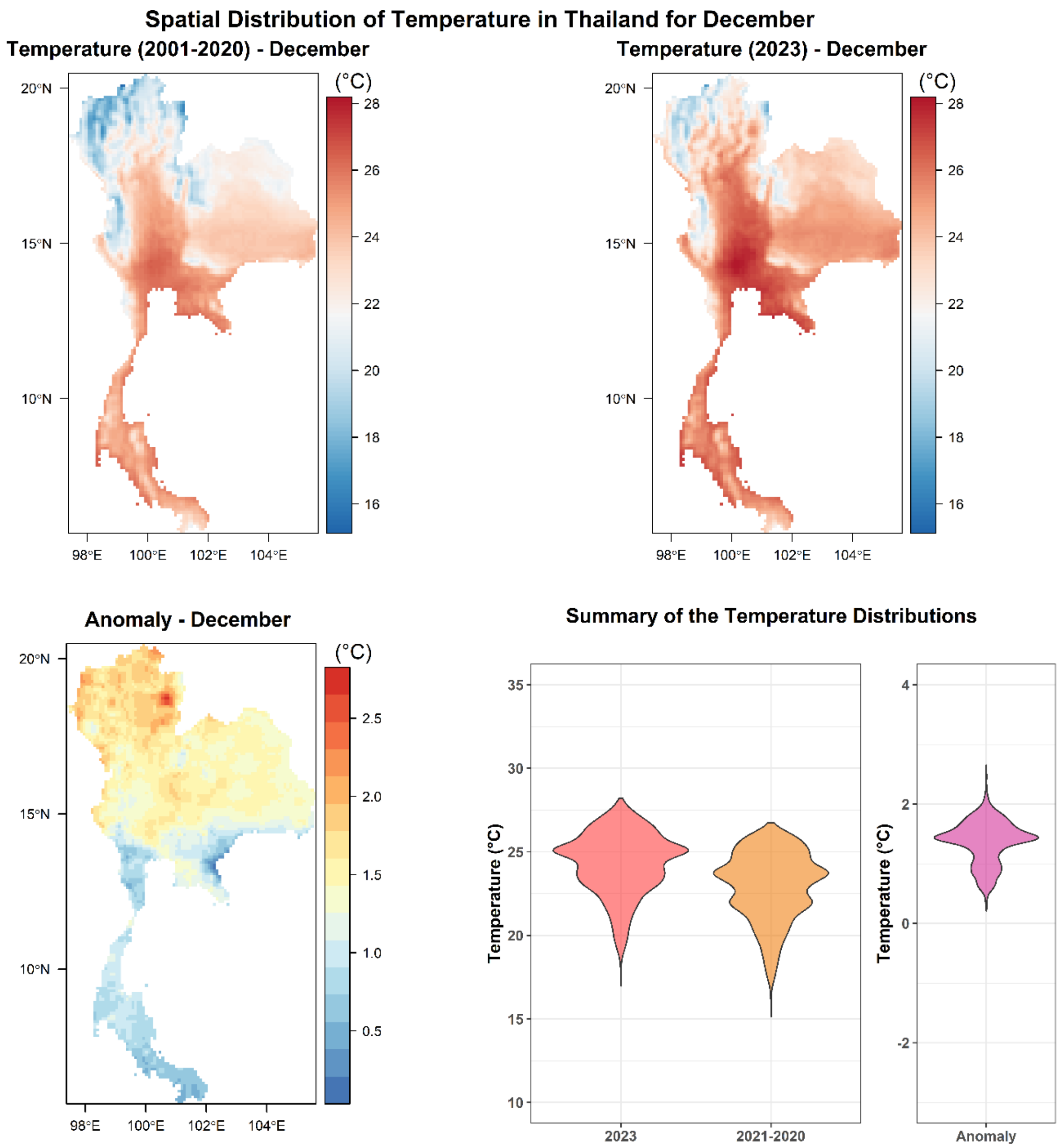

__Figure 82__ Maps and violin plots illustrate the spatial distribution of December temperatures in Thailand. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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Table 27 *Monthly averages of long-term temperatures (°C), 2023 monthly averages (°C), and temperature anomalies (°C) in Thailand.*

Month	**Temperature (2001-2020)**	**Temperature (2023)**	**Anomaly**
Jan	22.825	21.817	-1.009
Feb	24.847	24.603	-0.244
Mar	26.699	26.843	0.144
Apr	27.924	29.570	1.646
May	26.890	28.387	1.496
Jun	26.113	26.798	0.685
Jul	25.562	26.437	0.875
Aug	25.249	26.171	0.922
Sep	25.042	25.331	0.289
Oct	24.623	25.179	0.557
Nov	23.981	24.443	0.462
Dec	22.593	23.958	1.365

4.2.4. Trends of Rainfall in Thailand

The analysis of rainfall changes in Thailand was conducted using ERA5 rainfall data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term rainfall averages (2001-2020) with the recorded rainfall for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average rainfalls and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average rainfalls, the monthly rainfalls for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of rainfall changes, violin plots and box plots were used. Violin plots illustrated the distribution of rainfalls, showing the density and probability of different rainfall ranges over time. Box plots offered a clear visualization of the rainfall distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the rainfall changes in Thailand, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of rainfall trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual rainfall trend in Thailand indicates a decrease in average rainfall from 1673 mm to 1643 mm between 1991 and 2020, reflecting a decline of 30 mm over nearly three decades. The average rainfall during this period was 1957 mm. Additionally, the peak of rainfall distribution has shifted towards lower values compared to the distribution from 1971 to 2000, highlighting a slight reduction in annual rainfall over the past three decades.

Over the past two decades, Thailand has experienced notable changes in its monthly precipitation trends, impacting the country's agricultural landscape. From 2000 to 2010, key agricultural months like March, May, and August saw increases in average monthly rainfall by 7.22 mm, 27.18 mm, and 1.16 mm, respectively. These increases generally supported crop growth by providing sufficient water during critical growing periods. However, April and June recorded declines in rainfall, with decreases of 0.92 mm and 4.67 mm, respectively, which might have presented challenges during these months.

The following decade, from 2010 to 2020, marked a significant shift. Critical months such as March, April, and May experienced sharp declines in rainfall, with reductions of 9.90 mm, 20.56 mm, and 32.45 mm, respectively. These decreases during essential growing periods could lead to water stress for crops, potentially reducing yields and increasing the risk of crop failures. On the other hand, July and August saw increases in rainfall, with rises of 20.31 mm and 10.82 mm, respectively. While these increases during the monsoon season might seem beneficial, they could also lead to challenges like waterlogging and heightened pest infestations, potentially affecting crop health and productivity.

The changes in precipitation patterns are also evident during the off-season months. For instance, January, which saw a decrease of 3.69 mm in the 2000-2010 decade, experienced an increase of 20.67 mm in the 2010-2020 period. Similarly, December's rainfall trend shifted from a decrease of 4.22 mm to an increase of 9.37 mm over the same period. These off-season increases raise concerns about their limited agricultural benefit and the potential for off-season flooding, which could disrupt soil structure and create unfavourable conditions for the following planting season.

These changes in precipitation patterns, marked by reduced rainfall during key agricultural months and increased rainfall during off-season months, make it increasingly challenging for farmers to rely on historical weather patterns for planting and harvesting. As a result, there is a growing need for adaptive strategies, including shifting planting seasons, adopting drought-resistant crop varieties, and relying more on irrigation to manage reduced rainfall during crucial months. Additionally, improved water management systems will be essential to address the challenges posed by increased rainfall during the off-season, such as flooding and soil erosion.

The trends observed over these two decades emphasize the importance of a strategic approach to agriculture in Thailand. Farmers and policymakers must collaborate to develop adaptive strategies that can mitigate the impacts of changing precipitation patterns, ensuring sustainable agricultural productivity and food security in the face of an increasingly unpredictable climate.

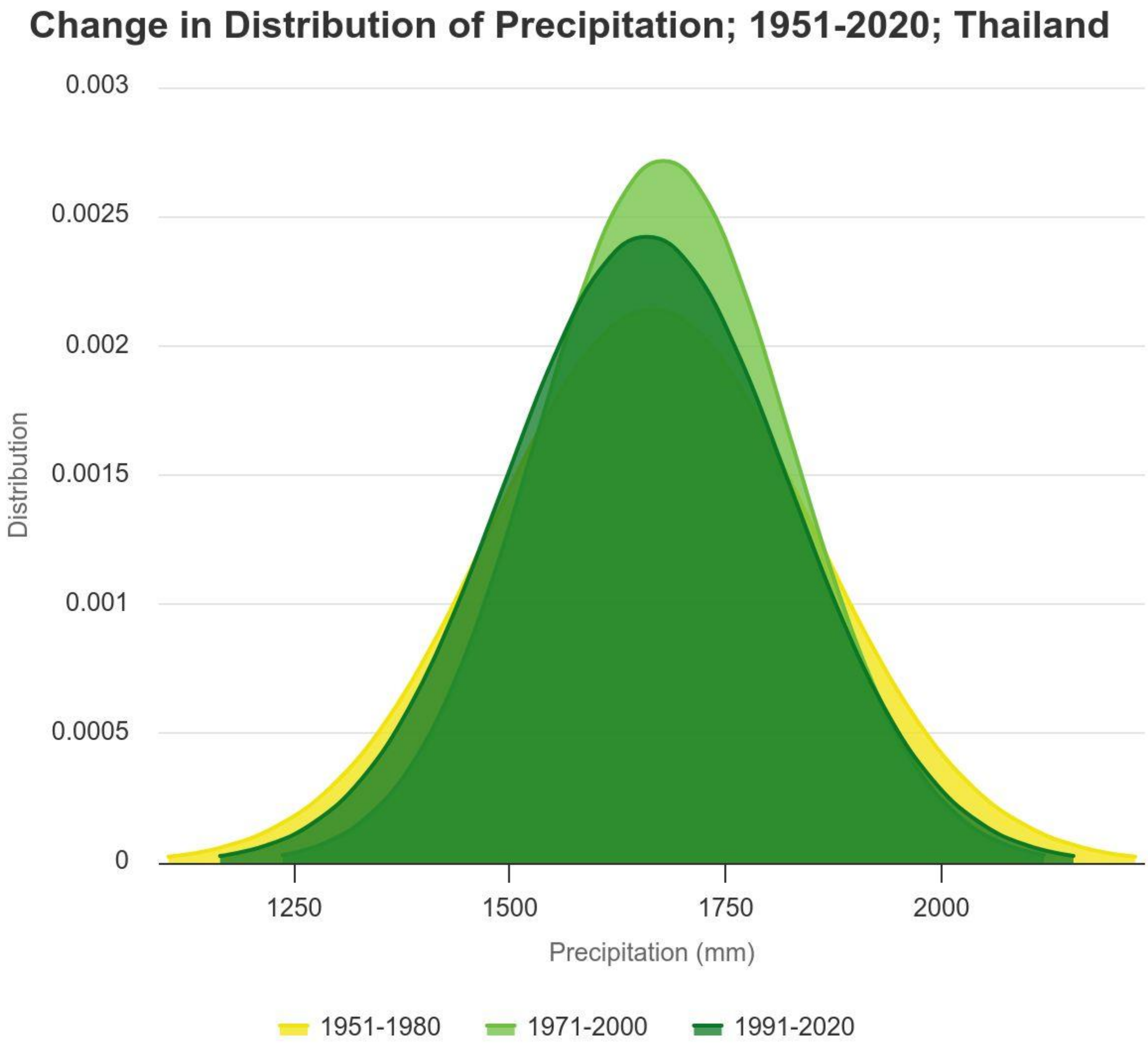

Figure 83 Change in distribution of average rainfall in Thailand for 1951 – 1980, 1971 – 2000, and 1991-2020 (CCKP, 2024b)

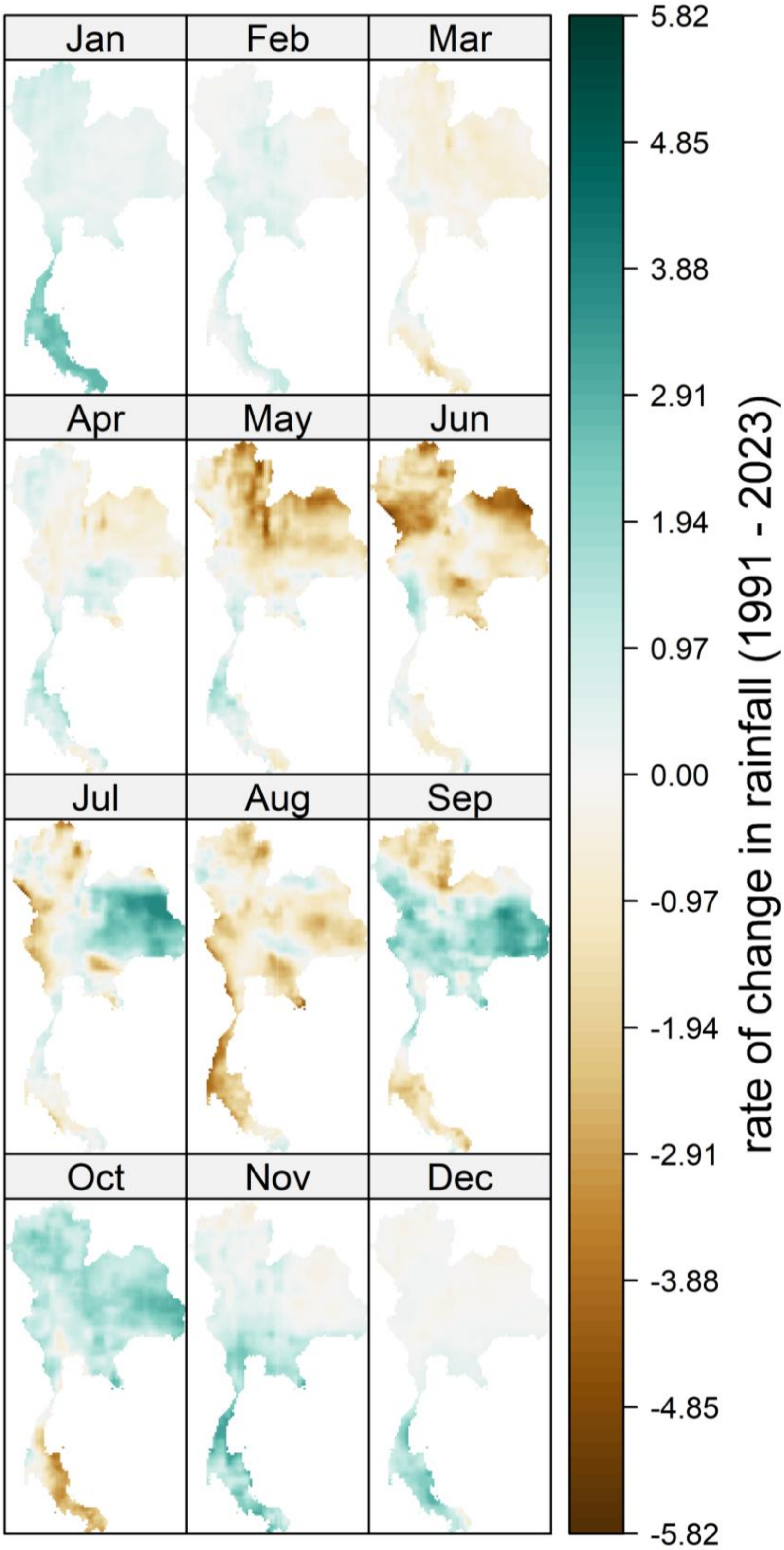

Figure 84 *Spatial patterns of rainfall trends in Thailand, indicating the rate of change in rainfalls from 1991 to 2023*

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Thailand's rainfall data over the past three decades reveals complex trends with significant implications for the country's agriculture, especially in its rice-growing regions. The data shows both increases and decreases in monthly rainfall across different years, affecting crop production cycles, water management, and overall food security.

This period from May to October is critical for rice planting, growing, and harvesting. The data shows significant variability. In May, rainfall fluctuated, rising from 166.87 mm in 1991 to a peak of 284.13 mm in 2000 and then moderating to 130.68 mm in 2023. The variability in May suggests an increasingly unpredictable onset of the monsoon, which is crucial for the timing of planting. Excessive rainfall during this early stage can lead to waterlogging, detrimental to young rice plants.

In June, rainfall peaked at 307.58 mm in 1994 and saw a significant decline to 143.48 mm in 2022. The erratic nature of June's rainfall impacts early crop growth stages, potentially leading to either insufficient water or excessive moisture, both of which can reduce yields.

July has generally seen an upward trend, with rainfall peaking at 388.61 mm in 2019. While sufficient water is generally beneficial, the risk of flooding and waterlogging increases, which can damage crops and reduce productivity. Similarly, rainfall in August has been high, reaching 376.16 mm in 2023. Like July, the increased rainfall brings both the benefit of ample water and the challenge of potential flooding, particularly in low-lying rice paddies.

September's rainfall trends have been inconsistent, ranging from 421.76 mm in 2009 to lower levels of 213.65 mm in 2018. This month is crucial for crop maturation, and such variability can result in unpredictable harvests, with either delays or insufficient water for optimal grain development. October, during the harvest period, has seen rainfall ranging from 253.73 mm in 1991 to a peak of 321.63 mm in 2021. Excessive rainfall during harvest can cause post-maturation damage.

The dry season months of January to March have shown significant fluctuations in rainfall. January's rainfall increased dramatically from 9.48 mm in 1991 to 71.72 mm in 2023. This rise in what is traditionally a dry month could disrupt water storage and management practices, potentially leading to waterlogged fields unprepared for early planting.

In February, rainfall has fluctuated, from a low of 5.23 mm in 1993 to a high of 80.68 mm in 2022. Such variability complicates planning for the dry season and can disrupt the preparation of fields for the upcoming growing season. March experienced a sharp drop in rainfall from 156.39 mm in 2001 to just 13.54 mm in 2023. The significant reduction during a crucial period for field preparation can severely impact agricultural planning and readiness for the growing season.

The observed rainfall trends highlight the growing unpredictability of Thailand's climate, posing challenges for agriculture. Increased rainfall in traditionally dry months necessitates improved water management systems to efficiently capture and store water for use during drier periods. Rising rainfall during monsoon months heightens the risk of flooding and waterlogging, which can be detrimental to crops, particularly rice, which is sensitive to both drought and excessive moisture.

The variability in rainfall patterns complicates crop planning and may require shifts in planting and harvesting schedules to align with changing rainfall patterns. There is also an urgent need to develop climate-resilient crop varieties capable of withstanding both excessive rainfall and potential droughts, ensuring stable yields despite changing climate conditions.

In conclusion, Thailand's rainfall data reflects increasing and decreasing trends across different months, significantly impacting agriculture. These changes underscore the need for adaptive strategies in water management, crop planning, and the development of resilient agricultural systems to cope with the challenges posed by climate change.

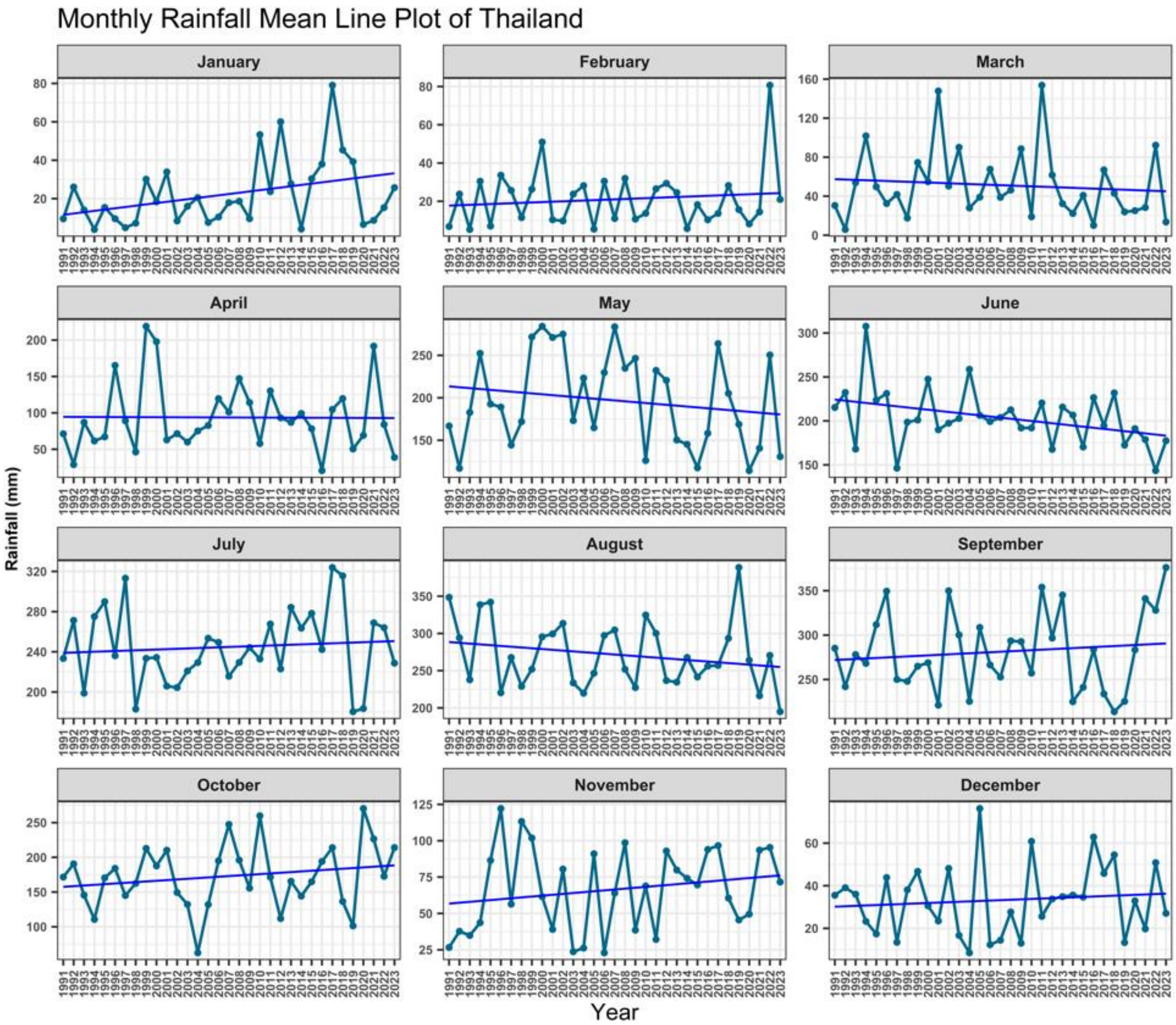

Figure 85 *Spatially aggregated mean monthly rainfall time series line plots with trend lines, depicting the variation of mean monthly rainfalls over time in Thailand.*

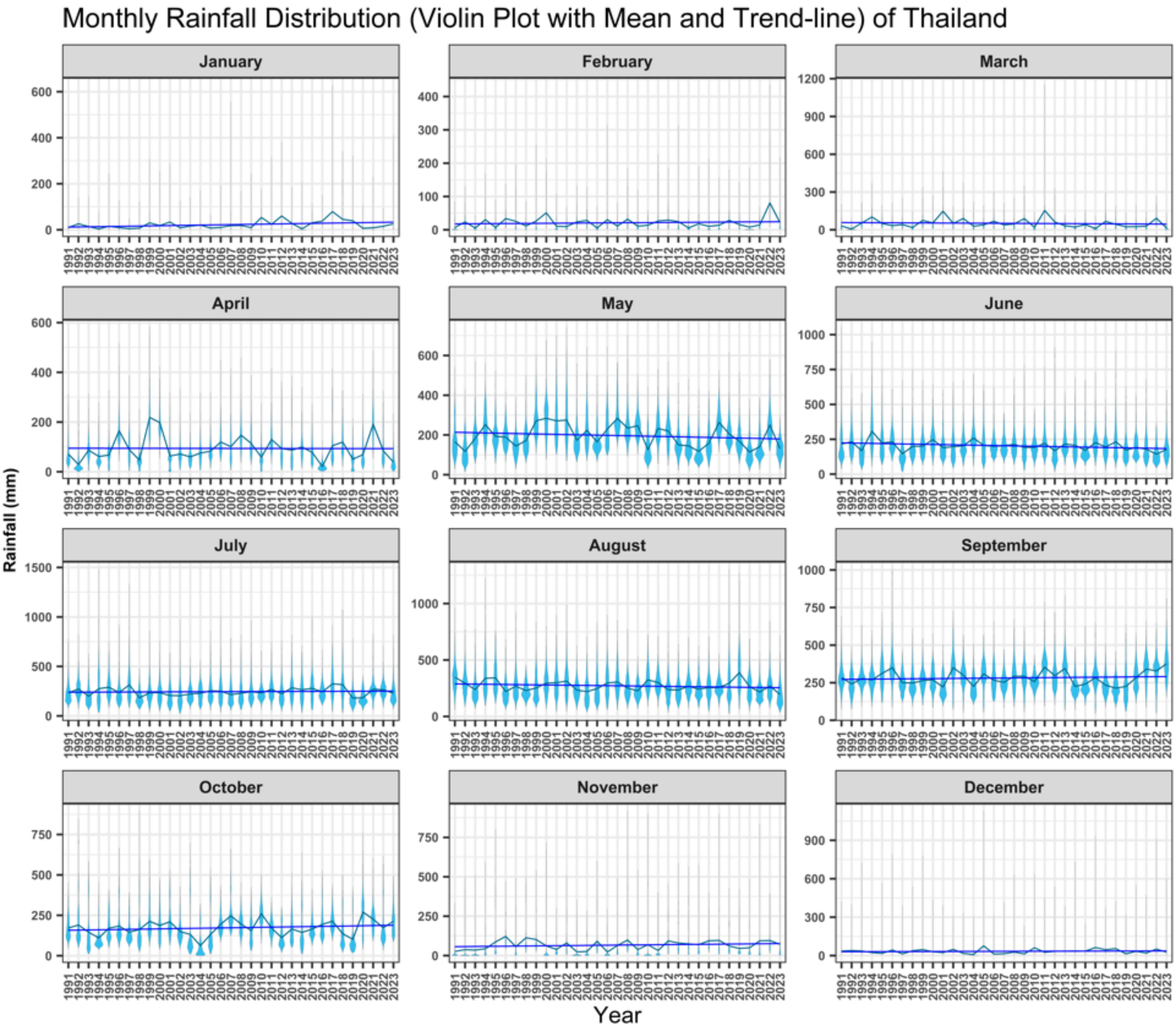

__Figure 86__ Distribution of mean monthly rainfall time series and violin plots in Thailand, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly rainfalls

Table 28 Spatially aggregated mean monthly rainfall (mm) in Thailand from 1991 to 2023, derived from ERA-5 data

Month/ Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	9.482	6.799	30.443	71.268	166.865	215.284	233.390	348.501	285.159	171.636	26.596	35.553
1992	26.044	23.748	5.858	28.985	116.967	232.368	271.244	294.252	241.895	190.552	37.683	39.045
1993	14.106	5.231	53.764	86.912	182.796	167.965	198.833	237.804	277.963	145.547	34.850	35.993
1994	3.915	30.467	101.806	61.507	252.311	307.577	275.084	338.570	268.120	110.660	43.615	23.267
1995	15.388	7.025	49.577	67.108	192.634	223.687	289.863	342.007	311.726	170.401	86.490	17.368
1996	9.547	33.633	32.507	165.113	189.095	231.228	236.080	220.344	349.359	184.093	122.122	43.828
1997	4.853	25.652	41.752	89.059	144.356	146.277	313.242	267.734	249.993	144.979	56.359	13.438
1998	7.224	11.430	17.573	46.284	171.918	198.586	182.992	228.909	247.855	162.485	113.260	38.073
1999	30.088	26.326	74.596	218.822	271.613	201.052	233.500	252.049	264.869	212.885	101.861	46.730
2000	18.340	50.988	54.756	197.776	284.128	247.454	234.362	295.496	268.867	187.620	61.524	30.541
2001	33.871	10.328	147.772	62.853	271.018	189.945	205.917	299.372	221.080	210.224	39.030	23.444
2002	8.350	9.759	50.306	71.408	274.963	197.391	204.441	313.584	349.874	149.318	80.486	48.120
2003	16.034	23.767	90.059	59.893	173.170	202.855	220.923	233.579	300.122	132.137	23.644	16.673
2004	20.511	28.140	27.905	75.233	223.249	258.743	229.295	219.736	225.296	62.416	26.205	8.485
2005	7.584	5.432	38.951	82.683	164.781	206.260	253.453	246.589	308.627	131.978	91.025	76.242
2006	10.435	30.484	67.634	119.534	229.679	199.357	249.423	297.268	266.381	195.010	22.887	12.274
2007	17.896	10.968	38.820	101.161	283.570	203.888	215.647	304.674	252.701	247.373	63.967	14.405
2008	18.600	31.950	46.242	147.225	234.732	212.650	229.435	251.823	293.417	196.016	98.585	27.654
2009	9.513	10.691	88.586	114.172	246.525	191.975	244.240	227.354	292.706	155.573	38.519	12.966
2010	53.321	13.697	18.911	57.894	126.140	192.011	232.864	324.751	257.136	259.804	68.905	60.843
2011	23.646	26.522	153.717	130.209	232.271	220.446	267.621	300.168	353.892	171.497	32.096	25.613
2012	60.023	29.335	61.608	93.202	220.511	167.605	222.980	236.832	296.599	111.820	92.923	33.765
2013	27.754	24.514	32.353	86.967	150.314	215.701	284.256	234.637	345.166	165.538	79.882	34.891
2014	4.154	5.701	22.274	99.137	145.202	206.651	263.551	267.768	224.993	144.190	74.138	35.580
2015	30.384	18.201	40.885	78.136	117.609	170.278	278.257	241.603	241.185	164.878	69.605	34.682
2016	37.974	10.315	10.083	20.706	158.233	226.535	242.324	256.147	283.832	194.034	93.959	62.857
2017	79.064	13.637	66.940	104.630	263.759	194.618	323.950	257.030	233.730	213.916	96.655	45.779
2018	45.342	28.205	43.004	119.625	205.189	231.834	315.606	293.482	213.651	136.430	60.549	54.504
2019	39.260	15.627	23.896	50.467	168.828	172.483	180.372	388.607	225.331	101.286	45.484	13.331
2020	6.544	8.131	25.141	69.102	114.269	191.263	183.594	263.968	283.319	270.253	49.495	32.929
2021	8.668	14.453	28.390	191.616	140.541	178.852	268.866	216.234	340.998	226.414	93.552	19.750
2022	15.325	80.683	92.215	84.011	250.382	143.483	264.041	270.524	327.907	172.697	95.380	50.828
2023	25.723	20.970	13.538	38.832	130.683	177.506	228.718	194.889	376.164	214.018	71.584	27.048

A comparison of monthly average rainfall between two periods—the long-term average from 2001 to 2020 and the recorded rainfall for 2023—was conducted for Thailand. This analysis also included rainfall anomalies for each month, highlighting deviations from the long-term averages, which have significant implications for agriculture.

Thailand's rainfall data for 2023 reveals several notable deviations from the long-term averages. In January 2023, the recorded rainfall was 25.723 mm, showing a slight decrease of 1.790 mm from the long-term average of 27.513 mm. February, however, experienced a modest increase, with rainfall measuring 20.970 mm, which is 3.200 mm above the long-term average of 17.770 mm. Conversely, March observed a significant decrease in rainfall, with only 13.538 mm recorded, 41.216 mm below the long-term average of 54.754 mm. This reduction in March could delay planting and impede the early stages of crop growth, potentially affecting overall yields. In

April, rainfall recorded was 38.832 mm, which is 48.380 mm below the long-term average of 87.212 mm. May also saw a reduction, with 130.683 mm recorded, 69.518 mm less than the long-term average of 200.201 mm. These reductions in April and May could adversely affect crop growth stages and overall productivity. Similarly, June and July also recorded below-average rainfall, with June measuring 177.506 mm (25.118 mm below the long-term average of 202.624 mm) and July recording 228.718 mm (13.690 mm below the long-term average of 242.407 mm). Although these months experienced less rainfall, the levels were still sufficient to support crop growth but could increase water demand and the potential risk of heat stress, thereby impacting crop health and productivity. August continued this trend of reduced rainfall, with 194.889 mm recorded, 78.060 mm below the long-term average of 272.949 mm. However, September saw a dramatic increase in rainfall, with 376.164 mm recorded, which is 102.712 mm above the long-term average of 273.452 mm. October also experienced an increase, with 214.018 mm recorded, 43.333 mm above the long-term average of 170.685 mm. November recorded 71.584 mm, which is 9.182 mm above the long-term average of 62.402 mm, indicating a continuation of this late-year trend. December, however, saw a slight decrease, with rainfall of 27.048 mm, 6.704 mm below the long-term average of 33.752 mm.

The seasonal variations in rainfall throughout 2023 reflect a complex dynamic that has significant implications for Thailand's agriculture. The pronounced decreases in rainfall early in the year could delay planting and slow crop establishment, while the reduced rainfall in mid-year months like June and July may require adjustments to water management practices. The significant increases observed in September and October could enhance crop growth during the late stages of development but also pose challenges for harvesting, especially if excessive moisture leads to waterlogged fields. Overall, these fluctuations in rainfall highlight the need for adaptive agricultural strategies in Thailand. Adjustments such as revising planting schedules, enhancing irrigation efficiency, and selecting crop varieties that can withstand variable moisture conditions are crucial to sustaining agricultural productivity. These measures will help mitigate the impacts of climate change on Thailand's croplands, ensuring stable yields in the face of increasingly unpredictable weather patterns.

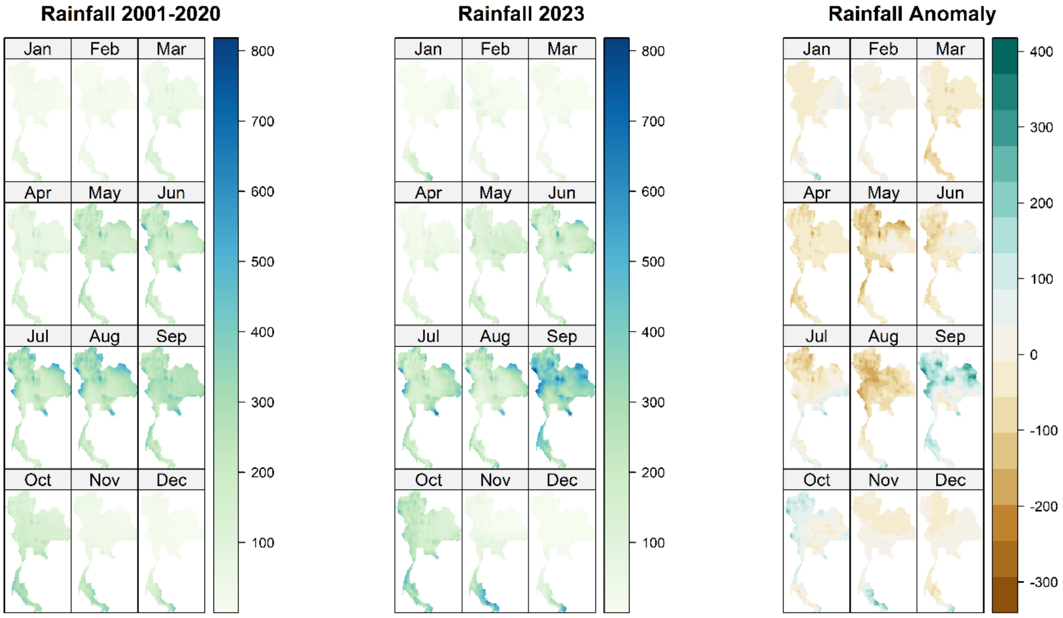

Figure 87 Spatial distribution of rainfalls in Thailand, displaying long-term monthly average rainfalls, monthly average rainfalls for 2023, and anomaly maps showing the difference between the 2023 rainfalls and the long-term averages

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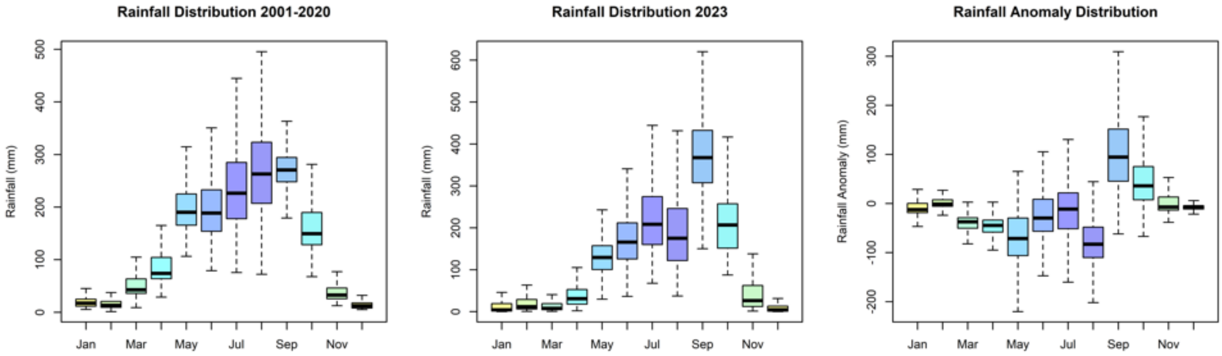

Figure 88 *Boxplot visualization of the mean monthly rainfalls in Thailand, comparing the long-term monthly averages, the monthly rainfalls recorded in 2023, and the corresponding rainfall anomalies*

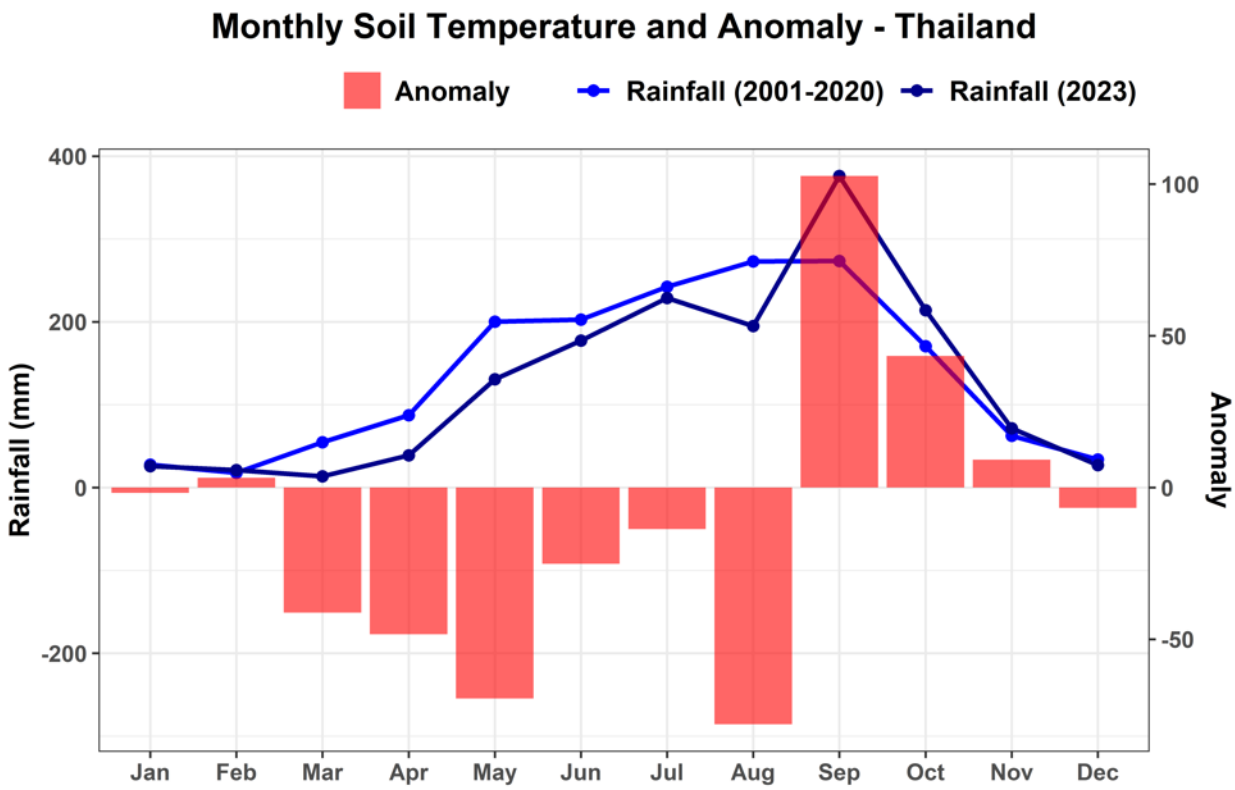

Figure 89 *Spatially aggregated monthly rainfall series in Thailand, showing the long-term averages, the rainfalls recorded in 2023, and the anomalies.*

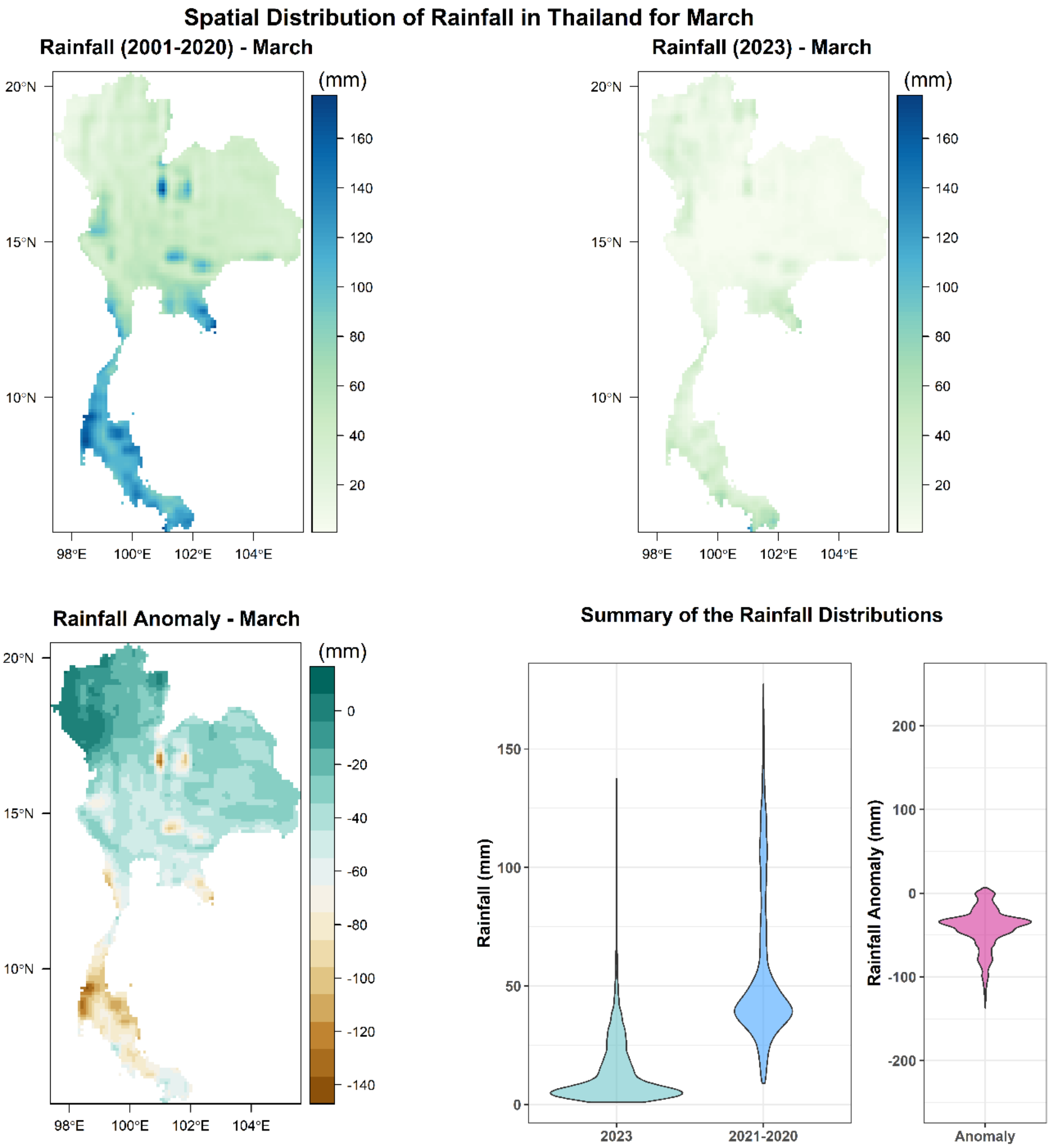

Figure 90 *Maps and violin plots illustrate the spatial distribution of January rainfalls in Thailand. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data*

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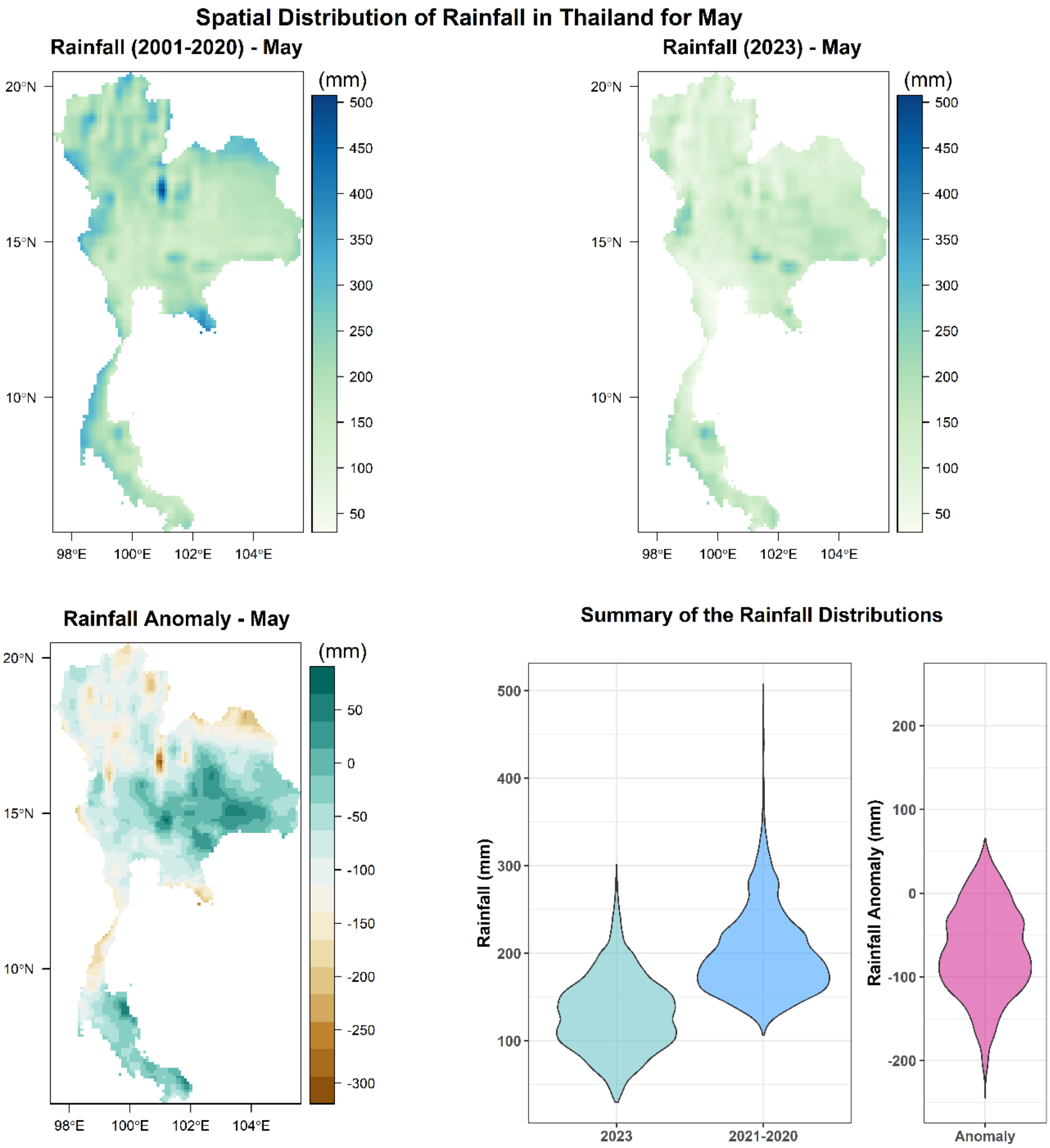

__Figure 91__ Maps and violin plots illustrating the spatial distribution of May rainfalls in Thailand. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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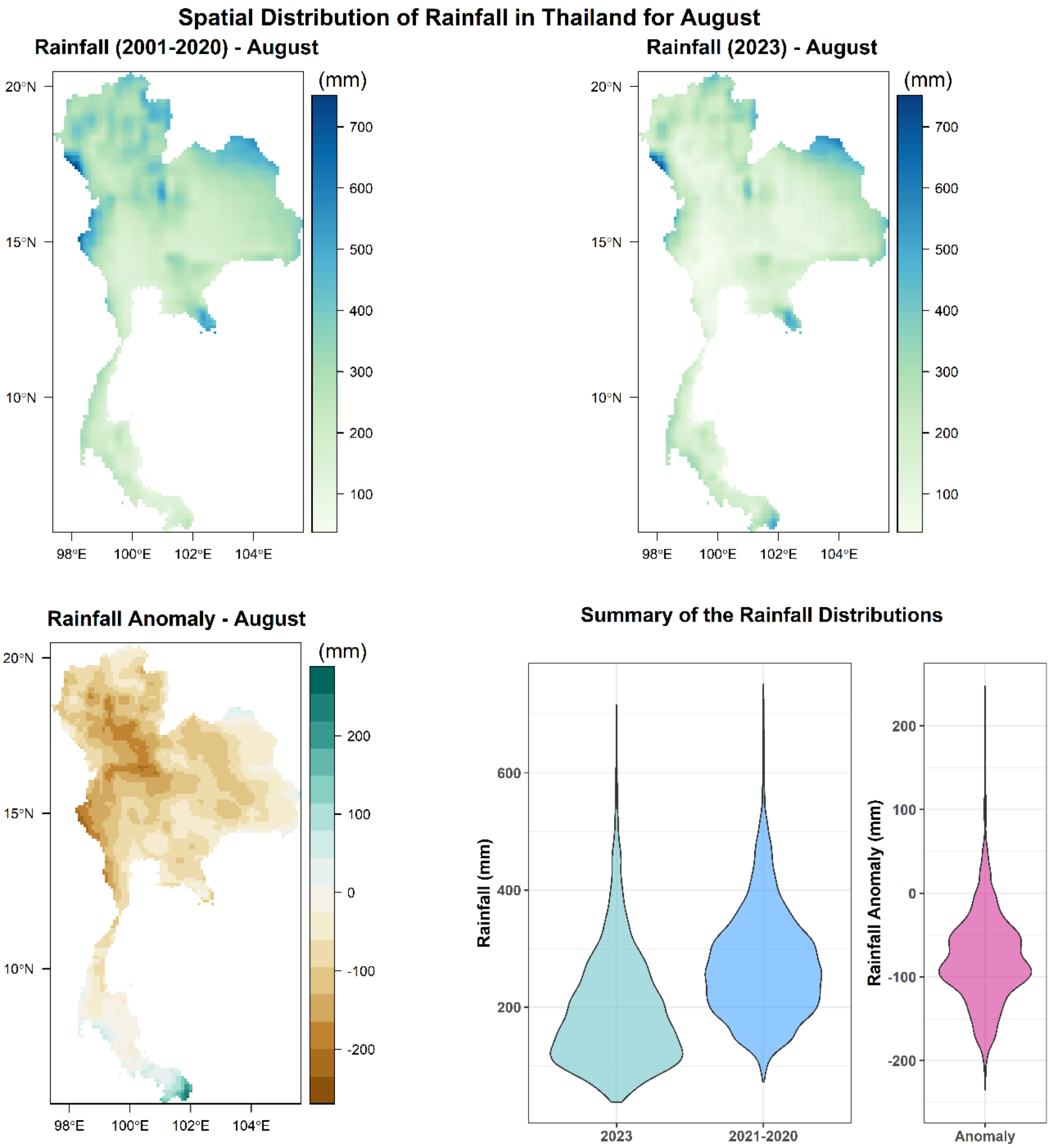

Figure 92 *Maps and violin plots illustrate the spatial distribution of August rainfalls in Thailand. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data*

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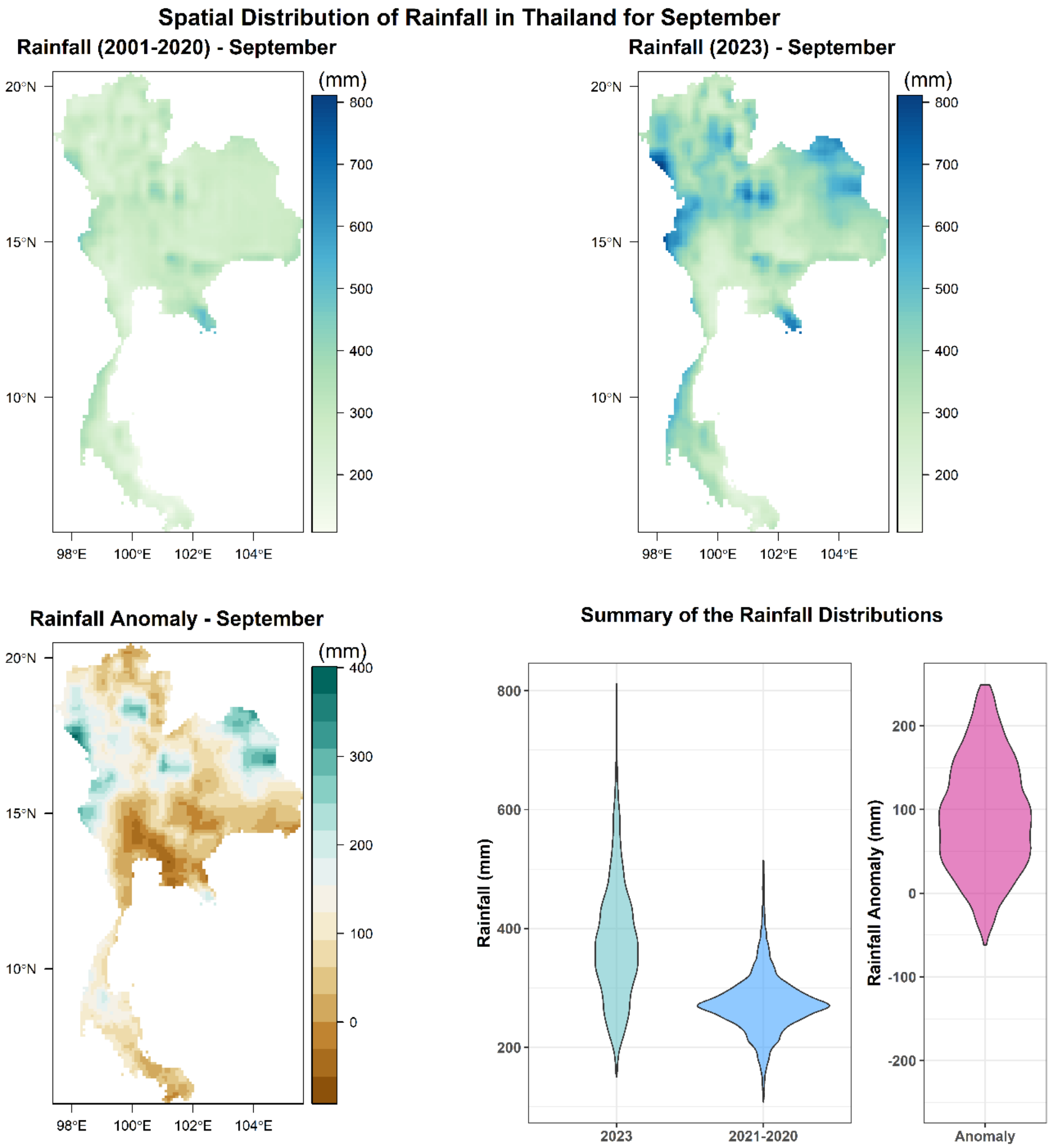

__Figure 93__ Maps and violin plots illustrate the spatial distribution of September rainfalls in Thailand. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 29 *Monthly averages of long-term rainfalls (mm), 2023 monthly averages (mm), and rainfall anomalies (mm) in Thailand*

Month	Rainfall (2001-2020)	Rainfall (2023)	Anomaly
Jan	27.513	25.723	-1.790
Feb	17.770	20.970	3.200
Mar	54.754	13.538	-41.216
Apr	87.212	38.832	-48.380
May	200.201	130.683	-69.518
Jun	202.624	177.506	-25.118
Jul	242.407	228.718	-13.690
Aug	272.949	194.889	-78.060
Sep	273.452	376.164	102.712
Oct	170.685	214.018	43.333
Nov	62.402	71.584	9.182
Dec	33.752	27.048	-6.704

4.2.5. Trends of NDVI in Thailand

To analyze the cascading impacts of changing conditions, such as variations in temperature and rainfall, the corresponding changes in vegetation greenness, which indicates crop biomass, were assessed using time series data on the Normalized Difference Vegetation Index (NDVI). The NDVI measures the "greenness" of ground cover and serves as a proxy to indicate the density and health of vegetation. NDVI values range from +1 to -1, with high positive values corresponding to dense and healthy vegetation, while low or negative values indicate poor vegetation conditions or sparse vegetative cover (Cohen et al., 2018) (Bayarjargal et al., 2006; Tucker et al., 1983).

The deviations in NDVI were analyzed using anomalies in NDVI maps, graphs, and tables, along with the time series values of NDVI. NDVI anomalies represent the variation of current decadal (10-day period) values compared to the long-term average (Tucker and Sellers, 1986). A positive anomaly (e.g., +5%) signifies enhanced vegetation conditions relative to the average, while a negative anomaly (e.g., -5%) indicates poorer vegetation conditions (Anyamba et al., 2010).

The data for this analysis was accessed through the Food and Agriculture Organization's (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS) (FAO-GIEWS, 2024). GIEWS monitors the condition of major food crops at both country and global levels to assess production prospects. To support this analysis and supplement ground-based information, GIEWS utilizes remote sensing data, which provides valuable insights into water availability and vegetation health during cropping seasons. In addition to rainfall estimates and NDVI, GIEWS relies on vegetation indicators derived from 10-day (decadal) vegetation data captured by the METOP-Advanced Very High-Resolution Radiometer (AVHRR) sensor at a 1 km resolution (for data from 2007 onwards). For data from 1984 to 2006, NDVI values are derived from the National Oceanic and Atmospheric Administration (NOAA)-AVHRR dataset at a 16 km resolution. Precipitation estimates for African countries (except Cabo Verde and Mauritius) are sourced from NOAA's Famine Early Warning Systems Network (FEWSNet), while data for other countries is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

In this assessment, monthly maps of NDVI anomalies were obtained for the years 2022, 2023, and up to July 2024. Time series statistics were generated at the sub-national level and then integrated at the country level to indicate the monthly variation in NDVI profiles over crop areas and the corresponding anomalies.

The long-term temporal profiles of croplands in Thailand, as reflected in NDVI (Normalized Difference Vegetation Index) data from 1991 to 2020, show distinct seasonal variations throughout the year. Typically, NDVI values are lower at the beginning of the year, gradually increasing through the growing season, peaking around September to November, and then declining towards the end of the year. This pattern aligns with the agricultural cycle, where vegetation greenness intensifies during the monsoon season, reflecting crop growth, and decreases post-harvest.

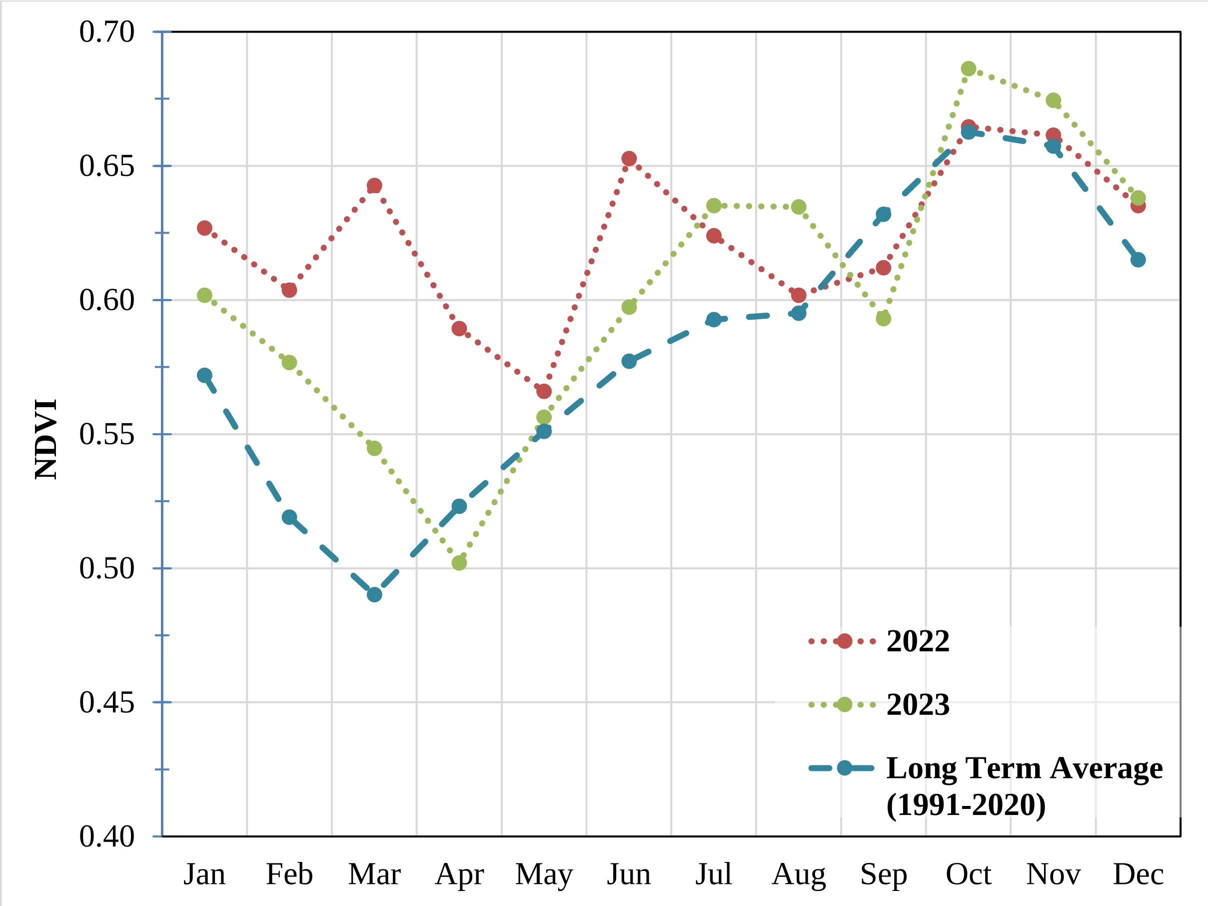

Figure 94 *Spatially aggregated mean monthly NDV profiles in Thailand from 1991 to 2023 showing monthly averages, long-term averages (1991-2020), and anomalies for 2022-23 over the crop area (FAO-GIEWS, 2024)*

In 2023, monthly NDVI anomalies reveal deviations from the long-term average, indicating unusual vegetation conditions. The year began with positive anomalies from January to March, suggesting above-average vegetation greenness. However, in April, a significant negative anomaly (-4.03%) was observed, potentially due to adverse weather conditions or delayed crop growth. The following months showed a mix of slight positive anomalies, with July and August registering notable increases in NDVI by 7.16% and 6.67%, respectively. September, however, experienced a negative anomaly (-6.16%), which could be indicative of early harvests or stress conditions affecting vegetation. The year ended with moderate positive anomalies, indicating overall healthier vegetation compared to the long-term average.

The NDVI anomalies in 2022 were particularly pronounced, with significant positive deviations from the long-term average. The early months, particularly March, recorded a 31.13% anomaly, indicating exceptionally vigorous vegetation growth, possibly due to favorable weather or agricultural practices. April and May also saw considerable positive anomalies, suggesting sustained crop health during these critical growing periods. However, the latter part of the year showed a reduction in the anomalies, with some negative deviations, particularly in September (-3.14%). Despite this, the overall trend for 2022 indicated a year of above-average vegetation greenness.

Examining the anomalies from 2021 to 2023 reveals a pattern of variability in NDVI profiles, with each year showing unique characteristics. In 2021, the anomalies were generally positive, particularly in May (13.42%) and June (11.36%), indicating robust vegetation during these months. However, March 2021 showed a slight negative anomaly (-0.86%), reflecting a brief period of below-average vegetation health. The years 2022 and 2023 continued this trend of variability, with 2022 exhibiting the most significant positive anomalies, while 2023 showed a more mixed pattern with both positive and negative deviations.

The observed changes and anomalies in NDVI from 2021 to 2023 can be attributed to several factors, including climatic variations, agricultural practices, and possibly the impacts of climate change. Positive anomalies could be driven by favorable weather conditions, such as timely monsoon rains or improved irrigation practices, leading to enhanced crop growth. Conversely, negative anomalies, particularly those observed in April 2023 and September 2023, might be linked to factors such as drought stress, extreme weather events, or changes in land use patterns that adversely affect vegetation.

Over the long term, from 1991 to 2023, NDVI profiles in Thailand's croplands have shown a gradual evolution, reflecting changes in agricultural intensity, land management practices, and possibly the effects of climate change. The overall trend suggests a slight increase in NDVI over the years, indicating improvements in crop productivity or changes in vegetation cover. However, the increasing frequency and magnitude of anomalies in recent years highlight the growing influence of climatic variability and the need for adaptive agricultural strategies to ensure sustainable crop production in the face of changing environmental conditions.

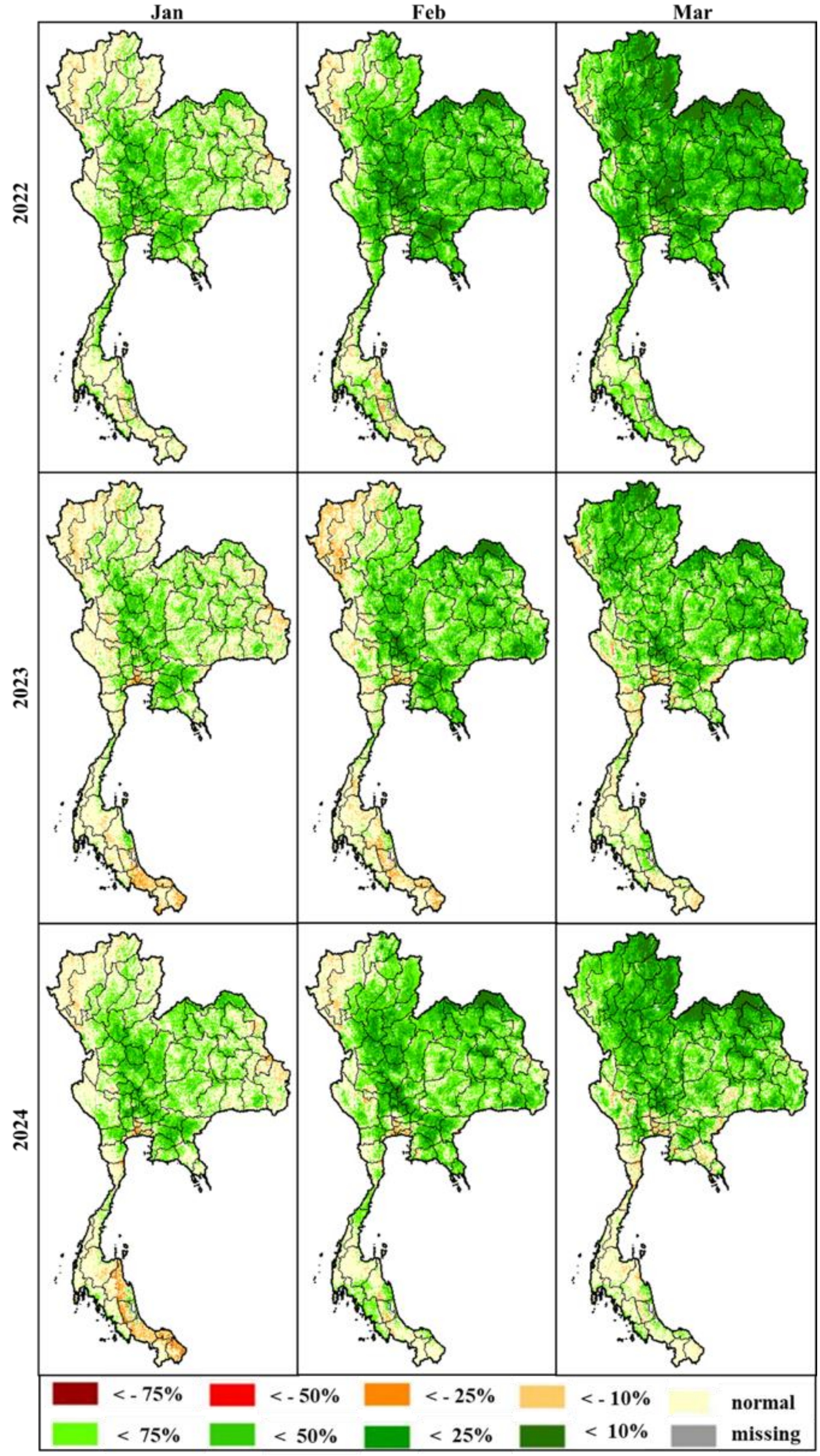

Figure 95 *Monthly NDVI anomaly maps of Thailand for 2022-24 (January, February, and March) (FAO-GIEWS, 2024)*

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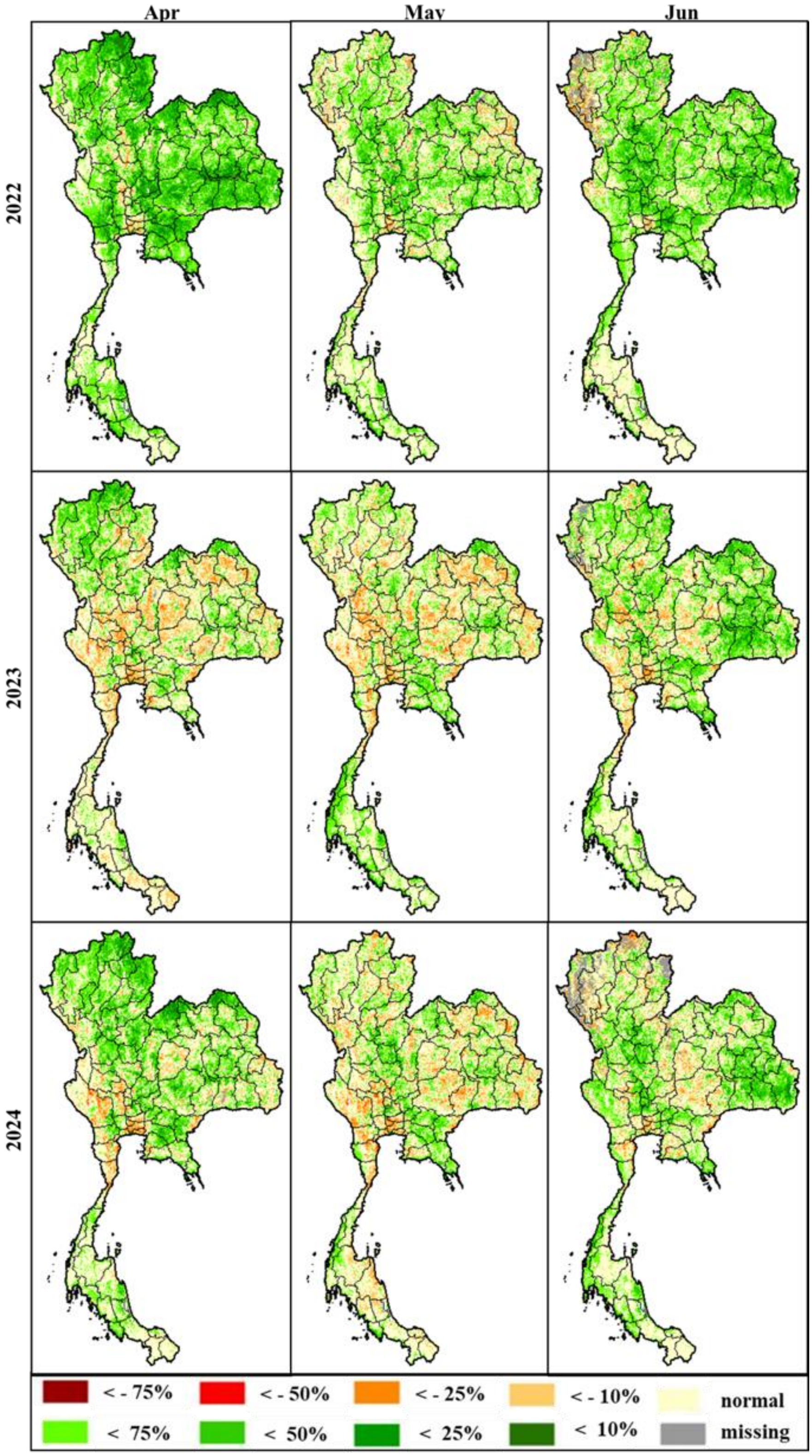

Figure 96 *Monthly NDVI anomaly maps of Thailand for 2022-24 (April, May, and Jun) (FAO-GIEWS, 2024)*

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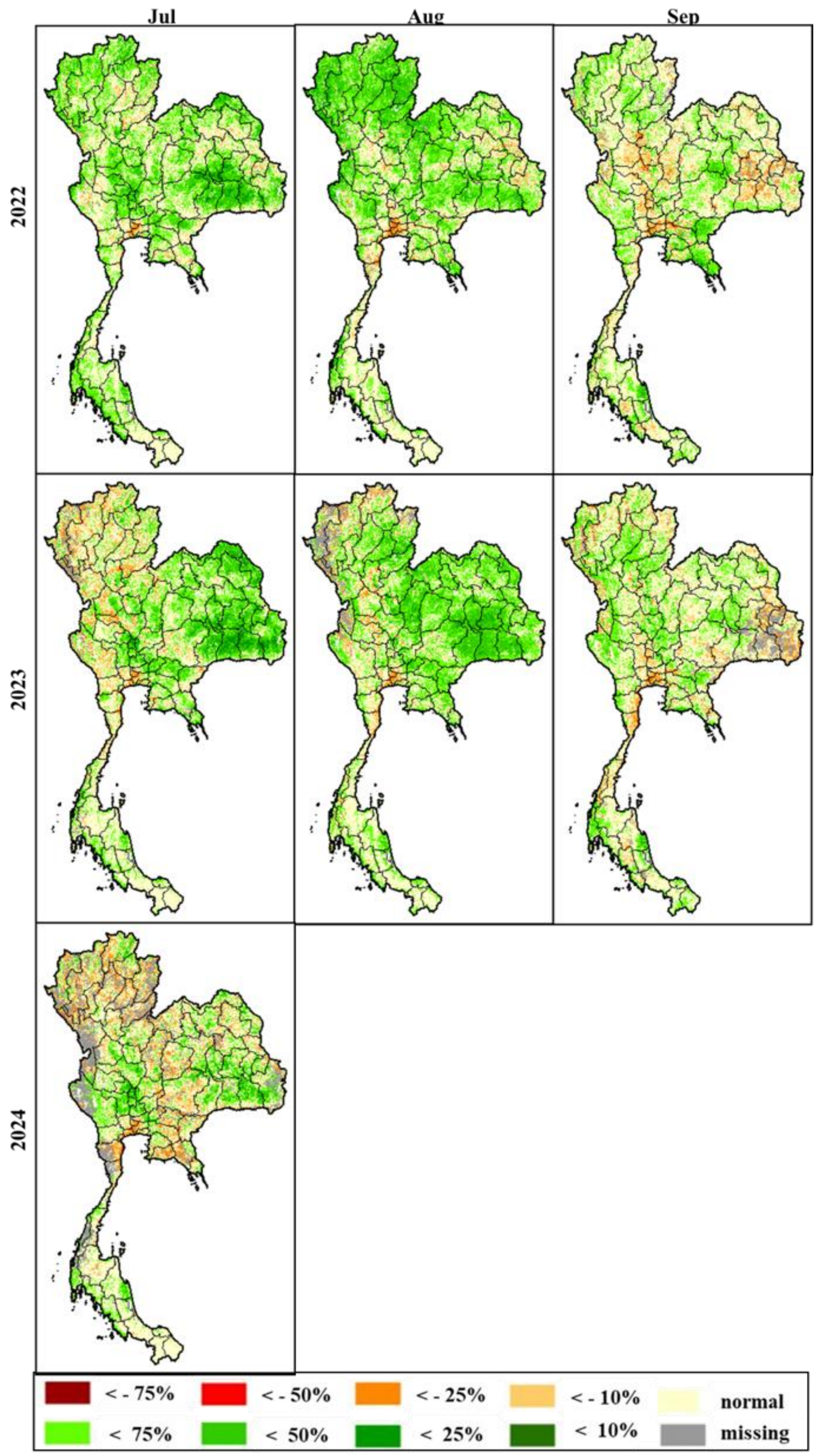

Figure 97 *Monthly NDVI anomaly maps of Thailand for 2022-24 (July, August, and September) (FAO-GIEWS, 2024)*

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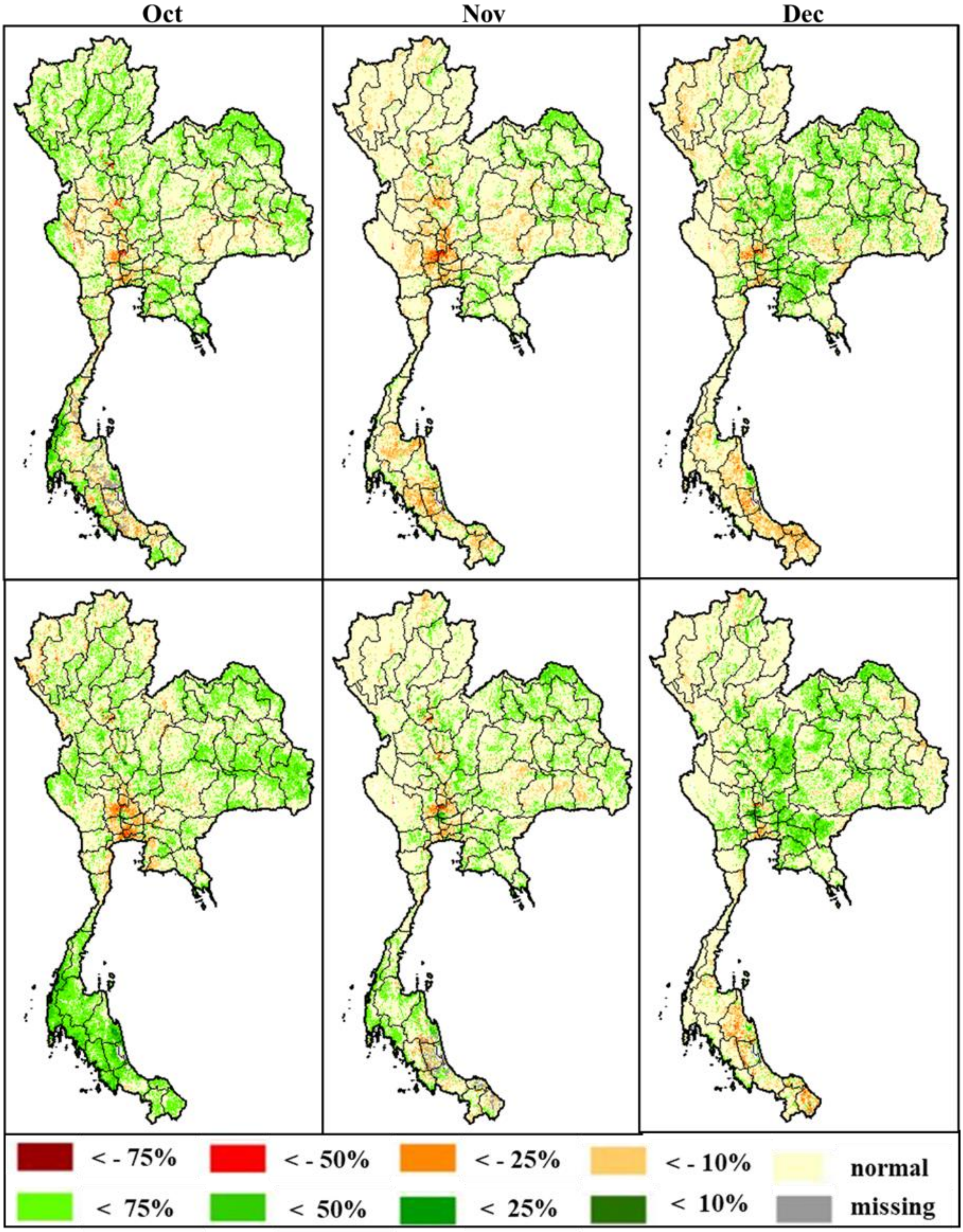

Figure 98 *Monthly NDVI anomaly maps of Thailand for 2022-24 (October, November, and December) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 30 *Spatially aggregated mean monthly NDV profiles in Thailand from 1991 to 2023, long-term average (1991-2020), and the anomalies for 2021-23 over the crop area (FAO-GIEWS, 2024)*

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0.588	0.514	0.471	0.491	0.532	0.562	0.513	0.410	0.493	0.598	0.605	0.528
1992	0.515	0.502	0.424	0.406	0.429	0.478	0.562	0.536	0.649	0.615	0.613	0.565
1993	0.518	0.464	0.449	0.512	0.550	0.615	0.589	0.563	0.613	0.648	0.582	0.497
1994	0.391	0.359	0.435	0.491	0.446	0.469	0.479	0.492	0.535	0.579	0.582	0.546
1995	0.552	0.500	0.471	0.502	0.558	0.611	0.594	0.535	0.642	0.681	0.645	0.613
1996	0.524	0.506	0.497	0.536	0.599	0.600	0.548	0.600	0.615	0.664	0.653	0.635
1997	0.580	0.504	0.531	0.591	0.582	0.466	0.453	0.602	0.676	0.732	0.724	0.636
1998	0.554	0.529	0.459	0.510	0.546	0.605	0.705	0.699	0.657	0.634	0.620	0.589
1999	0.494	0.481	0.453	0.560	0.530	0.606	0.620	0.668	0.661	0.591	0.584	0.554
2000	0.529	0.453	0.440	0.457	0.524	0.520	0.558	0.502	0.443	0.500	0.436	0.434
2001	0.575	0.500	0.449	0.568	0.577	0.557	0.569	0.575	0.658	0.655	0.692	0.645
2002	0.555	0.496	0.461	0.506	0.550	0.581	0.561	0.508	0.596	0.698	0.687	0.674
2003	0.641	0.561	0.562	0.597	0.570	0.610	0.670	0.607	0.593	0.659	0.691	0.634
2004	0.566	0.546	0.480	0.514	0.569	0.569	0.583	0.540	0.618	0.651	0.663	0.611
2005	0.504	0.463	0.417	0.497	0.488	0.504	0.544	0.526	0.648	0.623	0.629	0.598
2006	0.605	0.523	0.472	0.517	0.544	0.520	0.525	0.595	0.603	0.658	0.639	0.585
2007	0.569	0.528	0.473	0.463	0.537	0.564	0.575	0.592	0.599	0.623	0.652	0.625
2008	0.600	0.537	0.510	0.546	0.584	0.615	0.624	0.638	0.646	0.704	0.686	0.647
2009	0.592	0.532	0.555	0.588	0.587	0.623	0.631	0.668	0.670	0.688	0.697	0.630
2010	0.616	0.588	0.518	0.512	0.551	0.610	0.624	0.622	0.679	0.708	0.676	0.655
2011	0.621	0.551	0.535	0.563	0.581	0.609	0.654	0.643	0.631	0.679	0.679	0.621
2012	0.595	0.567	0.545	0.570	0.573	0.587	0.594	0.620	0.649	0.697	0.685	0.671
2013	0.620	0.541	0.536	0.538	0.578	0.616	0.628	0.664	0.665	0.691	0.683	0.647
2014	0.607	0.538	0.503	0.516	0.589	0.589	0.597	0.662	0.701	0.713	0.716	0.666
2015	0.600	0.528	0.503	0.539	0.576	0.595	0.616	0.675	0.690	0.726	0.725	0.676
2016	0.615	0.528	0.471	0.471	0.501	0.567	0.643	0.659	0.662	0.689	0.711	0.674
2017	0.662	0.595	0.548	0.572	0.578	0.625	0.619	0.670	0.700	0.717	0.684	0.669
2018	0.619	0.565	0.548	0.574	0.620	0.649	0.623	0.610	0.696	0.710	0.689	0.651
2019	0.586	0.553	0.512	0.512	0.546	0.588	0.628	0.561	0.626	0.731	0.686	0.619
2020	0.563	0.521	0.476	0.473	0.533	0.606	0.650	0.612	0.645	0.618	0.711	0.654
2021	0.581	0.569	0.486	0.538	0.625	0.643	0.626	0.651	0.619	0.685	0.665	0.646
2022	0.627	0.604	0.643	0.589	0.566	0.653	0.624	0.602	0.612	0.665	0.661	0.635
2023	0.602	0.577	0.545	0.502	0.556	0.597	0.635	0.635	0.593	0.686	0.674	0.638
2024	0.600	0.595	0.564	0.550	0.528	0.603	0.584	0.674				
Long Term Average (1991-2020)	0.572	0.519	0.490	0.523	0.551	0.577	0.593	0.595	0.632	0.663	0.657	0.615
Anomaly 2023	5.23	11.10	11.15	-4.03	0.96	3.50	7.16	6.67	-6.16	3.56	2.59	3.75
Anomaly 2022	9.61	16.31	31.13	12.68	2.71	13.09	5.27	1.11	-3.14	0.29	0.61	3.28
Anomaly 2021	1.61	9.59	-0.86	2.80	13.42	11.36	5.62	9.39	-2.11	3.41	1.15	5.11

Chapter 5: Agronomic Conditions and Droughts in Viet Nam

5.1. Geospatial data overview

This study utilized various data sources (Table 1) with Google Earth Engine (GEE) as the primary hub for data processing. GEE, a cloud computing platform for planetary-scale data analysis, ensures the flexibility and adaptability of the workflow. Please refer to the section 1.3 for an overview of the geospatial data used in this study. For the specific analysis of agronomic conditions and droughts in Viet Nam, all datasets were processed at the national scale to derive country-specific information. Additionally, regional-level maps and information are included to provide spatially exclusive perspectives, considering the regional context, particularly the neighboring countries.

5.2. Agronomic Conditions in Viet Nam

The agronomic conditions in Viet Nam were assessed through an in-depth analysis of land cover and land use composition, with a particular emphasis on cropland. This assessment utilized various land cover and land use datasets. Additionally, the distribution and patterns of soil texture across the country were examined. Long-term trends and patterns in precipitation, temperature and NDVI were evaluated. These indices provided insights into the health and viability of croplands under different environmental stresses.

5.2.1. Land cover land use composition and cropland in Viet Nam

The composition and spatial distribution of land cover and land use in Viet Nam and the surrounding region were assessed using several datasets. These included ESA's WorldCover map for 2022, with a 10-meter spatial resolution, and the GLCFCS30D Global 30-meter Land Cover Change Dataset (1985-2022). The GLC_FCS30D dataset represents a significant advancement in global land-cover monitoring, offering detailed insights into land-cover dynamics over a 30-meter resolution spanning from 1985 to 2022. This dataset provided four categories of cropland: rainfed cropland, irrigated cropland, herbaceous cover cropland, and tree or shrub cropland (orchard). In contrast, the ESA WorldCover map provided a single cropland category, but it missed tree crops or orchards in many parts, which is probably included in the Tree Cover class. To ensure consistency among the datasets, we also analyzed two datasets provided by the FAO (FAOSTAT, 2024b), including Land Cover and Land Use. The FAO's Land Cover information is compiled from publicly available Global Land Cover (GLC) maps: The European Space Agency (ESA) Climate Change Initiative (CCI) annual land cover maps (1992–2020), produced by the Université Catholique de Louvain (UCL)-Geomatics and now part of the European Copernicus Program. The FAOSTAT Land Use domain contains data on forty-four categories of land use, irrigation, agricultural practices, and five indicators relevant to monitoring agriculture, forestry, and fisheries activities at national, regional, and global levels. This data is available by country and year, with global coverage and annual updates.

The land cover composition in Cambodia (Table 7), as shown by the GLCFCS and ESA WorldCover datasets (Figure 9, Figure 10), highlights a diverse vegetative landscape with a significant presence of cropland and forest.

Cropland is diagonally distributed from the northwest to the centre and southeast of Cambodia, effectively dividing the forest into two patches: one in the northeast and the other in the southeast along the coast. According to ESA WorldCover, cropland covers 57,616 km² (31.82% of the area), while the largest land cover class in Cambodia is tree cover, accounting for 46.81% of the total area. Other land cover types include smaller proportions of shrubland, built-up areas, bare or sparse vegetation, water bodies, mangroves, and moss or lichen.

In Viet Nam, the distribution of land cover and land use reveals a complex and varied landscape, with a notable emphasis on cropland and its specific types. Irrigated cropland, a key component of the country's agricultural system, is concentrated in two primary regions: one in the northeast and another in the southwest, near the Cambodian border. This distribution highlights the reliance on irrigation for agriculture in these regions, contrasting with other areas where agriculture depends more on natural rainfall (Figure 99, Figure 100)

Overall, cropland covers approximately 28.13% of Viet Nam's total land area. The proportion of irrigated cropland is particularly significant, constituting 14.85% of the land. This highlights the importance of managed water systems in enhancing agricultural productivity across the country. In comparison, rainfed cropland, which relies on natural precipitation, covers 11.60% of the land area, illustrating the substantial role of rainfall in supporting agriculture in Viet Nam (Table 31).

Forest cover, or tree cover, is the most dominant land cover type, encompassing about 64% of the total area. This extensive forested region plays a vital role in the country's ecosystem, providing habitat, climate regulation, and other ecological benefits. According to ESA's WorldCover dataset, cropland accounts for approximately 15.35% of the total land area. This substantial proportion indicates a significant focus on agriculture within Viet Nam's land use strategy (Table 31).

In addition to cropland, other categories such as herbaceous cover cropland and tree or shrub cropland are present but occupy smaller proportions of the land. Herbaceous cover cropland, which includes areas with grasses and annual crops, represents 1.68% of the land. Tree or shrub cropland, including orchards and similar areas, makes up just 0.01% of the land area, suggesting that these specific types of cropland are less prevalent compared to other forms (Table 31).

Overall, the data highlights Viet Nam's diverse land use and cover, with a strong emphasis on both forested areas and various types of cropland. The distribution patterns of irrigated and rainfed cropland reflect the country's agricultural practices and the significant role of irrigation in

The FAO has also provided a detailed overview of the country's cropland estimates in its Land Cover and Land Use statistics (FAOSTAT, 2024b). According to the FAO's Land Cover dataset, herbaceous crops cover 22.06% of Lao PDR's land area. This category primarily includes annual crops and other herbaceous vegetation, which play a significant role in the country's agricultural sector. These forests are crucial for biodiversity, climate regulation, and ecosystem services.

On the other hand, The FAO's Land Use map shows that agricultural land constitutes 39.29% of the total land area, reflecting the country's heavy reliance on farming. Within this agricultural land, cropland covers 37.24% of the total area. This significant proportion indicates a substantial focus on crop production, crucial for the country's food security and economic development (Table 32).

Temporary crops, which include annual crops and short-term vegetation, cover 21.55% of the land. This high percentage highlights the importance of annual crop cultivation in Viet Nam's agriculture. Permanent crops, including orchards and perennial plants, cover 15.70% of the land, reflecting the role of long-term agricultural investments in the country's land use (Table 32).

In terms of irrigation, 14.63% of the land is equipped for irrigation. However, it is noted that the specific area of agriculture that is irrigated is not detailed, suggesting that while irrigation infrastructure exists, actual usage might vary (Table 32).

Cropland is a major component of land use, with a significant proportion dedicated to both temporary and permanent crops. The presence of extensive forest areas explains the importance of conservation and sustainable management practices. The distribution of land cover and land use highlights the balance between agricultural activities and natural ecosystems in Viet Nam.

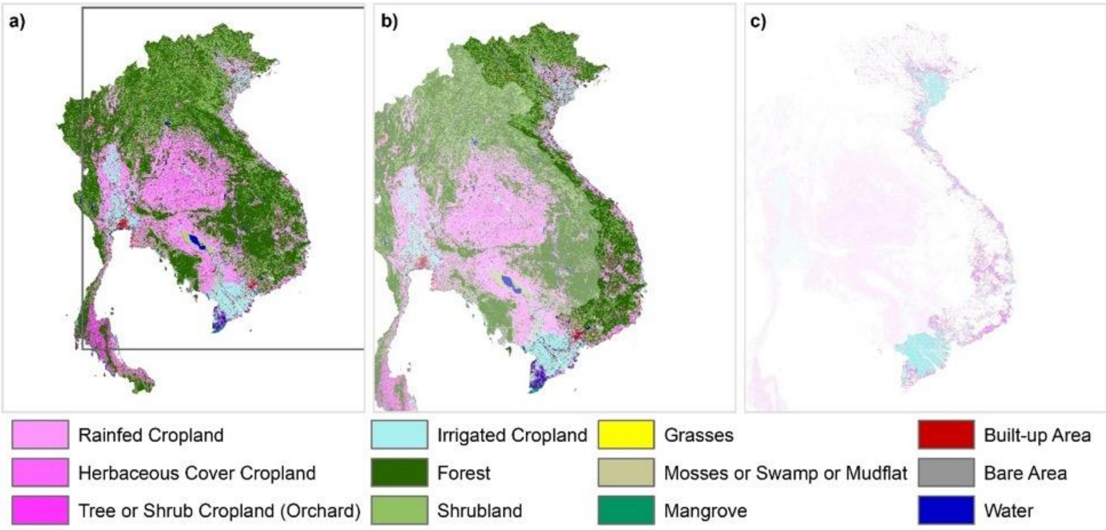

Figure 99 *The cropland and land cover land use composition of Viet Nam using the GLCFCS30D: a) Overview and location of Viet Nam in the region; b) Spatial distribution of land cover/land use patterns across Viet Nam; c) Distribution of cropland areas within Viet Nam. Data source: (Liu et al., 2023)*

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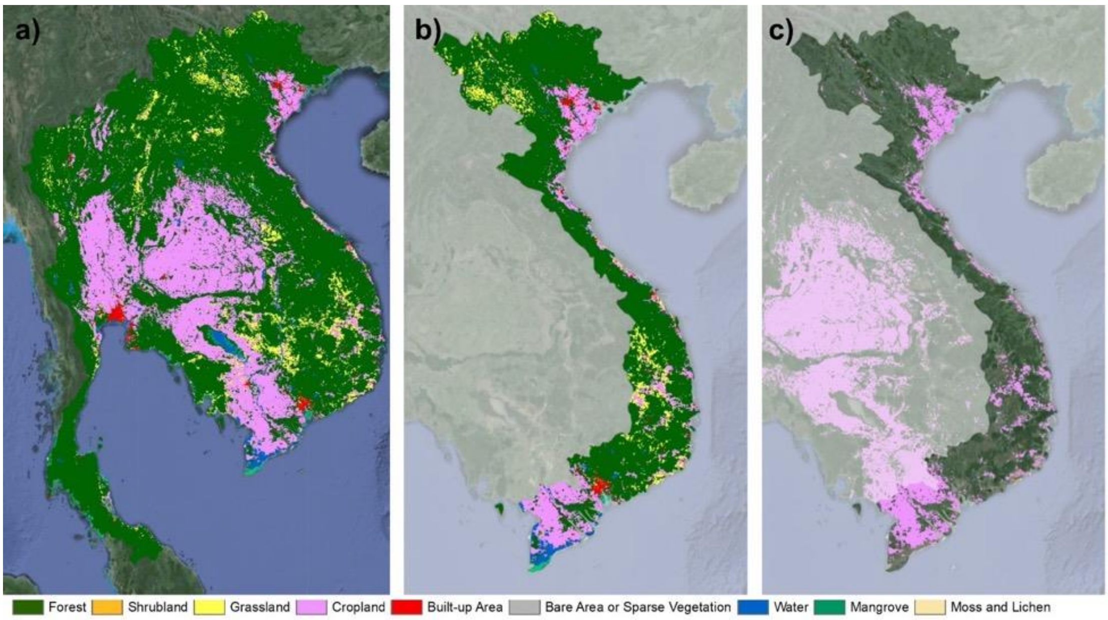

Figure 100 *The cropland and land cover land use composition of Viet Nam using the ESA's WorldCover Map: a) Overview and location of Viet Nam in the region; b) Spatial distribution of land cover/land use patterns across Viet Nam; c) Distribution of cropland areas within Viet Nam. Data Source: (Zanaga et al., 2022)*

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Table 31 *Distribution of vegetated land cover land use classes in Viet Nam from ESA's WorldCover and the distribution of cropland and its sub-classes from GLCFCS.*

ESA - World Cover			GLCFCS		
LCLU Classes	**Area (Km^2)**	**%**	**Cropland Classes**	**Area**	**%**
Tree cover	210572	63.81	Cropland	95280	28.13
Shrubland	1029	0.31	Rainfed Cropland	39280	11.60
Grassland	34159	10.35	Herbaceous Cover Cropland	5677	1.68
Cropland	50640	15.35	Tree or Shrub Cropland (Orchard)	36	0.01
Built-up Area	8882	2.69	Irrigated Cropland	50286	14.85
Bare or Sparse vegetation	11087	3.36	Forest	138492	40.89
Water	10957	3.32	Shrubland	77223	22.80
Mangroves	1565	0.47	Grassland	1327	0.39
Moss and lichen	1085	0.33	Mangrove	1388	0.41

Table 32 *Distribution of land cover land use classes in Viet Nam from the FAO's Land Cover (CCI LC) and the FAO's Land Use map (FAOSTAT, 2024b)*.

FOA - Land Cover - CCI LC			FAO - Land Use		
LCLU Class Name	**Area**	**%**	**LCLU Class Name**	**Area**	**%**
Artificial surfaces	3275	0.99	Agricultural land	123150	39.29
Herbaceous crops	72667	22.06	Cropland	116730	37.24
Woody crops	52795	16.03	Temporary crops	67540	21.55
Grassland	21128	6.41	Permanent crops	49200	15.70
Tree-covered areas	110387	33.51	Temporary meadows and pastures	0	0.00
Mangroves	2088	0.63	Temporary fallow	0	0.00
Shrub-covered areas	58552	17.77	Permanent meadows and pastures	6420	2.05
Shrubs and/or herbaceous vegetation	668	0.20	Land area equipped for irrigation	45850	14.63
Sparsely natural vegetated areas	61	0.02	Agricultural area actually irrigated		0.00
Terrestrial barren land	186	0.06	Arable land	67540	21.55
Inland water bodies	7637	2.32	Forest land	147949	47.20
			Naturally regenerating forest	103319	32.96
			Planted Forest	44630	14.24
			Other land	42330	13.51

5.2.2. Composition of Soil Texture in Viet Nam

To understand the general soil texture composition across Viet Nam and the cropland of Cambodia, the USDA's soil texture layer at 10 cm depth was used. The datasets consisted of 12 soil texture classes for six soil depths (0, 10, 30, 60, 100, and 200 cm) at a 250 m resolution, derived from predicted soil texture fractions using the soil texture package in R (Hengl, 2018).

In Viet Nam, the predominant soil texture across the landscape is Clay Loam, which makes up 76.87% of the total soil area (Figure 101, Table 33). This soil texture is highly favorable for agriculture due to its moisture retention and drainage properties. This soil type is especially significant in the southwest region of the country, where irrigated croplands are widespread. The Clay Loam supports efficient irrigation practices, making it ideal for intensive agricultural activities in this area (Figure 101). Conversely, the northeastern parts of Viet Nam are characterized by Silty Loam, which is particularly suited for rainfed agriculture. This soil texture is prevalent in scattered patches of rainfed cropland, benefiting crops that rely on natural rainfall (Figure 101). Silty Loam's ability to retain moisture is crucial for these rainfed areas, enhancing their productivity despite the lack of irrigation. Overall, while Clay Loam dominates the broader landscape, the regional variations in soil texture, such as Silty Loam in the northeast, play a key role in supporting diverse agricultural practices across Viet Nam.

For croplands, Clay Loam continues to be a major soil type, covering 63.13% of the agricultural areas (Table 33). This widespread presence indicates that a significant portion of Viet Nam's cropland benefits from the favorable conditions provided by Clay Loam, which supports a diverse range of crops and enhances overall agricultural productivity. In contrast, Silt Loam, which covers 9.27% of the total soil area, is more prevalent in cropland, accounting for 17.61% of the agricultural land. This suggests that Silt Loam is important for rainfed crops, particularly in areas where moisture retention is critical. The presence of Silt Loam in the northeastern parts of Viet Nam aligns with the distribution of rainfed croplands, indicating its suitability for crops that rely on natural rainfall. Additionally, Loam covers 10.84% of the total soil area and 12.39% of cropland, highlighting its balanced texture that supports a variety of crops. Other soil types such as Silty Clay and Sandy Clay cover minimal areas and are less significant for large-scale agriculture but may still be relevant in specific local conditions (Table 33).

Overall, the soil texture data underscores the importance of Clay Loam in Viet Nam's agricultural landscape, particularly for irrigated crops. Silty Loam's role in rainfed areas further highlights the diverse soil requirements for different types of farming practices. Understanding these soil textures is essential for optimizing land use and improving agricultural productivity in Viet Nam.

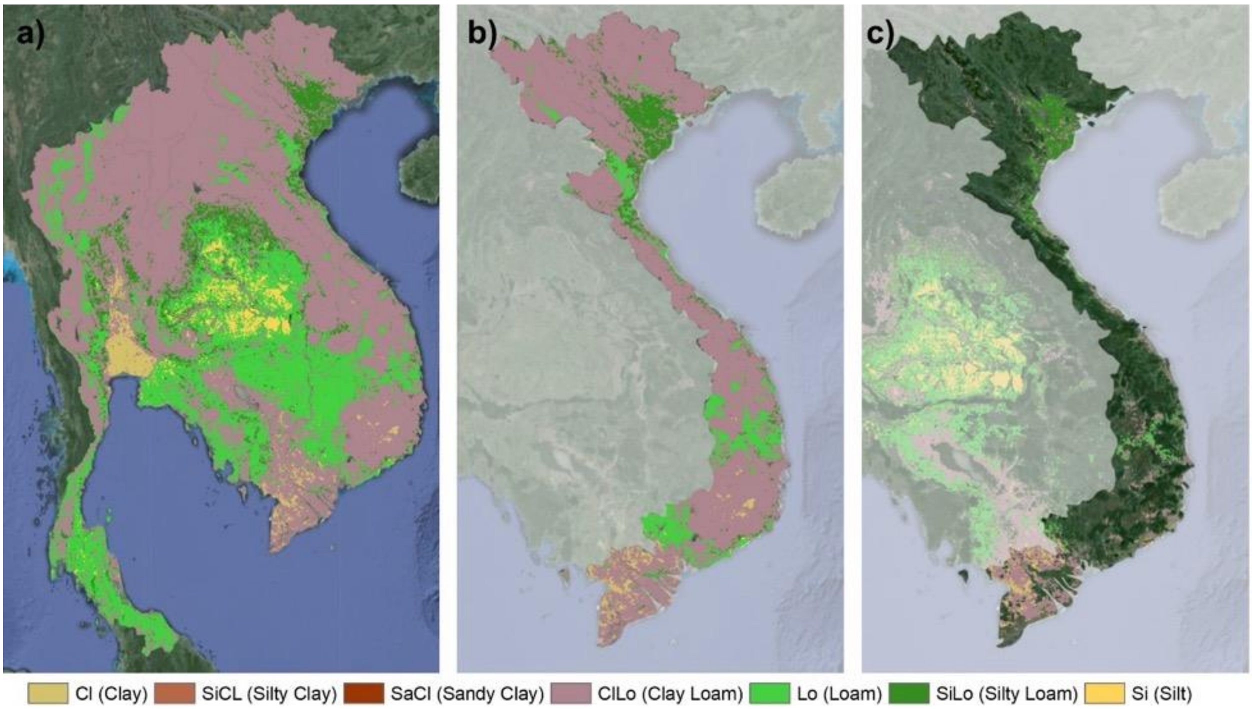

Figure 101 *The soil texture composition (at 10 cm depth) of Viet Nam using the USDA's soil texture data: a) Overview and location of Viet Nam in the region; b) Spatial distribution of soil texture patterns across Viet Nam; c) Distribution of soil texture masked over the cropland areas.*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 33 *Distribution of the soil texture classes (at 10 cm depth) in Viet Nam and masked over the cropland*

Soil Texture Class	Viet Nam		Viet Nam - Cropland	
	Area	(%)	Area	(%)
Cl (Clay)	9629	2.90	6654	6.58
SiCl (Silty Clay)	32	0.01	28	0.03
SaCl (Sandy Clay)	8	0.00	1	0.00
ClLo (Clay Loam)	255513	76.87	63797	63.13
Lo (Loam)	36020	10.84	12523	12.39
SiLo (Silty Loam)	30830	9.27	17796	17.61
Si (Silt)	367	0.11	256	0.25

5.2.3. Trends of Air Temperature in Viet Nam

The analysis of temperature changes in Viet Nam was conducted using ERA5 temperature data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term temperature averages (2001-2020) with the recorded temperatures for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average temperatures and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average temperatures, the monthly temperatures for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of temperature changes, violin plots and box plots were used. Violin plots illustrated the distribution of temperatures, showing the density and probability of different temperature ranges over time. Box plots offered a clear visualization of the temperature distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the temperature changes in Cambodia, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of temperature trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank (CCKP, 2024b), the annual trend of temperature in Cambodia shows that the average temperature has increased from 23.50°C to 24.35°C between 1991 and 2020. This reflects an increase of 0.85°C for nearly three decades. This highlights the significant warming trend experienced in Cambodia, consistent with global patterns of rising temperatures due to climate change.

The comparative analysis of monthly temperature change rates between two decades, 2000-2010 and 2010-2020, reveals a consistent increase in the rate of temperature change across all months in the more recent decade (2010-2020) compared to the earlier one (2000-2010).

In January, the change rate increased from 0.07 to 0.25. February saw an increase from 0.09 to 0.20. March, which had a slight decrease of -0.05 in the 2000s, experienced an increase to 0.22 in the 2010s. April's change rate nearly tripled from 0.11 to 0.32. May recorded a dramatic shift from -0.20 to 0.72, indicating a notable warming trend. June transitioned from a slight decrease of -0.08 to an increase of 0.46. July's temperature change rate rose from -0.01 to 0.26, while August experienced an increase from -0.03 to 0.36. September and October observed significant increases from 0.02 to 0.52 and from 0.04 to 0.27, respectively. November, which initially had a decrease of -0.23, showed the highest increase among all months, reaching 0.73. December's change rate increased from 0.24 to 0.34.

These trends indicate a significant and widespread increase in the rate of temperature change over the past decade, reflecting accelerated warming.

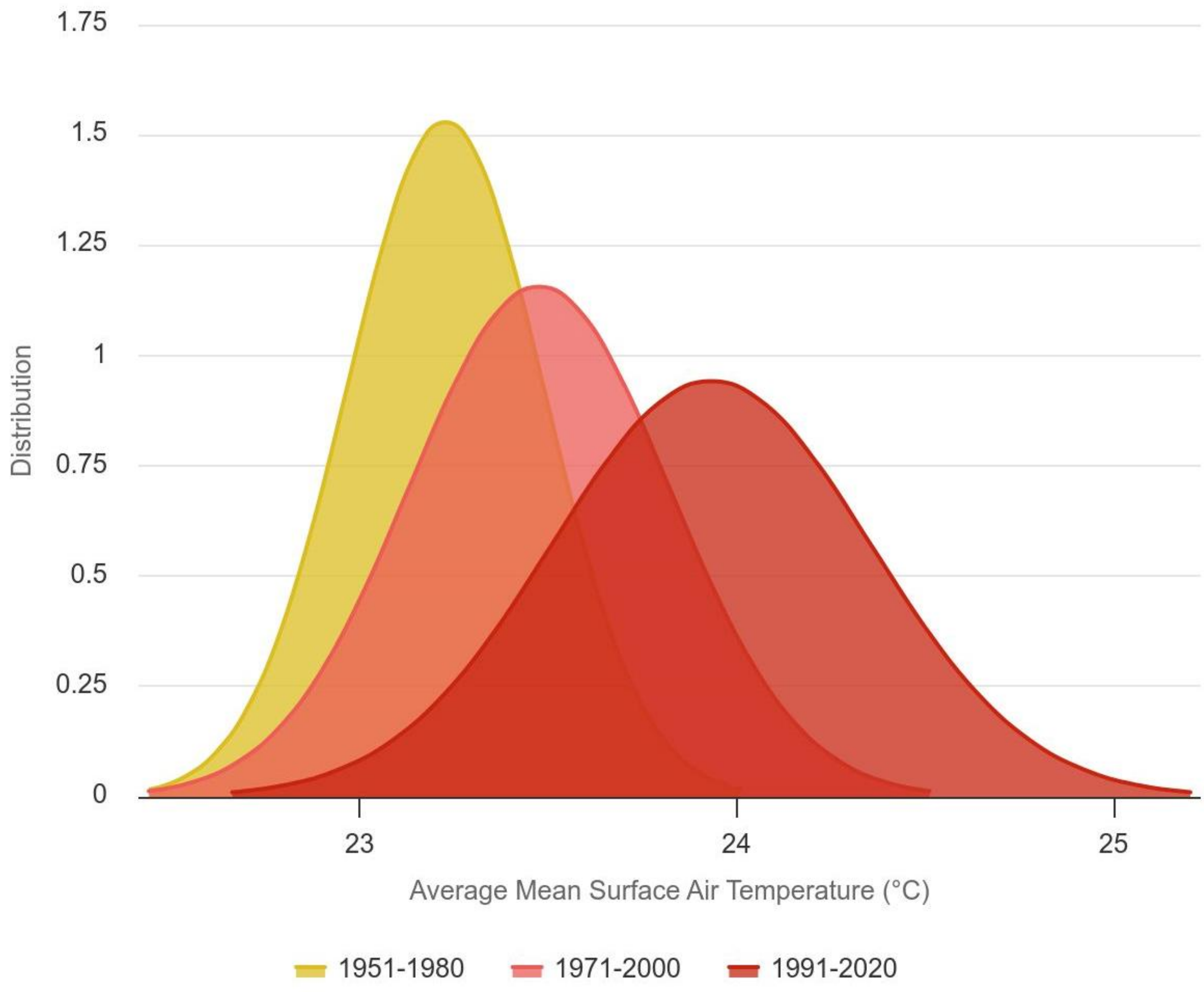

Figure 102 *Change in distribution of average mean surface air temperature in Viet Nam from 1991-2020 (CCKP, 2024b)*

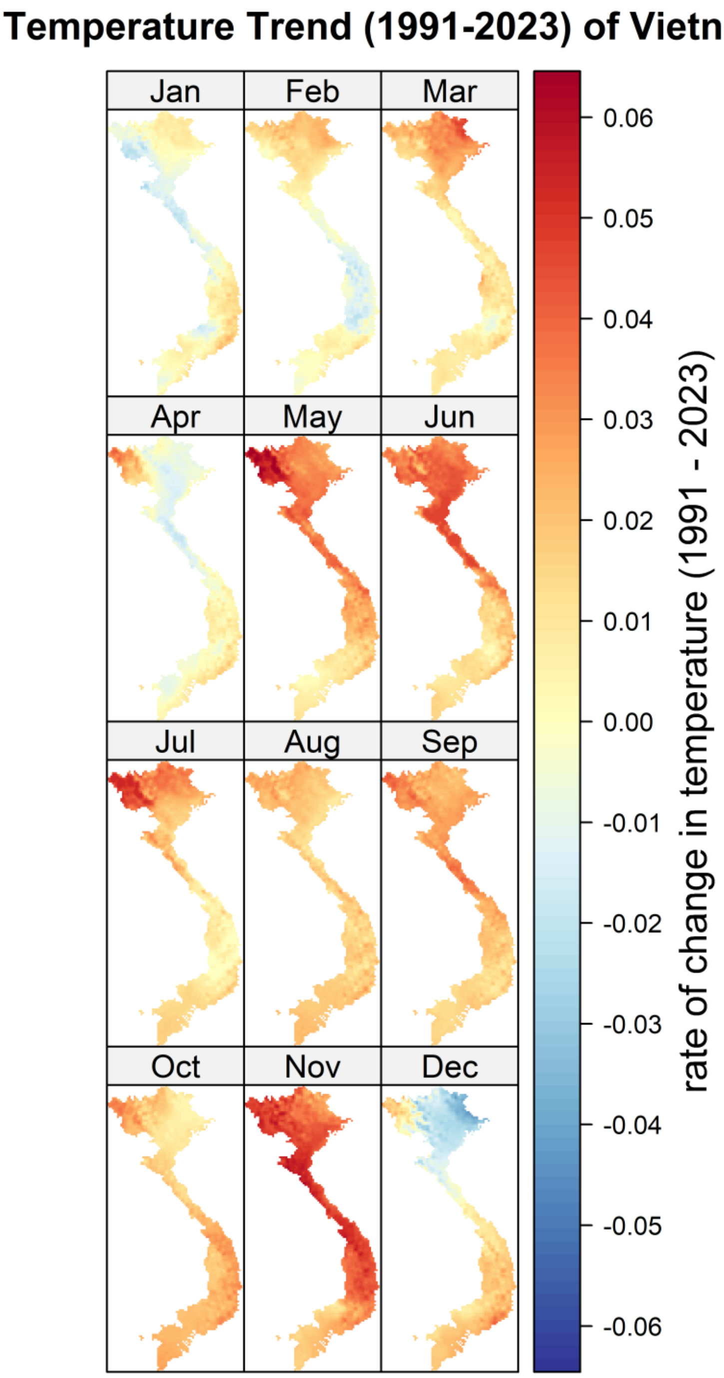

Figure 103 *Spatial patterns of temperature trends in Viet Nam, indicating the rate of change in temperatures from 1991 to 2023*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Over the years, there has been a noticeable variation in temperatures across different months A clear trend of increasing temperatures over the years is observed, with significant implications for croplands in Cambodia.

From May to October, which are critical months for agriculture, there have been notable increases in temperature. May temperatures have risen from an average of 26.00°C in 1999 to 29.68°C in 2020, reflecting a significant warming trend during the planting season for rice. June temperatures have increased from 25.70°C in 1999 to 27.83°C in 2019, impacting early crop growth stages. July and August have also seen rising temperatures, with July increasing from 25.70°C in 2000 to 27.36°C in 2019, and August from 25.70°C in 2000 to 27.38°C in 1998. September temperatures have risen from 25.34°C in 2022 to 26.69°C in 2017, crucial for crop maturation. October has shown an increase from 24.80°C in 1992 to 26.55°C in 2019, affecting the harvest period.

Currently, the temperatures during these critical agricultural months continue to trend upward. In 2023, May's average temperature was 28.73°C, June was 27.16°C, July was 26.64°C, August was 27.02°C, September was 26.11°C, and October was 26.17°C. These increases pose challenges for agricultural productivity, potentially leading to heat stress on crops, altered growing seasons, and reduced yields.

The consistent rise in temperatures emphasizes the need for adaptive farming practices and resilient crop varieties to mitigate the adverse effects of climate change on Cambodia's croplands. These fluctuations and significant changes in critical agricultural months underline the importance of adapting farming practices to cope with the rising temperatures and the broader impacts of climate change on Cambodia's cropland productivity. The year 2023 shows generally warmer temperatures compared to the early 1990s, aligning with the global trend of rising temperatures.

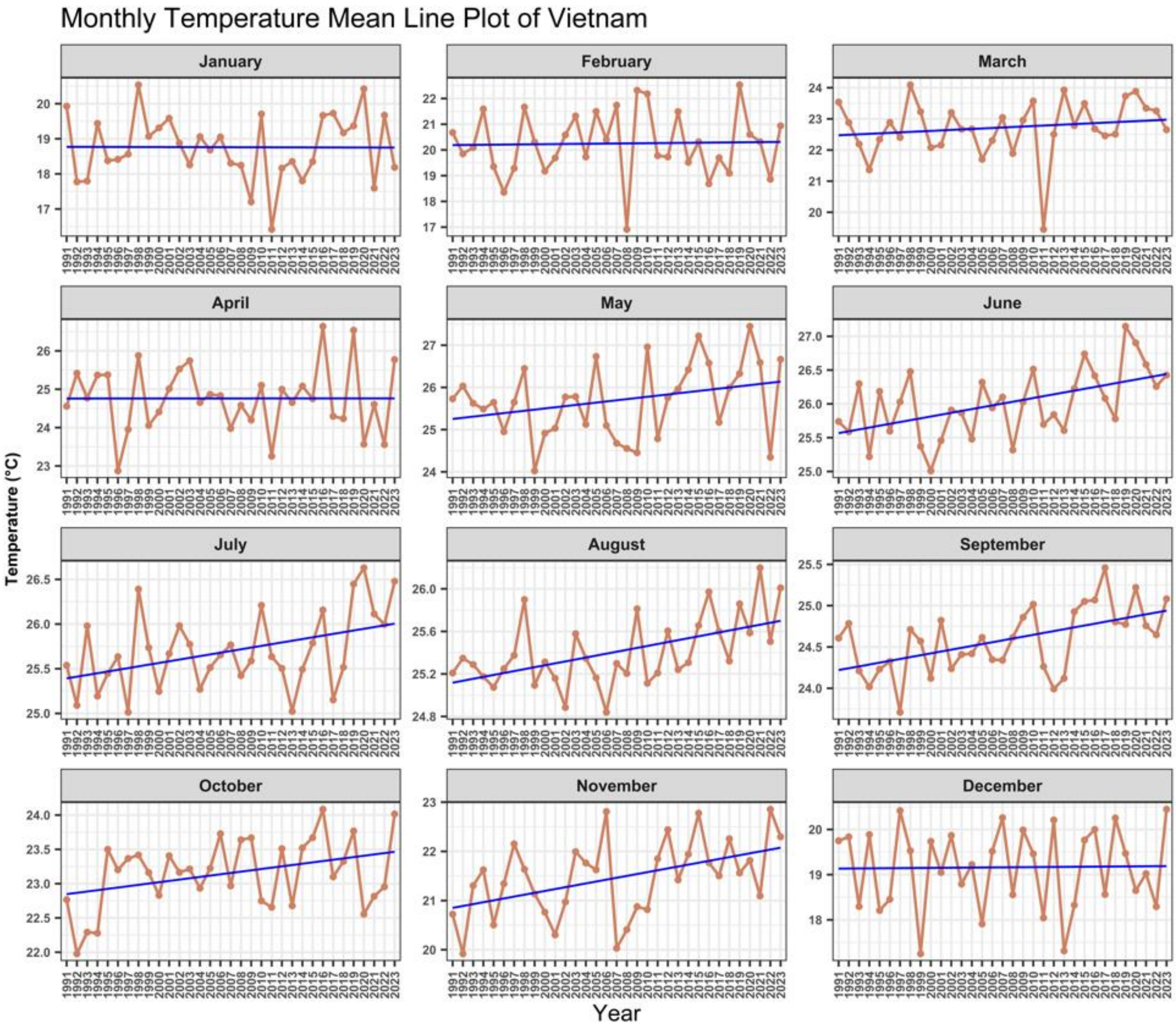

Figure 104 Spatially aggregated mean monthly temperature time series line plots with trend lines, depicting the variation of mean monthly temperatures over time in Viet Nam.

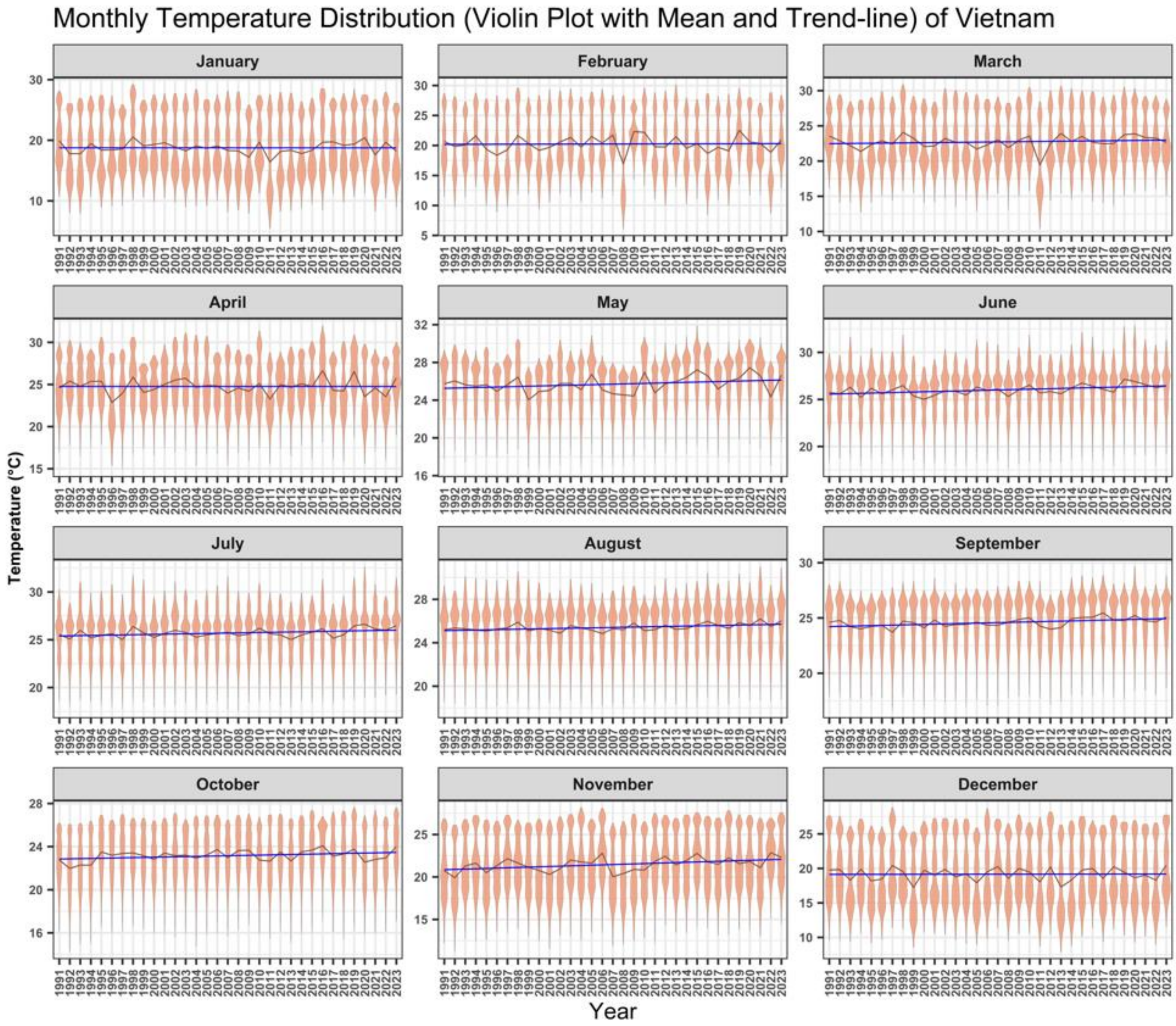

Figure 105 Distribution of mean monthly temperature time series and violin plots in Viet Nam, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly temperatures

Table 34 Spatially aggregated mean monthly air temperature (°C) of Viet Nam from 1991 to 2023, derived from the ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	19.93	20.68	23.54	24.56	25.73	25.74	25.54	25.21	24.61	22.77	20.72	19.75
1992	17.77	19.85	22.88	25.42	26.03	25.59	25.09	25.35	24.78	21.98	19.92	19.84
1993	17.80	20.09	22.19	24.77	25.62	26.30	25.98	25.29	24.21	22.29	21.30	18.29
1994	19.44	21.59	21.36	25.37	25.49	25.22	25.19	25.18	24.02	22.28	21.63	19.89
1995	18.38	19.35	22.34	25.38	25.65	26.18	25.45	25.07	24.23	23.50	20.50	18.21
1996	18.41	18.35	22.89	22.87	24.95	25.60	25.63	25.25	24.32	23.20	21.34	18.45
1997	18.56	19.28	22.40	23.95	25.65	26.03	25.01	25.37	23.71	23.37	22.15	20.42
1998	20.54	21.67	24.09	25.88	26.45	26.48	26.39	25.90	24.71	23.42	21.64	19.53
1999	19.07	20.31	23.23	24.06	24.02	25.37	25.74	25.09	24.57	23.16	21.14	17.25
2000	19.31	19.18	22.08	24.41	24.91	25.01	25.25	25.31	24.12	22.83	20.76	19.73
2001	19.58	19.69	22.16	25.01	25.03	25.46	25.67	25.16	24.82	23.41	20.30	19.05
2002	18.88	20.58	23.20	25.53	25.77	25.91	25.98	24.88	24.24	23.17	20.97	19.87
2003	18.26	21.32	22.67	25.74	25.78	25.86	25.77	25.58	24.41	23.21	21.99	18.79
2004	19.06	19.73	22.67	24.65	25.12	25.48	25.27	25.35	24.42	22.93	21.76	19.22
2005	18.68	21.50	21.70	24.87	26.73	26.32	25.51	25.16	24.61	23.22	21.63	17.91
2006	19.05	20.40	22.31	24.83	25.10	25.94	25.66	24.84	24.35	23.73	22.81	19.52
2007	18.31	21.74	23.04	23.98	24.68	26.10	25.77	25.30	24.34	22.97	20.03	20.26
2008	18.25	16.91	21.89	24.58	24.55	25.32	25.42	25.20	24.62	23.64	20.41	18.56
2009	17.20	22.32	22.96	24.20	24.45	26.03	25.59	25.81	24.86	23.67	20.88	19.99
2010	19.71	22.18	23.57	25.10	26.96	26.51	26.21	25.11	25.02	22.75	20.82	19.46
2011	16.42	19.78	19.45	23.25	24.78	25.70	25.63	25.21	24.26	22.66	21.85	18.04
2012	18.16	19.73	22.50	25.00	25.76	25.84	25.50	25.60	23.99	23.51	22.44	20.21
2013	18.35	21.49	23.93	24.65	25.96	25.61	25.02	25.24	24.12	22.68	21.42	17.31
2014	17.80	19.52	22.78	25.08	26.42	26.23	25.49	25.31	24.93	23.52	21.94	18.33
2015	18.35	20.32	23.49	24.75	27.22	26.74	25.79	25.66	25.05	23.67	22.78	19.77
2016	19.67	18.68	22.68	26.64	26.58	26.42	26.16	25.97	25.07	24.08	21.77	20.00
2017	19.73	19.69	22.46	24.30	25.17	26.08	25.15	25.60	25.46	23.10	21.50	18.56
2018	19.17	19.09	22.51	24.23	25.99	25.78	25.52	25.32	24.80	23.32	22.26	20.25
2019	19.37	22.53	23.73	26.54	26.33	27.15	26.45	25.86	24.77	23.77	21.56	19.47
2020	20.42	20.60	23.88	23.57	27.45	26.90	26.63	25.59	25.22	22.56	21.82	18.65
2021	17.59	20.32	23.34	24.61	26.59	26.58	26.11	26.20	24.76	22.82	21.10	19.02
2022	19.67	18.86	23.26	23.56	24.35	26.26	26.00	25.50	24.65	22.95	22.85	18.29
2023	18.19	20.93	22.65	25.77	26.67	26.43	26.48	26.01	25.08	24.02	22.30	20.44

A comparison of monthly average temperatures between two periods—the long-term average from 2001 to 2020 and the recorded temperatures for the year 2023—was assessed for Viet Nam. This analysis also included temperature anomalies for each month, indicating deviations from the long-term average.

In January 2023, the average temperature was 17.838°C, which is 0.534°C cooler than the long-term average of 18.371°C. February showed a shift with slightly warmer temperatures, recording an anomaly of +0.545°C, resulting in an average temperature of 20.585°C compared to the long-term average of 20.040°C. March saw a negligible decrease, with an anomaly of -0.029°C, bringing the average temperature to 22.300°C, close to the long-term average of 22.329°C. Cooler temperatures in the early part of the year could delay the planting season and slow the initial growth stages of crops, potentially reducing yields.

April observed a significant increase in temperature, with an average of 25.424°C, which is 0.948°C warmer than the long-term average of 24.476°C. May continued this warming trend with an anomaly of +0.875°C, leading to an average temperature of 26.317°C compared to the long-term average of 25.442°C. Both June and July had temperatures above the long-term averages, with June being 0.358°C warmer and July 0.769°C warmer than their respective long-term averages. These increases in temperature during the mid-year could accelerate crop growth, but also increase water requirements and the risk of heat stress, potentially impacting crop health and productivity.

August recorded a temperature of 25.660°C, resulting in an anomaly of +0.622°C over the long-term average of 25.038°C. September, October, and November also experienced temperature increases, with anomalies of +0.415°C, +0.738°C, and +0.750°C, respectively. The average temperatures in these months were above their long-term averages. Warmer temperatures during these months could lead to an extended growing season but also heighten the risk of drought and pest infestations, which could adversely affect crop yields.

December concluded the year with a significant increase, recording an average temperature of 20.095°C, which was 1.284°C warmer than the long-term average of 18.811°C. Warmer winters can impact certain crops that require cooler temperatures for vernalization, potentially affecting flowering and fruiting stages.

Overall, the data reveals that 2023 in Viet Nam had a mix of cooler and warmer months compared to the long-term averages, with most months showing warming anomalies, particularly in the latter half of the year. This trend of increasing temperatures, especially during crucial growing months, has significant implications for cropland in Viet Nam. Warmer temperatures can lead to changes in growing seasons, increased water demand, and greater stress on crops. These factors necessitate adaptive measures such as altering planting schedules, implementing water management strategies, and adopting heat-resistant crop varieties to sustain agricultural productivity and food security in the face of changing climatic conditions.

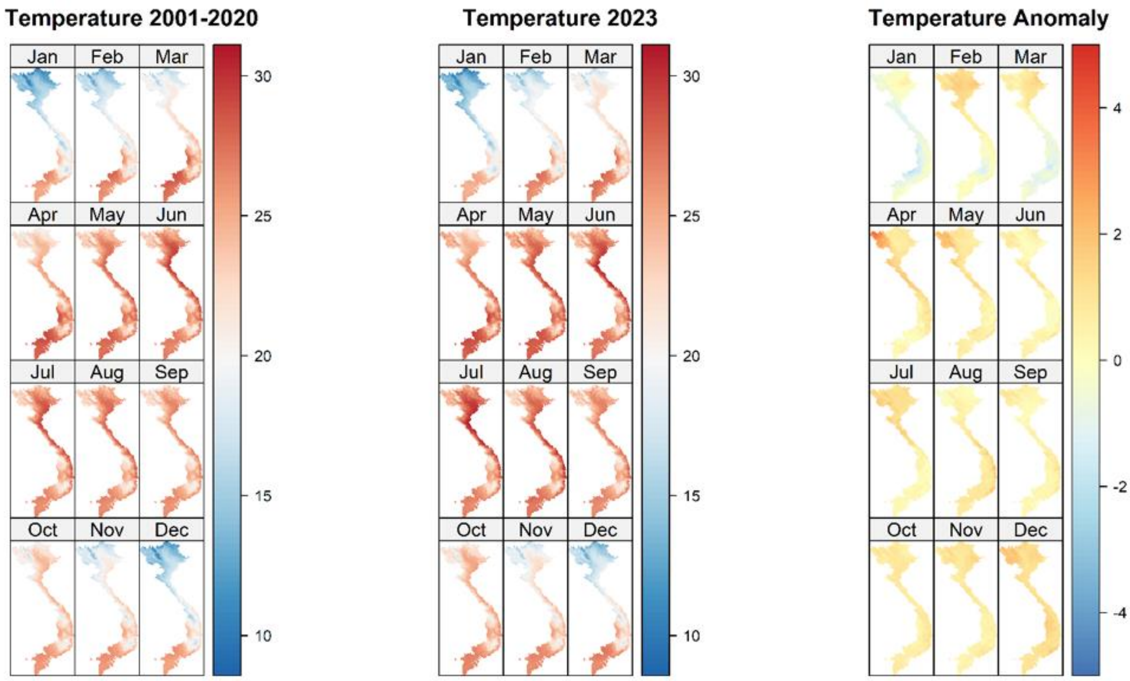

Figure 106 *Spatial distribution of temperatures in Viet Nam, displaying long-term monthly average temperatures, monthly average temperatures for 2023, and anomaly maps showing the difference between the 2023 temperatures and the long-term averages*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

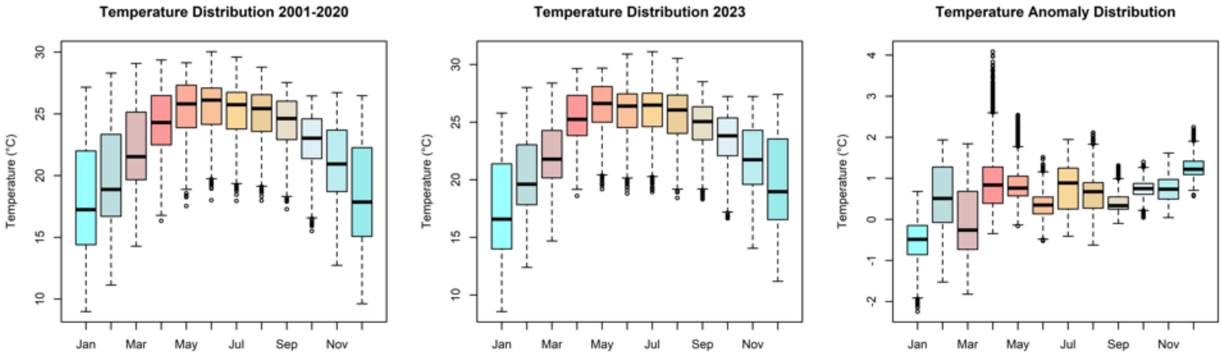

__Figure 107__ Boxplot visualization of the mean monthly temperatures in Viet Nam, comparing the long-term monthly averages, the monthly temperatures recorded in 2023, and the corresponding temperature anomalies

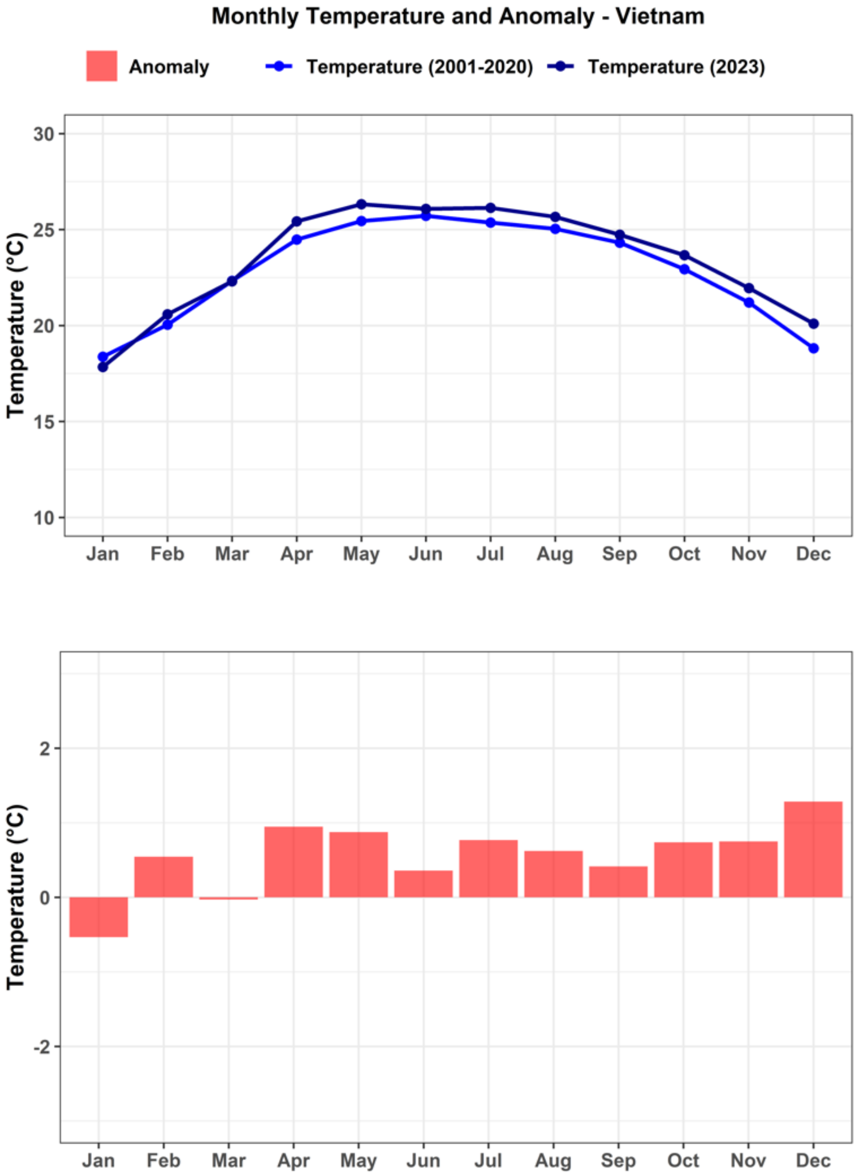

__Figure 108__ Spatially aggregated monthly temperature series in Viet Nam, showing the long-term averages, the temperatures recorded in 2023, and the anomalies.

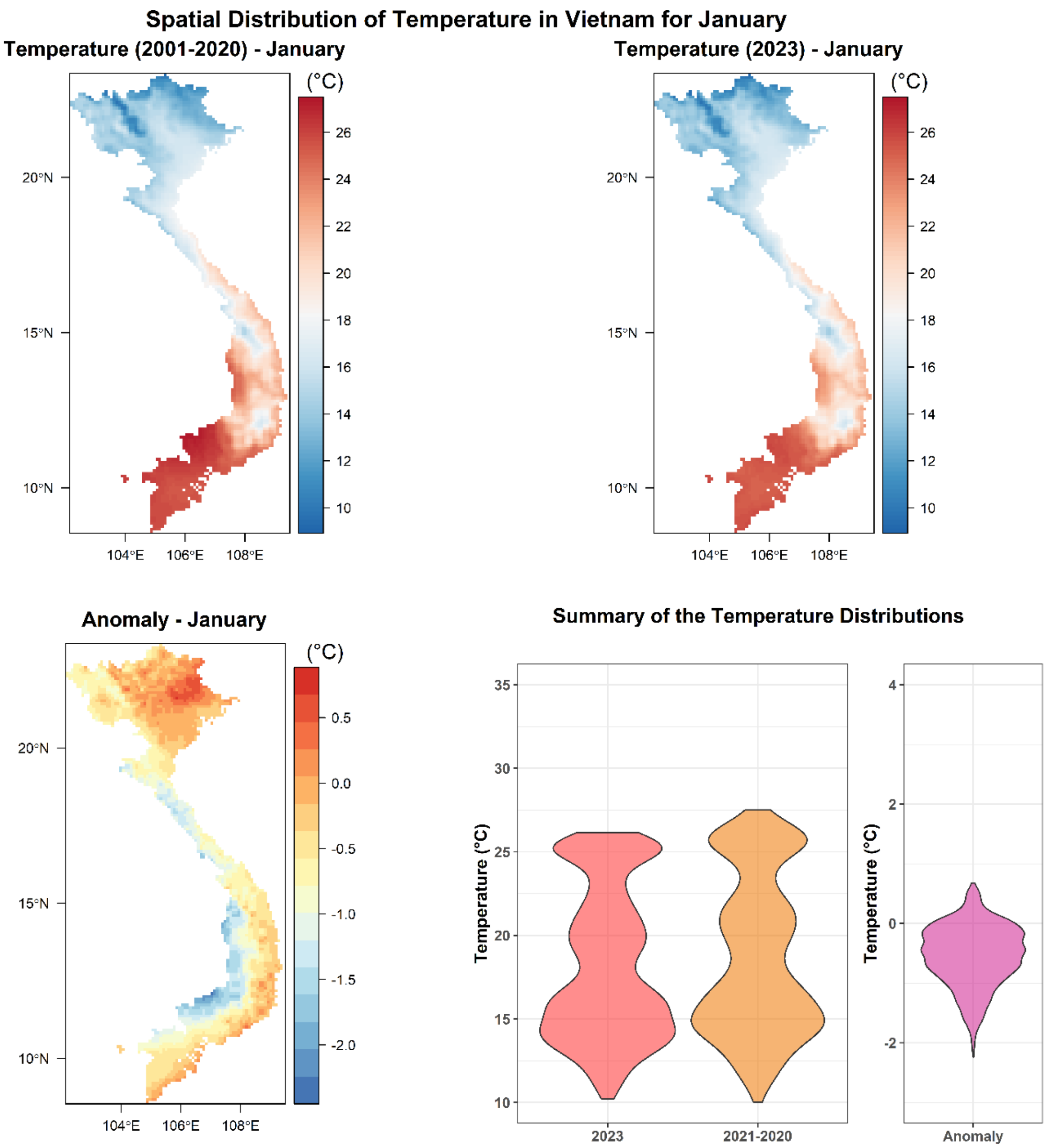

***Figure 109** Maps and violin plots illustrate the spatial distribution of January temperatures in Viet Nam. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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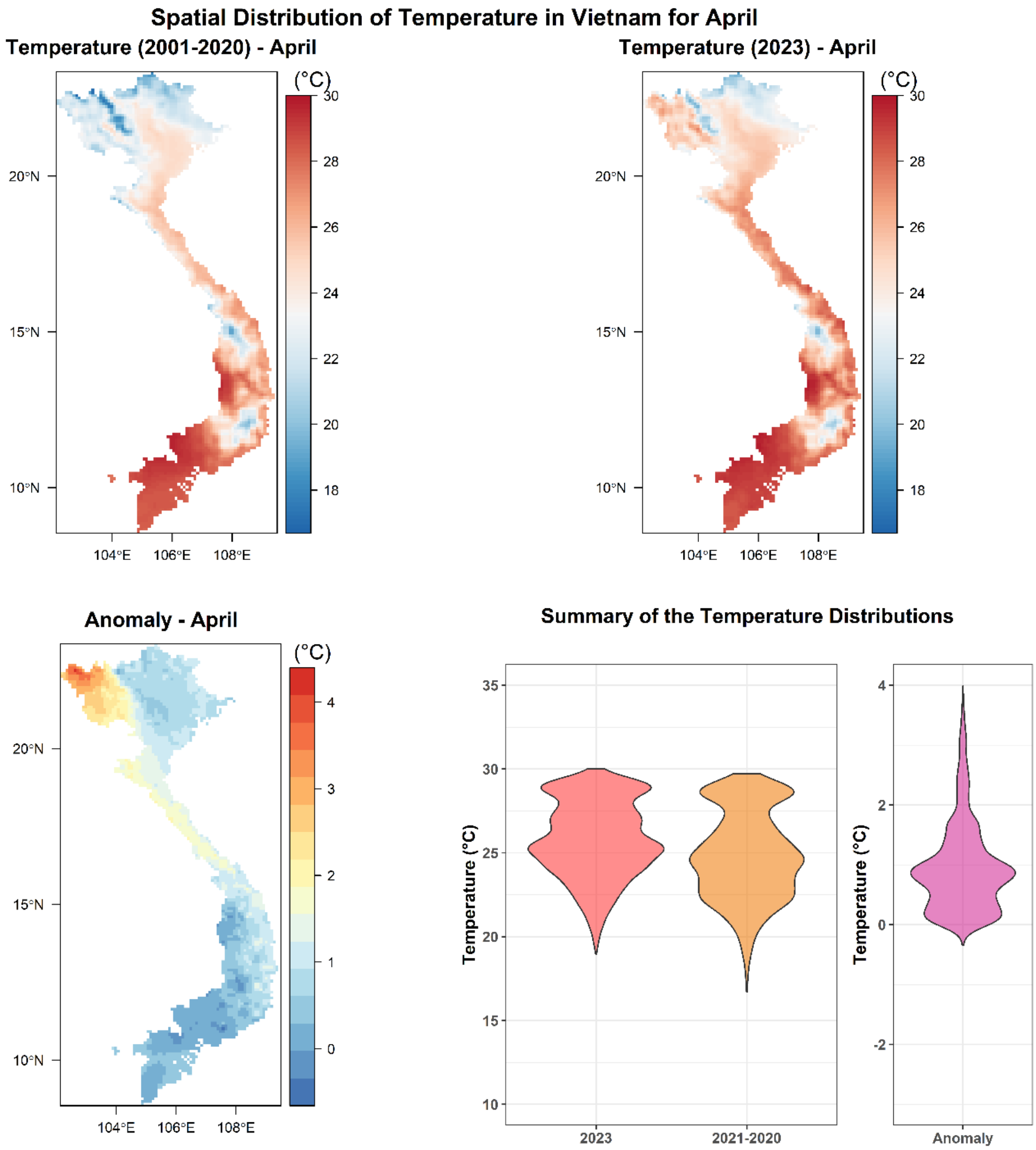

Figure 110 Maps and violin plots illustrate the spatial distribution of May temperatures in Viet Nam. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

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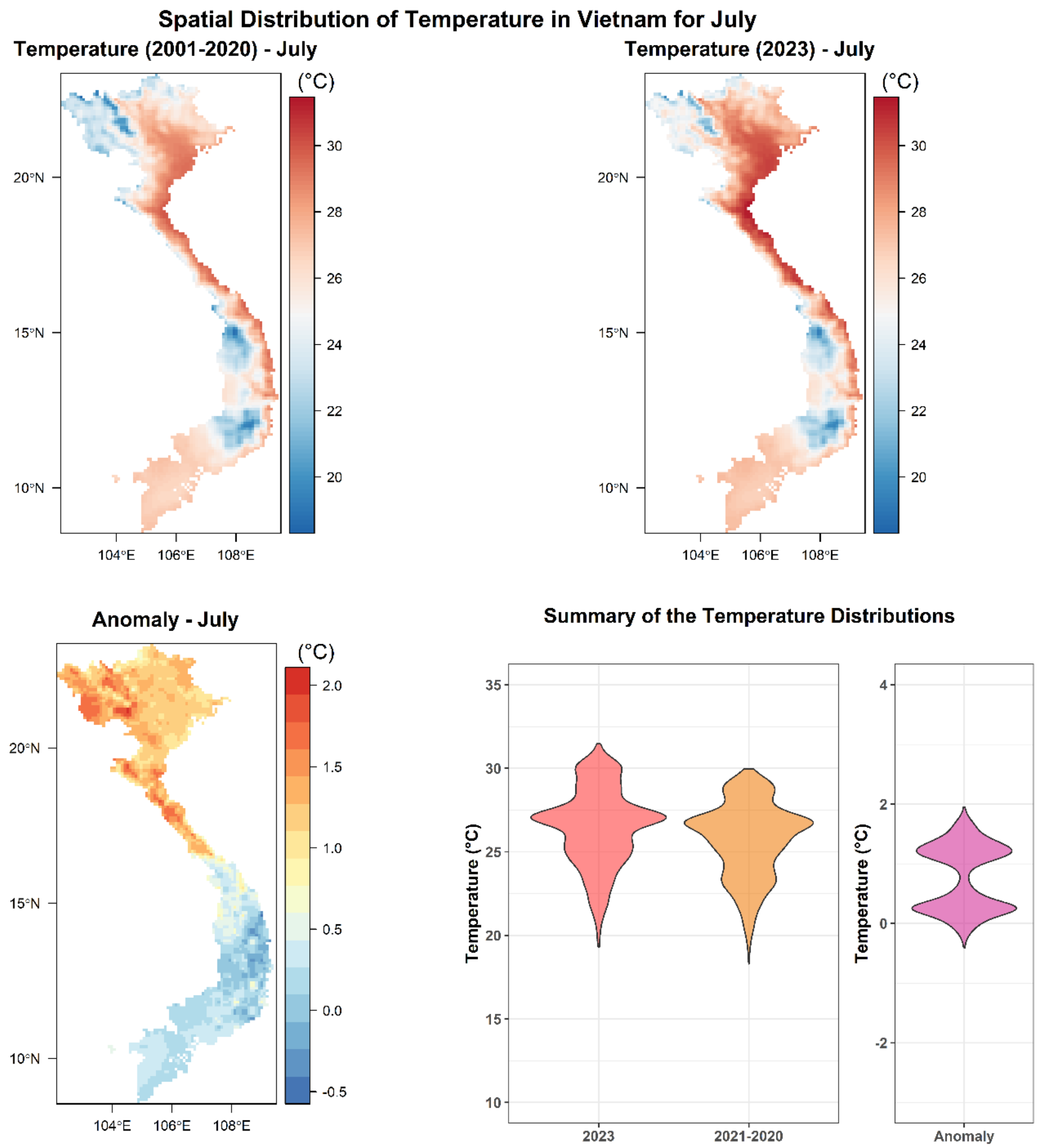

Figure 111 *Maps and violin plots illustrate the spatial distribution of August temperatures in Viet Nam. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data*

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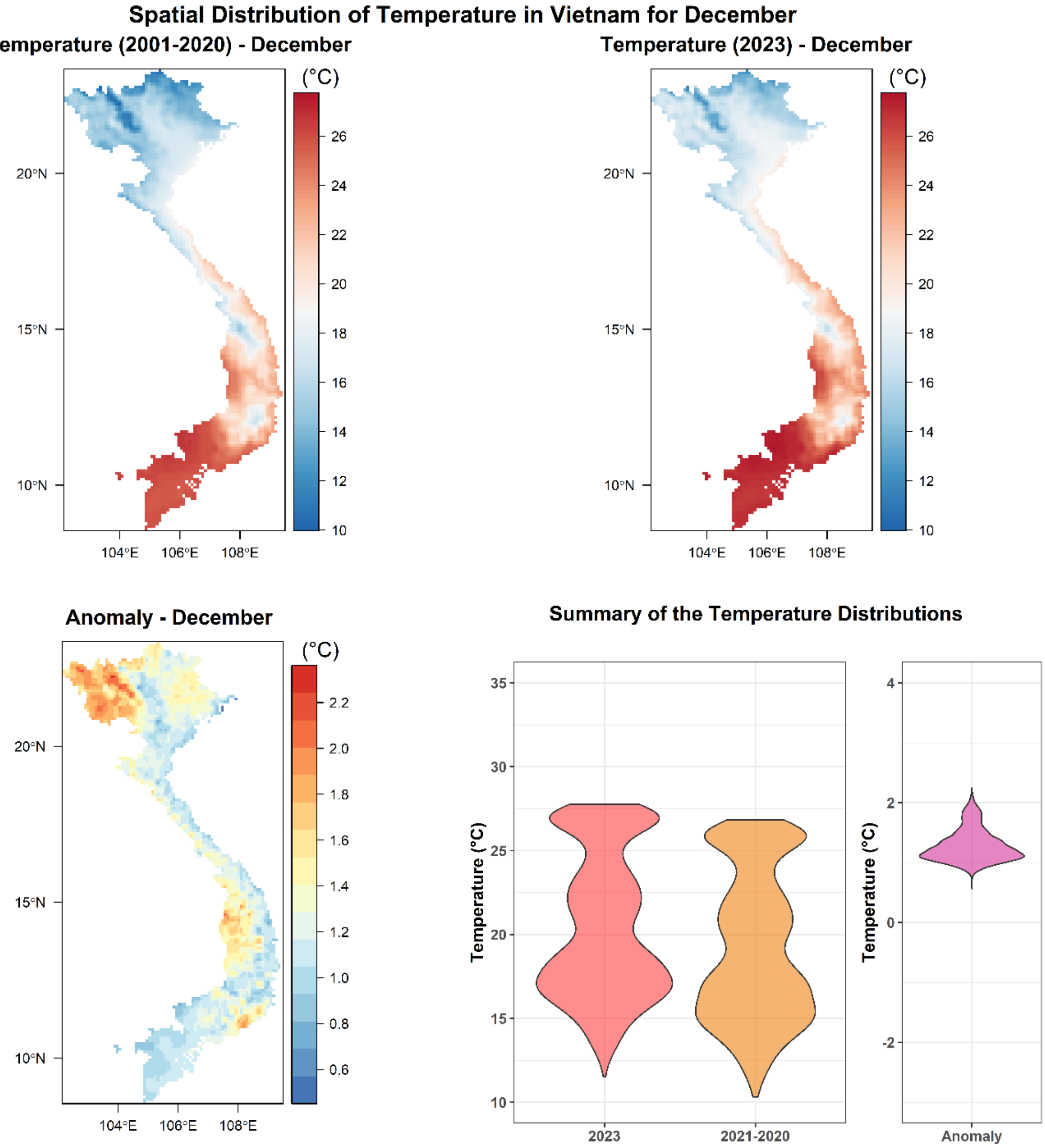

__Figure 112__ Maps and violin plots illustrate the spatial distribution of December temperatures in Viet Nam. The maps display the long-term average temperature, the recorded temperature in 2023, and the temperature anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 35 *Monthly averages of long-term temperatures (°C), 2023 monthly averages (°C), and temperature anomalies (°C) in Viet Nam.*

Month	Temperature (2001-2020)	Temperature (2023)	Anomaly
Jan	18.371	17.838	-0.534
Feb	20.040	20.585	0.545
Mar	22.329	22.300	-0.029
Apr	24.476	25.424	0.948
May	25.442	26.317	0.875
Jun	25.718	26.076	0.358
Jul	25.359	26.128	0.769
Aug	25.038	25.660	0.622
Sep	24.318	24.732	0.415
Oct	22.928	23.666	0.738
Nov	21.196	21.946	0.750
Dec	18.811	20.095	1.284

5.2.4. Trends of Rainfall in Viet Nam

The analysis of rainfall changes in Viet Nam was conducted using ERA5 rainfall data, which was processed in Google Earth Engine (GEE), followed by statistical analysis in R. This comprehensive study aimed to identify patterns and trends by comparing long-term rainfall averages (2001-2020) with the recorded rainfall for 2023 and producing various visualizations to enhance the understanding of these patterns.

To assess recent anomalies, the difference between the long-term average rainfalls and the monthly averages for 2023 was calculated. This resulted in the creation of anomaly maps for each month of 2023. Additionally, mean monthly maps were generated for all datasets, which included the long-term monthly average rainfalls, the monthly rainfalls for 2023, and the corresponding anomaly maps.

To provide a deeper insight into the spatial and temporal patterns of rainfall changes, violin plots and box plots were used. Violin plots illustrated the distribution of rainfalls, showing the density and probability of different rainfall ranges over time. Box plots offered a clear visualization of the rainfall distribution, highlighting the median, quartiles, and potential outliers.

For consistency and to provide a broader context, the study incorporated trend analysis from the World Bank's Climate Change Knowledge Portal. This external data source helped validate the findings and offered a comparative perspective on the observed trends.

The comprehensive set of visualizations and analyses provided a detailed understanding of the rainfall changes in Viet Nam, revealing both spatial and temporal patterns and highlighting significant anomalies in the recent climate data. This integrated approach allowed for a robust discussion and analysis of rainfall trends, supporting better-informed decisions and policies related to climate change adaptation and mitigation.

According to the Climate Change Knowledge Portal by the World Bank, the annual rainfall trend in Viet Nam indicates a decrease in average rainfall from 2074 mm to 2025 mm recorded between 1971-2000 and 1991-2020, reflecting a decline of 50 mm. The peak of rainfall distribution has shifted towards lower values compared to the distribution from 1971 to 2000, highlighting a slight reduction in annual rainfall over the past three decades.

Over the past two decades, Viet Nam has witnessed significant shifts in its monthly precipitation trends, profoundly affecting the country's agricultural landscape. These changes have varied across different months, with both increases and decreases in average rainfall, posing new challenges for farmers.

From 2000 to 2010, key agricultural months such as March, May, and June saw increases in average monthly rainfall, with rises of 2.71 mm, 11.59 mm, and 6.59 mm, respectively. These increases generally supported crop growth by providing essential water during critical growing periods. However, April and July recorded declines in rainfall, with decreases of 8.79 mm and 6.29 mm, respectively, potentially complicating farming efforts during these months.

The decade from 2010 to 2020 marked a more pronounced shift in precipitation patterns. Critical months like March, April, and May experienced notable declines in rainfall, with reductions of 0.54 mm, 8.50 mm, and 18.09 mm, respectively. These decreases during vital growing periods could lead to water stress for crops, potentially reducing yields and increasing the risk of crop failures. On the other hand, July and August saw increases in rainfall, with rises of 20.81 mm and 13.94 mm, respectively. While these increases during the monsoon season might appear beneficial, they could also present challenges such as waterlogging and heightened pest infestations, potentially affecting crop health and productivity.

The changes in precipitation patterns are also evident during the off-season months. For instance, January, which saw a decrease of 3.46 mm in the 2000-2010 decade, experienced a significant increase of 18.60 mm in the 2010-2020 period. Similarly, December's rainfall trend shifted from a decrease of 2.59 mm to an increase of 8.01 mm over the same period. These off-season increases raise concerns about their limited agricultural benefit and the potential for off-season flooding, which could disrupt soil structure and create unfavourable conditions for the subsequent planting season. These changes in precipitation patterns, marked by reduced rainfall during key agricultural months and increased rainfall during off-season months, complicate farmers' ability to rely on historical weather patterns for planting and harvesting. As a result, there is a growing need for adaptive strategies, including shifting planting seasons, adopting drought-resistant crop varieties, and relying more on irrigation to manage reduced rainfall during crucial months. Additionally, improved water management systems will be essential to address the challenges posed by increased rainfall during the off-season, such as flooding and soil erosion.

The trends observed over these two decades emphasize the importance of a strategic approach to agriculture in Viet Nam. Farmers and policymakers must collaborate to develop adaptive strategies that can mitigate the impacts of changing precipitation patterns, ensuring sustainable agricultural productivity and food security in the face of an increasingly unpredictable climate.

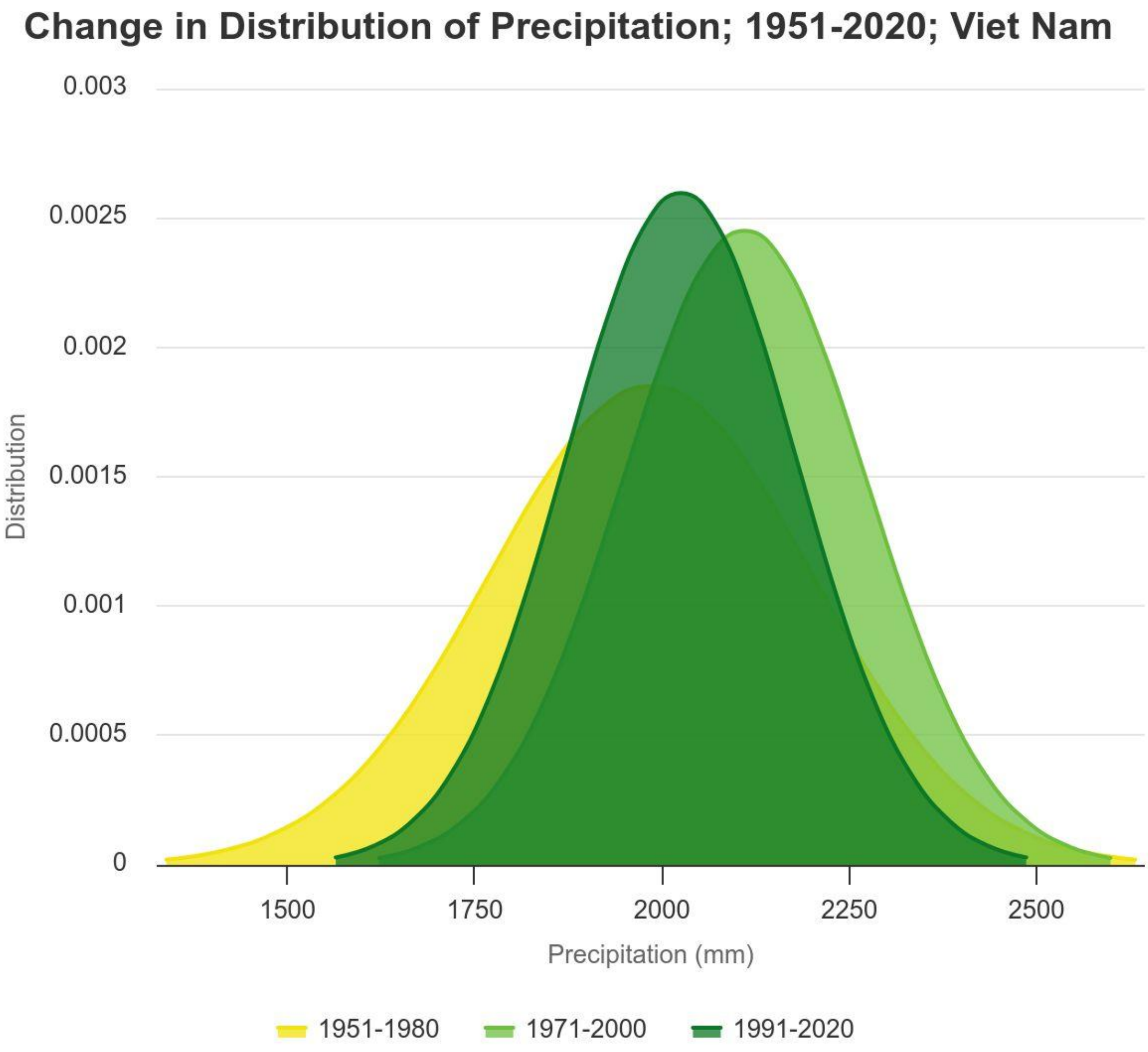

Figure 113 Change in distribution of average rainfall in Viet Nam for 1951 – 1980, 1971 – 2000, and 1991-2020 (CCKP, 2024b)

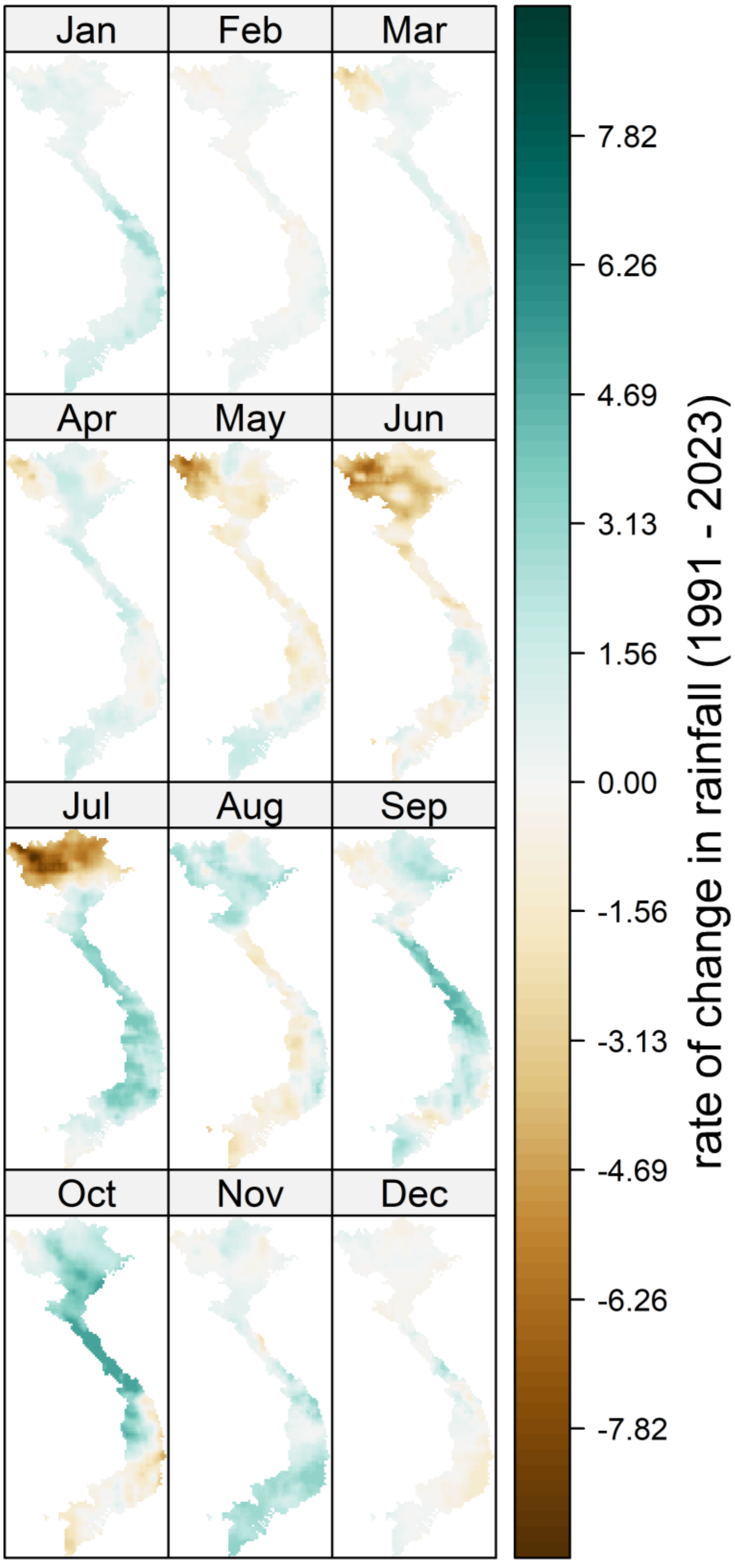

Figure 114 *Spatial patterns of rainfall trends in Viet Nam, indicating the rate of change in rainfalls from 1991 to 2023*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Viet Nam's rainfall data over the past three decades reveals significant variations that impact the country's agriculture, especially in its key rice-growing regions. The observed trends highlight both increases and decreases in monthly rainfall, which have substantial implications for crop production cycles, water management, and overall food security.

From May to October, a period crucial for rice planting, growth, and harvesting, there is considerable variability in rainfall. May has seen a notable increase in rainfall, rising from 153.28 mm in 1991 to 297.15 mm in 2022. This rise suggests that May has become wetter over time, potentially affecting planting timing. Excessive rainfall during this critical period can lead to waterlogging, which is detrimental to young rice plants. June also exhibits erratic rainfall, peaking at 294.88 mm in 1994 and dropping to a low of 174.66 mm in 2017. Such variability can disrupt early crop growth stages, potentially causing water stress or excessive moisture-related issues.

In July and August, there is a general upward trend in rainfall. July's rainfall increased to 371.33 mm in 2018, while August reached 359.83 mm in the same year. While increased rainfall can ensure adequate water supply, it also brings challenges such as flooding, which can damage crops and reduce productivity. September, crucial for crop maturation, displays significant fluctuations, with rainfall ranging from 389.49 mm in 2009 to 213.58 mm in 2017. These fluctuations can result in unpredictable harvests, with excessive rainfall potentially delaying harvests and causing crop losses, while insufficient rainfall may lead to poor grain development. October, the harvest month, shows variability with rainfall ranging from 184.21 mm in 2009 to 336.23 mm in 2010. Increased rainfall during harvest can cause post-maturation issues.

The dry season months, particularly January to March, also exhibit significant changes. January has seen a dramatic increase in rainfall from 48.70 mm in 1991 to 80.04 mm in 2023. This rise in a traditionally dry month could disrupt water storage practices essential for the dry season and lead to waterlogged fields unprepared for early planting. February shows an increase from 30.86 mm in 1991 to 46.58 mm in 2023, while March experienced a notable decrease, dropping from 87.11 mm in 1991 to 33.17 mm in 2023. Sharp declines during this period, typically used for field preparation, can severely impact agricultural planning and readiness for the upcoming growing season.

Overall, the observed trends highlight an increasing unpredictability in Viet Nam’s climate. The rise in rainfall during traditionally dry months necessitates better water management systems to capture and store water efficiently for drier periods. Additionally, the increasing rainfall during monsoon months heightens the risk of flooding and waterlogging, which can damage crops, particularly rice, which is sensitive to both drought and excessive moisture. The variability in rainfall patterns complicates crop planning and may require adjustments in planting and harvesting calendars to align with changing rainfall patterns. There is also a need for developing climate-resilient crop varieties capable of withstanding both excessive rainfall and potential droughts to ensure stable yields despite the changing climate. In conclusion, the rainfall data from Viet Nam underscores the need for adaptive strategies in water management, crop planning, and the development of resilient agricultural systems to navigate the challenges posed by climate change.

__Figure 116__ Spatially aggregated mean monthly rainfall time series line plots with trend lines, depicting the variation of mean monthly rainfalls over time in Viet Nam.

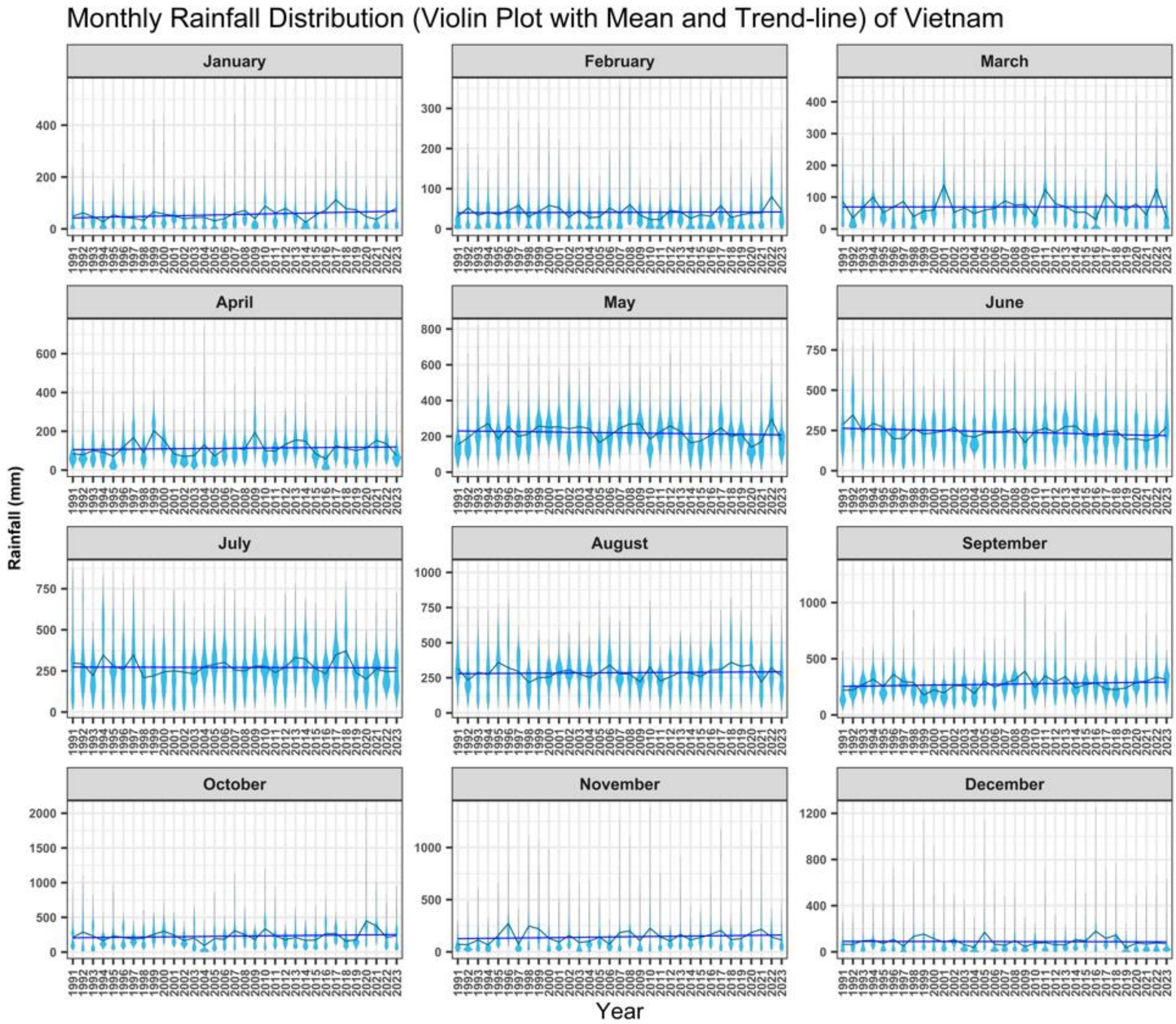

***Figure 117** Distribution of mean monthly rainfall time series and violin plots in Viet Nam, featuring mean and trend lines to illustrate the distribution, spatial variability, and central tendencies of monthly rainfalls*

Table 36 Spatially aggregated mean monthly air rainfall (mm) in Viet Nam from 1991 to 2023, derived from ERA-5 data

Month/Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	48.70	30.86	87.11	84.51	153.28	287.31	298.01	316.63	219.77	211.56	71.81	65.57
1992	61.96	52.36	34.58	78.60	192.20	346.29	292.38	233.44	221.52	288.33	69.92	65.41
1993	46.89	33.64	68.50	99.83	237.56	243.77	221.79	289.34	272.11	232.22	113.29	96.43
1994	28.07	41.57	100.44	92.54	271.79	294.88	347.16	272.73	317.51	164.23	67.07	99.60
1995	54.27	35.33	50.64	71.22	186.01	269.03	279.82	360.05	253.44	232.26	158.73	73.46
1996	44.46	45.57	68.94	118.41	254.95	199.06	258.91	320.92	361.07	210.99	272.87	107.90
1997	41.30	58.74	86.61	168.10	199.50	200.75	347.73	295.59	295.10	186.49	71.67	49.20
1998	32.94	30.57	38.73	90.24	213.35	261.67	209.22	215.60	289.39	201.11	246.92	135.22
1999	65.67	42.81	56.55	203.84	258.76	227.60	220.66	250.55	177.00	256.95	220.57	153.77
2000	57.77	58.51	59.21	154.94	249.88	235.63	244.81	254.37	223.31	301.58	131.48	114.53
2001	50.80	52.87	138.15	83.25	253.42	246.47	250.72	293.11	196.63	243.51	93.99	83.34
2002	38.90	29.39	51.79	70.24	241.53	267.56	242.66	305.58	261.80	167.52	159.56	104.44
2003	43.78	46.30	65.87	75.00	254.43	219.20	231.28	276.74	259.81	202.77	89.54	62.36
2004	44.33	27.90	48.64	131.50	242.40	208.21	277.83	252.89	191.69	93.10	101.72	39.73
2005	31.32	29.36	58.71	72.11	163.97	233.82	289.52	289.00	302.17	193.26	141.27	171.19
2006	39.81	51.87	64.68	108.10	203.86	235.96	302.57	340.34	247.86	184.22	73.14	67.67
2007	61.02	38.90	88.57	112.86	244.91	240.47	255.84	278.10	281.93	309.24	186.58	56.26
2008	71.45	60.42	74.81	107.43	268.80	262.56	250.61	276.37	311.90	250.31	199.80	97.44
2009	39.24	34.26	77.14	195.72	270.29	174.66	279.82	221.34	389.49	184.21	108.42	45.25
2010	88.52	23.70	40.26	100.55	184.17	243.50	278.78	325.16	242.51	336.23	226.30	75.23
2011	61.51	23.37	124.16	98.03	227.00	264.27	240.29	227.41	347.96	235.99	143.04	79.68
2012	78.71	45.73	79.80	132.50	258.19	238.78	272.92	257.19	293.85	178.32	105.02	62.61
2013	56.64	42.52	69.69	154.65	226.47	274.27	332.50	290.29	340.95	211.43	167.39	61.85
2014	25.34	26.25	52.59	150.28	163.56	277.27	322.19	283.50	240.05	169.49	115.45	105.09
2015	53.49	35.39	52.65	84.35	173.59	223.77	262.72	257.95	270.04	173.39	137.55	95.29
2016	72.05	31.19	29.50	57.69	207.29	214.33	232.86	303.82	284.65	267.46	167.20	179.26
2017	112.66	58.28	109.82	124.87	247.79	241.97	348.22	308.51	229.88	269.05	205.95	116.59
2018	78.03	28.06	70.90	111.24	199.64	247.32	371.33	359.83	226.36	157.19	116.90	145.58
2019	73.98	35.04	60.42	100.45	213.51	195.02	239.31	330.67	240.62	178.52	126.84	35.78
2020	46.83	39.33	79.38	113.08	138.86	197.84	201.54	342.57	289.69	448.81	184.92	76.60
2021	36.76	40.17	44.43	153.60	169.68	186.21	261.83	220.68	300.57	377.98	216.26	68.09
2022	59.69	80.70	124.53	135.69	297.15	208.48	245.77	319.66	336.52	212.06	142.15	77.66
2023	80.04	46.58	33.17	75.20	173.44	273.34	248.24	261.22	312.88	236.76	112.80	70.09

A comparison of monthly average rainfalls between the long-term period from 2001 to 2020 and the year 2023 reveals significant deviations that have notable implications for agriculture in Viet Nam.

In January 2023, the average rainfall was 80.038 mm, which is 21.618 mm above the long-term average of 58.419 mm. This substantial increase could disrupt water management practices typically planned for drier months. February also saw an increase, with rainfall averaging 46.582 mm, which is 8.577 mm above the long-term average of 38.005 mm. Conversely, March experienced a significant decrease, with 33.171 mm of rainfall, falling short by 38.705 mm from the long-term average of 71.877 mm. This reduction could delay planting and impact the initial stages of crop growth, potentially affecting overall yields.

April's rainfall was 75.196 mm, which is 33.999 mm below the long-term average of 109.195 mm. May also recorded less rainfall than usual, with 173.435 mm, 45.748 mm below the long-term average of 219.184 mm.

These reductions could affect crop growth stages and overall productivity. In contrast, June and July saw above-average rainfall, with June recording 273.342 mm, which is 37.980 mm above the long-term average of 235.362 mm, and July at 248.236 mm, which is 25.939 mm below the long-term average of 274.175 mm. The increased rainfall during these months could boost crop growth but may also raise water management challenges and the risk of heat stress.

August experienced a decrease, with 261.218 mm of rainfall, 29.799 mm below the long-term average of 291.018 mm. September saw an increase, with 312.880 mm, which is 40.388 mm above the long-term average of 272.492 mm. October also had increased rainfall, measuring 236.758 mm, 14.058 mm above the long-term average of 222.700 mm. November recorded 112.801 mm, which is 29.727 mm below the long-term average of 142.528 mm, while December had a slight decrease, with 70.086 mm, falling 17.975 mm below the long-term average of 88.062 mm.

These seasonal variations in rainfall throughout 2023 reflect complex dynamics impacting Viet Nam's croplands. The pronounced increases in mid-year rainfall, combined with significant variations later in the year, suggest a shifting climate pattern that could influence growing conditions. Reduced rainfall early in the year may delay planting and slow crop establishment, while increased mid-year rainfall might enhance crop growth but necessitate adjustments in water management practices. The variations in late summer and autumn, with both increases and decreases in rainfall, could affect crop maturation and harvesting. Overall, these fluctuations highlight the need for adaptive agricultural strategies, including revising planting schedules, enhancing irrigation efficiency, and selecting crop varieties that can withstand variable moisture conditions to sustain agricultural productivity and mitigate the impacts of climate change on Viet Nam's croplands.

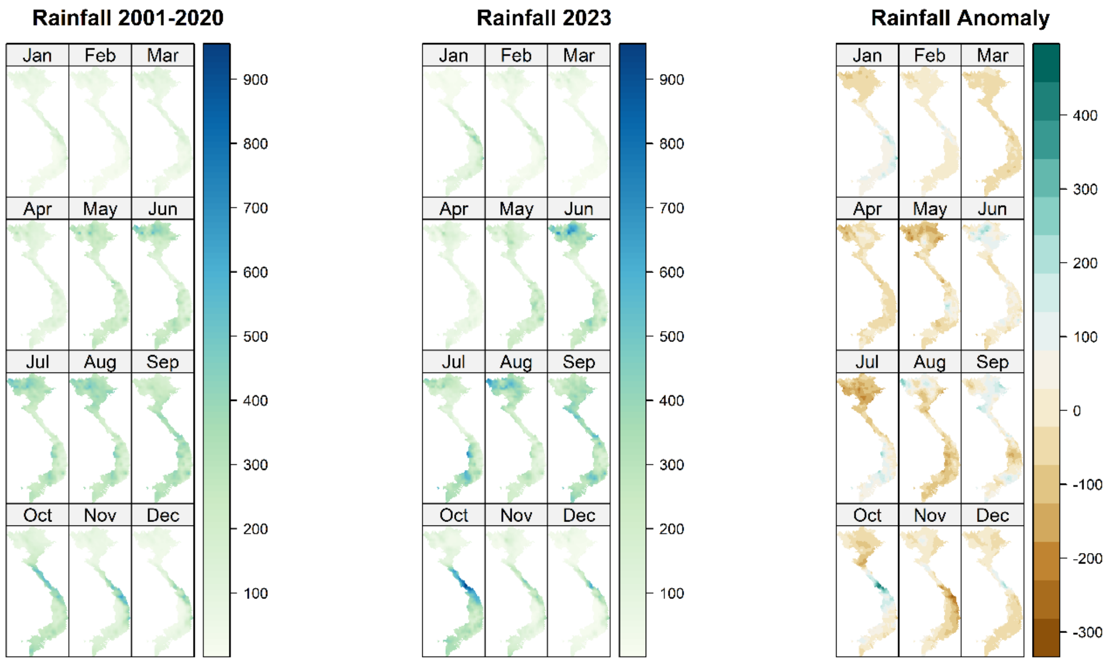

Figure 118 *Spatial distribution of rainfalls in Viet Nam, displaying long-term monthly average rainfalls, monthly average rainfalls for 2023, and anomaly maps showing the difference between the 2023 rainfalls and the long-term averages*

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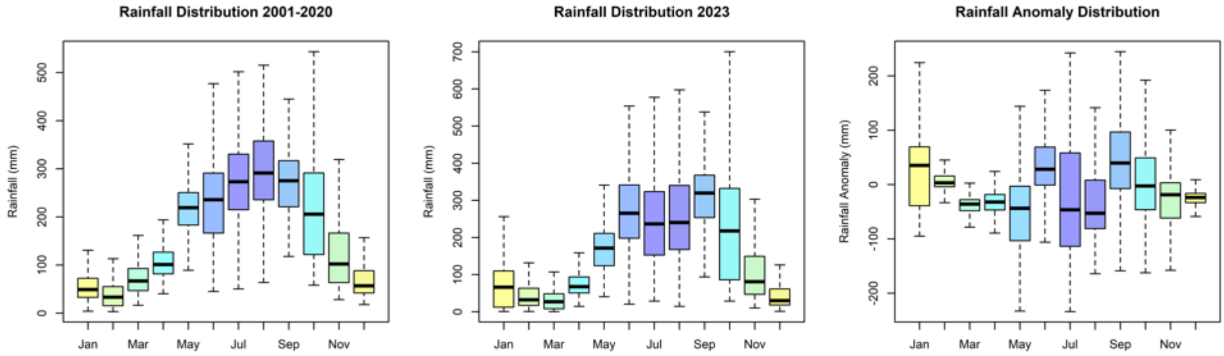

Figure 119 *Boxplot visualization of the mean monthly rainfalls in Viet Nam, comparing the long-term monthly averages, the monthly rainfalls recorded in 2023, and the corresponding rainfall anomalies*

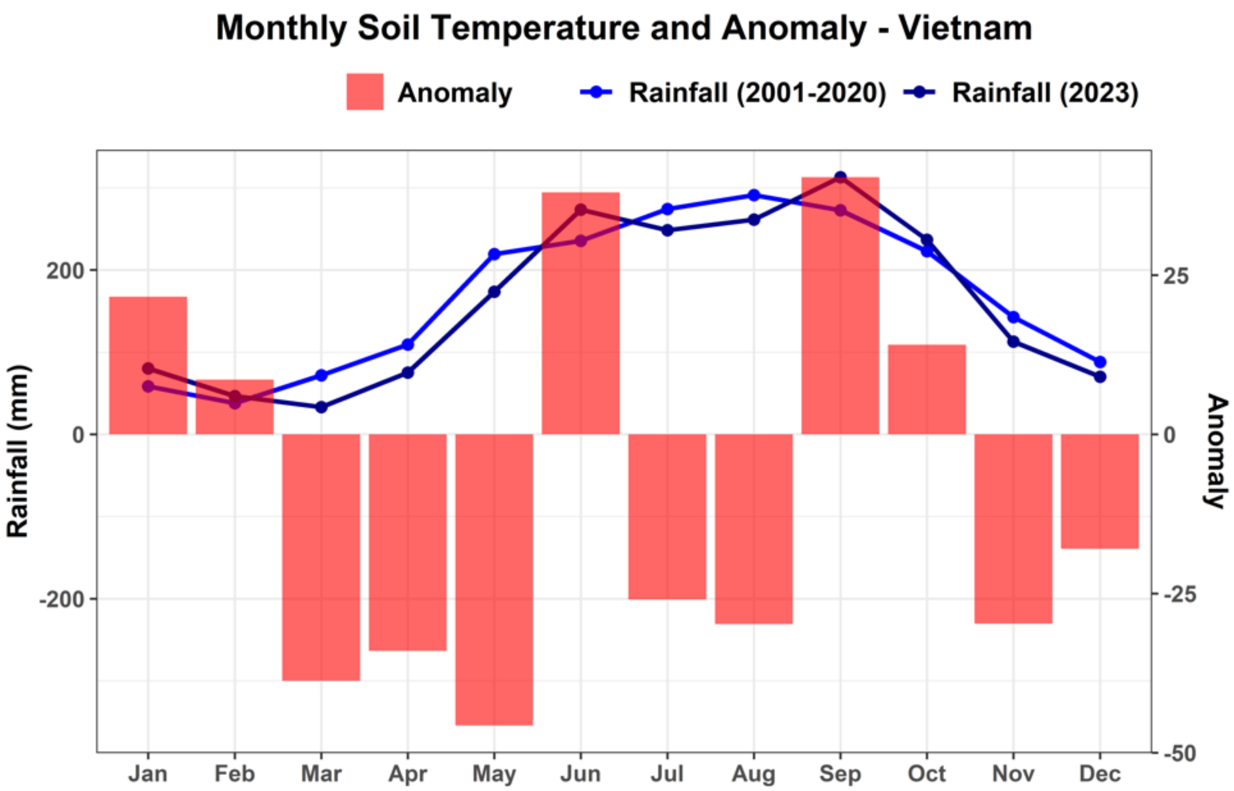

Figure 120 Spatially aggregated monthly rainfall series in Viet Nam, showing the long-term averages, the rainfalls recorded in 2023, and the anomalies.

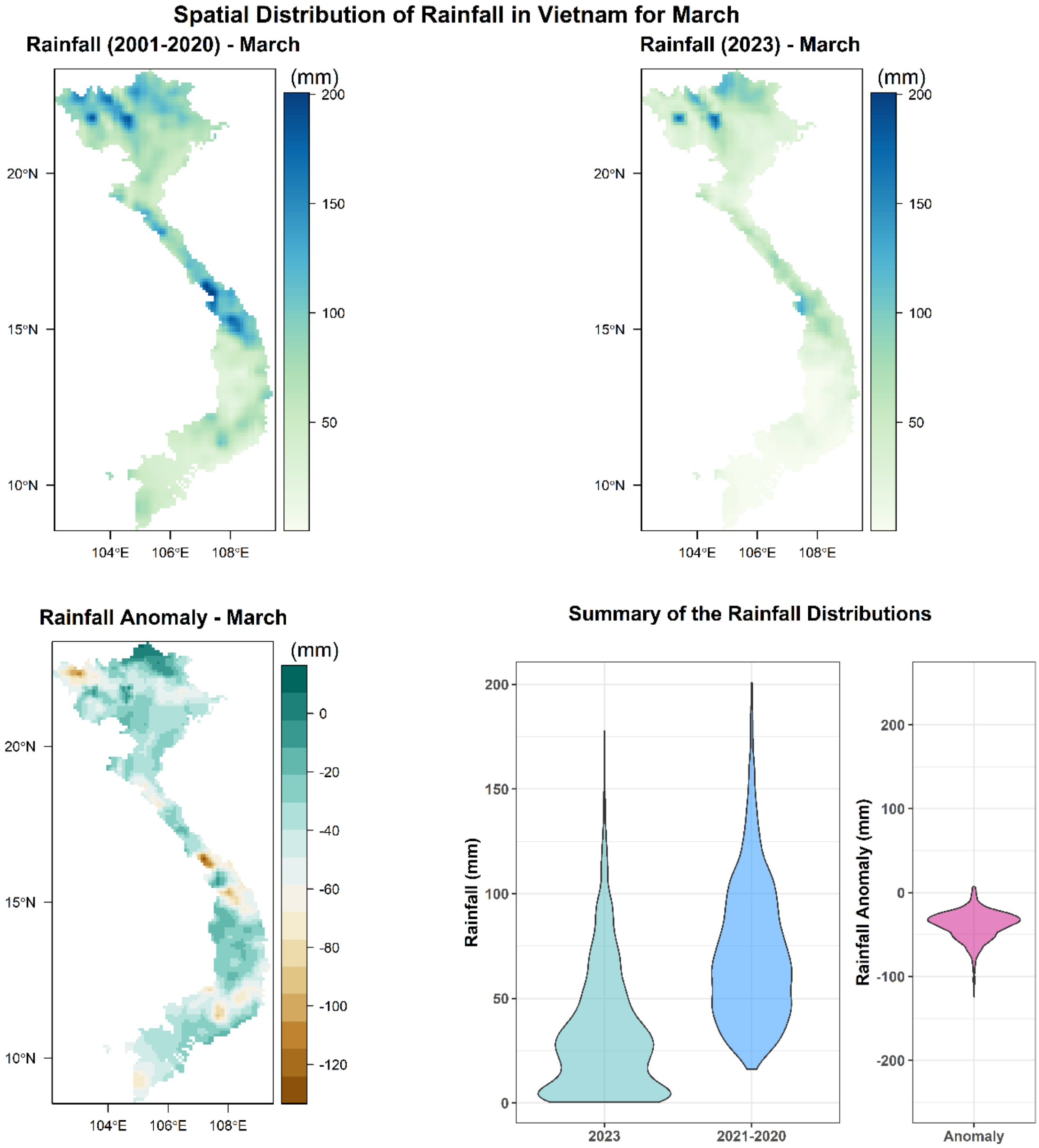

__Figure 121__ Maps and violin plots illustrate the spatial distribution of March rainfalls in Viet Nam. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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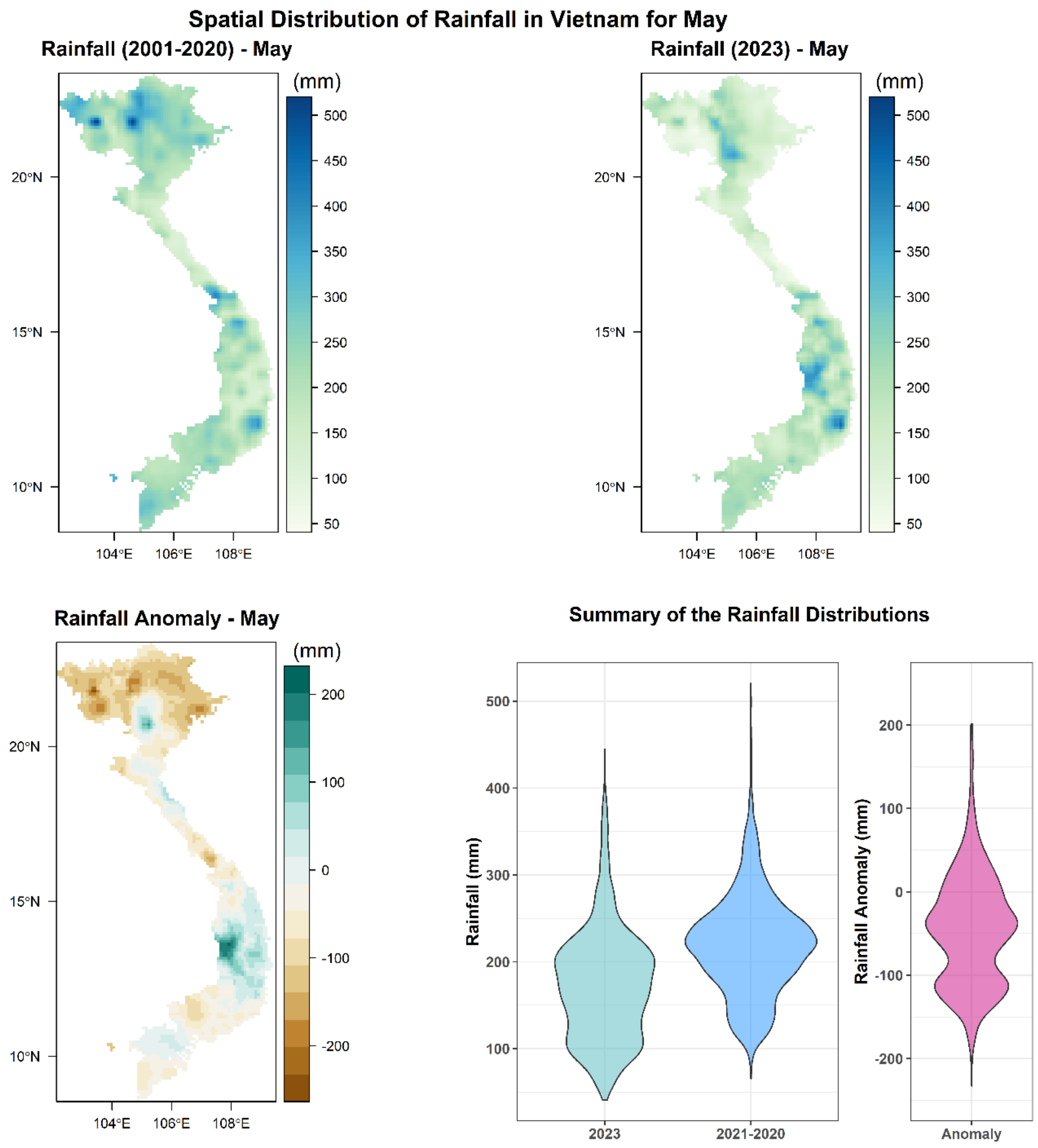

__Figure 122__ Maps and violin plots illustrate the spatial distribution of May rainfalls in Viet Nam. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

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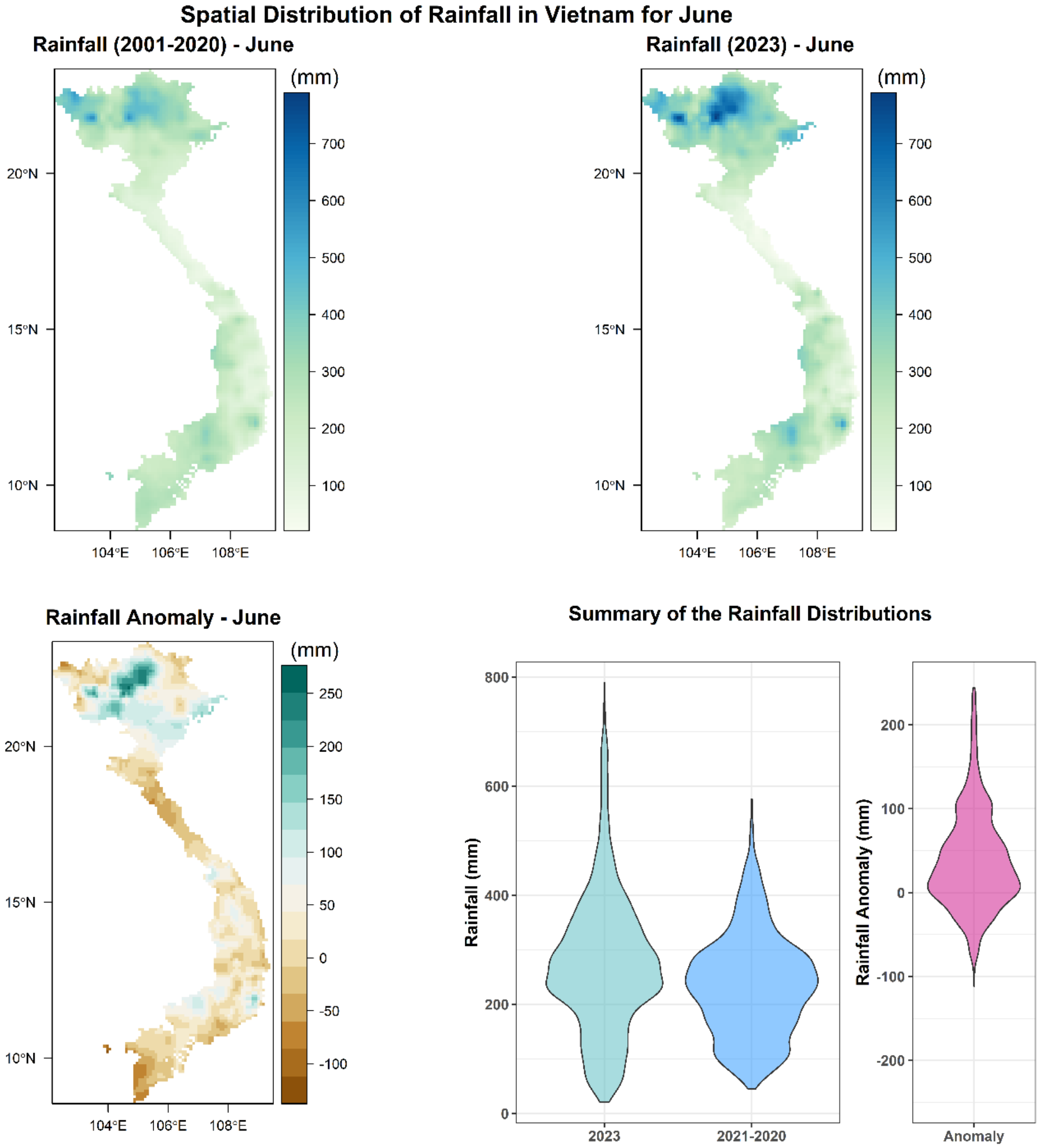

Figure 123 Maps and violin plots illustrate the spatial distribution of June rainfalls in Viet Nam. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

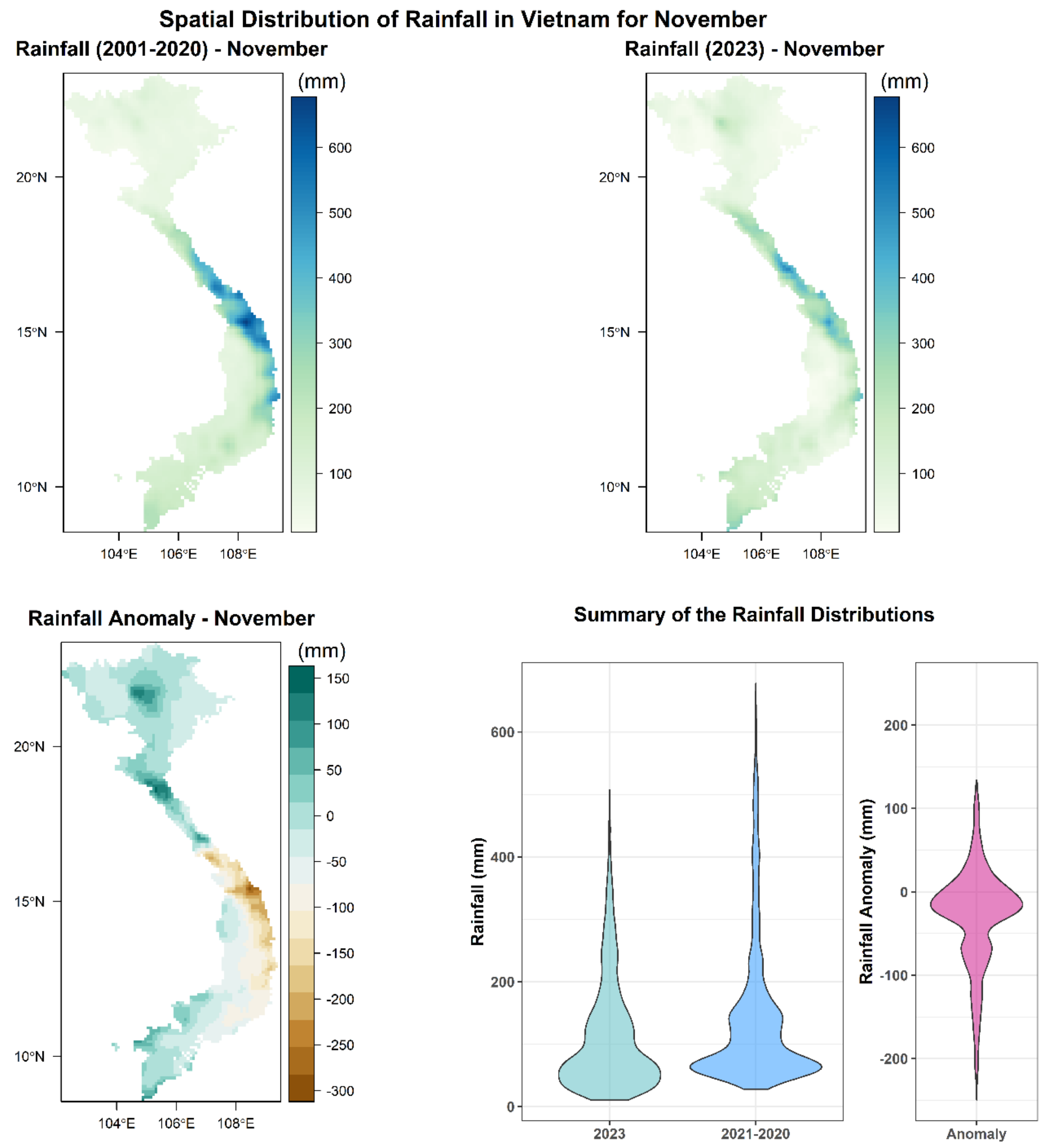

Figure 124 Maps and violin plots illustrate the spatial distribution of November rainfalls in Viet Nam. The maps display the long-term average rainfall, the recorded rainfall in 2023, and the rainfall anomaly, and the violin plots indicate the distribution of the data

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 37 *Monthly averages of long-term rainfalls (mm), 2023 monthly averages (mm), and rainfall anomalies (mm) in Viet Nam*

Month	Rainfall (2001-2020)	Rainfall (2023)	Anomaly
Jan	58.419	80.038	21.618
Feb	38.005	46.582	8.577
Mar	71.877	33.171	-38.705
Apr	109.195	75.196	-33.999
May	219.184	173.435	-45.748
Jun	235.362	273.342	37.980
Jul	274.175	248.236	-25.939
Aug	291.018	261.218	-29.799
Sep	272.492	312.880	40.388
Oct	222.700	236.758	14.058
Nov	142.528	112.801	-29.727
Dec	88.062	70.086	-17.975

5.2.5. Trends of NDVI in Viet Nam

To analyze the cascading impacts of changing conditions, such as variations in temperature and rainfall, the corresponding changes in vegetation greenness, which indicates crop biomass, were assessed using time series data on the Normalized Difference Vegetation Index (NDVI). The NDVI measures the "greenness" of ground cover and serves as a proxy to indicate the density and health of vegetation. NDVI values range from +1 to -1, with high positive values corresponding to dense and healthy vegetation, while low or negative values indicate poor vegetation conditions or sparse vegetative cover (Cohen et al., 2018) (Bayarjargal et al., 2006; Tucker et al., 1983).

The deviations in NDVI were analyzed using anomalies in NDVI maps, graphs, and tables, along with the time series values of NDVI. NDVI anomalies represent the variation of current decadal (10-day period) values compared to the long-term average (Tucker and Sellers, 1986). A positive anomaly (e.g., +5%) signifies enhanced vegetation conditions relative to the average, while a negative anomaly (e.g., -5%) indicates poorer vegetation conditions (Anyamba et al., 2010).

The data for this analysis was accessed through the Food and Agriculture Organization's (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS) (FAO-GIEWS, 2024). GIEWS monitors the condition of major food crops at both country and global levels to assess production prospects. To support this analysis and supplement ground-based information, GIEWS utilizes remote sensing data, which provides valuable insights into water availability and vegetation health during cropping seasons. In addition to rainfall estimates and NDVI, GIEWS relies on vegetation indicators derived from 10-day (decadal) vegetation data captured by the METOP-Advanced Very High-Resolution Radiometer (AVHRR) sensor at a 1 km resolution (for data from 2007 onwards). For data from 1984 to 2006, NDVI values are derived from the National Oceanic and Atmospheric Administration (NOAA)-AVHRR dataset at a 16 km resolution. Precipitation estimates for African countries (except Cabo Verde and Mauritius) are sourced from NOAA's Famine Early Warning Systems Network (FEWSNet), while data for other countries is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

In this assessment, monthly maps of NDVI anomalies were obtained for the years 2022, 2023, and up to July 2024. Time series statistics were generated at the sub-national level and then integrated at the country level to indicate the monthly variation in NDVI profiles over crop areas and the corresponding anomalies.

The long-term temporal NDVI profiles for croplands in Viet Nam reveal distinct seasonal patterns that reflect the general phenological cycles of vegetation. Typically, NDVI values are lower in the early months of the year, gradually increasing towards May, peaking during the mid-year months (June to August), and then slightly declining towards the end of the year. This pattern indicates a growth phase in the earlier months, followed by a peak in vegetation greenness during the monsoon season, and a decline as the harvest season approaches. This seasonal variability is a characteristic feature of cropland dynamics in tropical regions, influenced by the timing of planting, growth, and harvest cycles.

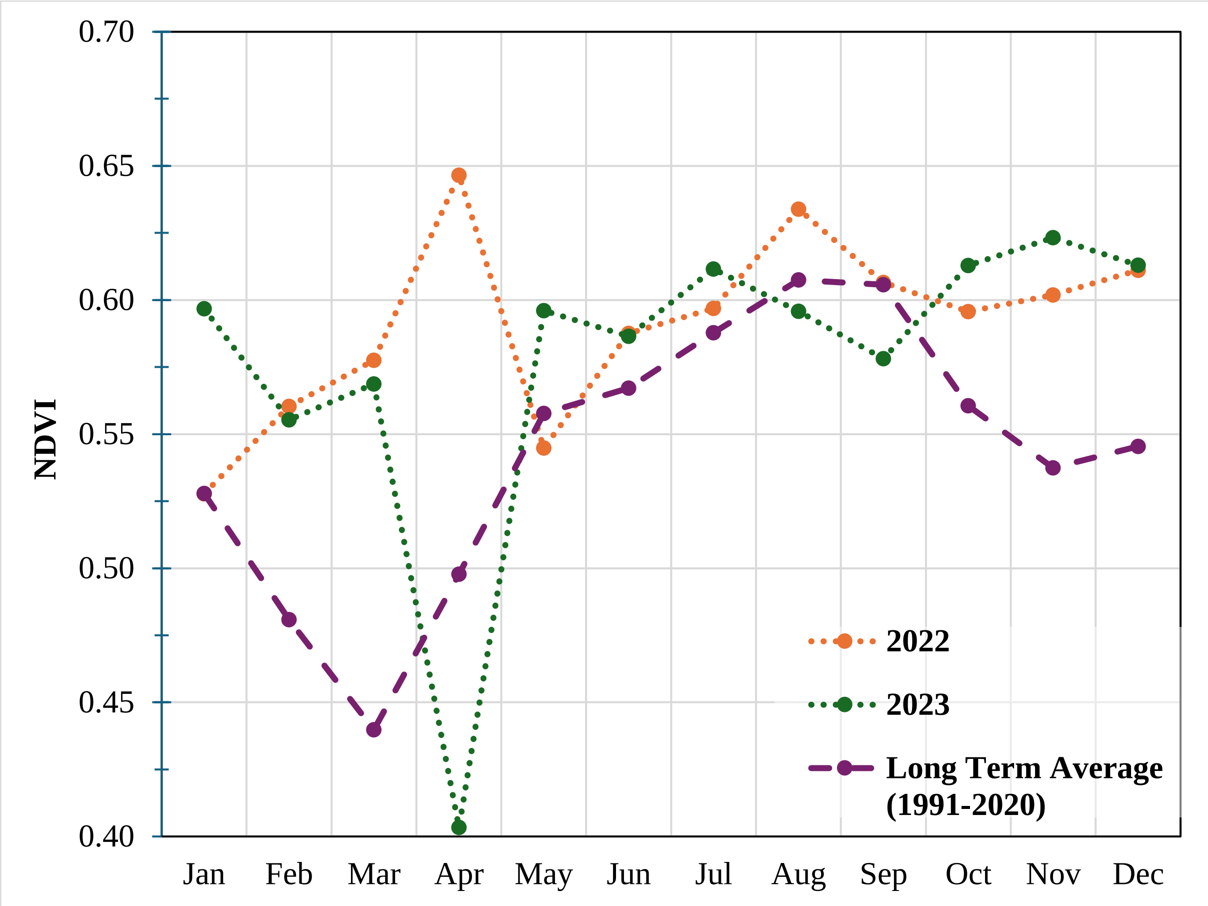

Figure 115 *Spatially aggregated mean monthly NDV profiles in Viet Nam from 1991 to 2023 showing monthly averages, long-term averages (1991-2020), and anomalies for 2022-23 over the crop area (FAO-GIEWS, 2024)*

The NDVI anomalies for 2023 present a mixed picture, with significant deviations from the long-term average. Notably, there was a substantial positive anomaly in March (+29.31%), indicating unusually vigorous vegetation growth during this month, likely due to favourable climatic conditions or agricultural practices. However, in April, a stark negative anomaly (-18.98%) was observed, suggesting a sudden reduction in vegetation greenness, possibly due to extreme weather events such as unseasonal drought or flooding. Other months, like January, February, October, November, and December, also showed positive anomalies, indicating periods of better-than-average vegetation health, whereas the mid-year months (June to September) experienced smaller deviations, suggesting relatively stable conditions during the peak growing season.

The year 2022 exhibited some of the highest positive anomalies, particularly in March (+31.33%) and April (+29.88%), which are consistent with unusual early-year growth. These anomalies could be indicative of an early onset of the growing season or exceptionally favourable weather conditions. Unlike 2023, April did not experience a negative anomaly, suggesting a more consistent growing season. However, anomalies in May (-2.31%) suggest that despite the early boost, some areas might have faced challenges, potentially related to climatic variability or pest issues. Overall, 2022 appears to have been a year with strong early growth, followed by stable conditions for the remainder of the year.

The period from 2021 to 2023 has seen significant variability in NDVI anomalies, reflecting changing environmental and agricultural conditions. In 2021, the anomalies were generally positive, with some negative deviations in April and March, suggesting occasional stress periods. The trends in 2022 and 2023, particularly the positive spikes in early 2022 and 2023 contrast with the more moderate anomalies in 2021, pointing to possible shifts in planting schedules, crop types, or external factors such as climate change or agricultural interventions. The variability across these years highlights the dynamic nature of agricultural landscapes in Viet Nam and the influence of both human and environmental factors on vegetation health.

The observed changes and anomalies in NDVI from 2021 to 2023 could be driven by several factors, including climate variability, changes in agricultural practices, and external influences such as pests or disease outbreaks. The positive anomalies in early 2022 and 2023 suggest periods of optimal growing conditions, potentially linked to favourable rainfall or temperature patterns. Conversely, the negative anomalies, particularly in April 2023, could be associated with adverse weather events or other stress factors. The ongoing impacts of climate change, including shifts in monsoon patterns and increasing temperature extremes, are likely contributing to the observed variability. Additionally, changes in crop management practices, such as the introduction of new crop varieties or shifts in planting schedules, could also be influencing NDVI patterns.

The evolution of NDVI profiles over the period from 1991 to 2023 reveals a trend towards increasing variability and a slight overall increase in NDVI values, particularly during the mid-year peak. This could indicate improvements in agricultural productivity or shifts towards more resilient crop types. However, the increased variability, particularly in the anomalies observed in recent years, suggests that these gains may be under threat from climatic and environmental changes. The data also hint at a potential lengthening of the growing season, with higher NDVI values appearing earlier in the year, particularly in recent years.

One unique observation from the profiles is the significant positive anomaly in March 2023, followed by a sharp negative anomaly in April 2023. This abrupt shift could indicate a specific event or change in agricultural practices that impacted crop health dramatically within a short period. Additionally, the generally positive anomalies in the latter months of 2022 and 2023 suggest a trend towards prolonged or more robust late-season growth, which could be an adaptive response to changing climate conditions or an indication of shifts in crop cycles.

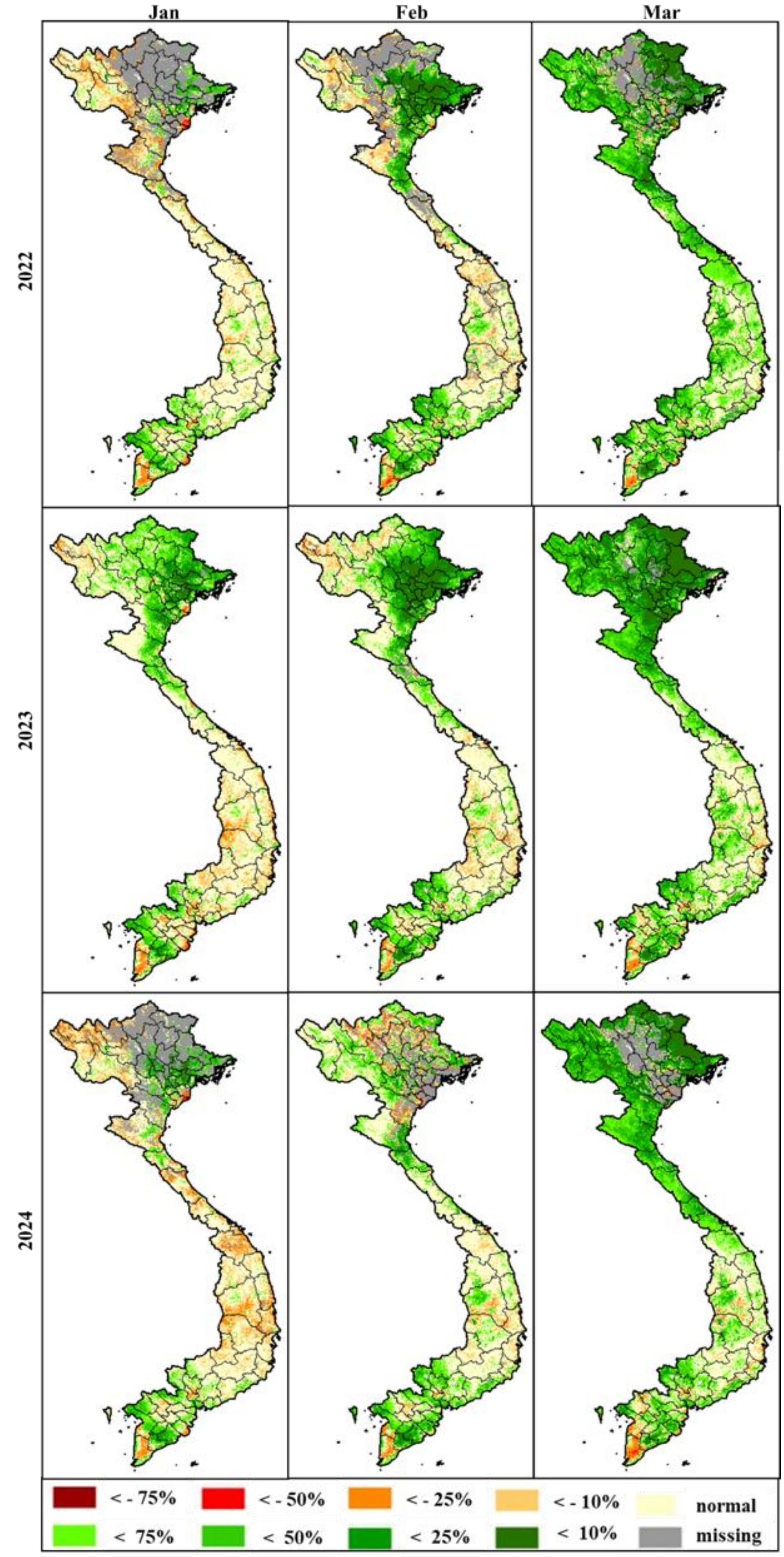

Figure 116 *Monthly NDVI anomaly maps of Viet Nam for 2022-24 (January, February, and March) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

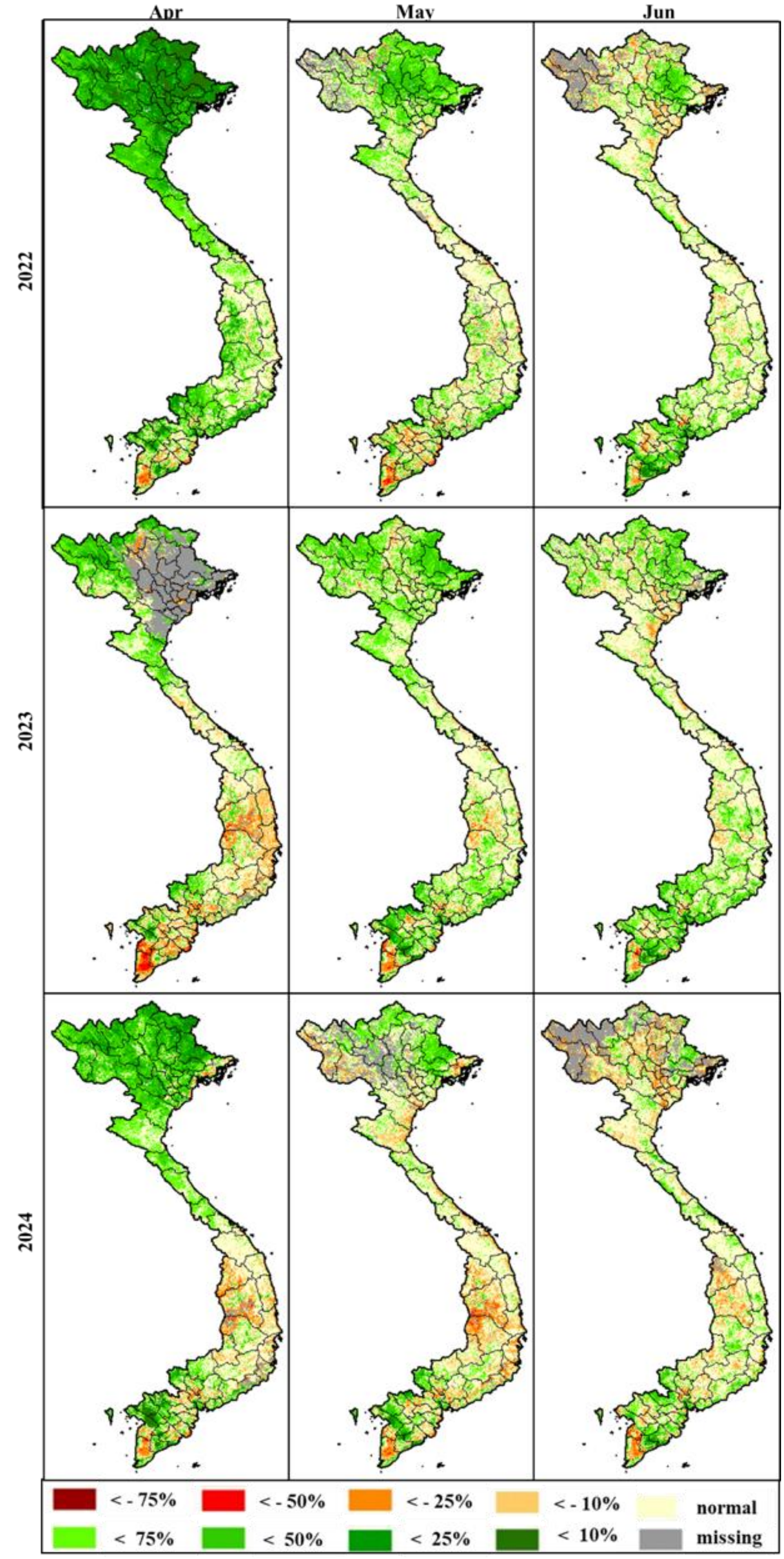

Figure 117 *Monthly NDVI anomaly maps of Viet Nam for 2022-24 (April, May, and Jun) (FAO-GIEWS, 2024)*

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

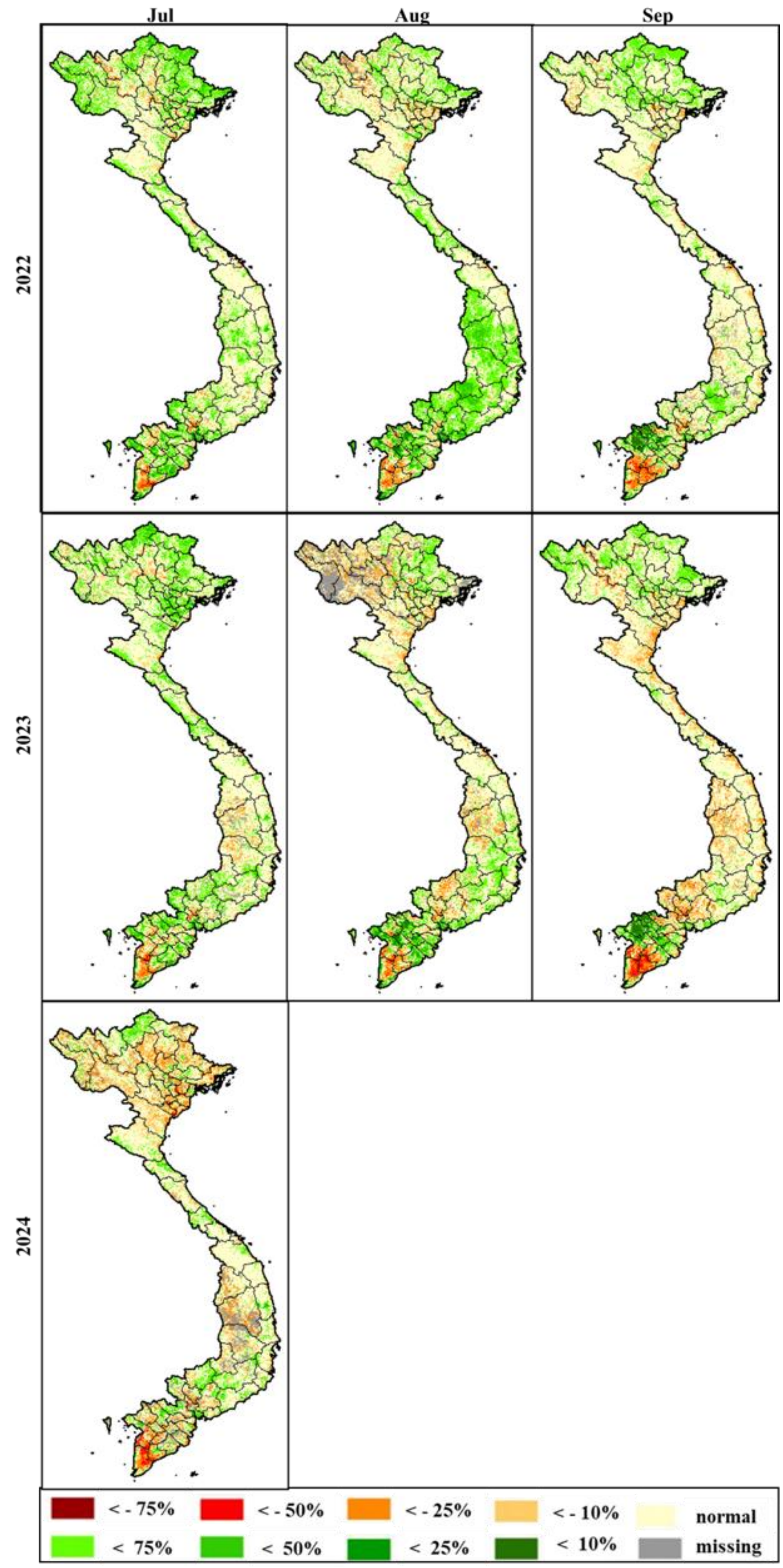

Figure 118 *Monthly NDVI anomaly maps of Viet Nam for 2022-24 (July, August, and September) (FAO-GIEWS, 2024)*

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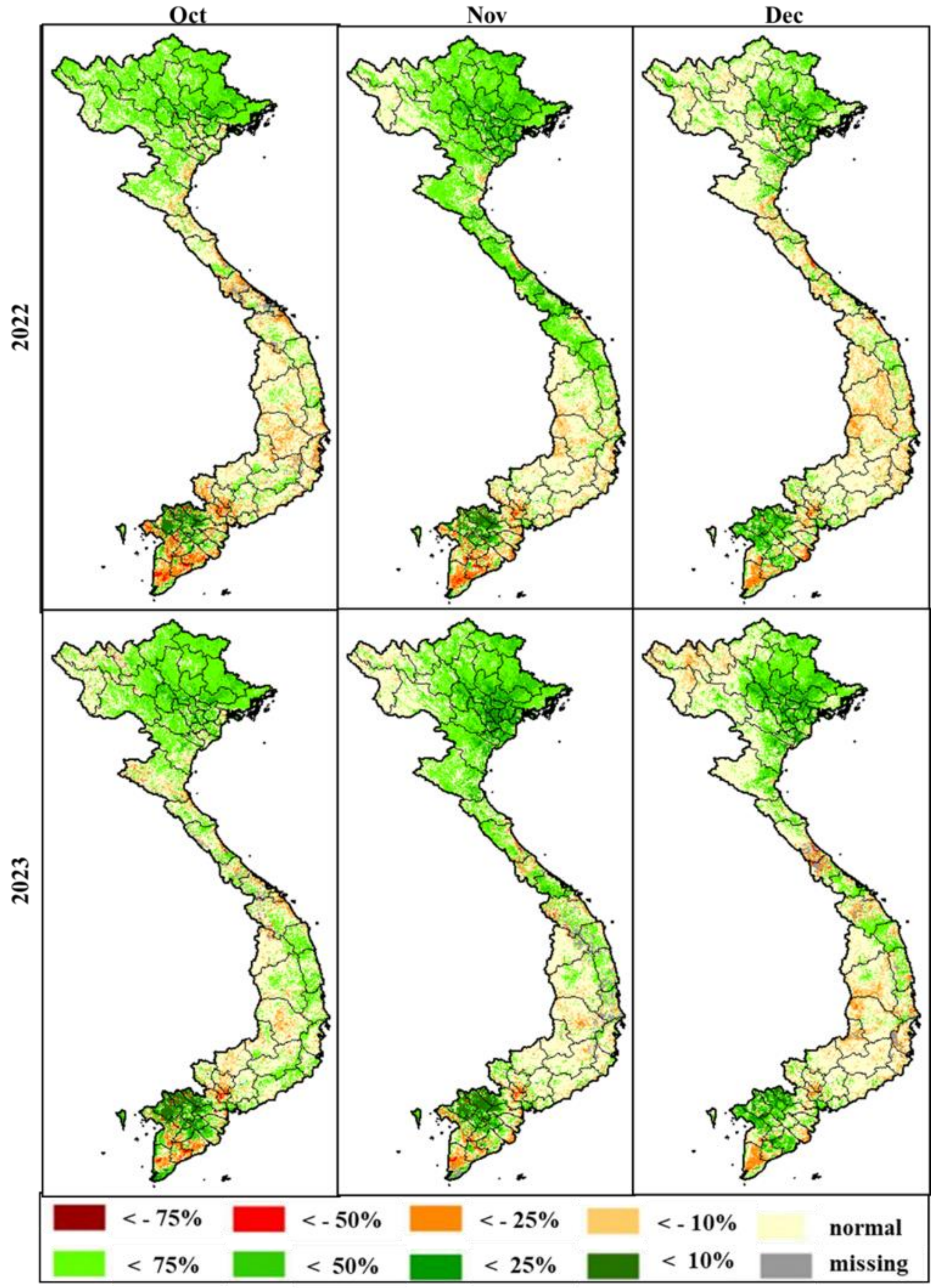

Figure 119 *Monthly NDVI anomaly maps of Viet Nam for 2022-24 (October, November, and December) (FAO-GIEWS, 2024)*

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Table 36 *Spatially aggregated mean monthly NDV profiles in Viet Nam from 1991 to 2023, long-term average (1991-2020), and the anomalies for 2021-23 over the crop area (FAO-GIEWS, 2024)*

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0.539	0.517	0.419	0.495	0.547	0.561	0.548	0.546	0.559	0.547	0.465	0.449
1992	0.46	0.449	0.35	0.451	0.52	0.526	0.601	0.585	0.631	0.517	0.501	0.581
1993	0.513	0.444	0.429	0.49	0.568	0.582	0.573	0.614	0.602	0.577	0.48	0.418
1994	0.414	0.351	0.307	0.45	0.488	0.493	0.535	0.561	0.524	0.474	0.433	0.454
1995	0.469	0.426	0.406	0.467	0.533	0.561	0.617	0.553	0.612	0.581	0.482	0.554
1996	0.456	0.47	0.42	0.485	0.621	0.604	0.541	0.62	0.648	0.557	0.436	0.518
1997	0.455	0.414	0.472	0.541	0.563	0.483	0.545	0.608	0.634	0.648	0.63	0.668
1998	0.58	0.497	0.494	0.544	0.518	0.555	0.69	0.668	0.635	0.575	0.473	0.487
1999	0.513	0.492	0.478	0.508	0.546	0.594	0.592	0.644	0.648	0.45	0.436	0.517
2000	0.52	0.432	0.315	0.43	0.57	0.6	0.529	0.58	0.516	0.415	0.305	0.283
2001	0.53	0.478	0.46	0.52	0.588	0.555	0.583	0.604	0.651	0.543	0.612	0.611
2002	0.591	0.445	0.44	0.484	0.507	0.541	0.581	0.6	0.645	0.648	0.579	0.652
2003	0.648	0.589	0.548	0.517	0.519	0.598	0.631	0.597	0.618	0.603	0.613	0.601
2004	0.491	0.477	0.369	0.465	0.555	0.583	0.543	0.575	0.628	0.56	0.585	0.655
2005	0.524	0.418	0.383	0.487	0.516	0.496	0.546	0.527	0.609	0.483	0.495	0.478
2006	0.554	0.422	0.407	0.521	0.531	0.512	0.541	0.586	0.546	0.592	0.592	0.578
2007	0.591	0.459	0.411	0.456	0.535	0.542	0.572	0.588	0.591	0.548	0.539	0.517
2008	0.525	0.458	0.432	0.498	0.588	0.582	0.609	0.632	0.609	0.583	0.577	0.542
2009	0.542	0.519	0.505	0.525	0.573	0.614	0.612	0.645	0.629	0.573	0.584	0.54
2010	0.526	0.55	0.455	0.474	0.541	0.574	0.622	0.628	0.622	0.58	0.547	0.563
2011	0.534	0.474	0.462	0.495	0.585	0.588	0.584	0.62	0.582	0.57	0.563	0.545
2012	0.54	0.519	0.48	0.548	0.604	0.565	0.6	0.607	0.606	0.564	0.593	0.583
2013	0.52	0.5	0.451	0.508	0.6	0.606	0.599	0.634	0.598	0.573	0.573	0.554
2014	0.527	0.505	0.464	0.495	0.588	0.581	0.607	0.655	0.622	0.573	0.556	0.582
2015	0.569	0.505	0.479	0.536	0.58	0.59	0.611	0.638	0.588	0.593	0.601	0.589
2016	0.57	0.534	0.456	0.482	0.559	0.59	0.626	0.648	0.607	0.575	0.586	0.58
2017	0.559	0.533	0.521	0.575	0.584	0.604	0.627	0.648	0.612	0.586	0.572	0.571
2018	0.533	0.52	0.499	0.526	0.603	0.598	0.589	0.614	0.602	0.607	0.564	0.55
2019	0.519	0.551	0.446	0.474	0.545	0.569	0.582	0.606	0.582	0.567	0.577	0.602
2020	0.522	0.476	0.432	0.487	0.557	0.566	0.603	0.591	0.615	0.554	0.575	0.542
2021	0.498	0.496	0.454	0.469	0.588	0.597	0.605	0.625	0.607	0.586	0.577	0.605
2022	0.528	0.56	0.578	0.647	0.545	0.588	0.597	0.634	0.607	0.596	0.602	0.611
2023	0.597	0.555	0.569	0.403	0.596	0.587	0.612	0.596	0.578	0.613	0.623	0.613
2024	0.543	0.524	0.544	0.553	0.529	0.548	0.534	0.598				
Long Term Average (1991-2020)	0.528	0.481	0.440	0.498	0.558	0.567	0.588	0.607	0.606	0.561	0.537	0.545
Anomaly 2023	13.05	15.51	29.31	-18.98	6.88	3.41	4.05	-1.91	-4.56	9.32	15.95	12.38
Anomaly 2022	-0.01	16.55	31.33	29.88	-2.31	3.60	1.54	4.35	0.14	6.25	11.98	12.02
Anomaly 2021	-5.62	3.18	3.25	-5.79	5.50	5.21	2.97	2.85	0.24	4.58	7.40	10.97

Chapter 6: Concluding Remarks

The agronomic assessment across Lao PDR, Cambodia, Thailand, and Viet Nam underscores the region's acute vulnerability to climate change, particularly regarding its impact on agriculture and food security. These countries, linked by the Mekong River basin, face significant climate risks, with Thailand, Viet Nam, and Cambodia among the most at-risk globally. Although Lao PDR faces less severe impacts, it is not exempt from climate challenges. The increasing frequency of droughts across the region emphasizes the urgency for effective climate adaptation strategies. For instance, Thailand has experienced eleven drought events since 2001, while Cambodia and Viet Nam have each seen four, and Lao PDR one. These droughts, coupled with unpredictable rainfall patterns, highlight the limitations of traditional crop monitoring methods, making satellite data essential for large-scale agricultural assessment.

In Cambodia, there has been a notable shift from rice to cassava, with cassava production increasing dramatically from 0.14 million tons in 2001 to 17.7 million tons in 2022. The country faces challenges related to temperature increases and variable rainfall, impacting agricultural productivity and necessitating adaptive strategies. Lao PDR has also seen cassava production surpass rice, with increasing crop diversity amid challenges related to fluctuating precipitation and temperature trends. Thailand, while maintaining stable rice production, has diversified into crops like cassava and sugarcane, though it faces challenges with low productivity and quality issues. The reliance on rainfed agriculture, varying soil types, and irrigation practices across these countries further complicates the region’s agricultural resilience.

Viet Nam’s agricultural landscape has evolved, with rice production remaining dominant but a significant rise in vegetable production. The country faces challenges from increased temperatures and shifting precipitation patterns, which create issues such as heat stress and water management difficulties. NDVI profiles across the region reveal seasonal patterns and recent deviations, reflecting the broader impact of climate variability on crop productivity. These findings highlight the urgent need for tailored adaptation strategies, improved water management, and resilient agricultural practices to mitigate the impacts of climate change on food security and agricultural sustainability in South-East Asia.

The food security concerns in Lao PDR, Cambodia, Thailand, and Viet Nam are becoming increasingly critical as climate change continues to impact agricultural productivity and sustainability. The region's heavy reliance on rainfed agriculture makes it particularly vulnerable to changing weather patterns, including more frequent and severe droughts, unpredictable rainfall, and rising temperatures. These climate-related challenges are threatening staple crop yields, such as rice, which is a primary food source across the region.

In Cambodia, the shift from rice to cassava reflects an adaptation to market demands and environmental changes, but it also raises concerns about the long-term sustainability of food production and the potential for reduced food availability. Lao PDR, which has seen a similar shift in crop production, faces risks to food security due to its limited irrigation infrastructure and dependency on natural rainfall. The increasing variability in weather patterns could lead to crop failures, directly affecting the food supply.

Thailand’s agricultural sector, despite its diversification, struggles with low productivity and quality issues, which could exacerbate food insecurity if these challenges are not addressed. The country’s reliance on smallholder farms also makes it vulnerable to climate shocks, potentially leading to reduced food availability and higher food prices. In Viet Nam, while the country has seen a rise in vegetable production, the impacts of climate change on water resources and crop health pose significant risks to food security. Heat stress and water management issues, driven by changing precipitation patterns, could threaten the stability of food production.

Overall, the region's food security is at risk due to the combined effects of climate change, evolving agricultural practices, and the challenges of adapting to new environmental conditions. Ensuring food security in the face of these challenges will require comprehensive strategies that include improving water management, adopting climate-resilient crops, and enhancing the capacity of farmers to adapt to changing conditions.

References

Abbas, S., Nichol, J., Qamer, F., Xu, J., 2014. Characterization of Drought Development through Remote Sensing: A Case Study in Central Yunnan, China. Remote Sens. 6, 4998–5018. https://doi.org/10.3390/rs6064998

Anyamba, A., Tucker, C.J., Eastman, J.R., 2010. NDVI anomaly patterns over Africa during the 1997/98 ENSO warm event. Int. J. Remote Sens. 22, 1847–1859. https://doi.org/10.1080/01431160010029156

Awokuse, T.O., Xie, R., 2015. Does Agriculture Really Matter for Economic Growth in Developing Countries? Can. J. Agric. Econ. Can. d'agroeconomie 63, 77–99. https://doi.org/10.1111/cjag.12038

Bayarjargal, Y., Karnieli, a, Bayasgalan, M., Khudulmur, S., Gandush, C., Tucker, C., 2006. A comparative study of NOAA–AVHRR derived drought indices using change vector analysis. Remote Sens. Environ. 105, 9–22. https://doi.org/10.1016/j.rse.2006.06.003

Bento, V.A., Gouveia, C.M., DaCamara, C.C., Trigo, I.F., 2018. A climatological assessment of drought impact on vegetation health index. Agric. For. Meteorol. 259, 286–295. https://doi.org/10.1016/j.agrformet.2018.05.014

Bhuiyan, C., Singh, R.P., Kogan, F.N., 2006. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. Int. J. Appl. Earth Obs. Geoinf. 8, 289–302. https://doi.org/10.1016/j.jag.2006.03.002

Britannica, 2024. Britannica [WWW Document]. URL https://www.britannica.com/

CCKP, 2024a. World Bank Climate Knowledge Portal for Development Practioners and Policy Makers. https://doi.org/https://climateknowledgeportal.worldbank.org/

CCKP, 2024b. World Bank, Climate Change Knowledge Portal (2024) [WWW Document]. URL https://climateknowledgeportal.worldbank.org/

Chaya, V., Poortinga, A., Nimol, K., Sokleap, S., Sophorn, M., Chhin, P., McMahon, A., Nicolau, A.P., Tenneson, K., Saah, D., 2024. Is Cambodia the World's Largest Cashew Producer? 1–13.

Chen, S., Olofsson, P., Saphangthong, T., Woodcock, C.E., 2023. Monitoring shifting cultivation in Laos with Landsat time series. Remote Sens. Environ. 288, 113507. https://doi.org/10.1016/j.rse.2023.113507

Chomchalow, N., 1993. Agricultural development in Thailand, in: Systems Approaches for Agricultural Development. Springer Netherlands, Dordrecht, pp. 427–443. https://doi.org/10.1007/978-94-011-2842-1_26

Cohen, W.B., Yang, Z., Healey, S.P., Kennedy, R.E., Gorelick, N., 2018. A LandTrendr multispectral ensemble for forest disturbance detection. Remote Sens. Environ. 205, 131–140. https://doi.org/10.1016/j.rse.2017.11.015

Cramb, R., 2020. White Gold: The Commercialisation of Rice Farming in the Lower Mekong Basin. Springer Nature Singapore, Singapore. https://doi.org/10.1007/978-981-15-0998-8

CRCP:Cambodia, 2021. Climate Risk Country Profile: Cambodia (2021): The World Bank Group and the Asian Development Bank.

CRCP:Lao-PDR, 2021. Climate Risk Country Profile: Lao PDR (2021): The World Bank Group and the Asian Development Bank.

CRCP:Thailand, 2021. Climate Risk Country Profile: Thailand (2021): The World Bank Group and the Asian Development Bank.

CRCP:Vietnam, 2021. Climate Risk Country Profile: Vietnam (2021): The World Bank Group and the Asian

Development Bank.

Eckstein, D., Kunzel, V., Laura, S., 2021. GLOBAL CLIMATE RISK INDEX 2021. Ger. e.V. https://doi.org/https://www.germanwatch.org/en/cri

EM-DAT, 2024. EM-DAT:The International Disaster Database. Centre for Research on the Epidemiology of Disasters (CRED) [WWW Document]. URL https://doc.emdat.be/

Factsanddetails, n.d. Facts and Details [WWW Document]. URL https://factsanddetails.com/

FAO-GIEWS, 2024. FAO GIEWS Vegetation Indicators NDVI Anomaly Earth Observation [WWW Document]. URL https://www.fao.org/giews/earthobservation/

FAO, 2024. Scaling up Climate Ambition on Land Use and Agriculture through Nationally Determined Contributions and National Adaptation Plans (SCALA) [WWW Document]. URL https://www.fao.org/in-action/scala/countries/thailand

FAO, 2018. Thailand - Country fact sheet on food and agriculture policy trends.

FAOSTAT, 2024a. FAO Statistics: Crops and Livestock Products [WWW Document]. URL https://www.fao.org/faostat/en

FAOSTAT, 2024b. FAO Statistics: Land, Inputs, and Sustainibility. Land, Land Cver, and Land Use [WWW Document]. URL https://www.fao.org/faostat/en/#data/RL

Fitzpatrick, J., 2019. Feed the Future Cambodia Harvest II Consultant Report: Situational Analysis of Cambodian Cashew Sector." Prepared by iDE for Abt Associates, Rockville, Maryland, December 30, 2019.

Hengl, T., 2018. Soil texture classes (USDA system) for 6 soil depths (0, 10, 30, 60, 100 and 200 cm) at 250 m (Version v02). Zenodo. https://doi.org/10.5281/zenodo.1475451

ITA, 2024. The International Trade Administration. (2024, January 8). Thailand - Country Commercial Guide. [WWW Document].

Katzfey, J., McGregor, J., Suppiah, R., 2014. High-resolution climate projections for Vietnam: Technical Report. CSIRO, Australia.

Kogan, F., Salazar, L., Roytman, L., 2012. Forecasting crop production using satellite-based vegetation health indices in Kansas, USA. Int. J. Remote Sens. 33, 2798–2814. https://doi.org/10.1080/01431161.2011.621464

Kogan, F.N., 1997. Global Drought Watch from Space. Bull. Am. Meteorol. Soc. 78, 621–636. https://doi.org/10.1175/1520-0477(1997)078<0621:GDWFS>2.0.CO;2

Lacombe, G., Hoanh, C.T., Smakhtin, V., 2012. Multi-year variability or unidirectional trends? Mapping long-term precipitation and temperature changes in continental Southeast Asia using PRECIS regional climate model. Clim. Change 113, 285–299. https://doi.org/10.1007/s10584-011-0359-3

Laostourism, 2024. laostourism [WWW Document]. URL https://www.laostourism.org/laos-geography/

Li, P., Feng, Z., Jiang, L., Liao, C., Zhang, J., 2014. A Review of Swidden Agriculture in Southeast Asia. Remote Sens. 6, 1654–1683. https://doi.org/10.3390/rs6021654

Liu, L., Zhang, X., Zhao, T., 2023. GLC_FCS30D: the first global 30-m land-cover dynamic monitoring product with fine classification system from 1985 to 2022 [Data set]. Zenodo. [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8239305

Luu, T.-T.-H., Le, T.-L., Huynh, N., Quintela-Alonso, P., 2021. Dragon fruit: A review of health benefits and nutrients and its sustainable development under climate changes in Vietnam. Czech J. Food Sci. 39, 71–94. https://doi.org/10.17221/139/2020-CJFS

Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P., Leyu, C.H., Lwin, T., Maitrepierre, L., Ouprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I., Yee, D., 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. Int. J. Climatol. 21, 269–284. https://doi.org/10.1002/joc.610

MONRE, 2016. Climate change and sea level rise scenarios for Vietnam. Vietnam Ministry of Natural Resources and Environment (MONRE).

Monteleone, B., Bonaccorso, B., Martina, M., 2020. A joint probabilistic index for objective drought identification: the case study of Haiti. Nat. Hazards Earth Syst. Sci. 20, 471–487. https://doi.org/10.5194/nhess-20-471-2020

NationsEncyclopedia, 2024. Nations Encyclopedia [WWW Document]. URL https://www.nationsencyclopedia.com/economies/Asia-and-the-Pacific/Laos-AGRICULTURE.html

Ngoc, V.B., 2020. Agricultural Development in Thailand: Experience and Implications for Vietnam. VNU J. Sci. Econ. Bus. 36. https://doi.org/10.25073/2588-1108/vnueab.4324

Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.-M., Tucker, C.J., Stenseth, N.C., 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends Ecol. Evol. 20, 503–10. https://doi.org/10.1016/j.tree.2005.05.011

Rueangrit, P., Jatuporn, C., Suvanvihok, V., Wanaset, A., 2020. Forecasting Production and Export of Thailand’s Durian Fruit: An Empirical Study using the Box–Jenkins Approach. Humanit. Soc. Sci. Lett. 8, 430–437. https://doi.org/10.18488/journal.73.2020.84.430.437

Saengsawang, S., Pankhao, P., Kaprom, C., Sriwongsitanon, N., 2017. Projections of future rainfall for the upper Ping River Basin using regression-based downscaling. Adv. Clim. Chang. Res. 8, 256–267. https://doi.org/10.1016/j.accre.2017.11.001

Sishodia, R.P., Ray, R.L., Singh, S.K., 2020. Applications of Remote Sensing in Precision Agriculture: A Review. Remote Sens. 12, 3136. https://doi.org/10.3390/rs12193136

Teck, V., Poortinga, A., Riano, C., Dahal, K., Legaspi, R.M.B., Ann, V., Chea, R., 2023. Land use and land cover change implications on agriculture and natural resource management of Koah Nheaek, Mondulkiri province, Cambodia. Remote Sens. Appl. Soc. Environ. 29, 100895. https://doi.org/10.1016/j.rsase.2022.100895

Tucker, C., Vanpraet, C., Boerwinkle, E., Gaston, A., 1983. Satellite remote sensing of total dry matter production in the Senegalese Sahel. Remote Sens. Environ. 13, 461–474. https://doi.org/10.1016/0034-4257(83)90053-6

Tucker, C.J., Sellers, P.J., 1986. Satellite remote sensing of primary production. Int. J. Remote Sens. 7, 1395–1416. https://doi.org/10.1080/01431168608948944

TWBG, 2023. CAMBODIA: Country Climate and Development Report. World Bank Group 189a – 190. https://doi.org/10.1596/978-1-4648-0484-7_world_bank_group

Weng, L., Dou, W., Chen, Y., 2023. Study on the Coupling Effect of Agricultural Production, Road Construction, and Ecology: The Case for Cambodia. Agriculture 13, 780. https://doi.org/10.3390/agriculture13040780

Westra, S., Fowler, H.J., Evans, J.P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E.J., Lenderink, G., Roberts, N.M., 2014. Future changes to the intensity and frequency of short-duration extreme rainfall. Rev. Geophys. 52, 522–555. https://doi.org/10.1002/2014RG000464

World Bank, 2021. Development of the Agribusiness Potential in the Laos-China Railway Corridor (English). Washington, D.C. : World Bank Group.

WorldBank, 2024a. Climate Knowledge Portal - World Bank [WWW Document]. URL https://climateknowledgeportal.worldbank.org/

WorldBank, 2024b. Data - The Wrold Bank [WWW Document]. URL https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=TH

Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W. Brockmann, C., Kirches, G., Wevers, J., Cartus, O., Santoro, M., Fritz, S., Lesiv, M., Herold, M., Tsendbazar, N.E., Xu, P., Ramoino, F., Arino, O., 2022. ESA WorldCover 10 m 2021 v200. https://doi.org/10.5281/zenodo.5571936

Zeng, J., Zhou, T., Qu, Y., Bento, V.A., Qi, J., Xu, Y., Li, Y., Wang, Q., 2023. An improved global vegetation health index dataset in detecting vegetation drought. Sci. Data 10, 1–12. https://doi.org/10.1038/s41597-023-02255-3

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