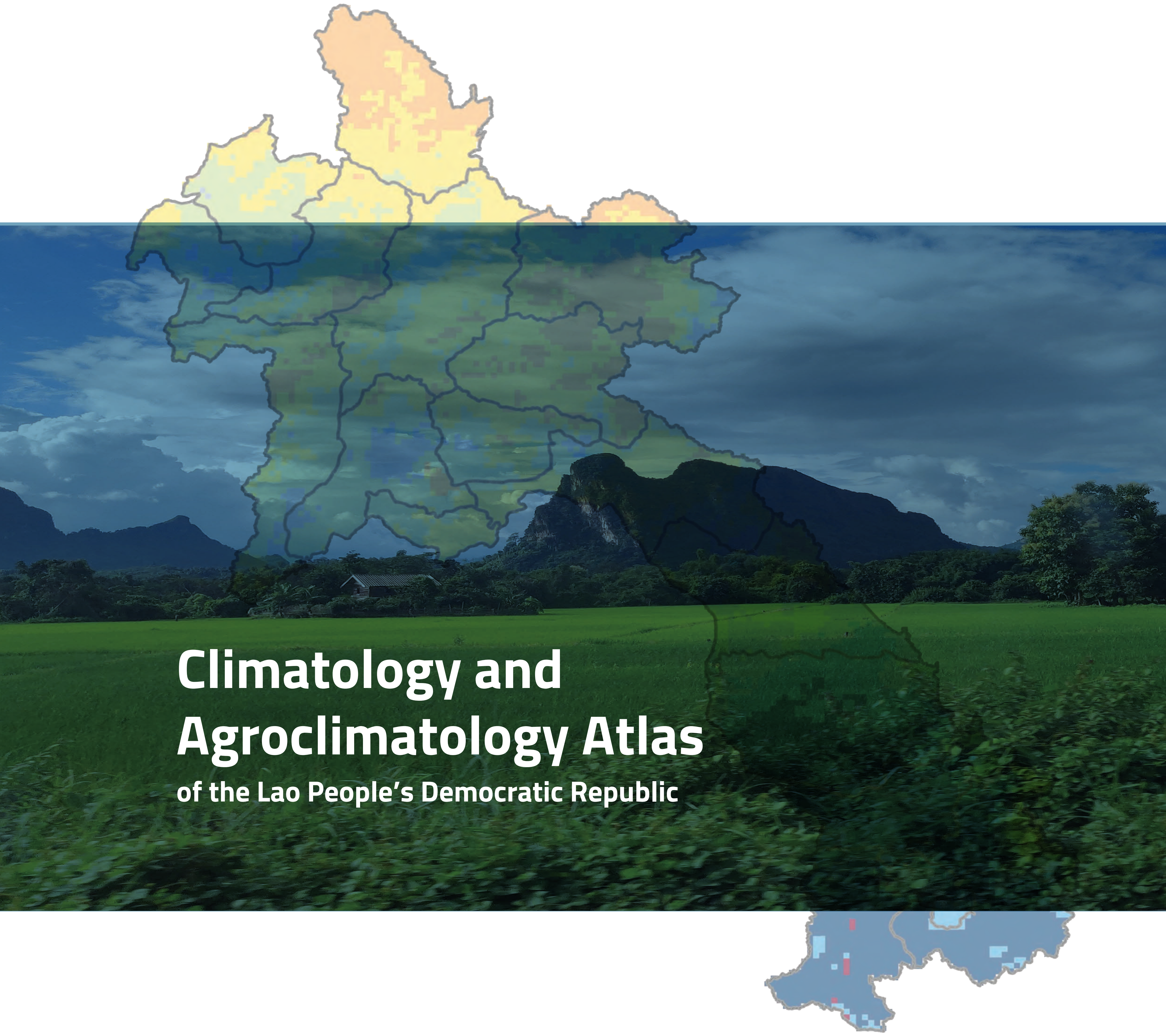
Food and Agriculture Organization of the United Nations



Climatology and Agroclimatology Atlas

of the Lao People's Democratic Republic

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Map on the cover: climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

Cover photograph: : ©FAO/Monica Petri.

Source of the map: all maps are produced by the Department of Meteorology and Hydrology, by the Department of Agricultural Land Management, and the SAMIS project. The maps contain climatological data produced by the same entities. The province boundaries were produced by the National Geographic Department in 2013.

Abstract

This atlas is a study of climate and agroclimate in the Lao People's Democratic Republic for the period 1990-2019 based on the downscaling of long-term observation data. It has been produced as part of the "Strengthening Agro-Climatic Monitoring and Information Systems (SAMIS) to improve adaptation to climate change and food security in Lao People's Democratic Republic" project. It aims to support the achievement of the Lao government's priority targets, as set out in the country's Ninth National Socio-Economic Development Plan (2021-2025).

The Department of Meteorology and Hydrology is the main body responsible for the national climate database and producing climate statistics. The Department of Agricultural Land Management (DALAM), part of the Ministry of Agriculture and Forestry (MAF), also provided their expertise in the use of advanced downscaling technologies. This atlas presents the results of the work carried out by these bodies. The information describes in detail the country's climate and how it has changed over the last 30 years.

Producing the dataset involved advanced scientific and geospatial technology which combined cloud-computing processing and dynamical downscaling. All this technology was implemented in the country by national experts through a continuous capacity building process that included topics relating to geospatial science and computer technology, data management, and statistical analysis.

Foreword Department of Meteorology and Hydrology

As global interest in climate change in South East Asia is growing, several international entities and donors have been supporting the Government of Lao People's Democratic Republic over the last few years to intervene in disaster risk reduction and vulnerability of the affected rural population.

Lao population is aware of the climate vagaries and perceive the emergency and risk for their future. However, so far, detailed information about the climate status and change was lacking.

Analysing climate and climate change using local observation improves data quality in mountainous countries at the forefront of climate due to their exposure and vulnerability to hazards. At the same, climate studies provide decision-makers with a solid evidence base and are essential for navigating the complexities of the present global climate crisis. In fact, solutions to climate change are grounded on social, economic and political decision making. In the Lao People's Democratic Republic, national policy regulates ground observation management and limits its use.

For this, the Department of Meteorology and Hydrology has worked to improve data sharing as much as possible while conforming to the present regulation. In this framework, this atlas constitutes a one-stop platform for visualizing existing climate status and climate change information in a relatively easy to use manner.

During the last few years, with the support of FAO and of the project Strengthening Agro-climatic Monitoring and Information Systems (SAMIS) to improve adaptation to climate change and food security in Lao People's Democratic Republic, the Lao capacities on observation and interpretation of climatological datasets has been upgraded. The present atlas is will reinforce the application of 9th National Socioeconomic Development Plan (NSEDP) and support the achievement the United Nations' (UN's) Sustainable Development Goals (SDGs) by taking urgent action to combat climate change and its impacts.

Users should also consider that this Climate and Agro-meteorology Atlas represent a first edition, for this some part might be incomplete and will be updated in a future edition.

Mrs Outhone PHETLUANGSY
Director General, Department of Meteorology and Hydrology

Foreword Asian Institute of Technology

During the last few years, the Government of Lao People's Democratic Republic has taken up the challenge to make climate data public and integrate it into general public use with the support of the project Strengthening Agro-climatic Monitoring and Information Systems (SAMIS) to improve adaptation to climate change and food security in Lao People's Democratic Republic.

In this context, a myriad of capacity development exercises have been conducted, and globally recognized scientists have contributed to the critical accomplishment of the government experts. Since the book Climate of Laos was published in the 1969 edition by the US Department of Air Force, there has not been a coherent study of the country's climate. The Asian Institute of Technology has taken up the challenge through different activities and has supported the downscaling of the national climatological observation data, with landmark methodologies resulting in important scientific publications.

In Lao People's Democratic Republic, sensors can now record and transmit weather observations continuously, automatically and in real-time. The internet allows anyone from anywhere to view the latest forecast through the Laos Climate Service for Agriculture (LaCSA). Looking at mobile apps and computer monitors has become something equivalent to looking out of your window - and seeing weather from anywhere in the world.

However, weather sensor technology and the weather forecast do not provide complete information on climate change, in order to raise the general public's awareness of weather and do not meet people's expectations on understanding the climate that is changing. In this framework, this atlas provides an image of climate evolution over the past 30 years simply and understandably for the use of the general and technical public. This atlas contains climate change visualized in simple maps or graphs. The blend of colour charts and text make it functional and easy to use. Additionally, the authors attempt to show how these data could apply to public agricultural interests.

The atlas is composed of a national climate change assessment first and a provincial analysis second. While it has been decided that future scenarios would not be listed in this atlas, they are available in the Land Resources Information Management System (LRIMS). In addition, all source maps available in this atlas are be available from the same source.

Almost every aspect of weather is in the news every day because it affects just about everyone in some way. Global economies depend on forecasts of crop yields, efficient transportation and how national resource use and material consumption affect global climate and ecology. In consequence, climate science has evolved into an interdisciplinary science that brings together all disciplines.

The atlas explains how climatology uses statistics to determine long-term weather trends, but also reveals that these projections can be erroneous or misleading without a homogeneous climate dataset. The dataset maintained by the Department of Meteorology and Hydrology is used here to its full potential and benefits of multiple intersectoral collaboration and capacity exchanges. The benefits that Lao People's Democratic Republic and its people will derive from the information contained in this book will prove that the time and budget invested in this product were worthwhile for the Lao's future.

MKHazarika

Dr. Manzul K. Hazarika
Director, Geoinformatics Center, AIT

Contents

Abbreviations and acronyms

DCA	Division of Climatology and Agrometerology
DMH	Department of Meteorology and Hydrology
DCC	Department of Climate Change
DALAM	Department of Agricultural Land Management
ETp	Evapotranspiration
GCM	Global Climate Model
GDD	Growing Degree Days
GEF	Global Environment Facility
GIS	Geographic information system
ICZ	Intertropical Convergence Zone
LRMIS	Land Resources Information Management System
MAF	Ministry of Agriculture and Forestry
MONRE	Ministry of Natural Resources and Environment
PDR	People's Democratic Republic
NSEDP	National Socioeconomic Development Plan
SAMIS	Strengthening Agro-climatic Monitoring and Information Systems to improve adaptation to climate and food security in Lao PDR
SPI	Standardized Precipitation Index
WRF	Weather Research and Forecasting

Acknowledgements

First of all, the authors would like to thank the scientific leader of this work and one of the authors of this atlas, Kwang-Hyung Kim. They also want to thank technical staff from the Department of Meteorology and Hydrology (DMH), including Sengkeo Keomanivong and Viengkham Sithivong, for contributing through their daily work, as well as Senduangdeuan Phouthanoxay, Head of Component 1 of the SAMIS project, coordinating these efforts.

The Climatology and Agroclimatology Atlas of the Lao People's Democratic Republic is, however, the result of the outstanding efforts of a number of different institutions and individuals working in close partnership. From the Department of Agricultural Land Management (DALAM), the authors wish to acknowledge the exceptional technical assistance of two GIS experts - Sorlaty Sengxeu and Larzoy Lattada who helped with the downscaling of the climate data. This last activity was scientifically guided by staff from the Asian Institute of Technology, including Rajitha Athukorala, Thaileng Thol and Panduka Neluwala.

FAO Project Coordinator Monica Petri oversaw the activities of all the teams involved and was supported in this work by Khambane Inthipunya, national meteorologist and GIS expert and Vandy Phothiyalay, who coordinated the four-year capacity development programme that provided training on Python, climate data downscaling and R.

The authors would also like to acknowledge the coordination and support provided by the heads of the organizations involved. Outhone Phetluangsy, Director General of the Ministry of Natural Resources and Environment's (MONRE's) Department of Meteorology and Hydrology, and Viengxay Manivong, SAMIS National Project Director and Deputy Director General both contributed significantly to this work. In addition to which, Saysongkham Sayavong, Head of the GIS unit at DALAM and Head of Component 2 of SAMIS kindly agreed to help with the data development.

At FAO level, this work would not have been possible without the dedication and support provided to SAMIS by the Regional Officer for Asia and the Pacific, and the authors would like to thank Beau Damen in particular. Furthermore, FAO has supported the visibility and publication of this atlas through the work of FAO Representative Nasar Hayat.

This work was carried out in close collaboration with MONRE's various decentralized offices, including its Provincial and District Offices, who were involved in the collection of more than 30 years of field observation data for the entire country, primarily using manual sensors. Without the work of these officials over time, this atlas would not exist, and the authors thus view it as the unboxing and disclosure of this precious information and the efforts of all these individuals.

» Introduction

Over the last four years, the Lao People's Democratic Republic has developed a series of information systems and tools focusing on adaptation to climate change. The availability of data in the country is being increased, and the capacity to manage this data is being developed. However, there is still work to be done in terms of both showcasing the data to users and allowing for the data to be regularly used for decision-making. The Lao government therefore asked the Food and Agriculture Organization of the United Nations (FAO) to produce an atlas which would serve as a decision-support tool, containing maps and graphs on climate and climate change based on national observation data and the most advanced climate science. The atlas provides a one-stop platform for visualizing existing climate data which can be used by multiple sectors, and is a climate service that brings complex climate data to users in an easy-to-grasp format. The added value of the atlas lies in the fact that it is demand-driven: it translates complex data into a format that corresponds to the needs of the decision makers.

In an attempt to plan for and tackle these changing conditions, the Lao government proposed that the Lao office of the Food and Agriculture Organization of the United Nations (FAO) support this work to improve the country's 1) data collection and development of an agroclimatic monitoring systems at both the provincial and national levels, in order to support all food security-related activities; and 2) data analysis, and development of a land resource information systems, in order to support land management and decision makers in the formulation of policy aimed at reducing climate change risks at the local level. In response to this proposal by the Lao government, FAO has developed the "Strengthening Agro-Climatic Monitoring and Information Systems to improve adaptation to climate change and food security in Lao People's Democratic Republic" project, otherwise known as the SAMIS project, which is financed by the Global Environment Facility (GEF), and implemented in conjunction with the Department of Meteorology and Hydrology (DMH), part of the Ministry of Natural Resources and Environment (MONRE), and the Department of Agricultural Land Management (DALAM), part of the Ministry of Agriculture and Forestry (MAF).

The text, graphs and maps in the atlas tell a compelling story: climate change is here, it's a serious challenge, and it is necessary to take anticipatory action. The information provides a storyline that engages and raises awareness among county agricultural officers, who then relay this information to farmers. The atlas is also an example of the renewed interest that the Lao government is placing, through the approval of the country's 9th National Socioeconomic Development Plan (NSEDP), on achieving the United Nations' (UN's) Sustainable Development Goals (SDGs). This atlas will allow the government to pursue cross-sector solutions, as today's complex challenges – from stemming the spread of disease to improving the management of land for development – cannot be tackled effectively in isolation. It should be seen as a tool that focuses on root causes and the connections between challenges in order to produce solutions that respond to people's daily realities.

On its own, the atlas does not provide an assessment of the impact of potential actions. These are interconnected challenges that cannot simply be studied on their own. It is for this reason that the SAMIS project is supporting the government of the Lao People's Democratic Republic to take a multi-scale and multi-actor approach to systemizing these data and using this and other information to develop the country's agricultural sector. The impact of climate change on the livelihoods of farmers in the Lao People's Democratic Republic has been studied as part of another atlas, and MAF has already started using these data in agroecological zoning modelling to produce present and future crop production scenarios for the purposes of both policy development and local level planning.

» The scope of this atlas |

The Climatology and Agro-Climatology Atlas is a tool intended to help the people of Laos, including researchers, businesses, and community and political leaders, to learn about climate and climate change.

The DMH has developed a climate atlas for the Lao People's Democratic Republic to study the country's climate over a specific timeframe and help better prepare for the extreme weather conditions of the future. The weather of the future will likely have a negative impact, posing a risk of flooding, torrential rainstorms and drought. Decision makers have hitherto relied on DMH who possess expertise and data. This atlas presents a cohesive image of the extreme weather of the future, offering the advantage to society of allowing the country to adapt to the consequences of climate change. All stakeholders will be able to use the common dataset to plan appropriate climate adaptation measures, without over- or under dimensioning their scope.

In particular, the Climatology and Agro-Climatology Atlas will help decision makers to consider how future climate change will affect their respective areas. It would be a poor investment, for instance, if a municipality were to construct infrastructure that does not take climate change into consideration, or build it in the wrong location. The best way to adapt to climate change is therefore to arrive at solutions based on climate data, combined with knowledge of current local conditions.

Observation data for the Lao People's Democratic Republic are available subject to the payment of a fee in accordance with Prime Ministerial Decree 03 of 26 December 2012. However, the use of climate data is essential to the country's current development needs. The DMH is committed to ensuring the availability and validity of data, providing an authoritative dataset that increases transparency by making data available, improves the quality of the information that is available, and increases the public's access to this information. As part of this commitment, a joint national database was established to support the planning of climate change adaptation measures, and provide reliable information on the extreme weather conditions of the future, current estimates of how the climate will change and access to consistent information across administrative boundaries. The DMH's commitment also includes informing the Lao people of the need to adapt to the climate in their own immediate environment.

The Climatology and Agro-Climatology Atlas will is available as an online tool within the Land Resources Information Management System (LRMIS), a platform jointly developed by MONRE and MAF that is available at: https://lrims-dalam.net.

» NATIONAL CLIMATE MAPS | 1

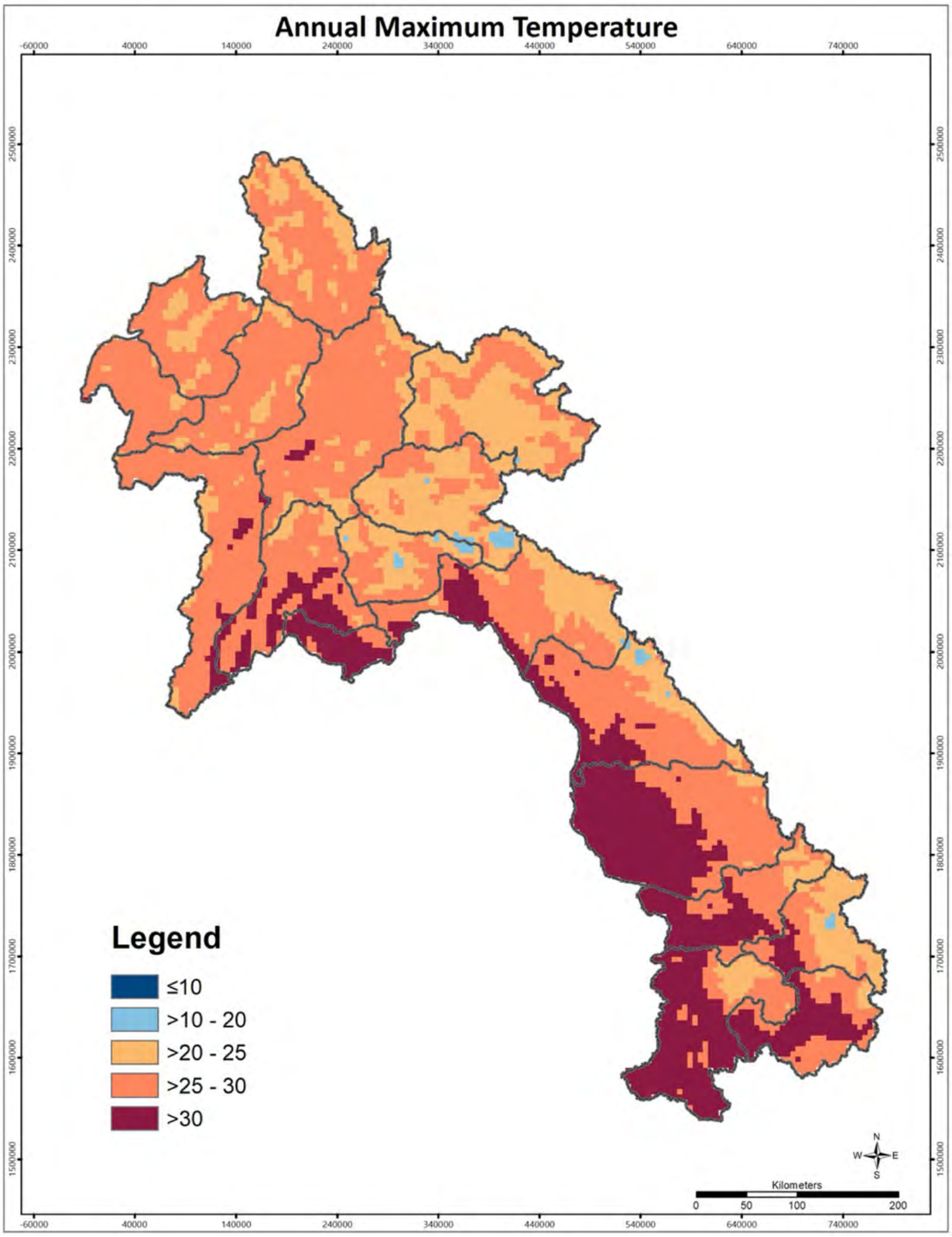
Introduction

The main goal of this chapter is to construct a list of gridded climatological maps for the Lao People's Democratic Republic for the period 1990-2019 using a 5 km spatial resolution obtained by downscaling using the WRF model. All the gridded data and maps generated are accompanied by their metadata.

This section is divided into three parts. In the first part, various indicators related to temperature are studied, leading to the expected conclusion that there is a consistent trend of temperature increases throughout the country.

The second part presents a rainfall analysis describing expected changes in climate, and showing that rainfall is much more variable across the seasons than has been presented in previous studies or research on nearby countries. The final part consists of an analysis of agro-climatological factors, revealing clear patterns of improved growing degree days (GDD) in certain areas of the country, while others seem to be more exposed to drought.

Minimum and maximum temperatures, 1990–2019



Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What do these maps show?

These temperature maps show minimum and maximum temperatures across the Lao People's Democratic Republic. Blue areas on the map had an annual average temperature cooler than 20 °C; the darker the blue, the cooler the average temperature. Orange to red areas had an average temperature above 20 °C; the darker the shade, the warmer the annual average temperature.

What do the maps tell us?

As might be expected, maximum and minimum temperatures were higher at lower altitudes. Valley areas, even those in the country's northernmost provinces, were found to have higher maximum temperatures. Valley bottoms and plains in the south of the country had the highest temperatures. The lowest maximum temperatures were found at elevations along the border with Vietnam and in the highland areas of Louangphabang, Vientiane Province, Xiangkhoang, and parts of Bolikhamxai and the Bulaven Plateau.

Average minimum temperatures follow a similar pattern. Extensive areas of Louangphabang, Vientiane Province, Xiangkhoang, and parts of the Bulaven Plateau experience relatively low temperatures during the cool season. In the far north, Phongsali, the highland areas of Louangnamtha, and northern regions of Louangphabang and Oudomxay were also found to have lower minimum temperatures. Similarly, low minimum temperatures were found on the Bulaven Plateau and near the border with Vietnam in the provinces of Xekong and Attapu.

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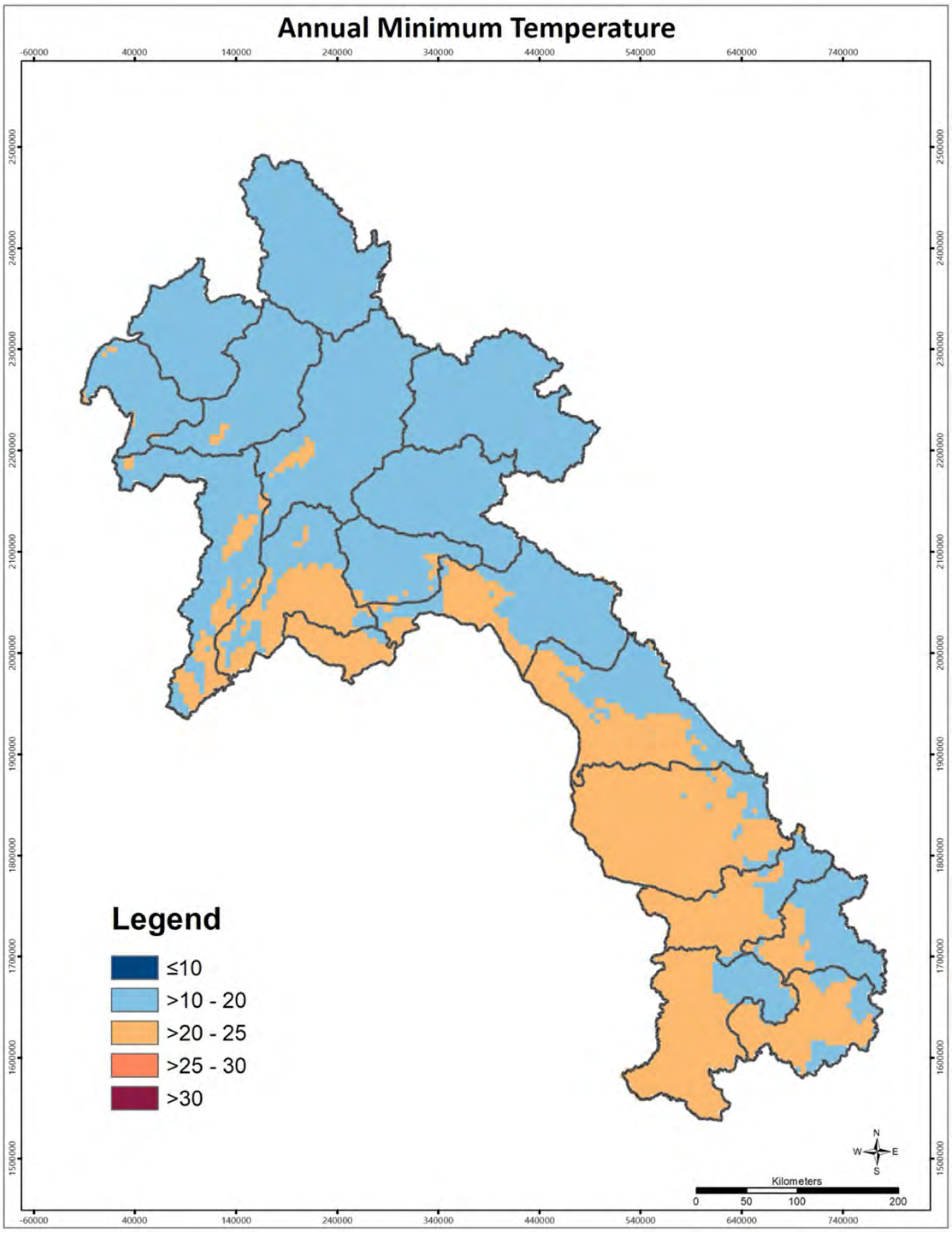


Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

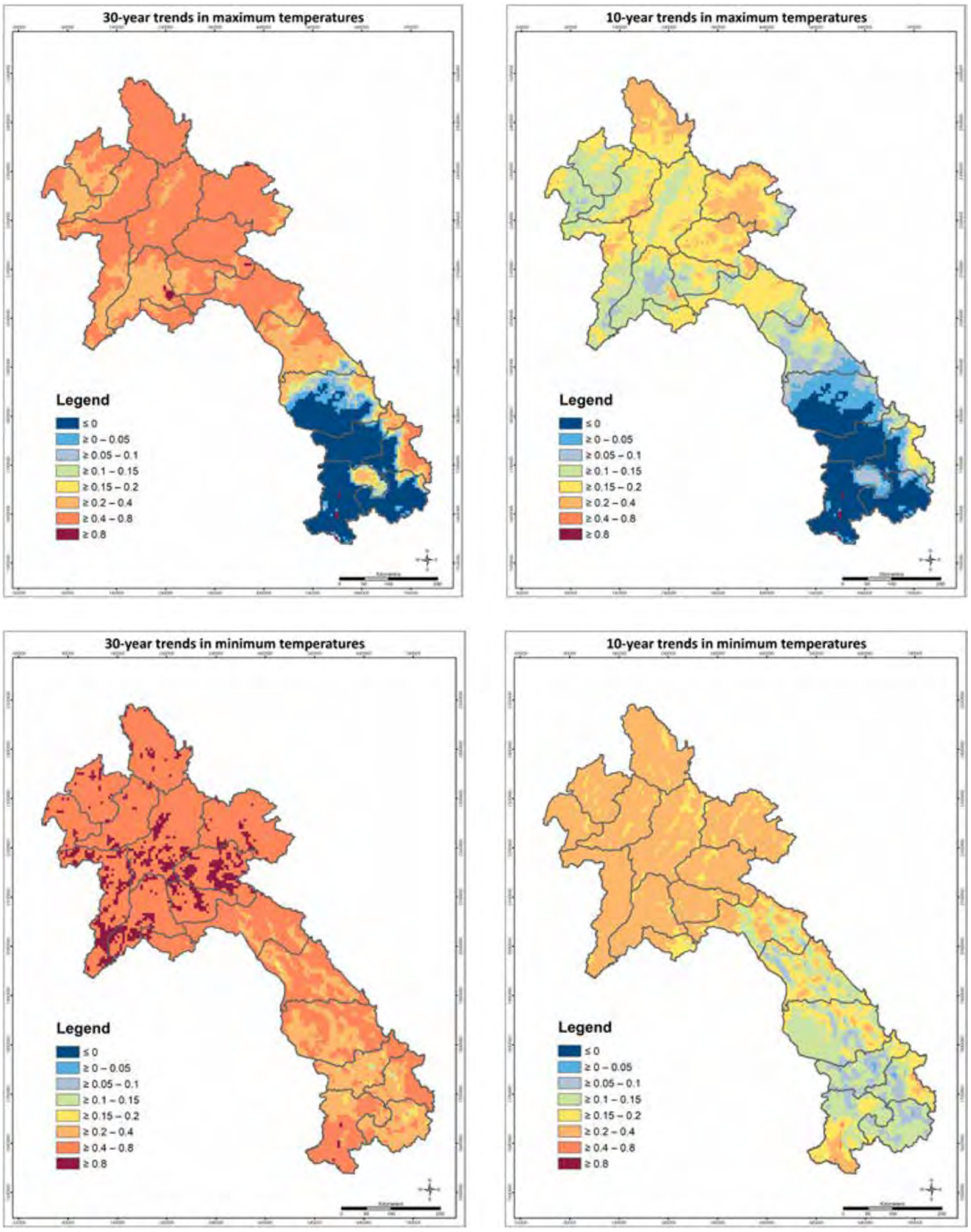
Why do these data matter?

The temperature range we can expect within a year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. The annual maximum and minimum temperature refer to the average of the maximum and minimum temperatures over the course of a year, respectively

Temperature trends for the past 10 and 30 years



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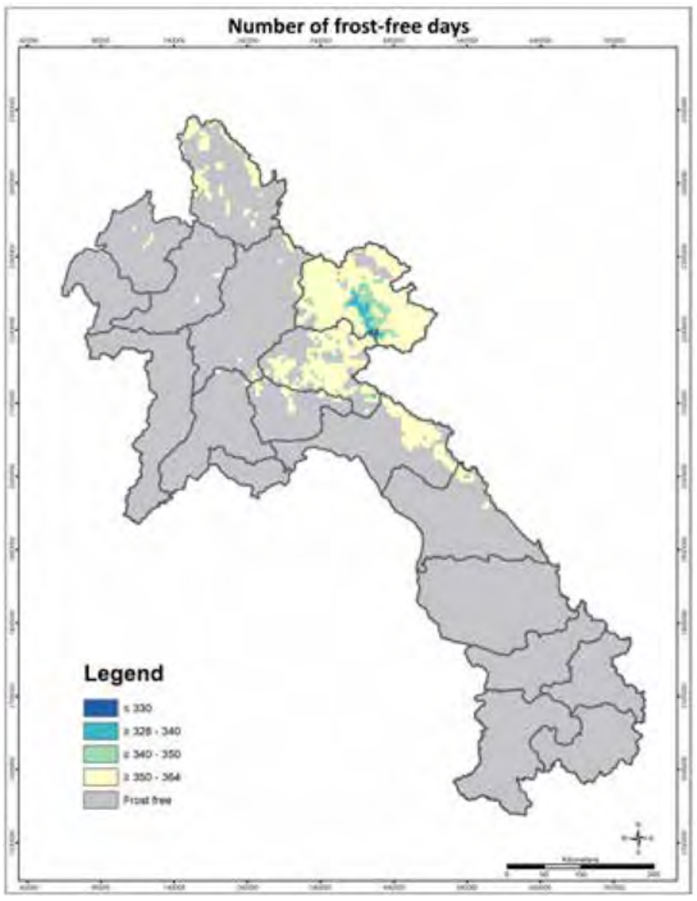
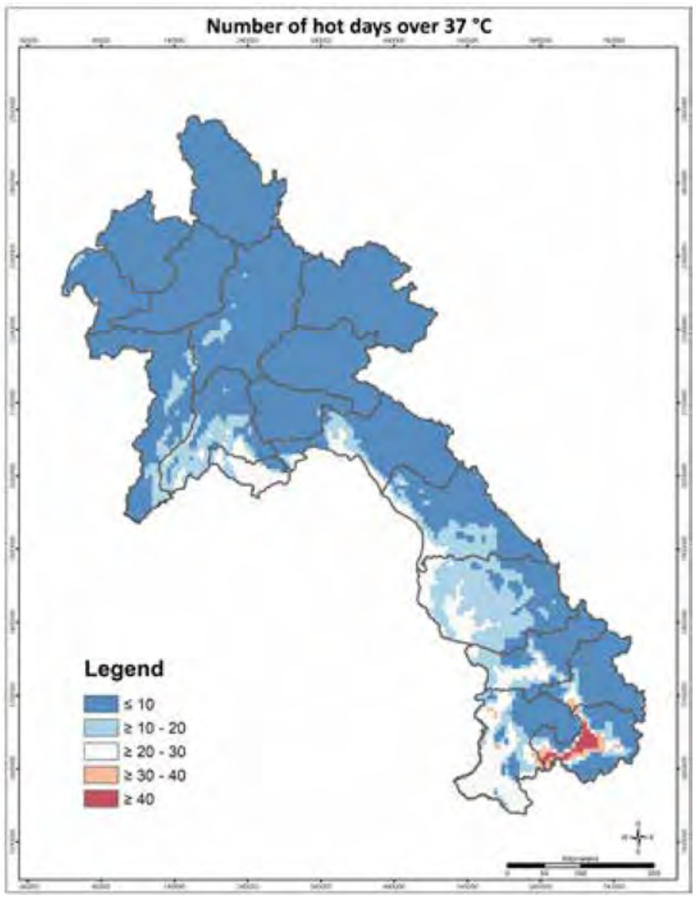
Number of days with extreme temperature events





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What does this map show?

This map shows how many days Laos were free from frost: the darker the shade of blue, the lower the number of days without frost.

What does the map tell us?

A number of areas in Xiangkhoang, Xaisomboun and east-ern parts of Bolikhamxai have up to 25 frost days per year.

Why do these data matter?

Changes in the length of frost-free periods and when they occur have an impact on plants and animals used in agriculture. The average length of the growing season (and its year-to-year variability) is an important consideration when selecting or predicting what plants might grow well in a region. Longer periods without frost mean plants and crops have a longer window in which to grow and mature. If projections show an increase in the number of frost-free days, then the annual growing season will be longer, and the period of cold weather correspondingly shorter.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. The number of frost-free days represents the number of consecutive days including the 'summer' in the middle, without any daily minimum temperatures equal to or below 0 °C.

What does this map show?

This map shows the number of days above 37 °C. The blue areas represent the areas that have a lower number of days above 37 °C; the darker the blue, the lower the number of days. Orange to red areas show the areas with high number of days above 37 °C; the darker the red, the higher the number of days.

What do the maps tell us?

As might have been expected, the number of days above 37 °C was generally higher in valley bottoms. Most of the country's highlands experienced less than 10 days on which the temperature exceeded 37 °C. According to the map, an area encompassing Attapu, Champasak and Xekong experienced high temperatures over a relatively higher number of days.

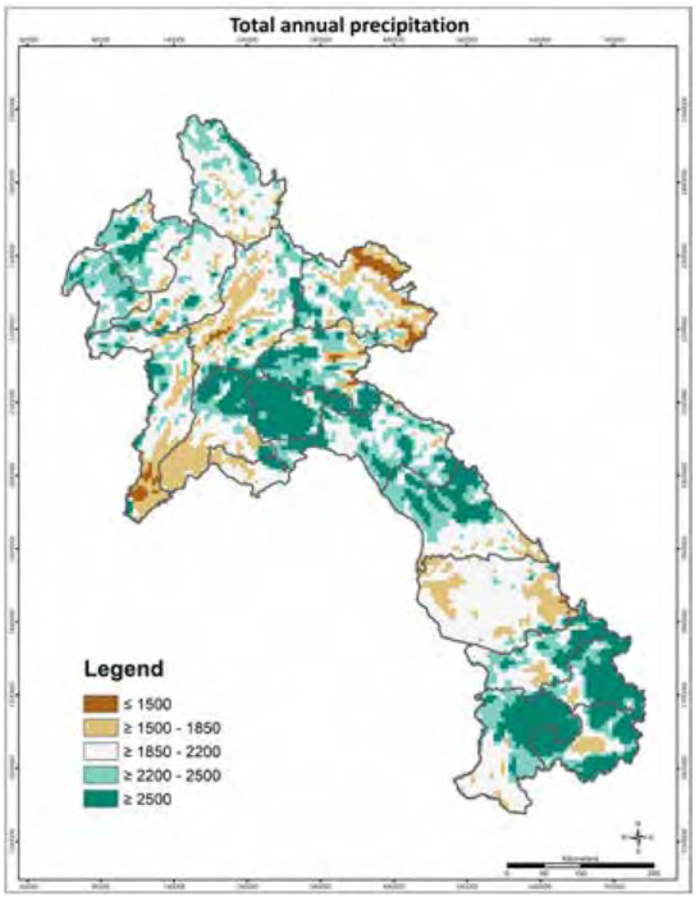
Why do these data matter?

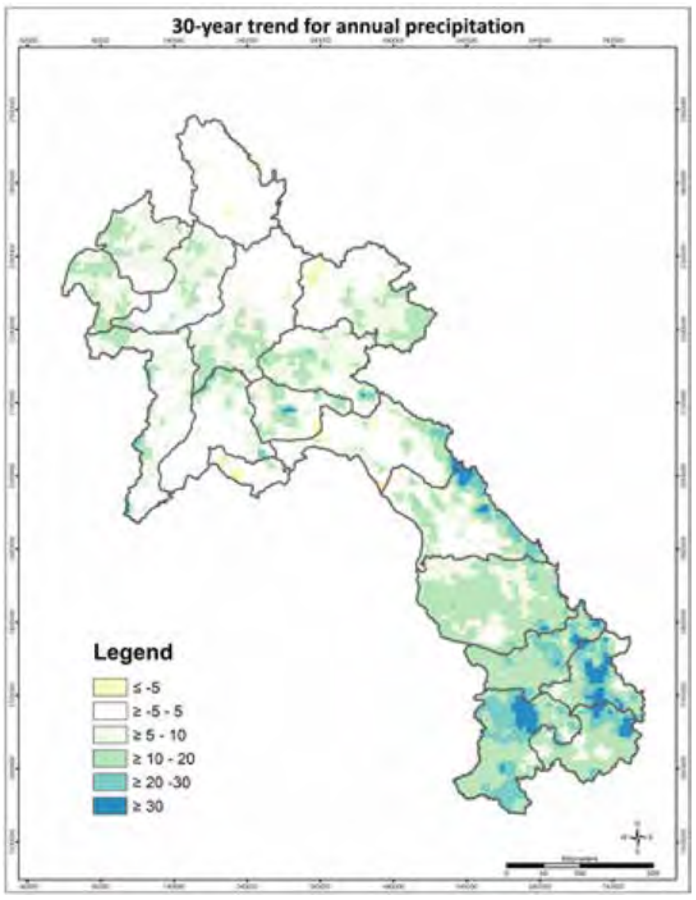
High temperatures are important: they determine whether plants and animals will thrive, and they may restrict or permit agricultural work taking place outdoors. It is useful to know how high summer temperatures are likely to become in the future, as when temperatures are very hot, not only do crops suffer from heat stress, sometimes resulting in crop loss, but also people - especially the elderly - are much more likely to suffer from heat exhaustion and heatstroke. Many outdoor activities become dangerous or impossible in very high temperatures. Persistent high temperatures increase the risk of drought, which can severely impact food production and increases the risk of wildfires. Although Laotians are used to extremely hot summers, further warming will nonetheless result in unfamiliar risks, as well as a very different experience of the summer season.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. The number of days over 37 °C is defined as the number of days on which the maximum temperature was

Annual precipitation, 1990–2019





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What does this map show?

This map shows the total amount of annual precipitations. The darker the green colour on the map, the higher annual precipitation levels. The driest areas in the country are in Xaignabouri, Vientiane Province, and Huaphanh.

What does the map tell us?

As might have been expected, more rainfall occurred at higher altitudes and rainfall pattern are influenced by altitude. In particular, higher amounts of precipitation were recorded in Xekong, Attapu, Champsak, and to a lesser extent, along the border with Vietnam in Salavan. Also, high elevation areas of Xaisomboun, Vientiane province and Xiangkhoang present higher rainfall. Other areas with high rainfall were found in Khammouan and Bolikhamxai.

Why do these data matter?

Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short and long-term risk of drought. Although it varies depending on the region, climate change may change precipitation totals over the years. Analysing this precipitation map helps us to understand the current level of annual precipitation at the site of interest over the course of 30 years.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. To calculate the 30-year average for annual precipitation, daily precipitation for each year were summated to obtain 30 total annual precipitation amounts.

What does this map show?

The precipitation trend maps show increases or decreases in annual precipitation across the Lao People's Democratic Republic. Areas shown in white experienced a minor change in annual precipitation of close to 0 (between 5 and -5 mm). The blue areas on the map became wetter, experiencing increased rainfall over the 30 years; the darker the blue, the greater the increase in precipitation. A significant part of the country has experienced more than 5 mm precipitation increase annually, with some areas experiencing up to 30 mm precipitation increase. Yellow areas became drier over the same period.

What does the map tell us?

Trends in annual precipitation appear to be different between the south and the north of the country. Annual precipitation over the last 30 years have remained stable or increased only slightly in the north, while the increasing rates of annual precipitation are relatively higher in the south of the country.

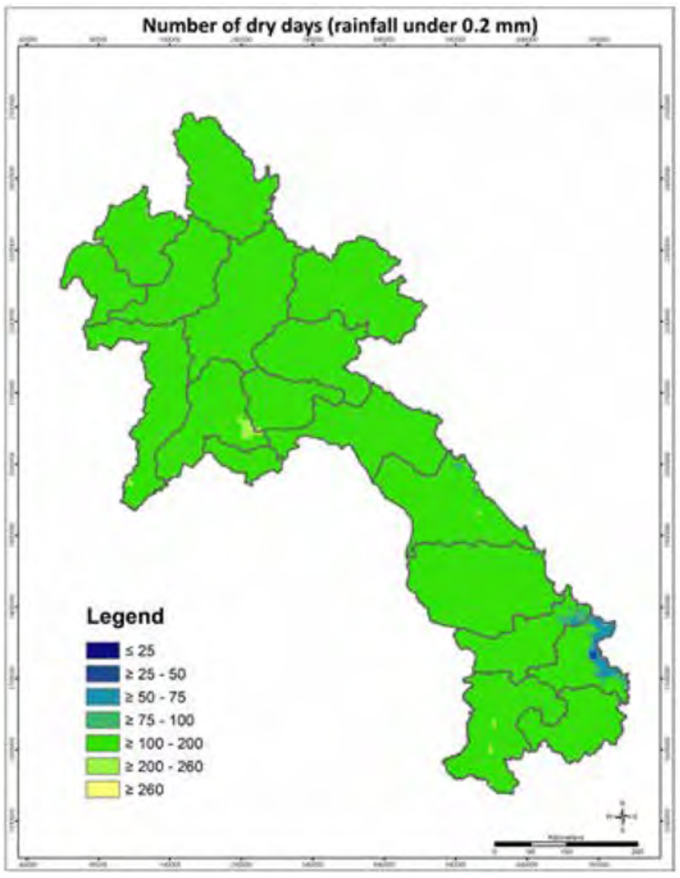
Why do these data matter?

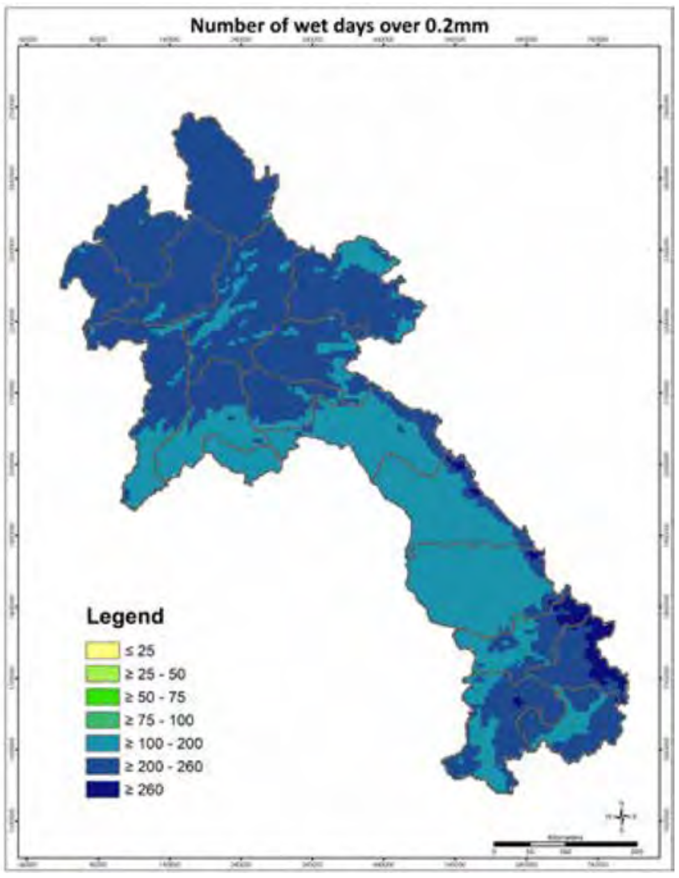
Precipitation is critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short and long-term risk of drought. Although it varies depending on the region, climate change may affect precipitation trends over the years. Analysing this precipitation trend map helps us to understand precipitation changes at the site of interest over the course of 30 years.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. To calculate the 30-year trend for annual precipitation, daily precipitation levels were collated to obtain total annual precipitation amount for each year, and a statistical trend analysis was carried out to identify any significant trends in the total annual precipitation amounts over the 30 years.

Number of days with extreme precipitation-related events





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What does this map show?

This map shows the number of dry days; the darker the shade of blue, the lower the number of dry days without precipitation less than 0.2 mm.

What does the map tell us?

The map shows that the majority of the country sits in the 100-200 dry days range over the year. Only small patches of the countries present a different distribution.

Why do these data matter?

Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought. For the dry days map, locations that experience precipitation frequently have a low number of dry days, whereas locations that experience precipitation infrequently have a high number of dry days.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. For the dry days map, a threshold value of 0.2 mm was chosen as representing a dry day in the Climate Atlas; a dry day is thus a day with less than 0.2 mm of precipitation.

What does this map show?

This map shows the number of wet days; the darker the shade of blue, the higher the number of days with precipitation over 0.2 mm.

What does the map tell us?

There was rainfall on more than 200 days across the entire northern part of the country, especially highland areas, as well as in the south (Xekong, Attapu, Salavan and Champasak). In contrast, in all the areas located on a plain, from Xaignabouli and Vientiane down to the south in the parts of Salavan and Champasak that lie next to the Mekong River, the number of rainy days was much lower and included between 100 and 200.

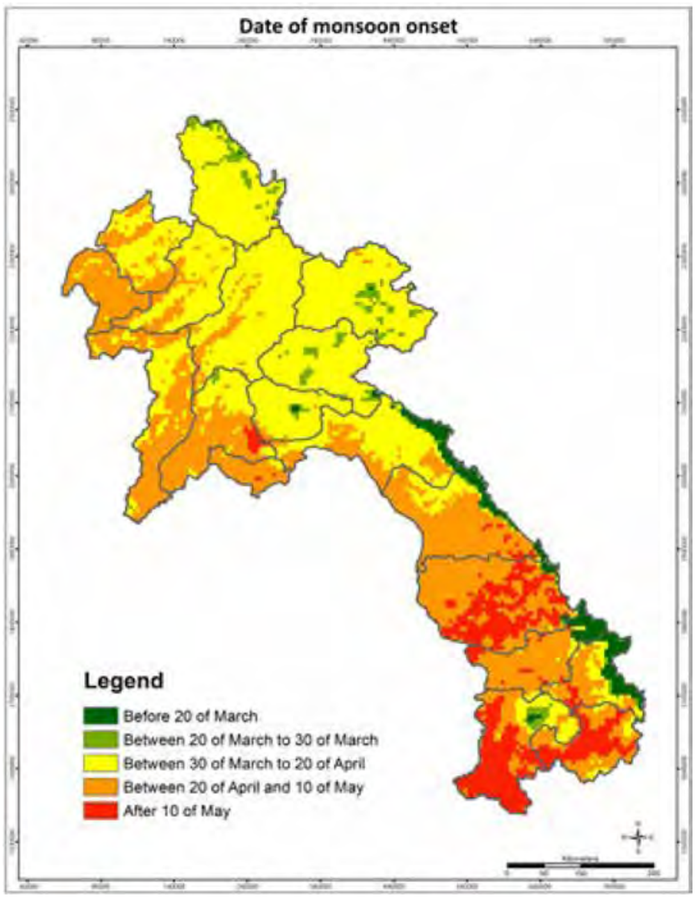
Why do these data matter?

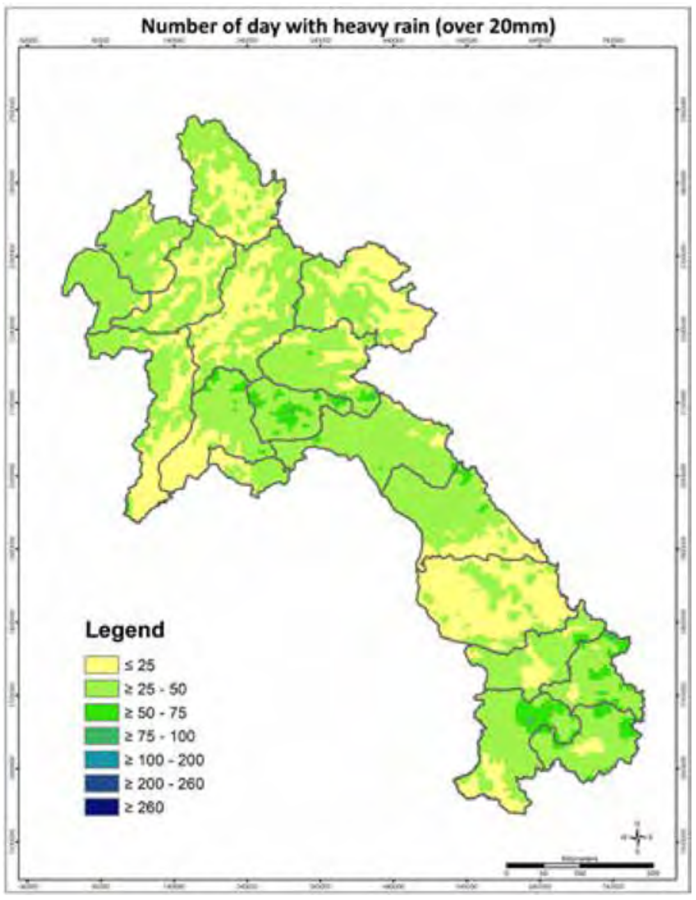
Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought. For the wet days map, locations that experience precipitation frequently have a high number of wet days, whereas locations that experience precipitation infrequently have a low number of wet days.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. For the wet days map, a threshold value of 0.2 mm was chosen as representing a dry day in the Climate Atlas;

Number of days with extreme precipitation-related events





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What does this map show?

This map shows the timing of the arrival of the monsoon: the greener the area, the earlier the rains start, and the darker the shade of red, the later in the year the monsoon arrives.

What does the map tell us?

According to the map, areas along the border with Vietnam do not appear to have a climate that equates to normal monsoon behaviour; more studies on this may therefore be needed. The monsoon arrives earlier in the provinces of Xaisomboun, Xiangkhoang, Houaphan and Phongsali; again, more studies are required. In the rest of the country, the monsoon starts on average around 20 April or later. In some areas in the south located on plains and influenced by lower pressure coming from Vietnam, the monsoon appears to arrive later, around 10 May.

Why do these data matter?

In a monsoon-affected region, monsoon rainfall is critical for the spring and summer planting of crops, which depend on enough soil moisture to germinate, encourage rooting, and/or ensure vigorous vegetative growth during initial cropping stage. Sometimes, a delay in the onset of the monsoon will cause delays in the planting of rice and other crops. This tends to shorten the cropping period and increases the risk of pests, often leading to yield loss.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software and 30 years of observation data for each site of interest. The date of the onset of the monsoon refers to the first of one or two consecutive wet days on which there was at least 20 mm of rainfall, provided that this was not followed by a seven-day dry spell (less than 5 mm of rainfall) in the 20 days following the onset.

What does this map show?

This map shows the number of days on which there was heavy rainfall; the darker the shade of green and blue, the higher the number of days with heavy rainfall.

What does the map tell us?

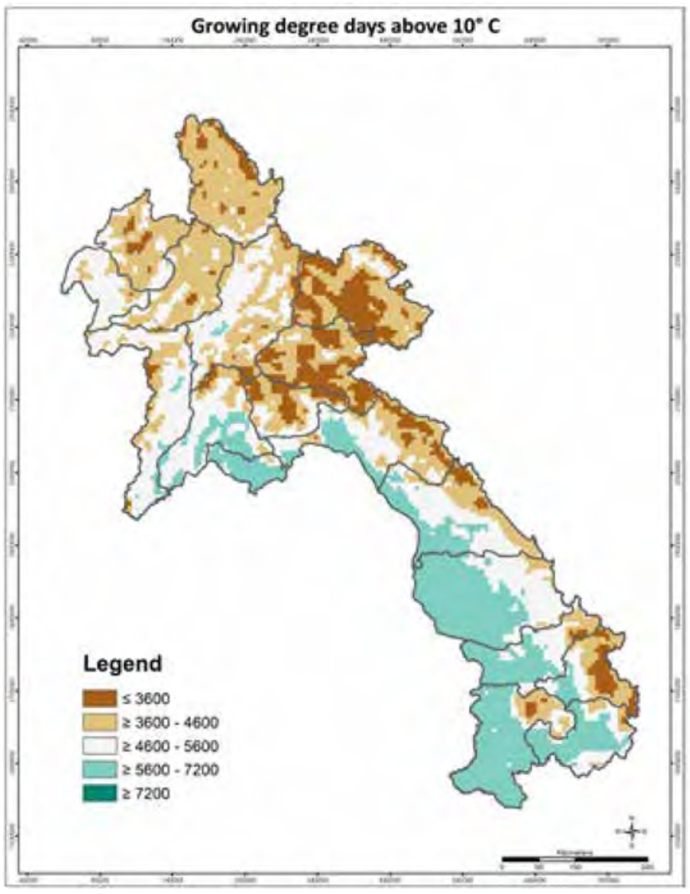
More than 50 days of intense rainfall are located in patches of mountain areas in the north of the country such as Xaisomboun, Xieng Khuan, Vientiane Province. In the south, a similarly high number of days with intense rainfall are located in the highlands of Xekong, Attapu, Champasak and small parts of Salavan. More generally, all highland areas have at least 25 days of intense rainfall per year, while valleys and plain areas have less than 25 days of intense rainfall.

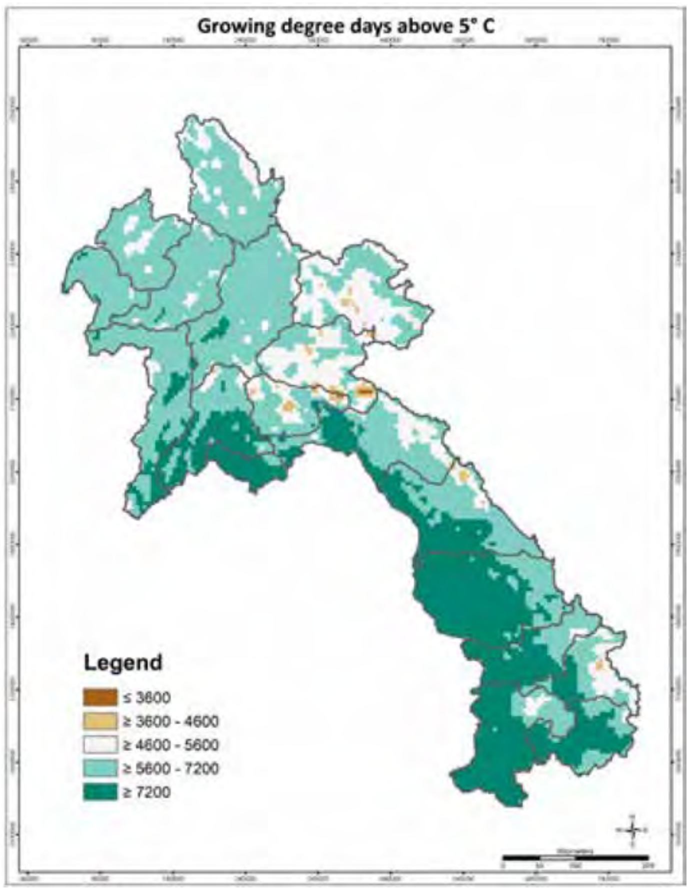
Why do these data matter?

Heavy rainfall events can create a number of challenges. In cities and towns, heavy rainfall can overwhelm storm drains and **cause** flash flooding. They can also cause problems in rural areas by drowning crops, eroding topsoil and damaging roads. In particular, heavy rainfall directly following a long dry spell increases the risk of soil erosion and encourages sudden growths in the populations of insect pests, such as armyworm.

How was this information produced?

GCM data were dynainically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. A day with heavy rain was defined as a day on which there was at least 20 mm of rainfall.





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What does this map show?

The darker the shade of green, the higher the number of growing degree days (GDDs).

What does the map tell us?

Total GDDs in each area are varied across the country. Although crops such as wheat, lettuce, canola and forage crops can be grown across the entire country, certain areas with enough GDDs, exceeding a minimum GDDs required to complete a growing cycle of the crops, will be eligible for multiple cropping in a year. The higher the value in the white to dark green range, the more suitable the climate is for those multiple cropping practices.

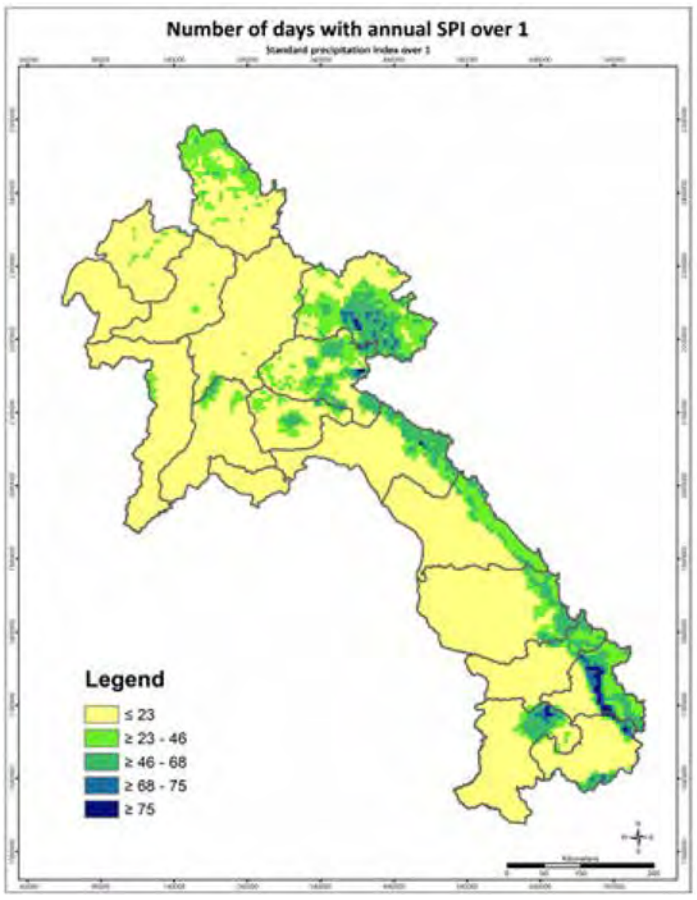
Why do these data matter?

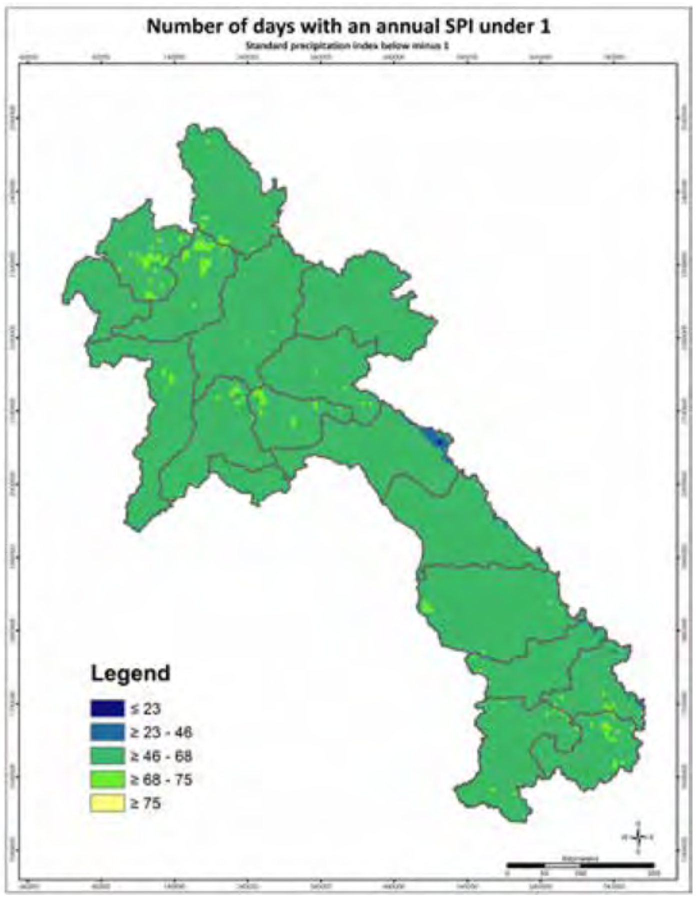
Growing degree days (GDDs) are often used to determine whether a climate is warm enough to support plants and insects with temperature-dependent growth rates.

GDDs accumulate whenever the daily mean temperature is above a specified threshold temperature. For instance, GDDs above 5 °C are generally used to assess the growth of wheat, lettuce, canola and forage crops.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software and 30 years of observation data for each site of interest). The number of growing degree days above 5 °C is defined as the annual sum of the number of degrees Celsius in which each day's mean temperature is above a base temperature of 5 °C.





Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What do these maps show?

Standardized Precipitation Index (SPI) values over 1 indicate greater than median precipitation (i.e. wet conditions), while SPI values below -1 indicate less than median precipitation (i.e. dry conditions. In the map of the number of days with an SPI above 1, the darker the blue, the wetter the conditions. In the map of the number of days with an SPI below -1, the darker the orange or red colour, the drier the conditions.

What do the maps tell us?

The maps show that that the entire country is susceptible to droughts to one extent or another, the exception being the highlands along the border with Vietnam. It is noticeable that areas located on plains in Louangnamtha, Louangphabang, Xaisomboun and the north of Vientiane Province appear to be particularly susceptible to drought. Statistically, it seems that over the last 30 years, Xiangkhoang, Houaphan and Phongsali had relatively a wetter climatology.

Why do these data matter?

The SPI is widely used to characterize meteorological drought over a range of different timescales. Over short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage.

A three-month SPI provides a comparison of precipitation over a specific three-month period with precipitation amounts for the same three-month period going back as far as historical records allow. The three-month SPI thus reflects short-and medium-term moisture conditions, providing an estimation of meteorological drought conditions for a given season.

How was this information produced?

GCM data were dynamically downscaled using the WRF model and national observation data. The map data were generated using R (software) and 30 years of observation data for each site of interest. R's SPI package was used to calculate the three-month Standardized Precipitation Index. In brief, the SPI algorithms used in the package transform the observed precipitation data to Gaussian equivalents, and the transformed precipitation data are then used to compute the dimensionless SPI value, defined as the standardized anomaly of the precipitation.

»
NATIONAL MONTHLY CLIMATOLOGY MAPS | 2

Introduction

The section provides a visual comparative view of the minimum and maximum temperatures and total precipitation for each month averaged over the last 30 years.

What do these maps show?
These maps show average monthly maximum and minimum temperatures, as well as precipitation amounts, for the Lao People's Democratic Republic for the climatological period 1990–2019.

On the temperature maps, blue areas indicate cooler temperatures; the darker the blue, the cooler the average temperature. Dark blue areas had an average temperature cooler than 10 °C, while in pale blue areas, the average temperature was between 10 °C and 20 °C. Orange and red areas on the maps indicate were warmer temperatures above 20 °C; the darker the shade, the warmer the average temperature for that month.

On the precipitation maps, white areas received an average of zero measurable precipitation over the course of the month. The darker the shade of brown, the lower the level of precipitation for that month. Areas shown in the darkest brown received a monthly average of less than 70 mm of rainfall. The darker the shade of blue, the higher the level of precipitation for that month. Areas shown in the darkest blue received 1 300 mm or more of rainfall.

Why do these data matter?
Tracking average temperatures across seasons and the year provides scientists and practitioners with a way of monitoring climate at the national scale. Energy companies use this information to estimate demand for heating and air conditioning. Agricultural businesses also use these data to optimize the timing of planting, harvesting and putting livestock to pasture.

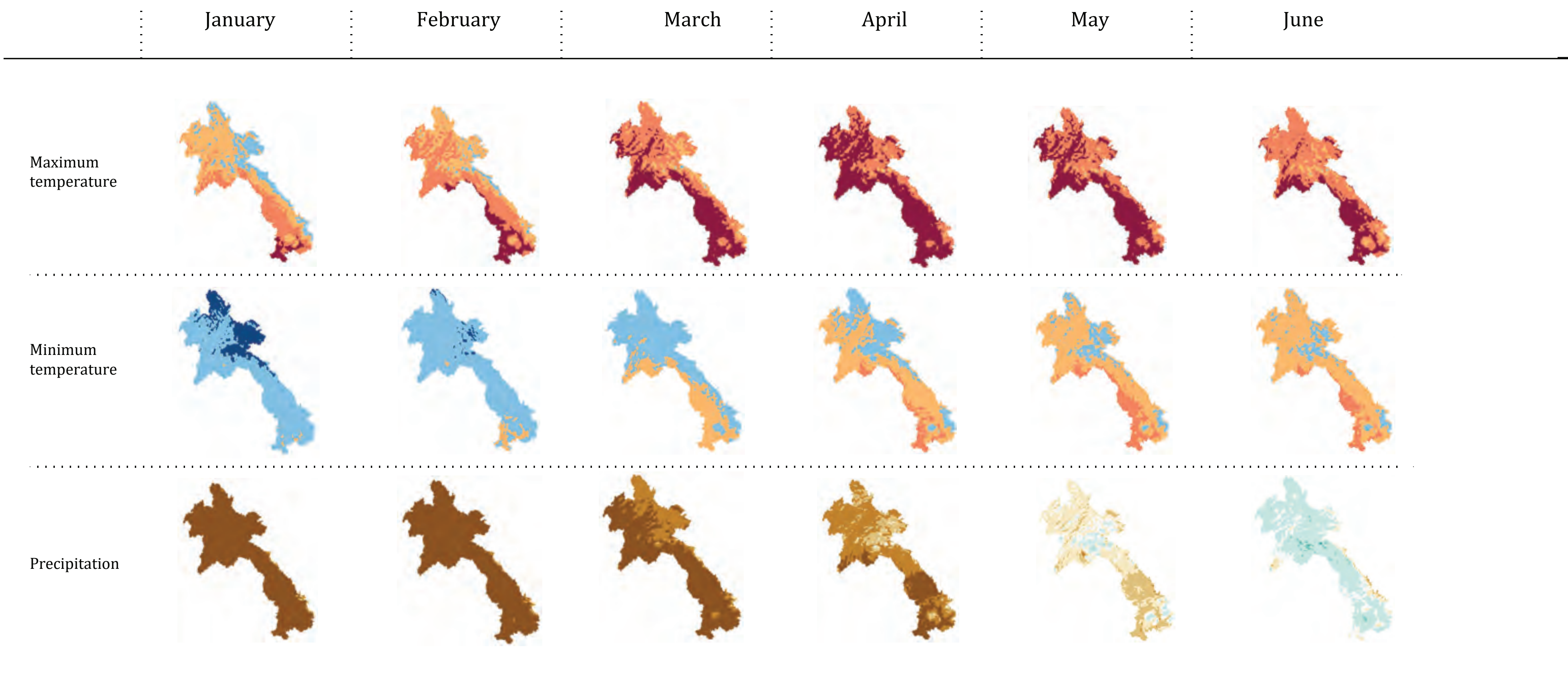
Average monthly precipitation values provide insight into the "normal" rainfall conditions for each month. This type of information is widely used in a range of different planning situations, from designing energy distribution networks, to determining when crops and plants will emerge, to choosing the right place and time for recreational activities.

The temperature range we can expect within a year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions. Average monthly temperatures and precipitation levels across the year illustrate seasonal variations in climate that are important when determining seasonal vegetative growth or the cropping periods for plants with varying temperature and water requirements.

How was this information produced?
These maps were produced based on existing data from the Department of Meteorology and Hydrology. GCM data were dynamically downscaled using the WRF model and national observation data. To meet the needs of a broad audience, these data are presented here in a simplified visual style. The series of snapshots were produced following management and manipulation of the dataset by the Division of Climatology and Agrometerology (DCA). The capacity to perform climate downscaling and modelling was developed by the DMH in collaboration with DALAM and DCC. To produce the images, a set of scripts was used to access the source data and represent them on previously generated base maps.

The map data were generated using R (software) and 30 years of observation data for each site of interest. The monthly maximum temperature refers to the average of the daily maximum temperatures for each month. Twelve average maximum temperatures were thus obtained for January to December of each year, and averaged across 30 years. The monthly minimum temperature refers to the average of the daily minimum temperatures for each month. Twelve average minimum temperatures were thus obtained for January to December of each year, and averaged across 30 years. The monthly precipitation levels refer to the sum of the daily rainfall amounts recorded in each month. Twelve total precipitation amounts were thus obtained for January to December of each year, and averaged across 30 years.

Monthly climatology maps of the Lao People's Democratic Republic



Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

What do the maps tell us?

The maps show the seasonality of the main climatological indicators. Maximum temperatures increase the highest from March to May, decrease slightly in July, and then reach a second peak in August and September. Minimum temperatures are recorded the coolest (below 10 °C) in December and January, especially in the northern mountainous provinces, while they showed distinct seasonality of reaching the peak in May and June compared to the one of maximum temperature. Monthly precipitation maps show apparent seasonality of rainfall in the country. From November to February, extremely dry conditions (less than 70 mm rainfall per a month) persist, while the Monsoon, starting in May and ending in September, brings enough rainfall all over the country.

What do these maps show?

The table shows monthly comparisons of the minimum and maximum temperature as well as rainfall across the Lao People's Democratic Republic. All legends are standardized.

What do the maps tell us?

The maps show the seasonality of the main climatological indicators.

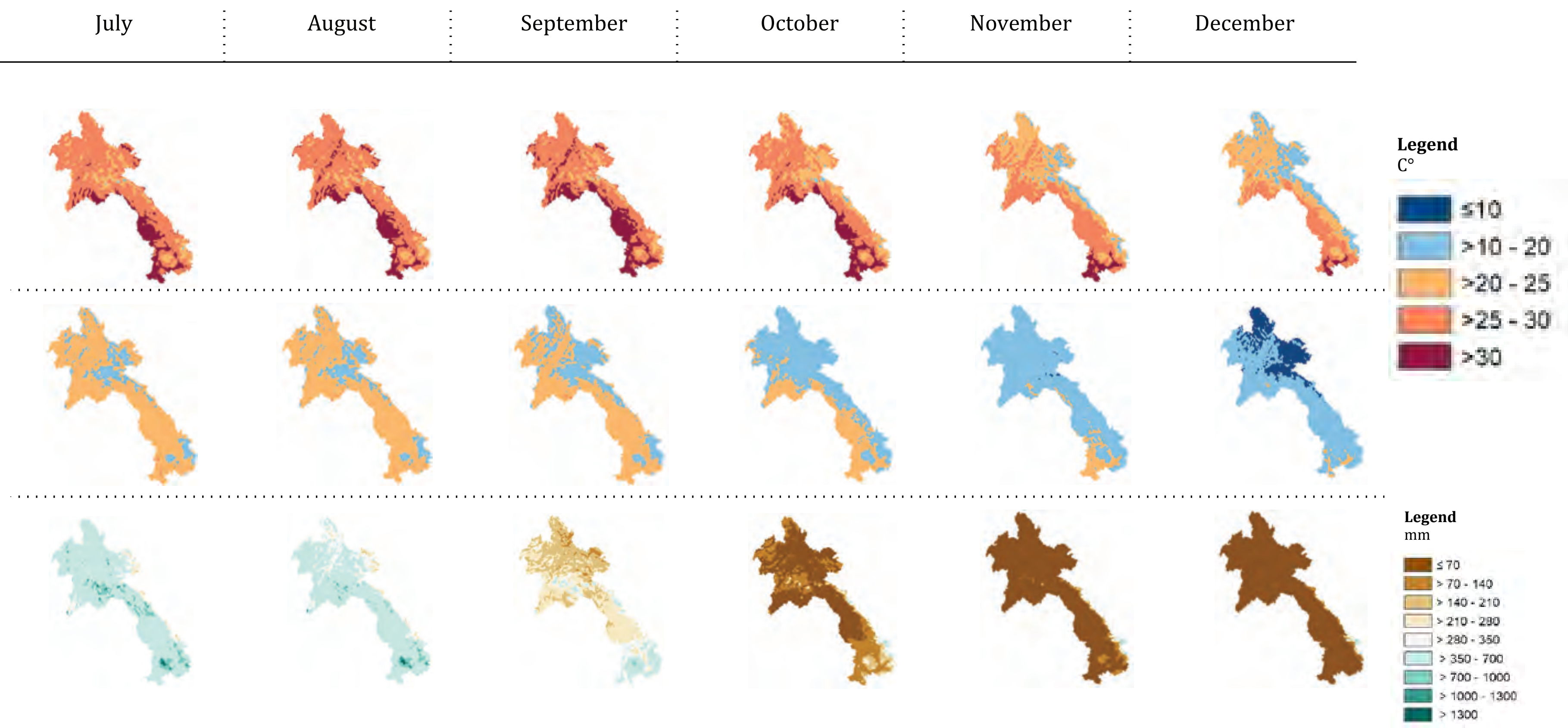
Why do these data matter?

The maps give an indication of the climate zones in the different regions in the country.

How was this information produced?

This information was generated using R and 30 years of observation data for the sites of interest. The monthly maximum temperature refers to the average of the daily maximum temperatures for a given month. The 12 monthly maximum temperatures for January to December of each year were then averaged over 30 years. Monthly precipitation refers to the sum of daily rainfall in a given month. The 12 monthly total precipitation amounts for January to December of each year were then averaged over 30 years.

Monthly climatology maps of the Lao People's Democratic Republic



Climate data by DALaM of MAF and DMH of MONRE, 2022. Administrative boundaries of Lao People Democratic Republic, National Geographic Department, 2013.

CLIMATIC AND AGROCLIMATIC STUDY BY PROVINCE

3

Phongsali »

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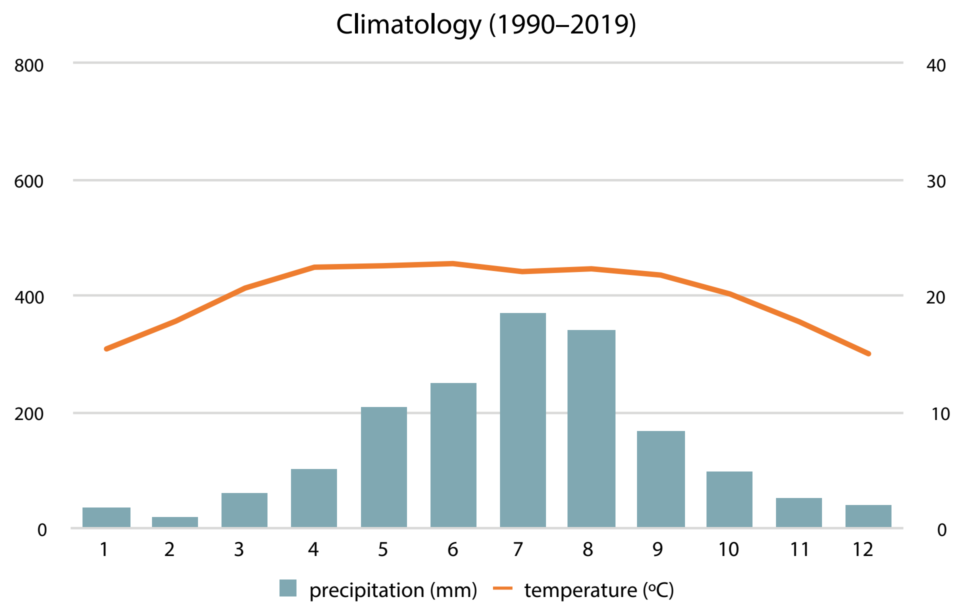
Phongsali climatology



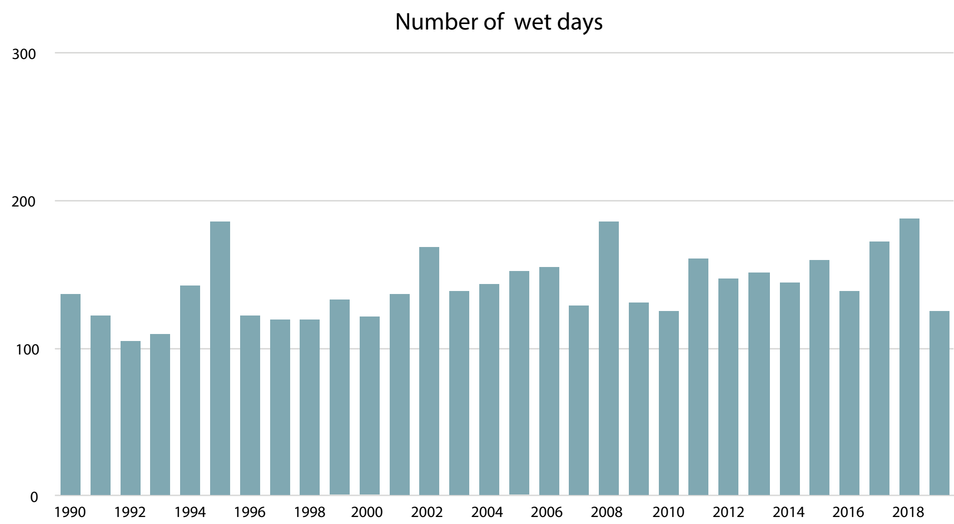
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	37	15	19.5	11.3
Feb	19	18	22.8	12.8
Mar	60	21	25.8	15.5
Apr	100	22	27.5	17.4
May	208	23	27.1	18.1
Jun	251	23	26.5	19.0
Jul	372	22	25.2	18.9
Aug	339	22	25.8	18.9
Sep	165	22	25.4	18.2
Oct	96	20	23.7	16.6
Nov	52	18	21.6	13.9
Dec	39	15	18.8	11.2

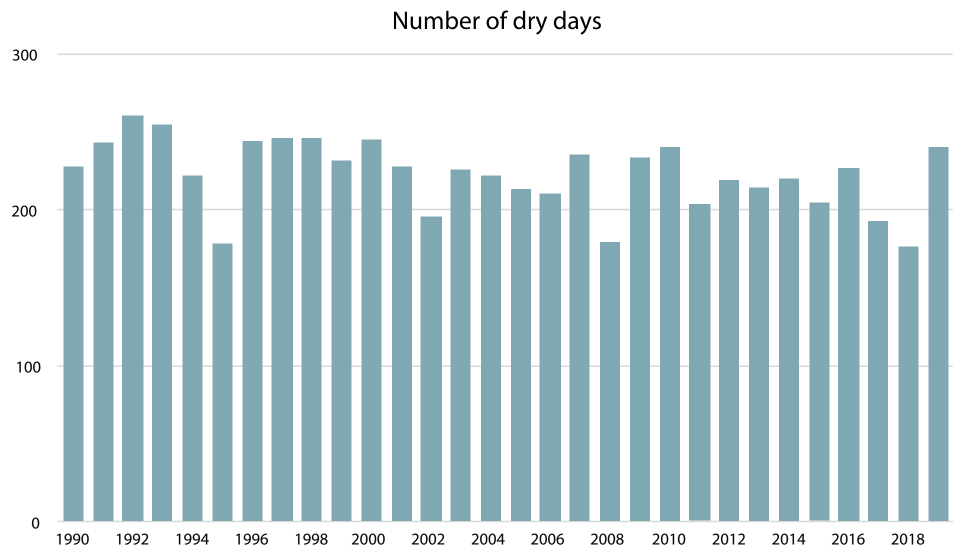
Phongsali is found in the northeast of the Lao People's Democratic Republic, a region that also includes the provinces of Houaphan and Xiangkhoang. The climatology of the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in July (371.6 mm). After this, the amount of precipitation decreases until it reaches a low of 19.09 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C, starting in December and continuing to February of the following year. Phongsali has the second coldest temperatures of the three northeast provinces, and is generally considered in Laos as having a cold climate. At the Phongsali weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990-2019 was 15.99 °C to 24.14 °C, the minimum temperature range was 11.22 °C to 19.02 °C, and the maximum temperature range was 18.8 °C to 27.5 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Phongsali start to decrease from November to January during the Northeast Monsoon. Maximum temperatures start to increase from the end of January, and reach their peak level of 27.5 °C in April, during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase at the beginning of February, reaching a high of 19.02 °C before starting to fall again. Increases in minimum and maximum temperatures between March and August are related to the Intertropical Convergence Zone (ICZ) moving toward the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (371.5 mm) falling in July in Phongsali.

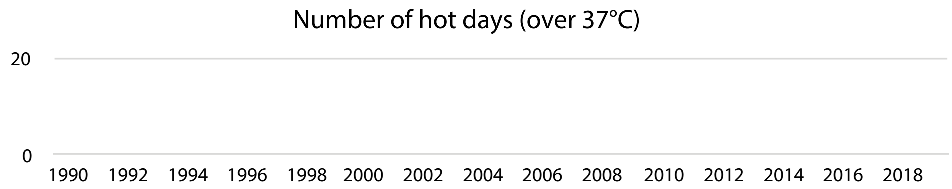
Land cover in the province ranges from grassland to sparse and thick forest (deciduous, semi-evergreen and evergreen forests); there is more shrubland and sparse forest in the north of the province, while the south and west tend to be covered by sparse forest, dwelling areas and agricultural food production areas. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover.

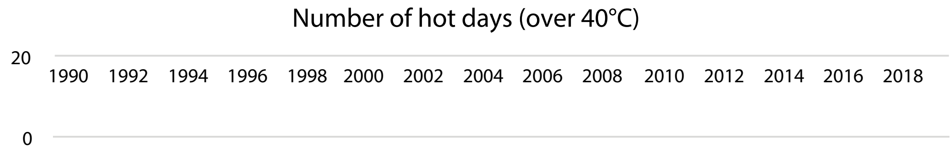
Climate change: Precipitation over the last 30 years

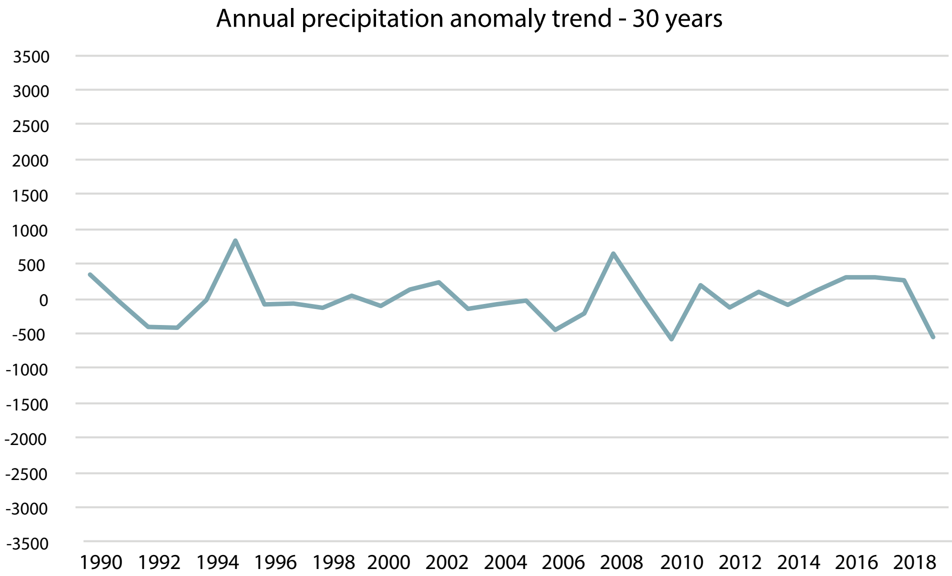




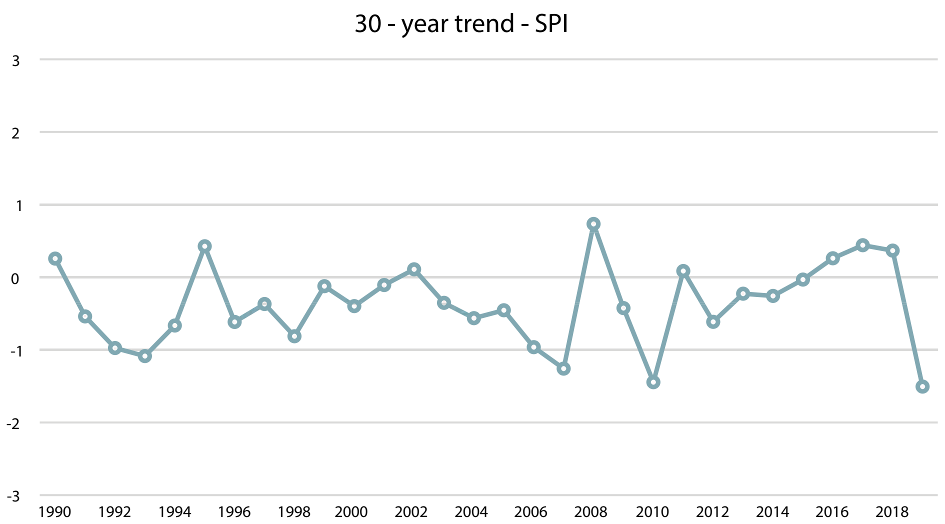
Phongsali climatology





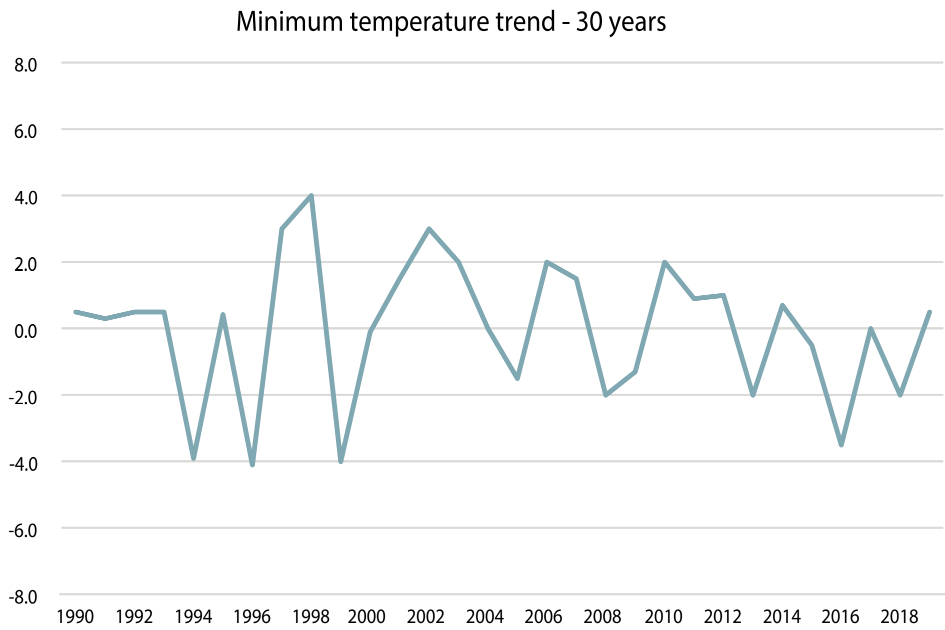


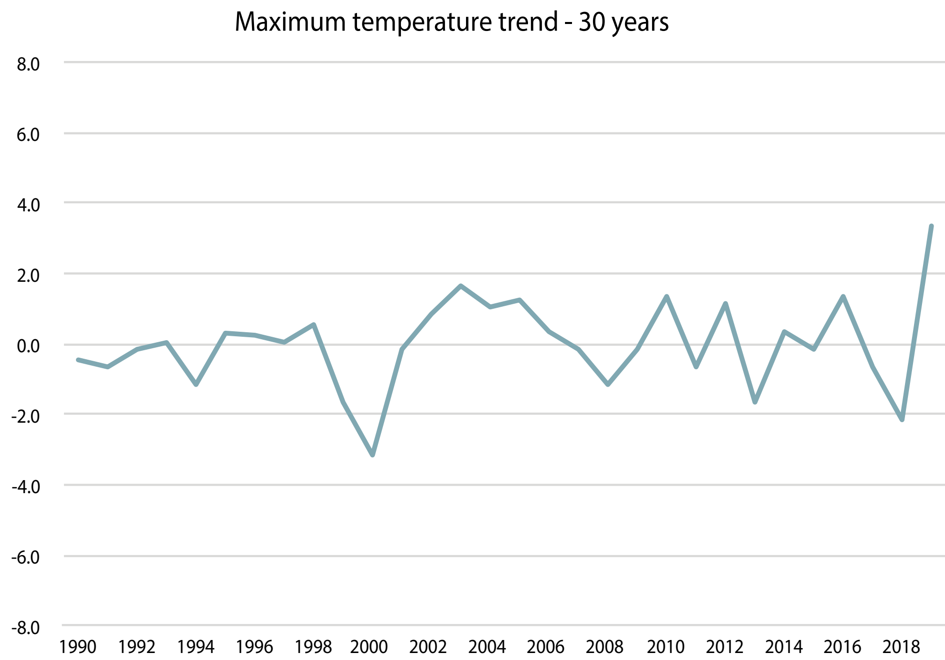
According to the 30 years of observation data on rainfall in Phongsali Province from the Phongsali weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has decreased significantly. The year with the lowest number of dry days (177) was 2018, and the year with the highest number (261) was 1992. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has increased: 1992 saw the lowest number of wet days (105), while 2018 saw the highest number



(188). The trend analysis shows that there has been no trend in rainfall over the 30 years, with the lowest amount of annual rainfall recorded as 1 154.1 mm (in 2010) and the highest as 2 571.8 mm (in 1995). The Standardized Precipitation Index (SPI) (not included in this publication), however, suggests that there has been a slight increase over the period, indicating a slightly drier climate, with the driest year occurring in 2019 and the wettest year in 2008.

Climate change: Temperature over the last 30 years



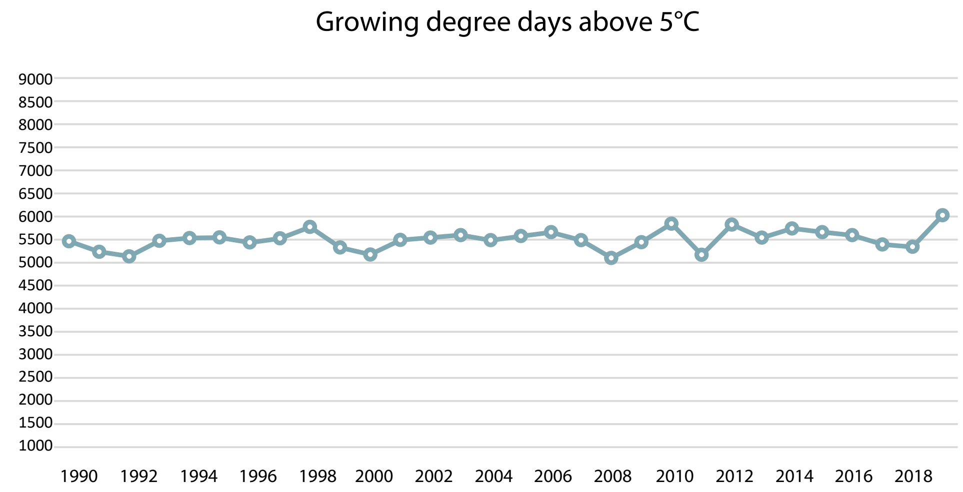


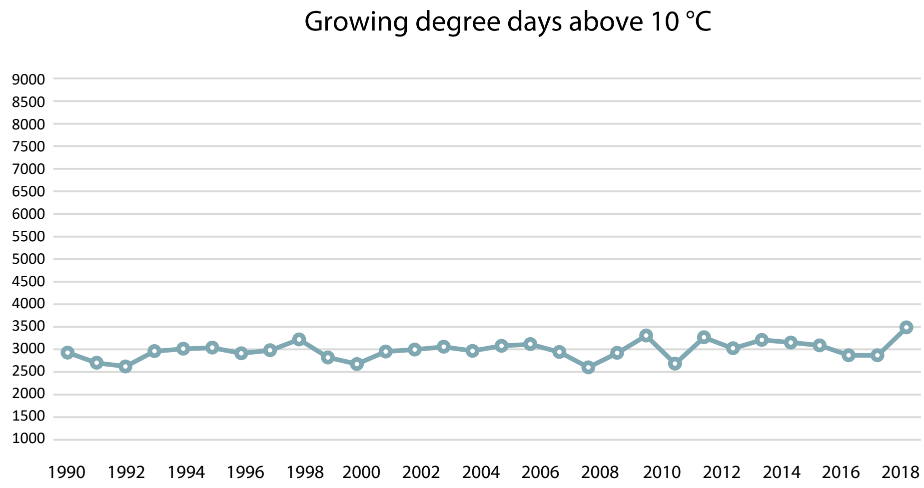
The 30 years of data on temperature conditions show that minimum temperatures have remained stable over this period, ranging from 14.73 °C to 17.22 °C, while maximum temperatures, ranging from 22.68 °C to 25.81 °C, have slightly increased.

Phongsali agroclimatology

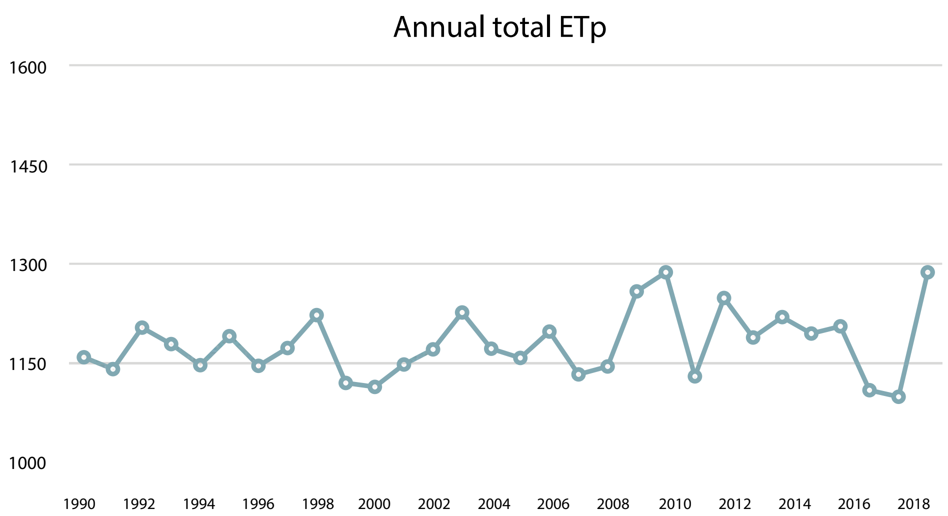
Agroclimatology

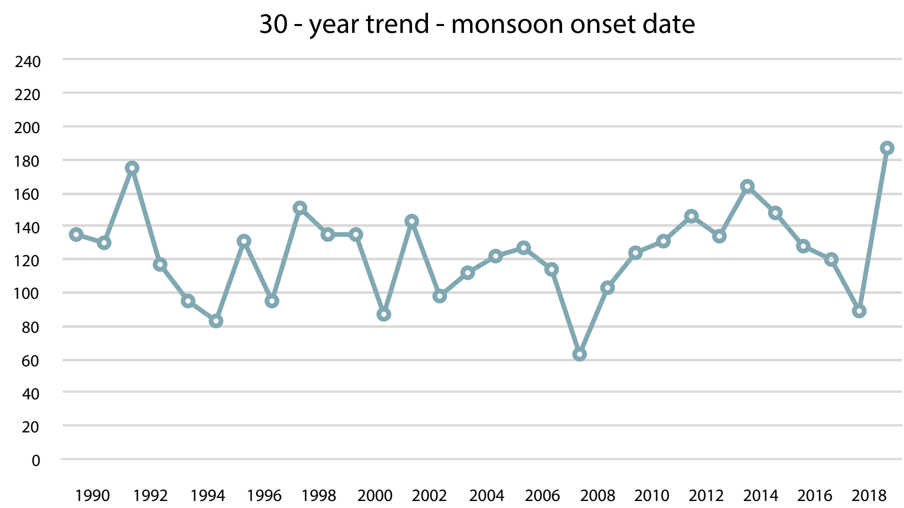
The graph showing growing degree days (GDDs) over 10 °C reveals a significant increasing trend in heat accumulation over the past 30 years (1990–2019) of 8.97 °C per year from a low of 2 601 °C in 2008) to a high of 3 485 °C in 2019). The result of this is a shorter development cycle for crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant			Maintenance		Harvest		
Steep slope agriculture		Prepare and plant			Maintenance					Harvest		
Maizes					Prepare and plant		Maintenance		Harvest			
Cassava	Harvest		Prepare and plant		Maintenance							
Annual crops and grasslands	Harvest				Prepare and plant		Maintenance					
Orchards and plantations			Prepare and plant			Maintenance					Harvest	
Coffee			Prepare and plant			Maintenance						Harvest
Tea	Prepare/ Plant/ Maintain/ Harvest											
Sugarcane			Prepare and plant		Maintenance					Harvest		

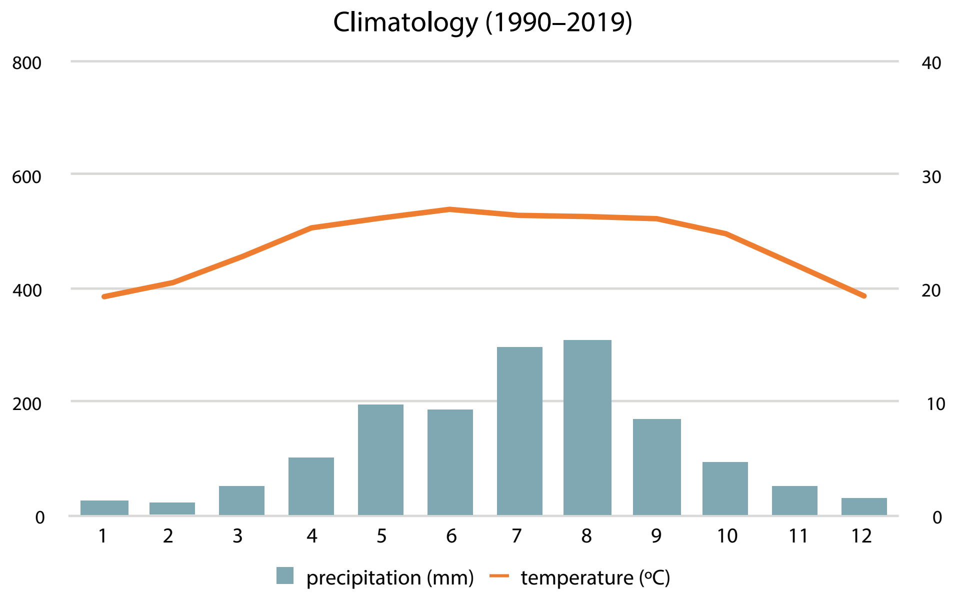




Potential evapotranspiration (ETp) appears to have slightly increased as well, with the lowest ETp occurring in 2018, and the highest in 2019. The date of the onset of the monsoon (graph not included in the publication) appears to occur later now than it did 30 years ago, meaning that there is a delay in the seasonal rainfall needed for the cropping season. The earliest monsoon start date occurred in 2008, and the latest in 2019.

Louangnamtha

» Louangnamtha climatology



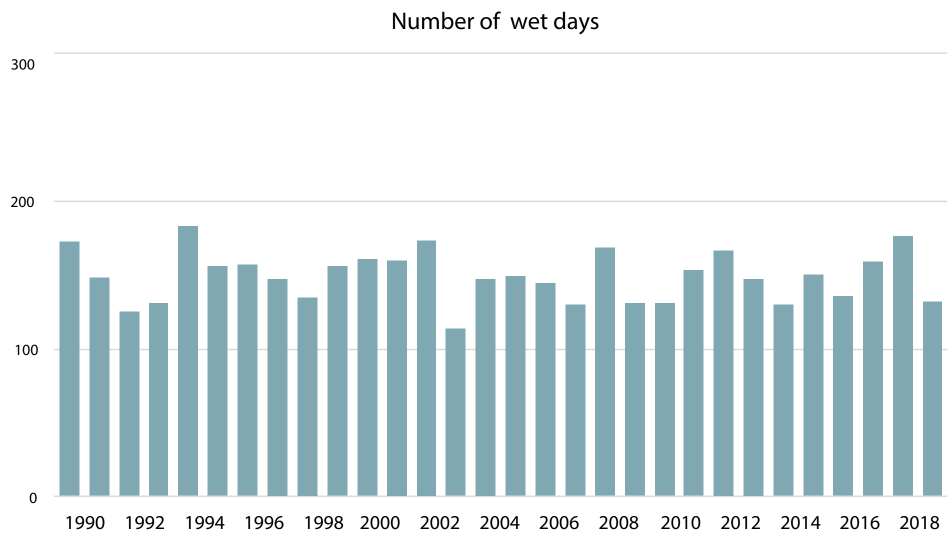
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	26	19	26.2	12.3
Feb	24	21	28.9	12.1
Mar	56	23	31.0	14.6
Apr	108	25	32.3	18.4
May	201	26	31.4	20.9
Jun	190	27	31.1	22.8
Jul	294	26	30.0	22.8
Aug	307	26	30.1	22.6
Sep	172	26	30.5	21.8
Oct	94	25	29.6	19.9
Nov	58	22	27.6	16.4
Dec	31	19	25.2	13.6

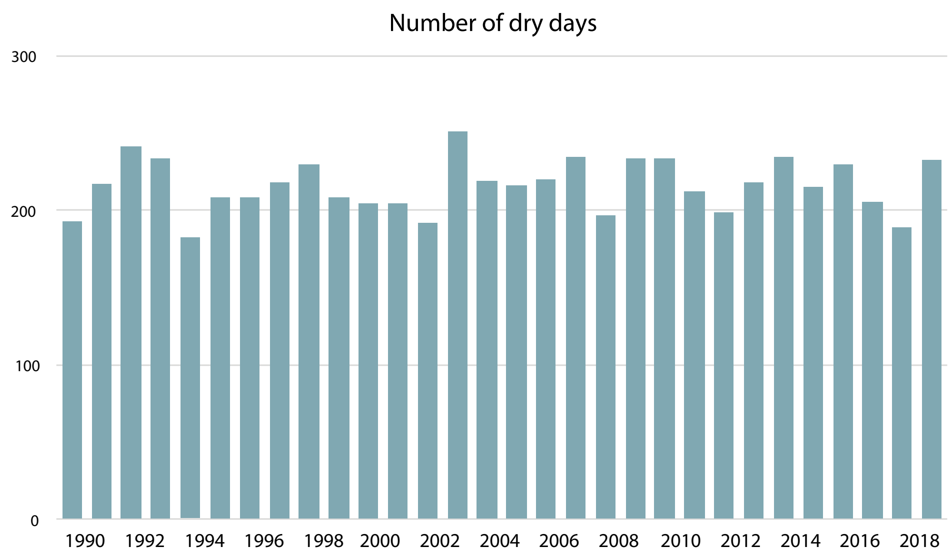
Louangnamtha is found in the northwest of the Lao People's Democratic Republic, a region that also includes the provinces of Bokeo, Oudomxay, Xaignabouli and Louangphabang. The climatology graph for the province shows that the rainy season starts in April and continues to October. There is a lot of rainfall during this period, with most rain falling in August (310 mm). After this, the amount of precipitation decreases until it reaches a low of 21 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C, starting in November and continuing to April of the following year. Louangnamtha is the second coldest of the northwestern provinces after Bokeo, and its climate is generally considered to be moderate to cold. At the Louangnamtha weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 12.15 °C to 32.3 °C, the minimum temperature range was 12.15 °C to 22.79 °C, and the maximum temperature range was 25.22 °C to 32.3 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Louangnamtha start to decrease from November and continue to be low until the end of January during the Northeast Monsoon. Maximum temperatures start to increase from February and reach their peak level of 32.3 °C in April, during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase in February, reaching a high of 22.79 °C in June before starting to fall again. Increases in minimum and maximum temperatures between April and August are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (310.1 mm) falling in August in Louangnamtha.

Land cover in the province ranges from grassland to sparse and thick forest (deciduous, semi-evergreen and evergreen forests). The northeast of the province tends to be shrubland, sparse forest and areas of agricultural production; central and southeast regions are dominated by the provincial capital of Louangnamtha and a large number of plantations and areas of agricultural production; and the south is covered by healthy deciduous and evergreen forest. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover.

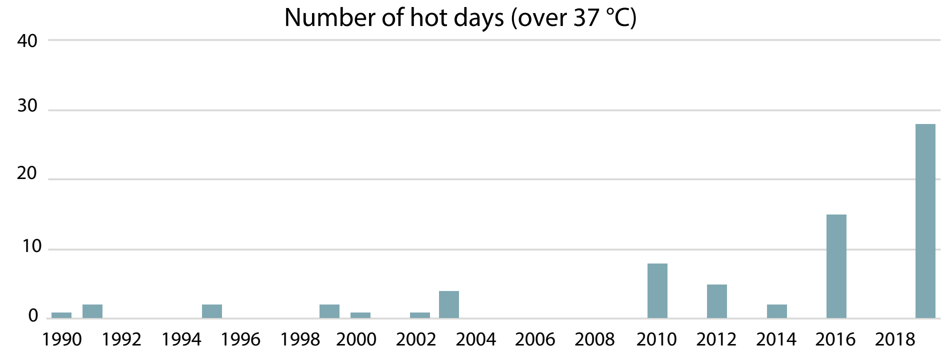
Climate change: Precipitation over the last 30 years



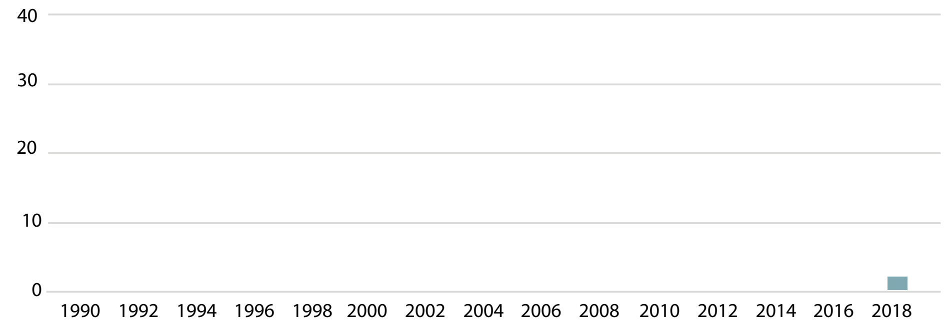


» Louangnamtha climatology

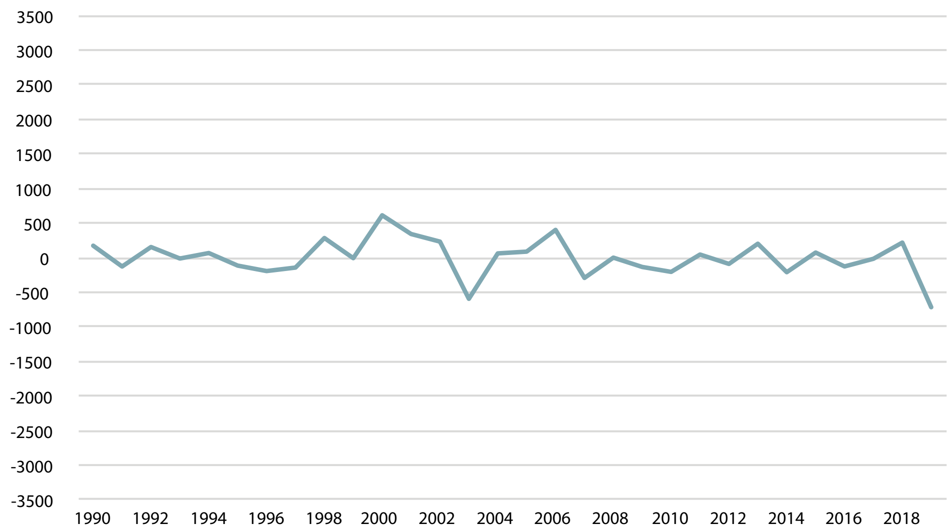
Number of hot days (over 37 °C)



Number of hot days (over 40 °C)

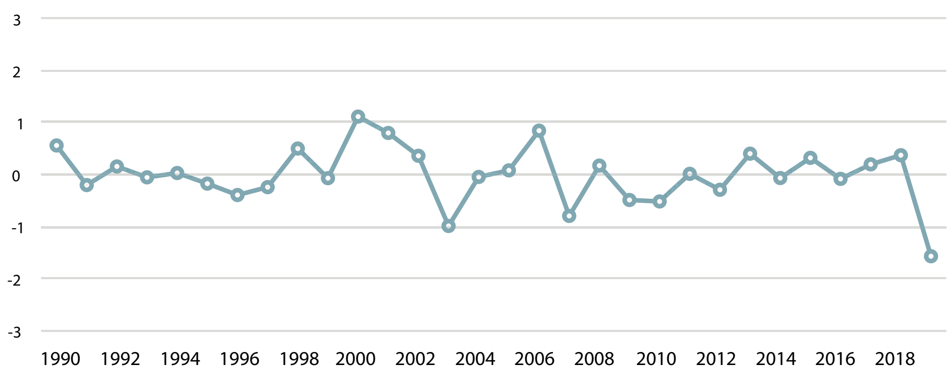


Annual precipitation anomaly trend - 30 years



According to the 30 years of observation data on rainfall in Louangnamtha Province from the Louangnamtha weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has remained stable; 1994 saw the lowest number of dry days (182) and 2003 saw the highest (251). Similarly, the number of wet days (with more than 0.2 mm of rainfall) has also remained stable; the year with the smallest number of wet days (114) was 2003 and the year with the highest (183) was 1994.

30 - year trend - SPI

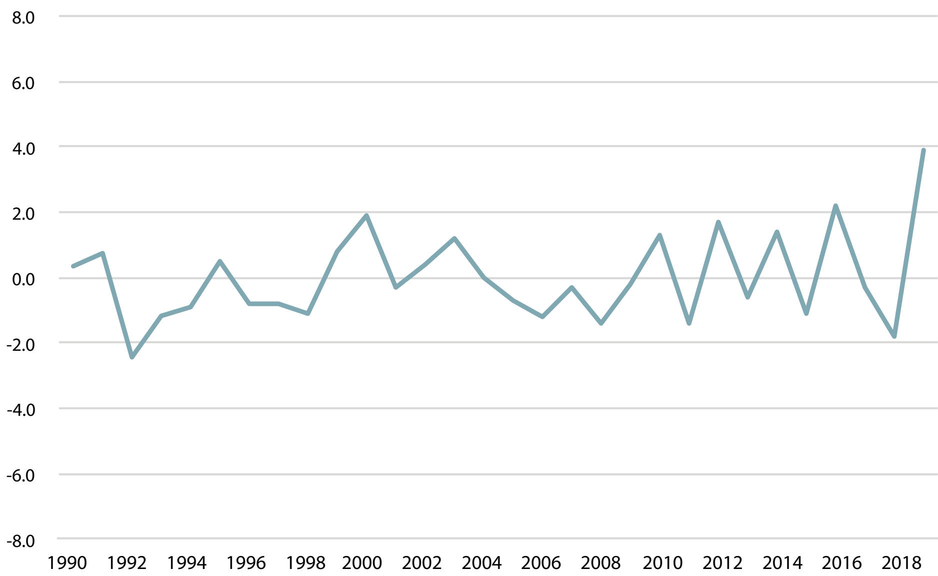


The trend analysis, however, shows that precipitation levels have slightly decreased over the 30 years, with the lowest amount of annual rainfall recorded in 2019 (883.1 mm) and the highest in 2000 (2 162.3 mm). Similarly, the SPI graph also suggests that there has been a slight decrease over the period, indicating a slightly drier climate, with the driest year occurring in 2019 and the wettest year in 2000.

Climate change: Temperature over the last 30 years

Minimum temperature trend - 30 years

Maximum temperature trend - 30 years

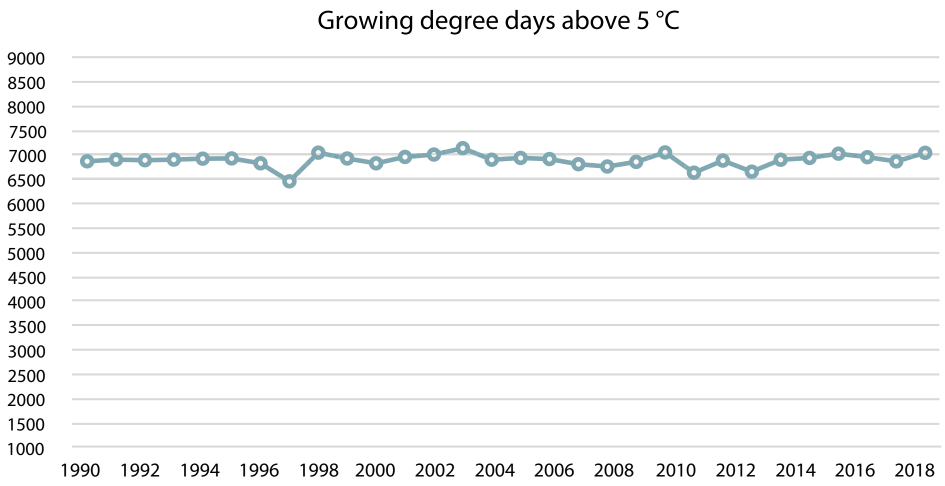


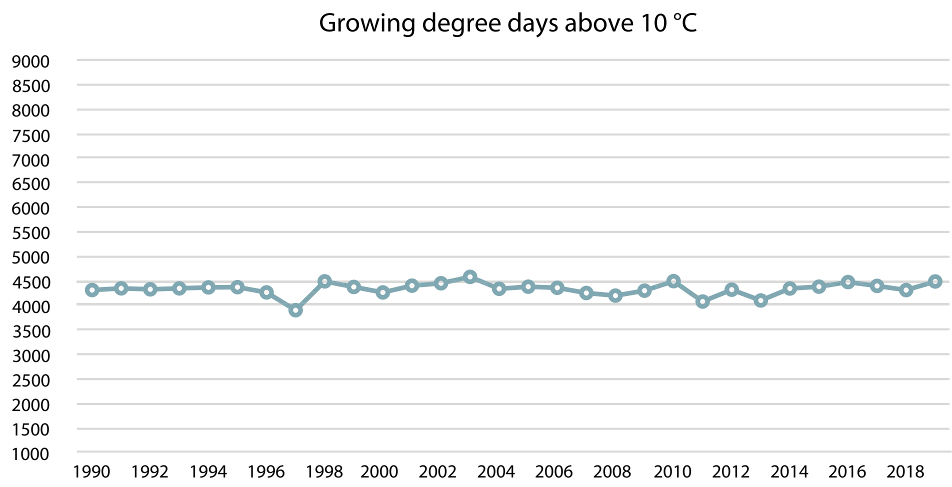
The 30 years of data on temperature conditions show that minimum temperatures have decreased significantly at a rate of 0.03 °C per year, with these temperatures ranging from 12.5 °C to 22.79 °C. Maximum temperatures, meanwhile, have also increased significantly at a rate of 0.03 °C per year, with these temperatures ranging from 25.22 °C to 32.3 °C. Days with a temperature exceeding 40 °C first started to appear in 2019, while the number of days on which the temperature exceeded 37 °C increased steeply over the 30 years to reach a high of 28 days in 2019, indicating an increased risk of heatwaves.

Louangnamtha agroclimatology

Agroclimatology

Looking at the GDDs over 10 °C reveals that heat accumulation has remained stable over the past 30 years (1990–2019), with a low of 3 901 °C (in 1997) and a high of 4 580 °C (in 2003), which has had a significant impact on the development cycle of crops, pests and diseases in the province.





<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Rainfed rice</td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td colspan="2">Harvest</td><td></td></tr>
<tr><td>Irrigated rice</td><td>Prepare and plant</td><td colspan="2">Maintenance</td><td>Harvest</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Prepare and plant</td></tr>
<tr><td>Steep slope agriculture</td><td></td><td></td><td colspan="4">Prepare and plant</td><td colspan="3">Maintenance</td><td colspan="2">Harvest</td><td></td></tr>
<tr><td>Maizes</td><td></td><td></td><td colspan="3">Prepare and plant</td><td colspan="4">Maintenance</td><td colspan="2">Harvest</td><td></td></tr>
<tr><td>Annual crops and grasslands</td><td colspan="11">Prepare/ Plant/ Maintain/ Harvest</td><td></td></tr>
<tr><td>Orchards and plantations</td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="5">Maintenance</td><td colspan="3">Harvest</td></tr>
<tr><td>Sugarcane</td><td colspan="2">Prepare and plant</td><td colspan="7">Maintenance</td><td colspan="3">Harvest</td></tr>
<tr><td>Cassava</td><td colspan="2">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="7">Maintenance</td><td>Harvest</td></tr>
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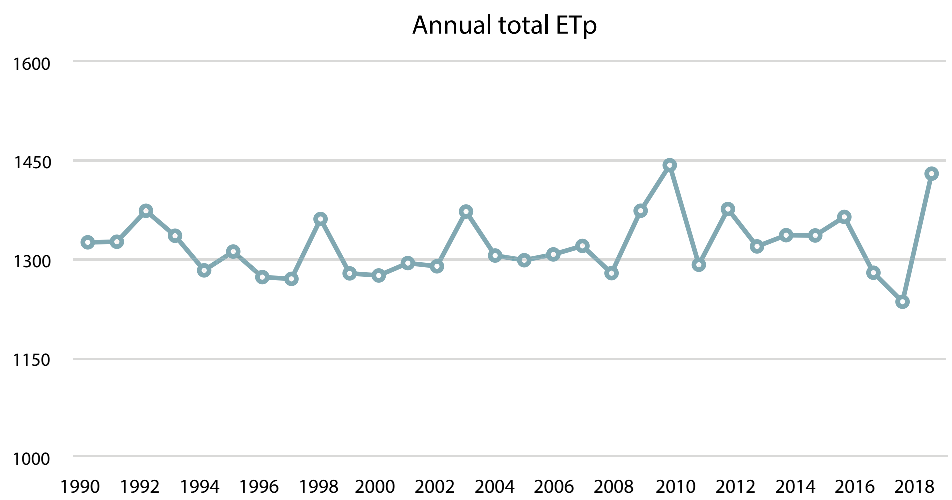
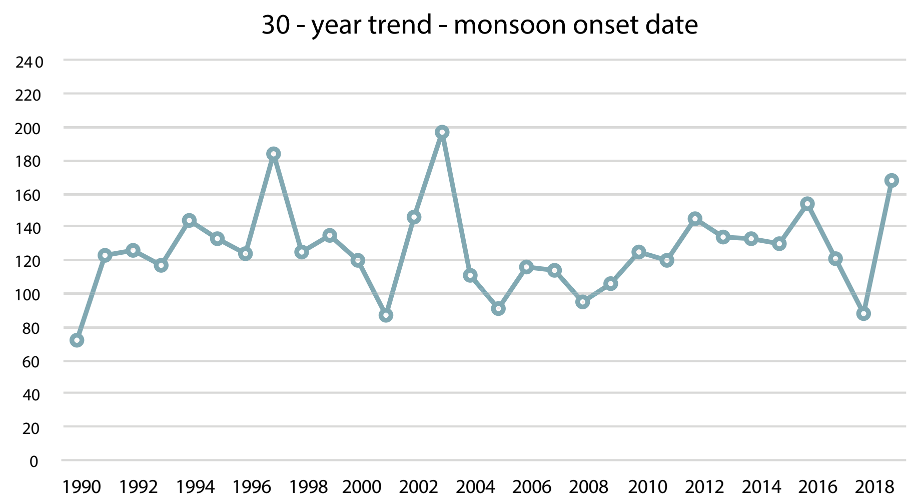
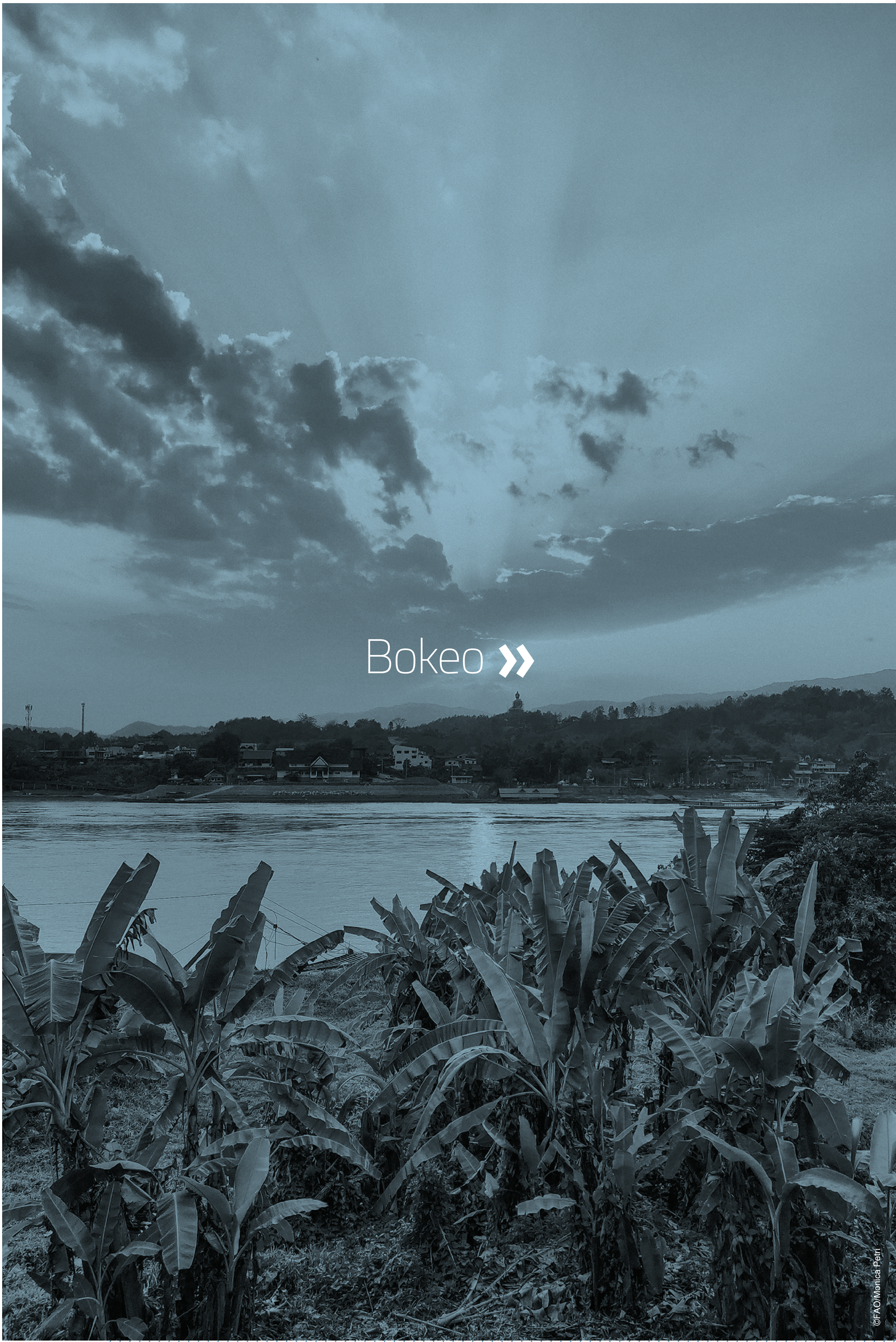


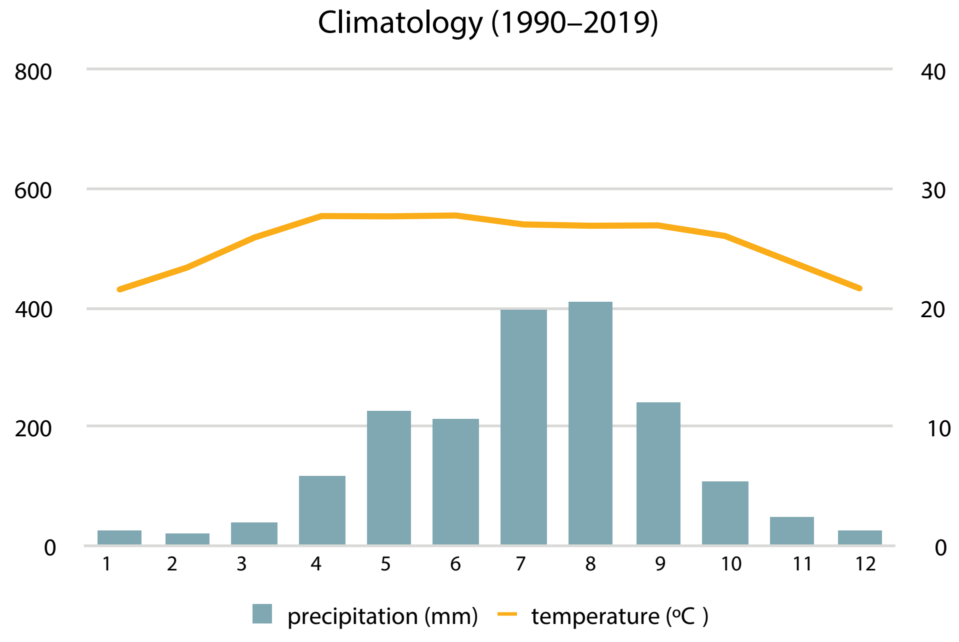


Potential evapotranspiration (ETP) has also remained relatively stable, with the lowest ETp value recorded in 2018 and the highest in 2010. Similarly, the date of the onset of the monsoon has not changed significantly, the earliest start date occurred in 1990, and the latest in 2013 and 2003.

Bokeo »



Bokeo climatology



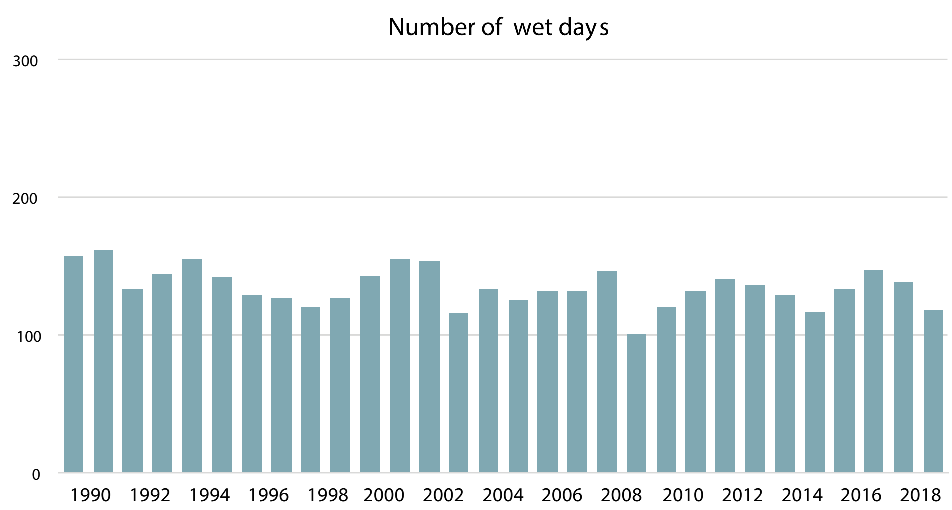
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	23	21	28.3	14.6
Feb	19	23	31.0	15.6
Mar	43	26	33.5	18.3
Apr	112	28	34.2	21.2
May	226	28	32.6	22.7
Jun	207	28	31.8	23.6
Jul	395	27	30.5	23.4
Aug	412	27	30.5	23.2
Sep	249	27	31.1	22.7
Oct	109	26	30.8	21.1
Nov	50	24	29.3	18.1
Dec	23	21	27.3	15.5

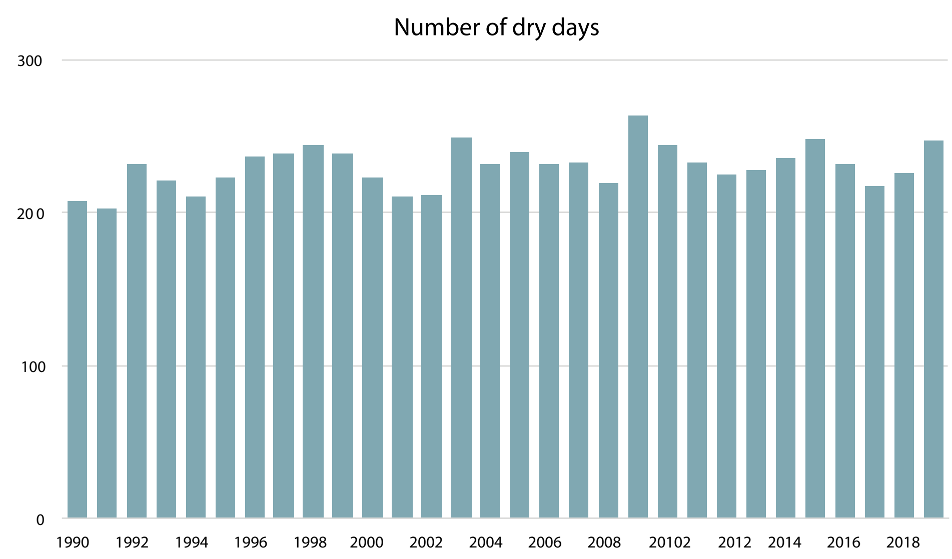
Bokeo is found in the northwest of the Lao People's Democratic Republic, a region that also includes the provinces of Louangnamtha, Oudomxay, Xaignabouli and Louangphabang. The climatology graph for the province shows that the rainy season starts in April and continues to October. There is a lot of rainfall during this period, with most rain falling in August (411.26 mm). After this, the amount of precipitation decreases until it reaches a low of 18.2 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C, starting from November and continuing to March of the following year. Bokeo has the coldest temperatures of the five northwestern provinces, and is generally considered as having a moderate-to-cold climate. At the Houayxai weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 20.06 °C to 30.95 °C, the minimum temperature range was 19.29 °C to 21.08 °C, and the maximum temperature range was 29.68 °C to 33.25 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Bokeo start to decrease from December to February during the Northeast Monsoon. Maximum temperatures start to increase from March and reach their peak level of 34.21 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase in March, reaching a high of 23.6 °C in June before starting to fall again. Increases in minimum and maximum temperatures between March and August are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (411.3 mm) falling in August in Bokeo.

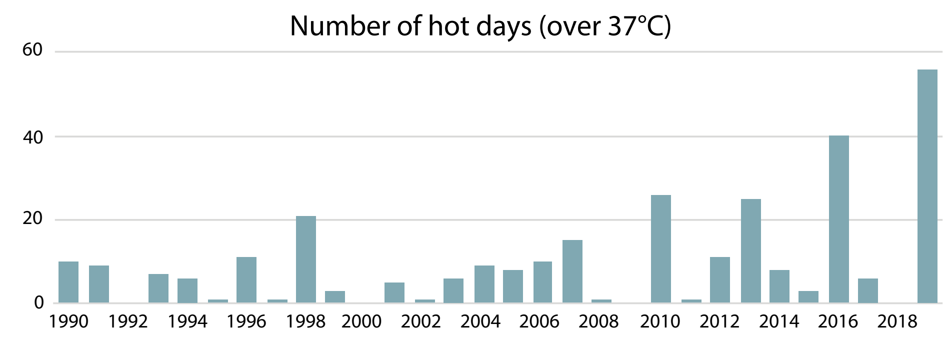
Land cover in the province ranges from grassland to sparse and thick forest (deciduous, semi-evergreen and evergreen forests). The north of Bokeo tends to be covered by shrubland and sparse forest, while in southern and western regions there is more sparse forest, dwelling areas and agricultural food production areas. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover.

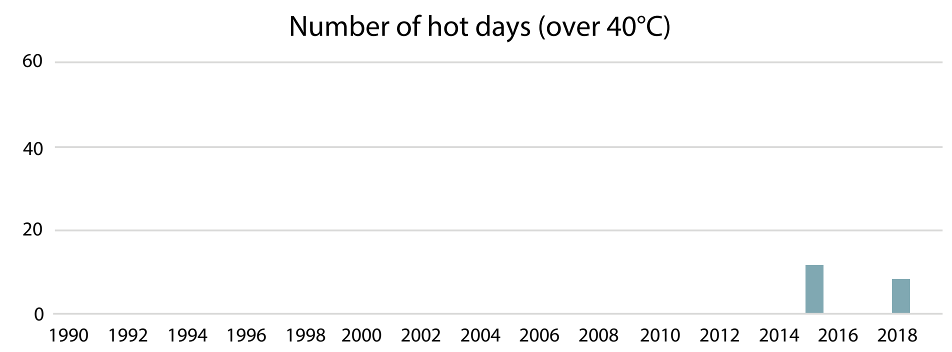
Climate change: Precipitation over the last 30 years

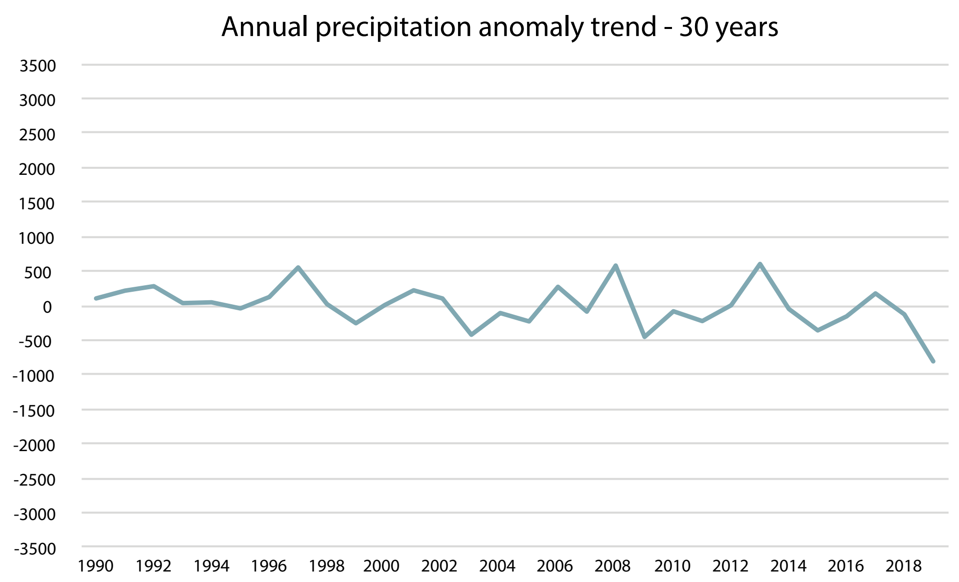




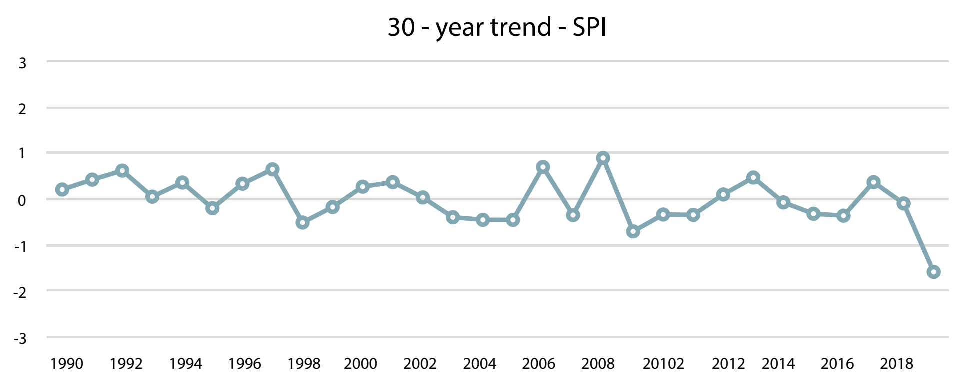
Bokeo climatology





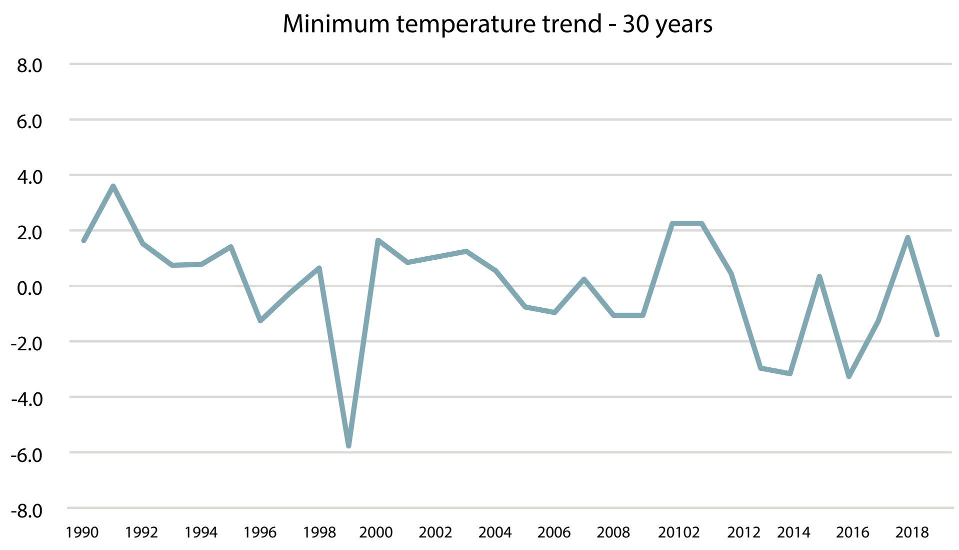


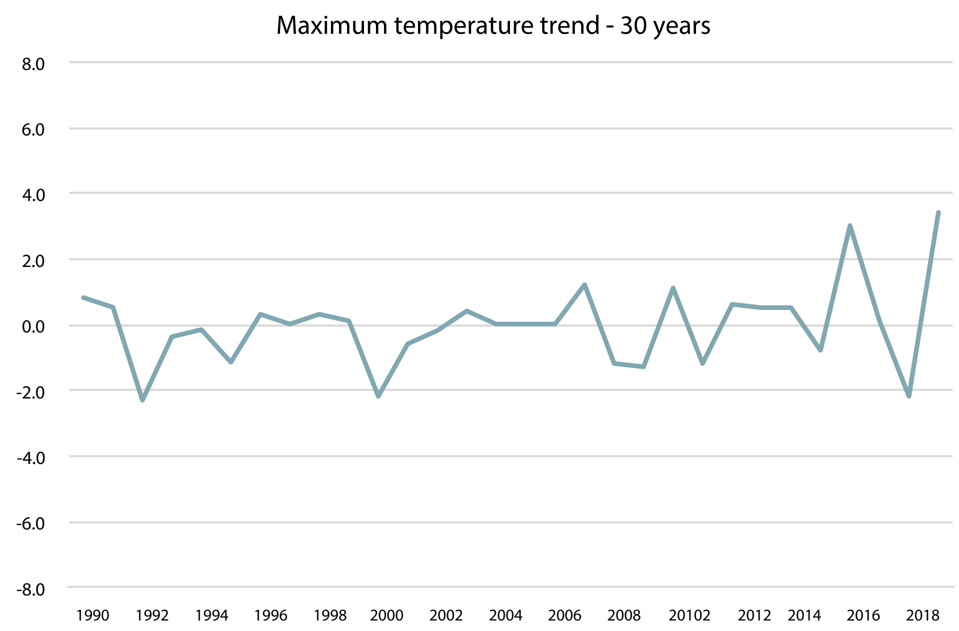
According to the 30 years of observation data on rainfall in Bokeo Province from the Houayxai weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has increased: the lowest number of dry days (203) was recorded in 1991 and the highest number (263) in 2009. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has decreased: the smallest number of wet days (101) occurred in 2009 and the highest number (162) in 1991. The trend analysis



confirms this, revealing that precipitation levels have decreased significantly over the 30 years, with 2019 seeing the lowest amount of annual rainfall (1 049.4 mm) and 2013 seeing the highest amount (2 460.5 mm). The SPI graph, meanwhile, suggests that there was an increase over the period, indicating a slightly drier climate, with the driest years occurring in 2010 and 2015, and the wettest in 1994 and 1996.

Climate change: Temperature over the last 30 years



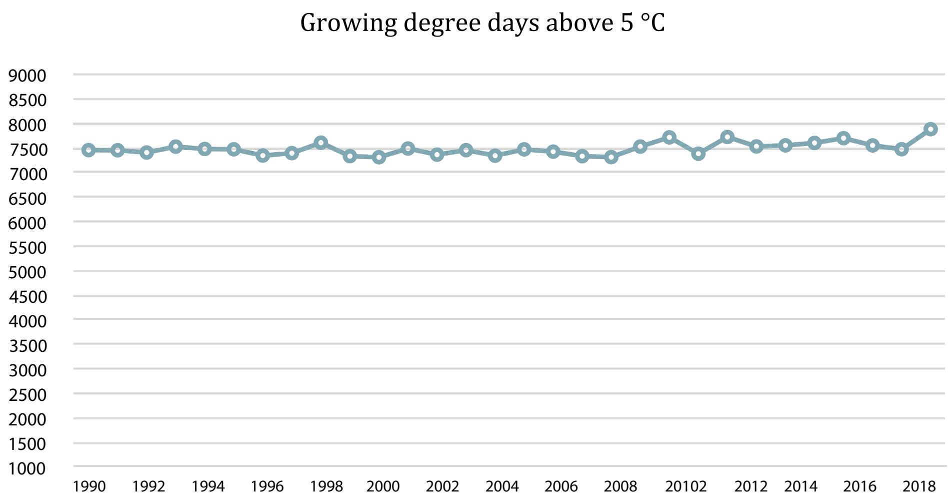


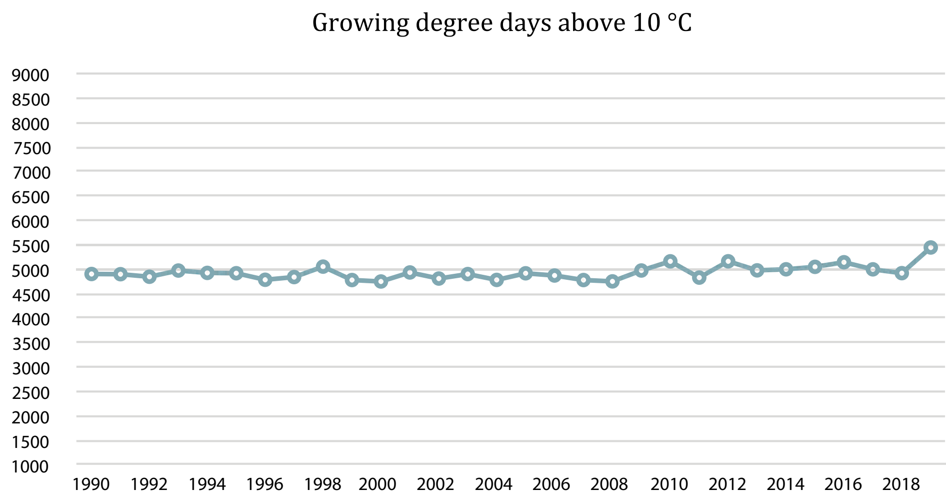
The 30 years of data on temperature conditions show that minimum temperatures have decreased at a rate of 0.08 °C per year, with these temperatures ranging from 19.3 °C to 21.1 °C. Maximum temperatures have also slightly increased, with these temperatures ranging from 29.7 °C to 33.2 °C. The number of days on which the temperature exceeded 40 °C drastically increased between 2016 and 2019, and the number of days on which it exceeded 37 °C increased steeply over the period to reach a high of 56 days in 2019, indicating an increased risk of heatwaves.

Bokeo agroclimatology

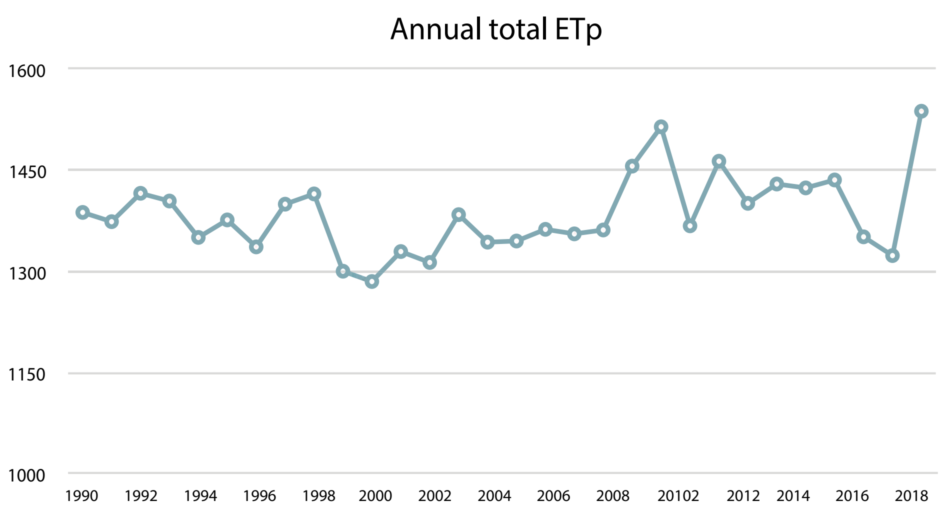
Agroclimatology

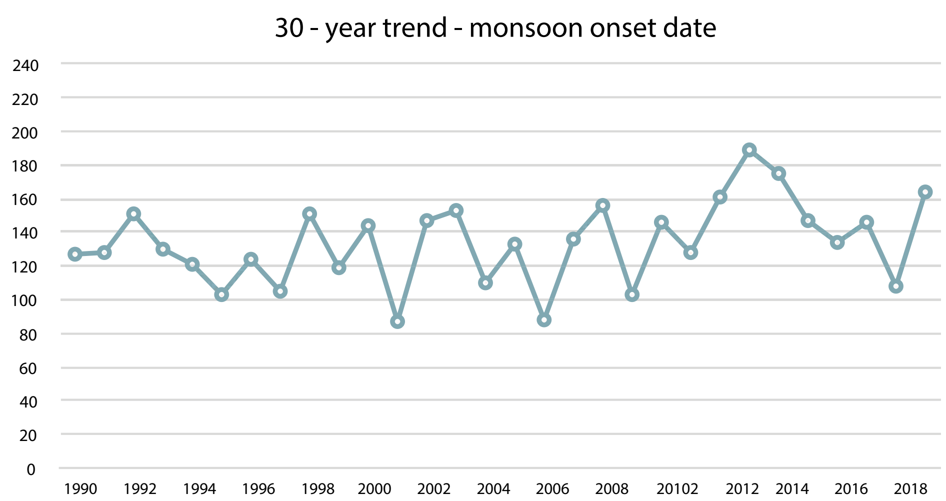
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation has increased over the past 30 years (1990–2019) from a low of 4 748 °C in 2000 to a high of 5 444 °C in 2019, resulting in a shorter development cycle for crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant			Maintenance			Harvest	
Irrigated rice	Prepare and plant	Maintenance			Harvest						Prepare and plant	
Steep slope agriculture				Prepare and plant			Maintenance			Harvest		
Maizes					Prepare and plant		Maintenance			Harvest		
Orchards and plantations	Harvest		Prepare and plant		Maintenance							
Annual crops and grasslands	Prepare/ Plant/ Maintain/ Harvest				Prepare/ Plant/ Maintain/ Harvest						Prepare/ Plant/ Maintain/ Harvest	





Potential evapotranspiration (ETP) has also slightly increased: the lowest ETp value was recorded in the year 2000 and the highest in 2019. The date of the onset of the monsoon appears to occur later now than it did 30 years ago, meaning that there is a delay in the seasonal rainfall needed for the cropping season. The earliest monsoon start date occurred in 2001, and the latest in 2013 and 2019.

Xaignabouli »

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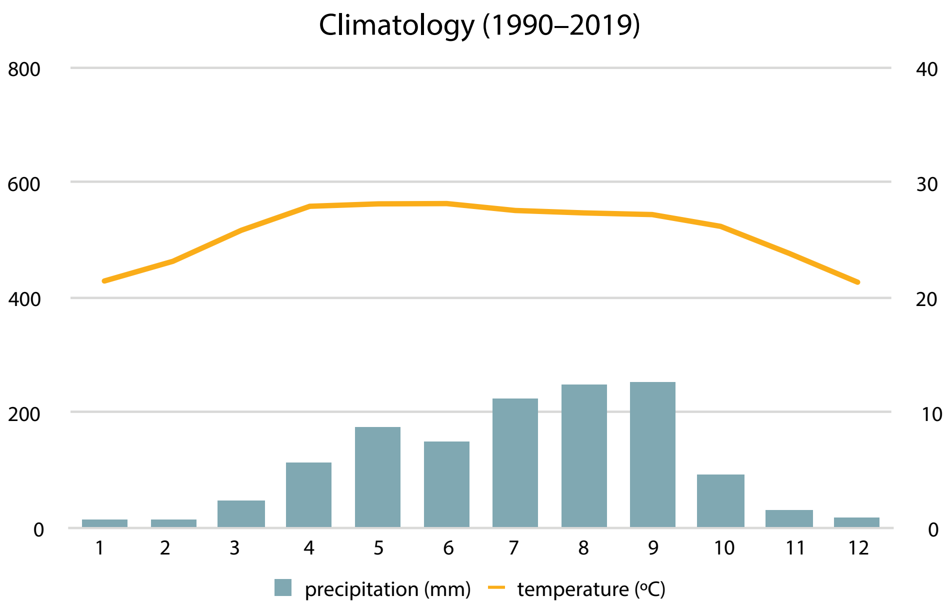
» Xaignabouli climatology



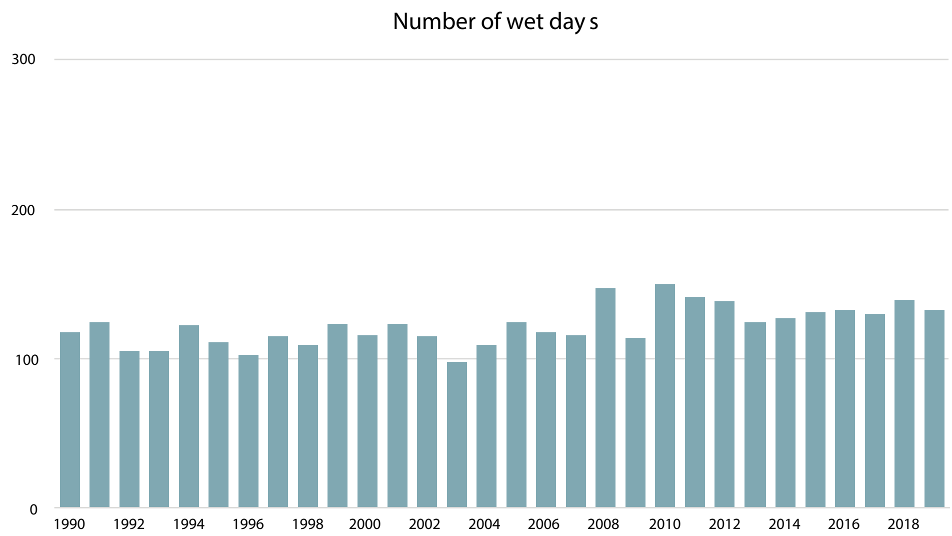
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	12	23	31.0	15.3
Feb	48	26	33.2	18.5
Mar	111	28	34.1	21.7
Apr	184	28	32.6	23.6
May	149	28	31.7	24.4
Jun	219	28	30.8	24.2
Jul	241	27	30.7	24.0
Aug	249	27	30.9	23.5
Sep	98	26	30.3	21.9
Oct	31	24	28.9	18.5
Nov	17	21	27.1	15.4
Dec	12	23	31.0	15.3

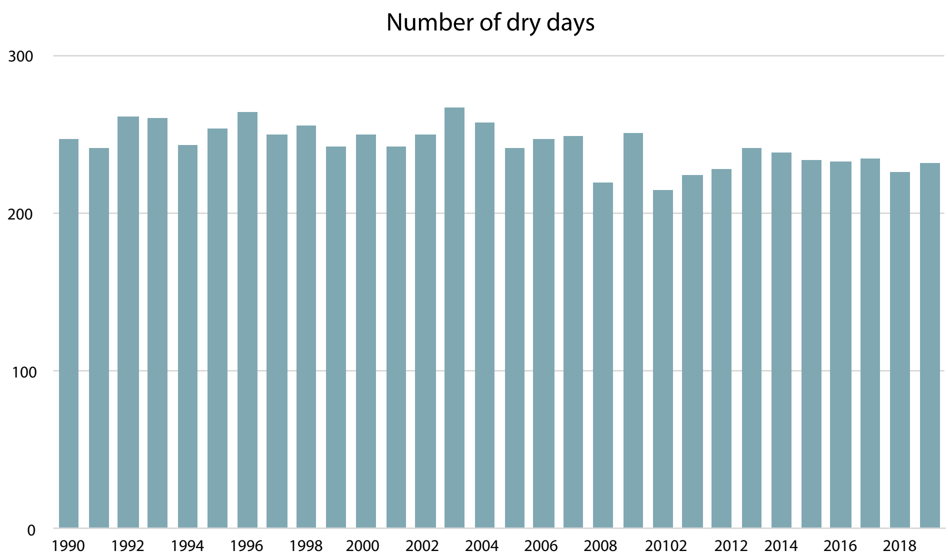
Xaignabouli is found in the northwest of the Lao People's Democratic Republic, a region that also includes the provinces of Louangnamtha, Bokeo, Louangphabang and Oudomxay. The climatology for the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in September (251.39 mm). After this, the amount of precipitation decreases until it reaches a low of 12.92 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C, starting from November and continuing to March of the following year. Xaignabouli has the second warmest temperatures of the five northwestern provinces, and is generally considered as having a warm climate. At the Xaignabouli weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 14.88 °C to 34.14 °C, the minimum temperature range was 14.88 °C to 24.45 °C, and the maximum temperature range was 27.17 °C to 34.14 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Xaignabouli start to decrease from October to January during the Northeast Monsoon. Maximum temperatures start to increase from mid-February and reach their peak level of 34.14 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase in mid-February, reaching a high of 24.45 °C in June before starting to fall again. Increases in minimum and maximum temperatures between March and August are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (251.4 mm) falling in September in Xaignabouli.

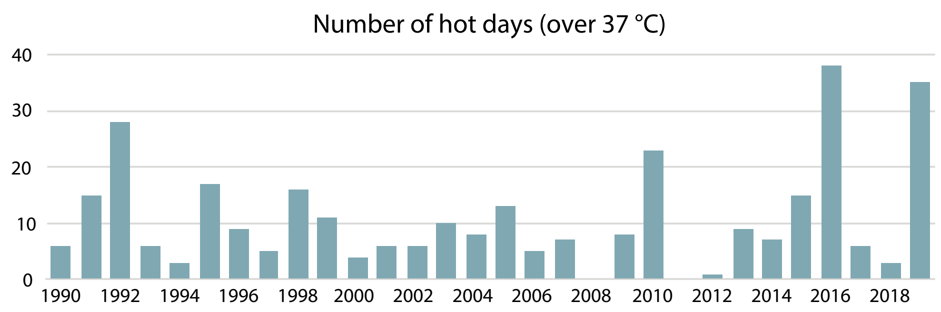
The province has a mountainous topography, with large differences in elevation between different areas causing a rain shadow effect (large amounts of rainfall in one area and very little on the opposite side of the mountainous terrain). Land cover in Xaignabouli consists of agricultural land (much of which is located in the south and northwest of the province), grassland, deciduous forest, and semi-evergreen and evergreen forest. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover or are covered by grassland.

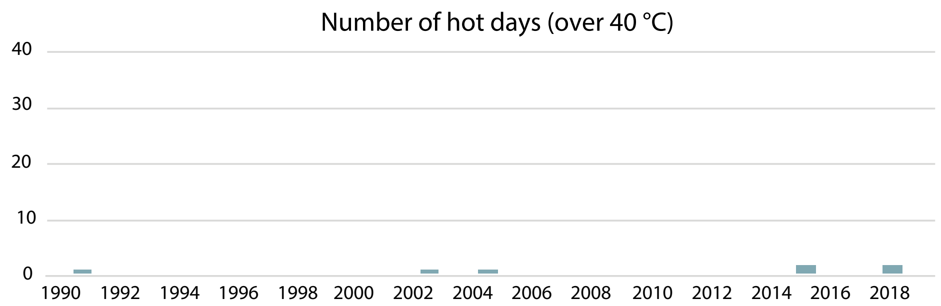
Climate change: Precipitation over the last 30 years

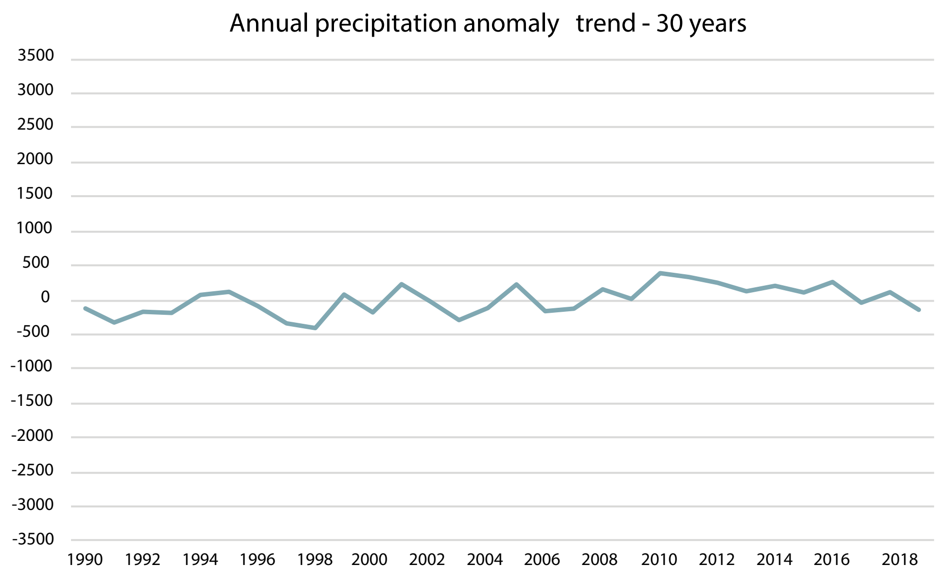




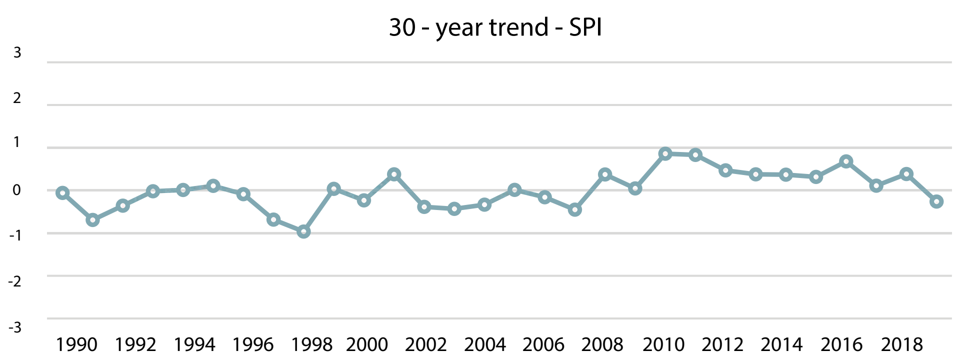
Xaignabouli climatology





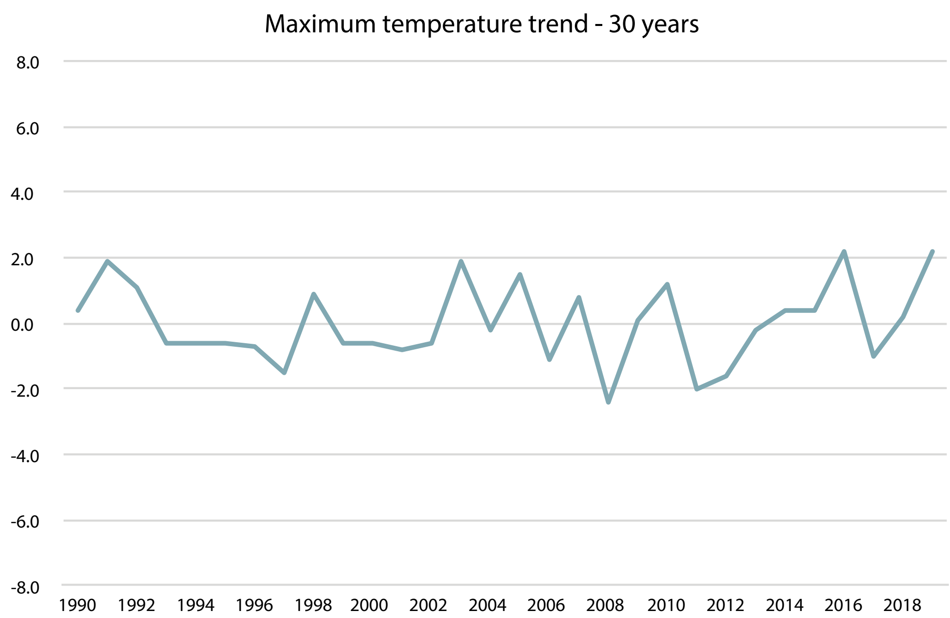


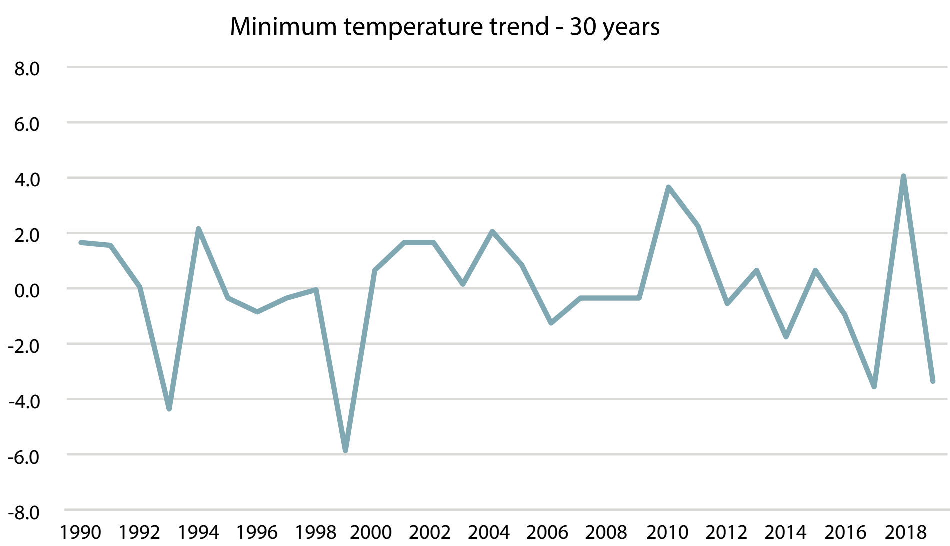
According to the 30 years of observation data on rainfall in Xaignabouli Province from the Xaignabouli weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has decreased, with the lowest number of dry days (215) recorded in 2010 and the highest number (267) in 2003. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has increased, with the smallest number (98 days) occurring in 2003 and the highest number (150 days) in 2010.



The trend analysis shows that precipitation levels have increased significantly - by 12 mm per year – over the 30 years, with 1998 seeing the lowest amount of annual rainfall (973.6 mm) and 2010 seeing the highest (1 770.8 mm). The SPI graph also suggests that there was a significant increase over this period, with the driest year occurring in 1998, and the wettest in 2010.

Climate change: Temperature over the last 30 years





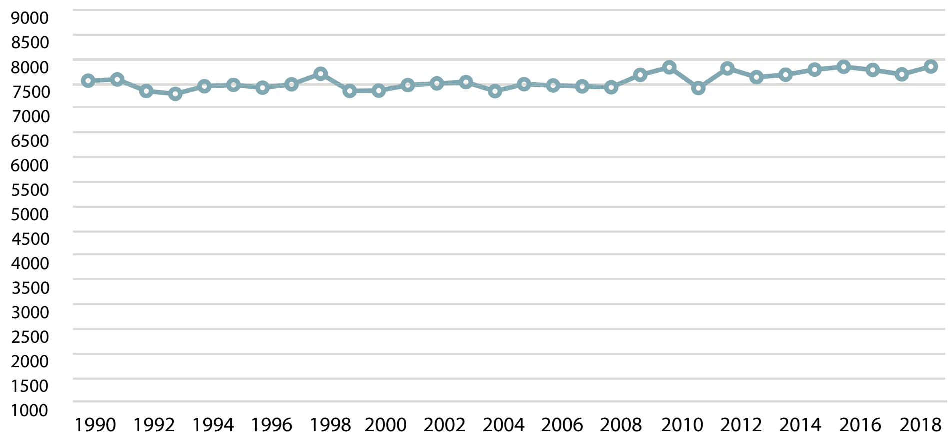
The 30 years of data on temperature conditions show that minimum temperatures have remained relatively stable, with these temperatures ranging from 14.88 °C to 24.45 °C. Maximum temperatures, meanwhile, have increased, with these temperatures ranging from 27.17 °C to 34.14 °C. The number of days on which the temperature exceeded 40 °C began to appear more frequently as of 2003; and the number of days on which it exceeded 37 °C increased over the period to reach a high of 38 days in 2016, indicating an increased risk of heatwaves.

Xaignabouli agroclimatology

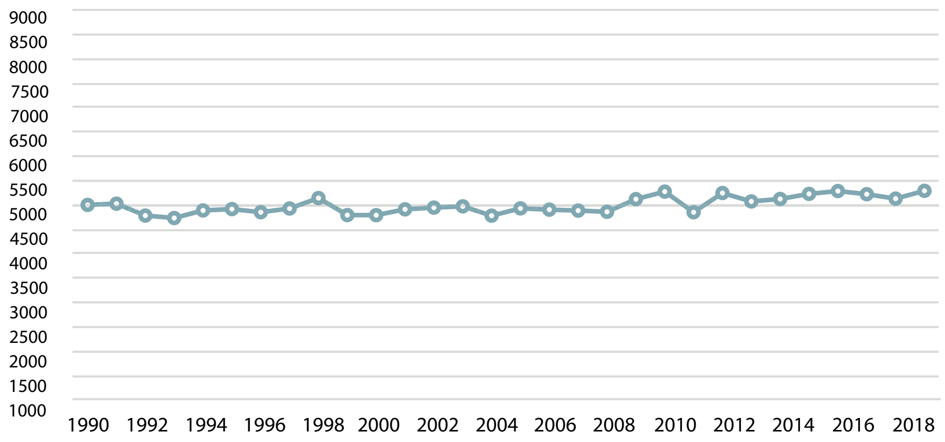
Agroclimatology

Looking at the growing degree days (GDDs) over 10°C reveals that heat accumulation has increased significantly over the 30 years (1990–2019) at a rate of 13 °C per year from a low of 4 734 °C in 1993 to a high of 5 291 °C in 2019, which has had a significant impact on the development cycle of crops, pests and diseases in the province.

Growing degree days above 5 °C

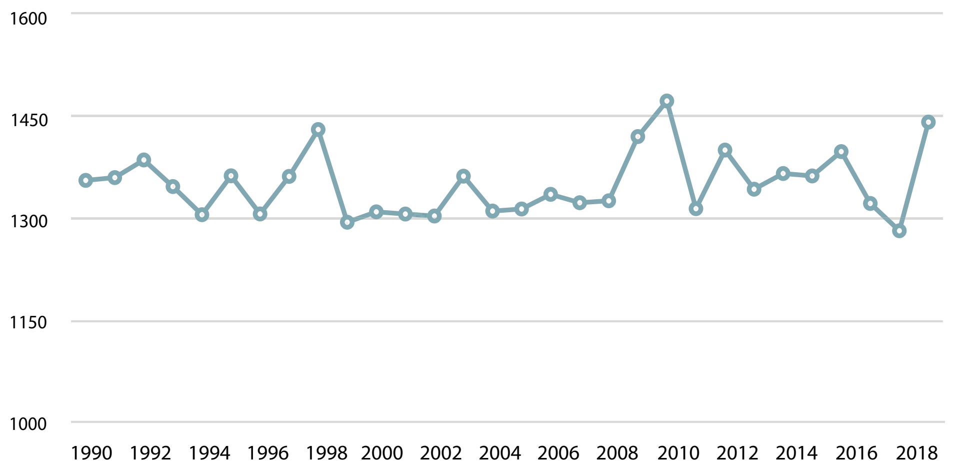


Growing degree days above 10 °C

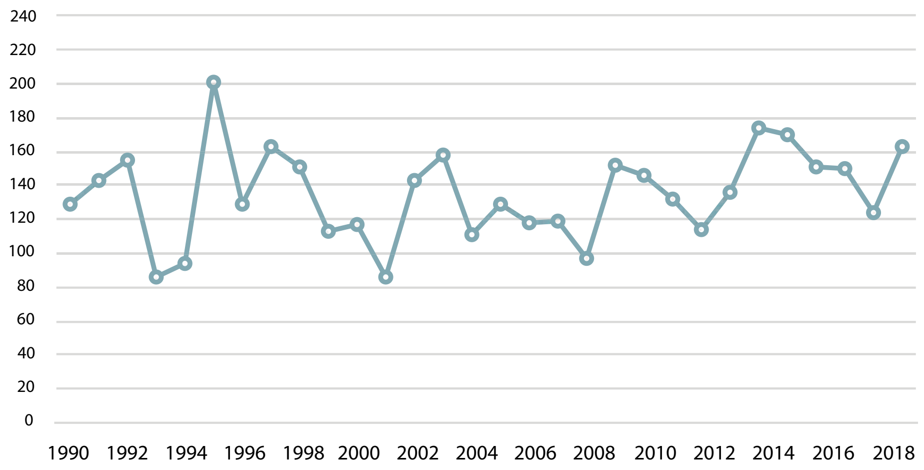


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Prepare and plant	Maintenance		Harvest								Prepare and plant
Steep slope agriculture				Prepare and plant		Maintenance			Harvest			
Orchards and plantations	Harvest			Prepare and plant		Maintenance						
Maizes				Prepare and plant		Maintenance				Harvest		
Annual crops and grasslands	Prepare/ Plant/ Maintain/ Harvest											
Cassava	Harvest			Prepare and plant		Maintenance						

Annual total ETp



30 - year trend - monsoon onset date



Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with the lowest ETp value recorded in 2018 and the highest in 2010. Similarly, the date of the onset of the monsoon has not changed significantly; the earliest start date occurred in 1993, and the latest in 1995.

Louangphabang »

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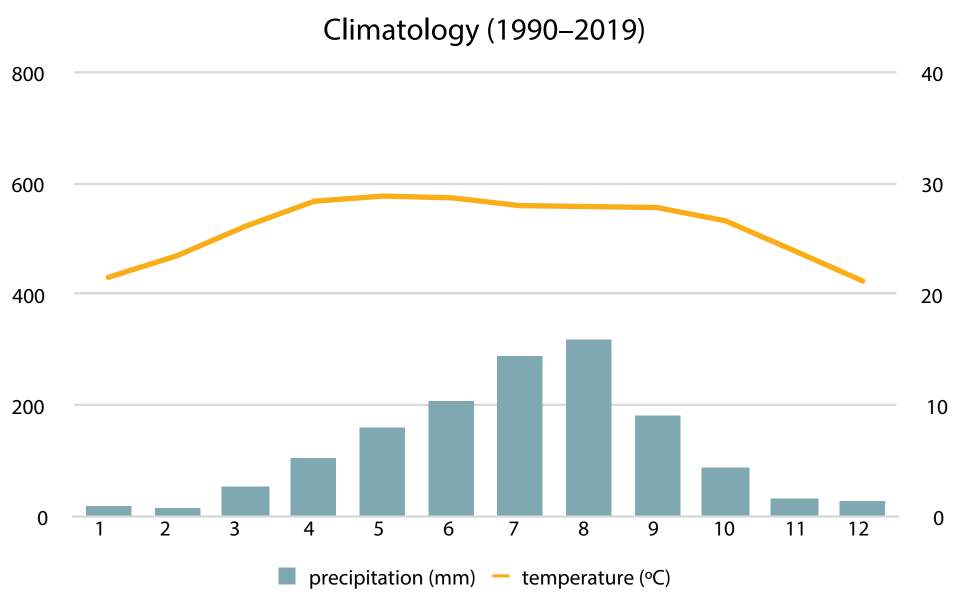
Louangphabang climatology



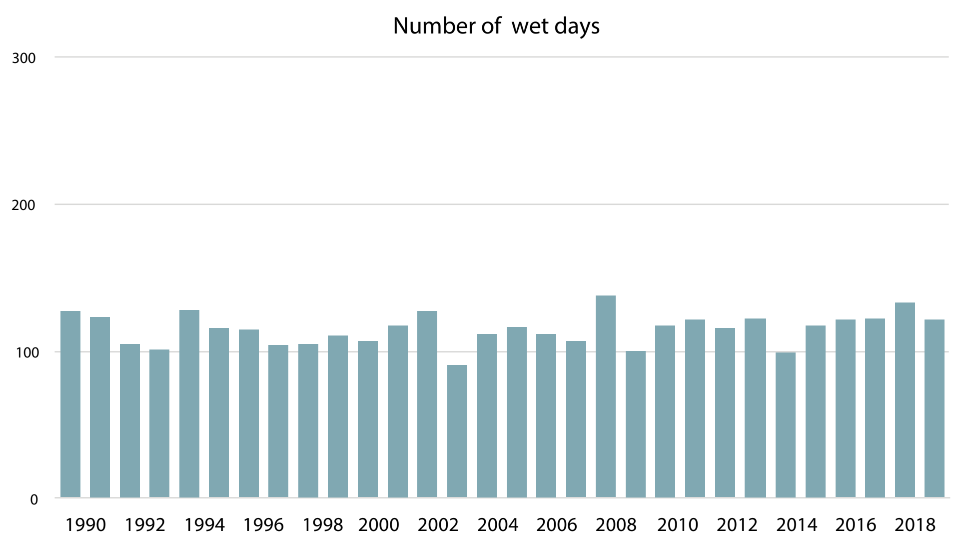
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	16	22	28.4	14.6
Feb	12	23	31.7	15.3
Mar	51	26	34.0	18.3
Apr	106	28	35.2	21.5
May	162	29	34.3	23.2
Jun	207	29	33.2	24.0
Jul	275	28	32.1	23.9
Aug	305	28	32.1	23.8
Sep	183	28	32.4	23.2
Oct	94	27	31.7	21.3
Nov	33	24	29.6	17.9
Dec	24	21	27.4	14.8

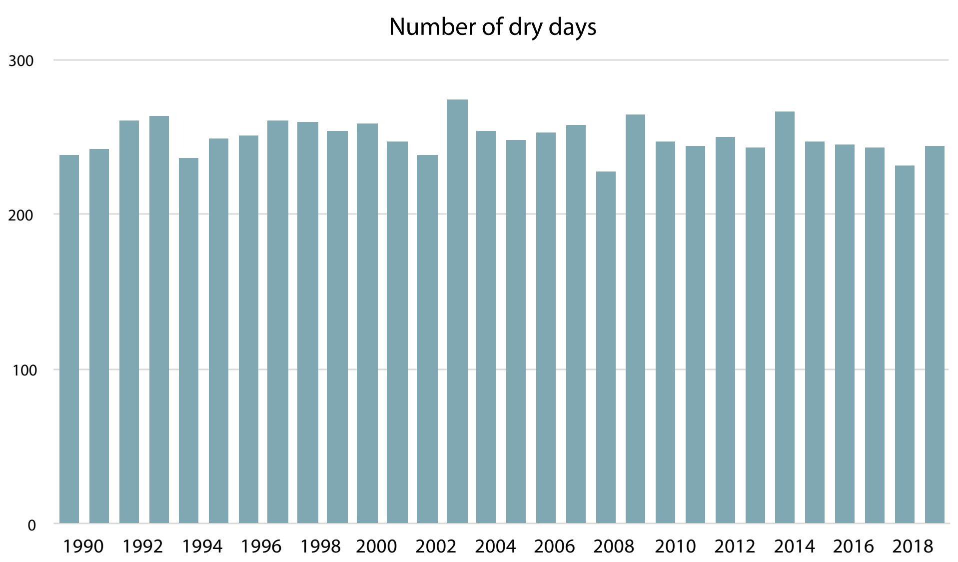
Louangphabang is found in the northwest of the Lao People's Democratic Republic, a region that also includes the provinces of Louangnamtha, Bokeo, Xaignabouli and Oudomxay. The climatology for the province shows that the rainy season starts in May and continues to September. There is a lot of rainfall during this period, with most rain falling in August (320.16 mm). After this, the amount of precipitation decreases until it reaches a low of 13.5 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C, starting from November and continuing to January of the following year. Louangphabang is the warmest of the five northwestern provinces, and is generally considered as having a warm climate. At the Houay Khot weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 14.75 °C to 35.27 °C, the minimum temperature range was 14.75 °C to 24.07 °C, and the maximum temperature range was 27.38 °C to 35.27 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Louangphabang start to decrease from October to January during the Northeast Monsoon. Maximum temperatures start to increase from mid-January and reach their peak level of 35.27 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase in mid-January, reaching a high of 24.07 °C in June before starting to fall again. Increases in minimum and maximum temperatures between March and August are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (320.16 mm) falling in August in Louangphabang.

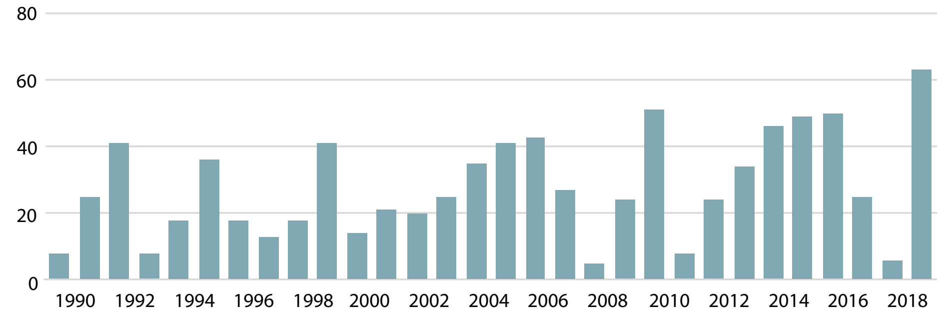
Land cover in the province ranges from forest to mountains depending on each area's geographic location. Vegetative land cover ranges from grassland to deciduous, semi-evergreen or evergreen forest depending on the precipitation levels in each area. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover or are covered by grassland.

Climate change: Precipitation over the last 30 years

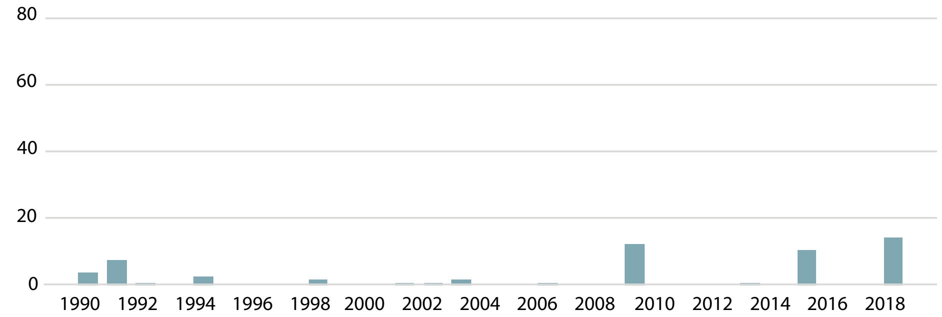




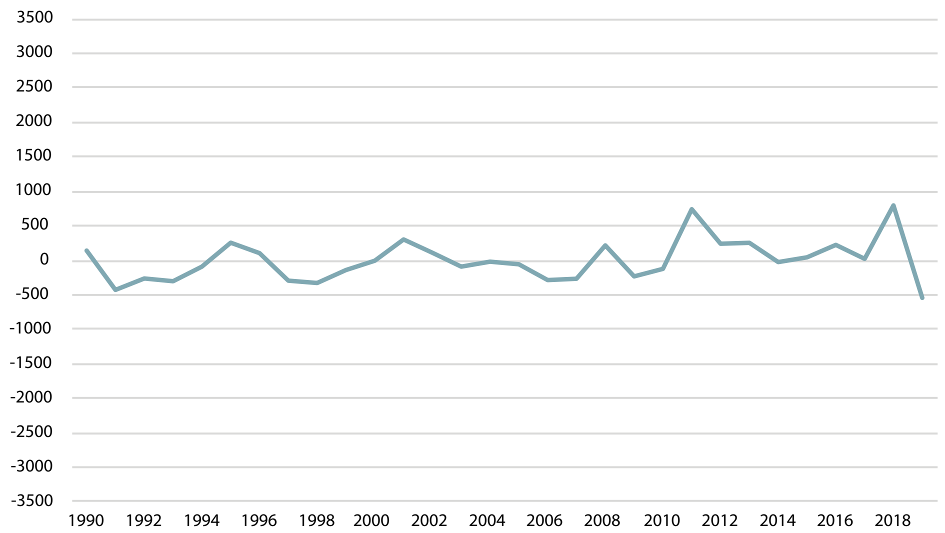
Louangphabang climatology



Number of hot days (over 37 °C)

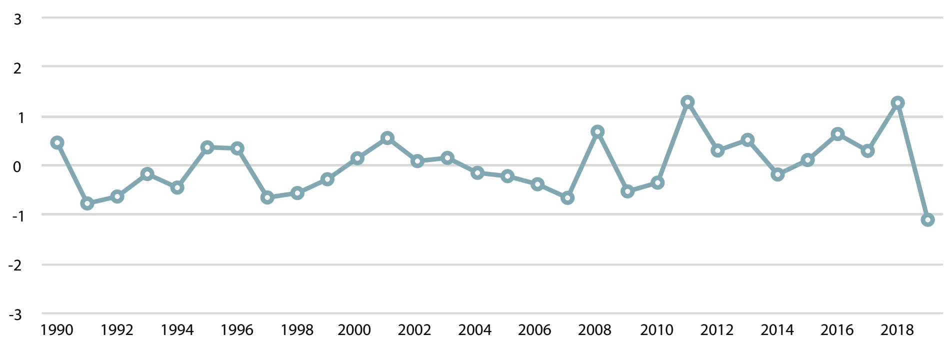


Number of hot days (over 40 °C).



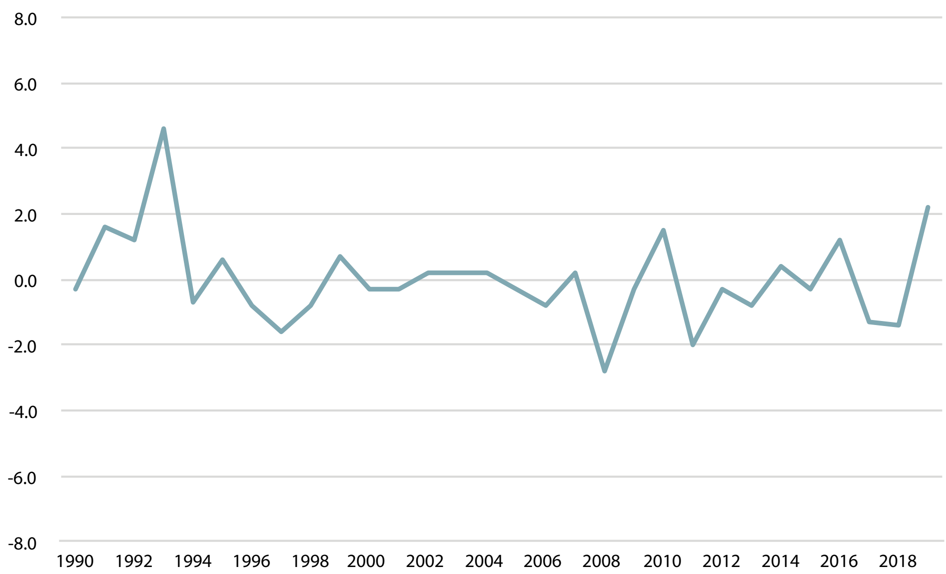
Annual precipitation anomaly trend - 30 years

According to the 30 years of observation data on rainfall in Louangphabang Province from the Houay Khot weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has slightly decreased, with the lowest number of dry days (228) recorded in 2008 and the highest number (274) in 2003. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has slightly increased, with 2003 seeing the smallest number of wet days (91) and 2008 seeing the highest number (138). The trend analysis shows that precipitation levels have increased over the 30 years, with the lowest amount of rainfall recorded as 948 mm (in 2019) and the highest as 2 288 mm (in 2018). The SPI graph also suggests that there was an increase over this period, with the driest year occurring in 2019, and the wettest in 2011.

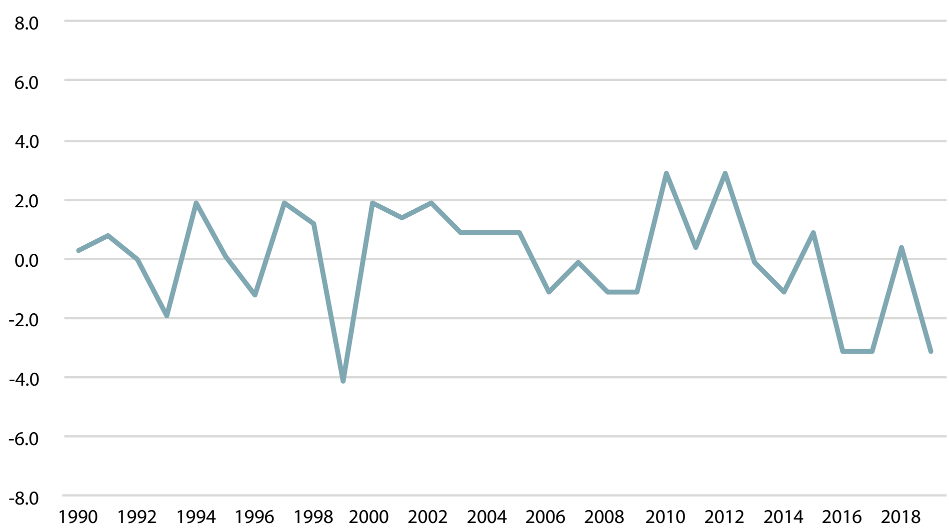


30 - year trend - SPI

Climate change: Temperature over the last 30 years



Maximum temperature trend - 30 years



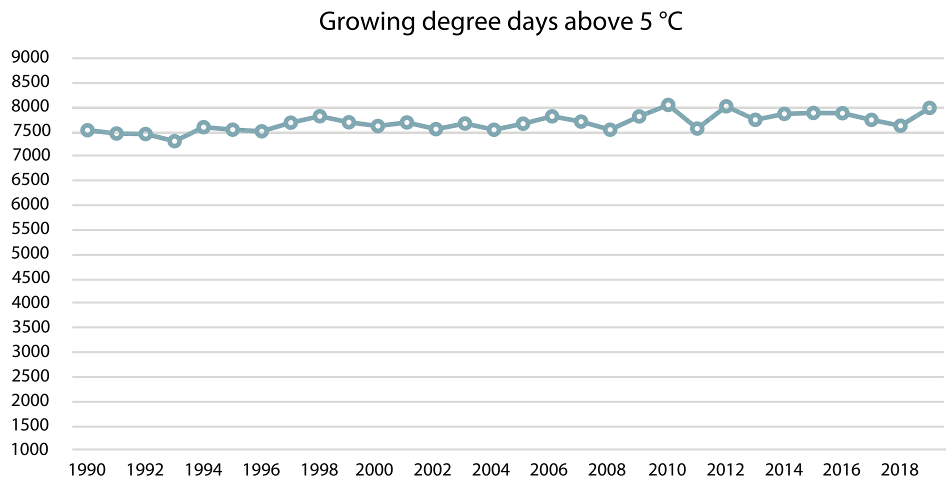
Minimum temperature trend - 30 years

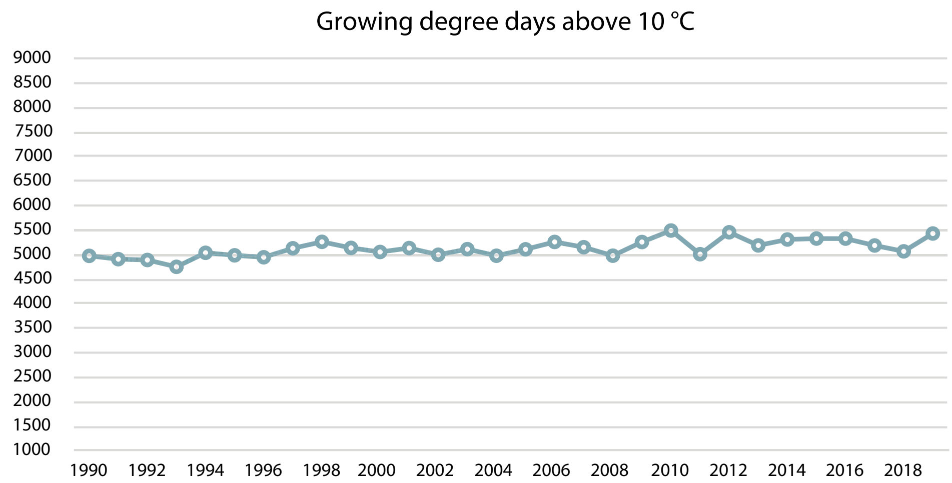
The 30 years of data on temperature conditions show that temperatures have remained relatively stable, with annual minimum temperatures ranging from 14.75 °C to 24.07 °C and maximum temperatures ranging from 27.38 °C to 35.27 °C. The number of days on which the temperature exceeded 40 °C increased over the period to reach a high of 15 days in 2019. Similarly, the number of days on which the temperature exceeded 37 °C also increased, with a high of 63 days occurring in 2019, indicating an increased risk of heatwaves.

Louangphabang agroclimatology

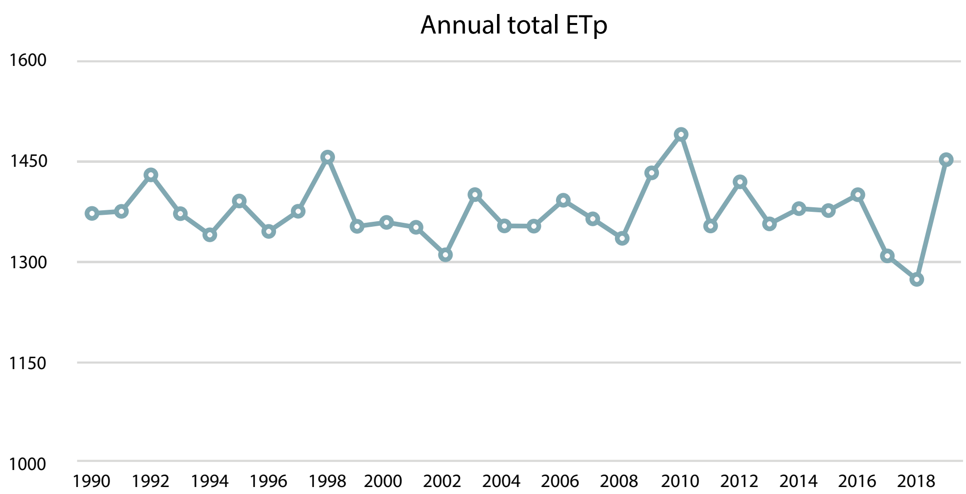
Agroclimatology

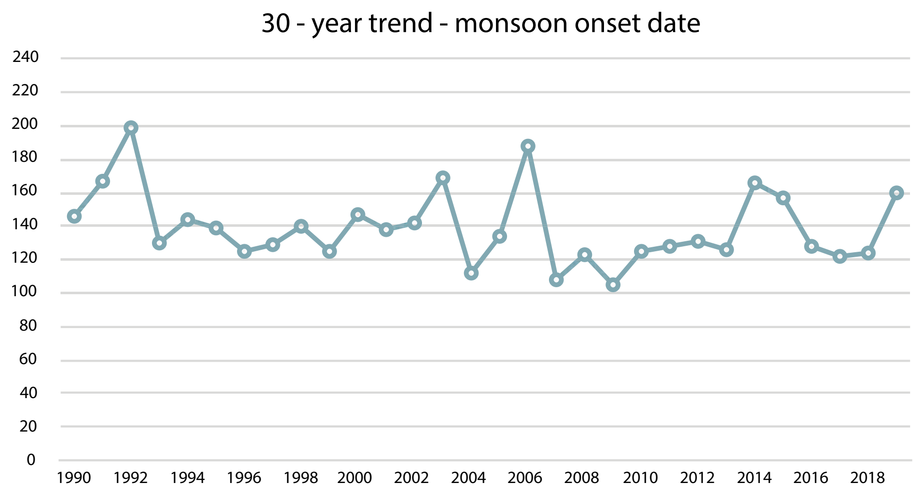
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation has significantly increased over the 30 years (1990–2019) at a rate of 13.8 °C per year from a low of 4 753 °C in 1993 to a high of 5 493 °C in 2010, which has had a significant impact on the development cycle of crops, pests and diseases in the province.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice						Prepare and plant			Maintenance		Harvest	
Irrigated rice	Prepare and plant		Maintenance		Harvest							
Maizes		Prepare and plant					Maintenance		Harvest			
Annual crops and grasslands	Prepare/ Plant/ Maintain/ Harvest											
Steep slope agriculture	Prepare and plant		Maintenance							Harvest		
Cassava	Harvest			Prepare and plant		Maintenance						Harvest
Orchards and plantations		Prepare and plant		Maintenance							Harvest	





Potential evapotranspiration (ETp), meanwhile, has remained relatively stable, with the lowest ETp value coming from 2018 and the highest from 2010. The monsoon onset does not show a significant trend: the latest date presented is in 2009, and the earliest presented is in 1992.

Houaphan »

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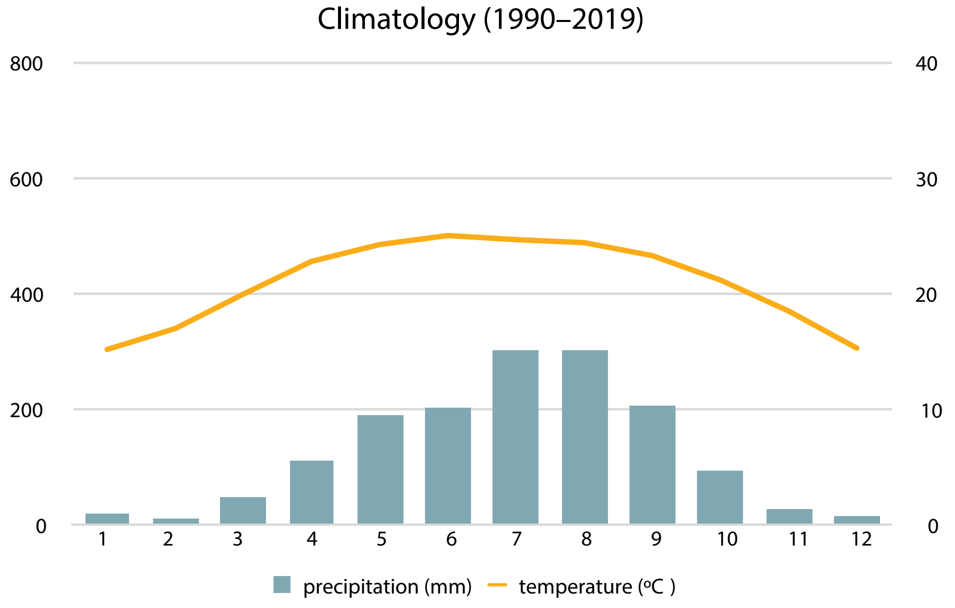
» Houaphan climatology



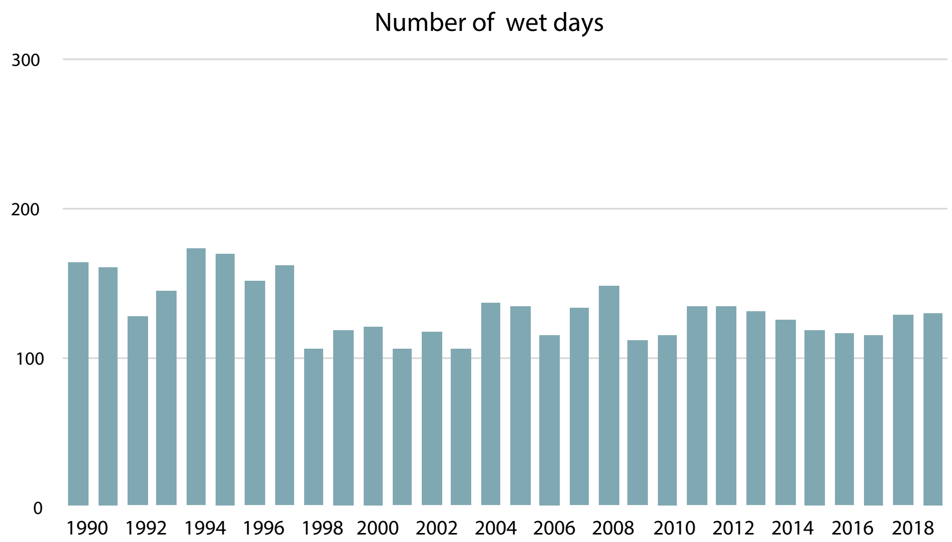
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	20	15	20.3	9.7
Feb	8	17	22.9	10.7
Mar	47	20	26.2	13.5
Apr	111	23	28.6	16.8
May	190	24	29.1	19.2
Jun	198	25	29.1	20.7
Jul	283	25	28.7	20.7
Aug	284	24	28.3	20.4
Sep	210	23	27.2	19.2
Oct	95	21	24.9	17.2
Nov	28	18	23.0	13.8
Dec	13	15	20.0	10.4

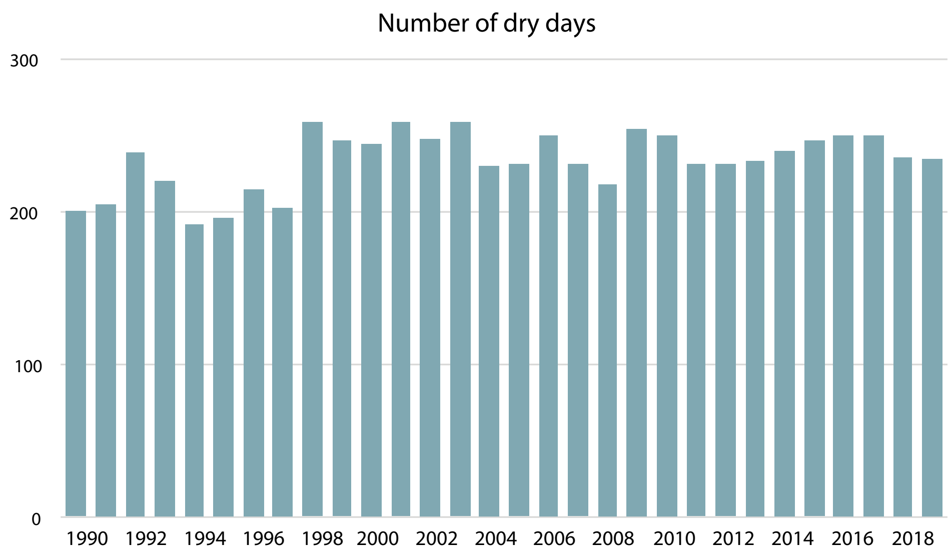
Houaphan is found in the northeast of the Lao People's Democratic Republic, a region that also includes the provinces of Phongsali and Xiangkhoang. The climatology for the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in July (301.33 mm). After this, the amount of precipitation decreases until it reaches a low of 8.47 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C during December and January of the following year. Houaphan has the second coldest temperature of the three northeast provinces, and is generally considered as having a cold climate. At the Xamnue weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 16.08 °C to 25.74 °C, the minimum temperature range was 15.45 °C to 17.09 °C, and the maximum temperature range was 23.96 °C to 27.12 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Houaphan start to decrease from the end of October to February during the Northeast Monsoon. Maximum temperatures start to increase from the end of January and reach their highest level of 27.5 °C in May during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid May to September). Minimum temperatures start to increase in March, reaching a high of 20.75 °C in June before starting to fall again. Increases in minimum and maximum temperatures between March and August are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (301.33 mm) falling in July in Houaphan.

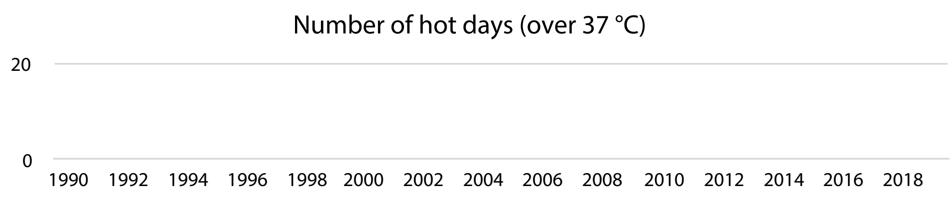
The province is located in a mountainous region with steep slopes and is covered with dense vegetation. There tend to be more areas dedicated to agriculture in the east of Houaphan, more dense forest (deciduous and evergreen) in the southeast, and more sparse vegetative cover (grassland and deciduous forest) in the north. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover or are covered by grassland.

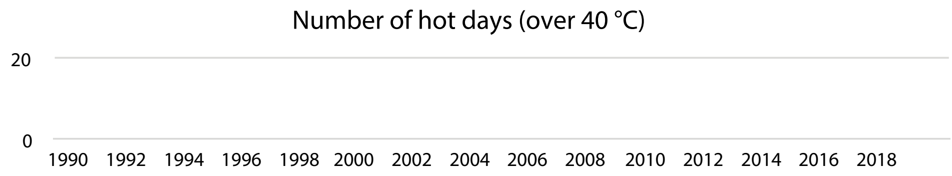
Climate change: Precipitation over the last 30 years

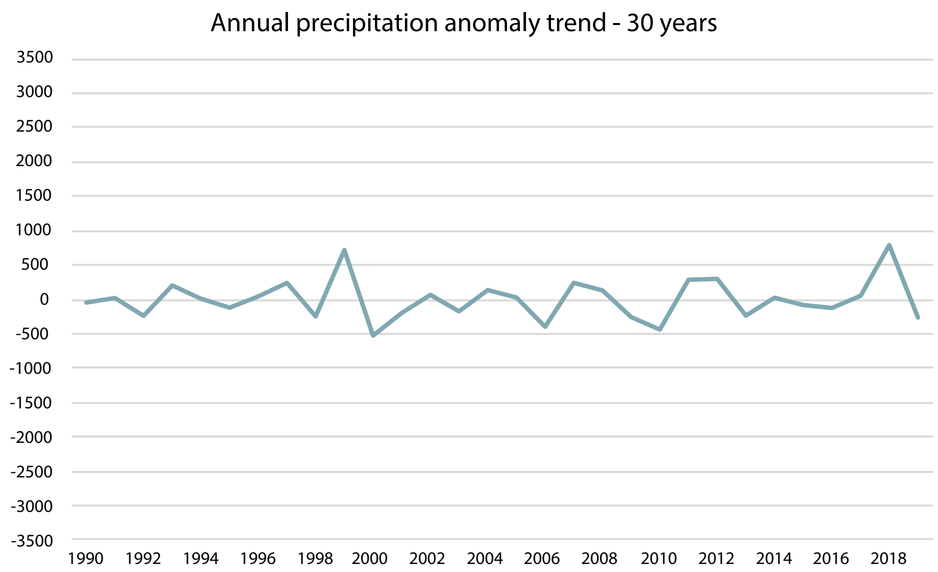




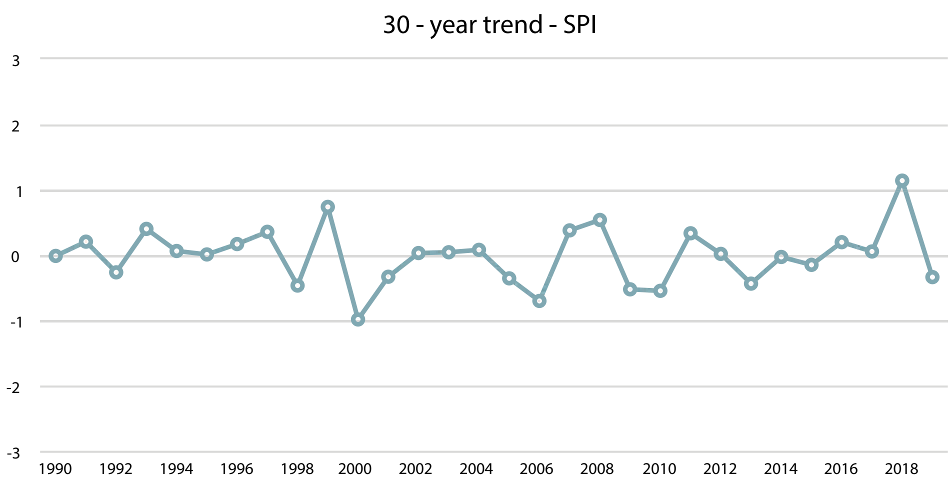
Houaphan climatology





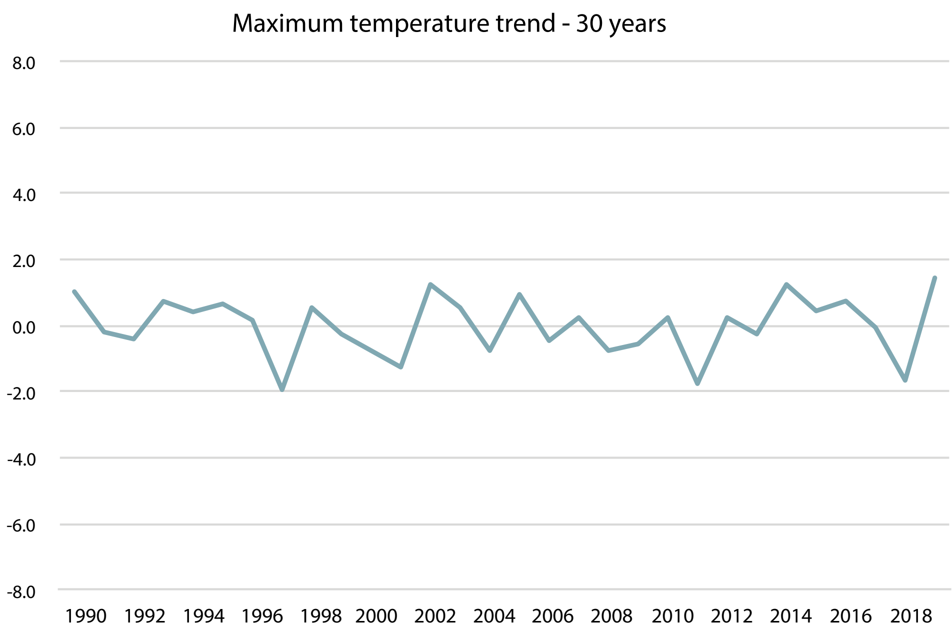


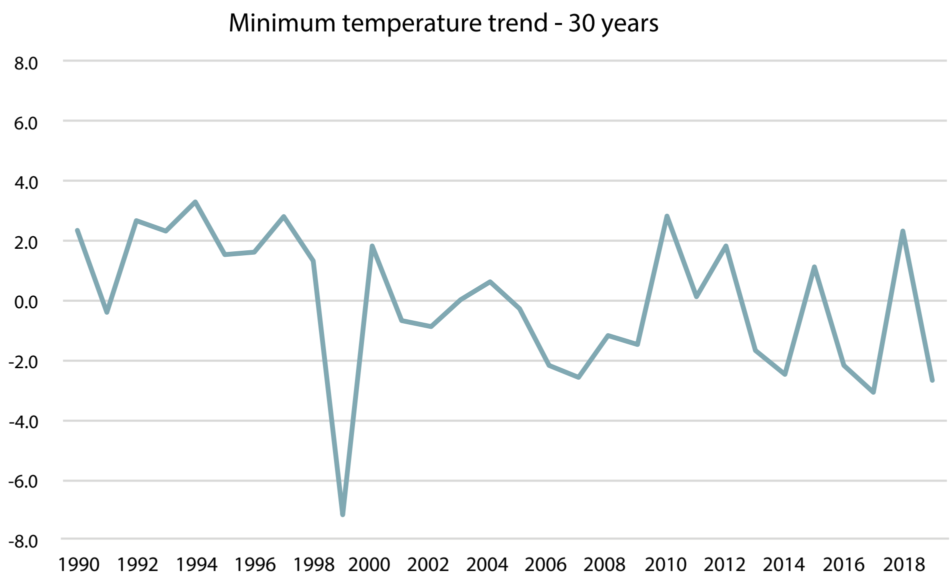
According to the 30 years of observation data on rainfall in Houaphan Province from the Xamnue weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has increased significantly, with the lowest number of dry days (192) recorded in 1994 and the highest (259 days) in 1998, 2001 and 2003. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has decreased, with the smallest number (106 days) occurring in 1998, 2001 and 2003, and the highest



number (173 days) in 1994. The trend analysis shows that precipitation levels have slightly increased over the 30 years, with 2000 seeing the lowest amount of rainfall (994 mm) and 2018 seeing the highest (2 311 mm). The SPI graph, however, reveals no significant increase or decrease, with the driest year occurring in 2000, and the wettest in 2018.

Climate change: Temperature over the last 30 years





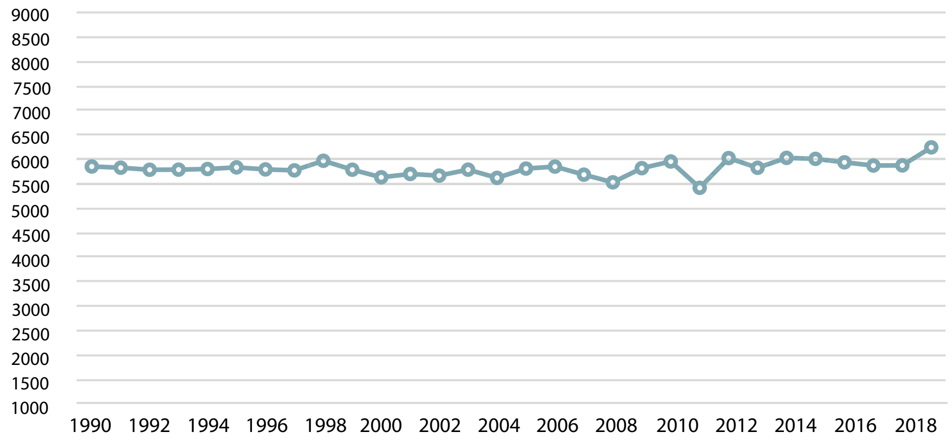
The 30 years of data on temperature conditions show that minimum temperatures have decreased significantly over the period at a rate of 0.1 °C per year, with annual averages ranging between 15.45 °C and 17.09 °C. Maximum temperatures, meanwhile, have remained stable, with annual averages ranging between 23.96 °C and 27.12 °C.

Houaphan agroclimatology

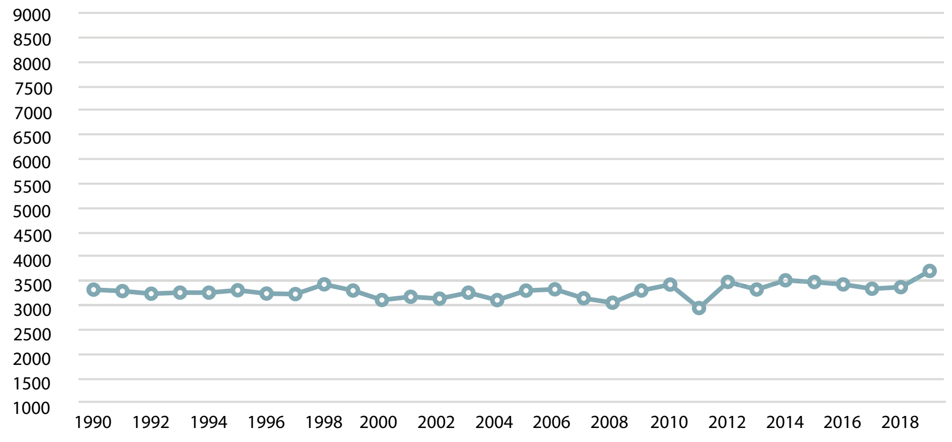
Agroclimatology

Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 6.6 °C per year from a low of 2 945 °C in 2011 to a high of 3 706 °C in 2019, resulting in a shorter development cycle for crops, pests and diseases.

Growing degree days above 5 °C



Growing degree days above 10 °C



<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Rainfed rice</td><td></td><td></td><td></td><td colspan="3">Prepare and plant</td><td colspan="4">Maintenance</td><td colspan="2">Harvest</td></tr>
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<tr><td>Cassava</td><td colspan="3">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="6">Maintenance</td><td>Harvest</td></tr>
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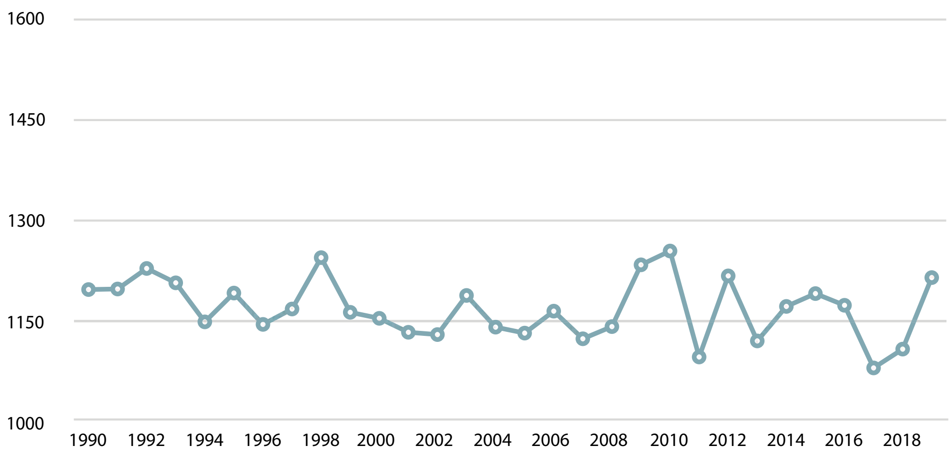
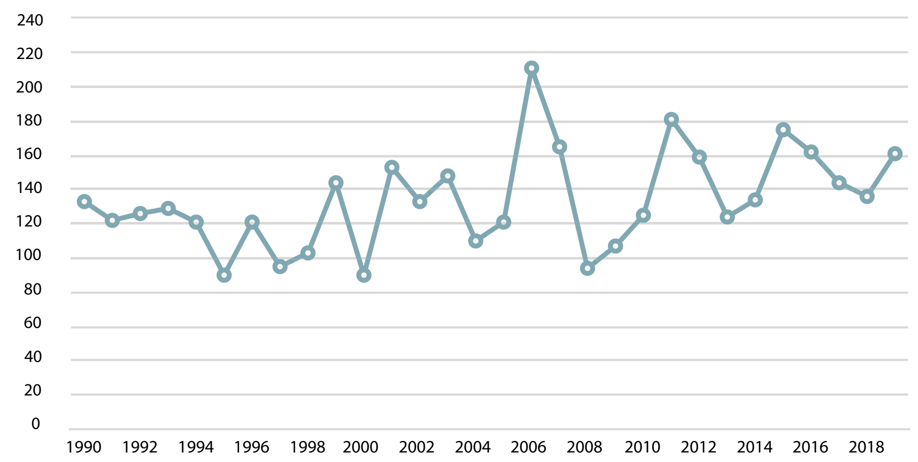
Annual total ETp



30 - year trend - monsoon onset date



Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with the lowest ETP value occurring in 2017 and the highest in 2010. The date of the onset of the monsoon now appears to occur significantly later than it did 30 years ago, with this delay increasing on average by 1.4 days per year, meaning that the seasonal rainfall needed for the cropping season also occurs later. The earliest start date for the monsoon was recorded in 2000, and the latest in 2006.

Xiangkhoang »

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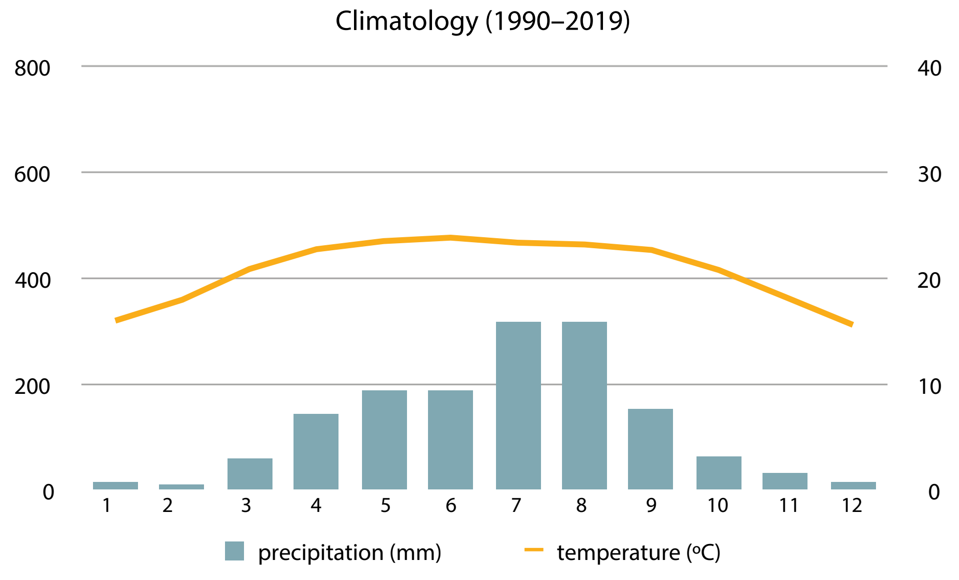
Xiangkhoang climatology



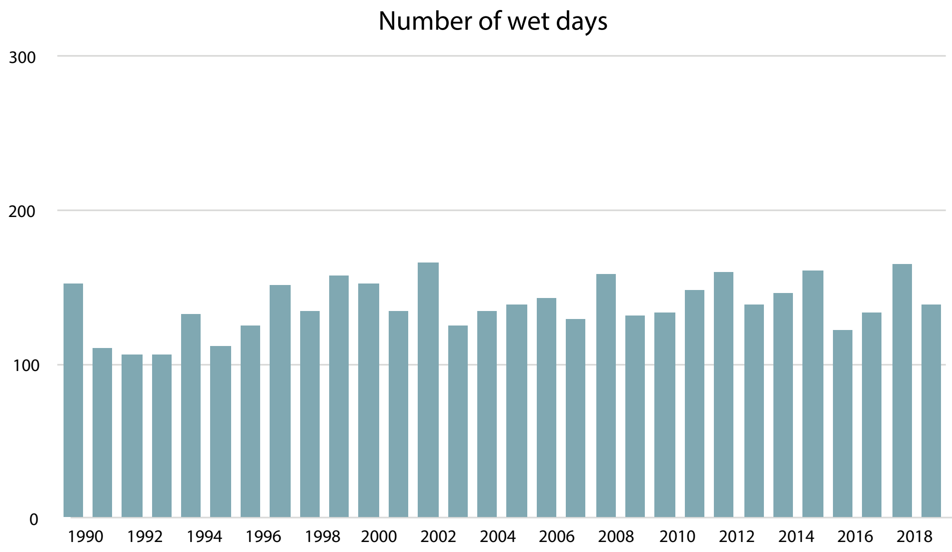
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	19	18	24.5	11.5
Feb	13	20	27.8	13.0
Mar	56	23	30.7	16.3
Apr	112	26	32.1	19.7
May	170	27	31.7	21.7
Jun	165	27	31.6	22.9
Jul	259	27	30.8	22.7
Aug	265	27	30.5	22.5
Sep	131	26	30.3	21.5
Oct	47	24	28.7	19.2
Nov	32	21	27.1	15.3
Dec	14	18	23.9	12.1

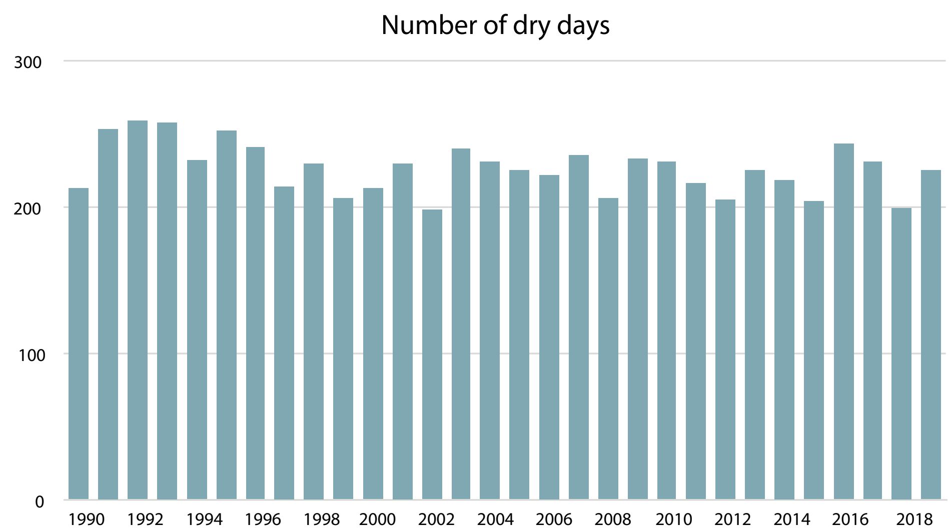
Xiangkhoang is found in the northeast of the Lao People's Democratic Republic, a region that also includes the provinces of Phongsali and Houaphan. The climatology for the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in July (317.5 mm). After this, the amount of precipitation decreases until it reaches a low of 10.82 mm in February of the following year. As monthly rainfall decreases, temperatures also fall below 20 °C from December to February of the following year. Xiangkhoang is the coldest of the three northeast provinces, and is generally considered as having a cold climate. At the Xiangkhoang weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 14.2 °C to 27.4 °C, the minimum temperature range was 14.2 °C to 16.5 °C, and the maximum temperature range was 25.0 °C to 27.4 °C.

The fact that the province has a mountainous topography with higher elevations means that it has lower temperatures compared to those in central and southern regions. According to the climatology graph, temperatures in Xiangkhoang start to decrease from the end of September to January during the Northeast Monsoon. Maximum temperatures start to increase from February and reach their highest level of 28.85 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from February, reaching a high of 20.1 °C in June before starting to fall again. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (317.5 mm) falling in July in Xiangkhoang.

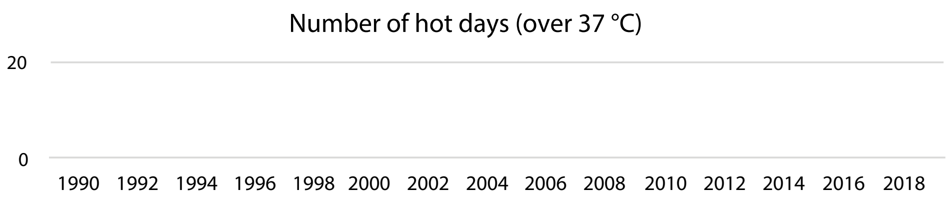
The province is situated in a mountainous region; flat, high land at elevations of 1000 m above mean sea level cover the west, making it suitable for agricultural production and dwelling places, while the rest of the province is mountainous with steep slopes and dense vegetation. Certain parts of the east of Xiangkhoang are low-lying (500-800 m above sea level) with large open areas containing farms and villages; the south of the province is covered by thick forest (deciduous and evergreen); and most areas in the north are covered by sparse vegetation, including grassland, shrubland, deciduous forest and, to a lesser extent, semi-evergreen forest. Most of the province is covered by mountains, which directly impacts monsoon wind flow, meaning that some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover.

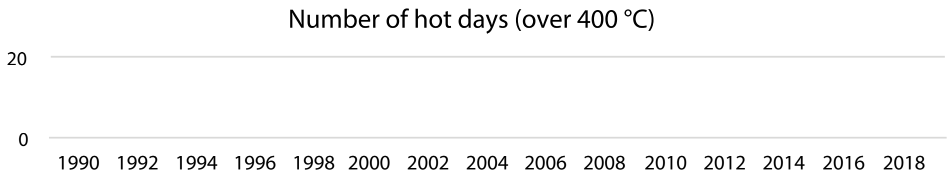
Climate change: Precipitation over the last 30 years

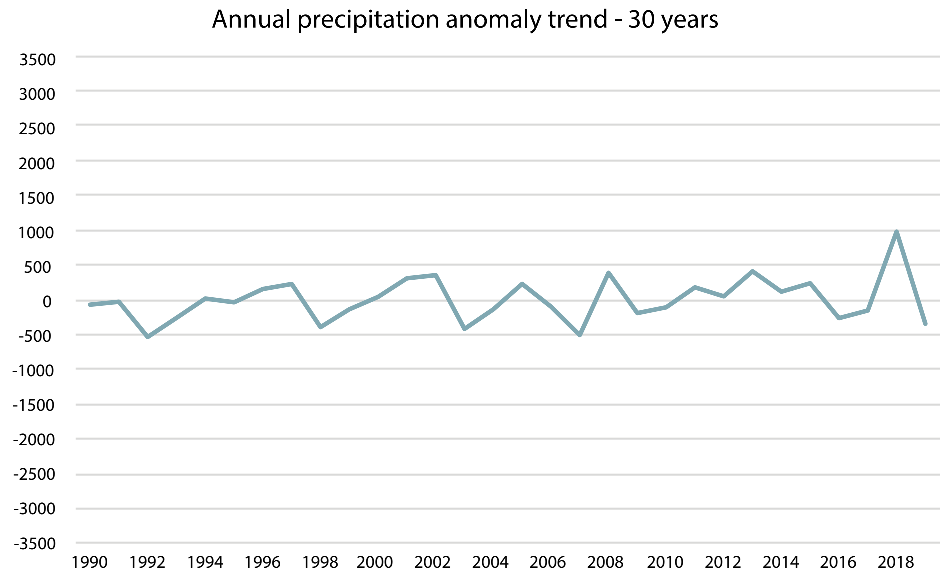




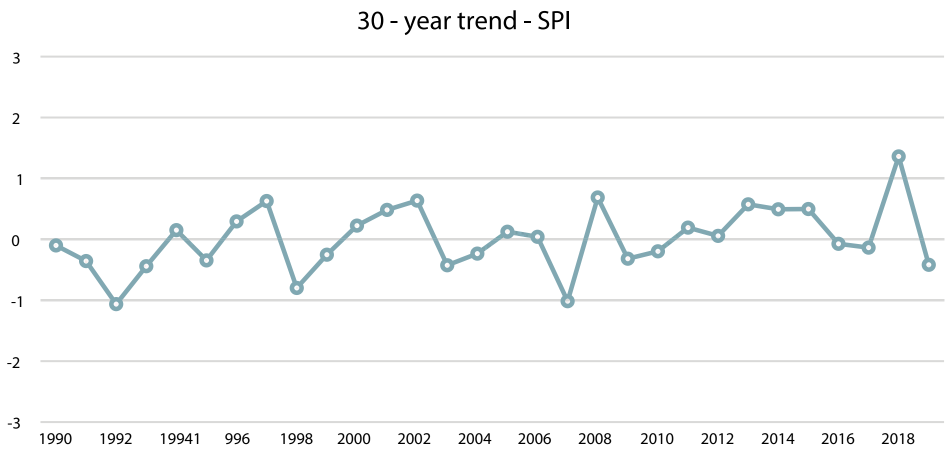
Xiangkhoang climatology





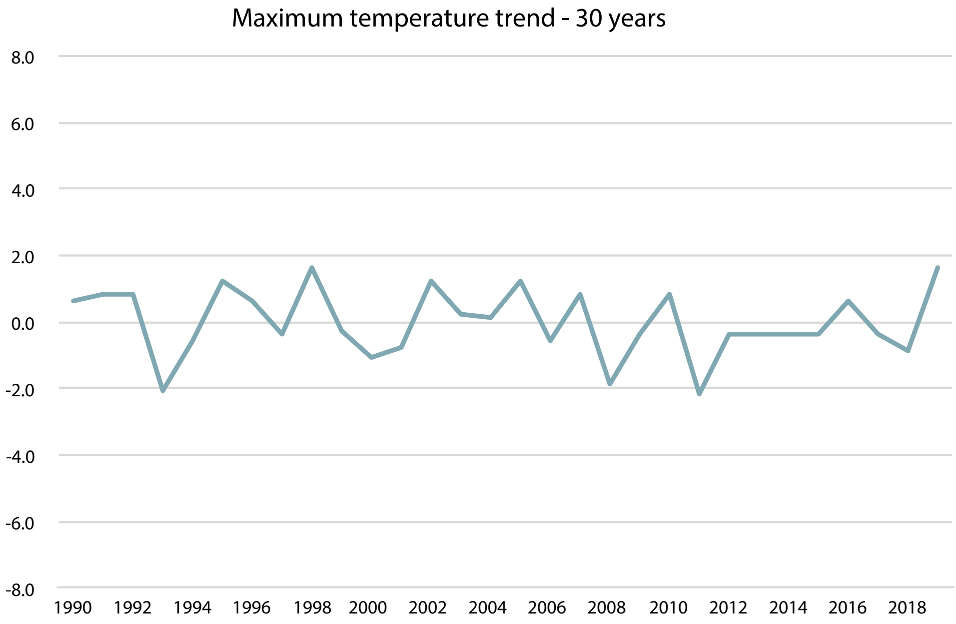


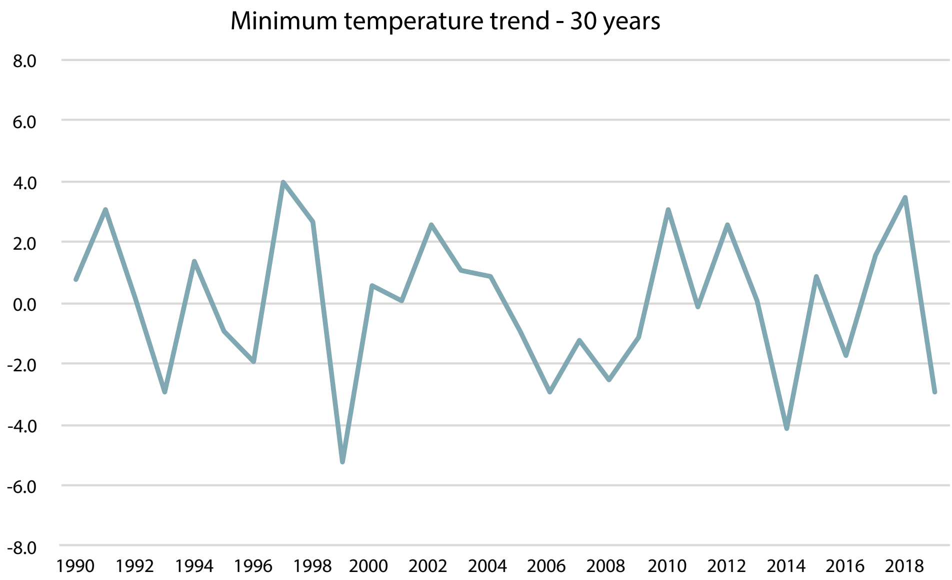
According to the 30 years of observation data on rainfall in Xiangkhoang Province from the Xiangkhoang weather observation station, the number of dry days (with less than 0.2 mm of rainfall) trend decreased significantly, with 2002 seeing the lowest number of dry days (199) and 1992 seeing the highest number (259). The number of wet days (with more than 0.2 mm of rainfall), meanwhile, increased, with the smallest number of wet days (107 days) occurring in 1992 and 1993, and the highest number



(166 days) in 2002. The trend analysis shows that precipitation levels have slightly increased over the 30 years, with the least amount of annual rainfall recorded as 974.5 mm (in 1992) and the highest amount as 2 487 mm (in 2018). The SPI graph, meanwhile, suggests that there has been a dramatic increase, with the driest year occurring in 1992, and the wettest year in 2018.

Climate change: Temperature over the last 30 years



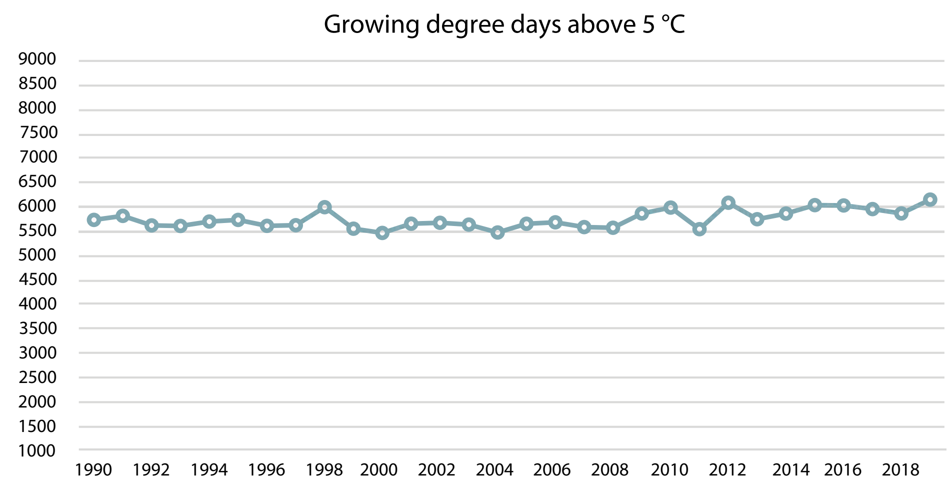


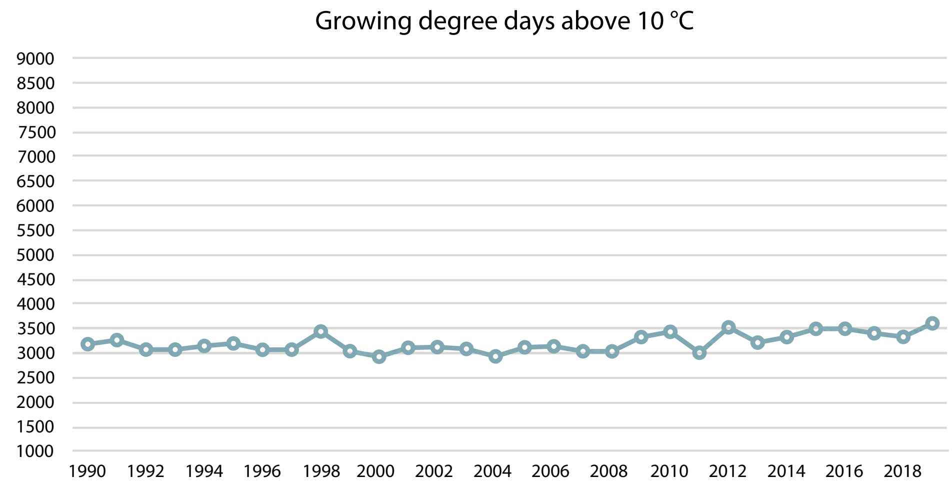
The 30 years of data on temperature conditions show that minimum and maximum temperatures have slightly increased, with annual averages for minimum temperatures ranging between 14.2 °C and 16.5 °C, and those for maximum temperatures ranging between 23.96 °C and 27.12 °C.

» Xiangkhoang agroclimatology

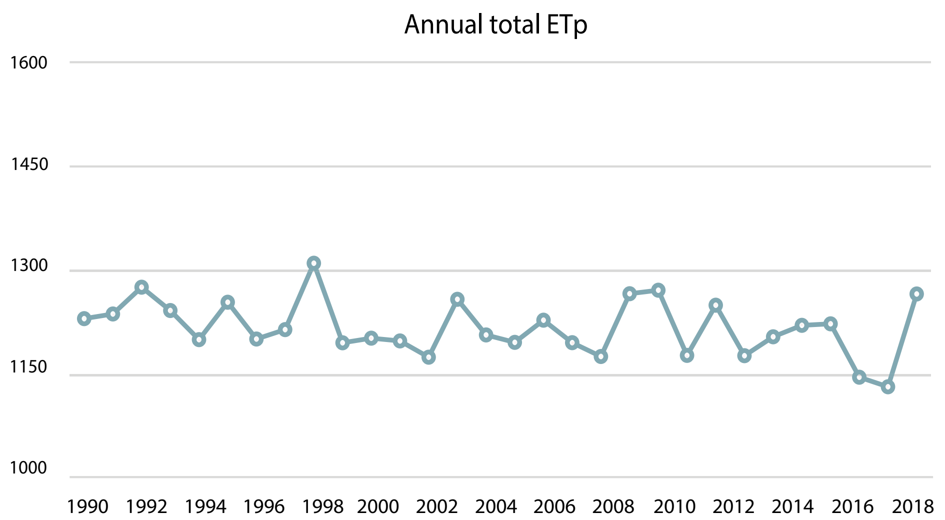
Agroclimatology

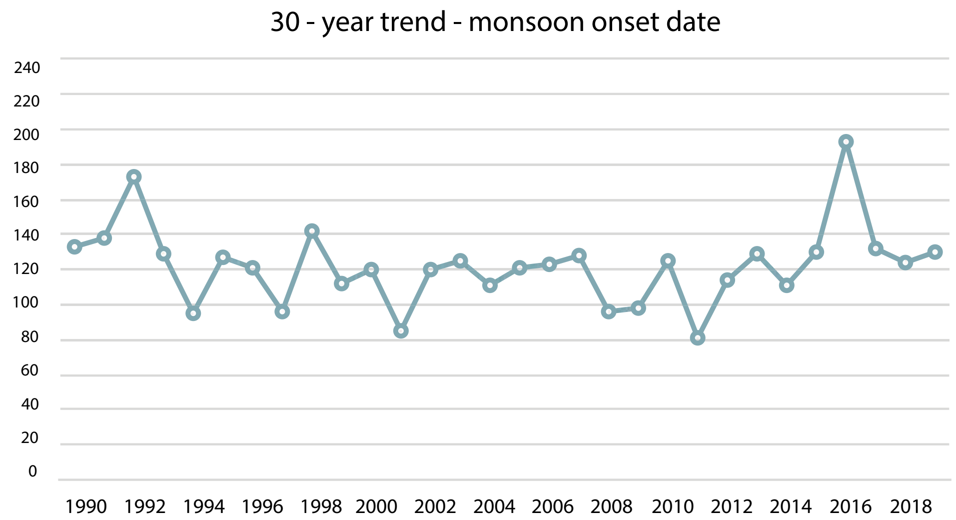
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 11.7 °C per year from a low of 2 929 °C (in 2000) to a high of 3 607 °C (in 2019), resulting in a shorter development cycle for crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Maintenance			Harvest							Prepare and plant	
Annual crops and grasslands	Prepare and plant			Maintenance			Harvest					
Orchards and plantations			Prepare and plant		Maintenance					Harvest		
Maizes				Prepare and plant		Maintenance					Harvest	
Coffee	Harvest		Prepare and plant		Maintenance					Harvest		





Potential evapotranspiration (ETP), meanwhile, has slightly decreased: the lowest ETp value occurred in 2018 and the highest in 1998. The date of the onset of the monsoon does not appear to have changed significantly over the period, with the earliest start date recorded in 2011, and the latest in 2016.

Vientiane Province »

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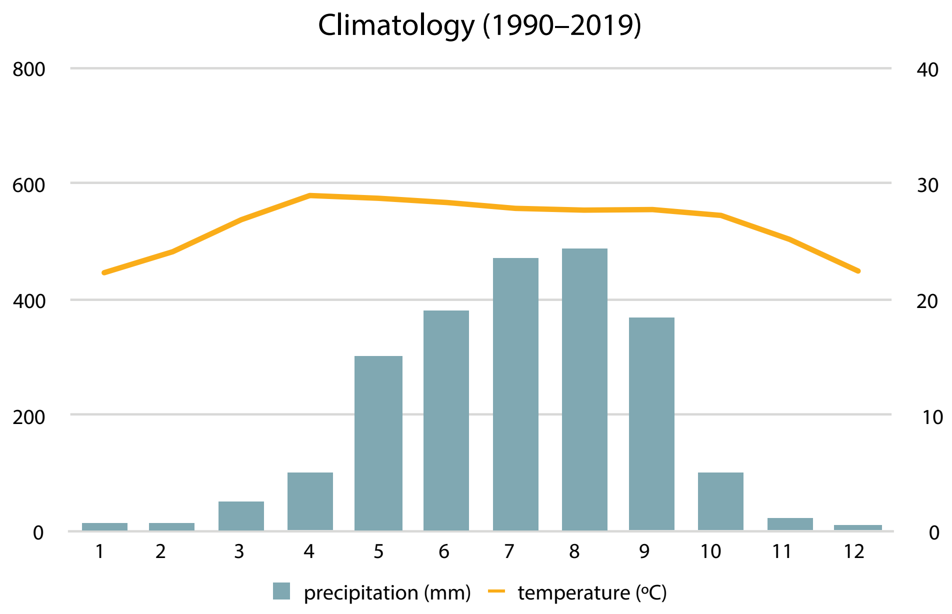
Vientiane province climatology



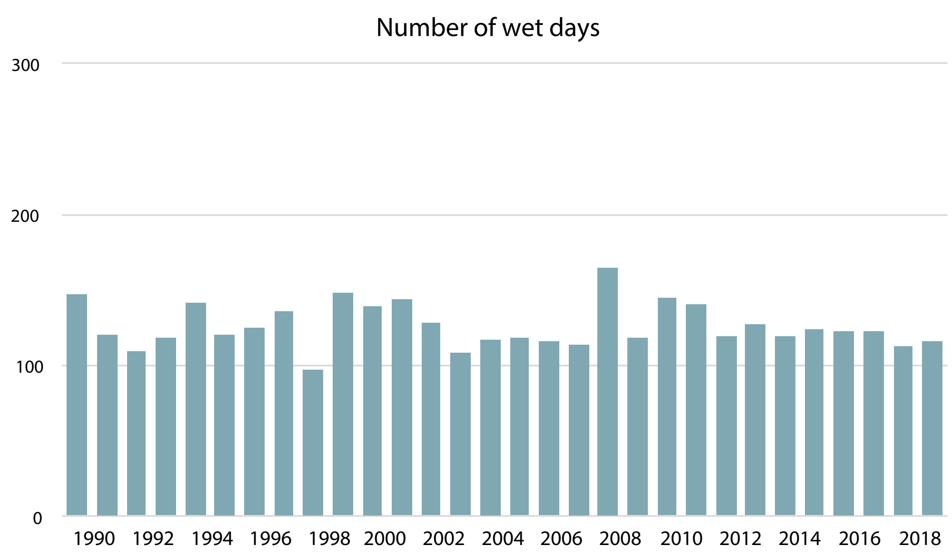
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	19	18	24.5	11.5
Feb	13	20	27.8	13.0
Mar	56	23	30.7	16.3
Apr	112	26	32.1	19.7
May	170	27	31.7	21.7
Jun	165	27	31.6	22.9
Jul	259	27	30.8	22.7
Aug	265	27	30.5	22.5
Sep	131	26	30.3	21.5
Oct	47	24	28.7	19.2
Nov	32	21	27.1	15.3
Dec	14	18	23.9	12.1

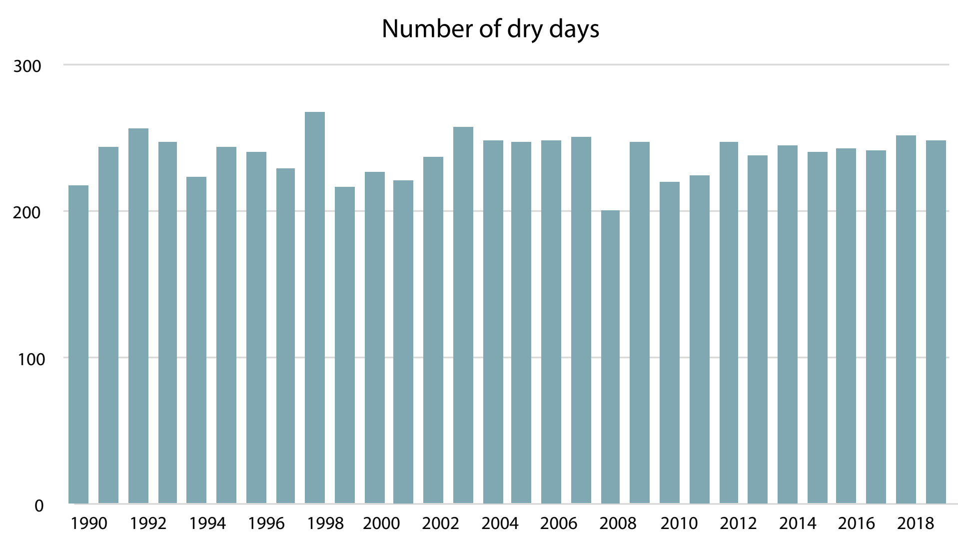
Vientiane Province is found in the centre of the Lao People's Democratic Republic, a region that also includes the provinces of Vientiane Capital, Bolikhamxai, Khammouan, Xaisomboun and Savannakhet. The climatology for the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in August (486.08 mm). After this, the amount of precipitation decreases until it reaches a low of 8.94 mm in December and February. As monthly rainfall decreases, temperatures also fall below 20 °C from November to February of the following year. Vientiane Province is the third warmest of the six central provinces, and is generally considered in Laos as having a warm climate. At the Phonhong weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 15.76 °C to 34.7 °C, the minimum temperature range was 15.7 °C to 24.7 °C, and the maximum temperature range was 28.7 °C to 34.7 °C.

The fact that most areas of Vientiane Province are located on a plain at low elevations means that it has warmer temperatures compared to provinces in the north of the country. According to the climatology graph, temperatures in the province start to decrease from November to mid-February during the Northeast Monsoon. Maximum temperatures start to increase from February and reach their highest level of 34.7 °C in April during the spring transition (mid-March to midMay), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from February, reaching a high of 24.7 °C in June before starting to fall again. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (486.08 mm) falling in August in Vientiane Province.

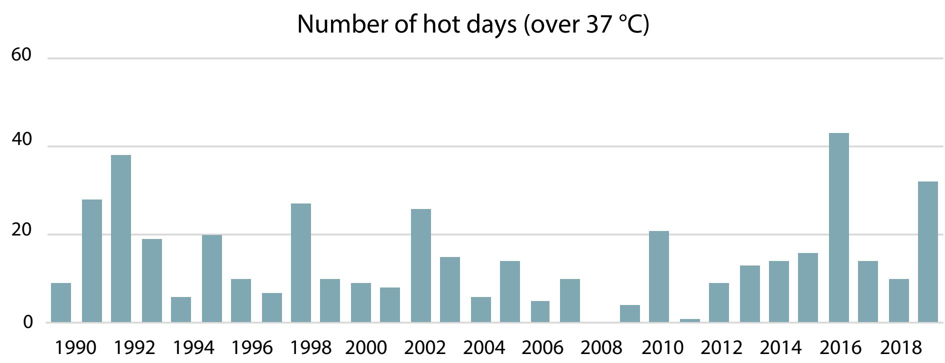
The province is located in the centre of the country next to Vientiane Capital and, to the east, Xaisomboun. Many areas, particularly in the south, are situated on a low-lying plain, making them suitable for agricultural production and dwelling places. The north is covered by rough mountainous terrain with thick deciduous and evergreen forest, while the southwest tends to have more sparse vegetation, such as grassland, deciduous forest and, to a lesser extent, semi-evergreen forest. The varying densities of the forests covering each area indicate differences in the availability of moisture and rainfall in those areas.

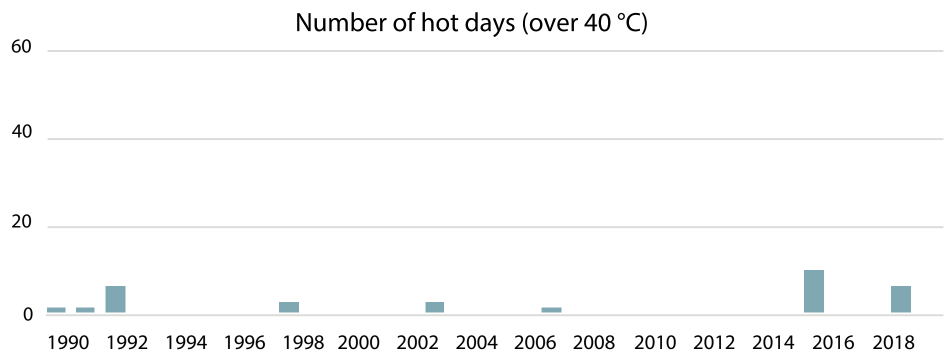
Climate change: Precipitation over the last 30 years

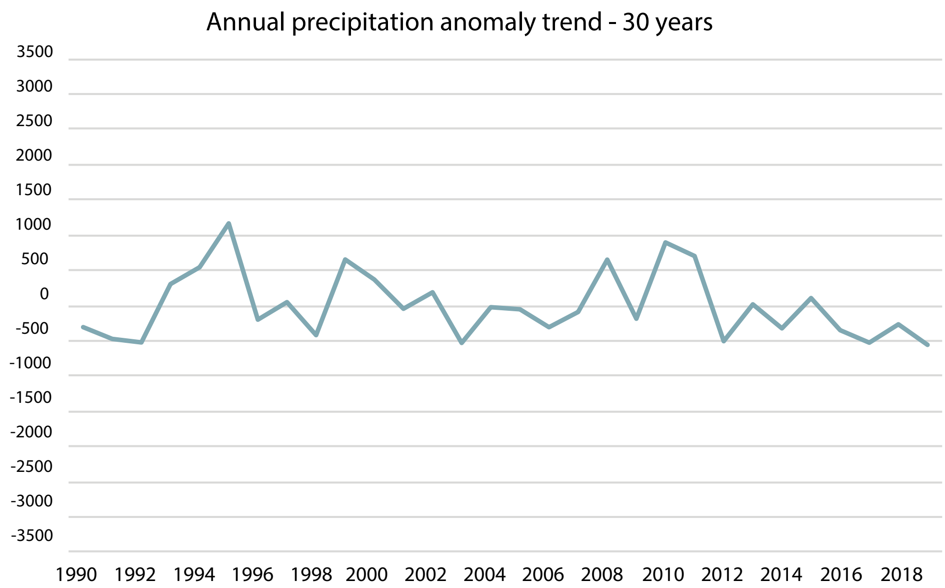




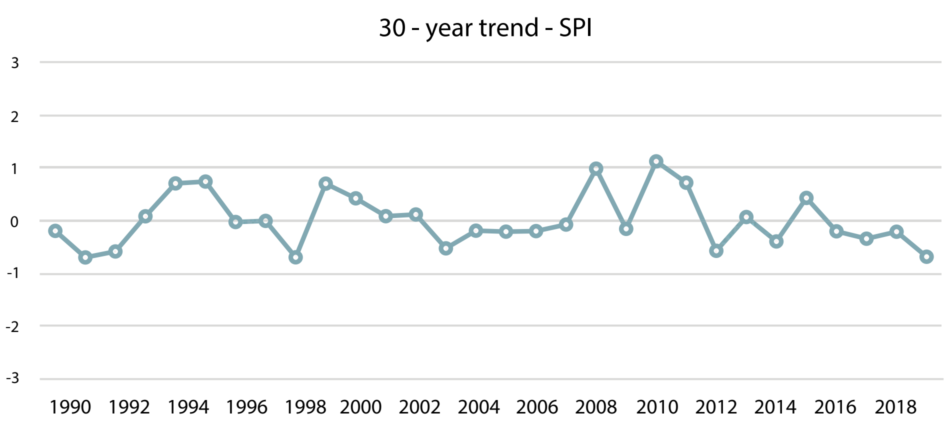
Vientiane province climatology



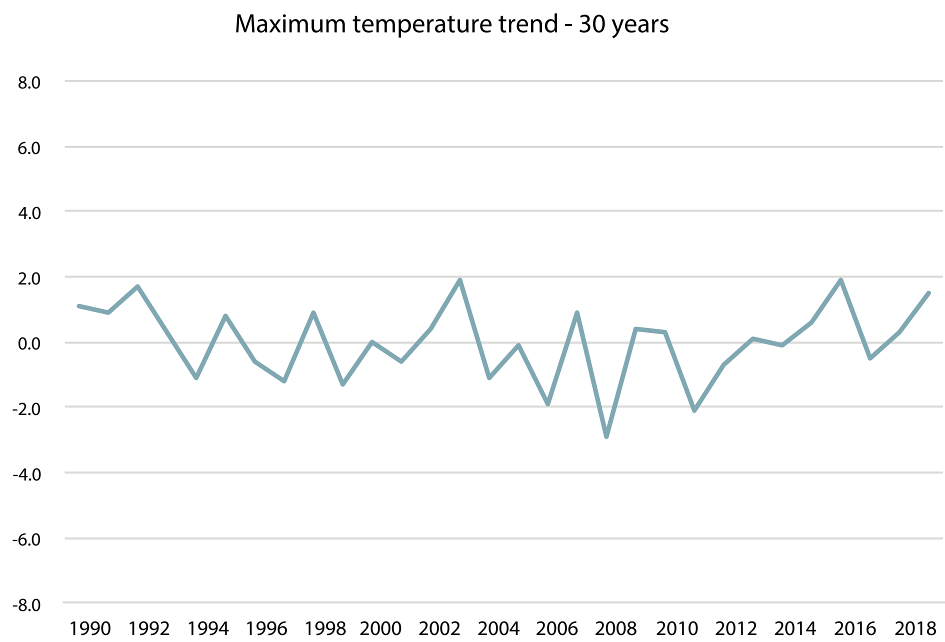


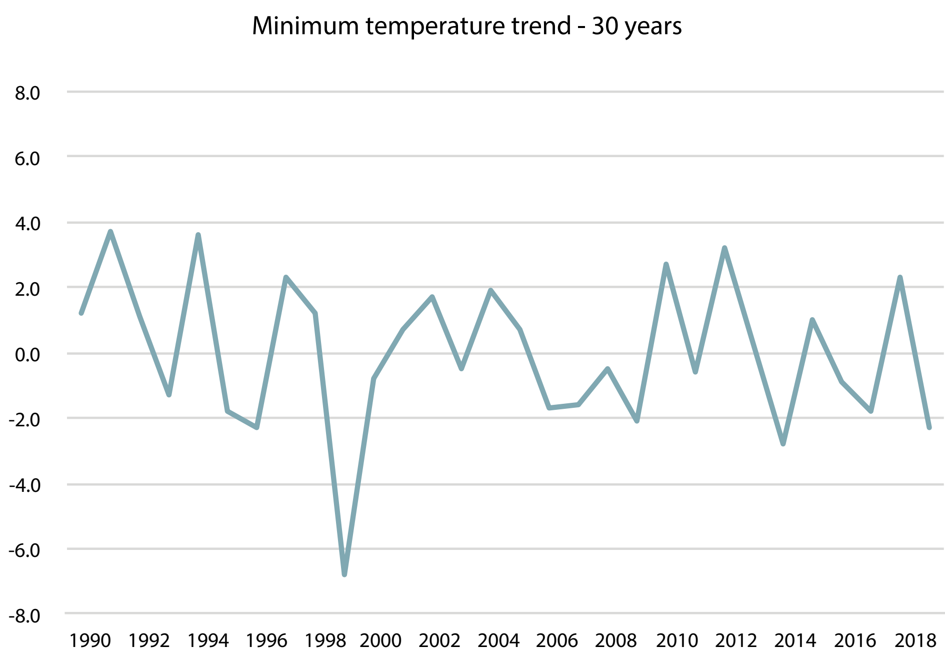


According to the 30 years of observation data on rainfall in Vientiane Province from the Phonhong weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has slightly increased, with the lowest number of dry days (201) recorded in 2008 and the highest number (268) in 1998. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has slightly increased, with the smallest number (97 days) in 1998 and the highest number (165 days) in 2008. The trend analysis shows that precipitation levels have decreased over the 30 years, the low being 1 765 mm (in 2019) and the highest being 3 488.2 mm (in 1995). The SPI graph, meanwhile, reveals no significant increase or decrease; the driest years were in 1991, 1998 and 2019, and the wettest year was in 2010.



Climate change: Temperature over the last 30 years



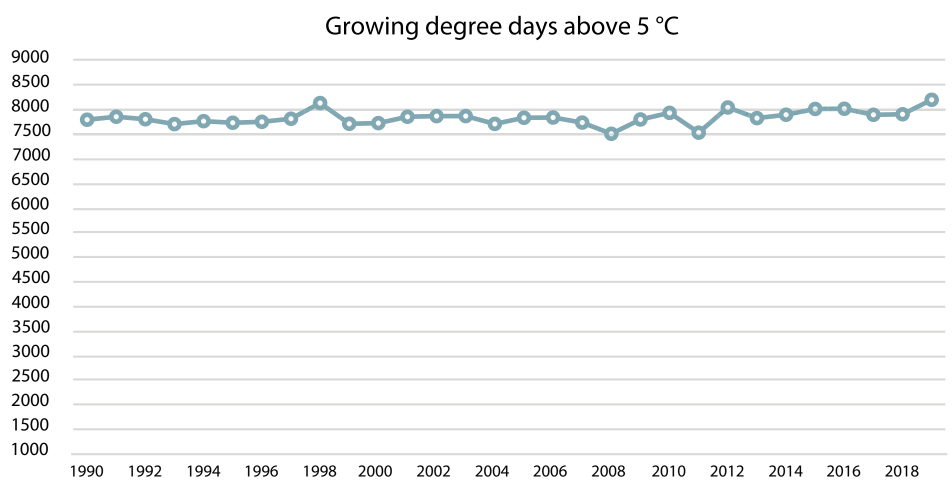


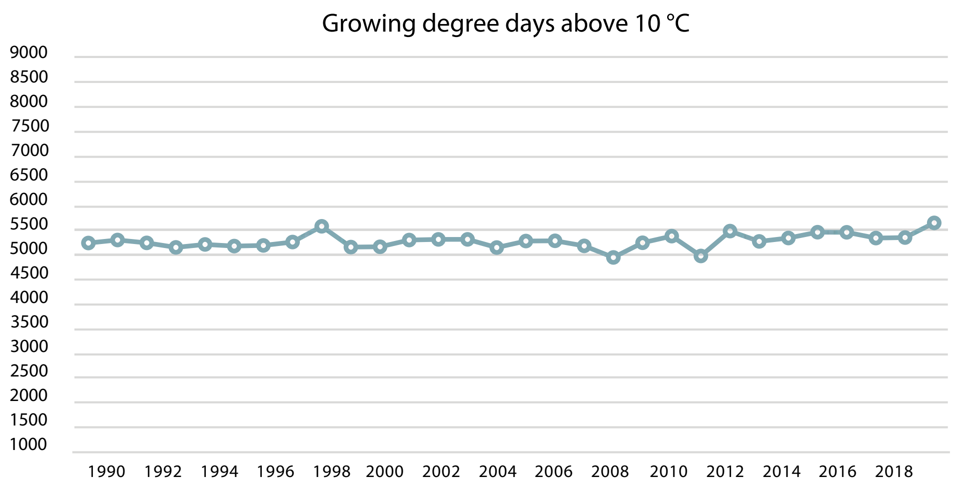
The 30 years of data on temperature conditions show that temperatures have remained relatively stable, with annual averages for minimum temperatures ranging between 15.7 °C and 24.7 °C, and those for maximum temperatures ranging between 28.7 °C and 34.7 °C. The number of days on which the temperature exceeded 37 °C increased over the period to reach a high of 43 days in 2016. Similarly, the number of days on which the temperature exceeded 40 °C also increased, particularly as of 2015, the peak (eight days) again occurring in 2016.

Vientiane province agroclimatology

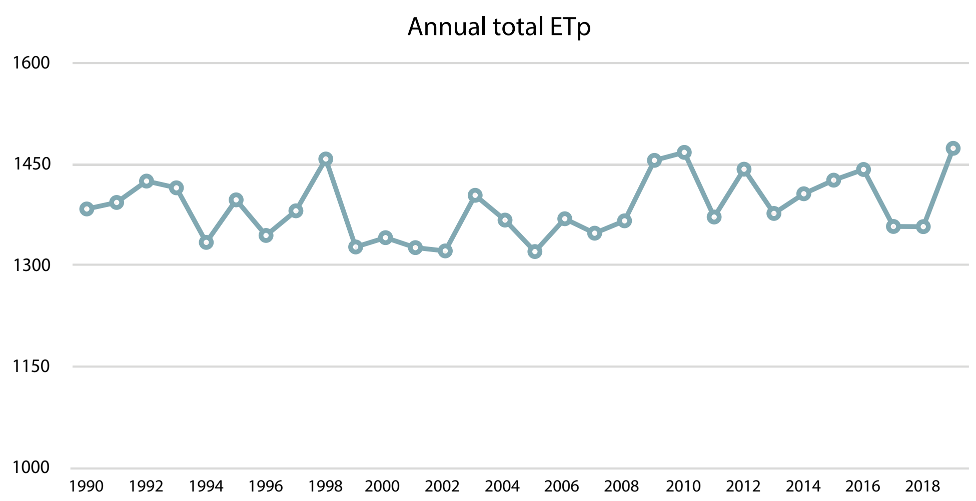
Agroclimatology

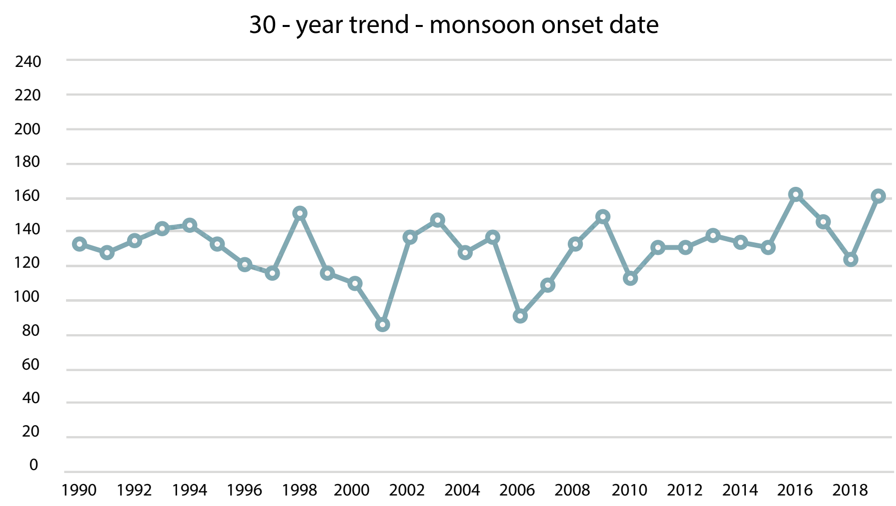
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 6.2 °C per year from a low of 4 951 °C (in 2008) to a high of 5 652 °C (in 2019), which has had an impact on the development cycle of crops, pests and diseases.



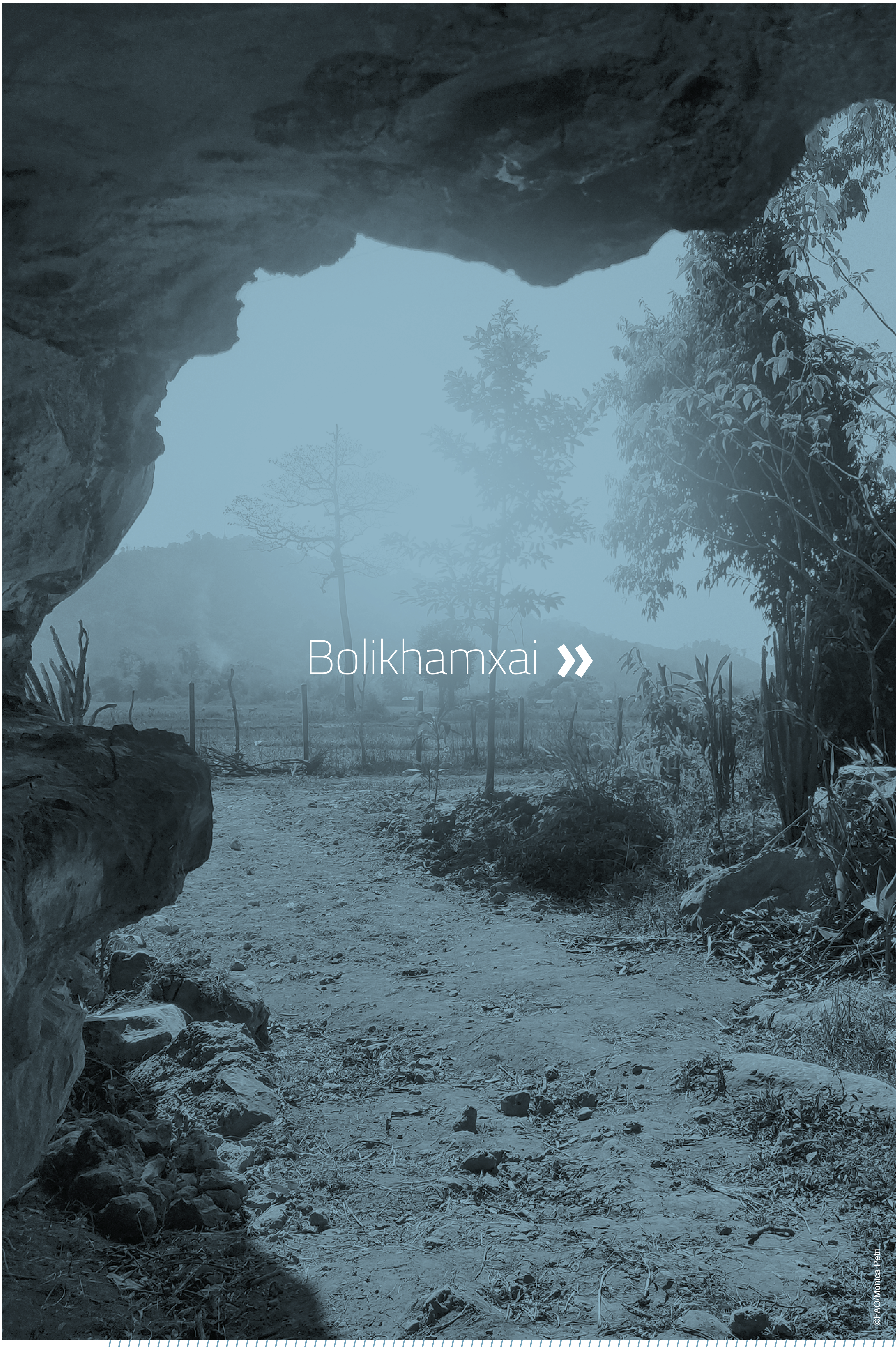


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Prepare and plant	Maintenance		Harvest							Prepare and plant	
Cassava				Prepare and plant		Maintenance					Harvest	
Annual crops and grasslands					Prepare and plant			Maintenance			Harvest	
Maizes	Prepare and plant	Maintenance		Harvest	Prepare and plant		Maintenance			Harvest		Prepare and plant
Orchards and plantations		Prepare and plant				Maintenance				Harvest		





Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with the lowest ETp recorded in 2002 and 2005, and the highest in 2019. The date of the onset of the monsoon does not appear to have changed significantly over the period, with the earliest start occurring in 2001 and the latest in 2016 and 2019.


Bolikhamxai »
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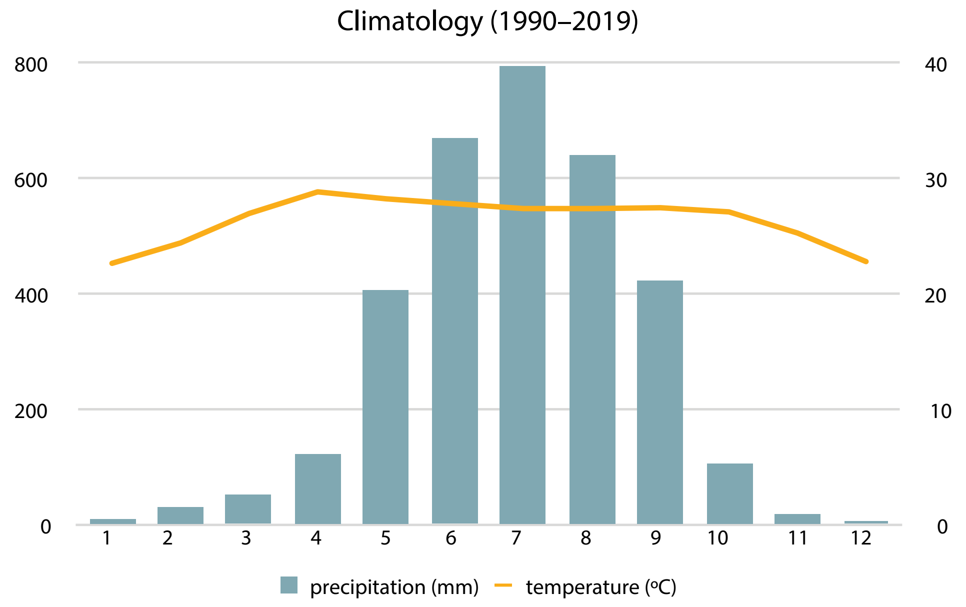
Bolikhamxai climatology



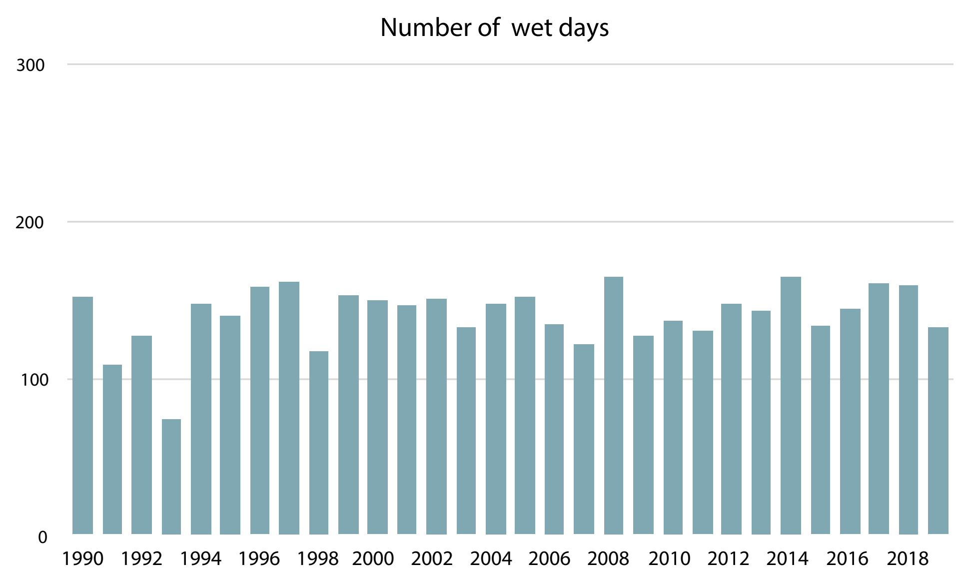
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	10	23	29.0	16.2
Feb	28	24	30.8	18.2
Mar	53	27	32.6	21.1
Apr	124	29	33.9	23.4
May	401	29	32.9	24.3
Jun	690	28	32.1	24.6
Jul	796	28	31.5	24.4
Aug	640	28	31.5	24.4
Sep	431	28	31.8	23.9
Oct	113	27	31.8	22.6
Nov	17	25	30.6	20.0
Dec	5	23	28.7	17.0

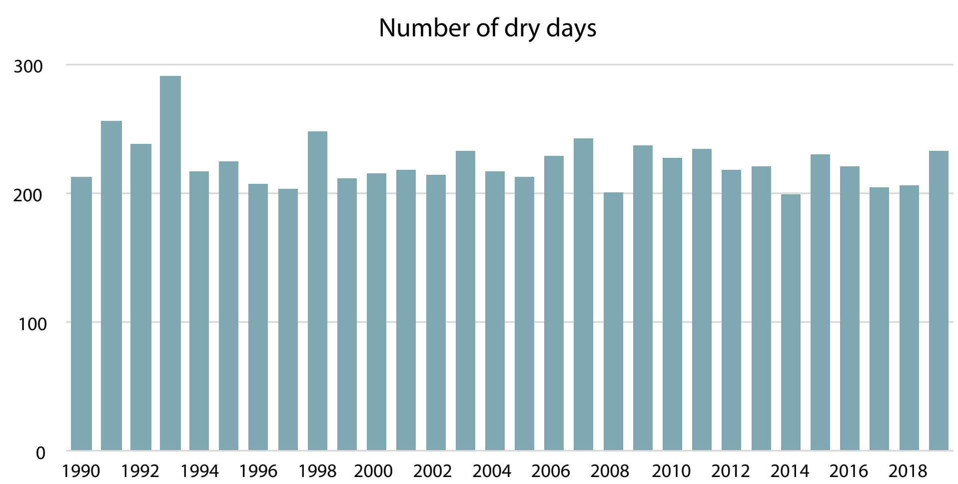
Bolikhamxai is found in the centre of the Lao People's Democratic Republic, a region that also includes the provinces of Vientiane Capital, Xaisomboun, Vientiane Province, Khammouan and Savannakhet. The climatology for the province shows that the rainy season starts in May and continues to September. There is a lot of rainfall during this period, with most rain falling in July (796.1 mm). After this, the amount of precipitation decreases until it reaches a low of 5.3 mm in December. As monthly rainfall decreases, temperatures also fall below 20 °C from December to February of the following year. Bolikhamxai is the second coldest province of the country's six central provinces. However, it is generally considered in Laos as having a warm climate. At the Phonhong weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 16.4 °C to 34.2 °C, the minimum temperature range was 16.4 °C to 24.1 ° C, and the maximum temperature range was 24.1 °C to 34.2 °C.

The province contains both areas of low-lying plain with warmer temperatures and mountainous terrain at higher elevations with cooler temperatures. According to the climatology graph, temperatures in Bolikhamxai start to decrease from November to the end of January during the Northeast Monsoon. Maximum temperatures start to increase from January and reach their highest level of 34.2 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from the beginning of February, reaching a high of 24.1 °C in June before starting to fall again. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, especially in Bolikhamxai, which is the rainiest of the country's provinces. Precipitation levels reach their peak of 796.1 mm in July in Bolikhamxai Province.

Mountainous, high-altitude terrain covers 70 percent of the province, while the remaining 30 percent is located at lower elevations on a plain. High mountainous areas are without exception covered by forest, which ranges from sparse deciduous to evergreen, and low-lying areas, such as those in the west along the Mekong River, tend to be reserved for dwellings and agricultural production. Forest coverage in Bolikhamxai ranges from sparse to very thick forest depending on the amount of rain that falls in each area. Since the province is the rainiest in the country, however, forest cover tends to be thicker and denser than it is in the north.

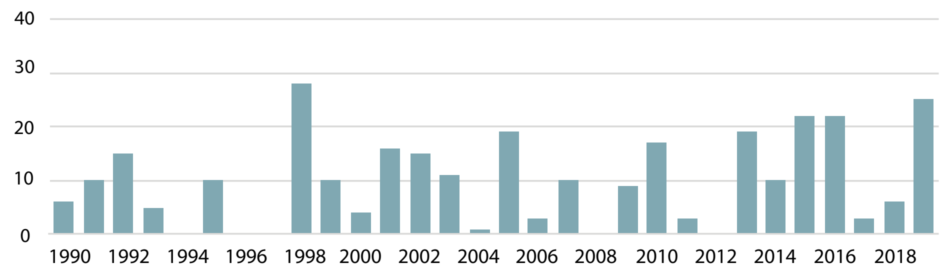
Climate change: Precipitation over the last 30 years



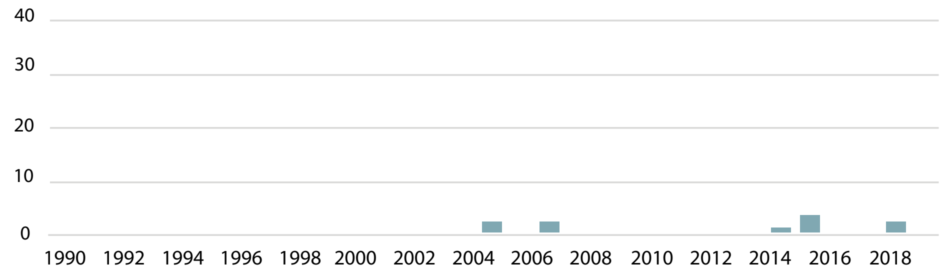


Bolikhamxai climatology

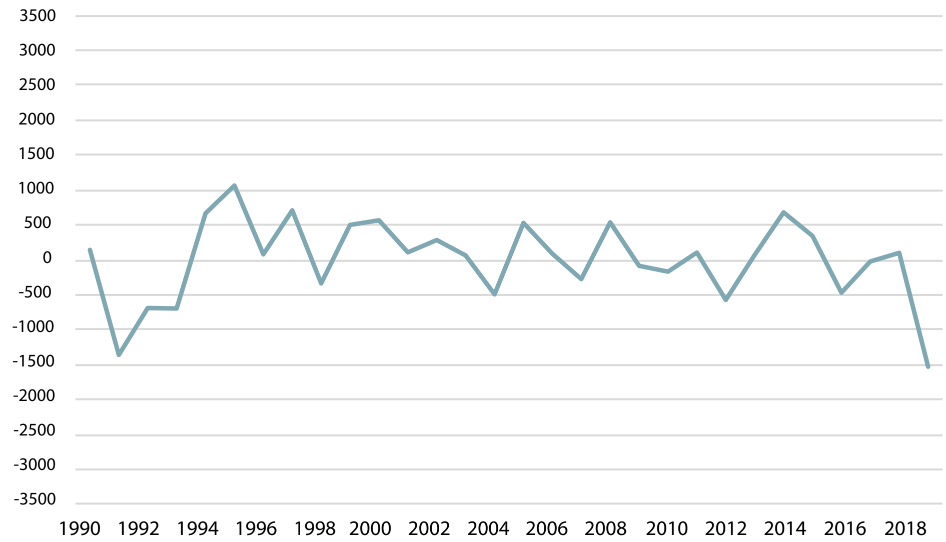
Number of hot days (over 37 °C)



Number of hot days (over 40 °C)

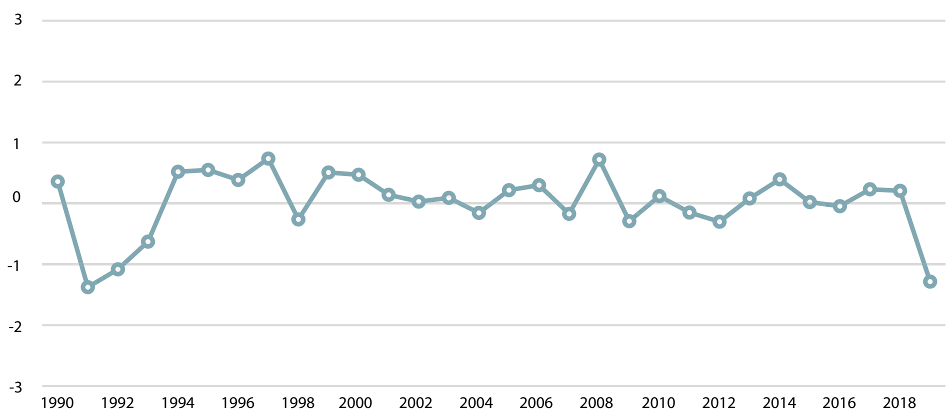


Annual precipitation anomaly trend - 30 years



According to the 30 years of observation data on rainfall in Bolikhamxai Province from the Pakxan weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has decreased: the highest number of dry days (291) occurred in 1993 and the lowest number (200) in 2014. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, increased slightly, with the smallest number of wet days (74) occurring in 1993 and the highest number (165) in 2008 and 2014.

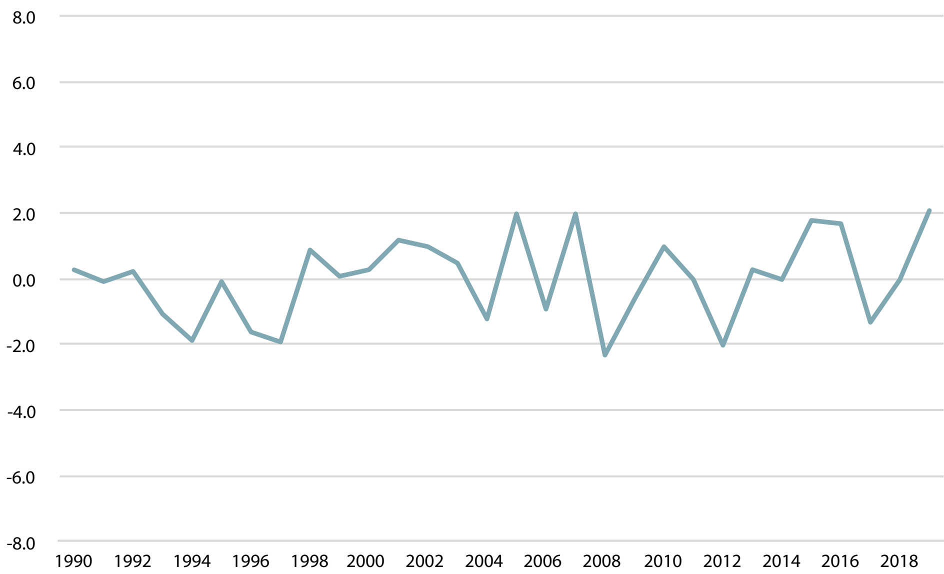
30 - year trend - SPI



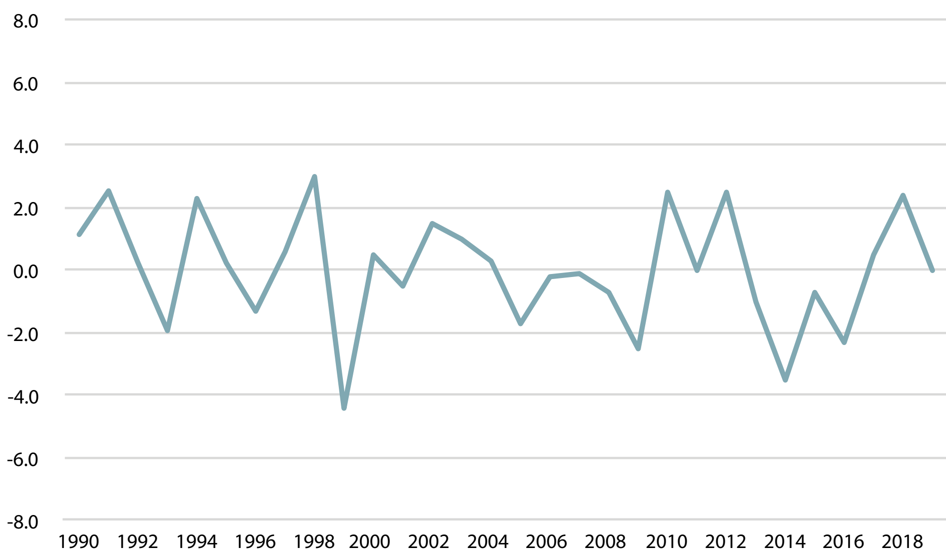
However, the trend analysis shows that precipitation levels have decreased slightly over the 30 years from a high of 4 345 mm in 1995 to a low of 1 752 mm in 2019. The SPI graph, meanwhile, reveals no significant increase or decrease, with the driest years recorded in 1991 and 2019, and the wettest year in 1997.

Climate change: Temperature over the last 30 years

Maximum temperature trend - 30 years



Minimum temperature trend - 30 years

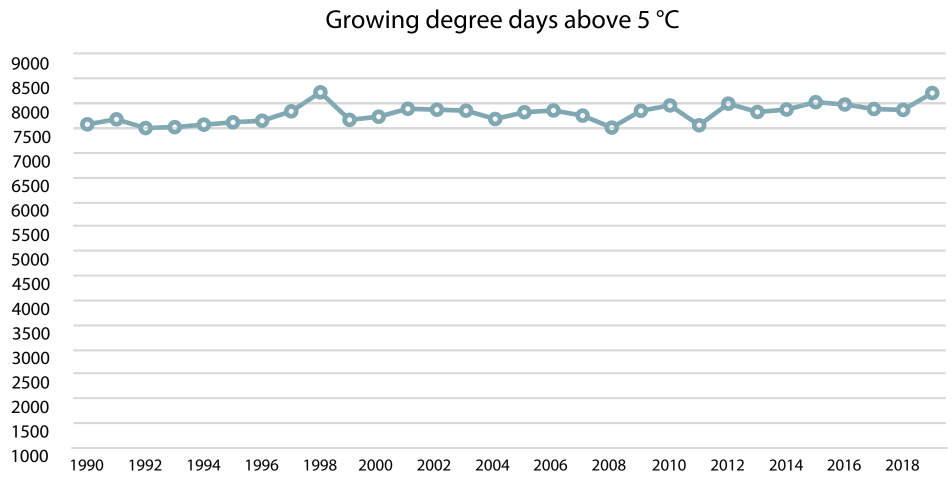


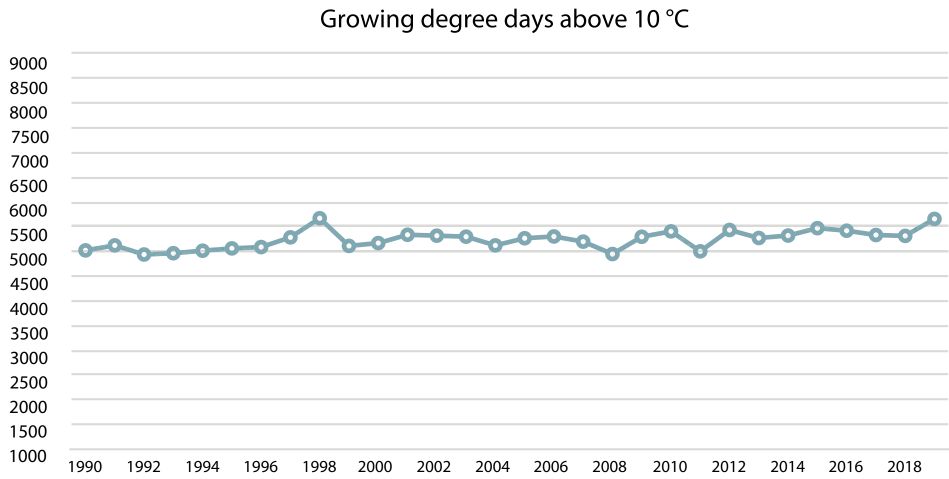
The 30 years of data on temperature conditions show that minimum and maximum temperatures have slightly increased, with annual averages for minimum temperatures ranging between 20.03 °C and 22.99 °C, and those for maximum temperatures ranging between 30.08 °C and 32.52 °C. The number of days on which the temperature exceeded 37 °C increased over the period to reach a high of 28 days in 1998. Days with a temperature over 40 °C first started to occur in 2005 and have become more frequent since 2015, with 2016 seeing the highest number of such three days.

Bolikhamxai agroclimatology

Agroclimatology

Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 12.5 °C per year, with a low of 4 938 °C (in 1992) and a high of 5 672 °C (in 1998), which has had an impact on the development cycle of crops, pests and diseases.





<table>
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<tr><td>Rainfed rice</td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="4">Maintenance</td><td>Harvest</td><td></td></tr>
<tr><td>Irrigated rice</td><td colspan="3">Maintenance</td><td>Harvest</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td></tr>
<tr><td>Steep slope agriculture</td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td>Harvest</td><td></td><td></td></tr>
<tr><td>Cassava</td><td colspan="2">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="7">Maintenance</td><td>Harvest</td></tr>
<tr><td>Sugarcane</td><td colspan="2">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="7">Maintenance</td><td>Harvest</td></tr>
<tr><td>Orchards and plantations</td><td colspan="2">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="7">Maintenance</td><td>Harvest</td></tr>
<tr><td>Maizes</td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="2">Maintenance</td><td colspan="2">Harvest</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Annual crops and grasslands</td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="2">Maintenance</td><td colspan="2">Harvest</td><td></td><td></td><td></td><td></td></tr>
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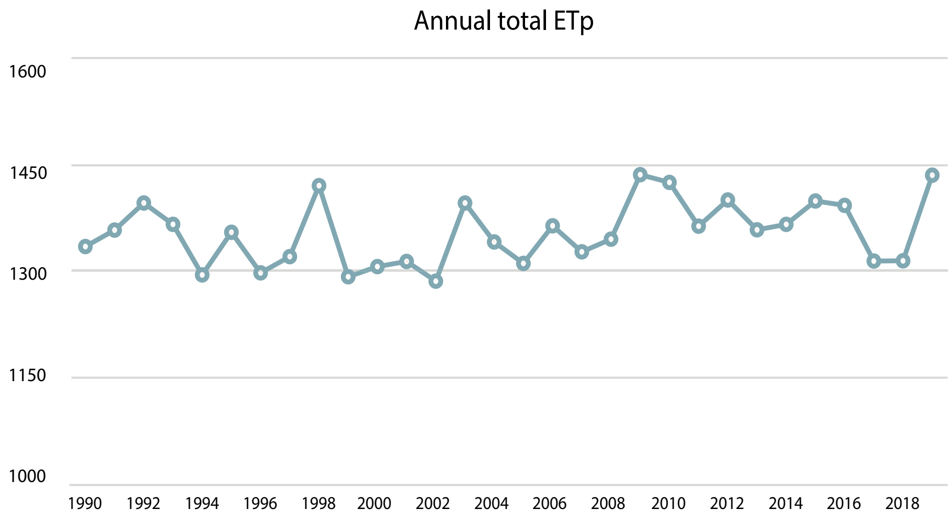

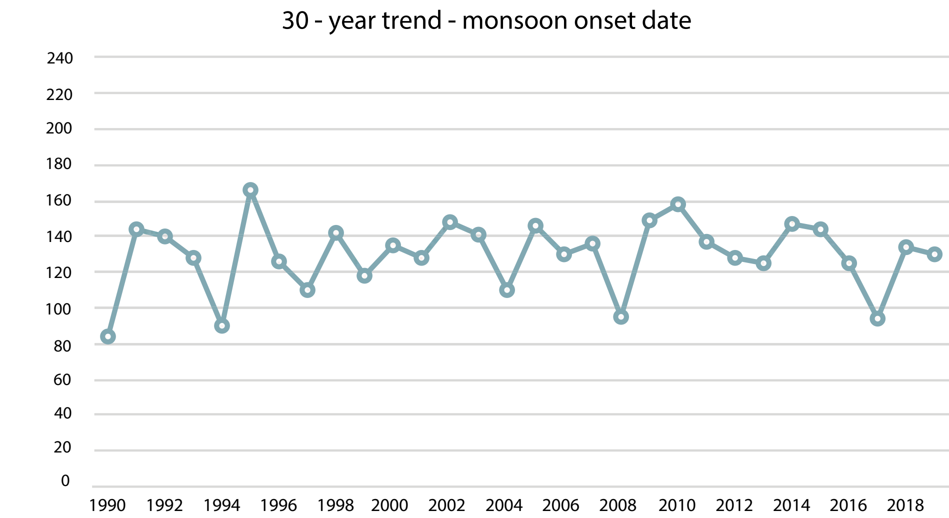

Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with 2002 seeing the lowest ETp value and 2019 seeing the highest. The date of the onset of the monsoon does not appear to have changed significantly over the period; the earliest start date was in 1990 and the latest was in 1995.

Xaisomboun »

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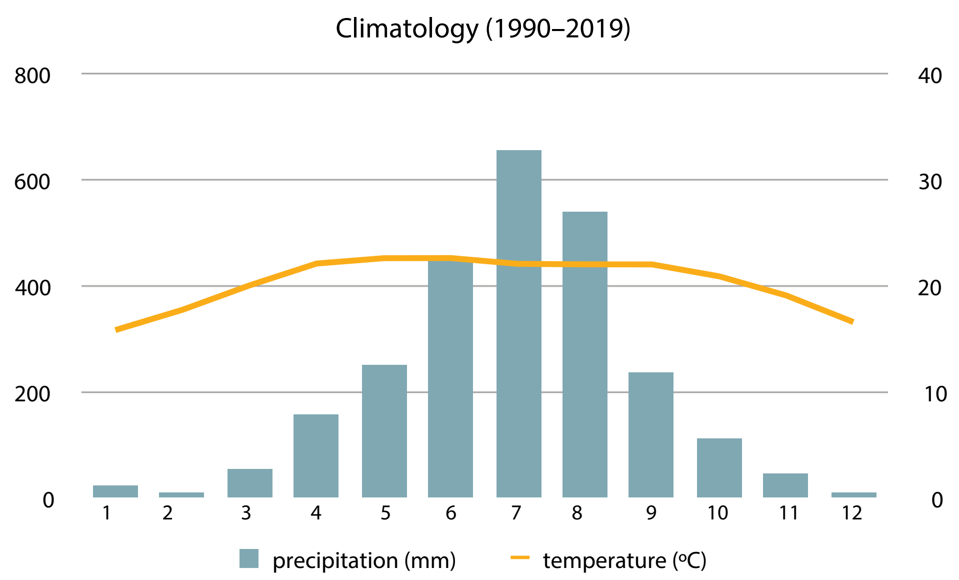
» Xaisomboun climatology



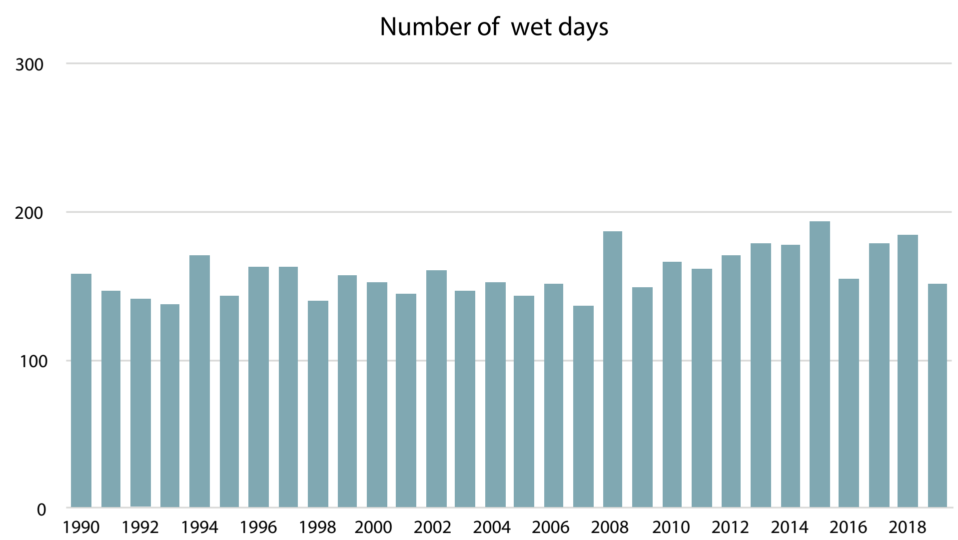
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	37	16	23.3	8.2
Feb	13	18	25.5	10.0
Mar	56	20	27.1	13.2
Apr	158	22	28.0	16.2
May	257	23	27.1	18.1
Jun	433	23	26.3	19.1
Jul	611	22	25.4	18.9
Aug	508	22	25.7	18.6
Sep	255	22	26.2	17.8
Oct	132	21	25.9	15.9
Nov	46	19	25.3	12.7
Dec	22	17	23.4	9.7

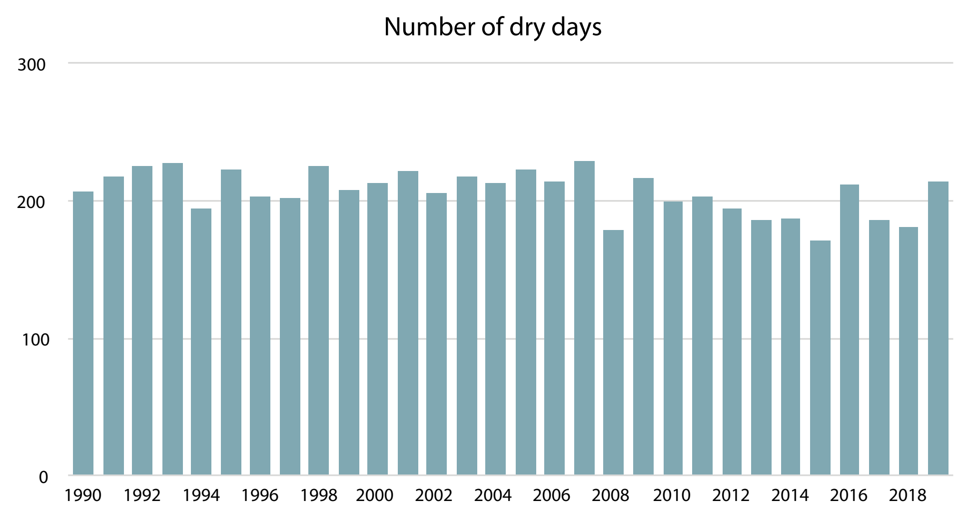
Xaisomboun is found in the centre of the Lao People's Democratic Republic, a region that also includes the provinces of Vientiane Capital, Vientiane Province, Khammouan, Bolikhamxai and Savannakhet. The climatology for the province shows that the rainy season starts in April and continues to September. There is a lot of rainfall during this period, with most rain falling in July (656.5 mm). After this, the amount of precipitation decreases until it reaches a low of 12.4 mm in December and February. As monthly rainfall decreases, temperatures also fall below 20 °C from November to February of the following year. Xaisomboun has the coldest temperatures of the six central provinces, and is generally considered in Laos as being the coldest province in the country. At the Xaisomboun weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 8.4 °C to 28.1 °C, the minimum temperature range was 8.4 °C to 19.05 °C, and the maximum temperature range was 23.3 °C to 28.1 °C.

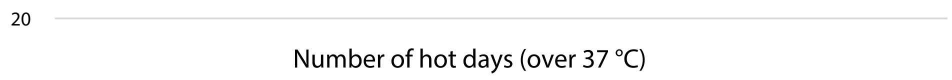
The province has a high-elevation mountainous topography, giving it the lowest temperatures in the country. According to the climatology graph, temperatures in Xaisomboun start to decrease from November to January during the Northeast Monsoon. Maximum temperatures start to increase from February and reach their highest level of 28.1 °C in April during the spring transition (mid-March to midMay), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from February, reaching a high of 19.05 °C in June before starting to fall again. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, with most rain (656.5 mm) falling in July in Xaisomboun.

The province is situated in a mountainous region with high elevation, and the land cover varies: central and eastern areas are covered by sparse grassland, areas of deciduous forest, and plains used for dwellings and agriculture; while the south and west, where there is a greater availability of moisture, tend to have more reservoirs and areas of very dense green forest (mainly evergreen and deciduous). Given Xaisomboun's mountainous topography, which is directly influent to monsoon wind flow, some areas receive more rain and thus have denser vegetation cover, while others receive less rain and have more sparse vegetation cover.

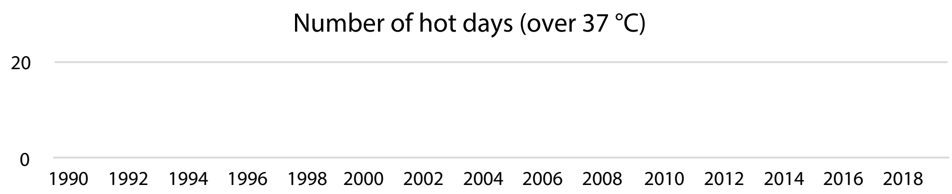
Climate change: Precipitation over the last 30 years

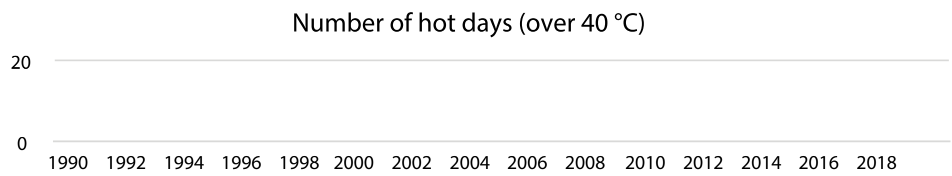


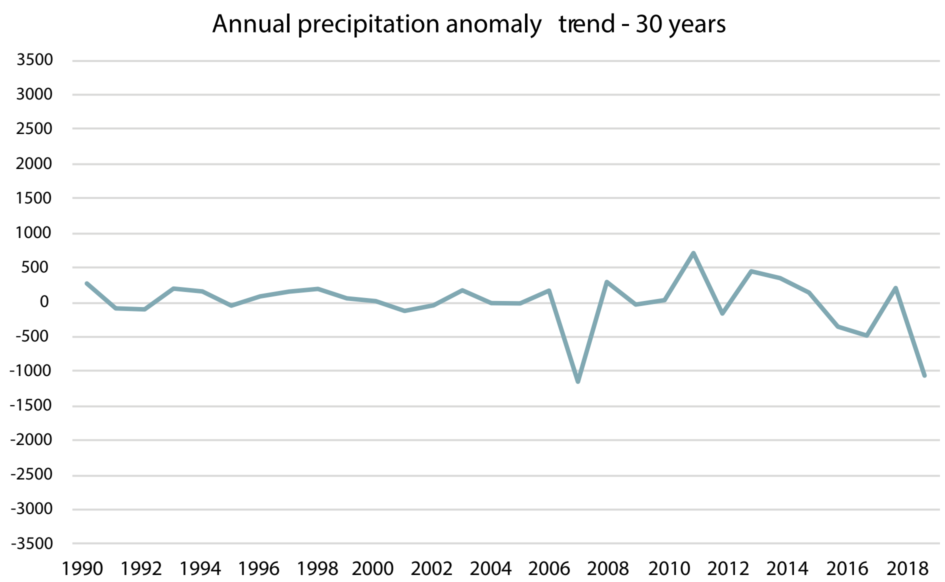




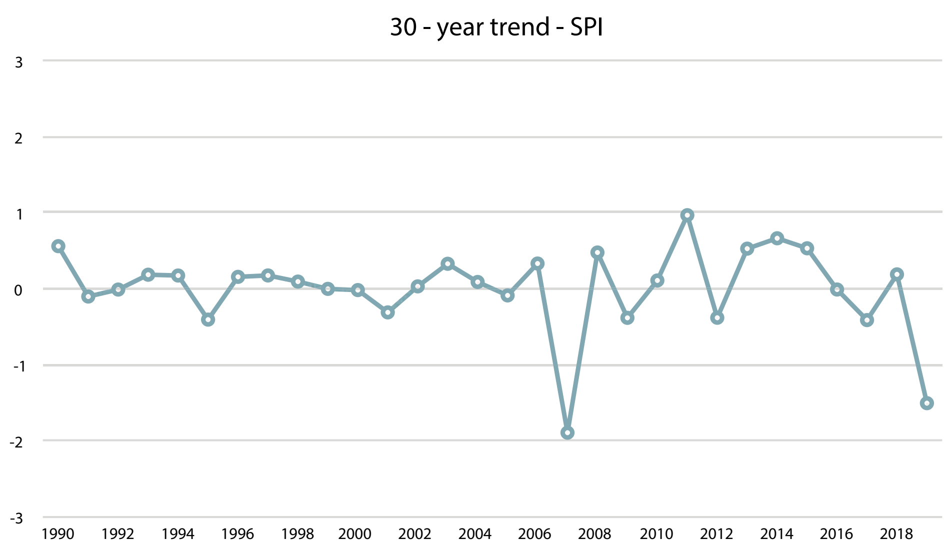
Xaisomboun climatology





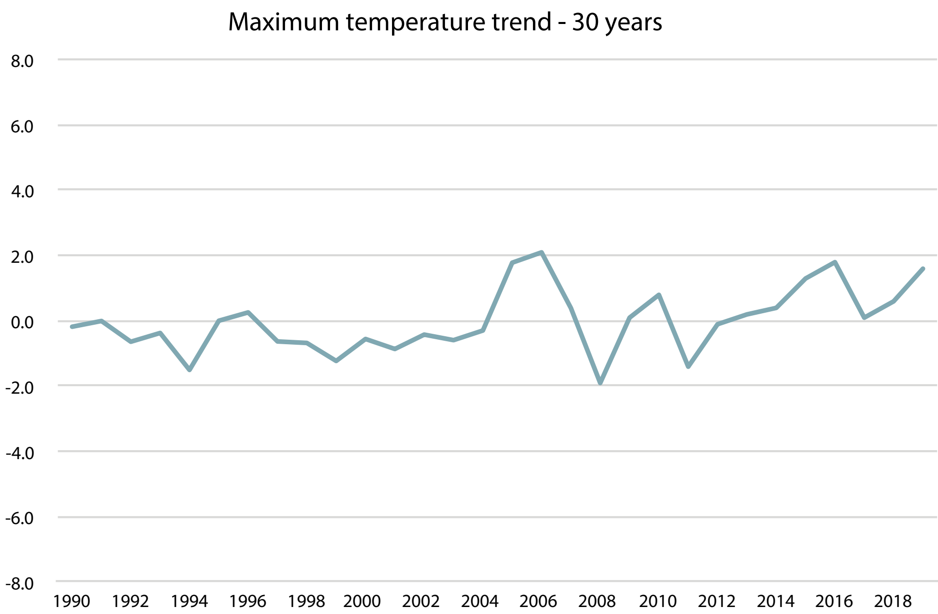


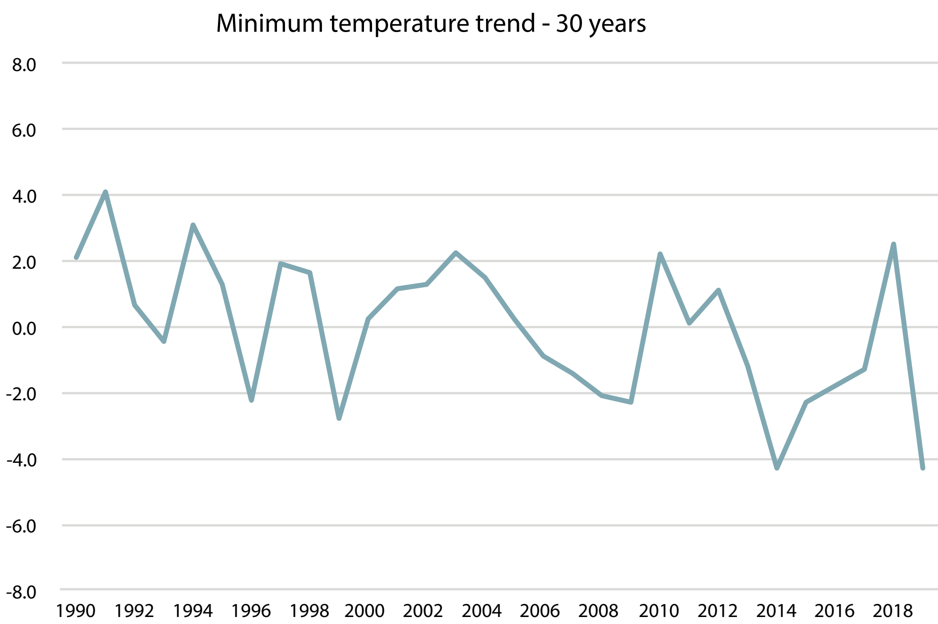
According to the 30 years of observation data on rainfall in Xaisomboun Province from the Xaisomboun weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has decreased significantly, with the lowest number of dry days (171) occurring in 2015 and the highest number (229) in 2007. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has increased, with 2007 seeing the smallest number (136 days) and 2015 seeing the highest



(194 days). However, the trend analysis shows that precipitation levels have decreased over the 30 years, with the low being 1 408 mm (in 2007) and the high being 3 269 mm (in 2011). Similarly, the SPI graph shows a slight decrease in the precipitation index, with the driest year occurring in 2007 and the wettest in 2011.

Climate change: Temperature over the last 30 years



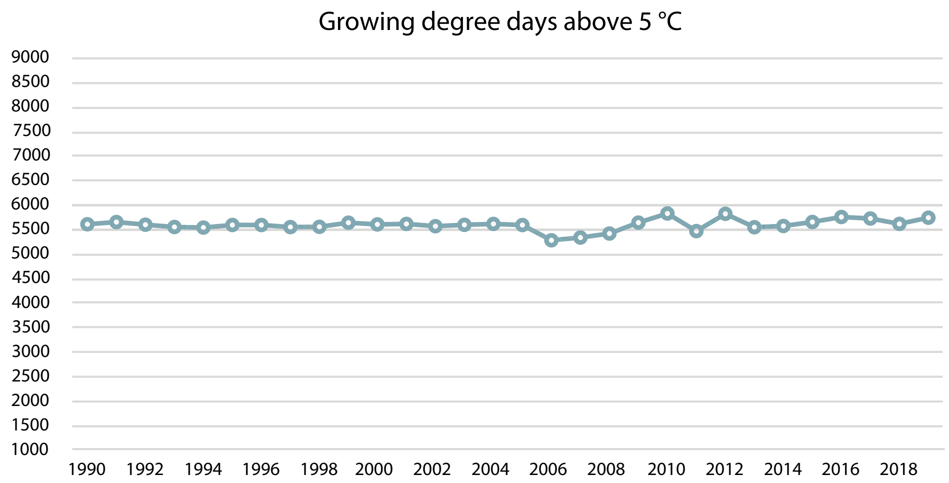


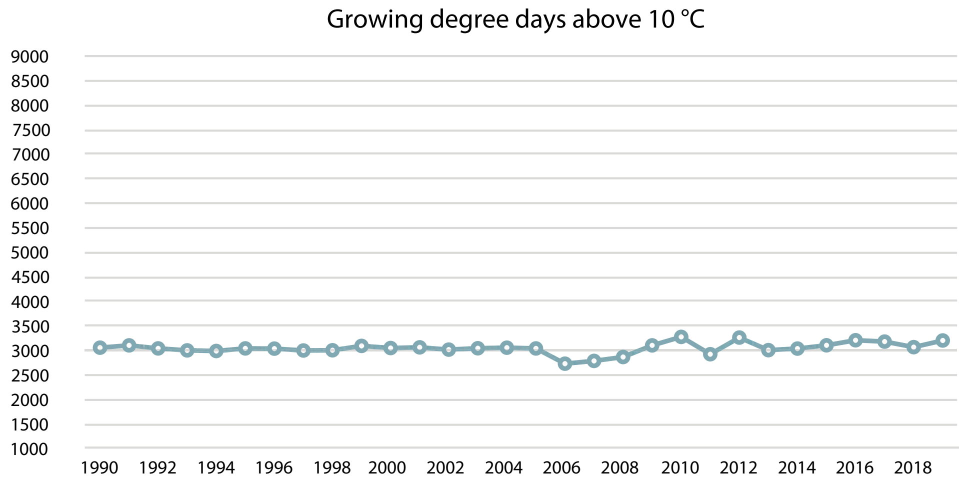
The 30 years of data on temperature conditions show that minimum temperatures have decreased significantly, with annual averages ranging from 8.4 °C to 19.05 °C, whereas maximum temperatures, ranging from 23.4 °C to 28.1 °C, have increased significantly. Looking at the growing degree days (GDDs) over 5 °C reveals that there was a slight increase in heat accumulation between 1990 and 2019, with a low of 1 176 °C (in 2002) and a high of 3 277 °C (in 2010), resulting in a shorter development cycle for crops, pests and diseases.

Xaisomboun agroclimatology

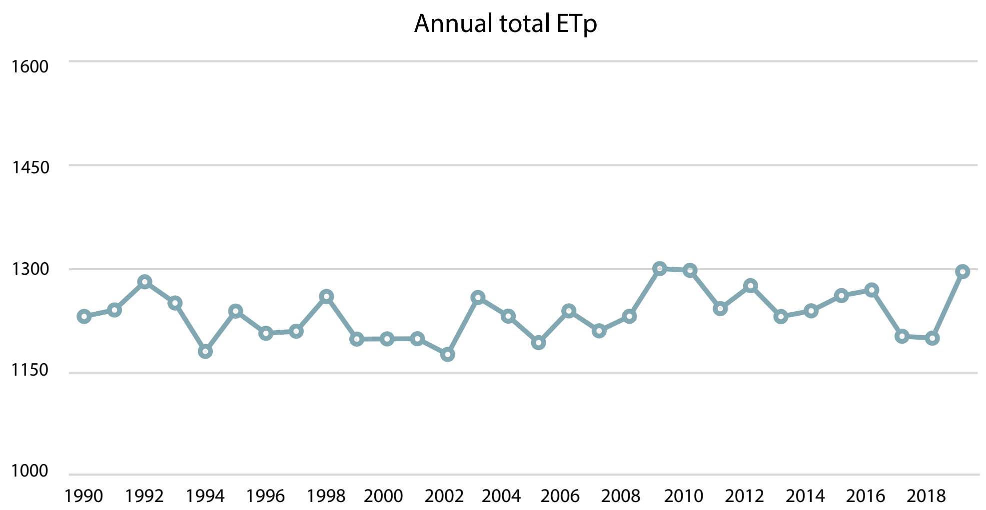
Agroclimatology

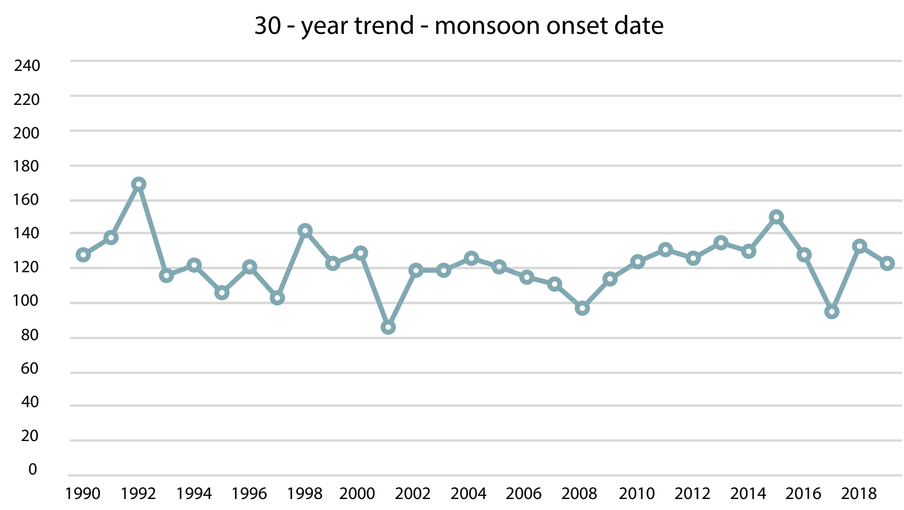
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 12.5 °C per year, with a low of 4 938 °C (in 1992) and a high of 5 672 °C (in 1998), which has had an impact on the development cycle of crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice				Prepare and plant			Maintenance				Harvest	
Irrigated rice	Maintenance			Harvest							Prepare and plant	
Maizes			Prepare and plant		Maintenance		Harvest					
Cassava	Harvest		Prepare and plant		Maintenance							Harvest
Orchards and plantations			Prepare and plant		Maintenance					Harvest		
Annual crops and grasslands	Maintenance		Harvest							Prepare and plant		Maintenance
Steep slope agriculture			Prepare and plant		Maintenance					Harvest		





Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with 2002 seeing the lowest ETp value and 2009 the highest. The date of the onset of the monsoon does not appear to have changed significantly over the period; the earliest start date was in 2001 and the latest was in 1992.

Khammouan

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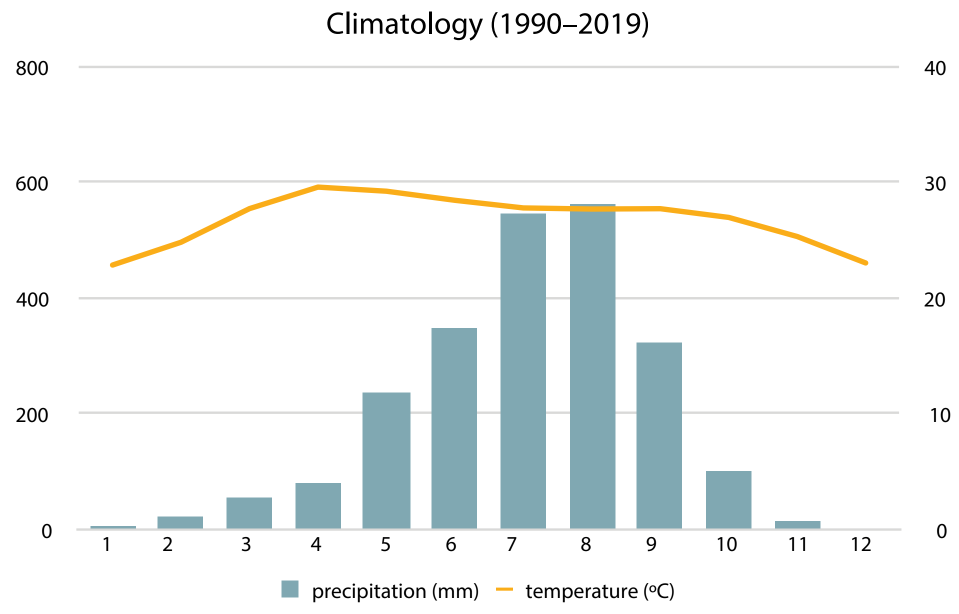
Khammouan climatology



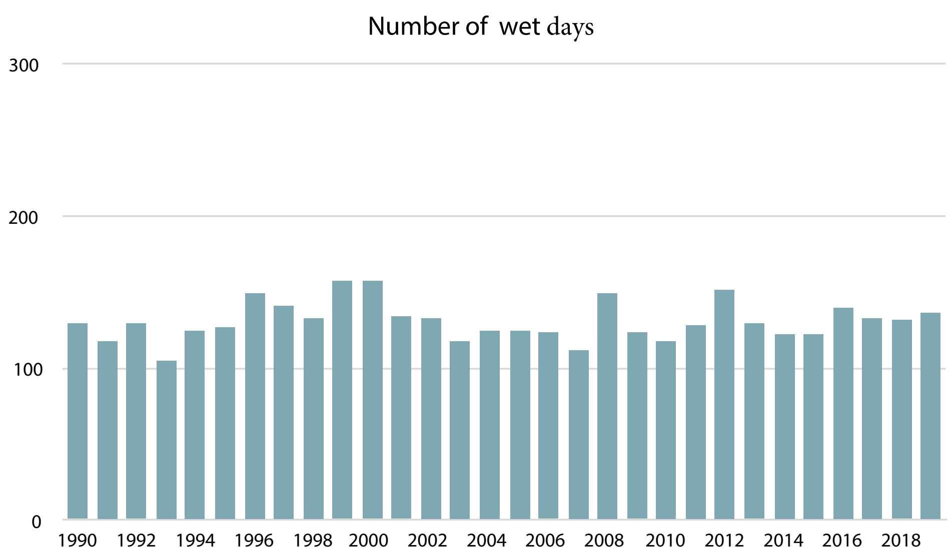
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	4	23	29.2	15.8
Feb	22	24	31.0	17.9
Mar	50	27	33.3	21.4
Apr	81	29	34.8	23.9
May	240	29	33.5	24.6
Jun	345	28	31.9	24.6
Jul	514	28	31.0	24.4
Aug	546	28	30.9	24.2
Sep	314	28	31.3	23.8
Oct	112	27	31.4	21.9
Nov	15	25	30.7	19.2
Dec	3	23	28.8	16.3

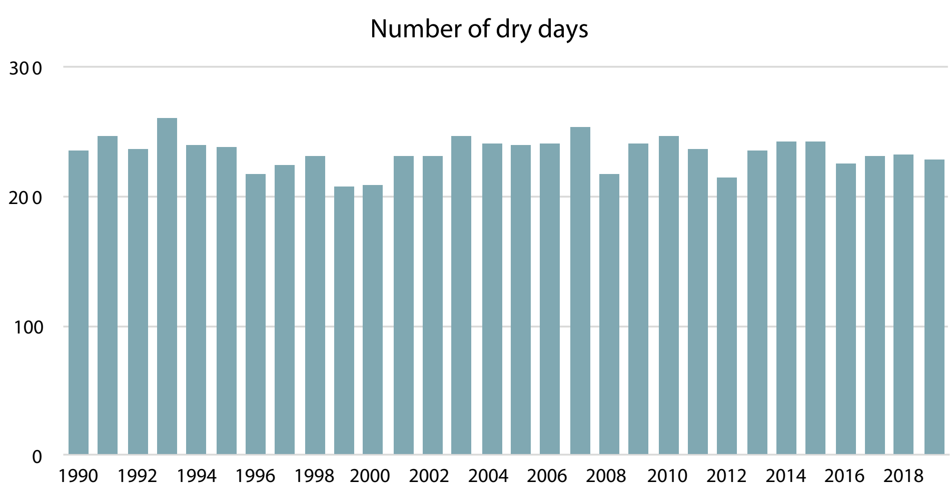
Khammouan is found in the centre of the Lao People's Democratic Republic, a region that also includes the provinces of Vientiane Capital, Xaisomboun, Vientiane Province, Bolikhamxai, Khammouan and Savannakhet. The climatology for the province shows that the rainy season starts in May and continues to September. There is a lot of rainfall during this period, with most rain falling in August (560.0 mm). After this, the amount of precipitation decreases until it reaches a low of 2.62 mm in December. As monthly rainfall decreases, temperatures also fall below 20 °C from November to February of the following year. Khammouan is the second warmest of the six central provinces, and is generally considered in Laos as having a warm climate. At the Thakhek weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 16.0 °C to 35.19 °C, the minimum temperature range was 16.0 °C to 24.67 °C, and the maximum temperature range was 29.45 °C to 35.19 °C.

The province contains both areas of low-lying plain with warmer temperatures and mountainous terrain at higher elevations with cooler temperatures. According to the climatology graph temperatures in Khammouan start to decrease from November to the end of January during the Northeast Monsoon. Maximum temperatures start to increase from January and reach their highest level of 35.2 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from January, reaching a high of 24.67 °C in June before starting to fall again. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, especially in Khammouan, which experiences large amounts of rainfall. Precipitation levels reach their peak of 560.0 mm in August.

Western parts of the province are located on a plain and therefore tend to contain more dwelling places and farms, as well as some forest cover. The east, meanwhile, tends to be covered by rocky mountains and forest, characterized by high elevations and steep slopes. The southwest of the province, along the Mekong River, contains agricultural areas, and thick deciduous and evergreen forest; the central portion extending from north to south is generally covered by rocky mountains with sparse forest and steep slopes; while Khammouan's eastern edge (stretching from north to south) is covered by thick and healthy deciduous and evergreen forest. Vegetation cover is denser and healthier in Khammouan than it is in the north of country due to higher moisture and precipitation levels.

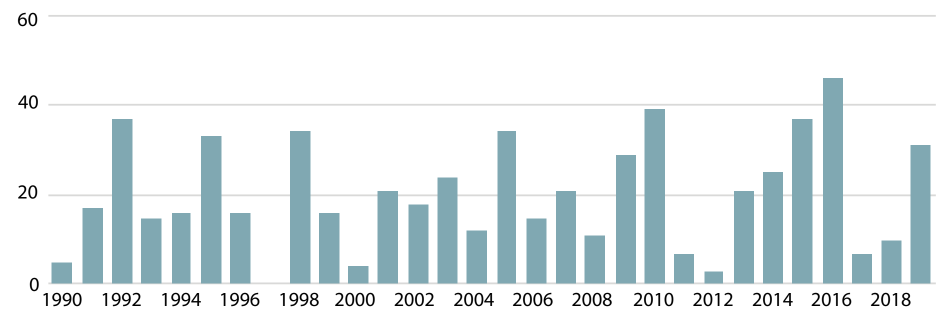
Climate change: Precipitation over the last 30 years



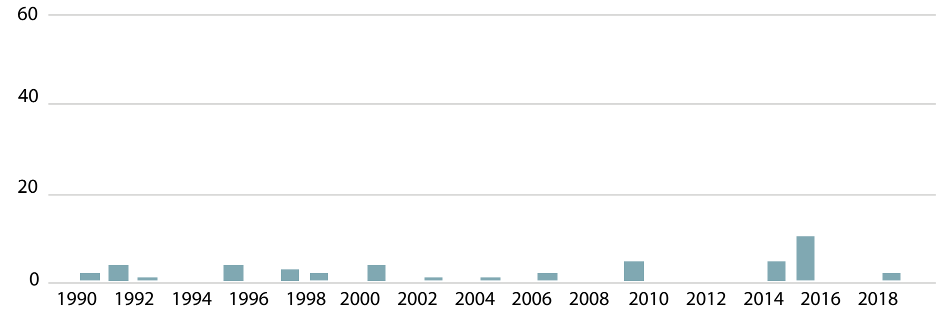


Khammouan climatology

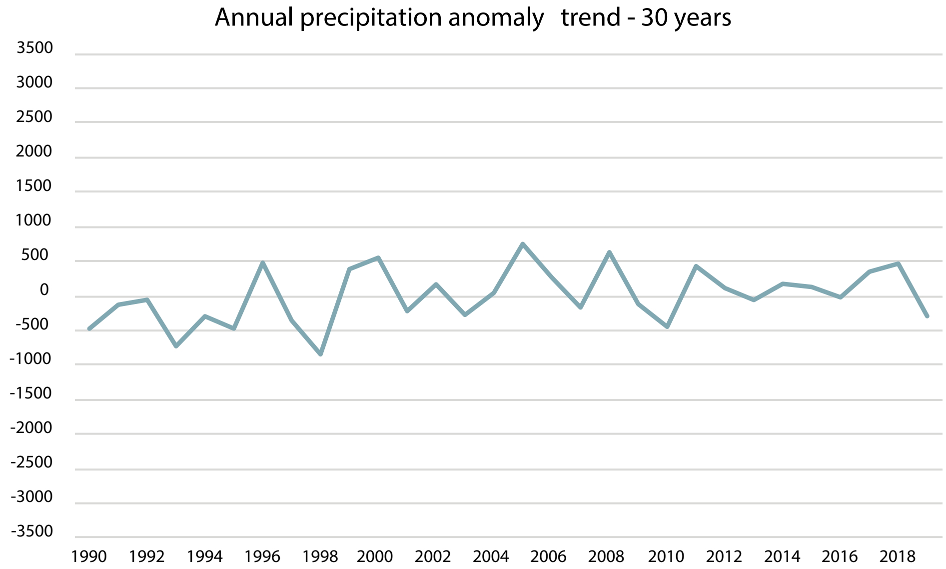
Number of hot days (over 37 °C)



Number of hot days (over 40 °C)

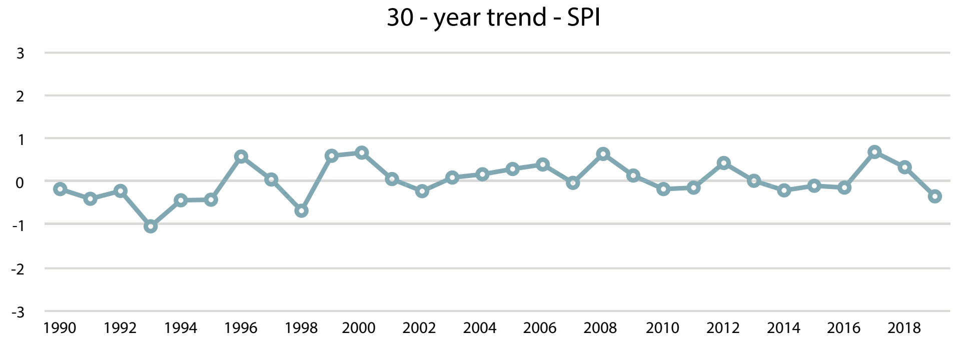


Annual precipitation anomaly trend - 30 years



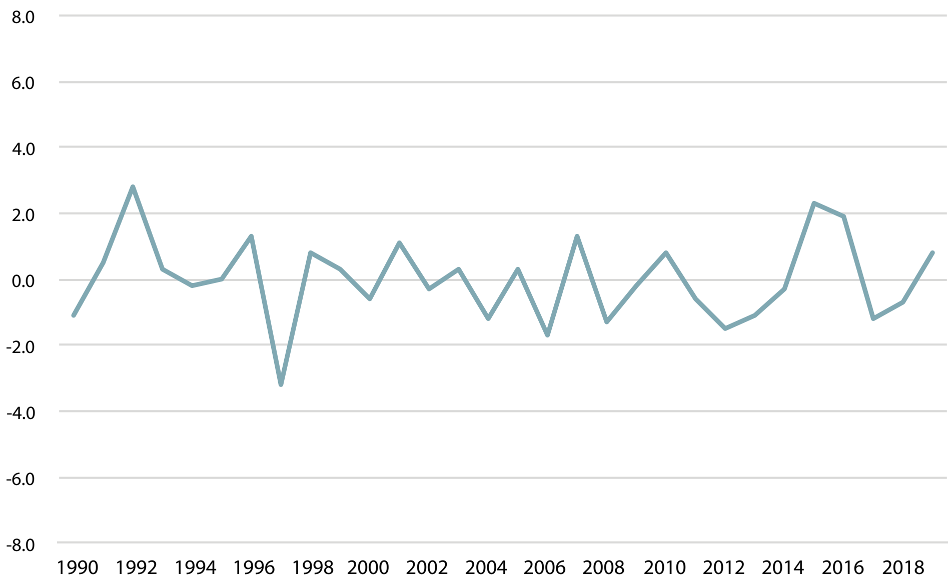
According to the 30 years of observation data on rainfall in Khammouan Province from the Thakhek weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has remained relatively stable, with 1999 seeing the lowest number of dry days (208) and 1993 seeing the highest (260). Similarly, the number of wet days (with more than 0.2 mm of rainfall) has remained more or less stable; the smallest number of wet days (105) was recorded in 1993 and the largest (157) in 1999 and 2000. Nevertheless, the trend analysis shows that precipitation levels have significantly increased over the 30 years, the low being 1 444.3 mm (in 1998) and the high being 3 038.9 mm (in 2005). The SPI graph also suggests that there has been an increase, with the driest year occurring in 1993 and the wettest year in 2017.

30 - year trend - SPI

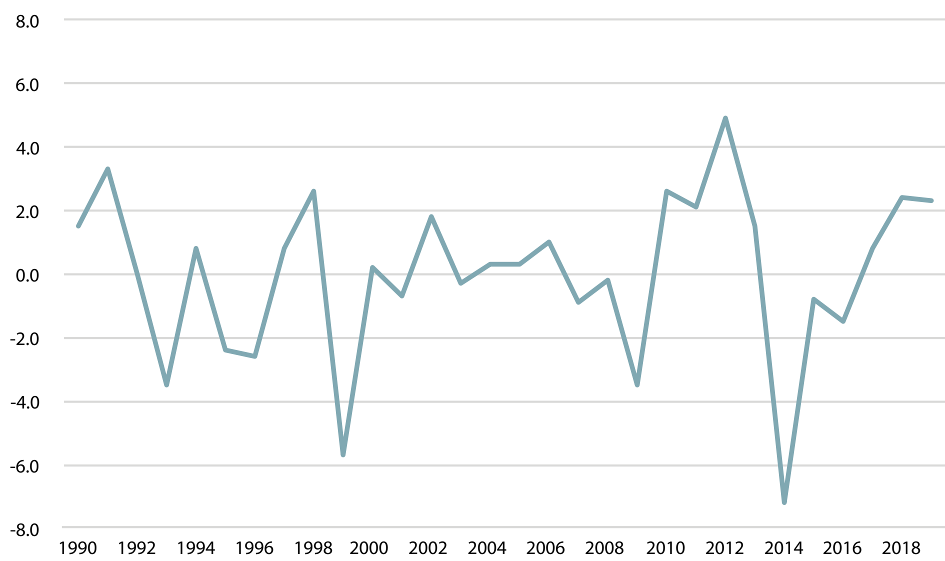


Climate change: Temperature over the last 30 years

Maximum temperature trend - 30 years



Minimum temperature trend - 30 years

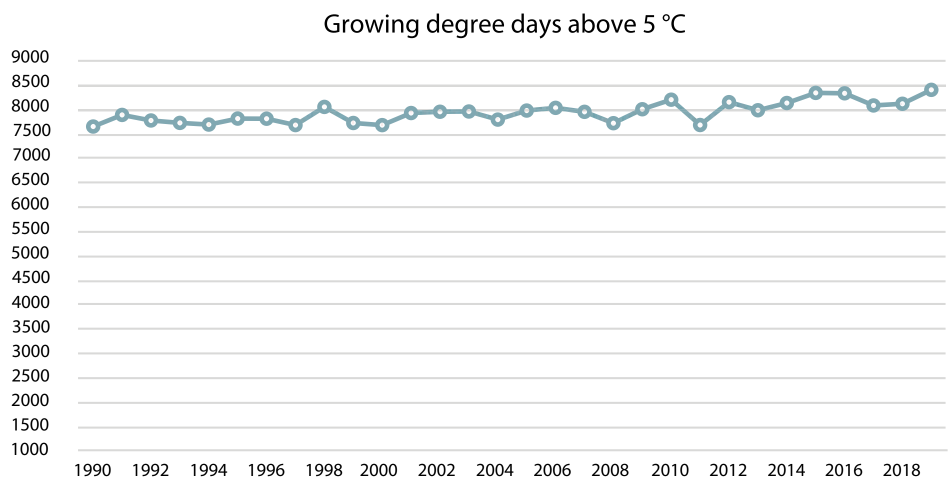


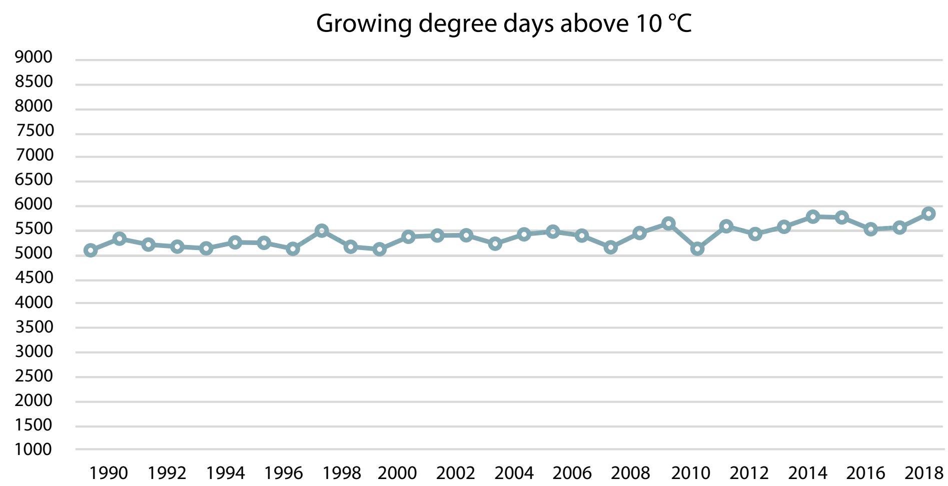
The 30 years of data on temperature conditions show that minimum and maximum temperatures have remained relatively stable, with the annual averages for minimum temperatures ranging from 16.0 °C to 24.67 °C, and those for maximum temperatures ranging from 29.45 °C to 35.19 °C. The number of days on which the temperature exceeded 37 °C increased over the period to reach a high of 46 days in 2016, while the number of days on which it exceeded 40 °C also slightly increased, the peak level of 11 days occurring in 2016.

Khammouan agroclimatology

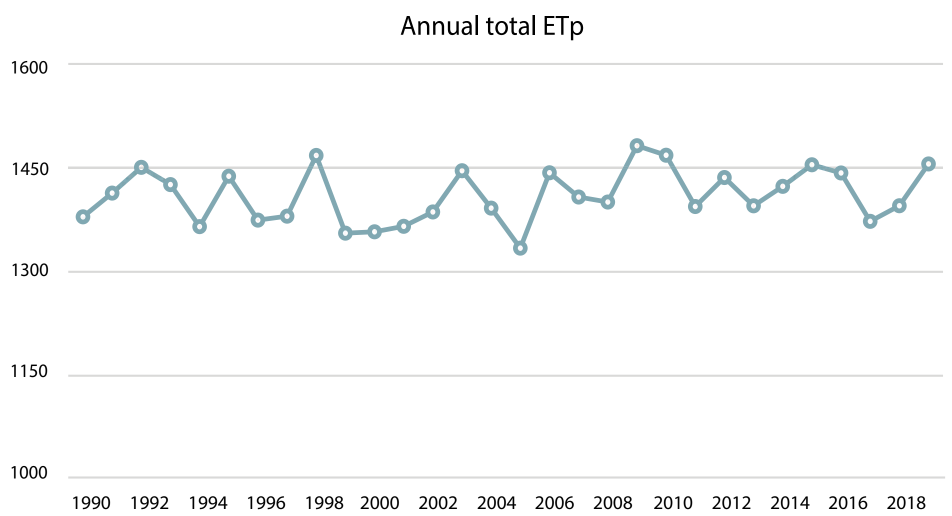
Agroclimatology

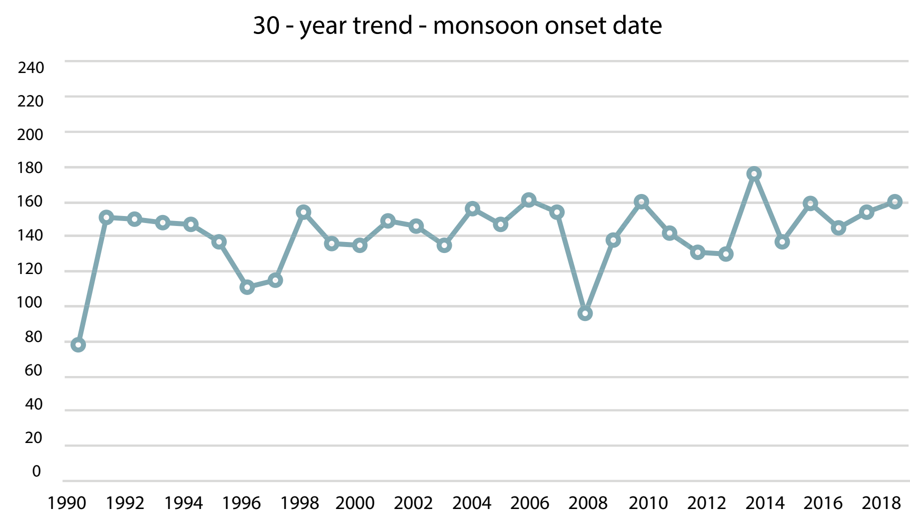
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased significantly between 1990 and 2019 at a rate of 18.2 °C per year from a low of 5 099 °C in 1990 to a high of 5 851 °C in 2019, which has had a significant impact on the development cycle of crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Maintenance			Harvest							Prepare and plant	
Maizes			Prepare and plant		Maintenance		Harvest					
Annual crops and grasslands	Maintenance			Harvest						Prepare and plant		
Cassava	Harvest				Prepare and plant		Maintenance					
Orchards and plantations	Harvest		Prepare and plant		Maintenance							Harvest





Potential evapotranspiration (ETP), meanwhile, has remained relatively stable, with 2005 seeing the lowest ETp value and 2009 the highest. The date of the onset of the monsoon now appears to occur significantly later than it did 30 years ago, with the earliest start date occurring in 1990 and the latest in 2014.

Savannakhet »

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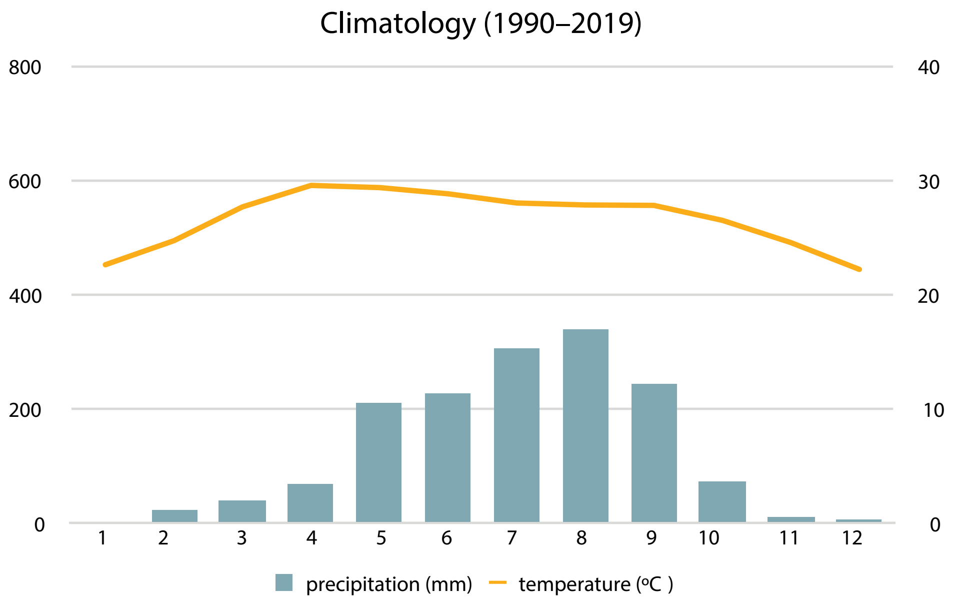
Savannakhet climatology



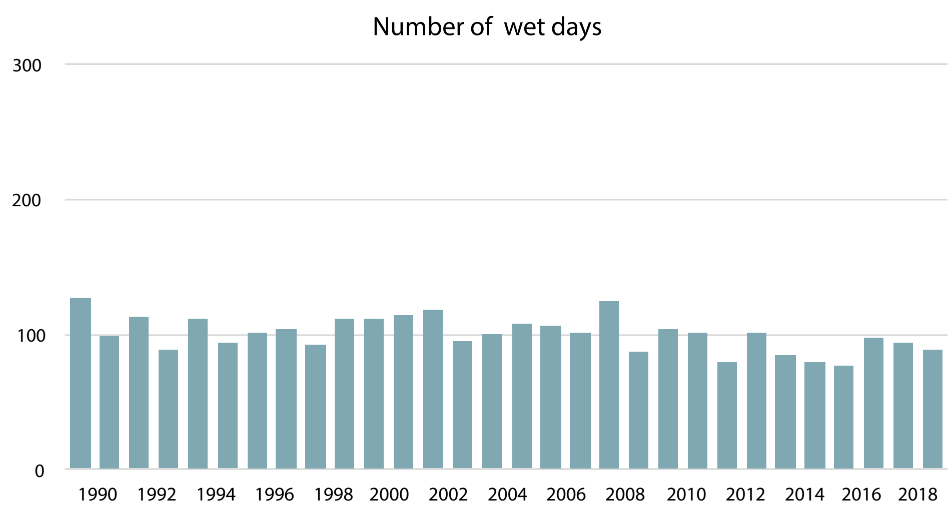
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	3	23	29.5	15.6
Feb	19	25	31.6	17.7
Mar	41	28	33.9	21.3
Apr	73	30	35.0	24.0
May	211	29	33.7	24.9
Jun	229	29	32.4	25.2
Jul	283	28	31.3	24.7
Aug	328	28	31.0	24.6
Sep	229	28	31.4	24.1
Oct	81	26	31.0	21.9
Nov	8	25	30.0	19.0
Dec	4	22	28.4	15.9

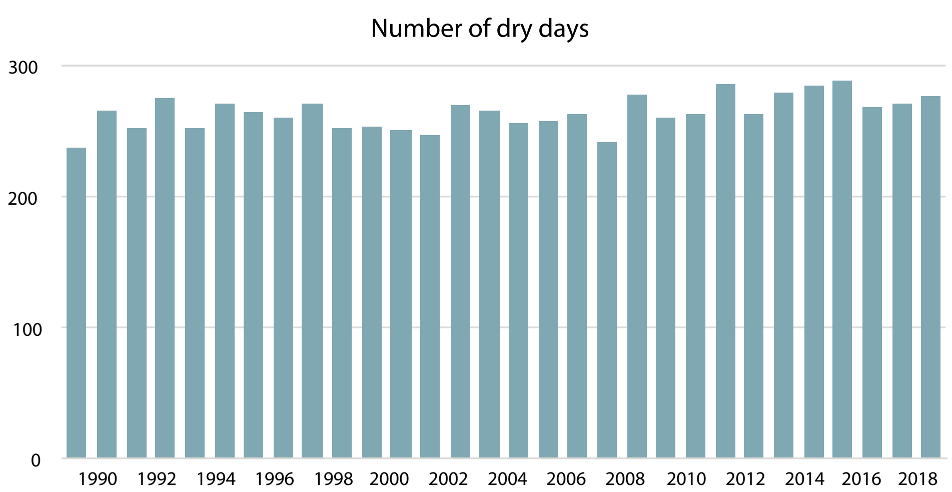
Savannakhet is found in the centre of the Lao People's Democratic Republic, a region that also includes the provinces of Vientiane Capital, Xaisomboun, Vientiane Province, Bolikhamxai and Khammouan. The climatology for the province shows that the rainy season starts in May and continues to September. There is a lot of rainfall during this period, with most rain falling in August (337.14 mm). After this, the amount of precipitation decreases until it reaches a low of 3.2 mm in January. As monthly rainfall decreases, temperatures also fall below 20 °C from November to February of the following year. Savannakhet is the second warmest of the six central provinces, and is generally considered in Laos as having a warm climate. At the Savannakhet weather observation station, the temperature variation range (between the average minimum and maximum temperatures) for 1990–2019 was 15.81 °C to 35.11 °C, the minimum temperature range was 15.81 °C to 25.27 °C, and the maximum temperature range was 28.59 °C to 35.11 °C.

Much of Savannakhet consists of low-lying plain with warmer temperatures, although there are some areas of mountainous terrain at higher elevations with cooler temperatures. According to the climatology graph, temperatures in the province start to decrease from October to January of the following year during the Northeast Monsoon. Maximum temperatures start to increase from mid-January and reach their highest level of 35.11 °C in April during the spring transition (mid-March to mid-May), before decreasing again during the Southwest Monsoon (from mid-May to September). Minimum temperatures start to increase from mid-January, reaching a high of 25.27 °C in June before starting to fall again during the Northeast monsoon. Warmer temperatures between April and September are related to the Intertropical Convergence Zone (ICZ) moving towards the Northern Hemisphere, which causes a predomination of the Southwest Monsoon over Laos, leading to heavy rainfall during this period, including in Savannakhet, one of the driest provinces in the country, its 30-year average being just 1 541 mm per year. Precipitation levels reach their peak of 337.14 mm in August.

At its centre and extending out to the west, Savannakhet contains large areas of flat land at low elevations, much of which is devoted to agriculture interspersed by very sparse forest (grassland and degraded deciduous forest). The east side of the healthier deciduous, semi-evergreen and evergreen forests grow. Temperatures in the province depend on the altitude in each area. Savannakhet has less forest cover and more degraded forests compared to the country's other provinces; it also receives the least rain, despite being located in a region strongly affected by the Southwest Monsoon.

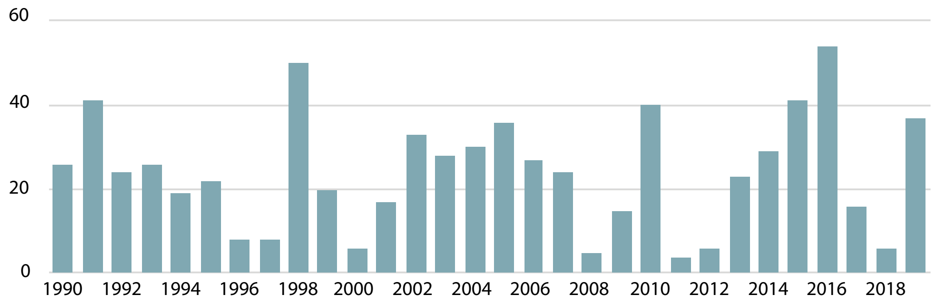
Climate change: Precipitation over the last 30 years



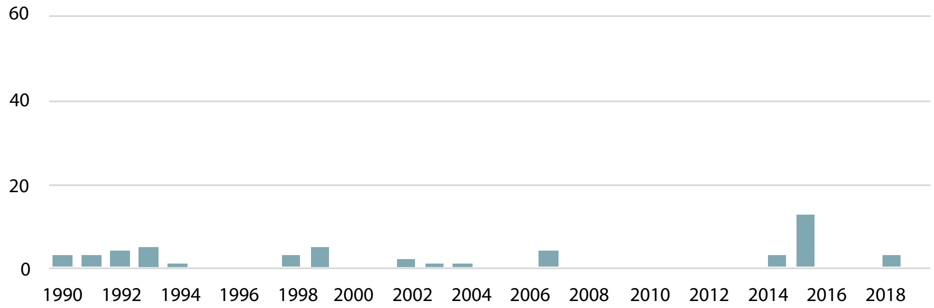


Savannakhet climatology

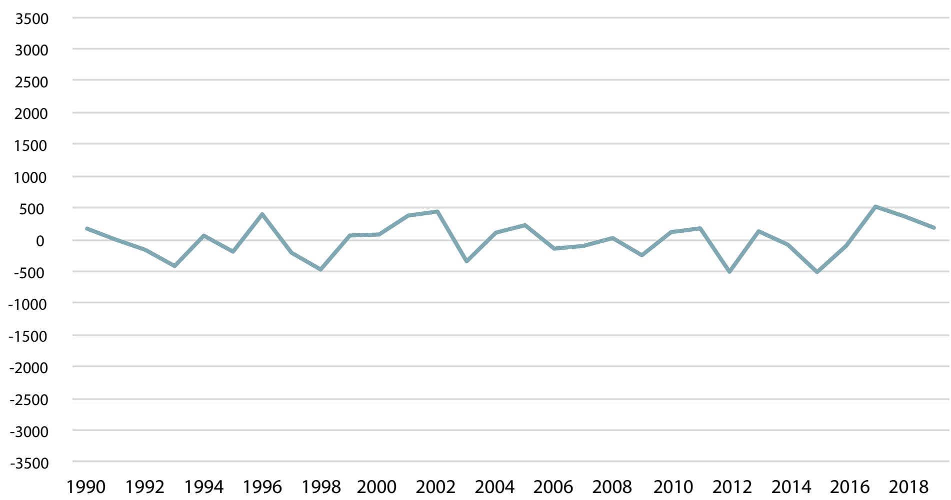
Number of hot days (over 37 °C)



Number of hot days (over 40 °C)

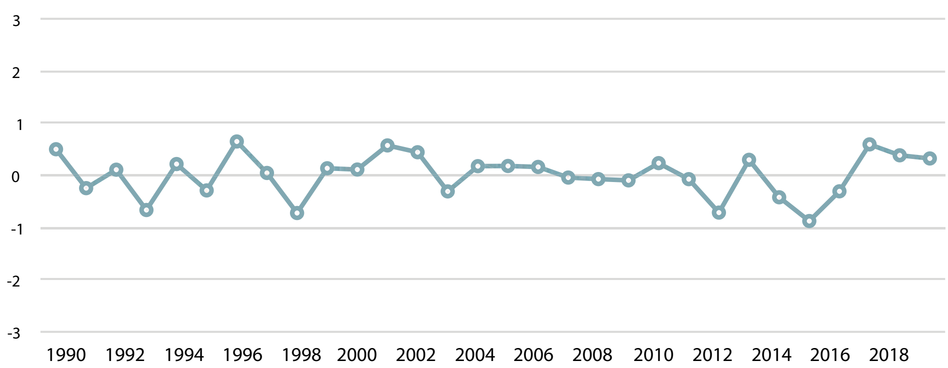


Annual precipitation anomaly trend - 30 years



According to the 30 years of observation data on rainfall in Savannakhet Province from the Savannakhet weather observation station, the number of dry days (with less than 0.2 mm of rainfall) has increased: the lowest number of dry days (238) was recorded in 1990 and the highest (289) in 2016. The number of wet days (with more than 0.2 mm of rainfall), meanwhile, has decreased, with 2016 seeing the smallest number of wet days (77) and 1990 seeing the largest (127). However, the

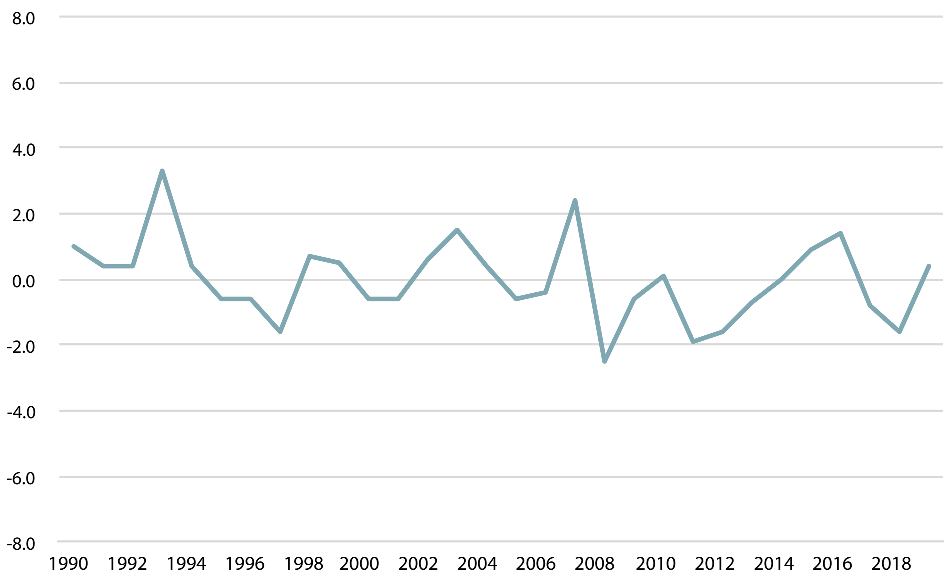
30 - year trend - SPI



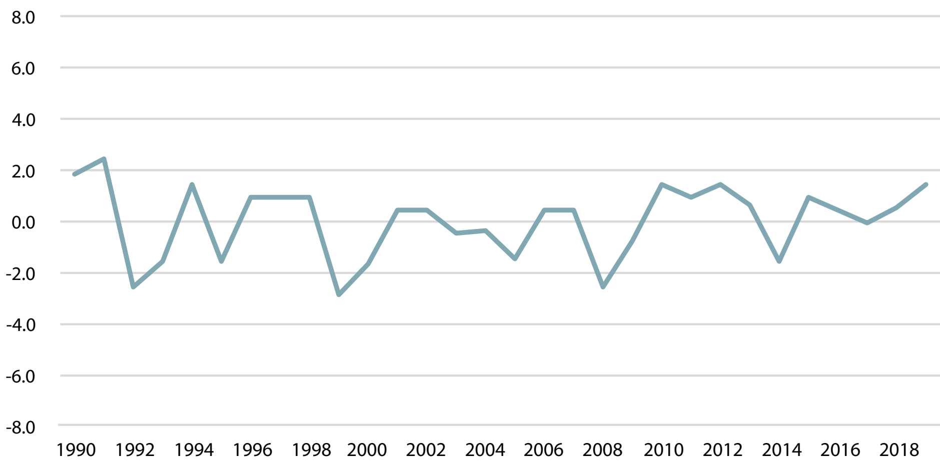
trend analysis shows that precipitation levels have remained relatively stable, with a low of 1 030 mm in 2015 and a high of 2 059.7 mm in 2017. Similarly, the SPI graph reveals no significant increase or decrease, with the driest year occurring in 2005 and the wettest year in 1998.

Climate change: Temperature over the last 30 years

Maximum temperature trend - 30 years



Minimum temperature trend - 30 years

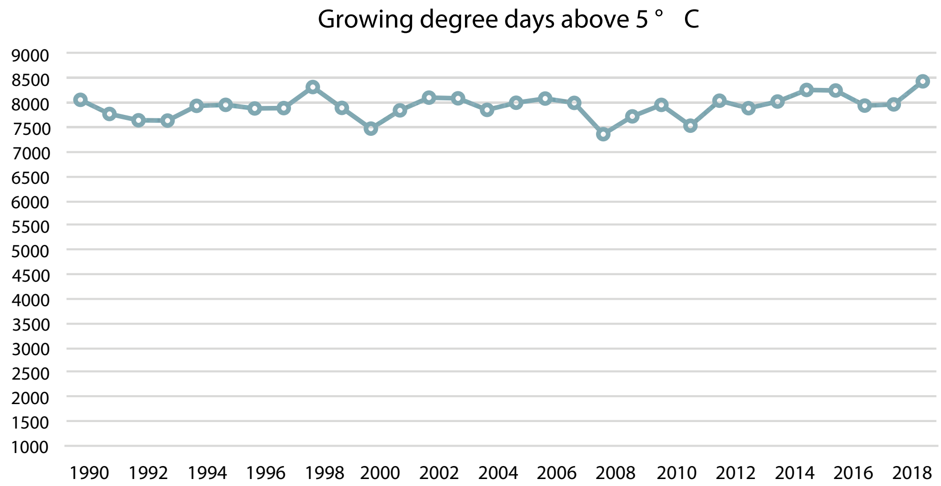


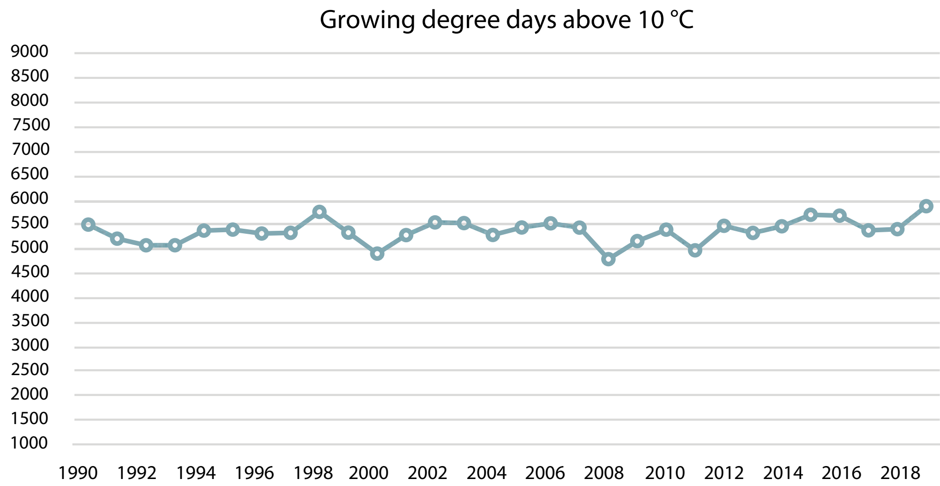
The 30 years of data on temperature conditions show that minimum and maximum temperatures have remained relatively stable, with the annual averages for minimum temperatures ranging from 15.81 °C to 25.27 °C, and those for maximum temperatures ranging from 28.59 °C to 35.11 °C. The number of days on which the temperature exceeded 37 °C has also remained stable (2016 saw it peak at 54 days), as has the number of days on which it exceeded 40 °C, which reached a high of 13 days in 2016.

Savannakhet agroclimatology

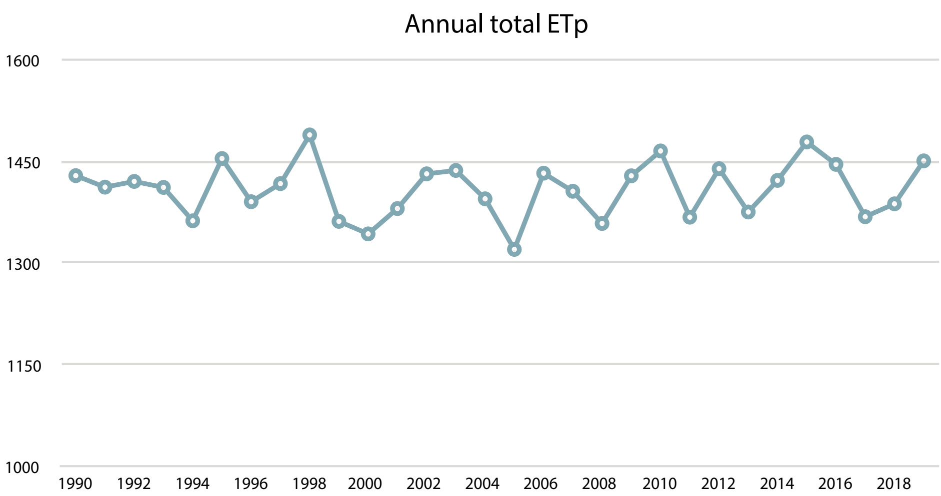
Agroclimatology

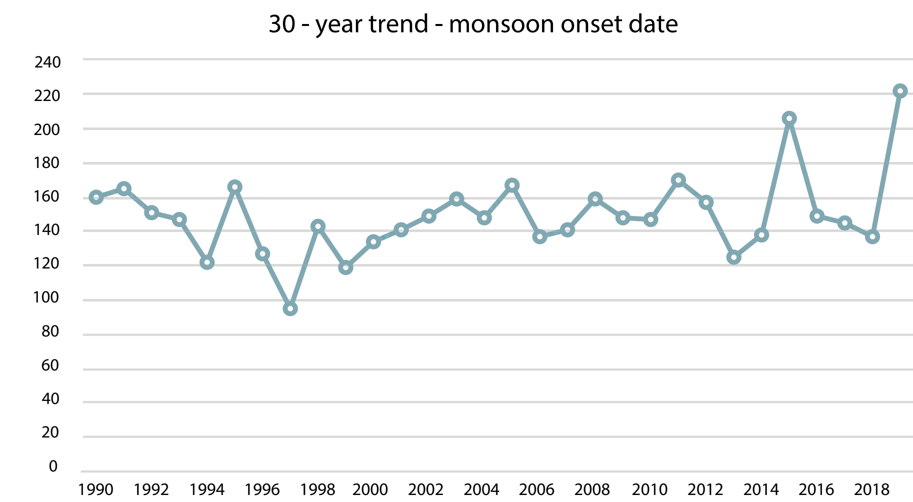
Looking at the growing degree days (GDDs) over 10°C reveals that heat accumulation increased between 1990 and 2019, with a low of 4 796 °C (in 2008) and a high of 5881 ° C in 2019), which has had a significant impact on the development cycle of crops, pests and diseases.



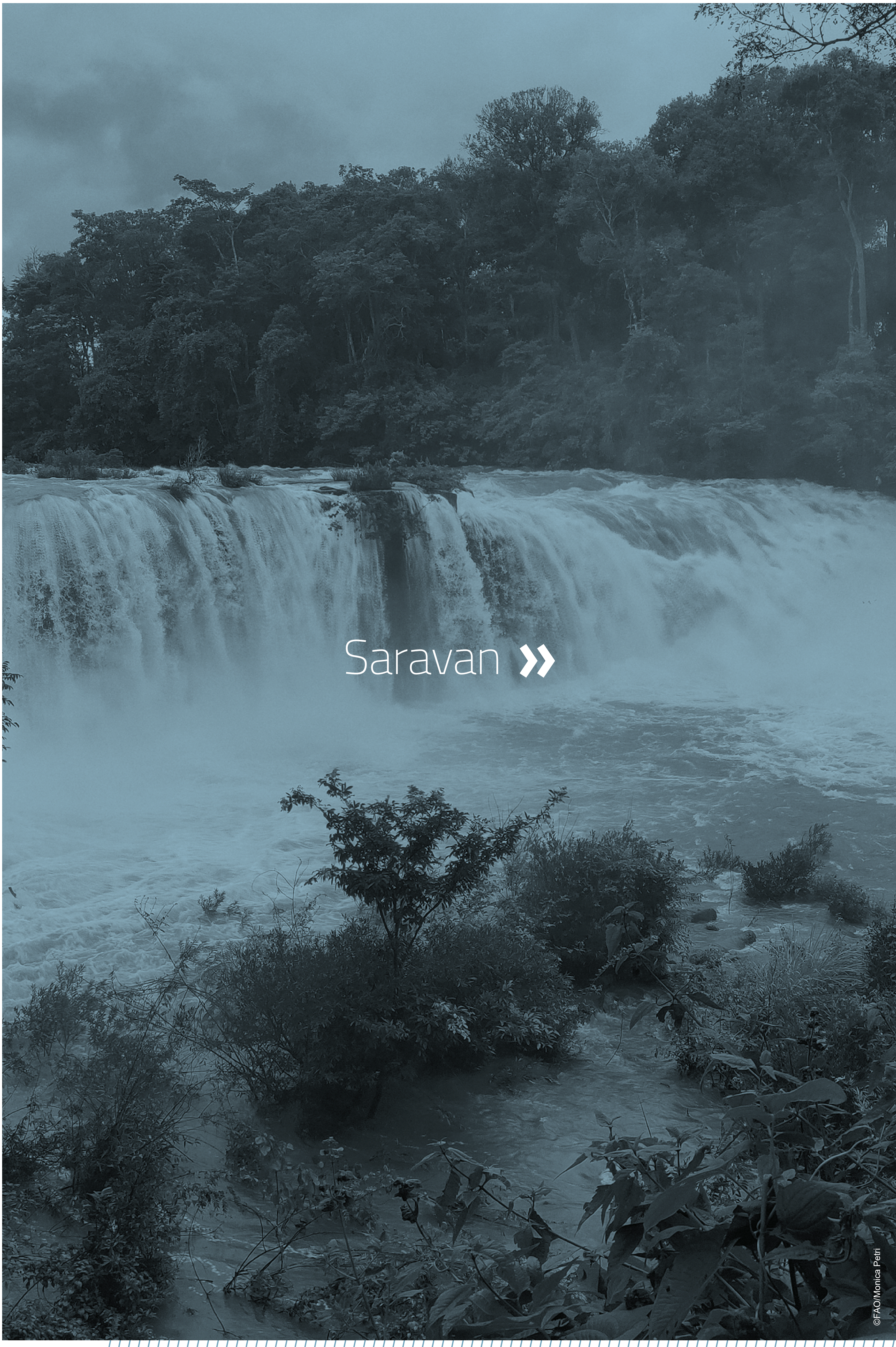


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Se p	Oct	Nov	Dec
Ra infed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Maintenance				Harvest						Prepare and plant	
Maizes	Harvest								Prepare and plant		Maintenance	
Annual crops and grasslands	Harvest								Prepare and plant		Maintenance	
Orchards and plantations	Harvest		Prepare and plant		Maintenance							Harvest
Sugarcane	Prepare/ Plant/ Maintain/ Harvest					Prepare/ plant/ Maintain/ Harvest						
Cassava	Harvest				Prepare and plant		Maintenance					





There has been no significant increase or decrease, meanwhile, in potential evapotranspiration (ETP); the lowest ETp value occurred in 2005 and the highest in 1998. The date of the onset of the monsoon now appears to occur later than it did 30 years ago, with the earliest start date recorded in 1997 and the latest in 2019.


Saravan »
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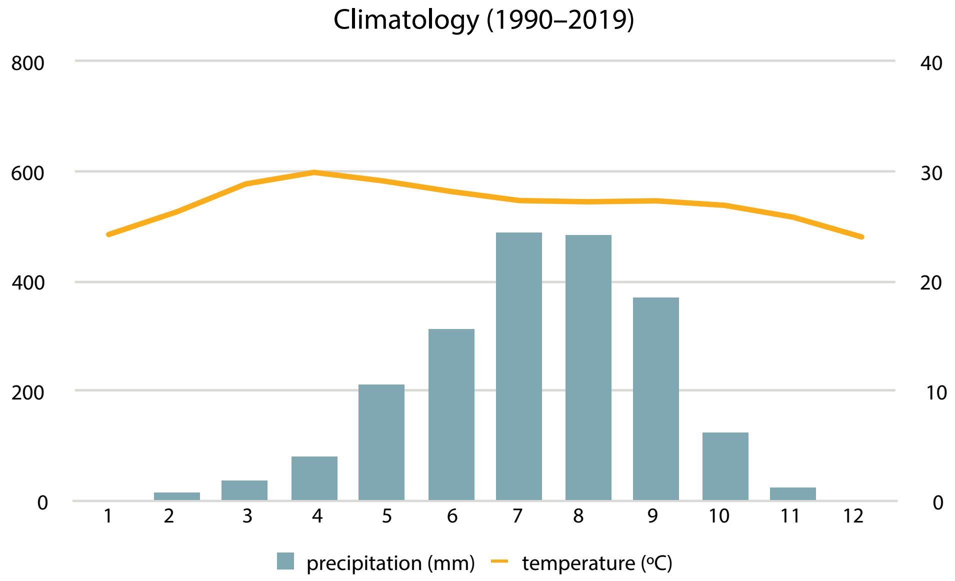
Saravan climatology



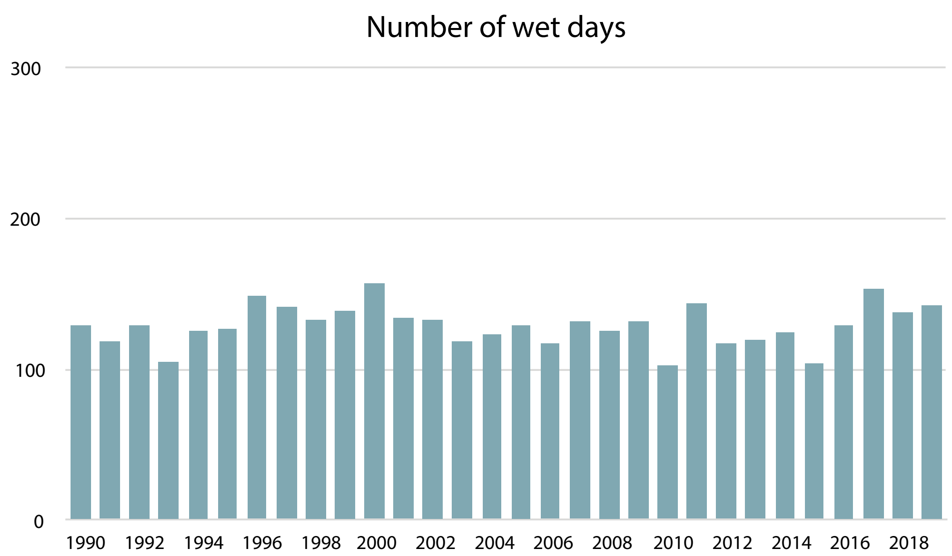
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	3	24	31.3	17.0
Feb	15	26	33.2	19.3
Mar	33	29	35.0	22.6
Apr	78	30	35.3	24.5
May	214	29	33.4	24.9
Jun	303	28	31.5	24.7
Jul	472	27	30.3	24.4
Aug	471	27	30.2	24.3
Sep	365	27	30.5	24.0
Oct	128	27	31.0	22.6
Nov	24	26	31.0	20.5
Dec	4	24	30.1	17.7

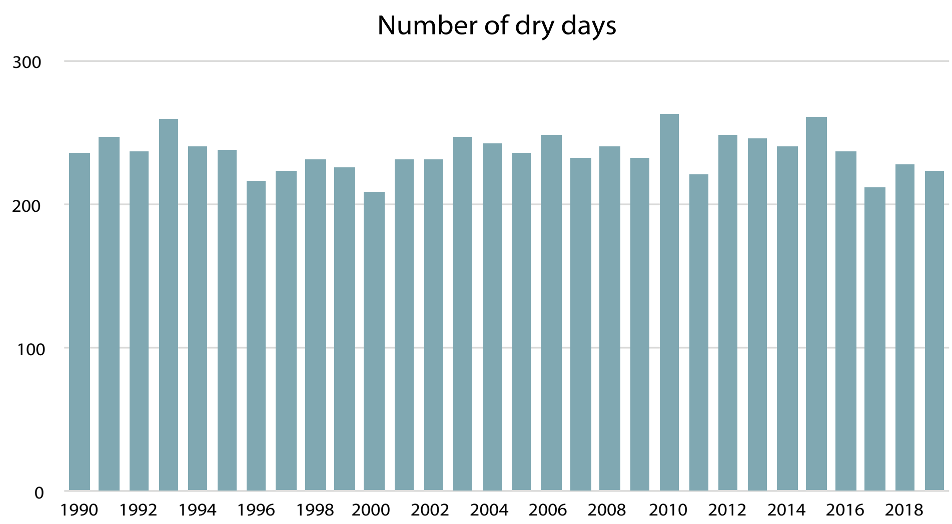
Saravan province lies in the zone of the four Southern provinces of Lao, consisting of Saravan, Xekong, Champasack, and Attapue. The climatology of the province shows that the rainy season starts from May and continues to September. There is significant rainfall in this period, particularly in July, with 489.57 mm in a single month. The rainfall subsequently continues to decrease, reaching its lowest level at 3.25 mm in January of the following year. As the monthly rainfall decreases, the temperature also falls under 20 °C from December to February of the following year. Saravan is one of the cooler of the four Southern Provinces and is one of the warmer provinces in the country. At Saravan weather observation station, the 30-year average temperature variation (minimum to maximum) ranges from 17.13°C to 35.30 °C, with a minimum temperature range of between 17.13 °C and 24.89°C, and a maximum temperature range of between 30.09 °C and 35.30 °C.

Saravan consists of almost half plain land with low elevation and half mountainous terrain. The province has warmer temperatures in the plain-low elevation zone and cooler temperatures in the mountain-high elevation zone. The climatology graph above shows that during the Northeast monsoon, the temperature in the province starts to decrease from November until January of the following year, while the maximum temperature starts to increase from mid-January, reaching its highest level in April at 35.30 °C during the spring transition (mid-March to mid-May), then decreasing again during the Southwest monsoon (from mid-May to September). The minimum temperature starts to increase from mid-January to reach a maximum in May at 24.89 °C and then begins to fall during the Northeast monsoon. With regard to the warmer temperatures from May to September, the moving toward the Northern hemisphere of the Intertropical Convergence Zone (ICZ) causes a strong predomination of Southwest monsoon over Lao, resulting in significant rainfall in this period. Saravan is one of the rainiest provinces in Lao: the 30-year annual total rainfall average is 2 151.15 mm, with the maximum rainfall of 489.57 mm occurring in July.

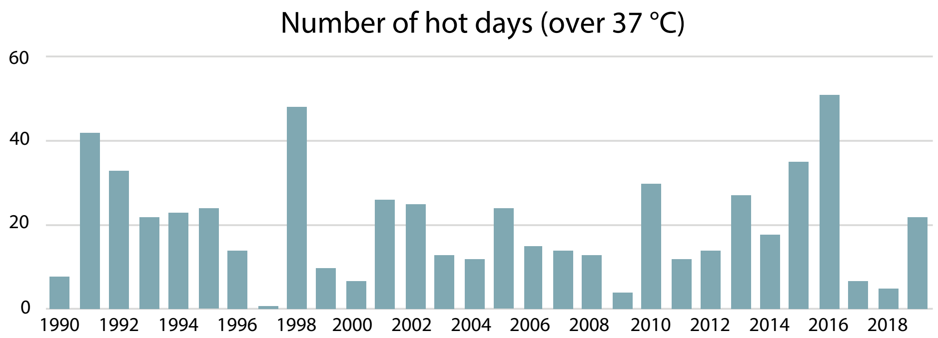
Saravan's topographic coverage is almost half plain land with lower elevation and highland mountainous areas. The northeast side of the province is mountainous with high elevation and steep slopes, covered mostly by forest ranging from sparse deciduous to thick deciduous and healthy evergreen forest; while the areas in the southwest of the province are mainly devoted to habitat and agricultural production areas (mostly paddy fields), with very spare forest cover (grass land and deciduous forest). Temperatures in the province vary based on the altitude of topographic conditions in each area. Saravan province sees significant rainfall as it is located in the zone that is strongly influenced by the Southwest seasonal monsoon; the vegetation in the area is therefore denser and healthier than areas in the North.

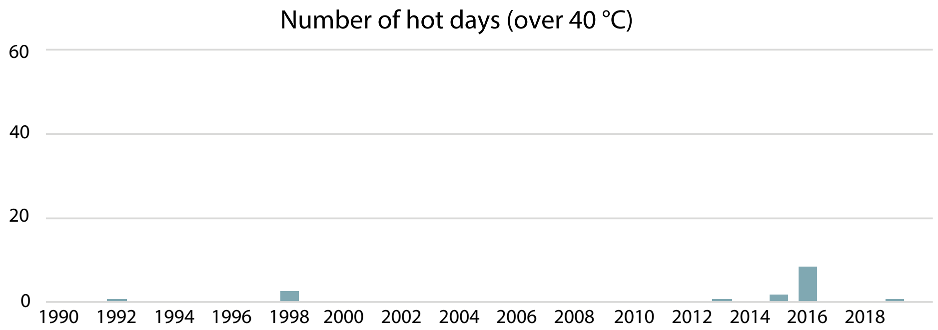
Climate change: Precipitation over the last 30 years

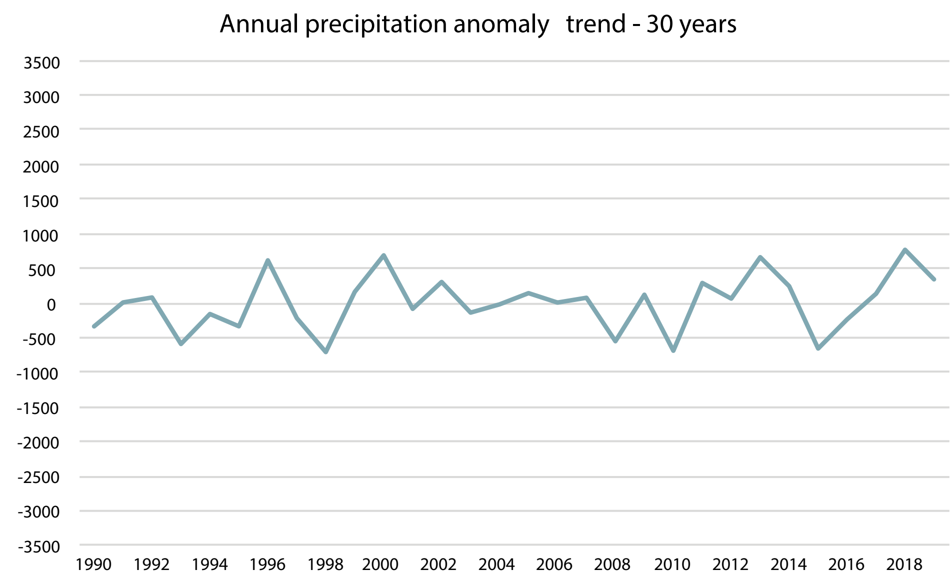




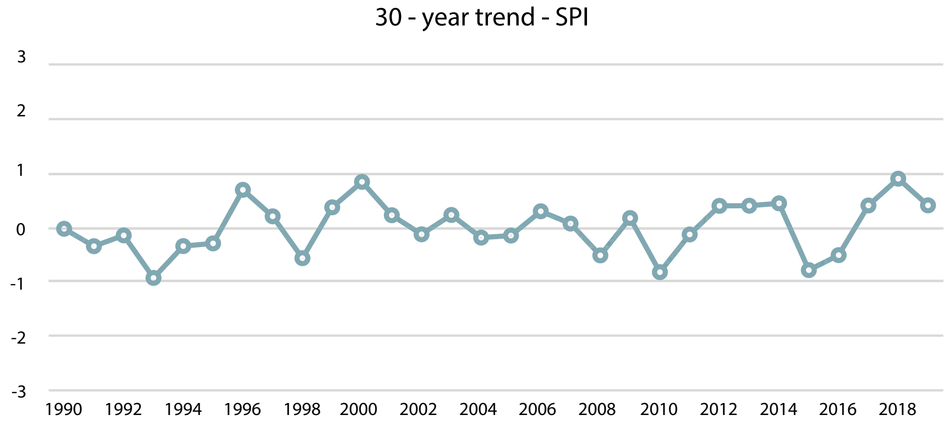
Saravan climatology





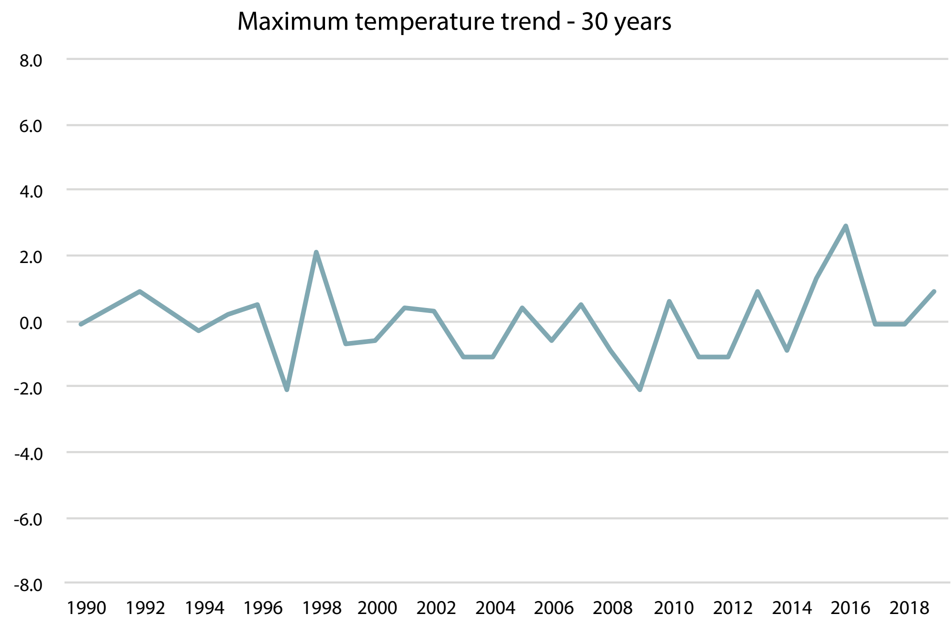


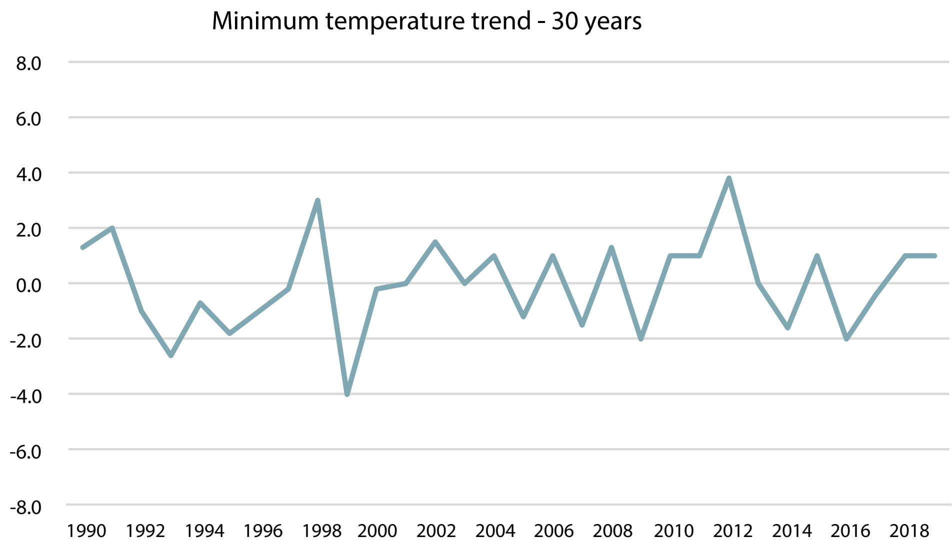
The 30-year data for Saravan province at Saravan weather observation station reveal that the number of dry days (less than 0.2 mm daily rainfall) shows no significant trend, with the minimum number (209 days) in 2000 and the maximum number (263 days) in 2010; while the number of wet days (more than 0.2 mm daily rainfall) also reveals no significant trend, with the lowest number (102 days) in 2010, and the maximum number (157 days) in 2000. However, the rainfall trend is increasing: the



30-year annual total rainfall ranged from the lowest annual rainfall 1 444.3mm (in 1998) to the highest annual rainfall 2 920 mm (in 2018). The SPI shows an increasing trend, whereby the driest year occurred in 1993 and the wettest in 2018.

Climate change: Temperature over the last 30 years



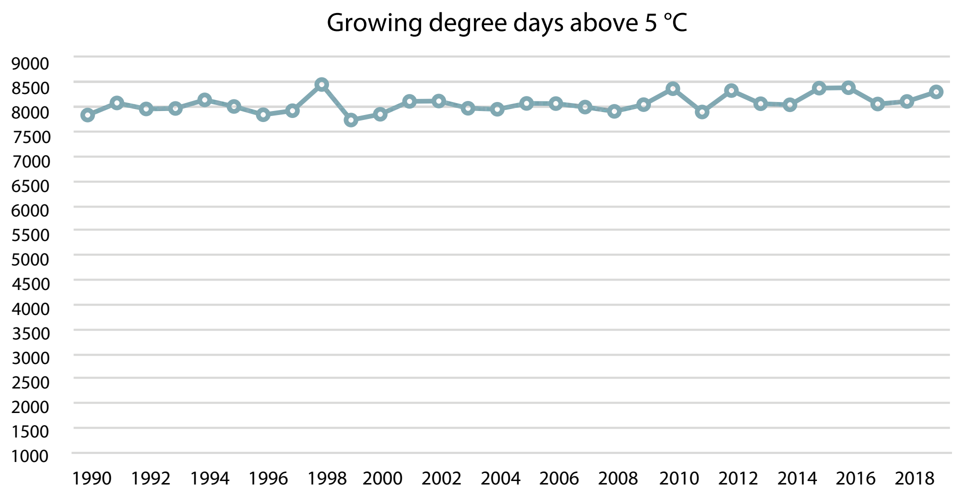


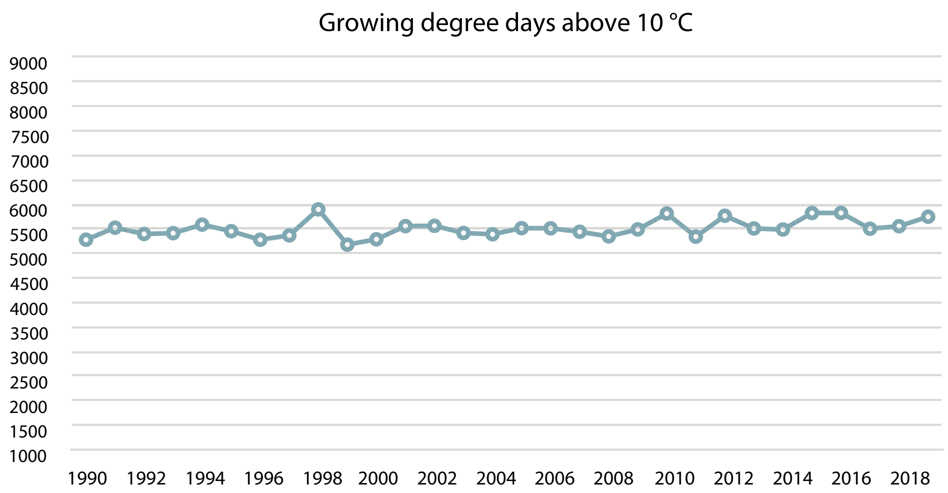
The 30 years of data on temperature conditions show that minimum and maximum temperatures reveal no significant trends: the minimum annual variation range is from 21.31 and 23.47 °C, and the maximum annual variation range is from 31.06 and 32.84 °C. The number of days over 37 °C reveals a decreasing trend: the maximum (51 days) occurred in 2016; and the number of days over 40 °C has increased since 2013, with the maximum number (nine days) in 2016.

» Saravan agroclimatology

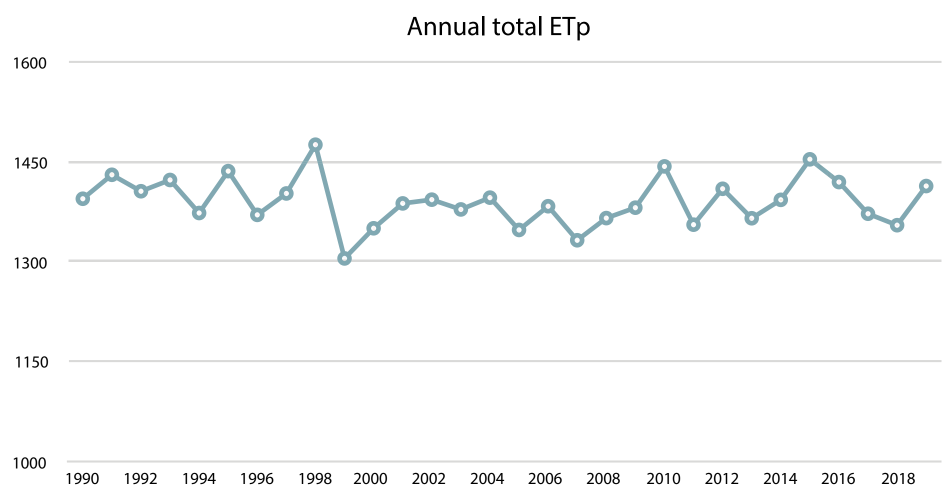
Agroclimatology

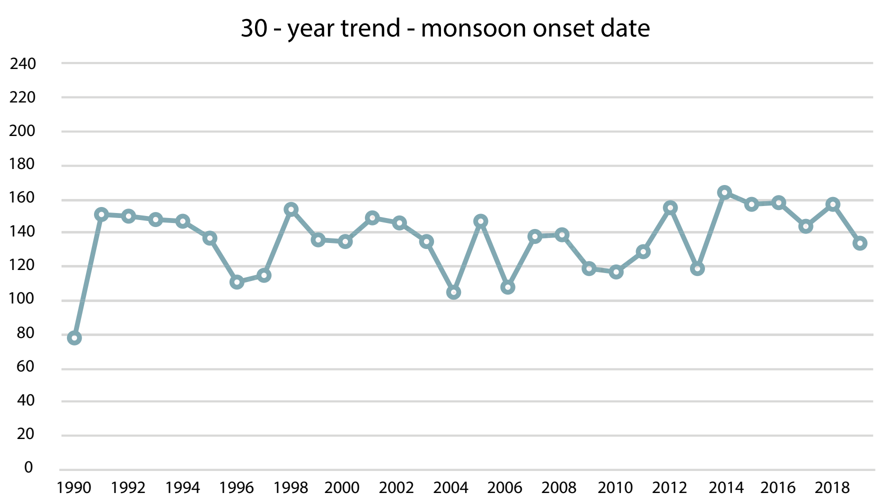
Looking at the growing degree days (GDDs) over 10 °C reveals that heat accumulation increased between 1990 and 2019, with a low of 5 179 °C (in 2008) and a high of 5 881 °C (in 2019), which has had a significant impact on the development cycle of crops, pests and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Maintenance			Harvest							Prepare and plant	
Steep slope agriculture			Prepare and plant		Maintenance					Harvest		
Cassava	Harvest		Prepare and plant		Maintenance							Harvest
Annual crops and grasslan	Maintenance		Harvest							Prepare and plant		
Coffee	Harvest		Prepare and plant		Maintenance					Harvest		
Orchards and plantations	Harvest		Prepare and plant		Maintenance						Harvest	

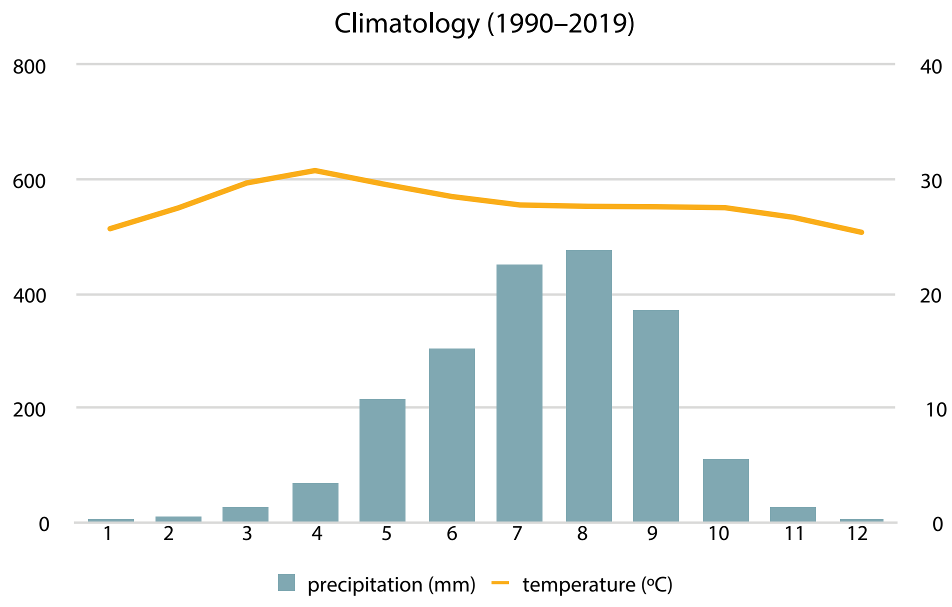




There has been no significant increase or decrease, meanwhile, in potential evapotranspiration (ETp); the lowest ETp value occurred in 2005 and the highest in 1998. The date of the onset of the monsoon now appears to occur later than it did 30 years ago, with the earliest start date recorded in 1997 and the latest in 2019.

Champasack »

Champasack climatology



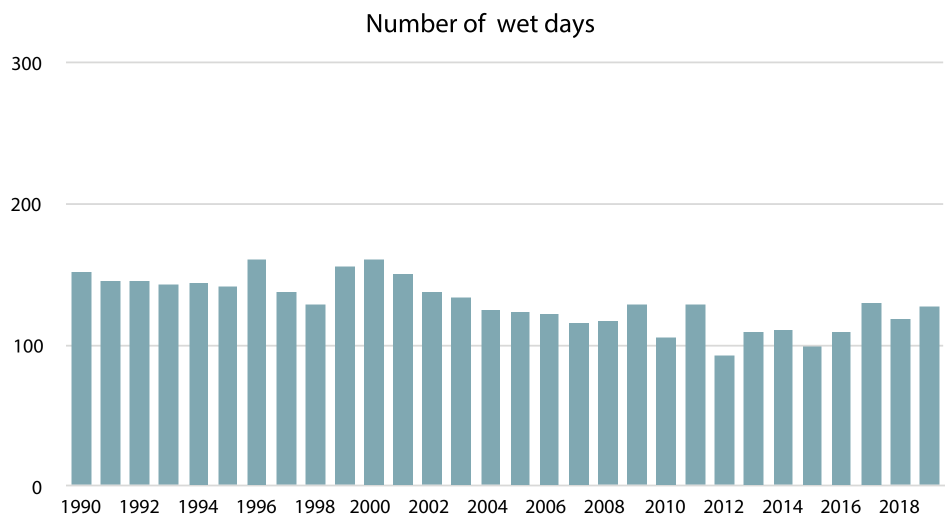
Month	Precipitation (mm)	Temperature (°C)	Tmax	Tmin
Jan	5	26	32.2	19.1
Feb	10	27	33.6	21.2
Mar	28	30	35.2	24.1
Apr	71	31	35.6	25.8
May	225	30	33.7	25.4
Jun	310	28	31.8	25.0
Jul	431	28	31.0	24.5
Aug	455	28	30.8	24.4
Sep	356	28	31.0	24.2
Oct	121	27	31.6	23.1
Nov	24	27	31.7	21.3
Dec	5	25	31.2	19.2

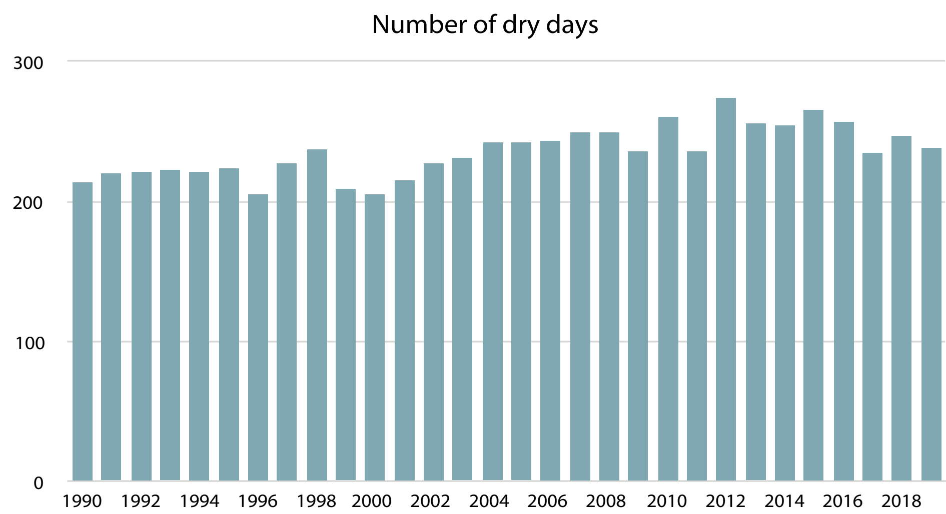
Champasack province lies in the zone of four Southern provinces of Lao, which consists of Champasack, Saravan, Sekon, and Attapue. The climatology of the province shows that the rainy season starts from May and continues until September. There is significant rainfall in this period, with the highest rainfall recorded in August at 476.27 mm in a single month. Following this month the rainfall continues to decrease, reaching its lowest level of 4.56 mm in January of the following year. As monthly rainfall decreases, the temperature also falls below 20 °C during December to January of the following year. Champasack is one of the hottest provinces in the country as well as in the zone of the four Southern provinces; at Pakse weather observation station, the 30-year average annual temperature variation (minimum to maximum) is between 19.13 °C and 35.72 °C, with minimum temperatures ranging between 19.13 °C and 25.81 °C, and maximum temperature ranges between 30.78 °C and 35.72 °C.

Champasack province is half mountain and plain land area, while the higher elevation mountainous zone enjoys cooler temperatures than the flat and low altitude areas. The climatology graph above shows that during the Northeast monsoon, the temperature in the province starts to decrease from November until January of the following year: maximum temperatures start to increase from mid-January, reaching their highest levels in April at 35.72 °C during the spring transition (mid-March to mid-May), then decreasing again during the Southwest monsoon (from mid-May to September). The minimum temperature starts to increase from mid-January to reach a maximum in April at 25.81 °C and then starts to fall during the Northeast monsoon. With regard to warmer temperatures from April to October, the moving toward the Northern hemisphere of the Intertropical Convergence Zone (ICZ) causes a strong predomination of Southwest monsoon over Lao, resulting in significant rainfall in this period, Champasack is one of the rainier provinces in the Southern zone and indeed in the country as a whole: the 30-year annual total rainfall average is 2 071.4 mm, where the rainiest period is in June-September.

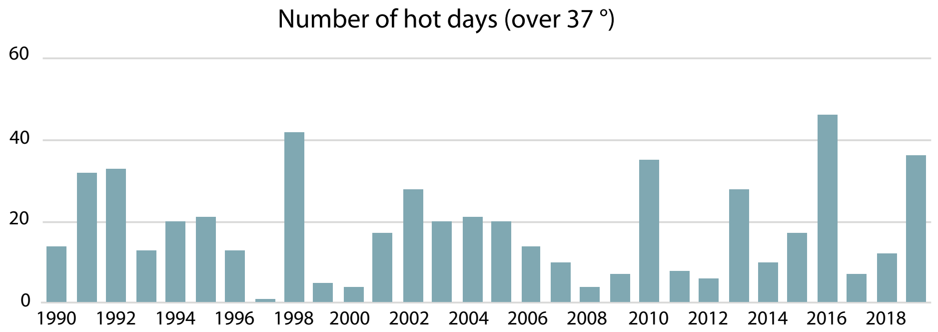
Champasack's topographic coverage is mostly low elevation plain land and highland mountainous area. The western side on the border with Thailand is low elevation plain land, mostly residential and dedicated to agricultural production (mainly paddy fields), with minor vegetation (deciduous and evergreen forest) in the mountainous area next to border. The mountainous Southeast side of the province features a very healthy dense evergreen forest; while the Northeast side in the highland Pakxong district is a plain area with a high elevation topographic and cooler temperatures, the areas are mostly devoted to the agriculture industry. Champasack is located in the zone of high influence of the Southwest Seasonal Monsoon, resulting in significant rainfall, and thus enjoys one of the denser and healthier natural forest covers in the region.

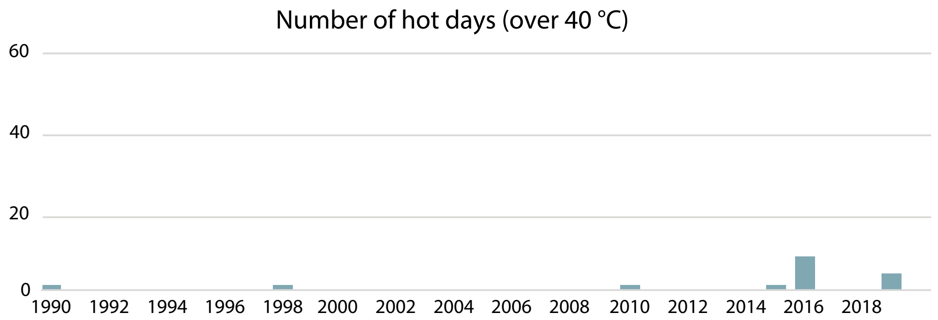
Climate change: Precipitation over the last 30 years

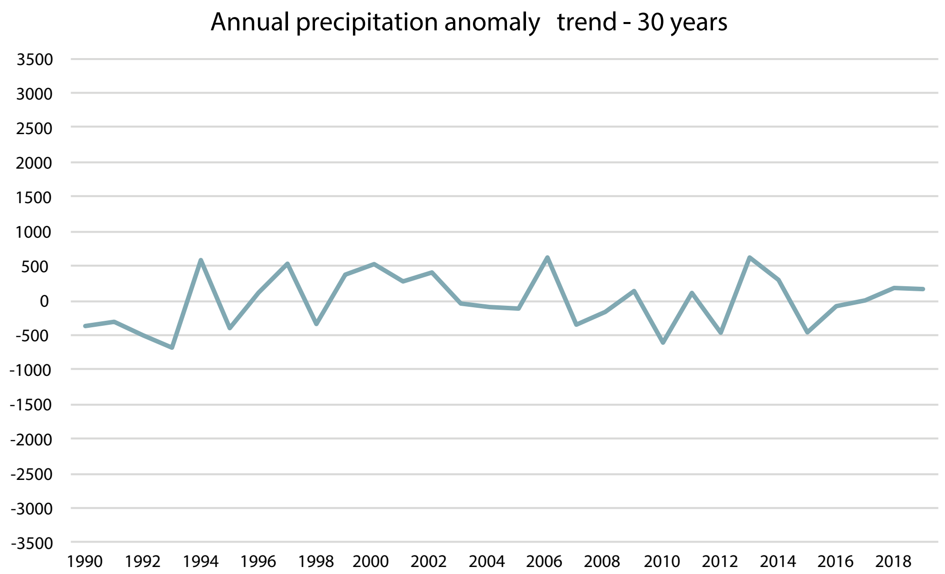




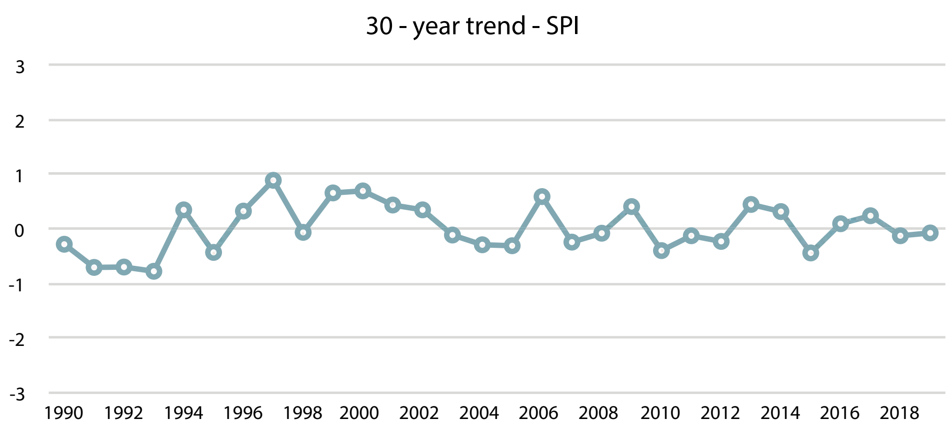
Champasack climatology



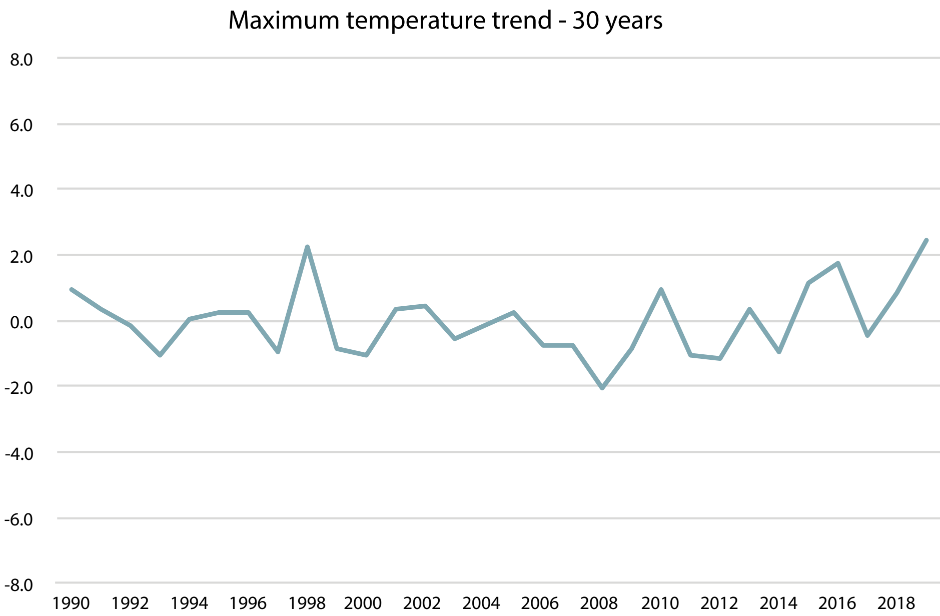


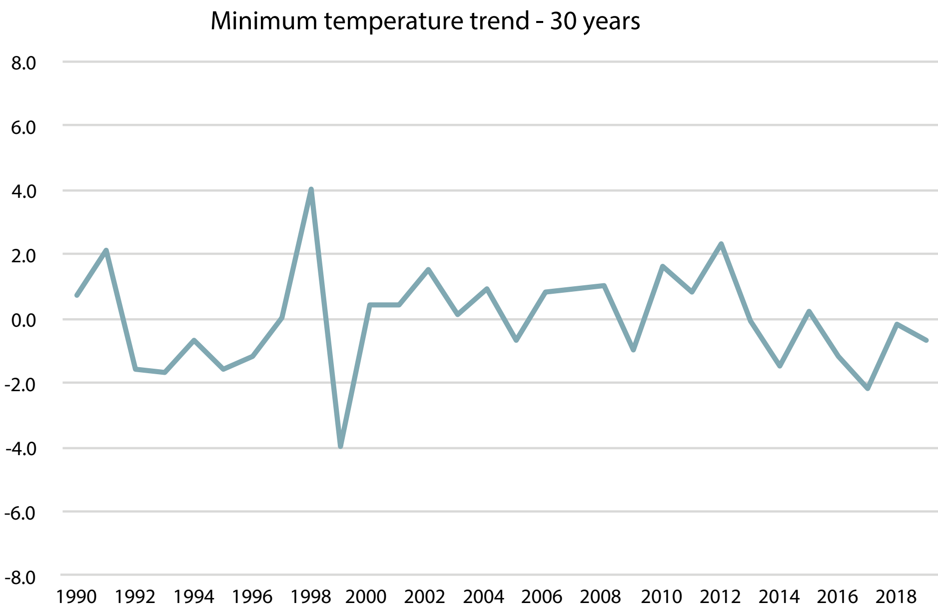


The 30-year observation data for Champasack province at Pakse weather observation station reveal that the number of dry days (less than 0.2 mm daily rainfall) shows an increasing trend, with the minimum number (205 days) recorded in 2000 and the maximum number (274 days) in 2012; while the number of wet days (more than 0.2 mm daily rainfall) shows a decreasing trend: the smallest number (92 days) was recorded in 2012, and the maximum number (161 days) in 2000. But the rainfall shows a slightly increasing trend: the 30-year annual total rainfall varies from the lowest point of 1 391.5 mm (in 1993) to highest of 2 694.5 mm (in 2006). The SPI shows no significant trend: the driest year occurred in 1993 while the wettest year occurred in 1997.



Climate change: Temperature over the last 30 years



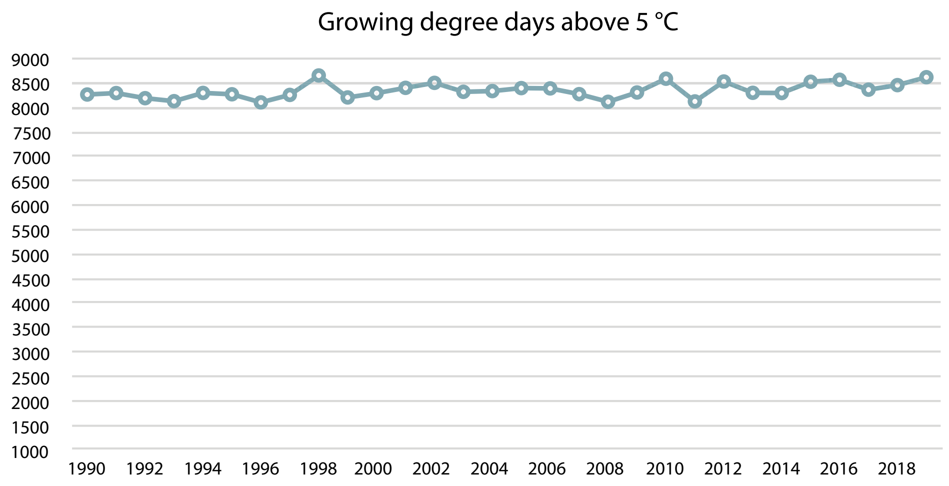


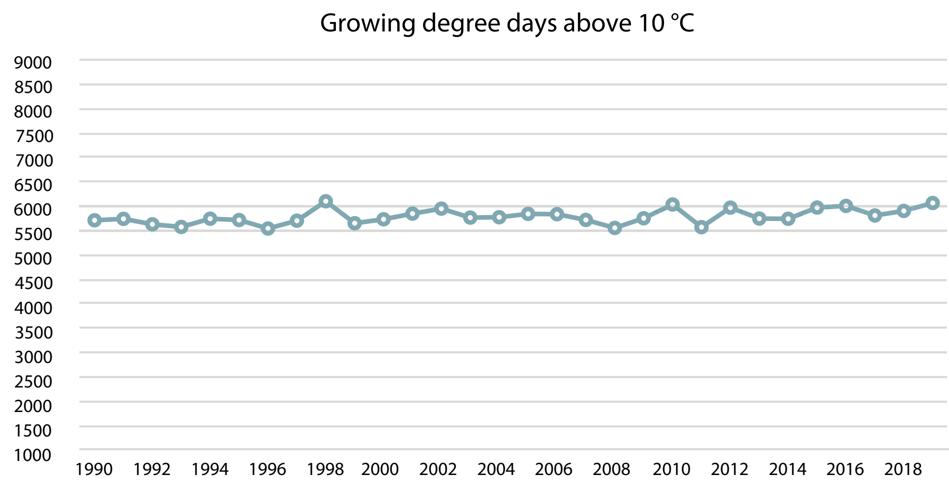
The 30 years of data on temperature conditions show that the minimum and maximum temperatures reveal no significant trend: the annual temperature variation ranges between 19.13 and 35.72 °C, with a minimum annual variation between 19.13 and 25.81 °C, and a maximum between 30.78 and 35.72 °C. The number of days at more than 37 °C shows no significant trend, with the maximum number (46 days) in 2016; whereas the number of days at more than 40 °C has increased since 2010, with the maximum (six days) recorded in 2016.

Champasack agroclimatology

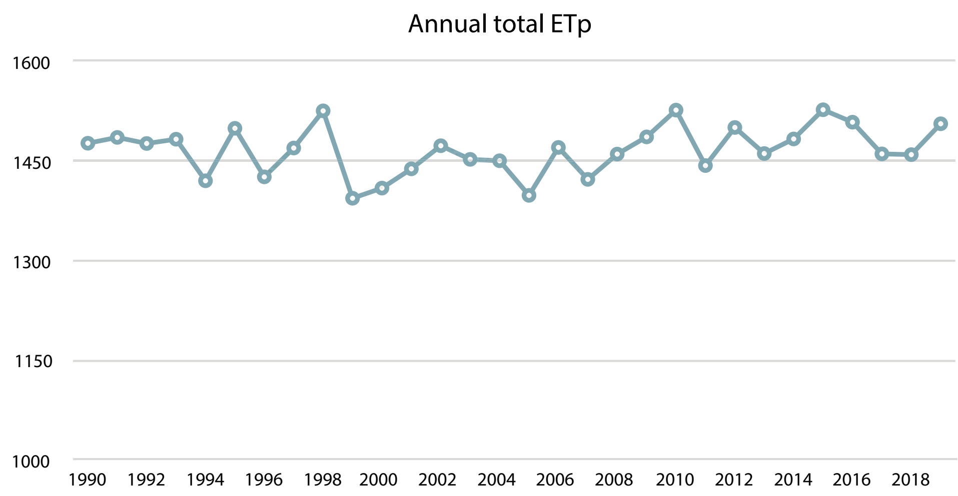
Agroclimatology

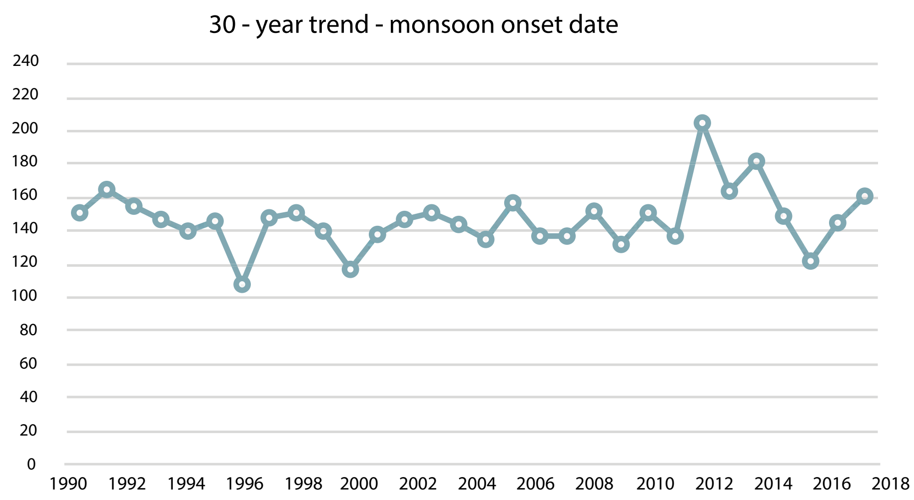
Growth Degree Days (GDD) over 10 °C show a significant increasing trend by 8.1 °C per year, with annual heat accumulation in past 30 years (1990–2019) ranging from the lowest point of 5 542 °C (in 1996) to the highest of 6 100 °C (in 1998), resulting in a significant impact on the development cycle of crops, pests, and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice					Prepare and plant		Maintenance				Harvest	
Irrigated rice	Maintenance		Harvest								Prepare and plant	
Coffee	Harvest		Prepare and plant		Maintenance					Harvest		
Cassava	Harvest		Prepare and plant		Maintenance							Harvest
Orchards and plantations			Prepare and plant		Maintenance					Harvest		
Maizes	Harvest								Prepare and plant		Maintenance	
Annual crops and grasslands	Maintenance		Harvest							Prepare and plant		

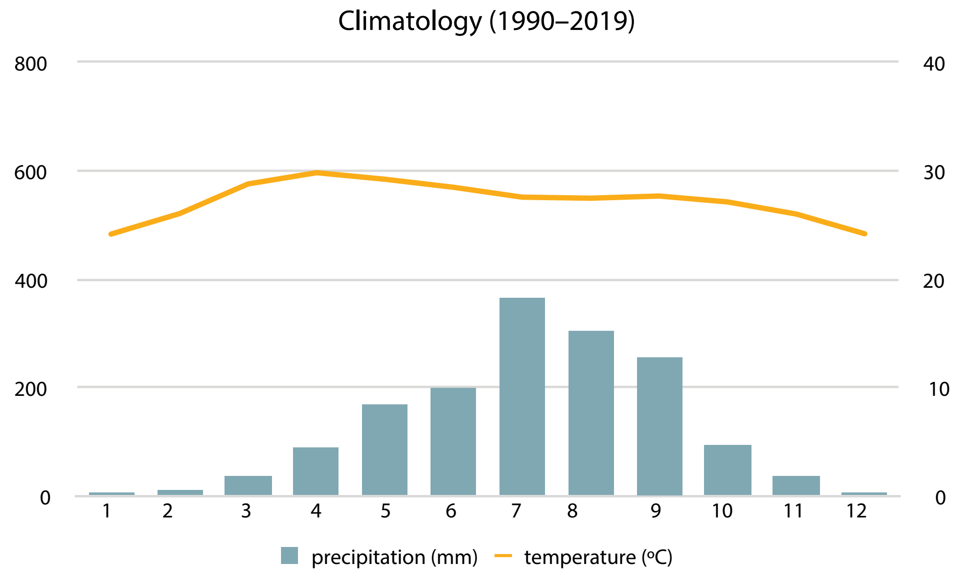




The potential evapotranspiration (ETP) shows no significant trend: the lowest ETp was recorded in 1999, and the highest in 2015. The date of the onset of the monsoon does not appear to have changed significantly over the period, with the earliest start date recorded in 1996, and the latest in 2013.

Sekong »

Sekong climatology



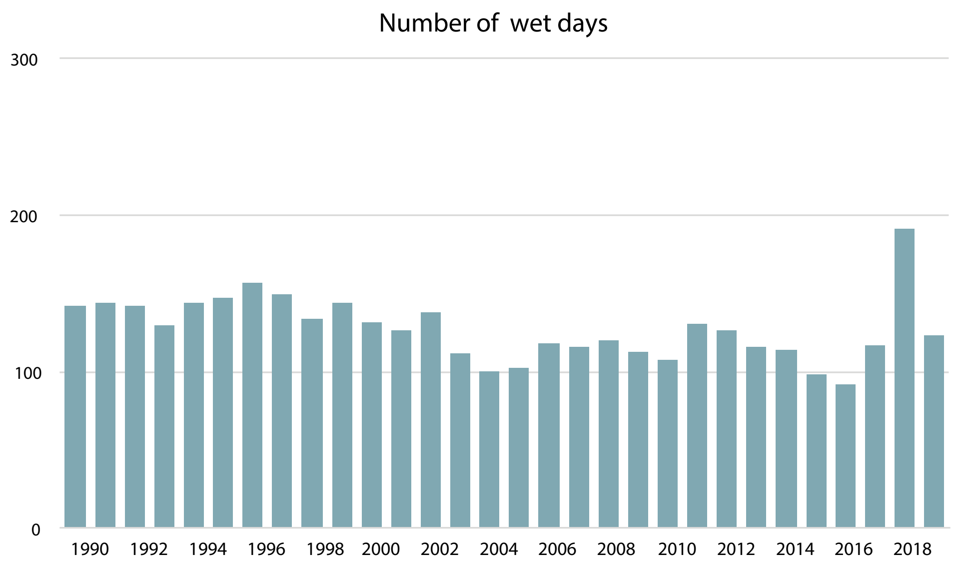
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	2	24	32.2	15.8
Feb	10	26	34.1	17.9
Mar	37	29	36.1	21.4
Apr	87	30	36.0	23.5
May	164	29	34.0	24.4
Jun	189	28	32.4	24.4
Jul	303	28	31.2	24.0
Aug	272	28	31.1	23.9
Sep	239	28	31.6	23.7
Oct	98	27	31.9	22.2
Nov	32	26	31.8	20.1
Dec	4	24	31.2	17.0

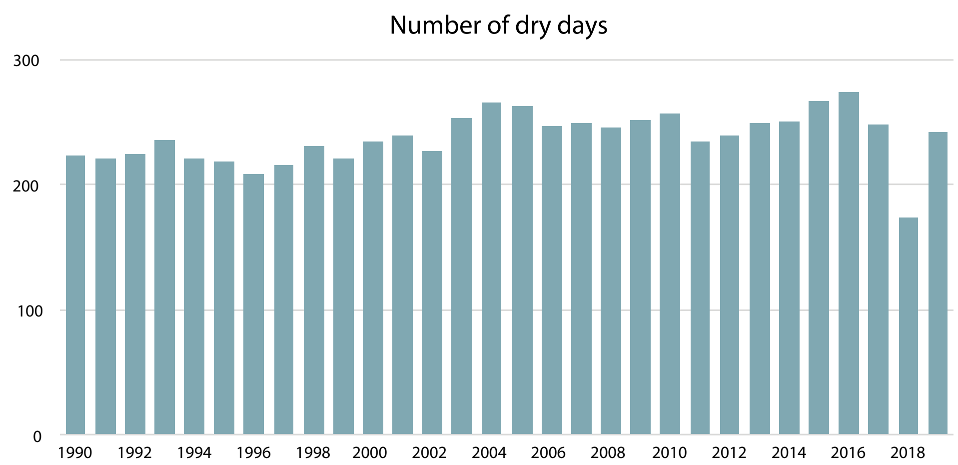
Sekong province is in the zone of the four Southern provinces of Lao, consisting of Sekong, Saravan, Champasack, and Attapue. The climatology of the province shows that the rainy season starts from May and continues to September. There is significant rainfall in this period, with the highest rainfall in July, with 364.75 mm in a single month, following which the amount continues to decrease to its lowest level of 4.38 mm in December. As monthly rainfall decreases, the temperature also falls below 20 °C between December and February of the following year. Sekong is one of the hottest in the four Southern provinces and indeed in the country: at Sekong weather observation station, the 30-year average annual temperature variation (minimum to maximum) is between 15.99 °C to 36.05 °C, with minimum temperatures ranging between 15.99 °C and 24.45 °C, and maximum temperatures ranging between 31.0 °C and 36.05 °C.

Sekong is a mountainous province in the South of Lao People's Democratic Republic, a minor plain area in the Southwest with warmer temperatures than most of the higher elevation mountainous areas in the province. The climatology graph above shows that during the Northeast monsoon, the temperatures in the province start to decrease from October until January of the following year; the maximum temperatures start to increase from mid-January to their highest level in April at 36.05 °C during the spring transition (mid-March to mid-May), then decrease again during the Southwest monsoon (from mid-May to September). The minimum temperatures start to increase from mid-January to a maximum in June at 24.45 °C and then start to fall during the Northeast monsoon. With regard to the warmer temperatures during April to October, the moving toward the Northern hemisphere of the Intertropical Convergence Zone (ICZ) causes a strong predomination of the Southwest monsoon over Lao, resulting in significant rainfall in this period. Sekong is one of the less rainy provinces in the Southern zone and in the country as a whole: the 30-year annual total rainfall average is 1 568 mm, while the rainiest period is in July-September.

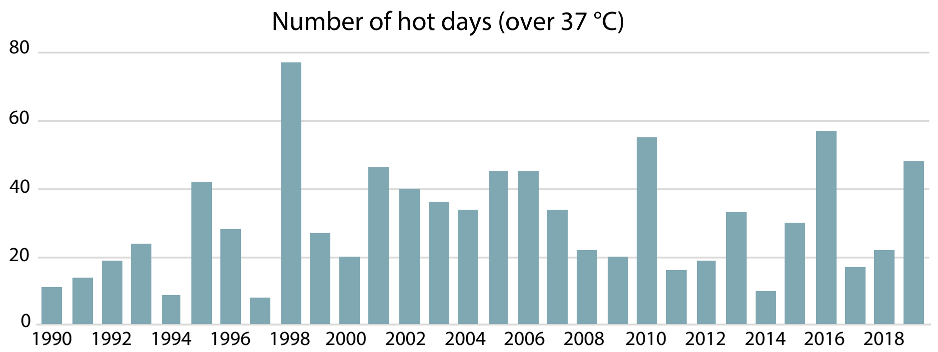
Sekong's topographic coverage is mountainous with high elevation and steep slopes, whereas forest coverage ranges in density depending on the availability of rainfall and climate patterns in each area. The minor plain is in the area to the west of the province where Sekong town is situated, and the surrounding areas are used for agricultural production; the Northeast side of the province is covered by thick and healthy forest, such as spare deciduous, thick deciduous, semi-evergreen forest and evergreen forest, while the Southeast side is mainly covered by forest with grassland, minor-shrub land, deciduous forest and evergreen forest. The observation point at Sekong has indicated that the rainfall is less than that of neighbouring provinces, strongly influenced by the Southwest Seasonal Monsoon. Forest, coverage in the area is therefore healthier compared to the Mid to North provinces of the country.

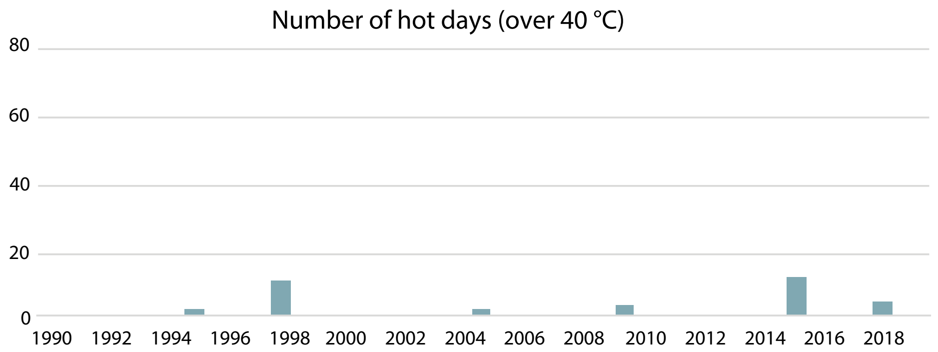
Climate change: Precipitation over the last 30 years

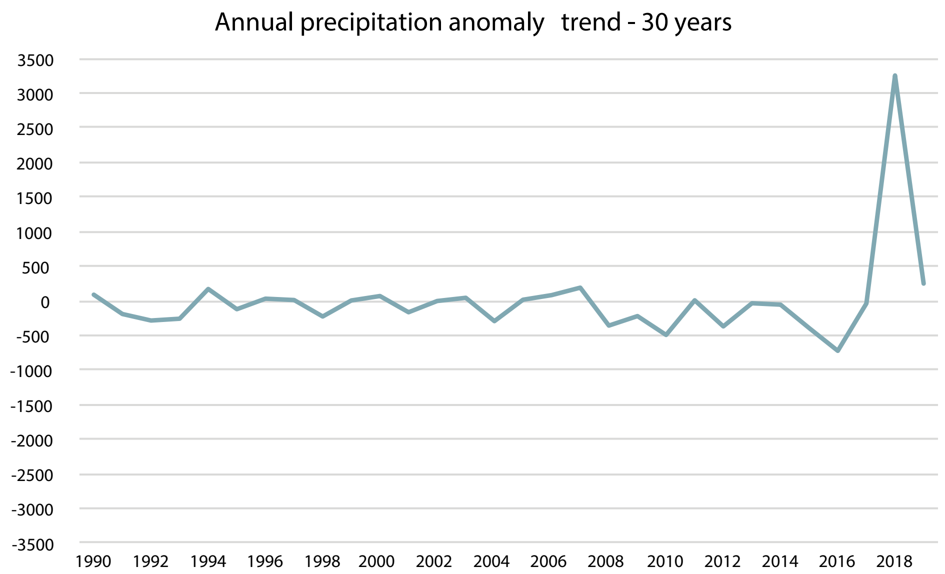




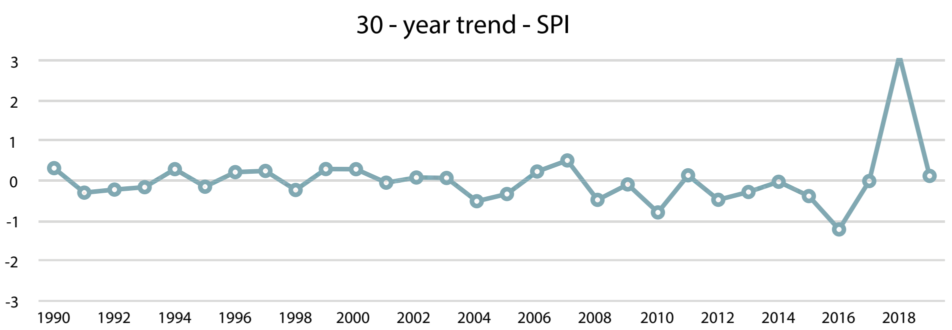
Sekong climatology





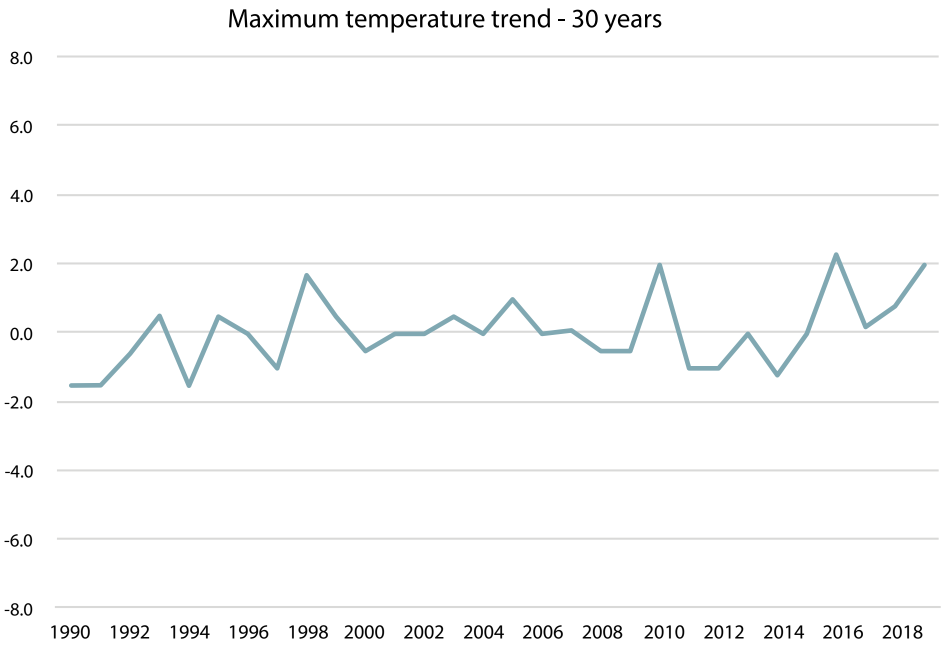


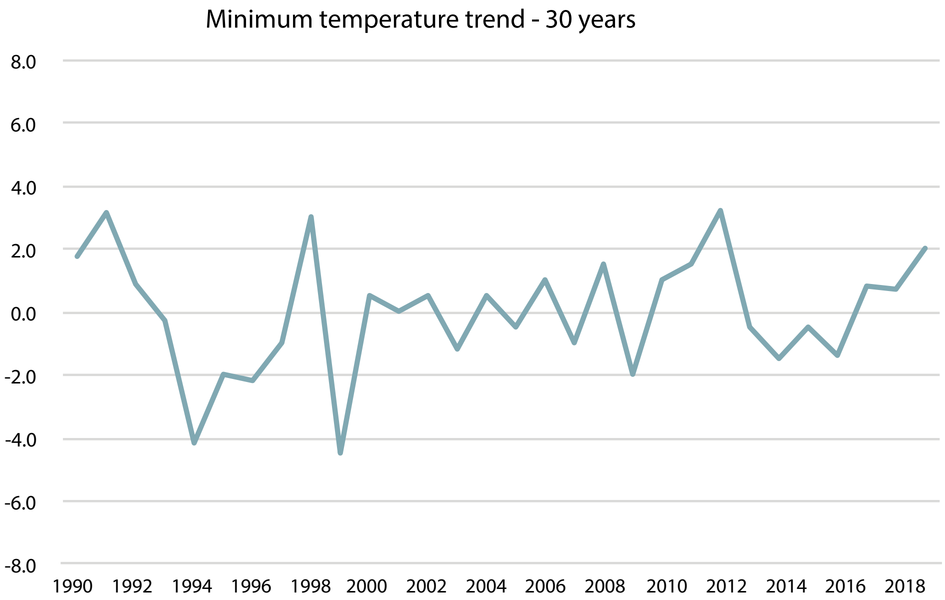
The 30-year observation data for the province at Sekong weather observation station reveals that the number of dry days (less than 0.2 mm daily rainfall) shows an increasing trend, with the minimum number (174 days) recorded in 2018 and the maximum (274 days) in 2016; while the number of wet days (more than 0.2 mm daily rainfall) shows a decreasing trend: the lowest number (92 days) was recorded in 2016, and the maximum (191 days) in 2018. But the rainfall shows an increasing



trend: the 30-year annual total rainfall varied from the least 845 mm (in 2016) to the highest of 4 824 mm (in 2018). The SPI reveals no significant trend: whereas the driest year occurred in 2016, the wettest year was in 2018.

Climate change: Temperature over the last 30 years



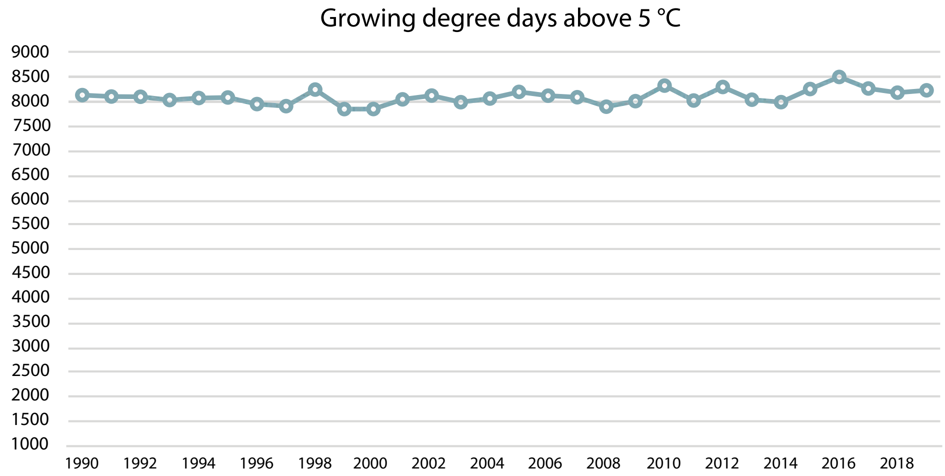


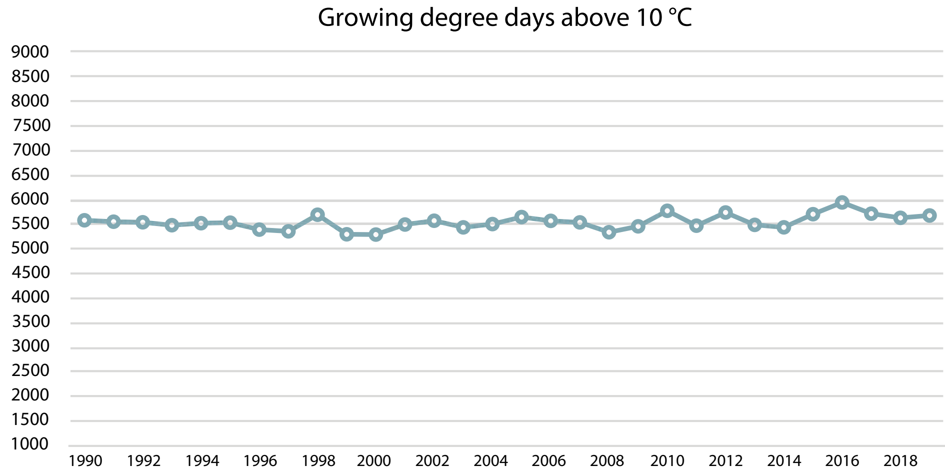
The 30 years of data on temperature conditions show that the maximum reveals an increasing trend with an annual variation range of between 31.74 and 33.85 °C. Minimum temperatures show no significant trend: the minimum annual variation range is between 20.70 and 22.96 °C. The number of days over 37 °C shows an increasing trend, with the maximum number (77 days) recorded in 1998, while the number of days with temperatures over 40 °C has increased since 1994, reaching a maximum (11 days) in 2016.

» Sekong agroclimatology

Agroclimatology

Growth Degree Days (GDD) over 10 °C show a significant increasing trend of 7.2 °C per year, with annual heat accumulation over the past 30 years (1990–2019) ranging from the lowest point of 5 293 °C (in 2000) to the highest of 5 945 °C (in 2016), resulting in a significant impact on development cycle of crops, pests, and diseases.





<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Rainfed rice</td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td>Harvest</td><td></td><td></td></tr>
<tr><td>Irrigated rice</td><td colspan="3">Maintenance</td><td>Harvest</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td></tr>
<tr><td>Cassava</td><td></td><td></td><td>Prepare and plant</td><td colspan="8">Maintenance</td><td>Harvest</td></tr>
<tr><td>Maizes</td><td></td><td></td><td></td><td></td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td>Harvest</td><td></td><td></td></tr>
<tr><td>Coffee</td><td colspan="2">Harvest</td><td></td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td colspan="2">Harvest</td><td></td><td></td></tr>
<tr><td>Orchards and plantations</td><td colspan="4">Harvest</td><td colspan="2">Prepare and plant</td><td colspan="6">Maintenance</td></tr>
<tr><td>Steep slope agriculture</td><td></td><td colspan="4">Prepare and plant</td><td colspan="4">Maintenance</td><td colspan="2">Harvest</td><td></td></tr>
<tr><td>Annual crops and grasslands</td><td colspan="3">Maintenance</td><td>Harvest</td><td colspan="2">Prepare and plant</td><td colspan="3">Maintenance</td><td>Harvest</td><td colspan="2">Prepare and plant</td></tr>
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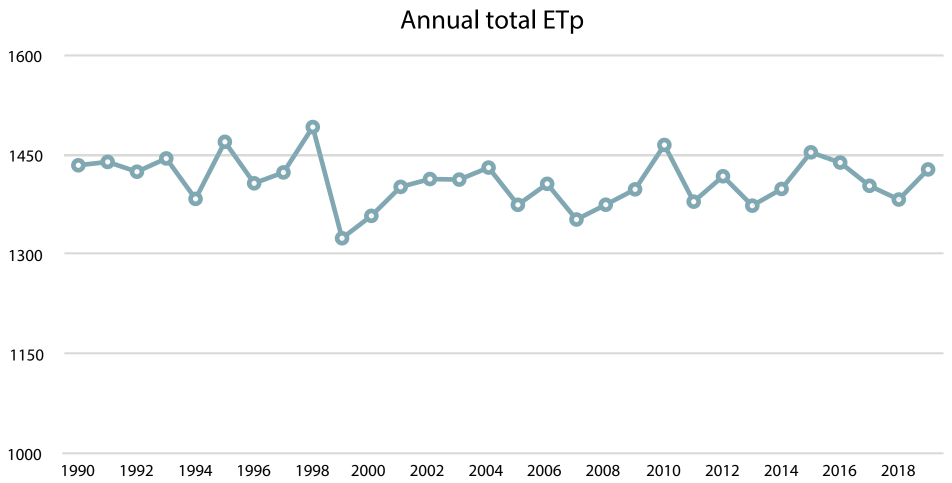

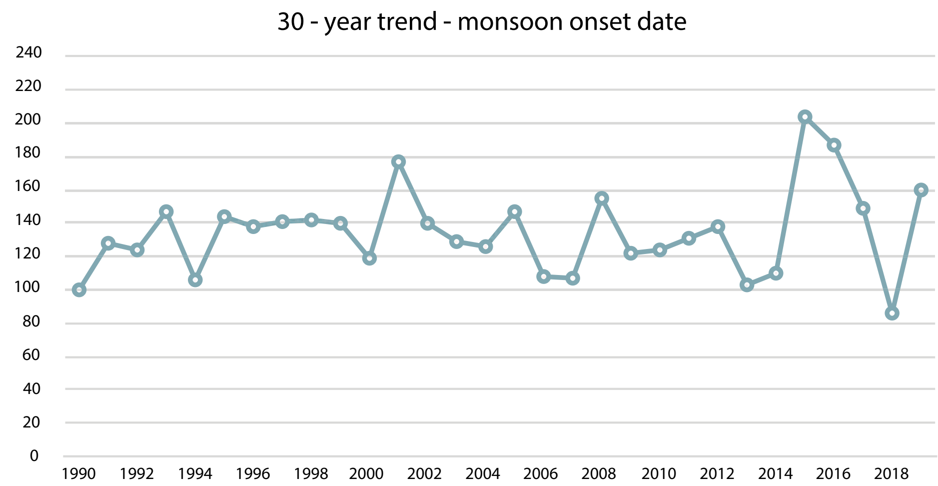

The potential evapotranspiration (ETP) shows no significant trend, with the lowest ETp recorded in 1999, and the highest in 1998. The date of the onset of the monsoon does not appear to have changed significantly over the period, with the earliest start date recorded in 2018, and the latest in 2015.

Attapue »

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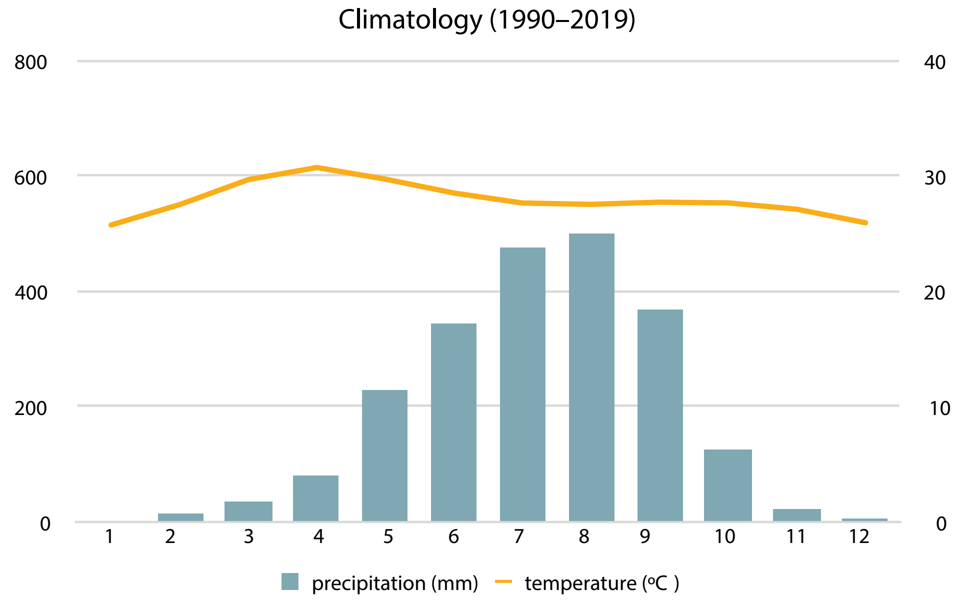
Attapue climatology



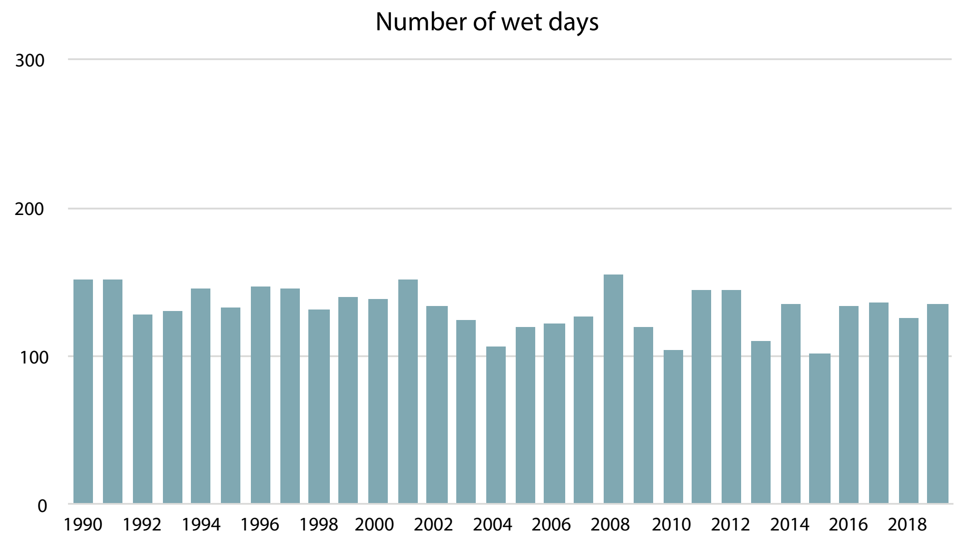
Month	Precipitation (mm)	Temperature (ºC)	Tmax	Tmin
Jan	3	26	32.5	18.7
Feb	14	27	34.2	20.6
Mar	34	30	35.9	23.4
Apr	86	31	36.3	25.0
May	232	30	34.3	25.0
Jun	342	29	32.3	24.7
Jul	463	28	31.2	24.2
Aug	469	28	31.1	24.0
Sep	373	28	31.5	23.9
Oct	133	28	32.1	23.0
Nov	25	27	32.3	21.9
Dec	6	26	31.7	20.0

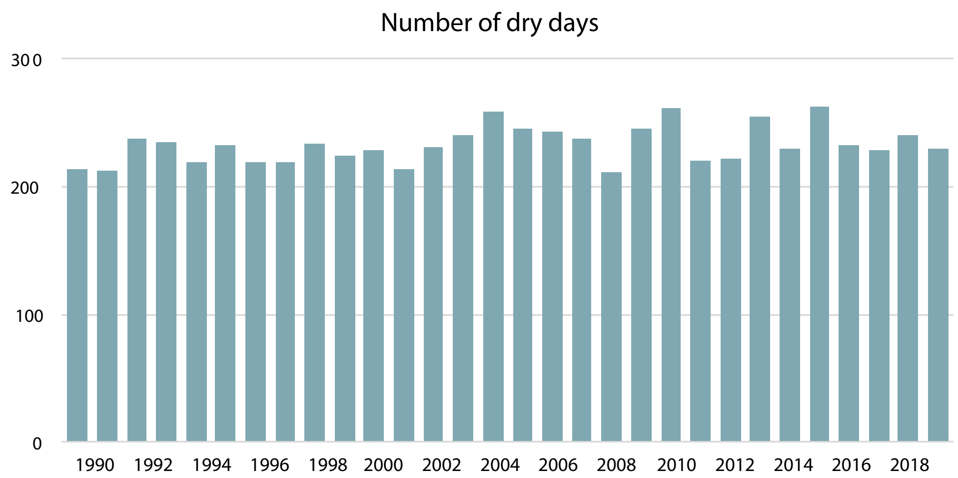
Attapue province lies in the zone of the four Southern provinces of Lao, consisting of Attapue, Saravan, Sekon, and Champasack. The climatology of the province shows that the rainy season starts from May and continues until October. There is significant rainfall in this period, particularly in August, with 500.2 mm in a single month, after which the amount continues to decrease until January of the following year, with the lowest rainfall of 2.26 mm. As the monthly rainfall decreases, the temperature also falls below 20 °C from December to January of the following year. Attapue is a one of the hottest provinces, not only in the zone of the Southern provinces zone but in the country as a whole. At Attapue weather observation station, the 30-year average annual temperature variation (minimum to maximum) varies between 18.97 °C and 36.36 °C.

Attapue province is half mountain and plain land area, whose elevated mountainous zone posts cooler temperatures than the flat and low altitude area. The climatology graph above shows that during the Northeast monsoon, the temperatures in the province start to decrease from November through to January of the following year, while maximum temperatures start to increase from mid-January to reach their highest level in April at 36.36°C during the spring transition (mid-March to mid-May), before decreasing again during the Southwest monsoon (from mid-May to September). The minimum temperatures start to increase from mid-January, reaching a maximum in April at 25.09°C and then beginning to fall during the Northeast monsoon. With regard to the warmer temperatures from April to October, the moving toward the Northern hemisphere of the Intertropical Convergence Zone (ICZ) causes a strong predomination of Southwest monsoon over Lao resulting in significant of rainfall during this period, Attapue records the highest rainfall of the four Southern provinces with a 30-year annual total rainfall average of 2 201.5 mm, with May-September as the rainiest period.

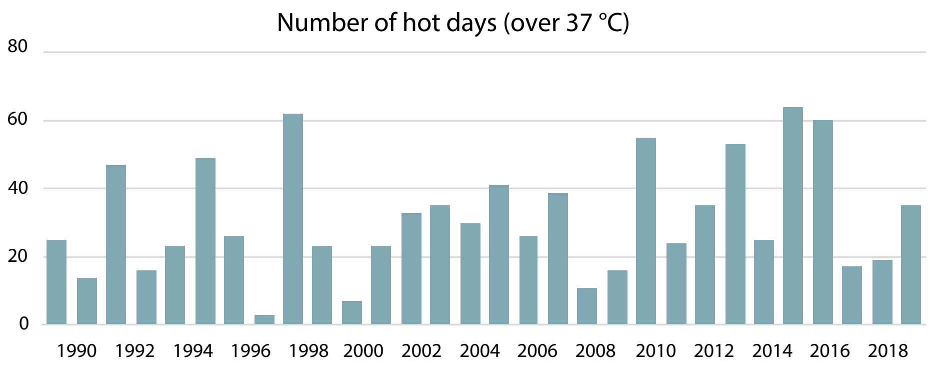
Attapue's topographic coverage is mostly mountainous areas; the plain low elevation land is found on the west side along the Sekong river valley and the border to Champasack province: the forest cover in the area is sparse deciduous and degraded forest. The remainder to the eastern side is mountainous with higher elevation and steep slopes, with forest coverage in the area dominated by dense and healthy forest, varying between dense deciduous, semi-evergreen and evergreen forest types. Attapue is the rainiest among the four Southern provinces as it is situated in a zone that is strongly influenced by the Southwest seasonal monsoon; the vegetation in the area is therefore denser and healthier than areas in the Middle and the North of the country.

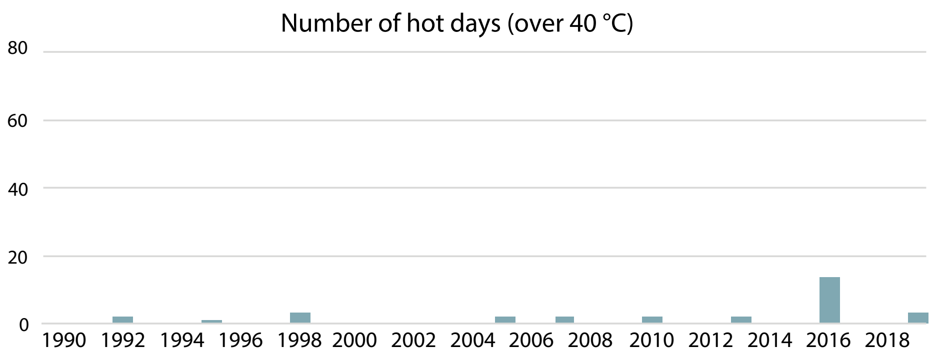
Climate change: Precipitation over the last 30 years

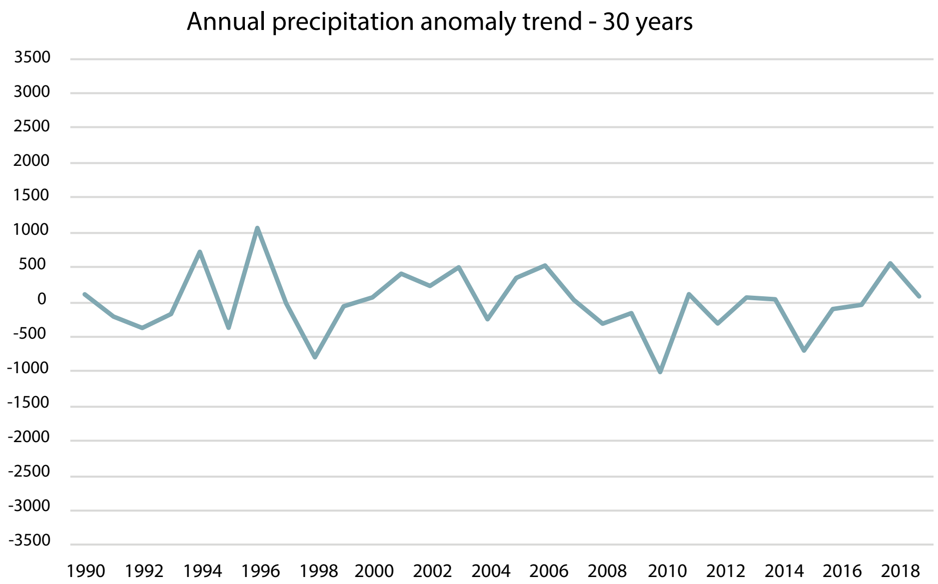




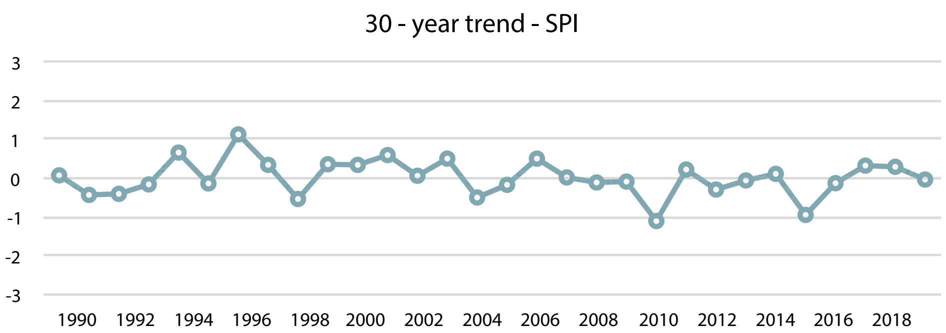
Attapue climatology





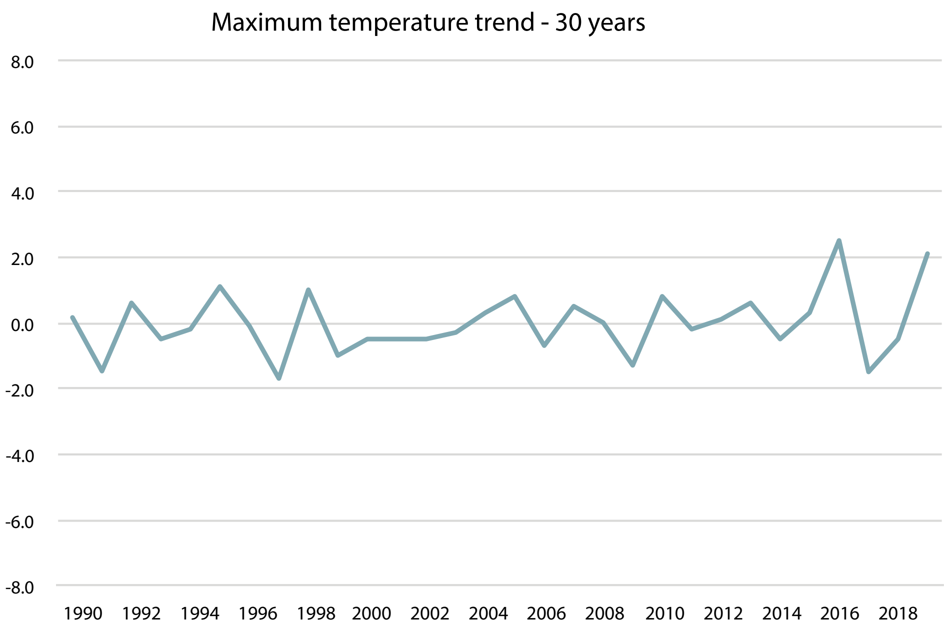


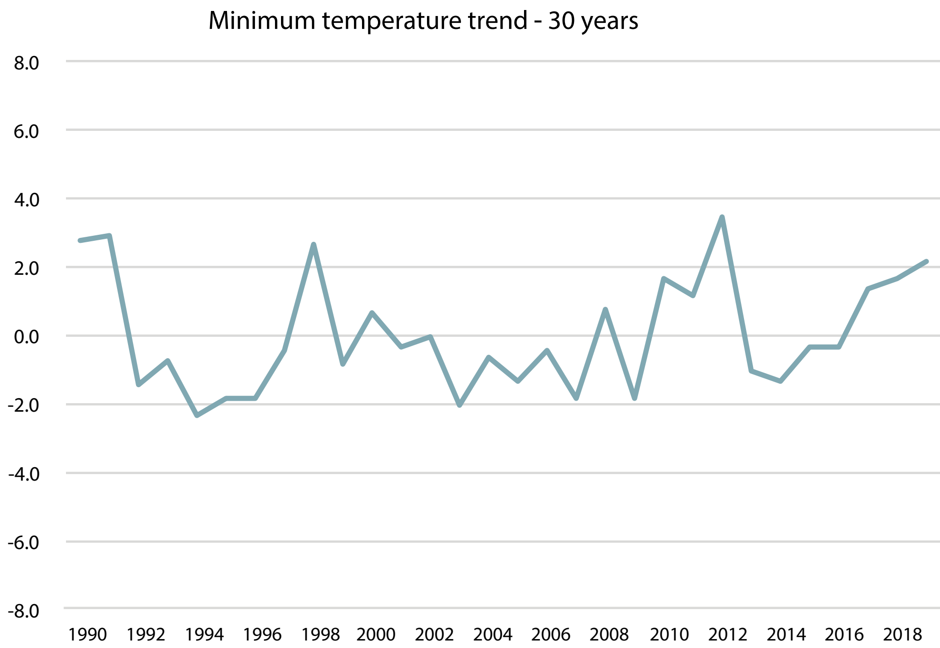
According to the 30-year observation data for Attapue province at Pakse weather observation station, the number of dry days (less than 0.2 mm daily rainfall) shows an increasing trend, with the minimum (211 days) recorded in 2008 and the maximum (263 days) in 2015; while the number of wet days (more than 0.2 mm daily rainfall) shows a decreasing trend, with the lowest number (102 days) in 2015, and the maximum (155 days) in 2008. But the rainfall shows no significant trend: the 30-year



annual total rainfall ranges from the lowest of 1 195 mm (in 2010) to the highest of 3 267 mm (in 1996). The SPI shows no significant trend: whereas the driest year occurred in 2010; the wettest occurred in 1996.

Climate change: Temperature over the last 30 years



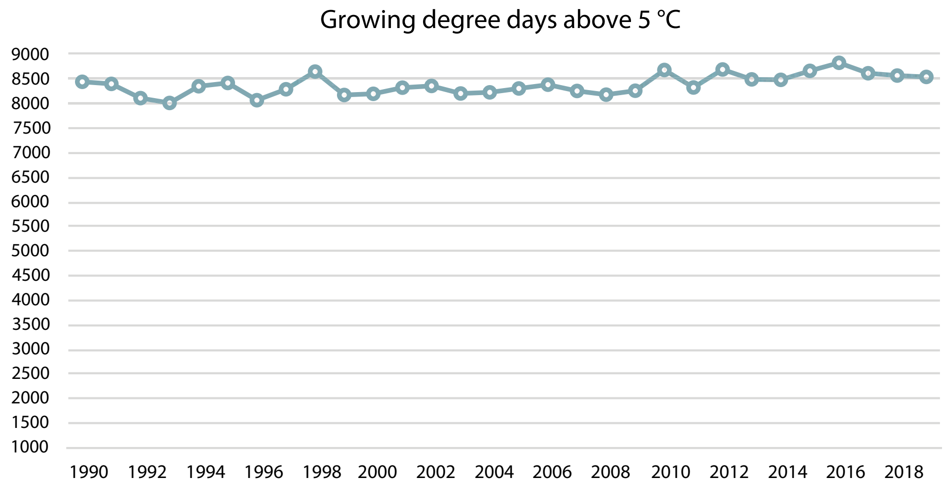


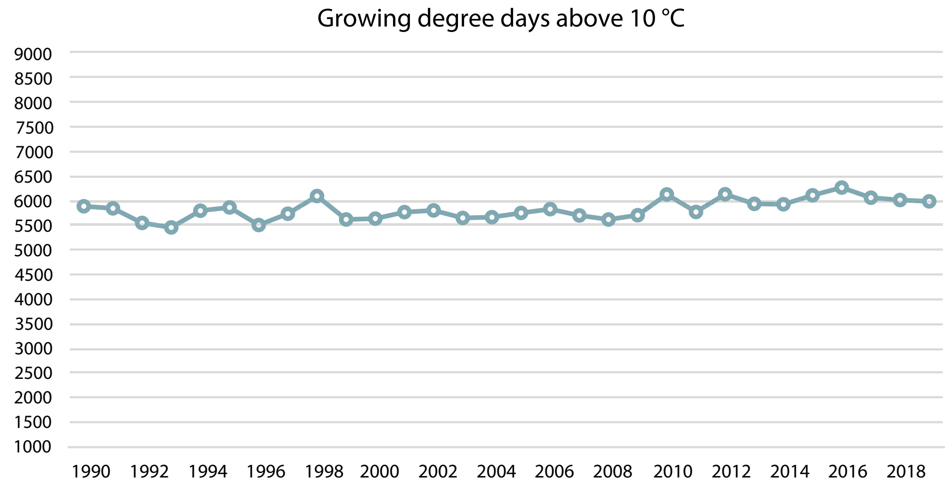
The 30 years of data on temperature conditions reveals that the minimum and maximum temperature show no significant trend, the annual temperature variation range is between 18.97 and 36.36 °C, while the minimum temperature variation range is between 18.97 and 25.09 °C, and the maximum temperature variation range is between 31.01 and 36.36 °C. The number of days over 37 °C shows an increasing trend - the maximum number (64 days) occurred in 2015; and the number of days at over 40 °C has increased since 2005, while the maximum (12 days) appeared in 2016.

Attapue agroclimatology

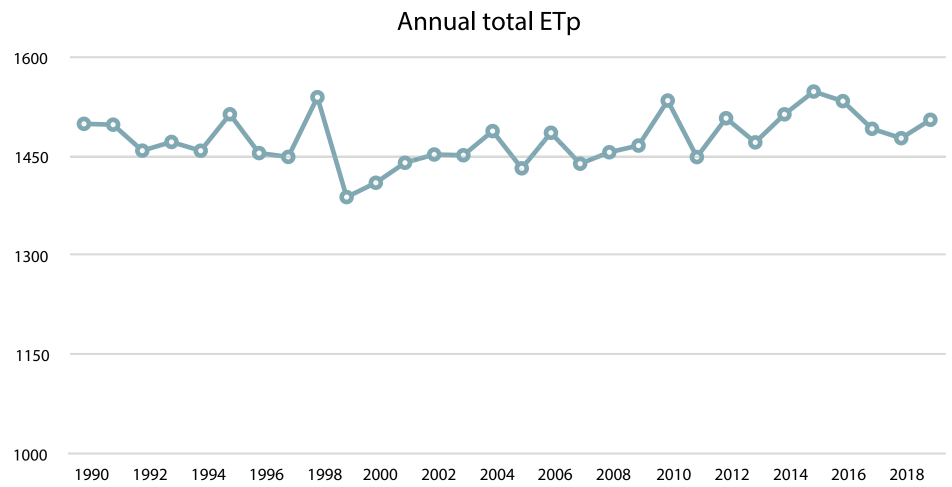
Agroclimatology

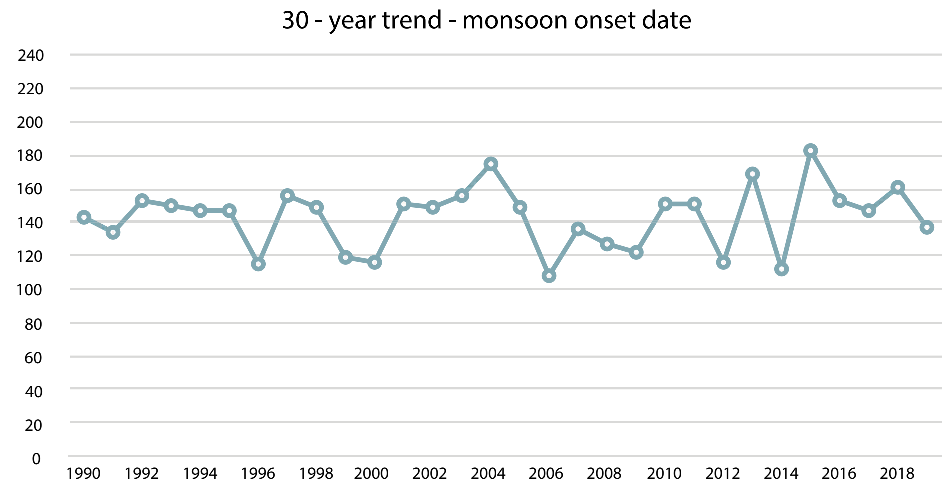
Growth Degree Days (GDD) over 10 °C showed a significant increase by 13.5 °C per year, with the annual heat accumulation in the past 30 years (1990–2019) ranging from the lowest point of 5 456 °C (in 1993) to the highest of 6 265 °C (in 1998), resulting in a significant impact on the development cycle of crops, pests, and diseases.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfed rice						Prepare and plant		Maintenance			Harvest	
Irrigated rice	Maintenance			Harvest							Prepare and plant	
Steep slope agriculture			Prepare and plant		Maintenance					Harvest		
Cassava	Harvest		Prepare and plant		Maintenance							Harvest
Maizes			Prepare and plant		Maintenance			Harvest				
Orchards and plantations			Prepare and plant		Maintenance					Harvest		
Annual crops and grasslands	Maintenance	Harvest									Prepare and plant	Maintenance
Coffee	Harvest		Prepare and plant		Maintenance					Harvest		





The potential evapotranspiration (ETP) shows no significant trend, with the lowest ETp recorded in the year 1999, and the highest in 2015. The date of the onset of the monsoon does not appear to have changed significantly over the period, with the earliest start date recorded in 2006, and the latest in 2015.

Appendixes »

APPENDIX 1

Dynamical downscaling of historical observation data

Historical climate data for the Lao People's Democratic Republic were dynamically downscaled using version 4.0 of the Weather Research and Forecasting (WRF) model, as well as version 1.3 of CORDEX. The initial and boundary conditions for each simulation were obtained from one of two data sources covering the past 30 years:

- 1990-1999: ERA-Interim Project (https://rda.ucar.edu/datasets/ds627.0/)
- 2000-2019: NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999 (https://rda.ucar.edu/datasets/ds083.2))

A prior study was carried out to identify whether the two datasets would be suitable for simulating the climate in the Lao People's Democratic Republic. NCEP FNL was revealed to be more accurate and was therefore used as the data source for 2000-2019, despite the fact that the ERA-Interim dataset covers the period from 1979 to the present day.

The optimum set of physics parameterizations for the WRF model for the Lao People's Democratic Republic was identified following a detailed study using DMH records from 19 weather stations. The published journal article on the data, methodology and results can be accessed at https://doi.org/10.1155/2021/6630302.

The final set of optimum physics options identified for the Lao People's Democratic Republic was:

- Planetary boundary layer options (bl_pbl_physics) = Yonsei University scheme (YSU)
- Cumulus physics options (cu_physics) = Betts-Miller-Janjic scheme (BMI)
- Micro physics options (mp_physics) = Purdue Lin scheme (Lin)
- Shortwave radiation physics (ra_sw) = Dudhia shortwave scheme (Dudhia)
- Longwave radiation physics (ra_lw) = RRTM longwave scheme (RRTM)
- Land surface options (sf_surface_physics) = Unified NOAH land surface model
- Surface layer options (sf_sfclay_physics) = Revised MM5 Scheme (MM5)

The simulation of the downscaling of 30 years of data was carried out in parallel by 320 computer cores using DigitalOcean cloud computer resources with the optimum physics options described above. This involved more than 43 200 hours of core computation time and generated a volume of more than 20 TB of data. The final results for the six main variables were then extracted using a set of tools such as NetCDF Operators (NCO) or Climate Data Operators (CDO).

APPENDIX 2

Glossary of indicators, map data and methodology for calculations

30-year trend for annual precipitation

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. To calculate the 30-year trend for annual precipitation, daily precipitation levels for each year were summated to obtain 30 total annual precipitation amounts, and a statistical trend analysis was carried out to identify any significant trends over the 30 years.

A statistical trend analysis is a process for testing hypotheses. The null hypothesis (HO) is that there is no trend; each test has its own parameters for accepting or rejecting HO. Failure to reject H0 does not prove that there is not a trend, but indicates that the evidence is not sufficient to conclude with a specified level of confidence that a trend exists.

A simple linear regression of Y on time is a test for linear trend:
$Y = \beta O + \beta 1t + \varepsilon$

The null hypothesis is that the slope coefficient B1 = 0. The t-statistic on B1 is tested to determine if it is significantly different from zero. If the slope is nonzero, the null hypothesis is rejected and it can be concluded that there is a linear trend in Y over time, with rate equal to ß1.

(2) Description: Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short and long-term risk of drought. Although it varies depending on the region, climate change may affect precipitation trends over the years. Analysing these trends helps us to understand precipitation changes at the site of interest over the course of 30 years.

30-year trend for maximum temperatures

(3) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. To obtain the 30-year maximum temperature trend, the average of the maximum temperatures for a year was calculated and a statistical trend analysis was carried out to identify any significant trends over 30 years.

A statistical trend analysis is a process for testing hypotheses. The null hypothesis (HO) is that there is no trend; each test has its own parameters for accepting or rejecting HO. Failure to reject H0 does not prove that there is not a trend, but indicates that the evidence is not sufficient to conclude with a specified level of confidence that a trend exists.

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The null hypothesis is that the slope coefficient ß1 = 0. The t-statistic on B1 is tested to determine if it is significantly different from zero. If the slope is nonzero, the null hypothesis is rejected and it can be concluded that there is a linear trend in Y over time, with rate equal to β1.

(2) Description: For a series of observations over time such as the 30-year maximum temperature trend, it is natural to wonder whether these values are rising, falling, or remaining static. Climate change, caused by human-induced greenhouse gas emissions, increases global temperatures, which affects trends in air temperatures over the years. Analysing these trends helps us to understand how temperatures have changed at the site of interest over the course of
30 years.

30-year trend for minimum temperatures

(3) Methodology: This information was generated using R and 30 years of observation data for the site of interest. To obtain the 30-year minimum temperature trend, the average of the minimum temperatures for a year was calculated and a statistical trend analysis was carried out to identify any significant trends over 30 years.
Statistical trend analysis is a process for testing hypotheses. The null hypothesis (HO) is that there is no trend; each test has its own parameters for accepting or rejecting H0. Failure to reject H0 does not prove that there is not a trend, but indicates that the evidence is not sufficient to conclude with a specified level of confidence that a trend exists.

A simple linear regression of Y on time is a test for linear trend: $Y = 30 + B1t+$
The null hypothesis is that the slope coefficient ß1 = 0. The t-statistic on B1 is tested to determine if it is significantly different from zero. If the slope is nonzero, the null hypothesis is rejected and it can be concluded that there is a linear trend in Y over time, with rate equal to ß1.

APPENDIX 2

Glossary of indicators, map data and methodology for calculations

(2) Description: For a series of observations over time such as the 30-year minimum temperature trend, it is natural to wonder whether these values are rising, falling, or remaining static. Climate change, caused by human-induced greenhouse gas emissions, increases global temperatures, which affects trends in air temperatures over the years. Analysing these trends helps us to understand how temperatures have changed at the site of interest over the course of 30 years.

30-year trend for potential evapotranspiration (ETp)

(3) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The FAO Penman-Monteith method was selected as the method by which the evapotranspiration of the reference surface – in other words, potential evapotranspiration (ETp) - can be unambiguously determined

(4) Description: For a series of observations over time such as the 30-year minimum temperature trend, it is natural to wonder whether these values are rising, falling, or remaining static. Climate change, caused by human-induced greenhouse gas emissions, increases global temperatures, which affects trends in air temperatures over the years. Analysing these trends helps us to understand how temperatures have changed at the site of interest over the course of 30 years.

Annual maximum temperature

(1) Methodology: This information was generated using R (software) and 30 years of observation data for the site of interest. The annual maximum temperature refers to the average of the maximum temperatures over the course of a year.

(2) Description: The temperature range we can expect within a year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions.

Annual minimum temperature

(1) Methodology: This information was generated using R (software) and 30 years of observation data for the site of interest. The annual minimum temperature refers to the average of the minimum temperatures over the course of a year.

(2) Description: The temperature range we can expect within a year is a very important aspect of climate Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions.

Annual precipitation

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. Annual precipitation refers to the total amount of rainfall deposited on the surface over the course a year.

(2) Description: Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought.

Date of the onset of the monsoon

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The date of the onset of the monsoon refers to the first of one or two consecutive wet days on which there was at least 20 mm of rainfall, provided that this was not followed by a seven-day dry spell (less than 5 mm of rainfall) in the 20 days following the onset.

(2) Description: In a monsoon-affected region, monsoon rainfall is critical for the spring and summer planting of crops, which depend on enough soil moisture to germinate, encourage rooting, and/or ensure vigorous vegetative growth during initial cropping stage. Sometimes, a delay in the onset of the monsoon will cause delays in the planting of rice and other crops. This tends to shorten the cropping period and increases the risk of pests, often leading to yield loss.

Days with an annual SPI below -1

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. R's 'SPEI' package was used to calculate the three-month Standardized Precipitation Index. In brief, the SPI algorithms used in the package transform the observed precipitation data to Gaussian equivalents, and the transformed precipitation data are then used to compute the dimensionless SPI value,

defined as the standardized anomaly of the precipitation:

SPI = (P-P*) /op

APPENDIX 2

Glossary of indicators, map data and methodology for calculations

Days with an annual SPI over 1

(1) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. R's ‘SPEl package was used to calculate the three-month Standardized Precipitation Index. In brief, the SPI algorithms used in the package transform the observed precipitation data to Gaussian equivalents, and the transformed precipitation data are then used to compute the dimensionless SPI value,

defined as the standardized anomaly of the precipitation:
SPI = (P-P*) /op
where P = precipitation; P* = mean precipitation; op = standard deviation of precipitation.

(2) Description: The SPI is widely used to characterize meteorological drought over a range of different timescales. Over short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. A three-month SPI provides a comparison of precipitation over a specific three-month period with precipitation amounts for the same three-month period going back as far as historical records allow. The three-month SPI thus reflects short- and medium-term moisture conditions, providing an estimation of meteorological drought conditions for a given season. SPI values over 1 indicate greater than median precipitation (i.e. wet conditions), while SPI values below -1 indicate less than median precipitation (i.e. dry conditions).

(2) Description: The SPI is widely used to characterize meteorological drought over a range of different timescales. Over short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. A three-month SPI provides a comparison of precipitation over a specific three-month period with precipitation amounts for the same three-month period going back as far as historical records allow. The three-month SPI thus reflects short- and medium-term moisture conditions, providing an estimation of meteorological drought conditions for a given season. SPI values over 1 indicate greater than median precipitation (i.e. wet conditions), while SPI values below -1 indicate less than median precipitation (i.e. dry conditions).

Dry days (rainfall under 0.2 mm)

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. A threshold value of 0.2 mm was chosen to define a dry day in the Climate Atlas; a dry day is thus a day with less than 0.2 mm of precipitation.

(2) Description: Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought. Locations that experience precipitation frequently have a low number of dry days, whereas locations that experience precipitation infrequently have a high number of dry days.

Days with heavy rain (over 20 mm)

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. A day with heavy rain was defined as a day on which there was at least 20 mm of rainfall.

(2) Description: Heavy rainfall events can create a number of challenges. In cities and towns, heavy rainfall can overwhelm storm drains and cause flash flooding. They can also cause problems in rural areas by drowning crops, eroding topsoil and damaging roads. In particular, heavy rainfall directly following a long dry spell increases the risk of soil erosion and encourages sudden growths in the populations of insect pests, such as armyworm.

Frost-free days

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The number of frost-free days represent the number of days between the date of the last spring frost and the date of the first fall frost, equivalent to the number of consecutive days during the ‘summer’ without any daily minimum temperatures equal to or below 0 °C.

(2) Description: Changes in the length of frost-free periods and when they occur have an impact on plants and animals used in agriculture. The average length of the growing season (and its year-to-year variability) is an important consideration when selecting or predicting what plants might grow well in a region. Longer periods without frost mean plants and crops have a longer window in which to grow and mature. If projections show an increase in the number of frost-free days, then the annual growing season will be longer, and the period of cold weather correspondingly shorter.

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Glossary of indicators, map data and methodology for calculations

Growing degree days above 5 °C

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The number of growing degree days above 5 °C is defined as the annual sum of the number of degrees Celsius that each day's mean temperature is above a base temperature of 5 °C.

(2) Description: Growing Degree Days (GDD) are often used to determine whether a climate is warm enough to support plants and insects with temperaturedependent growth rates. GDD accumulate whenever the daily mean temperature is above a specified threshold temperature. For instance, GDDs above 5 °C are generally used to assess the growth of wheat, lettuce, canola and forage crops.

Growing degree days above 10 °C

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The number of growing degree days above 10 °C is defined as the annual sum of the number of degrees Celsius that each day's mean temperature is above a base temperature of 10 °C.

(2) Description: Growing Degree Days (GDD) are often used to determine whether a climate is warm enough to support plants and insects with temperaturedependent growth rates. GDDs accumulate whenever the daily mean temperature is above a specified threshold temperature. For instance, GDDs above 10 °C are generally used to assess either the growth of maize, rice, tomato, coffee and bean crops, or the growth and development of insect pests.

Monthly maximum temperature

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The monthly maximum temperature refers to the average of the daily maximum temperatures for a given month. The 12 monthly maximum temperatures for January to December of each year were then averaged over 30 years.

(2) Description: The temperature range we can expect within a year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions. Average monthly temperatures and precipitation levels across the year illustrate seasonal variations in climate that are important when determining seasonal vegetative growth or the cropping periods for plants with varying temperature and water requirements.

Monthly minimum temperature

(1) Methodology: This information was generated using R and 30 years of observation data for the site of interest. The monthly minimum temperature refers to the average of the daily minimum temperatures for a given month. The 12 monthly minimum temperatures for January to December of each year were then averaged over 30 years.

(2) Description: The temperature range we can expect within a year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect most aspects of agriculture, including crop growth, cropping activities, and a wide range of planning and policy decisions. Average monthly temperatures and precipitation levels across the year illustrate seasonal variations in climate that are important when determining seasonal vegetative growth or the cropping periods for plants with varying temperature and water requirements.

Monthly precipitation

(1) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. Monthly precipitation refers to the sum of daily rainfall in a given month. The 12 monthly total precipitation amounts for January to December of each year were then averaged over 30 years.

(2) Description: Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought. Average monthly temperatures and precipitation levels across the year illustrate seasonal variations in climate that are important when determining seasonal vegetative growth or the cropping periods for plants with varying temperature and water requirements.

Number of days over 37 °C

(1) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. The number of days over 37 °C is defined as the number of days on which the maximum temperature was greater than or equal to 37 °C.

(2) Description: High temperatures are important: they determine whether plants and animals will thrive, and they may restrict or permit agricultural work taking place outdoors. It is useful to know how high summer temperatures are likely to become in the future, as when temperatures are very hot, not only do

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crops suffer from heat stress, sometimes resulting in crop loss, but also people – especially the elderly - are much more likely to suffer from heat exhaustion and heatstroke. Many outdoor activities become dangerous or impossible in very high temperatures. Persistently high temperatures increase the risk of drought, which can severely impact food production and increases the risk of wildfires. Although Laotians are used to extremely hot summers, further warming will nonetheless result in unfamiliar risks, as well as a very different experience of the summer season.

Number of days over 40 °C

(1) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. The number of days over 40 °C is defined as the number of days on which the maximum temperature was greater than or equal to 40 °C.

(2) Description: High temperatures are important: they determine whether plants and animals will thrive, and they may restrict or permit agricultural work taking place outdoors. It is useful to know how high summer temperatures are likely to become in the future, as when temperatures are very hot, not only do crops suffer from heat stress, sometimes resulting in crop loss, but also people – especially the elderly - are much more likely to suffer from heat exhaustion and heatstroke. Many outdoor activities become dangerous or impossible in very high temperatures. Persistently high temperatures increase the risk of drought, which can severely impact food production and increases the risk of wildfires. Although Laotians are used to extremely hot summers, further warming will nonetheless result in unfamiliar risks, as well as a very different experience of the summer season.

Wet days (rainfall over 0.2 mm)

(1) Methodology: This information was generated using Rand 30 years of observation data for the site of interest. A threshold value of 0.2 mm was chosen to define a wet day in the Climate Atlas; a wet day is thus a day with at least 0.2 mm of precipitation.

(2) Description: Precipitation patterns are critical for many important issues, including water availability, crop production, the generation of electricity, the suppression of wildfires, seasonal and flash flooding, and the short- and long-term risk of drought. Locations that experience precipitation frequently have a high number of wet days, whereas locations that experience precipitation infrequently have a low number of wet days.

Contact information
Food and Agriculture Organization of the United Nations
Representation in the Lao People's Democratic Republic
128 Phone-Xay Road, Phonxay Village, Saysettha District, Vientiane Capital
01004 Vientiane
E-mail: FAO_LA@faoo.org
Website: http://www.fao.org/in-action/samis/en/

Department of Meteorology and Hydrology (DMH)
Souphanouvong Avenue,Ban Akat, Sikhothabong District,
Vientiane Capital, Lao People's Democratic Republic

Department of Agriculture Land Management (DALaM)
Nongviengkham village, Xaythany District,
Vientiane Capital, Lao People’s Democratic Republic

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