Impact of future tendency in climate change on agricultural practices and re-forestation

Pa Leaw Luang Sub-district, Suntisuk district, Nan province

This report is a part of
improving local community's livelihood and engagement in sustainable forest and land management in Thailand through Forest Landscape Restoration

Executive summary

Pa Leaw Luang is a sub-district in Santisuk District, Nan Province. Its location is approximately 4 kilometers north of Suntisuk District Office and approximately 32 kilometers from the city of Nan Province. The sub-district cover 10,607 ha. It is situated on a valley floor between the mountain range to the east and west. Flat and gentle slope land accounts for less than 15 % of the entire sub-district. The altitude ranges from 600 to 1200 meters above sea level. Slope land is generally steeper than 35 percent. Generally, farmers' household economies fall in the semi-subsistence category. Food security relies on farm produce and non-timber harvest from community forests while maize and para-rubber are the major sources of income. Apart from the bio-physical constraints that govern farming activities on slope land, farmers also have title legitimacy issues.

Recent climate records have shown highly fluctuating rainfall annual patterns. The average annual rainfall from 2017 to 2022 is 1,238 mm. Air temperature is mild year-round except in April and May when temperature can easily exceed 30 degrees Celsius.

Climate change models available at https://climateknowledgeportal.worldbank.org/country/thailand/climate-data-projections are employed to project climate data into the year 2023. For the purpose of this report, the Multi-Models Ensemble was selected to provide the baseline projection under different scenarios. Then CAMS-CSM1-0 and MIROC6 which have been subjected to evaluation against El-Nino Southern Oscillation (ENSO) were selected to verify whether there is any substantial anomaly under ENSO influence in Northern Thailand. Of the various climate parameters available as outputs, the five most relevant were selected. These five parameters were the mean monthly temperature, average maximum and minimum monthly temperature, cold spell duration index, mean monthly precipitation, and monthly maximum consecutive dry days. The projection was performed to the year 2039.

The results from every model show a minor increase in temperature compared to the reference period (1995-2015). When comparing projected temperature with climate records from 2017-2022, it is obvious that the average monthly temperature is already close to or higher than predicted by the models. The maximum and minimum temperatures exhibit the same tendency.

Cold spell duration index shows the tendency to decrease. MIROC6 result shows some anomaly among scenarios during mid-2030s.

Rainfall projection shows a more diverse result. While the median of Multi-model Ensemble more or less conforms to the recent record, CAMS-CSM1-0 predicts substantial annual rainfall may be less than 1,000 mm. MIROC6 on the other hand predicts that on average annual rainfall will be 200 mm. more. Every model predicts longer and more prominent dry seasons.

Maize and up-land rice which are grown in rainfed conditions are likely to be the most to suffer, owing to uncertainty in rainfall patterns. Paddy rice may face yield reduction owing to drought, providing that available resources are not managed properly. Para-rubber may also not perform well in high air temperatures, particularly during early tapping season. Teak, being a wild and local species, will prosper if it is not grown above 700 meters altitude. So suitable growing area will be very limit.

The foreseeable impact of climate change on the community in Pa Leaw Luang in the near future includes loss in biodiversity, food and income insecurity, and migration. To address the impacts of climate change on such semi-subsistence farming systems, it is crucial to implement strategies that enhance their resilience capacity from the farming practices aspect as well as financial and institutional aspect. The most practical option to cope with the impact of climate change is to alter agro-ecological system to a more bio-diversify and more sustainable farming systems. It is important to involve farmers in the planning and evaluation of adaptation options to ensure their participation and acceptance. Traditional knowledge and local wisdom should not be overlooked.

Content

Figures

Figures

page

Appendices

Appendices

1 . Introduction

Climate change is a global- scale changes in climate patterns which is caused by global warming. Global warming (which is the rise of the Earth average surface temperature) itself is largely owing to the rise of CO_2 concentration in the Earth's atmosphere due to human activities. The atmospheric CO_2 concentration has increased from 280 ppm before the industrial revolution to 413 ppm as observed at Mauna Loa, Hawaii on April 26th, 2017 [1]. And it is this increase of almost 50% that has triggered an increase in global temperature. [2] According to the Intergovernmental Panel on Climate Change (IPCC) [3] , the average global surface temperature in the first two decades of the 21st century was 0.99 Celsius higher than in 1850-1900. Out of these two decades, in the latter one (2011-2020), the surface temperature was 1.09 Celsius higher than in 1850-1900, with a larger increase over land than the ocean.

Global warming has presented an issue called climate change. Though these phrases may have been used interchangeably, but actually they are different. Climate change refers to long-term changes in weather patterns and growing seasons around the world. Of the climate attributes, there are evidence of observed changes in extreme such as heatwaves, heavy precipitation, drought, tropical cyclone etc.

Climate change has reduced food security and affected water security, hindering efforts to meet Sustainable Development Goals. Though overall agricultural production has increased, but the growth potential is hinder by this phenomenon. The changes in climate pattern has positive impact on the production system of high latitude regions, but a negative impact on mid and low latitude regions.

For South-East Asia, the region is highly vulnerable to climate change due to its geographic location and extensive coastline which makes the region prone to tropical cyclone. Furthermore, a large portion of its economy and population well- being relies on agriculture. Climate change is expected to bring about a range of effects in the region, including increased temperature, changes in annual rainfall pattern and amount, rising sea level and more frequent extreme climate events like rain storms and droughts. For agricultural sector, the following impacts can be expected [4].

- Higher temperatures and heat stress: Climate change is projected to increase the average temperature in Southeast Asia by 2.2 degrees Celsius to 4.8 degrees Celsius by 2100.

This will affect crop growth and development, reduce photosynthesis and biomass production, and increase water demand and evapotranspiration. Higher temperatures will also reduce the length of growing seasons and increase the risk of heat-induced sterility in crops such as rice.

- Changes in rainfall patterns and water availability: Climate change will alter the distribution and intensity of rainfall in Southeast Asia, leading to more frequent and severe droughts and floods. This will affect soil moisture, irrigation water supply, crop water requirements, and crop yields. Droughts will reduce rain-fed crop production and increase the dependence on irrigation, while floods will damage crops, infrastructure, and soil quality.
- Sea level rise and salinity intrusion: Climate change will cause sea levels to rise by 0.26 m to 0.82 m by 2100, affecting coastal areas and low-lying deltas in Southeast Asia. This will increase the risk of coastal erosion, flooding, storm surges, and saltwater intrusion into freshwater sources. Salinity intrusion will reduce soil fertility, crop productivity, and water quality for irrigation and domestic use.
- Pest and disease outbreaks: Climate change will affect the distribution and abundance of pests and diseases that affect crops and livestock in Southeast Asia. Higher temperatures, humidity, and rainfall will create favorable conditions for pest multiplication and disease transmission. Some pests and diseases may expand their range or shift to new areas, while new pests and diseases may emerge or re-emerge.
- As a consequence, there will be negative implications for food security due to lower yields, higher prices, and increased malnutrition.

Changes in temperature, rainfall patterns, and amount can affect crop suitability and yield. Certain areas may become less suitable for current crops, while others may become more suitable for different crops. Coupling with changes in water availability, distribution and demand, this may result in drastic land-use/land-cover changes.

Climate change can impact ecosystems, affecting the distribution and abundance of plant and animal species. This can lead to shifts in land use for conservation purposes or as a response to changes in resource availability.

For these aforementioned bio-physical changes, people who will suffer most are those ethnic minorities who live remotely in the highland region. This is owing to poverty, fewer opportunities to access resources, and lack of power at policy -making level.

Because climate changes affect people worldwide, in 1988 World Meteorological Organization (WMO) together with the United Nation Environment Programme (UNEP) had set up Intergovernmental Panel on Climate Change (IPCC) as an international body for assessing the science related to climate change. The IPCC has become an organization of governments that are members of the United Nations or WMO. The IPCC currently has 195 members. Its major function is to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.[5]

This report will explore scientific findings on climate change and its consequences relevant to the designated site of AFoCo's Project titled "Improving Local Community's Livelihood and Engagement in Sustainable Forest and Land Management in Thailand through Forest Landscape Restoration" and then provide general suggestions about mitigation and adaptation for farmers.

2. The target area

2.1 Location

Pa Leaw Luang Sub-district is located in Santisuk District, Nan Province. Its location is approximately 4 kilometers north of the Suntisuk District office and approximately 32 kilometers from the city of Nan Province. The sub-district covers 10,607 ha.

2.2 General information

Pa Leaw Luang Sub-district is situated on a valley floor between a mountain range on the east and west. Flat and gentle slope land accounts for less than 15 % of the whole sub-district. The altitude ranges from 600 to 1200 meters above sea level. Slope land is generally steeper than 35 percent. There are two main rivers, the Muap River and Yang River, with various branches of tributaries, including Huai Klua, Huai Li, Huai Yang, Huai Khao Lam, Huai In Kham, Huai Lak Puen, Huai Pong, Huai Hia, and Huai Din Daeng.

There are 7 reservoirs consisting Huai Khon Kaen Reservoir 1, Huai Khon Kaen Reservoir 2, Huai Lak Puen Reservoir, Huai Khao Lam Reservoir, Huai Yang Reservoir, Huai Suea Reservoir, and Huai Din Daeng Reservoir. According to the brief interview with the locals, the storage is not quite sufficient.

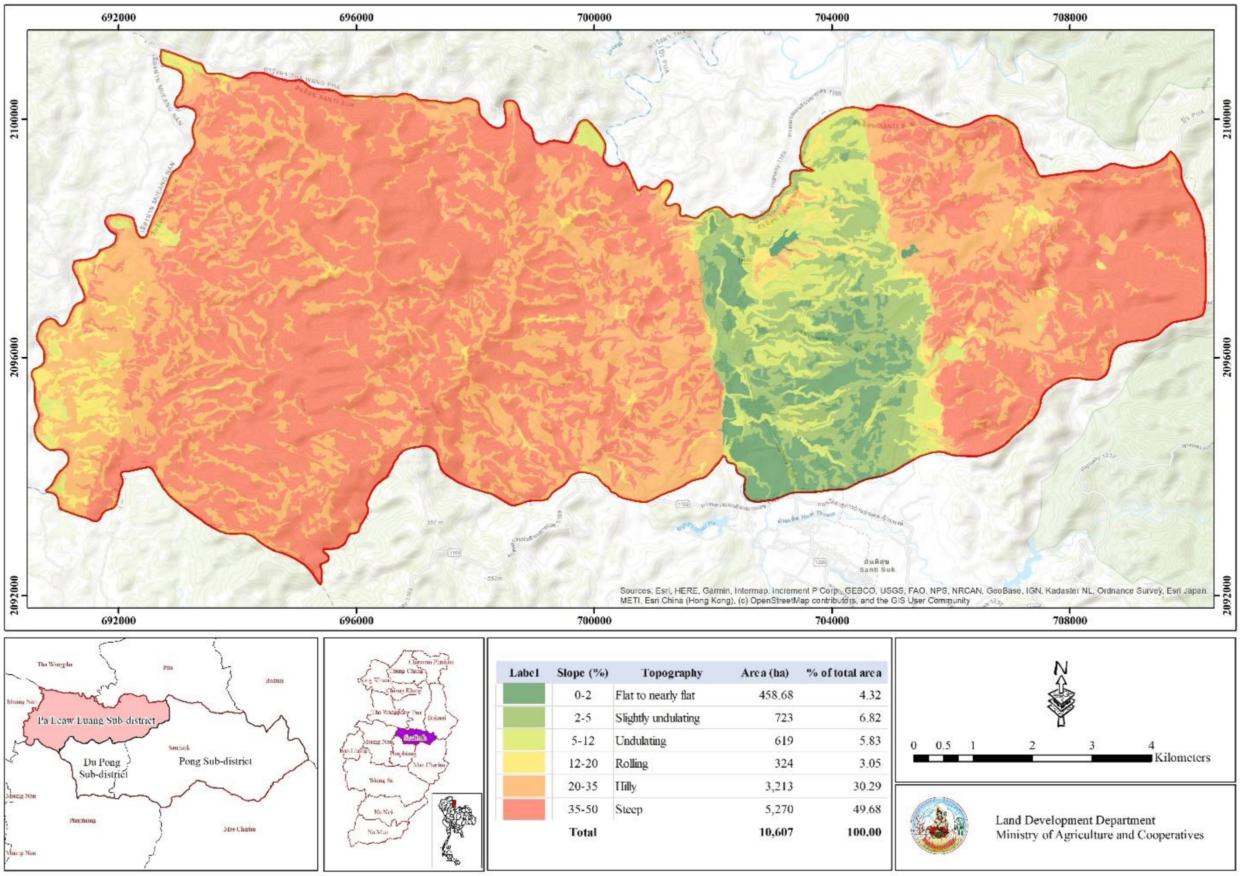


Figure 1 Topography of Pa Leaw Luang sub-district

Source: Office of Land Development Region 7

Farmland accounts for 57.98 % of the total area, followed by forest area (38.36%), urban area (1.81%), water source (1.14%), and miscellaneous land (0.71%), respectively as shown in Table 1.

Some arable land is in the national forest reserve area, the Lower Eastern Nan River Forest. All of the villages preserve their nearby forest as community forests.

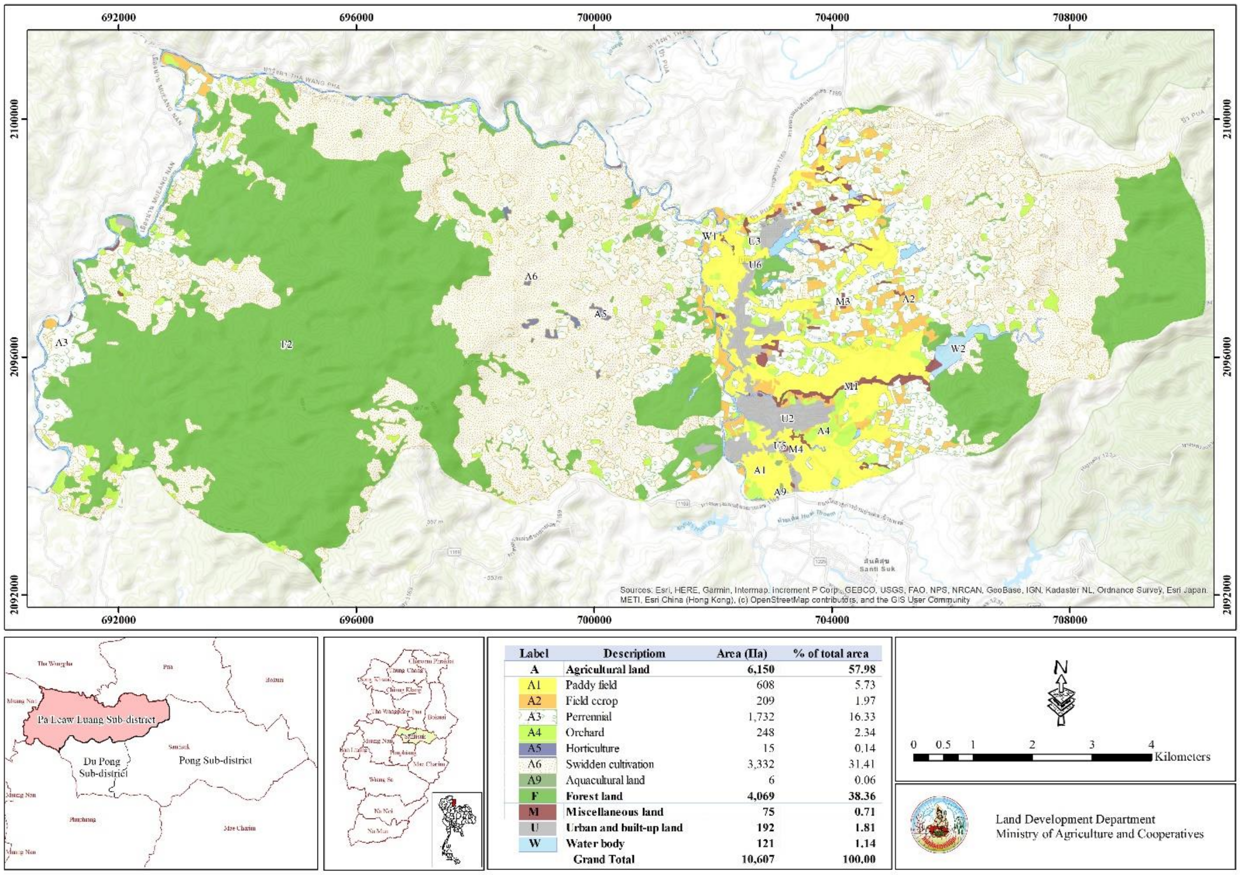


Figure 2 Land-use / land cover of Pa Leaw Luang sub-district

Source: Office of Land Development Region 7

Approximately, 80 percent of the villagers are farmers or work in the agricultural sector. This group of people are either self-employed or hire themselves as farm laborers. The major crops of the area are rice and corn followed by para-rubber and teak plantations. Most people have domestic fish ponds in which they raise tilapia, common silver barb, rohu, etc. Fish produce is either consumed in the household or sold in a nearby market. Livestock, such as chickens, ducks, pigs, cattle, and buffalo, are also raised in this area for domestic consumption.

Most of the soil is loamy which is suitable for agriculture. At present, soil resources are continuously degraded owing to inappropriate land use. The high rate of soil erosion, lack of organic matter, and acidity pose a major constraint to crop production. The farming-related problems from farmers' perception can be outlined as:

1) An inappropriate land-use i.e. farming on a steep slope
2) Soil degradation
3) Limited agricultural areas, some of them have low potential for agriculture
4) Land ownership. There is no title legitimacy in the upland, thus there is no incentive for farmers to adopt any sustainable land management
5) Soil pollution problems include toxic residues from farming activities, industry, and the community itself.

2.3 Socio-economic background

Pa Leaw Luang Sub-district is divided into 10 villages. There are 1,464 households with a total population of 4,332 of which 2,133 are males and 2,199 are females. The people have compulsory education. There are educational institutions including (1) kindergarten level (three child development centers), and (2) 2 primary schools (one of Grade 1 to Grade 6 and one of Grade 1 to Grade 3). All villages have a water supply system.

Generally, farmers' household economy falls into the semi-subsistence category. Food security relies on farm produce and non-timber harvest from community forests while maize and para-rubber are the sources of major income.

2.4 Recent climate records

The Thai Meteorological Department makes recent climate records available on its website. There are 2 stations in Nan province, one at Mueang Nan and one at Tha Wang Pha District. The following records are from a station in Mueang Nan District which is closer to the study site than Tha Wang Pha.

Figure 3. shows the average monthly temperature during the year 2017-2022. The temperatures are mild all year round and are within the range of 23 – 30 degrees Celsius, except for April and May when daily temperature exceeds 30 degrees. This is owing to the position of the sun which is above Nan's latitude during that period of the year yielding maximum insolation.

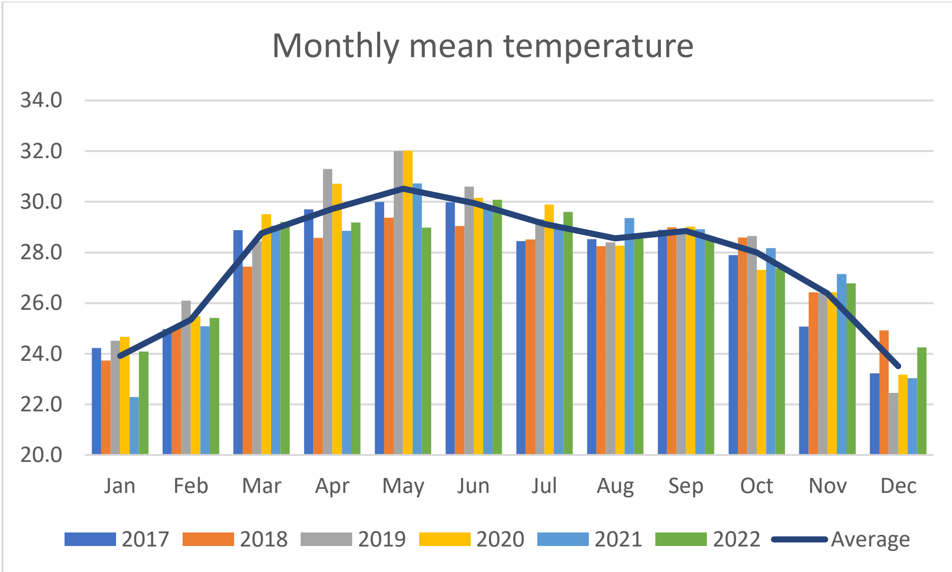


Figure 3. Nan's average daily temperature during 2017-2022

Source: Meteorological Department

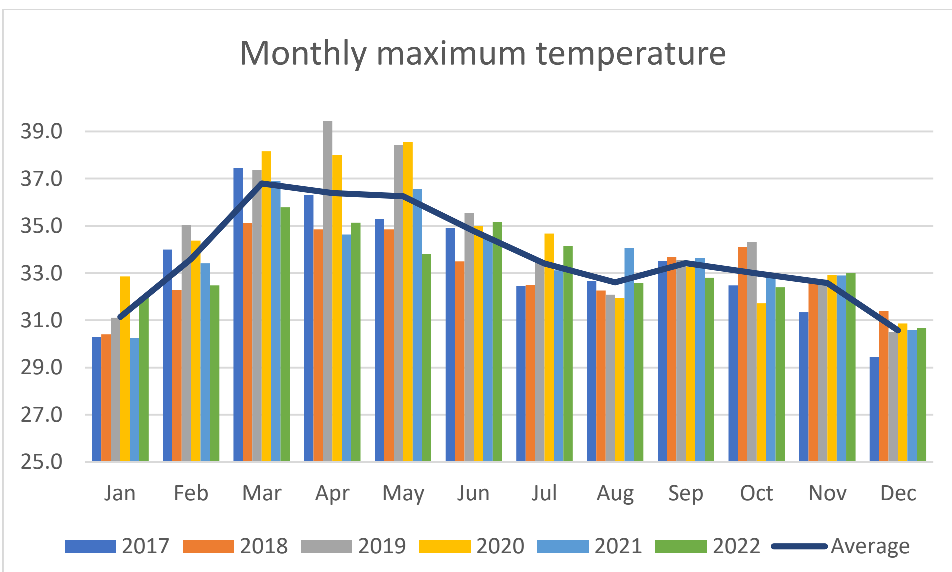


Figure 4. Nan's average maximum daily temperature during 2017-2022

Source: Meteorological Department

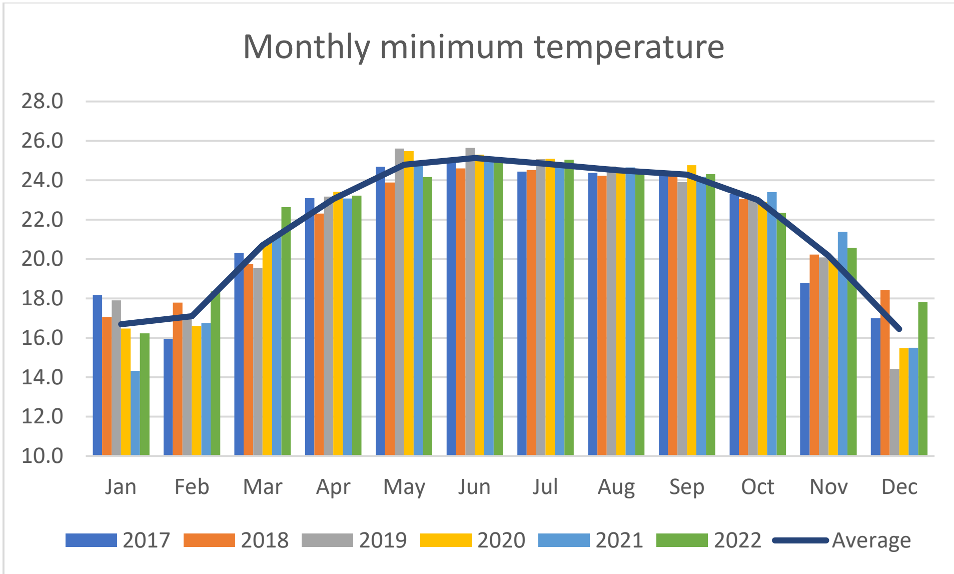


Figure 5. Nan's average minimum daily temperature during 2017-2022

Source: Meteorological Department

The mean monthly maximum and minimum temperatures are shown in Figures 4 and 5 accordingly. The mean monthly maximum was highly fluctuating during the hottest months of the year owing to unseasonal rainfall which came intermittently during March, April, and May. On the other hand, minimum temperature followed a more consistence pattern. The lowest temperature occurred either in December or January in conjunction with the arrival of a cold front from the higher latitude.

Recorded rainfall during the same period is shown in Figure 6. Annual rainfall amount and pattern were highly fluctuated from year to year with the lowest amount of 1117 mm. in 2018 and the highest amount of 1484 mm. in 2022. The average annual rainfall during that period is 1,238 mm.

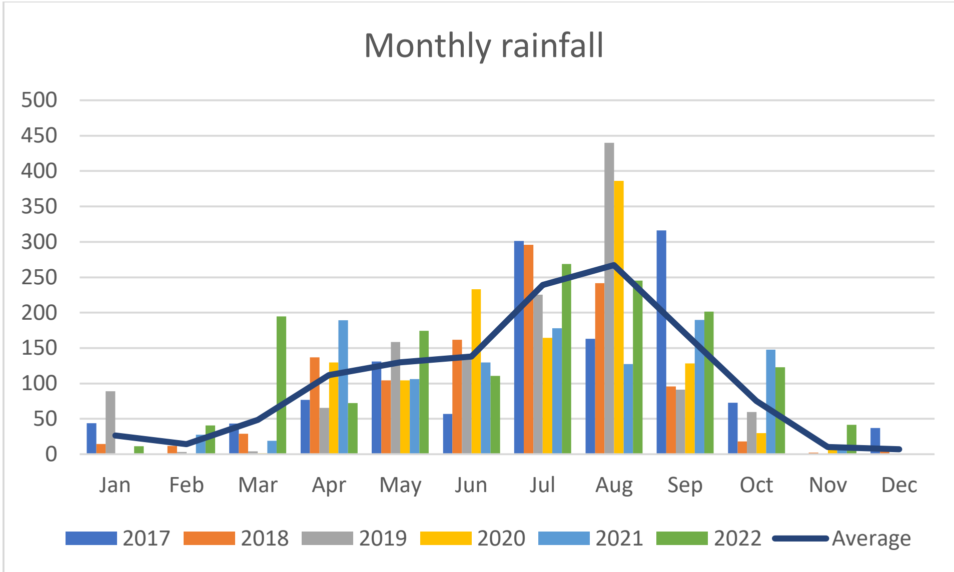


Figure 6. Nan's monthly rainfall during 2017 - 2022

Source: Meteorological Department

Rainfall might start as early as April, but a substantial amount normally started to occur in May. There seemed to be a slight decrease in June and then the monthly amount increased again in July to the peak in August before trailing off in September. Somehow there was no distinct bi-modal pattern in the trend line.

Figure 7. shows the monthly maximum consecutive dry days. Though May has a promising rainfall amount, but with fluctuation in rainfall pattern, the maximum number of consecutive dry days which had been recorded was still 11 days with an average of 7 days.

On average, reliable rainfall for crop growth may last well into October.

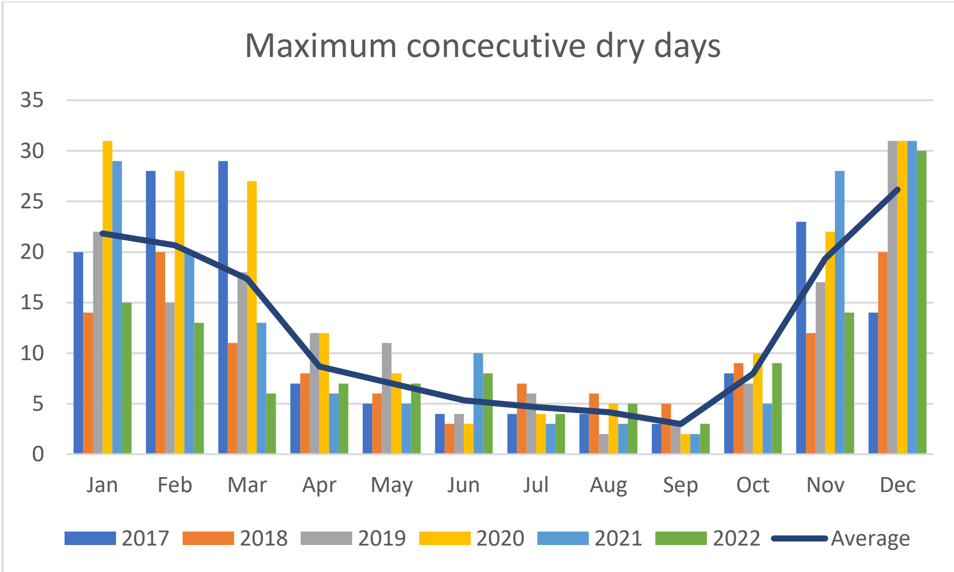


Figure 7. Nan's monthly maximum consecutive dry days

Source: Meteorological Department

3. Greenhouse gases emission scenarios and climate change models

Climate change models are computer simulations of the Earth's climate system, including the atmosphere, ocean, land, and ice. It uses mathematical equations based on the basic laws of physics, chemistry, and fluid motion to simulate the transfer of energy and materials through the climate system. It also takes into account factors that can affect the climate, such as seasons, volcanic eruptions, air pollution, and continental shifts.

The main inputs into the models are the external factors that change the amount of the sun's energy that is absorbed by the Earth. These external factors are called "forcings". They include changes in the sun's output, long-lived greenhouse gases – such as CO_2, methane (CH_4), nitrous oxides (N_2O), and halocarbons – as well as tiny particles called aerosols that are emitted when burning fossil fuels, and from forest fires and volcanic eruptions. Aerosols reflect incoming sunlight and influence cloud formation. To project climate into the future, the climate forcing is set to change according to a possible future scenario. Scenarios are possible stories about how quickly the human population will grow, how land will be used, how economies will evolve, and the atmospheric conditions (and therefore, climate forcing) that would result from each storyline.

3.1 Types of scenario being used in modeling climate change

As mentioned above, climate scenarios refer to a plausible future climate that has been constructed for explicit use in investigating the potential consequences of climate change. Climate scenarios should represent future conditions that account for both human- induced climate change and natural climate variability. Because scientists worldwide use climate models to explore and predict possible climate change, there need to be some presumptive agree- upon scenarios to drive such models. Here are the scenarios recently provided by the IPCC;

3.1.1 Representative Concentration Pathway (RCP)

In the 2014 Fifth Assessment Report (AR5) the IPCC introduced the Representative Concentration Pathways (RCPs) . RCPs describe different levels of greenhouse gases in the atmosphere as well as land-use changes that might occur in the future that can change the amount of the sun's energy trapped by earth (known as 'radiative forcing' and measured as watts per square meter).

Climate researchers adopted 4 pathways spanning a broad range of values to explore a broad range of possible futures to evaluate the corresponding range of global warming and climate changes. Those 4 pathways are; [6]

- RCP2.6 (radiative force = 2.6 watt/m^2): This is a pathway where stringent mitigation efforts are put in place to limit GHG emissions. It represents a future where global warming is limited to 2 degrees Celsius or below, which is the target agreed upon by many countries in the Paris Agreement.

- RCP4.5 (radiative force = 4.5 watt/m^2): This scenario assumes that some moderate mitigation measures are implemented to reduce GHG emissions, leading to a global temperature increase of around 2.4 degrees Celsius by the end of the 21st century.
- RCP6.0 (radiative force = 6.0 watt/m^2): In this pathway, emissions continue to rise at a moderate rate throughout the century, resulting in a global temperature increase of approximately 3 degrees Celsius.
- RCP8.5 (radiative force = 8.5 watt/m^2): This scenario, also known as the "business-as-usual" or "high-emission" pathway, represents a future where no significant climate mitigation policies are implemented. Under this scenario, global temperatures could rise by 4.5 degrees Celsius or more by the end of the century, leading to severe and potentially catastrophic climate impacts.

It is worth noting that RCPs are not predictions of the future but rather tools for understanding potential outcomes based on different assumptions about GHG emissions and mitigation efforts.

3.1.2 Shared Socioeconomic Pathway (SSP)

This school of thinking bases on the idea that global warming is caused by human activities, so how much the climate will change in the future strongly depends on how society grows and develops. Therefore, rather than offer a single set of future climate data, it is best practice to provide a range of future climate change scenarios that encompass various levels of greenhouse gas emissions. The SSP climate scenarios are a set of five narratives that describe different possible futures of the world in terms of socioeconomic development and greenhouse gas emissions. [7] Their narratives are as follows;

SSP1: The sustainable and "green" pathway describes an increasingly sustainable world. Global commons are being preserved, and the limits of nature are being respected. The focus is more on human well-being than on economic growth. Income inequalities between states and within states are being reduced. Consumption is oriented towards minimizing material resources and energy usage.

SSP2: The "Middle of the road" or medium pathway extrapolates the past and current global development into the future. Income trends in different countries are diverging significantly. There is a certain cooperation between states, but it is barely expanded. Global population growth is moderate, leveling off in the second half of the century. Environmental systems are facing a certain degradation.

SSP3: Regional rivalry. A revival of nationalism and regional conflicts pushes global issues into the background. Policies increasingly focus on questions of national and regional security. Investments in education and technological development are decreasing. Inequality is rising. Some regions suffer drastic environmental damage.

SSP4: Inequality. The chasm between globally cooperating developed societies and those stalling at a lower developmental stage with low income and a low level of education is widening. Environmental policies are successful in tackling local problems in some regions, but not in others.

SSP5: Fossil-fueled Development. Global markets are increasingly integrated, leading to innovations and technological progress. The social and economic development, however, is based on an intensified exploitation of fossil fuel resources with a high percentage of coal and an energy-intensive lifestyle worldwide. The world economy is growing and local environmental problems such as air pollution are being tackled successfully.

These pathways describe possible socio-economic conditions, land-use changes, and other human-caused climate drivers that influence greenhouse gas emissions, thus affecting radiative forcing.

The five SSP-based scenarios can be categorized along two broad axes: challenges to mitigation and challenges to adaptation (see Figure 8 below). SSP1 (Sustainability) has low challenges to both mitigation and adaptation. In this scenario, policies focus on human well-being, clean energy technologies, and the preservation of the natural environment. In contrast, SSP3 (Regional Rivalry) is characterized by high challenges to both mitigation and adaptation. In this scenario, nationalism drives policy, and focus is placed on regional and local issues rather than global issues. The other SSPs "fill in the spectrum" of possible futures. SSP4 (Inequality) is defined by high challenges to adaptation and low challenges to mitigation, SSP5 (Fossil-fueled Development) is characterized by high challenges to mitigation and low challenges to adaptation, and SSP2 (Middle of the Road) represents moderate challenges to both mitigation and adaptation. [8]

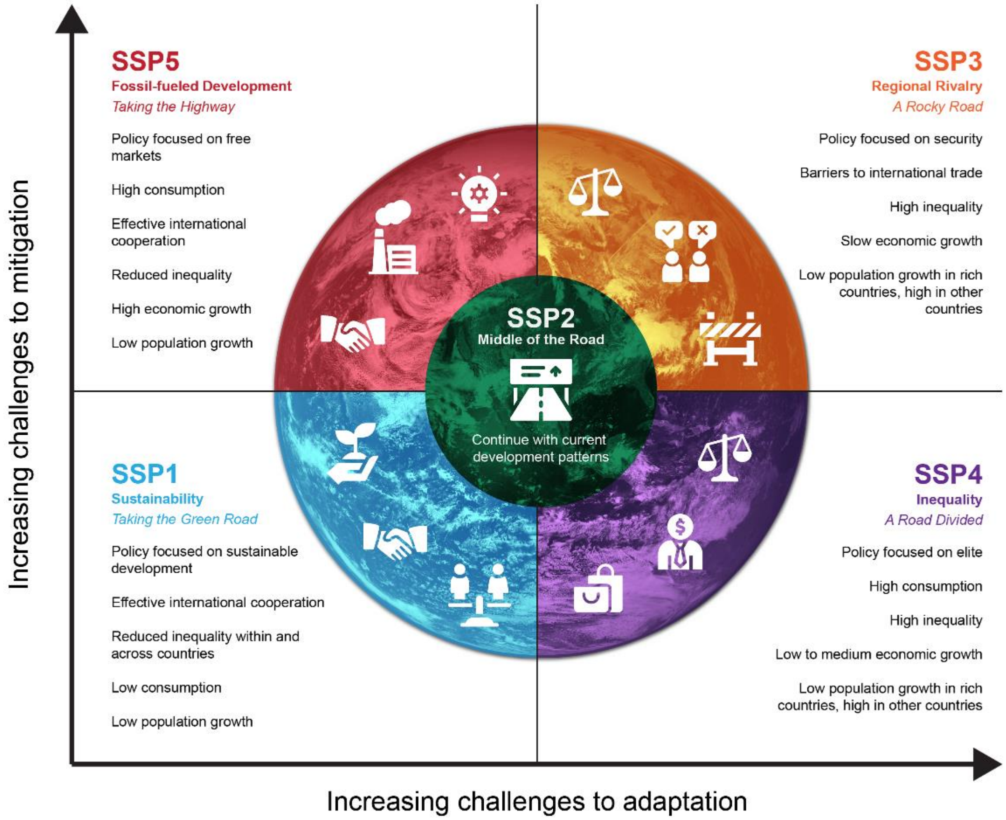


Figure 8 SSP's challenge to mitigation and challenge to adaptation

Source: https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

The first part of the IPCC Sixth Assessment Report which was released in August 2021 assessed the projected temperature outcomes of a set of five scenarios that are based on the framework of the SSPs. The names of these scenarios consist of the SSP on which they are based (SSP1-SSP5), combined with the expected level of radiative forcing in the year 2100 (1.9 to 8.5 W/m2). This results in scenario names SSPx-y.z are as follow [9][10];

SSP1- 1. 9: Very low greenhouse gases emissions. CO_2 emissions will be cut to net zero around 2050. This is the most optimistic scenario. Societies adopt emore environmentally friendly practices, focusing on people' s general well- being rather than economic growth. Investments in education and health increase and inequality decreases. Severe weather events are more frequent than present time, but the world has avoided the worst consequences of climate change.

Challenges for adaptation: low

Challenges for mitigation: low

SSP1-2.6: Low greenhouse gases emissions. CO_2 emissions will be cut to net zero around 2075. In this scenario, global CO2 emission is strongly reduced but less rapidly. This scenario presents the same socio-economic trends towards sustainable development as in the first scenario, but the temperature increase stabilizes at around 1.8°C by the end of this century.

Challenges for adaptation: moderate

Challenges for mitigation: moderate

SSP2-4.5: Intermediate greenhouse gases emissions. CO_2 emissions will be around current levels until 2050, then will be falling but not reaching net zero by 2100. Socio-economic factors follow their historical trends, with no significant change. Progress toward sustainability is slow, with disparate development and income growth. Under this scenario, temperatures rise by 2.7°C by the end of the century.

Challenges for adaptation: high

Challenges for mitigation: high

SSP3-7.0: High greenhouse gases emissions. CO_2 emissions will be double by 2100. Countries become more competitive with each other, prioritizing issues of national and food security. By the end of the century, average temperatures have risen by 3.6°C.

Challenges for adaptation: high

Challenges for mitigation: low

SSP5-8.5: Very high greenhouse gases emissions. CO2 emissions will be triple by 2075. This is the "worst case scenario". The world economy grows rapidly, but this growth is driven by fossil fuel exploitation and very energy-intensive lifestyles. By 2100, the average temperature of the planet will have risen by a catastrophic 4.4°C.

Challenges for adaptation: low

Challenges for mitigation: high

3.2 The climate models

The general purpose climate modeling tools for Thailand are freely available at https://climateknowledgeportal.worldbank.org/country/thailand/climate-data-projections. For the purpose of this report, the Multi- Models Ensemble is selected to provide the baseline projection under different scenarios. Then CAMS- CSM1- 0 and MIROC6 which have been subjected to evaluation against El-Nino Southern Oscillation (ENSO) [11][12][13] are selected to verify whether there is any substantial anomaly under ENSO influence in Northern Thailand.

The models use historical climate data from the years 1995- 2014 as a baseline. For the purpose of this report, the projection is done to the year 2039 which should serve the objective of generating farmers' mitigation and adaptation plans for immediate short-term climate change. Of the various climate parameters available as an output, the five most relevant are selected. Those five parameters are; mean monthly temperature, average maximum and minimum monthly temperature, cold spell duration index, mean monthly precipitation, and monthly maximum consecutive dry days.

Climate record from the year 2017-2022 is also examined alongside the present land use in order to establish an understanding of how farmers adapt to current climate variations. This understanding will serve as a baseline for suggestions to future adaptation to climate changes.

4. Modeling result

4.1 Temperature

Figures 9, 10 and 11 show the projected temperature shift in Nan Province in the year 2039 from Multi- Model Ensemble (the median among different results from the available models), CAMS-CSM1-0 and MIROC6. Each model has a different reference set of temperatures owing to different spatial interpolation algorithms. Somehow, each set of results shows a similar trend of a minor increase in mean monthly temperature, in most cases the increase in temperature is less than 1 degree for every scenario. Modeling results are shown in Tables 6-8. in the Appendix 2.

When compare projected temperature with climate records from 2017- 2022, it is obvious that the average monthly temperature is already close to or higher than what the models predict in 2039. So there should not be any further substantial increase in mean monthly temperature in the near future.

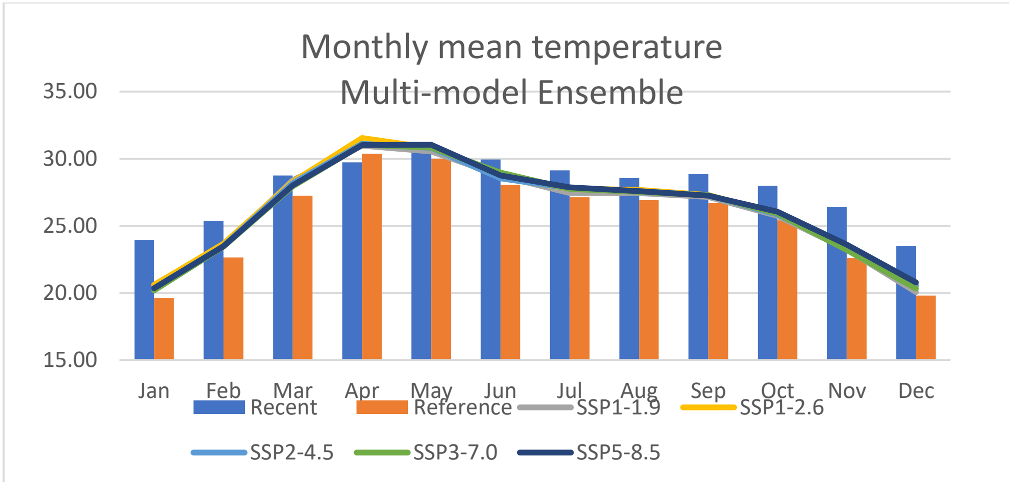


Figure 9. The median value of the projected mean monthly temperature from Multi- Model Ensemble compared with reference values from 1995-2014 and recent climate records from 2017-2022

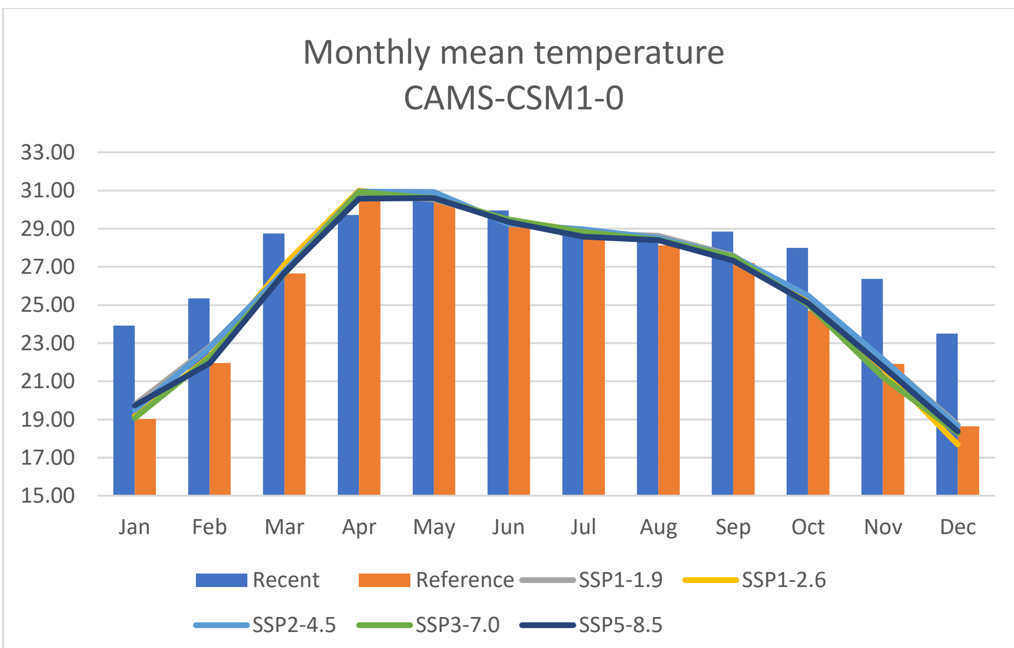


Figure 10. Projected mean monthly temperature from CAMS-CSM1-0 compared with reference values from 1995-2014 and recent climate records from 2017-2022

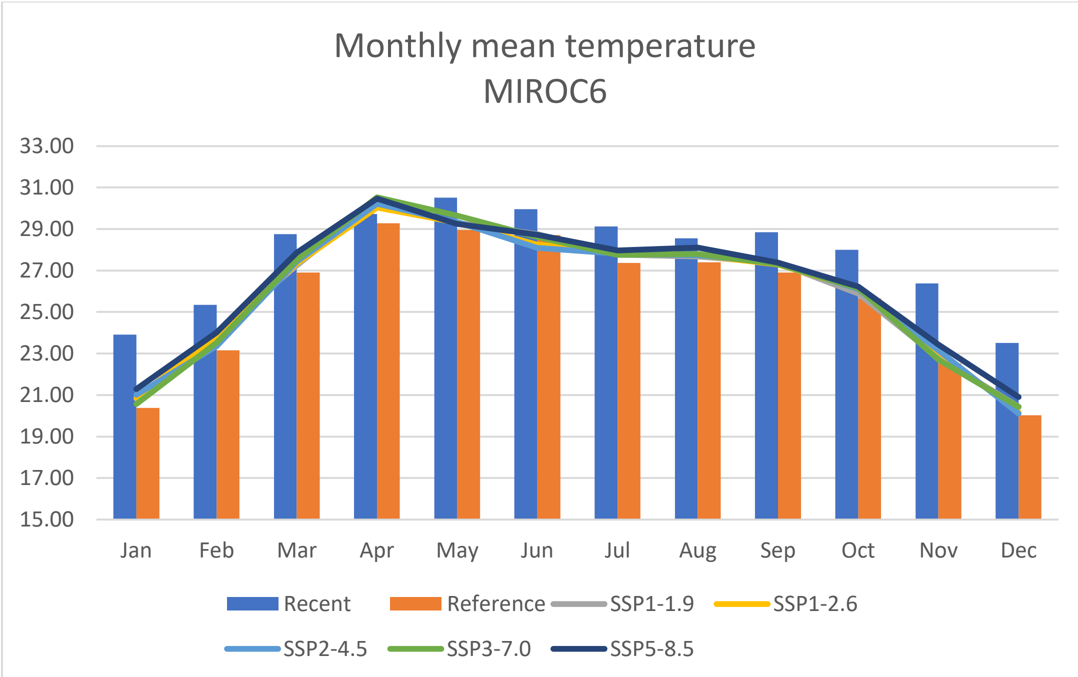


Figure 11. Projected mean monthly temperature from MIROC6 compared with reference values from 1995-2014 and recent climate records from 2017-2022

Mean monthly maximum temperature also follows the same trend. The recently recorded climate data indicates that the maximum monthly temperature is already close to or higher than the projected temperature from the 3 selected models, except for April where all models predict a possibility of higher temperature (Figure 12-14). Multi-model Ensemble also predicts higher temperatures in May. Modeling results are shown in Tables 9-11. in the Appendix 2. There is no substantial difference among the scenarios.

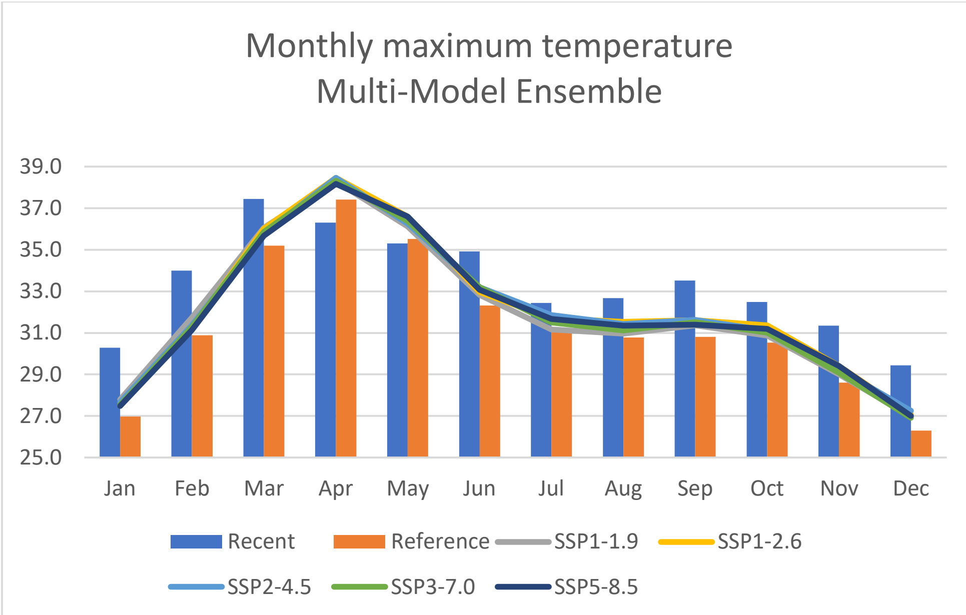


Figure12. The median value of the projected mean monthly maximum temperature from Multi-Model Ensemble compared with reference values from 1995-2014 and recent climate records from 2017-2022

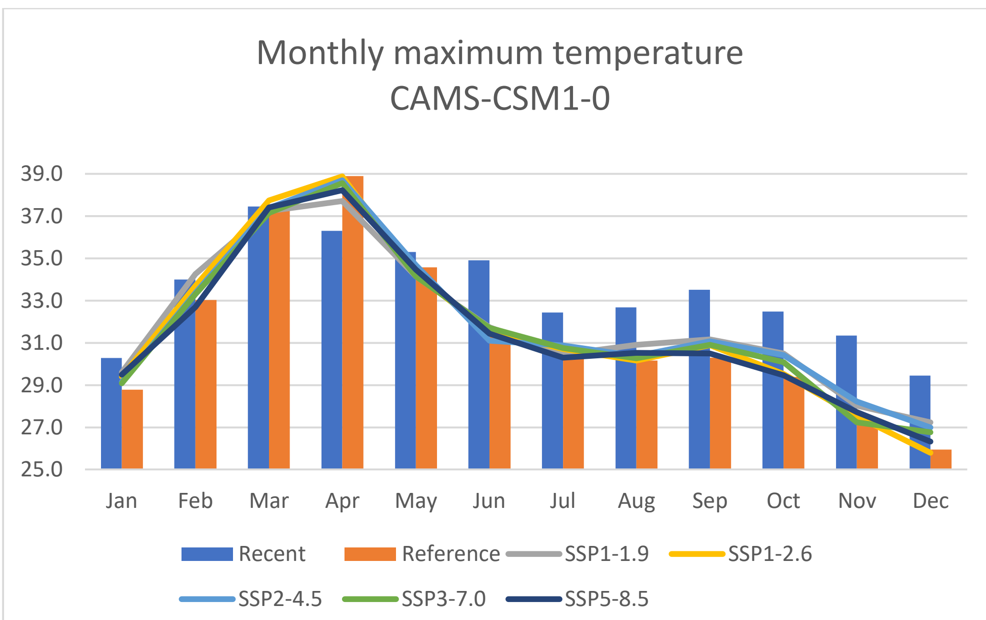


Figure 13. Projected mean monthly maximum temperature from CAMS-CSM1-0 compared with reference values from 1995-2014 and recent climate records from 2017-2022

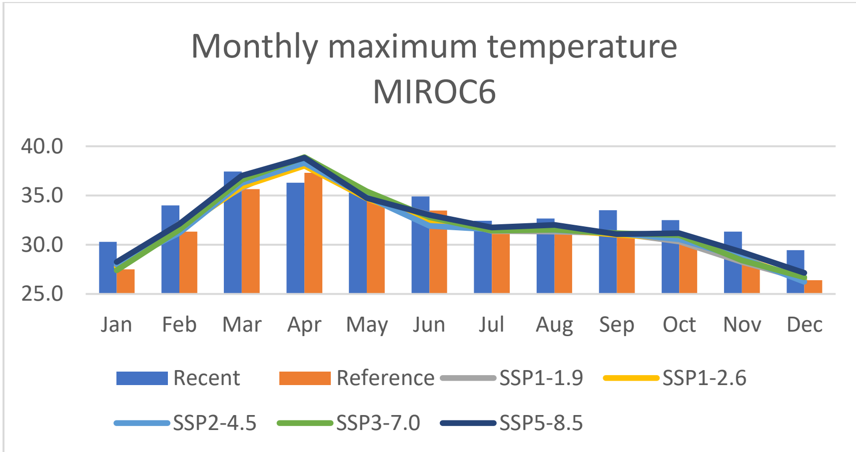


Figure 14. Projected mean monthly maximum temperature from MIROC6 compared with reference values from 1995-2014 and recent climate records from 2017-2022

CAMS-CSM1-0 does not provide a projection for mean monthly minimum temperature. The median of projection results from Multi-model Ensemble indicate that temperature will increase from the reference period but recent record shows 1-2 degree higher than the projection during October to February though this is a time when Nan Province is supposed to be under the influence of the cold front that moves down from higher latitude (Figure 15). MIROC6's result shows a similar trend (Figure 16). Detailed results can be seen in Tables 12 and 13 in Appendix 2.

The cold spell duration index (CSDI), which is defined as the annual count of days with at least 6 consecutive days when the daily minimum temperature is less than the 10th percentile of daily minimum temperature calculated for five days window centered on each calendar day, also has a tendency to decrease in every scenario. Results from the Multi-model Ensemble stars from comparatively lower values in 2023 when compared to MIROC6, and in 2039, the indices decrease to negative values for scenarios SSP1-1.9, SSP1-2.6 and SSP5-8.5. The indices are 1.15 and 1.67 for scenarios SSP2-4.5 and SSP3-7.0 respectively. While there are fluctuations in other scenarios, the SSP3-7.0 result stands out as the slowest to decrease (Figure 17). On MIROC6 every scenario shows the same tendency of decreasing indices for the next 10 years, but then from 2032 onwards scenarios SSP1-2.6, SSP2-4.5, and SSP3-7.0 have increasing CSDI (Figure 18). Scenario SSP2-4.5 shows the most prominent increase.

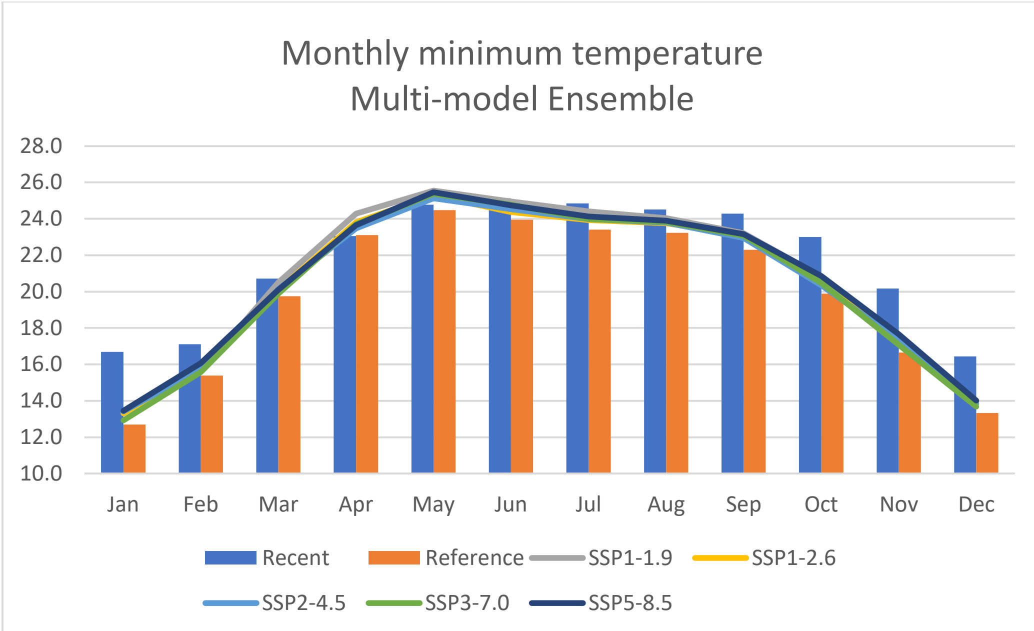


Figure 15 The median value of projected mean monthly minimum temperature from Multi-Model Ensemble compared with reference values from 1995-2014 and recent climate records from 2017-2022

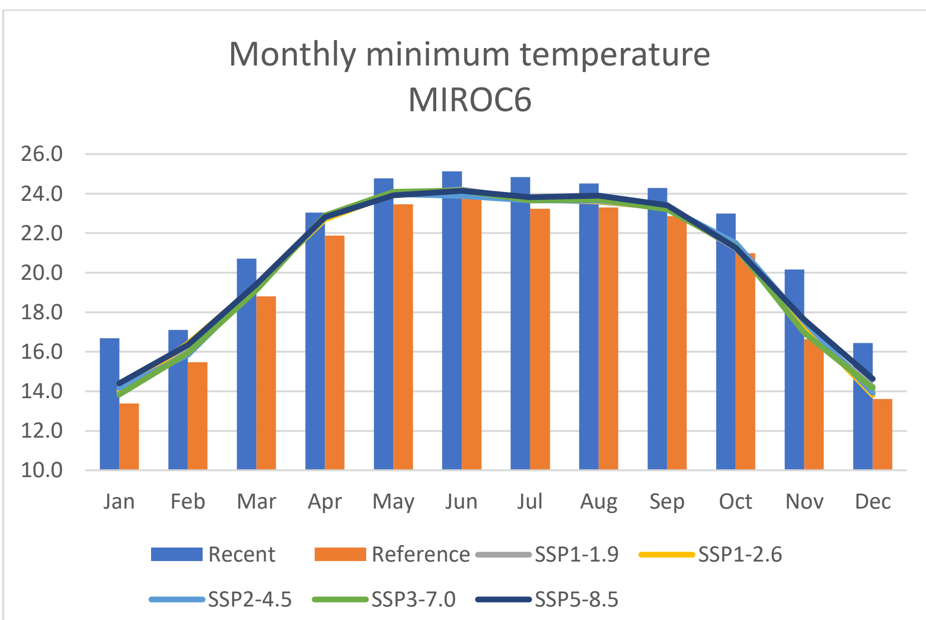


Figure 16 Projected mean monthly minimum temperature from MIROC6 compared with reference values from 1995-2014 and recent climate records from 2017-2022

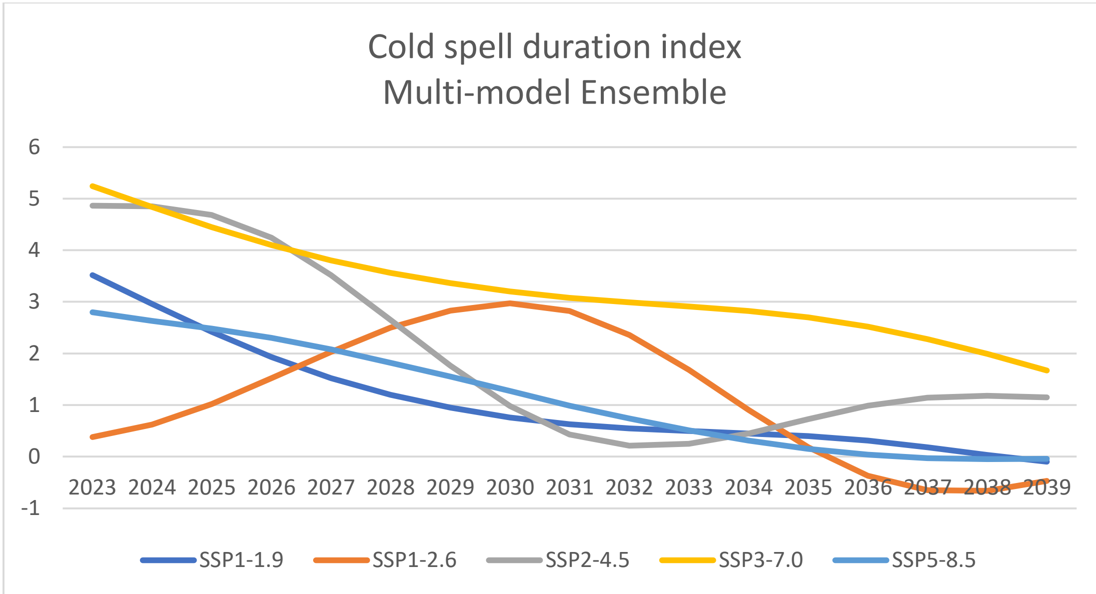


Figure 17. Cold spell duration index from the year 2023 to 2039, Multi-model Ensemble

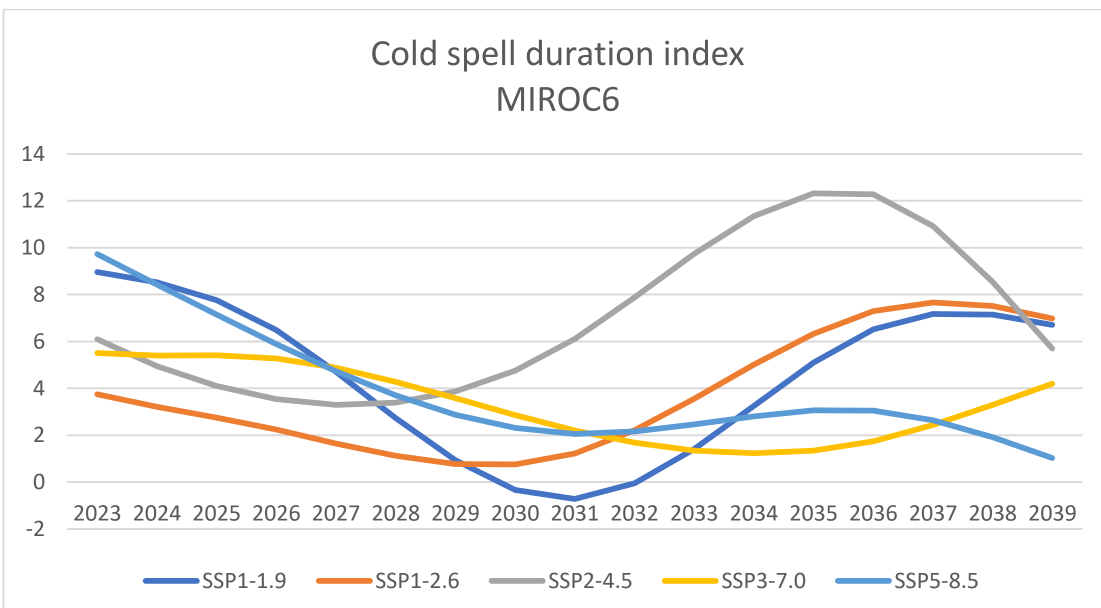


Figure 18. Cold spell duration index from the year 2023 to 2039, MIROC6

4.2 Rainfall

Rainfall projection for the year 2023 is very diverse (Figure 19). The median from Multi-model Ensemble predicts a slightly lower annual amount of rain compared to the reference which annual rainfall is as high as 1,492 mm. SSP1-1.9 projection is 1,289 mm. while in other scenarios annual rainfall is well over 1,300 mm. Somehow, these figures are significantly higher than the recent record where annual rainfall is only 1,238 mm. Those months in wet season have higher rain than the recent record while rain may almost vanish during dry season (Figure 19).

CAMS-CSM1-0, on the other hand, predict a a significantly lower amount of annual rainfall, particularly for scenario SSP2-4.5, SSP3-7.0, and SSP5-8.5 where the amount of annual rain falls below 1,000 mm. The rainfall pattern from every scenario is conforming to the pattern recently recorded.

MIROC6 then projects a very wet year. In scenarios SSP1-1.9, SSP1-2.6, and SSP2-4.5, annual rainfall is quite close to 1,500 mm. In this set of projections, wet season may start as early as April with a substantial rainfall amount from April until October.

Another parameter that needs to be considered is the maximum consecutive dry days. Multi-model Ensemble predicts a much higher maximum consecutive dry days than the recent record for the first five months of the year. There is no significant difference through the rest of the year. CAMS-CSM1-0 and MIROC6 follows a similar trend. This projection indicates a prolong dry season. There is no distinct difference among scenarios. (Figure 20)

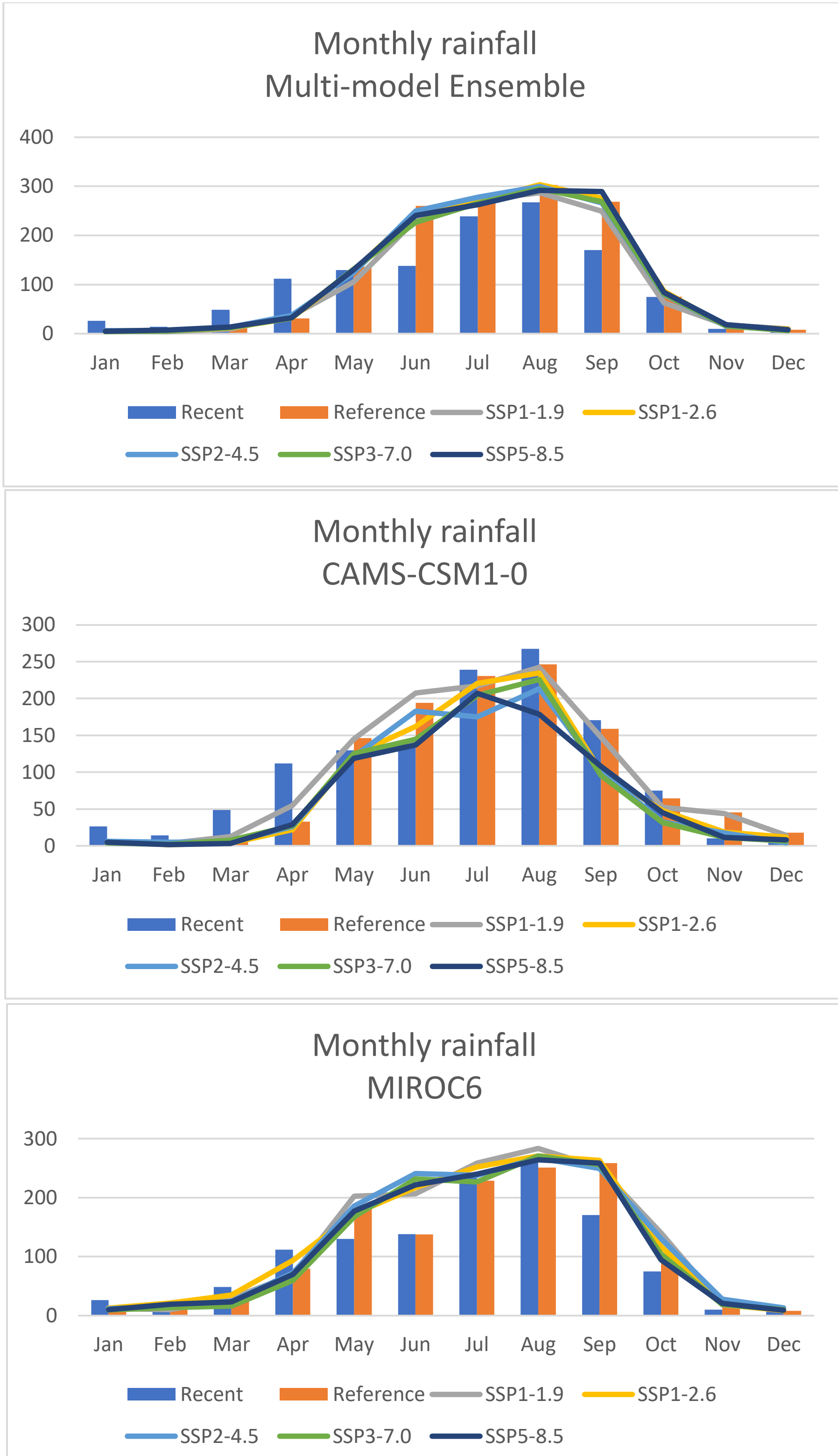


Figure 19. Projected monthly rainfall

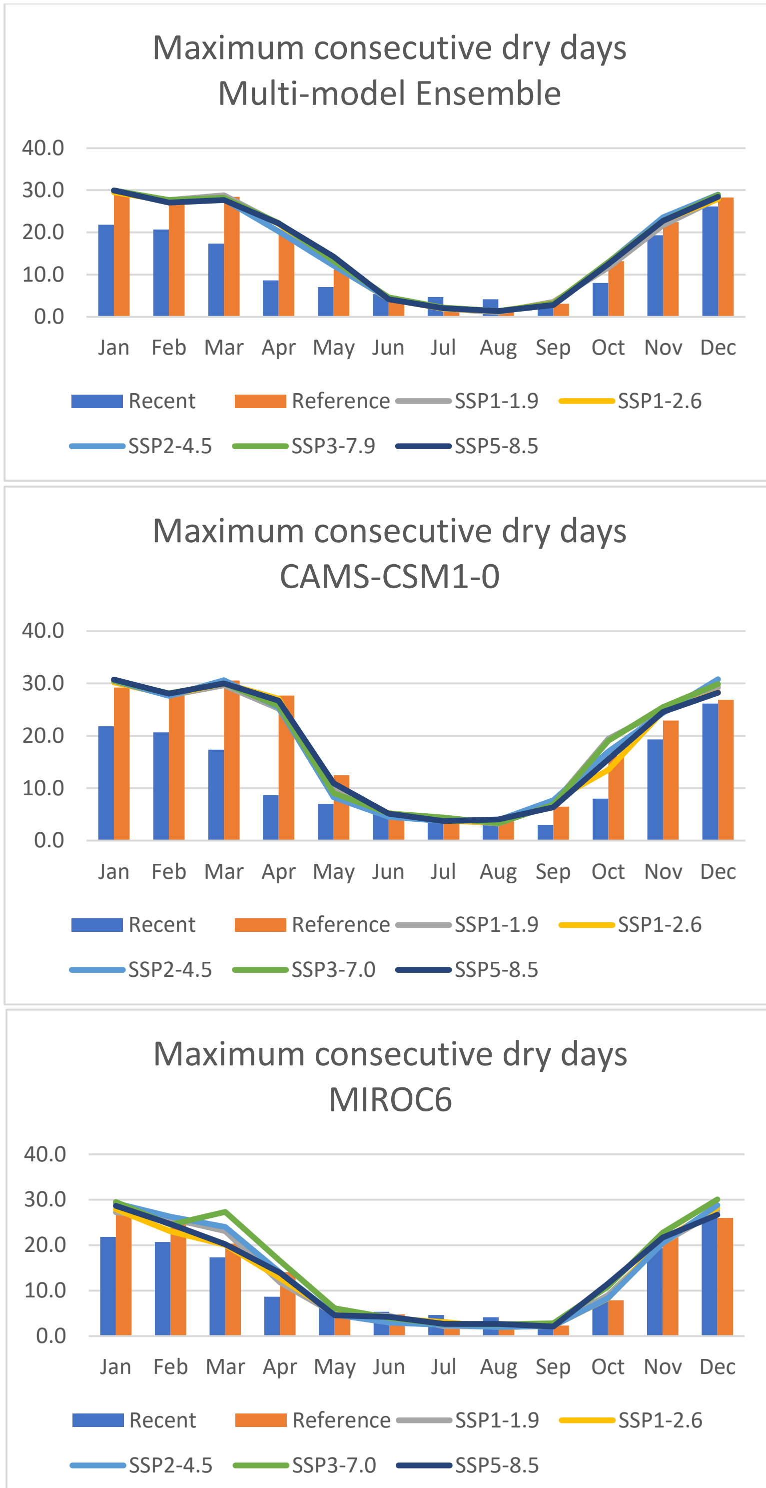


Figure 20. Projected maximum consecutive dry days

4.3 Implication of climate projection on agriculture

According to what is documented in the Sub-district Office, there are 4 major crops in Pa Leaw Luang namely; rice, maize, para-rubber, and teak. In general, the system is a mix between staple (paddy and up-land rice) and income-generating crops. For those in the second category, maize and para-rubber are the crucial source of income. Eighty percent of the sub-district population depends on those crops. Changes in climate pattern will affect existing crop as follow.

Rice (*Oryza sativa*)

Rice grown in paddy terraces normally depends on two combined sources of water, rainfall and stream flow. Without highly efficient irrigation infrastructure, cropping season starts in July, or may be as late as early August, when there is reliable rainfall and stream flow starts the rise above the level of dry season base flow. If rainfall the pattern follows Multi-model Ensemble or MIROC6 projection, there should be no problem in rice production because rainfall will be abundant. But, in case the rainfall patterns follow CAMS-CSM1-0 projection, particularly SSP1-2.6 through SSP5-8.5 where the annual amount of rainfall is below 1000 mm., there is a high risk for paddy rice to suffer from drought or even face failure.

Up-land rice which depends solely on rainfall needs a strategic planting date. Though rainfall amount seems to be reliable since May, the maximum consecutive dry days are still 12-14 days in Multi-model Ensemble projection and 8-10 days in CAMS-CSM1-0. Only MIROC6 projects a reliable consistent rainfall as early as May. In every model, the rainy season will last until October which rules out photo-sensitive varieties. Farmers should also avoid varieties with longer than 120 days harvest age.

Maize (*Zea mays*)

Maize is a major income generating crop for farmers in Pa Laew Luang Sub-district. Maize filed in this sub-district is far larger than those of paddy and up-land rice combined. At the time of writing this report, grain price is 11 plus baht, which provides a good incentive for farmers to carry on growing maize. Crop failure will have a severe impact on the household economy of the whole sub-district.

Because maize is grown in up-land rainfed conditions, it is exposed to the same climate constraint as up-land rice. A severe drought condition will be a disaster for farmers who depend on up-land rice for food security (up to around 30% of all farmers) and maize as a major source of income. It would be advisable that farmers have access to more diverse farming systems in order to build up their resilient capacity.

Para-rubber (*Hevea brasiliensis*)

In tapping season, para-rubber generates income almost on a daily basis. So, it has become a favorite option among farmers. Somehow, when considered from a climate- relate physiologial perspective, para- rubber is not a good option. The optimum temperature where para- rubber performs well are between 22- 28 Celsius, and minimum annual rainfall should not be lower than 1,350 mm. with at least 120 rain- days [14] [15]. Every model predicts mean monthly temperature close to the upper limit during the early tapping season which means the crop will suffer to some extent. In Multi- model Ensemble projection, annual rainfall will be quite close to the minimum requirement with the exception of SSP1-1.9 where annual rainfall will be only 1289 mm. CAMS-CSM1-0 predicts that annual rainfall will be much lower than the minimum requirement. MIROC6, on the other hand, predicts a much higher than minimum requirement annual rainfall.

Somehow, it is worth noticing that recently recorded climate data shows higher than optimum temperatures during the early tapping season and annual rainfall is lower than the minimum requirement for almost 100 mm.

Teak (*Tectona grandis*)

Teak can be viewed as either long- term investment or farmers' response to a lack of labor for day- to- day farming activities. Teak grows well in lower altitudes (less than 700 m.) and can survive in annual rainfall between 500-5000 mm. Somehow, optimum rainfall amount is between 1,270 – 3,600 mm. Too much or too small amount of rainfall may have negative effect on wood quality. Moreover, in order to get beautiful grain, teak also requires a distinctive dry season for 3-4 months. The optimum temperature falls between 13-40 degrees Celsius [16].

Generally speaking, being a wild and local species, teak will be least affected by climate change among the other economic crops. The number of maximum consecutive dry days, which is predicted to be higher than the present day, together with lower rainfall amount during the dry season is likely to enhance grain quality in the long run. Whether or not teak will be suitable for the economy of the community in the target area depends on legitimate factors which are beyond the scpe of this report.

The predicted higher average minimum monthly temperature and decline in cold spell duration index suggest that sub-tropical fruit trees such as lychee, longan, citrus and grape may not be suitable in the long run. Tropical fruit trees are preferable choices.

Higher temperatures and humidity may increase the reproduction, survival, and dispersal of some insect pests. On the other hand, higher temperatures may also reduce the lifespan and fecundity of some pests, such as aphids, or increase the activity of their natural enemies, such as parasitoids and predators.

Changes in rainfall patterns and drought frequency may affect the availability of water and nutrients for plants and pests, altering their growth and development. Drought stress may weaken plant defenses and increase their susceptibility to pests and diseases. Conversely, excessive rainfall may create favorable conditions for fungal and bacterial diseases, such as rice blast

Furthermore, extreme weather events, such as storms, floods, heat waves, and cold snaps, may cause direct damage to crops and pests, or create opportunities for pest invasions and disease outbreaks.

In which direction the system will shift depends very much on the agro-ecosystem and balance in its biosphere. The more diverse the system is, the better it can withstand the consequences of climate change.

5. Suggest mitigation and adaptation

Semi-subsistence farmers typically have limited resources and access to technology, making it difficult for them to adapt to the changing climate. The foreseeable impact of climate change on the community in Pa Leaw Luang in a near future include loss in biodiversity, food and income insecurity and migration. To address the impacts of climate change on semi-subsistence farming systems, it is crucial to implement strategies that enhance their resilience capacity from farming practices aspect as well as financial and institutional aspects.

Paddy rice is a main staple and closely relates to the community's food security. So, care should be taken to ensure successful harvesting regardless of climate variations. The possible measures are;

- Introducing rice varieties with shorter harvest ages in order to limit crop season within a time window with reliable rainfall and stream flow,
- Encourage individual farmers to adopt more efficient water management techniques such as land leveling, alternate wet/dry irrigation system, etc. and
- Building water management capacity at a community level.

Up-land rice is grown in rain-fed, sloping lands that are prone to drought, erosion, and nutrient depletion. Apart from shorten time window suitable for crop growth, climate change may exacerbate these problems by increasing the frequency and intensity of extreme weather events, such as heat waves, prolonged drought, heavy storm and flash flood. Around 30 % of people in the study area depend on up-land rice for their food security. Adaptation options are needed to sustain up-land rice production and livelihoods under changing climatic conditions. The possible options are;

- Adopting rice varieties that are tolerant to drought, heat, pests, and diseases and are not photo-sensitive.
- Implementing soil and water conservation practices to conserve moisture and nutrients, reduce erosion, and enhance soil fertility.
- Implementing more diverse cropping systems to reduce risk and increase resilience. For example, farmers can intercrop or rotate upland rice with other crops, such as legumes, and vegetables. This can improve soil health, pest control, income stability, and food security.

Maize are also grown in up-land rainfed condition, thus are prone to the same constraint as upland rice and have similar adaptation options. There are abundance of academic papers on maize intercropping with either legumes or low-standing trees. Somehow, in order to adopt any system, differences in rainfall patterns should be taken into account.

Climate change poses a serious threat to the production and quality of para-rubber. Higher temperatures and drought may reduce the growth and yield of para-rubber trees, as well as increase their susceptibility to pests and diseases. Changes in rainfall patterns and intensity may affect the tapping and processing of para-rubber latex, as well as the soil moisture and nutrient availability for the trees. Extreme weather events, such as storms, floods, heat waves, and cold snaps, may cause direct damage to para-rubber trees and infrastructure, or create opportunities for pest and disease outbreaks. Some of the possible adaptation options are:

- Adopting improved para-rubber varieties that are tolerant to drought, heat, pests, and diseases.
- Implementing soil and water management practices to conserve moisture and nutrients, reduce erosion, and enhance soil fertility. For example, farmers can use cover crops, contour planting or terraces to protect the soil from water loss and erosion. Farmers can also use drip irrigation, or water-saving techniques to optimize water use efficiency when water scarcity occurs.
- Adoption of a more bio-diversified agroforestry system in order to reduce risk from climate disasters and increase resilience capacity.

Though there is a possibility of a longer dry season and longer maximum consecutive dry days, but conventional water harvesting techniques such as Negarim micro-catchment, contour bund, or semi-circular bund where surface runoff is collected *in situ* are not advisable. This is owing to the fact that farmers are farming on steep slopes, and adding runoff water to the soil when it is already saturated with water makes the slope more prone to landslide. Water should be harvested from stream runoff and stored in sealed containers to be used during the dry season. Steep topography provides the potential to collect water in a small weir at the headwater and send it through pipelines to the farm at a lower altitude. A steep stream gradient also provides the potential to pump water up to high ground using stream energy itself. Pumping technology such as hydraulic ram or water-driven spiral pump are cheap and non-sophisticate. Once learned, they can be manufactured and repaired in local workshops. As long as there is stream flow, these pumps can work around the clock without running costs.

The most practical option to cope with the impact of climate change is to alter agroecological system to a more climate change-resilient farming systems. It involves the use of biodiversity, traditional knowledge, and sustainable practices to increase crop productivity and reduce the impacts of climate change.

It is also advisable to strengthen institutional support and social capital to enhance access to information, resources, markets, and services. Farmers can join farmer groups or cooperatives to share knowledge, skills, inputs, equipment, and marketing opportunities. Farmers can also benefit from extension services, training programs, weather information systems, insurance schemes, and credit facilities that can help them adopt and implement adaptation practices.

The suitability and effectiveness of these options may vary depending on the local socio-economic context and conditions. Therefore, it is important to involve farmers in the planning and evaluation of adaptation options to ensure their participation and acceptance. Traditional knowledge and local wisdom should not be overlooked.

References

[1] CoO$_2$.earth 2023 **Daily CO_2** . https://www.co2.earth/daily-co2 access on 15/9/23

[2] Letcher, Trevor M. 2019. **Managing Global Warming || Why do we have global warming?**. , (), *3–15*. doi:10.1016/B978-0-12-814104-5.00001-6

[3] IPCC, 2023: Summary for Policymakers. In: **Climate Change 2023**: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

[4] Shaw, R., Y. *et al*, 2022: Asia. In: **Climate Change 2022**: **Impacts, Adaptation and Vulnerability**. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

[5] IPCC 2023 **About the IPCC** https://www.ipcc.ch/about/ access on 15/9/23

[6] Richard Moss; et al. 2008. Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies (PDF). Geneva: **Intergovernmental Panel on Climate Change**. p. 132.

[7] Michael Böttinger and Dr. Dieter KasangThe nd **SSP Scenario**. https://www.dkrz.de/en/communication/climate-simulations/cmip6-en/the-ssp-scenarios access on 15/9/23

[8] Environmental and Climate Change Canada. nd. **Understanding Shared Socioeconomic Pathways (SSP)** https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/ access on 17/9/23

[9] IPCC. 2021. **Climate Change 2021 : The Physical Science Basis**. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ access on 17/9/23

[10] ORANO 2022 **Latest IPCC Climate Report**. https://www.orano.group/en/unpacking-nuclear/latest-ipcc-climate-report access on 17/9/23

[11] Rong, X. Y., J. Li, H. M. Chen, et al., 2018: **The CAMS climate system model and a basic evaluation of its climatology and climate variability simulation**. J. Meteor. Res., 32(6), 839–861, doi: 10.1007/s13351-018-8058-x.

[12] Hiroaki Tatebe *et al.* 2019 **Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6**. Geosci. Model Dev., 12, 2727–2765

[13] Kataoka, T., Tatebe, H., Koyama, H.,Mochizuki, T., Ogochi, K., Naoe, H., et al. (2020). **Seasonal to decadalpredictions with MIROC6: Description and basic evaluation**. Journal of Advances in Modeling Earth Systems, 12, e2019MS002035. https://doi.org/10.1029/2019MS002035

[14] กรมส่งเสริมการเกษตร มปป. **เทคโนโลยีการปลูกยางพารา** http://www.agriman.doae.go.th/home/t.n/t.n1/3fruit_Requirement/02-003-cropre-rubberplant.pdf access on 20/9/23

[15] P.Sanjeeva Rao; C.K Saraswathyamma; M.R Sethuraj (1998). **Studies on the relationship between yield and meteorological parameters of para rubber tree (Hevea brasiliensis)**. , 90(3), 0–245. doi:10.1016/s0168-1923(98)00051-3

[16] กรมป่าไม้ 2556. องค์ความรู้ไม้สักไทย http://forprod.forest.go.th/forprod/KM/PDF/teak.pdf access on 20/9/23

Appendices

Appendix 1. Nan climate records during 2017-2022

Table 1. Average monthly temperature (Celsius)

Month	Year						Average
	2017	2018	2019	2020	2021	2022	
Jan	24.2	23.7	24.5	24.7	22.3	24.1	23.9
Feb	25.0	25.0	26.1	25.5	25.1	25.4	25.3
Mar	28.9	27.4	28.4	29.5	29.1	29.2	28.8
Apr	29.7	28.6	31.3	30.7	28.9	29.2	29.7
May	30.0	29.4	32.0	32.0	30.7	29.0	30.5
Jun	30.0	29.0	30.6	30.2	29.9	30.1	30.0
Jul	28.4	28.5	29.3	29.9	29.0	29.6	29.1
Aug	28.5	28.2	28.4	28.3	29.4	28.5	28.6
Sep	28.9	29.0	28.7	29.0	28.9	28.6	28.9
Oct	27.0	28.6	28.7	27.3	28.2	27.4	28.0
Nov	25.1	26.4	26.4	26.4	27.1	26.8	26.4
Dec	23.2	24.9	22.5	23.2	23.0	24.3	23.5

Source: Meteorological Department

Table 2. Monthly maximum temperature (Celsius).

Month	Year						Average
	2017	2018	2019	2020	2021	2022	
Jan	30.3	30.4	31.1	32.9	30.3	32.0	31.1
Feb	34.0	32.3	35.0	34.4	33.4	32.5	33.6
Mar	37.5	35.1	37.4	38.2	36.9	35.8	36.8
Apr	36.3	34.8	39.4	38.0	34.6	35.1	36.4
May	35.3	34.9	38.4	38.6	36.6	33.8	36.3
Jun	34.9	33.5	35.5	35.0	34.5	35.2	34.8
Jul	32.4	32.5	33.5	34.7	33.1	34.2	33.4
Aug	32.7	32.3	32.1	31.9	34.1	32.6	32.6
Sep	33.5	33.7	33.6	33.3	33.6	32.8	33.4
Oct	32.5	34.1	34.3	31.7	32.9	32.4	33.0
Nov	31.3	32.6	32.7	32.9	32.9	33.0	32.6
Dec	29.4	31.4	30.5	30.9	30.6	30.7	30.6

Source: Meteorological Department

Table 3. Monthly minimum temperature (Celsius)

Month	Year						Average
	2017	2018	2019	2020	2021	2022	
Jan	18.2	17.1	17.0	16.5	14.3	16.2	16.7
Feb	16.0	17.8	17.2	16.6	16.8	18.4	17.1
Mar	20.3	19.7	19.5	20.9	21.2	22.6	20.7
Apr	23.1	22.3	23.2	23.4	23.1	23.2	23.0
May	24.7	23.9	25.6	25.5	24.9	24.2	24.8
Jun	25.1	24.6	25.6	25.3	25.2	25.0	25.1
Jul	24.4	24.5	25.1	25.1	24.8	25.0	24.8
Aug	24.4	24.2	24.7	24.6	24.7	24.5	24.5
Sep	24.3	24.3	23.9	24.8	24.2	24.3	24.3
Oct	23.3	23.1	23.0	22.9	23.4	22.3	23.0
Nov	18.8	20.2	20.1	19.9	21.4	20.6	20.2
Dec	17.0	18.4	14.4	15.5	15.5	17.8	16.4

Source: Meteorological Department

Table 4. Monthly rainfall (mm.)

Month	Year						Average
	2017	2018	2019	2020	2021	2022	
Jan	43.8	14.4	89.2	0	0.2	11.2	26.5
Feb	0	11.8	3.3	0.9	27.8	40.9	14.1
Mar	43.6	28.9	3.9	1.5	19.1	194.6	48.6
Apr	76.9	136.9	65.6	129.5	189.2	72.3	111.7
May	131.0	104.3	158.4	104.3	106.1	174.6	129.8
Jun	56.8	161.6	137.4	233.1	129.7	110.5	138.2
Jul	301.2	296	225.6	164.5	178.1	268.9	239.1
Aug	163.3	241.9	440.1	386.0	127.4	245.4	267.4
Sep	316.4	95.6	91.1	128.3	189.9	201.4	170.5
Oct	72.7	18.2	59.5	29.7	147.6	122.7	75.1
Nov	0.6	2.3	0.9	9.5	6.4	41.4	10.2
Dec	37.2	5.1	0	0	0	0.1	7.1
Annual	1243.5	1117	1275	1187.3	1121.5	1484	1238.05

Source: Meteorological Department

Table 5 Monthly maximum consecutive dry days (days)

Month	2017	2018	2019	2020	2021	2022	Average
Jan	20	14	22	31	29	15	22
Feb	28	20	15	28	20	13	21
Mar	29	11	18	27	13	6	17
Apr	7	8	12	12	6	7	9
May	5	6	11	8	5	7	7
Jun	4	3	4	3	10	8	5
Jul	4	7	6	4	3	4	5
Aug	4	6	2	5	3	5	4
Sep	3	5	3	2	2	3	3
Oct	8	9	7	10	5	9	8
Nov	23	12	17	22	28	14	19
Dec	14	20	31	31	31	30	26

Source: Meteorological Department

Appendix 2 Projected climate change to the year 2039

Table 6. Median of mean monthly temperature (Celsius). Result from Multi-model Ensemble projection.

	Mean monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	23.92	19.64	20.6	20.59	20.36	20.19	20.35
Feb	25.35	22.63	23.49	23.66	23.49	23.46	23.48
Mar	28.76	27.25	28.39	28.26	28.18	27.03	28.02
Apr	29.72	30.38	30.97	31.54	31.1	31.04	31.02
May	30.52	29.98	30.54	30.8	30.79	30.83	31.03
Jun	29.95	28.05	28.72	28.56	28.53	28.96	28.74
Jul	29.12	27.13	27.44	27.78	27.79	27.75	27.87
Aug	28.56	26.91	27.44	27.68	27.58	27.54	27.58
Sep	28.85	26.7	27.15	27.29	27.28	27.28	27.25
Oct	28.00	25.41	25.74	25.92	25.84	25.92	26.06
Nov	26.38	22.6	23.23	23.43	23.41	23.2	23.59
Dec	23.51	19.8	20.07	20.58	20.55	20.33	20.78

Table 7. Mean monthly temperature (Celsius). Result from CAMS-CSM1-0 projection

	Mean monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	23.92	19.03	19.79	19.18	19.5	19.07	19.73
Feb	25.35	21.96	22.81	22.3	22.76	22.24	21.95
Mar	28.76	26.65	26.69	27.13	26.77	26.63	26.68
Apr	29.72	30.75	30.78	31	30.94	30.93	30.57
May	30.52	30.58	30.55	30.61	30.92	30.6	30.61
Jun	29.95	29.18	29.46	29.46	29.26	29.48	29.35
Jul	29.12	28.52	28.76	28.88	28.96	28.83	28.59
Aug	28.56	28.13	28.63	28.39	28.51	28.42	28.4
Sep	28.85	27.2	27.6	27.44	27.54	27.55	27.33
Oct	28.00	24.69	25.12	25.23	25.49	25.01	25.1
Nov	26.38	21.91	22.16	21.7	22.16	21.23	21.77
Dec	23.51	18.64	18.73	17.69	18.62	18.29	18.38

Table 8. Mean monthly temperature (Celsius). Result from MIROC6 projection

	Mean monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	23.92	20.39	20.82	20.88	21.01	20.57	21.29
Feb	25.35	23.16	23.98	23.81	23.36	23.53	24.02
Mar	28.76	26.9	27.25	27.34	27.42	27.52	27.86
Apr	29.72	29.28	30.36	30.03	30.22	30.52	30.46
May	30.52	28.96	29.29	29.31	29.34	29.64	29.24
Jun	29.95	28.71	28.75	28.25	28.09	28.61	28.72
Jul	29.12	27.37	27.76	27.04	27.81	27.75	27.07
Aug	28.56	27.4	27.67	27.74	27.74	27.79	28.1
Sep	28.85	26.91	27.36	27.29	27.36	27.3	27.38
Oct	28.00	25.65	25.89	26.13	26.1	26.15	26.22
Nov	26.38	22.52	22.81	23.09	23.15	22.71	23.43
Dec	23.51	20.03	20.44	20.16	20.11	20.43	20.91

Table 9. Median of maximum monthly temperature (Celsius). Result from Multi-model Ensemble projection

	Maximum monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	30.3	26.97	27.79	27.5	27.66	27.54	27.48
Feb	34.0	30.88	31.73	31.24	31.36	31.28	31.13
Mar	37.5	35.2	36.07	36.02	35.77	35.87	35.68
Apr	36.3	37.42	38.3	38.46	38.46	38.33	38.18
May	35.3	35.52	36.13	36.61	36.27	36.39	36.61
Jun	34.9	32.32	32.82	32.97	33.2	33.19	33.07
Jul	32.4	31.02	31.16	31.71	31.85	31.51	31.67
Aug	32.7	30.78	30.96	31.53	31.42	31.11	31.35
Sep	33.5	30.81	31.36	31.61	31.62	31.52	31.39
Oct	32.5	30.53	30.87	31.36	31.12	31.01	31.2
Nov	31.3	28.61	29	29.41	29.25	29.08	29.4
Dec	29.4	26.3	26.98	27.08	27.25	26.91	27

Table 10. Maximum monthly temperature (Celsius). Result from CAMS-CSM1-0 projection

	Maximum monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	30.3	28.79	29.6	29.41	29.14	29.08	29.49
Feb	34.0	33.03	34.26	33.7	33.37	33.3	32.69
Mar	37.5	37.43	37.25	37.75	37.39	37.15	37.42
Apr	36.3	38.9	37.72	38.88	38.7	38.57	38.24
May	35.3	34.58	34.15	34.25	34.68	34.16	34.47
Jun	34.9	31.55	31.74	31.55	31.11	31.71	31.44
Jul	32.4	30.31	30.45	30.71	30.88	30.76	30.3
Aug	32.7	30.16	30.9	30.16	30.37	30.27	30.52
Sep	33.5	30.3	31.17	30.89	31.07	30.9	30.49
Oct	32.5	29.39	30.5	29.52	30.42	30.09	29.47
Nov	31.3	27.39	28.03	27.53	28.22	27.23	27.72
Dec	29.4	25.95	27.23	25.79	27	26.77	26.33

Table 11. Maximum monthly temperature (Celsius). Result from MIROC6 projection.

	Maximum monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	30.3	27.49	27.79	27.74	27.07	27.38	28.24
Feb	34.0	31.33	32.15	31.54	31.19	31.52	32.1
Mar	37.5	35.65	35.79	35.91	36.28	36.58	37.02
Apr	36.3	37.31	38.66	38.01	38.32	38.9	38.84
May	35.3	34.64	34.71	34.72	34.88	35.43	34.74
Jun	34.9	33.47	33.06	32.32	31.91	32.78	33.03
Jul	32.4	31.11	31.38	31.74	31.56	31.44	31.74
Aug	32.7	31.14	31.34	31.55	31.5	31.53	32
Sep	33.5	30.7	31.18	31.02	31.17	31.17	31.07
Oct	32.5	30.1	30.33	30.66	30.54	30.96	31.18
Nov	31.3	28.35	28.25	28.65	28.66	28.4	29.25
Dec	29.4	26.39	26.47	26.4	26.22	26.68	27.15

Table 12. Median of minimum monthly temperature (Celsius). Result from Multi-model Ensemble projection.

	Minimum monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	13.2	12.7	13.41	13.31	13.42	12.93	13.46
Feb	16.1	15.38	15.6	15.87	15.76	15.58	16.07
Mar	20.3	19.75	20.51	20.09	20.14	19.89	20.1
Apr	23.8	23.11	24.28	23.8	23.47	23.7	23.65
May	25.2	24.47	25.54	25.28	25.12	25.38	25.46
Jun	24.4	23.94	24.95	24.37	24.52	24.78	24.74
Jul	23.4	23.4	24.41	23.93	23.98	23.98	24.13
Aug	23.3	23.22	24.03	23.75	23.79	23.83	23.9
Sep	22.7	22.3	23.21	23.11	22.94	23.07	23.16
Oct	20.3	19.88	20.82	20.39	20.35	20.47	20.85
Nov	17.3	16.66	17.33	17.35	17.33	17.08	17.65
Dec	14.0	13.33	13.98	13.86	13.86	13.68	14.01

Table 13. Minimum monthly temperature (Celsius). Result from MIROC6 projection.

	Minimum monthly temperature						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	13.7	13.38	13.94	14.06	14.16	13.84	14.4
Feb	15.9	15.47	16.3	16.41	15.84	15.94	16.35
Mar	19.1	18.81	19.35	19.35	19.28	19.12	19.42
Apr	22.3	21.88	22.81	22.71	22.8	22.9	22.81
May	23.7	23.46	23.99	23.99	23.98	24.1	23.92
Jun	24.0	23.83	24.2	23.9	23.89	24.16	24.15
Jul	23.5	23.23	23.7	23.72	23.65	23.65	23.82
Aug	23.5	23.3	23.6	23.62	23.65	23.71	23.9
Sep	23.1	22.86	23.28	23.28	23.31	23.21	23.41
Oct	21.1	20.99	21.23	21.47	21.51	21.31	21.27
Nov	16.9	16.63	17.2	17.42	17.54	16.96	17.63
Dec	13.9	13.61	14.22	13.81	13.92	14.16	14.63

Table 14. Median of Cold Spell Duration Index. Result from Multi-model Ensemble projection.

Year	Scenario				
	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2023	3.52	0.38	4.86	5.24	2.8
2024	2.96	0.62	4.85	4.84	2.63
2025	2.42	1.02	4.68	4.45	2.48
2026	1.93	1.52	4.24	4.1	2.3
2027	1.52	2.03	3.52	3.8	2.08
2028	1.2	2.5	2.65	3.56	1.82
2029	0.95	2.83	1.76	3.36	1.55
2030	0.76	2.97	0.98	3.2	1.27
2031	0.63	2.82	0.43	3.08	0.99
2032	0.55	2.36	0.21	2.99	0.74
2033	0.5	1.68	0.25	2.91	0.51
2034	0.45	0.91	0.45	2.82	0.31
2035	0.4	0.18	0.73	2.7	0.15
2036	0.31	-0.37	0.99	2.52	0.04
2037	0.18	-0.65	1.14	2.28	-0.03
2038	0.03	-0.66	1.18	1.99	-0.05
2039	-0.1	-0.47	1.15	1.67	-0.04

Table 15. Cold Spell Duration Index. Result from MIROC6 projection.

Year	Scenario				
	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2023	8.96	3.75	6.09	5.5	9.72
2024	8.52	3.21	4.94	5.4	8.43
2025	7.76	2.75	4.1	5.41	7.14
2026	6.49	2.24	3.54	5.28	5.89
2027	4.7	1.65	3.29	4.88	4.73
2028	2.74	1.12	3.39	4.28	3.7
2029	0.94	0.77	3.87	3.58	2.87
2030	-0.33	0.76	4.76	2.86	2.31
2031	-0.72	1.22	6.11	2.2	2.06
2032	-0.05	2.22	7.88	1.68	2.16
2033	1.41	3.56	9.74	1.35	2.46
2034	3.26	5.01	11.34	1.23	2.81
2035	5.09	6.33	12.31	1.35	3.06
2036	6.51	7.29	12.27	1.74	3.05
2037	7.17	7.66	10.92	2.43	2.64
2038	7.14	7.51	8.54	3.3	1.91
2039	6.7	6.98	5.7	4.2	1.03

Table 16 Median of monthly rainfall (mm). Result from Multi-model Ensemble projection.

	Monthly rainfall						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	26	5	5	5	6	4	5
Feb	14	5	5	6	6	6	8
Mar	49	13	9	12	13	13	14
Apr	112	31	36	32	37	32	33
May	130	136	105	128	124	132	130
Jun	138	260	231	248	250	227	240
Jul	239	275	271	269	278	266	263
Aug	267	303	287	303	300	295	292
Sep	170	269	249	276	266	269	289
Oct	75	75	63	86	80	81	84
Nov	10	21	18	15	15	16	18
Dec	7	8	10	9	7	7	8
Annual	1238	1402	1289	1390	1383	1346	1384

Table 17 Monthly rainfall (mm). Result from CAMS-CSM1-0 projection.

	Monthly rainfall						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	26	6	4	5	6	4	5
Feb	14	4	3	2	5	2	2
Mar	49	9	13	4	5	8	3
Apr	112	33	55	22	26	27	29
May	130	146	145	124	121	125	119
Jun	138	194	207	162	183	145	137
Jul	239	231	217	221	175	204	207
Aug	267	246	242	235	213	226	179
Sep	170	159	148	101	102	96	108
Oct	75	65	52	48	33	32	45
Nov	10	45	44	19	17	11	11
Dec	7	18	14	12	4	7	8
Annual	1238	1157	1145	953	891	887	853

Table 18 Monthly rainfall (mm). Result from MIRC6 projection.

	Monthly rainfall						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	26	13	12	13	11	10	10
Feb	14	17	10	21	16	14	19
Mar	49	27	29	35	24	16	23
Apr	112	80	69	93	72	60	70
May	130	186	202	172	186	167	177
Jun	138	138	206	217	241	232	222
Jul	239	229	259	252	238	227	240
Aug	267	251	283	271	267	271	264
Sep	170	259	251	263	249	256	258
Oct	75	105	140	117	130	104	95
Nov	10	16	18	19	28	18	21
Dec	7	8	10	9	13	10	9
Annual	1238	1328	1491	1481	1475	1384	1409

Table 19 Median of maximum consecutive dry days. Result from Multi-model Ensemble projection.

	Maximum consecutive dry days						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	21.8	29.4	29.6	29.5	30.0	30.0	30.0
Feb	20.7	27.6	27.7	27.4	27.5	27.6	27.1
Mar	17.3	28.4	28.8	28.0	27.8	28.2	27.7
Apr	8.7	20.6	22.1	22.1	20.3	22.2	22.1
May	7.0	11.2	13.3	12.2	12.1	13.2	14.3
Jun	5.3	3.8	4.6	4.2	4.3	4.6	4.2
Jul	4.7	1.6	1.9	2.0	2.1	2.2	2.1
Aug	4.2	1.4	1.1	1.3	1.4	1.4	1.4
Sep	3.0	3.1	3.6	3.2	3.0	3.2	2.8
Oct	8.0	13.2	11.7	12.8	12.9	13.0	12.5
Nov	19.3	22.5	21.7	22.9	23.6	22.7	22.8
Dec	26.2	28.3	28.0	27.0	29.0	28.9	28.4

Table 20 Maximum consecutive dry days. Result from CAMS-CSM1-0 projection.

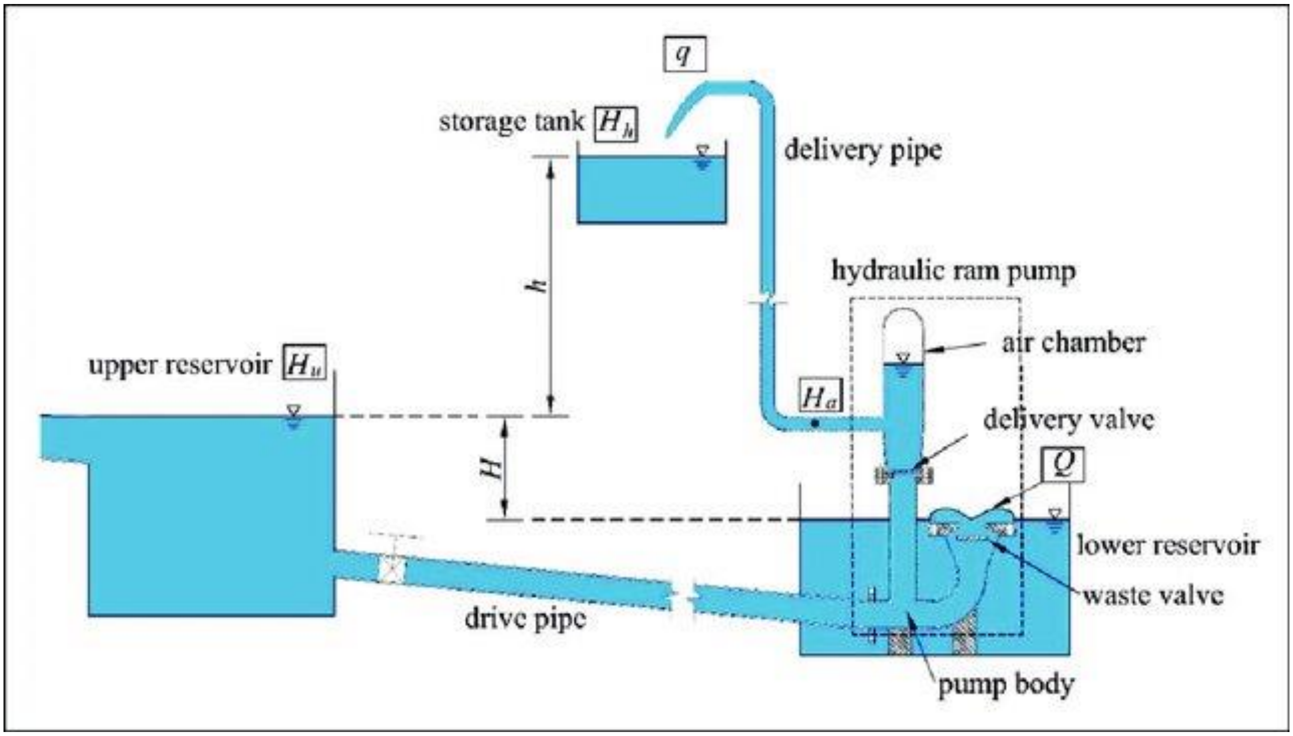
	Maximum consecutive dry days						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	21.8	29.2	30.7	30.2	30.5	30.6	30.7
Feb	20.7	27.0	27.7	27.8	27.6	28.1	28.1
Mar	17.3	30.5	29.6	30.0	30.7	30.0	30.0
Apr	8.7	27.7	25.2	27.1	25.4	25.7	26.7
May	7.0	12.4	10.1	8.5	8.2	9.1	10.9
Jun	5.3	5.2	4.6	5.3	4.5	5.2	5.1
Jul	4.7	4.0	4.0	3.7	3.7	4.4	3.8
Aug	4.2	3.7	3.2	3.5	3.9	3.3	4.0
Sep	3.0	6.5	7.0	7.6	7.7	6.9	6.4
Oct	8.0	16.2	19.4	13.5	17.0	19.1	15.5
Nov	19.3	22.9	24.9	24.7	24.4	25.5	24.6
Dec	26.2	26.9	29.2	28.3	30.8	29.9	28.3

Table 21 Maximum consecutive dry days. Result from MIROC6 projection.

	Maximum consecutive dry days						
	Recent	Reference	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Jan	21.8	27.3	27.3	27.0	29.2	29.5	28.6
Feb	20.7	24.6	25.8	23.0	26.2	24.5	24.6
Mar	17.3	20.3	23.1	20.1	24.0	27.3	20.2
Apr	8.7	14.1	11.8	12.7	14.0	16.6	14.0
May	7.0	4.7	4.9	5.1	4.7	6.1	4.6
Jun	5.3	4.8	4.4	3.9	2.9	4.0	4.2
Jul	4.7	2.0	2.1	3.1	2.5	2.7	2.6
Aug	4.2	2.4	2.1	2.0	1.9	2.6	2.6
Sep	3.0	2.3	2.3	2.3	2.3	2.8	2.1
Oct	8.0	7.0	9.0	8.3	8.4	10.9	11.5
Nov	19.3	21.9	20.5	21.1	20.5	22.8	21.7
Dec	26.2	26.0	27.5	28.2	28.8	30.1	26.6

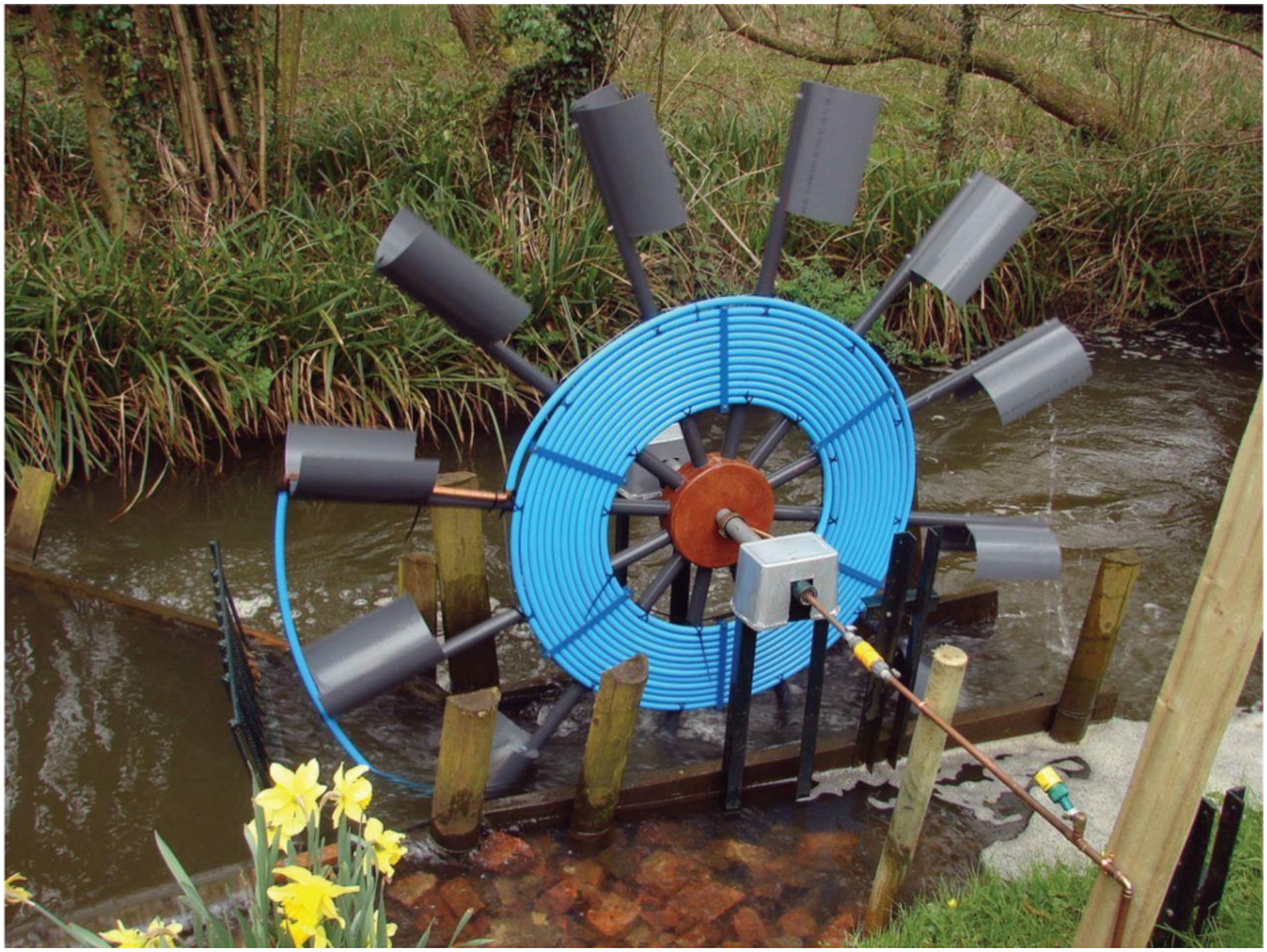
Appendix 3 Water pumping system with renewable energy

Hydraulic ram pump



Source : Guo, Xinlei *et al*. (2018). **Optimal design and performance analysis of hydraulic ram pump system**. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. 232. 095765091875676. 10.1177/0957650918756761.

Water wheel spiral pump



Source : Deane, J. and Jonathan B. 2018 **A hydrostatic model of the Wirtz pump**. Proc. R. Soc. A.47420170533 20170533 http://doi.org/10.1098/rspa.2017.0533