THAILAND'S BATTLE WITH CLIMATE CHANGE

2024

RECYGLO THAILAND

BACKING SUCCESS

RECYGLO's mission is to process materials in a safe, non-hazardous manner with an aim to keep the world environmentally clean; promoting sustainable development and implementing circular economy in order to create a more resilient future for all; helping businesses and individuals minimize their environmental impact through effective solutions.

Table of Contents

01	Introduction	1
02	Meteorological Data	2
03	Climate Change Impacts	6
04	Environmental Hazards (Case Studies)	22
05	Mitigation Strategies	28
06	Adaptation Strategies	32

EXECUTIVE SUMMARY

Thailand, located in Southeast Asia, faces significant challenges due to climate change driven by rapid economic growth and high greenhouse gas emissions. The country's tropical climate, influenced by monsoon winds, results in three distinct seasons and has seen increasing temperatures and fluctuating precipitation patterns in recent decades. These changes have led to more frequent extreme weather events such as floods, droughts, and heatwaves. Rising sea levels pose a severe risk to coastal areas, especially Bangkok, due to land subsidence. Unpredictable monsoon patterns are causing more intense rainfall and longer dry periods, while worsening air quality exacerbates health issues.

Source: Unicef Thailand

Climate change also threatens Thailand's rich biodiversity, impacting forests and marine ecosystems and causing habitat loss. The socioeconomic impacts are profound, with public health risks including heat stress, respiratory diseases, and the spread of infectious diseases. Agriculture faces challenges from altered precipitation and temperature, threatening food security, and infrastructure is at risk from floods and rising sea levels, leading to economic losses and displacement. Addressing these challenges requires comprehensive mitigation and adaptation strategies, including reducing greenhouse gas emissions through energy efficiency, renewable energy, and sustainable transportation; enhancing infrastructure resilience; improving water management; protecting coastal areas; and strengthening public health measures. Robust policies, international cooperation, and community engagement are essential for building resilience and ensuring sustainable development. Coordinated and immediate efforts are crucial to effectively address the impacts of climate change in Thailand.

"It's time to stand up and speak up. We are running out of time, and we cannot run out of action."

Christiana Figueres is widely known for her pivotal role in the United Nations Framework Convention on Climate Change (UNFCCC), particularly for her leadership as the Executive Secretary from 2010 to 2016. One of her notable speeches was during the Paris Agreement negotiations in 2015, where she passionately urged global leaders to take decisive action on climate change. Her speech emphasized the urgency of addressing climate change as a collective responsibility and highlighted the potential for transformative change through international cooperation and commitments. This speech was instrumental in shaping the agreement that emerged from the Paris climate talks.

Christiana Figueres
(Former Executive Secretary of the UNFCCC)

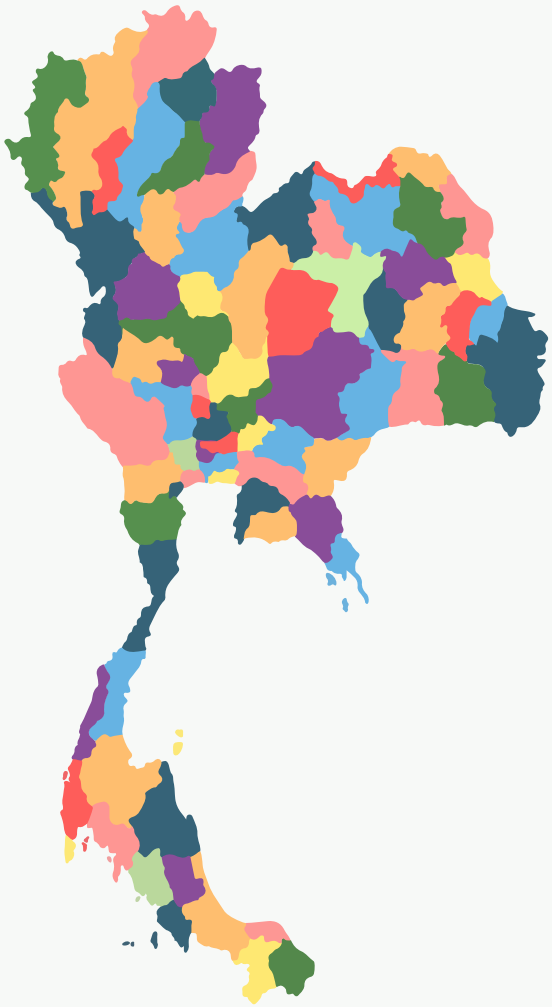
Greta Thunberg
(Climate Activist)

"I want you to act as if our house is on fire. Because it is."

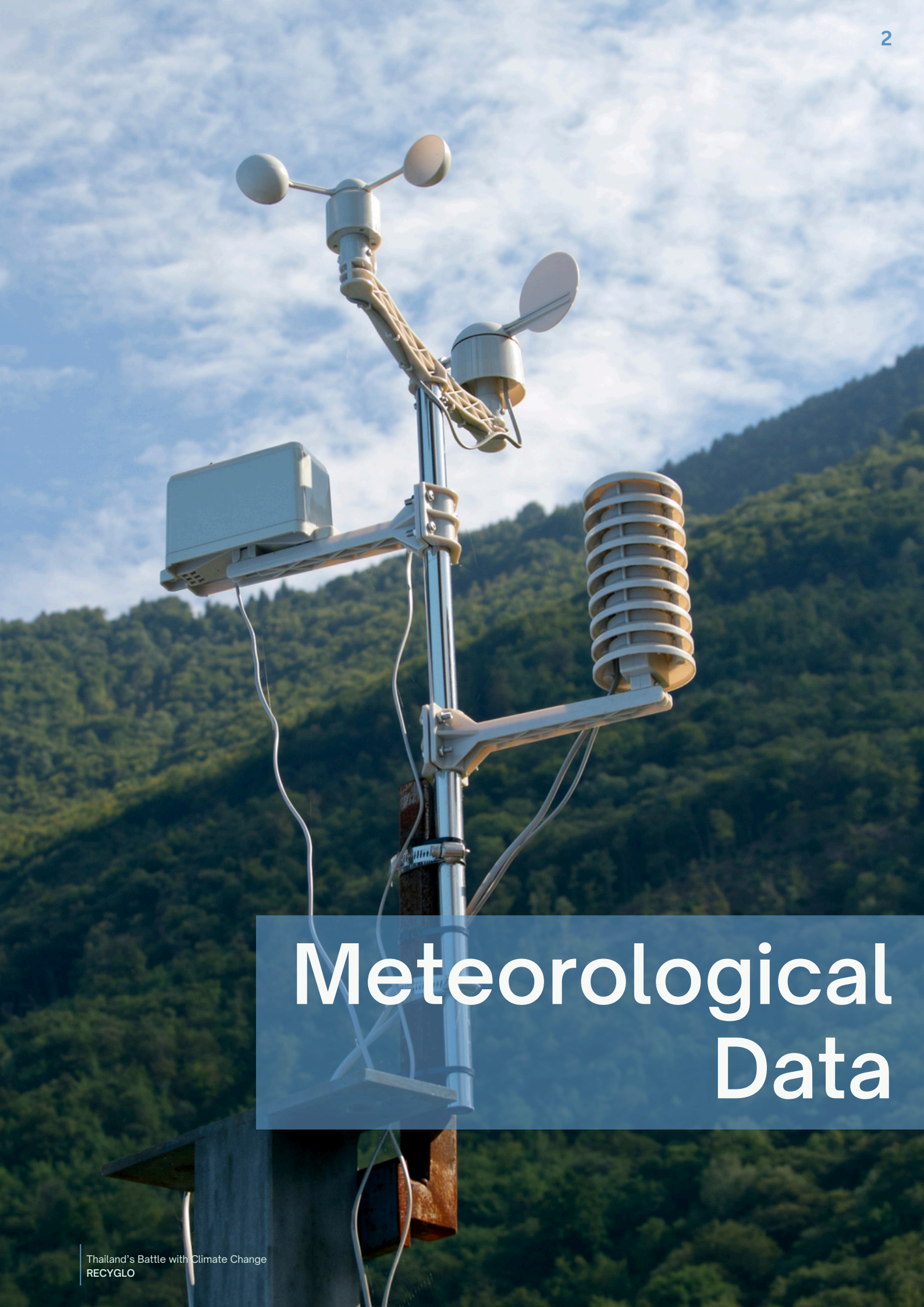
Greta Thunberg is known for her passionate advocacy for climate action, particularly through her speeches and activism. One of her remarkable speeches was delivered at the United Nations Climate Action Summit in New York in September 2019. In her powerful address, Greta Thunberg sharply criticized world leaders for their inaction on climate change, accusing them of betraying her generation by prioritizing economic growth over environmental sustainability. Her speech galvanized global attention and sparked a wave of youth-led climate strikes and protests around the world, amplifying the urgency of addressing climate change and demanding accountability from political leaders and policymakers.

Introduction

The Kingdom of Thailand, located in Southeast Asia, spans an area of 513,115 square kilometers. The country is divided into five regions: Central, North, Northeast, East, and South, comprising a total of 77 provinces [1]. Bangkok, the capital city, is a major urban center with a rapidly growing population of over 71 million people and this rapid economic expansion has led to a significant release of greenhouse gases (GHGs) into the atmosphere, contributing substantially to climate change. According to the International Energy Agency (IEA), Thailand ranked 23rd in GHG emissions in 2018 and Our World in Data (2020) also reported that Thailand's carbon dioxide (CO2) emissions from energy generation amounted to approximately 257.77 million tons [2].



Thailand is highly vulnerable to climate variability and change, facing increasing natural hazards such as heavy rainfall, floods, droughts, and sea level rise, which impact the country's coasts [3]. Given these challenges, it is crucial to address Thailand's environmental impact and implement strategies for mitigation and adaptation to combat the effects of climate change.



Meteorological Data

Overview

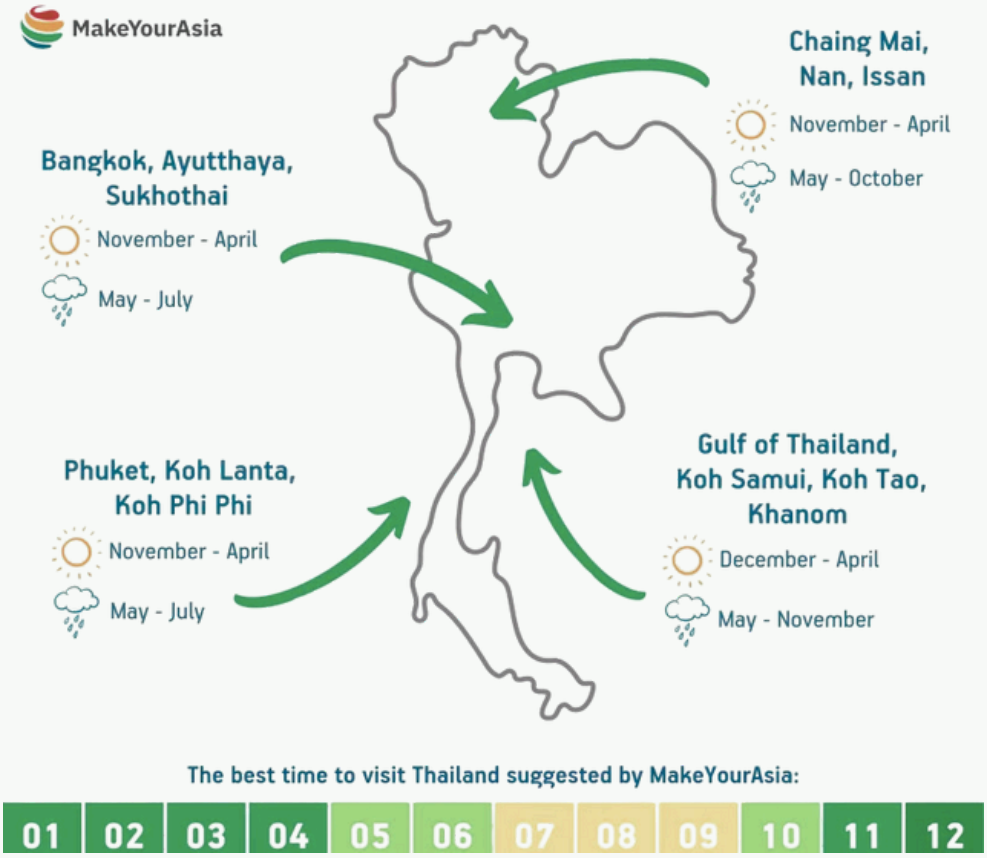


Fig. 1. Overview of weather in Thailand
(Source: MakeYourAsia)

Thailand lies entirely between the equator and the Tropic of Cancer and has a tropical climate influenced by seasonal monsoon winds, resulting in three distinct seasons: the rainy season, winter, and summer.

The rainy season, influenced by the southwest monsoon, spans from mid-May to mid-October, bringing abundant rainfall throughout the country, with the peak wet period occurring between August and September. However, the east coast of Southern Thailand experiences continued heavy rain until the end of the year [4]. Winter, or the northeast monsoon season, lasts from mid-October to mid-February. This period is generally mild and can become cool in December and January, particularly in northern Thailand. The east coast of Southern Thailand receives significant rainfall during October and November. Summer, or the pre-monsoon season, occurs from mid-February to mid-May, marking the transition from the northeast to the southwest monsoons. This season is characterized by warmer weather, especially in upper Thailand, with April being the hottest month when temperatures frequently exceed 40°C [1].

1 Temperature

Data from 2012 to 2021 show that Thailand experienced its highest temperatures in decades, with a notable peak of 44.6°C in April 2016 in Mae Hong Son. From 1981 to 1990, temperatures increased by 0.33°C per decade, slowing to 0.16°C and 0.14°C in the following decades. The average temperature rose by 0.09°C annually from 2011 to 2021. The mean maximum temperature was 33.7°C in 2020 and 33.0°C in 2021, while the mean minimum was 23.5°C in 2020 and 23.2°C in 2021. The annual mean temperatures were 28.0°C and 27.5°C for 2020 and 2021, respectively.

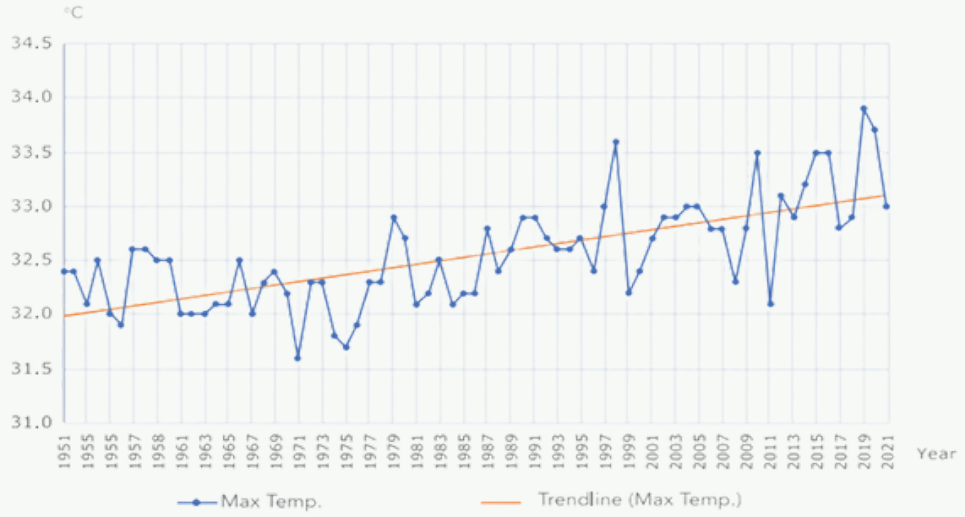


Fig. 2. Annual mean maximum temperature in Thailand (°C)

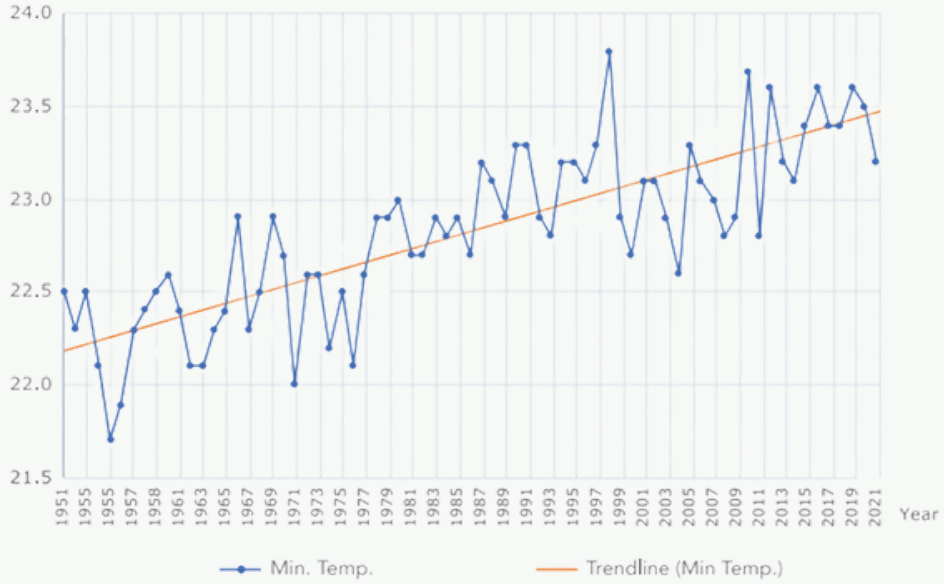


Fig. 3. Annual mean minimum temperature in Thailand (°C)

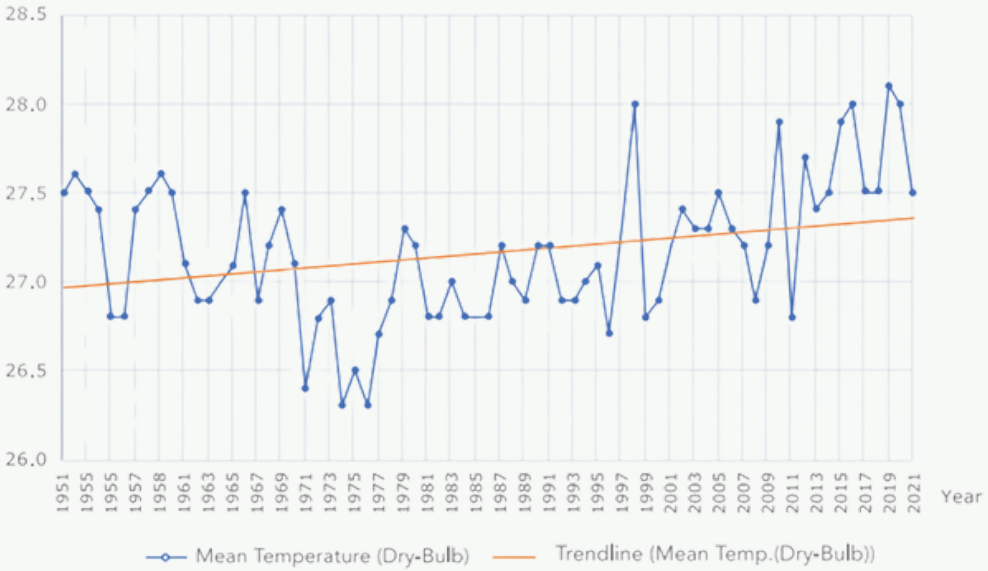


Fig. 4. Annual mean temperature in Thailand (°C)

2 Precipiation

Reports from the Thai Meteorological Department show that rainfall and rainy days have varied significantly over time. From 2015 to 2021, rainfall fluctuated, with 2019 recording the lowest rainfall in 40 years (1,343.4 mm), and 2017 the highest since 1951 (2,017 mm). In 2020 and 2021, annual rainfall was 1,528.8 mm and 1,759.3 mm, respectively. Notably, August and September mark the peak of rainy seasons, often resulting in floods. There's a distinct disparity in rainfall between Thailand's southern peninsula and its northern regions. During the southwest monsoon, the west coast of southern Thailand receives its heaviest rainfall in September, while the east coast experiences its peak in November. Significant rainfall persists until January with the onset of the northeast monsoon.

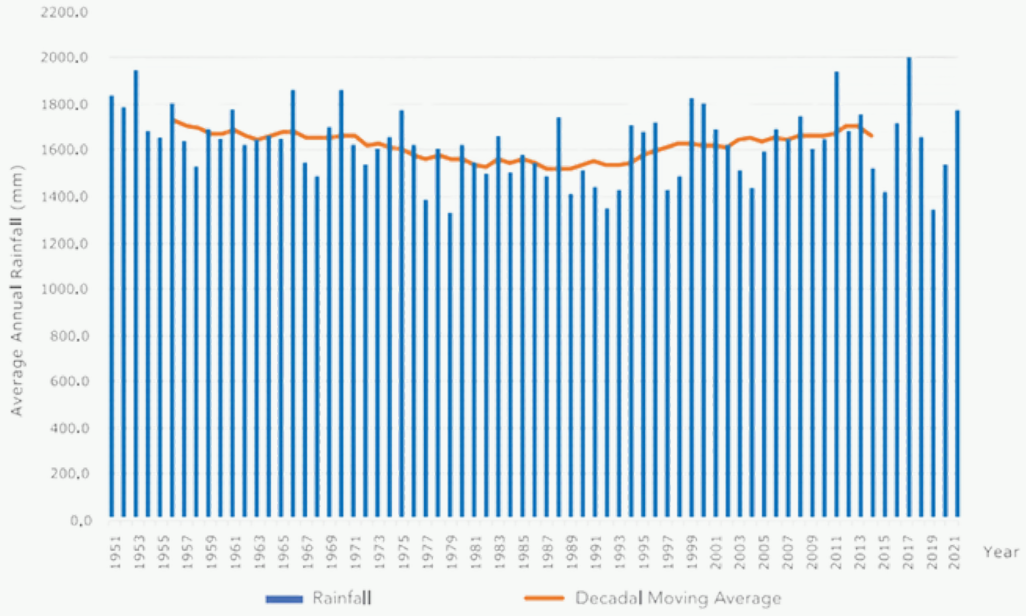


Fig. 5. Annual mean rainfall in Thailand (mm)

Climate Change Impacts

Thailand has been ranked ninth among the countries most affected by climate change over the last 20 years (2000-2019), according to the Global Climate Risk Index 2021 (CRI) [5]. This ranking reflects the severe human and economic consequences the country has faced due to numerous mega natural disasters. Increasing temperatures, changing precipitation patterns, increases in the frequency and intensity of extreme events, and sea level rise are expected to affect all sectors, including tourism, public health, and natural resource management.

1 Weather

Climate change significantly impacts weather conditions in Thailand by causing higher average temperatures and more frequent heatwaves, altering rainfall patterns with increased intensity and unpredictable monsoons, and raising sea levels that lead to coastal flooding and erosion. Additionally, the frequency and intensity of extreme weather events, such as storms and typhoons, will increase, resulting in more severe flooding and landslides.

Fig. 6. Effects of climate change on weather

(a) Temperature

Based on the baseline data of average yearly temperatures in Thailand, it is evident that temperatures have risen consistently over the ye5ars. This increase is primarily attributed to higher levels of greenhouse gases (GHGs) present in the atmosphere. GHGs arise from direct emissions such as CO2, CH4, and N2O, as well as indirect emissions like NOX, CO, NMVOCs, and SO2. Thailand's overall GHG emissions climbed from 245,899.56 GgCO2eq in 2000 to 372,716.86 GgCO2eq in 2019, marking an average annual rise of 2.21%. During the period from 2000 to 2019, the energy sector emerged as the leading contributor to GHG emissions, experiencing a 57.96% increase from 165,092.40 GgCO2eq in 2000 to 260,772.69 GgCO2eq in 2019. Initially constituting 67.14% of total emissions, the energy sector's share grew to 69.96% by 2019 [6].

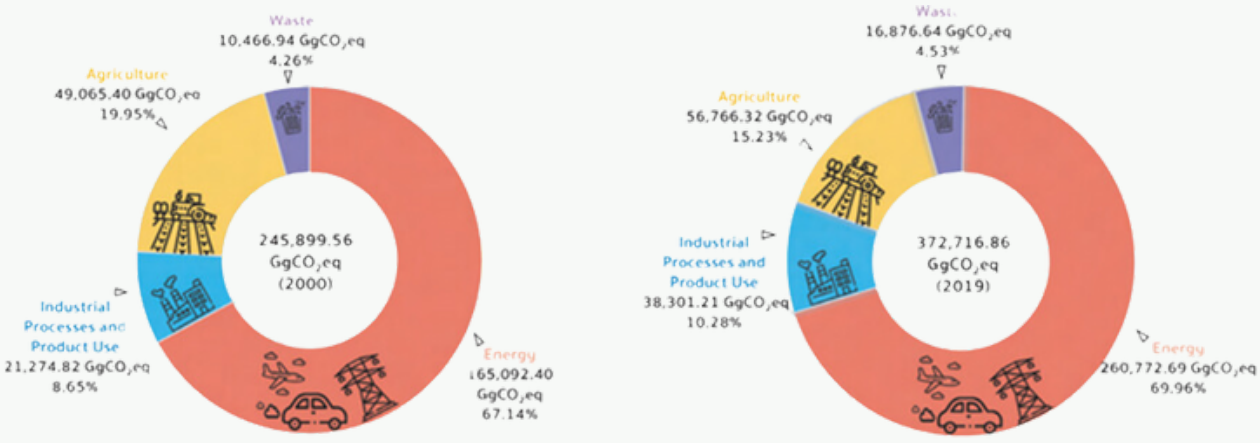


Fig. 7. Total GHG emissions by sector in 2000 and 2019

As of 2024, Thailand is grappling with a severe heat wave, leading to record-breaking temperatures across the nation. In April, over three dozen districts reported unprecedented highs, breaking records some of which date back to 1958. The highest temperature this year was recorded in Lampang at 44.2°C, nearing the national record of 44.6°C [7]. Using different greenhouse gas emission scenarios and climate models that consider past changes, it is projected that the average surface air temperature in Thailand could increase by up to 4°C by the end of the century [8].

(b) Sea Level

Global warming is causing global mean sea levels to rise in two primary ways. Firstly, the melting of glaciers and ice sheets worldwide is adding water to the ocean and secondly, as ocean water warms, it expands in volume. Since 1880, the global average sea level has risen by 8-9 inches as shown in Figure 8 [9].

Sea-level rise is one of the most significant effects of climate change and poses a major threat to Thailand. The country is experiencing significant impacts on its coastal regions due to rising sea levels. A 2013 study found that relative sea level rise in the Gulf of Thailand ranged from 1.4 to 12.7 mm per year between 1985 and 2009, with land subsidence at river mouths being the largest contributing factor [10].

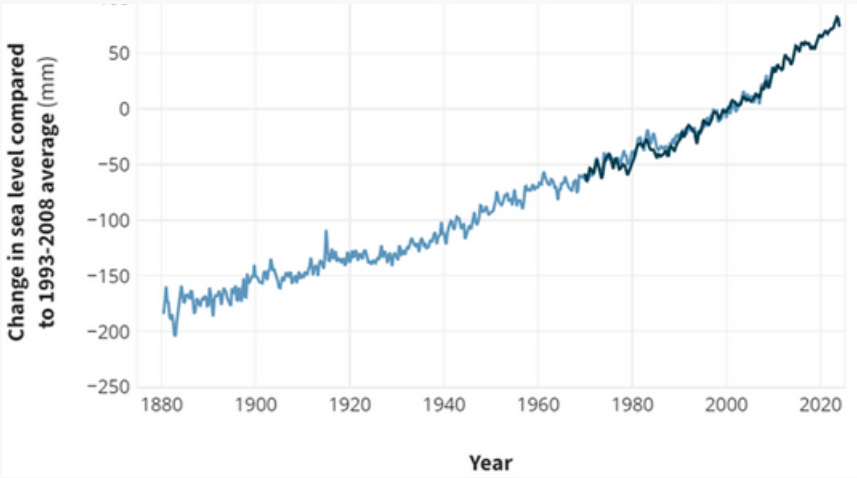


Fig. 8. Satellite data of global sea level (Source: NASA)

The Thai Office of Natural Resources and Environment Policy and Planning predicts that sea levels will rise by one meter over the next 40 to 100 years, potentially impacting at least 3,200 square kilometers of coastal land. Bangkok, situated on the Chao Phraya River delta in Thailand's central plain, is a low-lying city with an average elevation of 1.5 metres above sea level. Additionally, the city faces subsidence of the ground at a rate of approximately 3 cm per year. This issue is worsened by Bangkok's location on a soft clay alluvial plain, excessive extraction of groundwater, and the weight of large buildings. According to Thailand's National Reform Council, without urgent action, Bangkok could be underwater by 2030 due to the combined effects of rising sea levels, groundwater extraction, and the weight of city infrastructure [7]. Earth.Org has simulated significant flooding compounded by rising sea levels by 2100 to emphasize the urgency for action [11].

(c) Rainfall Patterns

Climate change alters traditional monsoon patterns, affecting Thailand's rainy seasons' timing and duration. As global temperatures rise, increased evaporation rates lead to greater atmospheric moisture content. This results in more frequent and intense rainfall events. Additionally, shifts in atmospheric circulation patterns caused by climate change alter how and where rainfall is distributed across the country. These changes collectively contribute to the unpredictability and variability of Thailand's future rainfall patterns.

A 2016 study by Atsamon [12] found that although there are fewer precipitation events across the country, these events have become more intense due to climate change. This change is caused by shifts in atmospheric circulation patterns, which lead to fewer overall precipitation events. However, when it does rain, the accumulated moisture results in much heavier rainfall. These shifts in atmospheric patterns also create longer dry periods with little to no rainfall, leading to dry conditions. The higher temperatures associated with climate change exacerbate these dry spells. When rain finally occurs after these dry periods, it tends to be much more intense and heavy. This pattern has resulted in more extreme precipitation events overall. Consequently, while the number of days with rain has decreased, the intensity of the rainfall on those days has increased. The graphs below illustrate this relationship, showing how the number of annual rainy days has declined while precipitation extremes have become more common. This demonstrates the impact of climate change on the frequency and intensity of rainfall events.

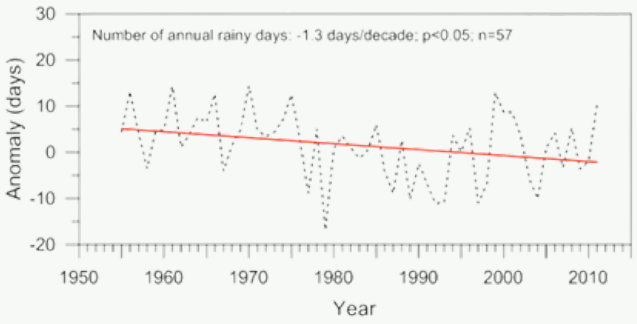


Fig. 9. Number of annual rainy days

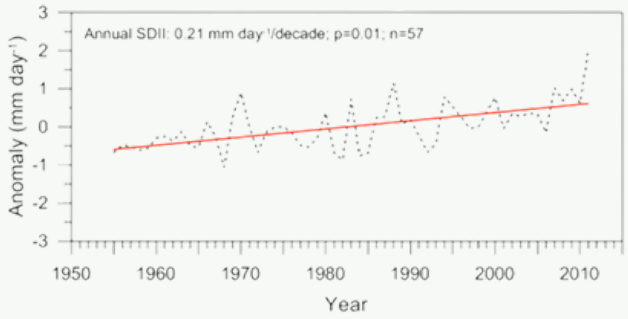


Fig. 10. Trends in precipitation extremes

2 Air Quality

Air pollution contributes to climate change, which in turn affects air quality. As the climate warms, air quality is expected to decline, with increased heat and sunlight raising ozone levels. Greenhouse gases like methane and carbon dioxide drive climate change. Ground-level ozone forms more efficiently in sunny, hot weather, reaching dangerous levels during summer and heat waves. Heat waves worsen air quality by increasing ozone and particulate pollution, as extreme heat and stagnant air trap pollutants. Droughts often accompany heat waves, leading to more frequent forest fires that release carbon monoxide and particulates, further degrading air quality. Climate change also alters atmospheric circulation, leading to more frequent stagnant air conditions that prevent the dispersion of pollutants, increasing ground-level particulate matter and ozone concentrations. Reduced rainfall in some regions exacerbates this by allowing pollutants to accumulate.

As of 2018, a network of 63 monitoring stations was established across the country: 28 in central Thailand, including the capital, Bangkok; 15 in the North, which is affected by haze from open burning; 11 in the East, a significant industrial area; 6 in the South, impacted by transboundary haze; and 3 in the North-East, a crucial agricultural region [13]. In 2020, overall air quality improved compared to 2019. Specifically, the annual average PM2.5 concentration was 23 micrograms per cubic meter (µg/m3), an 8% decrease from 2019 and PM10 levels were 43 µg/m3, reflecting a 9% reduction. The highest 8-hour average ozone concentration was 81 µg/m3, an 11% decrease from 2019. However, the Northern provinces experienced a slightly worse situation than in 2019, with 112 days where particulate matter exceeded the standard. The highest 24-hour average PM2.5 level reached 366 µg/m3, a 4% increase from 2019, primarily due to agricultural burning and dry weather conditions that facilitated forest fires [6].

It is projected that residents in Thailand will be exposed to an annual average PM2.5 concentration of 21.4 µg/m3, nearly double the World Health Organization's (WHO) target of 10 µg/m3 [14]. The following table illustrates PM2.5, PM10, and ozone levels in Bangkok, showing that these pollutants are higher in the summer, particularly PM2.5.

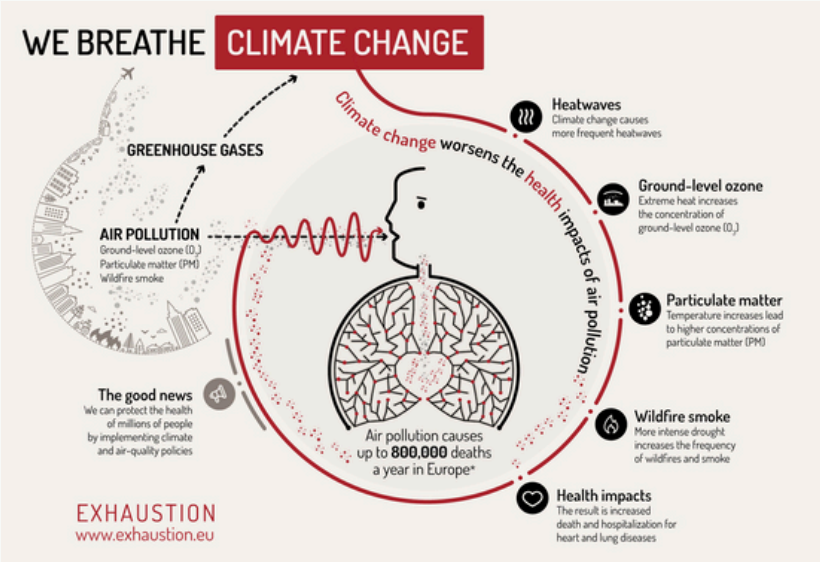
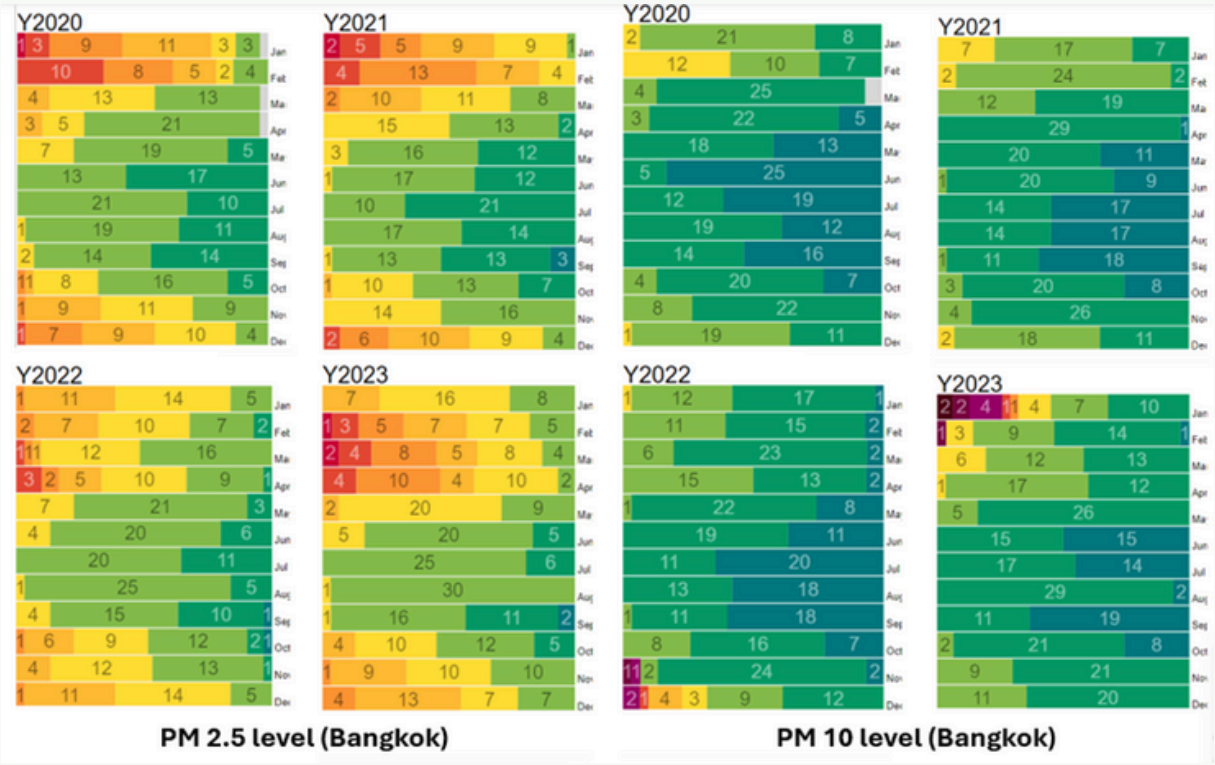


Fig. 11. Effects of climate change on human health (Source: Exhaustion.eu)



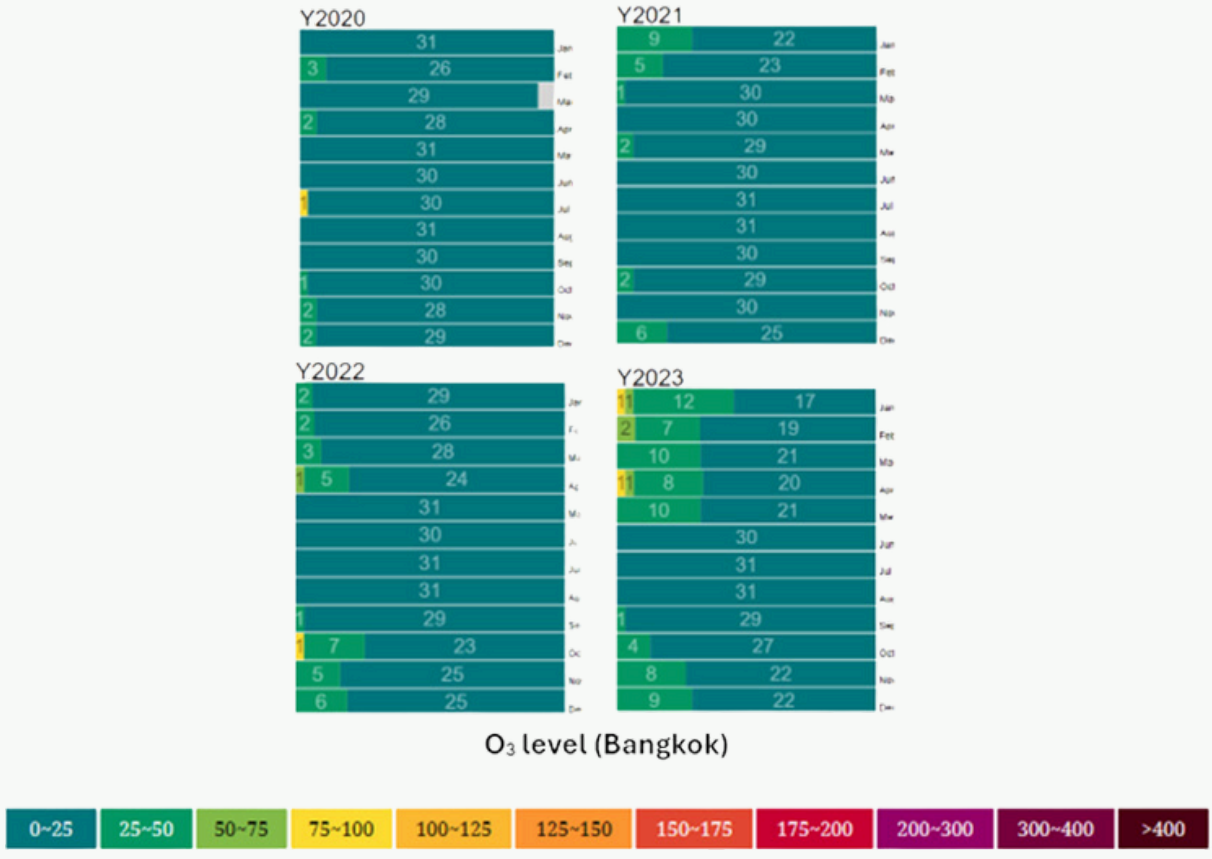


Fig. 12. Pollutants level in Bangkok
(Source: AQI)

3 Biodiversity

Thailand is renowned for its high species richness in both flora and fauna. Despite once boasting high biodiversity, much of it has been lost over time. Currently, Thailand ranks 16th globally in biodiversity, according to the World Conservation Monitoring Centre (WCMC) in 2004, considering species of amphibians, birds, reptiles, mammals, and vascular plants. Forests are a crucial ecosystem in Thailand. Historically, forests covered 53.33% of the country's area. However, this coverage rapidly declined, and by 1989, forested areas had dwindled to just 27.95%, prompting the cancellation of all forest concessions. Tropical forests, such as those in Thailand, are globally recognized as biodiversity hotspots, providing vital habitats for numerous species of fauna and flora and playing a significant role in global climate regulation [15].

Tropical forests are highly vulnerable to climate change, facing threats such as increased temperatures and altered rainfall patterns. Global climate models predict rising temperatures across tropical regions, along with greater rainfall variability and more frequent extreme events like droughts and wildfires. These changing climatic conditions are expected to cause shifts in ecosystems, species distributions, and species compositions. The extent of these impacts will vary based on the specific responses of ecosystems and their constituent species. One of the research papers has assessed the potential impacts of climate change on species in protected areas where spatial distribution modeling has been employed for 866 vertebrates and 591 plant species. Projections indicate that by 2070, most mammals, birds, and plants will experience declines, while most amphibians and reptiles are expected to increase. Overall, 54% of the modeled species will be threatened, and 11 species will face national extinction by 2070 [16].

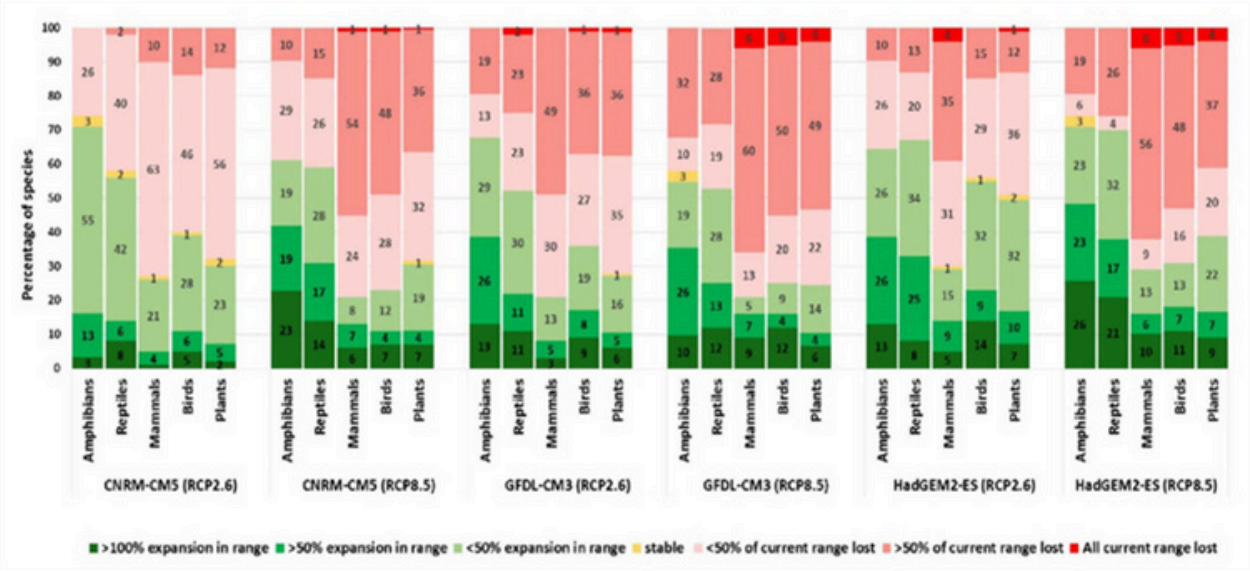


Fig. 13. Projected changes in suitable habitat by 2070

The changes in atmospheric conditions in 1991, 1995, and 1998 has also caused severe coral reef bleaching in the Andaman Sea. Additionally, during the 1997-1998 ENSO (El Niño and La Niña) events, significant coral reef bleaching occurred in the Gulf of Thailand, with some areas experiencing over 60% damage, a situation that continues to worsen.

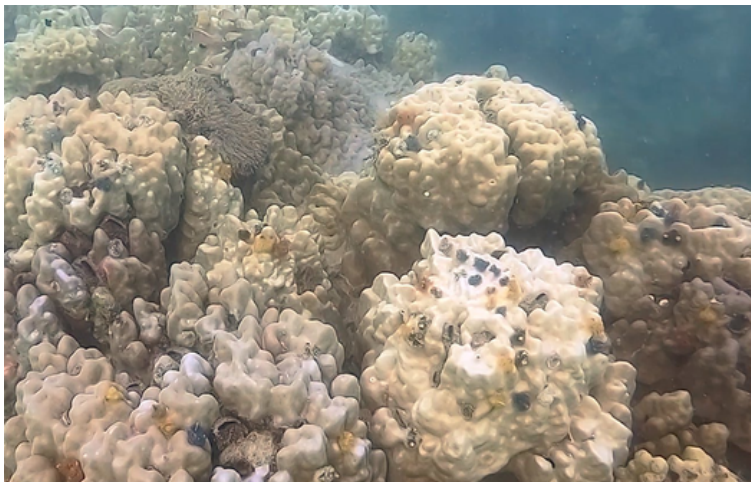


Fig. 14. Coral reef bleaching in Koh Tao

In 2010, a survey by the Department of Marine and Coastal Resources found that coral reef bleaching in Thai waters was caused by rising water temperatures, which typically range between 28-29 degrees Celsius. The degradation of coral reefs, which serve as habitats for many marine species, has substantial repercussions for the fishing industry, tourism, the economy, local lifestyles, and coastal protection.

The loss of biodiversity impacts the lifestyle, well-being, and food security of Thai people. It also diminishes the natural beauty, public happiness, and tourism, disrupting the natural balance. Furthermore, a compromised ecological system is less resilient to disasters, making the consequences harder to predict and manage [15].

4 Public Health

Climate change influences health through various means, including air quality, outdoor physical activity, nutrition quality and quantity, water quality and availability, sanitation in households and communities, health facilities and medical services, and overall physical safety and security.

There are three main pathways through which climate change affects health [8]:

1. **Direct Impacts:** These arise from changes in the frequency and intensity of extreme weather events, such as heatwaves, droughts, and heavy rainfall.
2. **Natural System Mediation:** Climate change affects natural systems, resulting in health impacts from disease vectors, waterborne diseases, and air pollution.
3. **Human System Mediation:** Climate change impacts human systems, leading to occupational health issues, undernutrition, and increased mental stress.

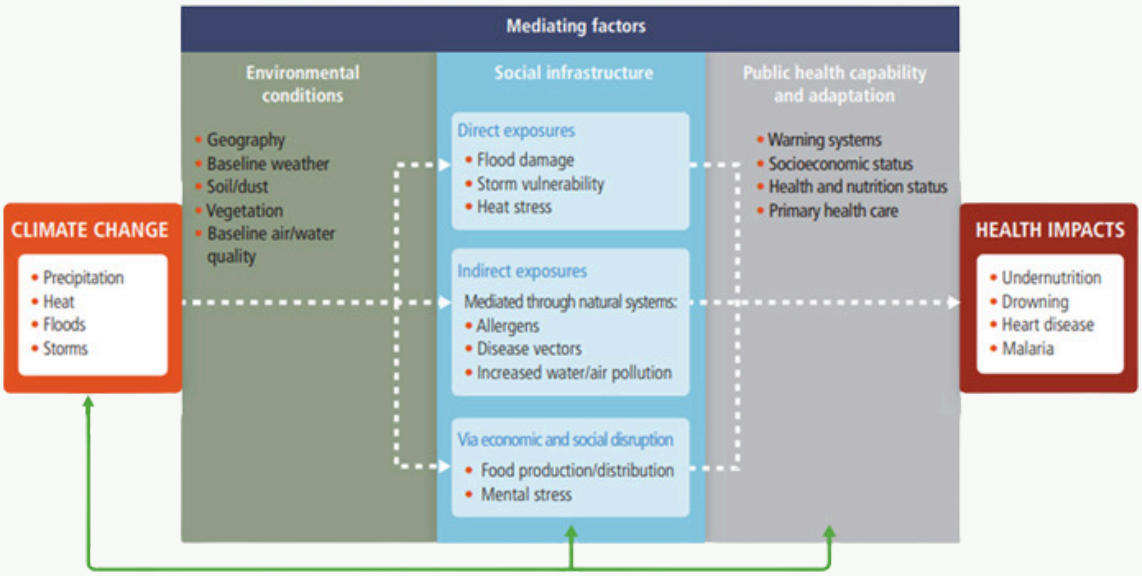


Fig. 15. Diagram showing the exposure pathways by which climate change affects health (Source: Smith et al.)

In Thailand, various health outcomes are influenced by fluctuations in temperature and precipitation. These include injuries, illnesses, and fatalities related to:

- Floods, cyclones and droughts
- High ambient temperature
- Air quality: respiratory diseases associated with air pollution
- Infectious diseases (eg. malaria, dengue)
- Food security: undernutrition

(a) Floods, cyclones and droughts

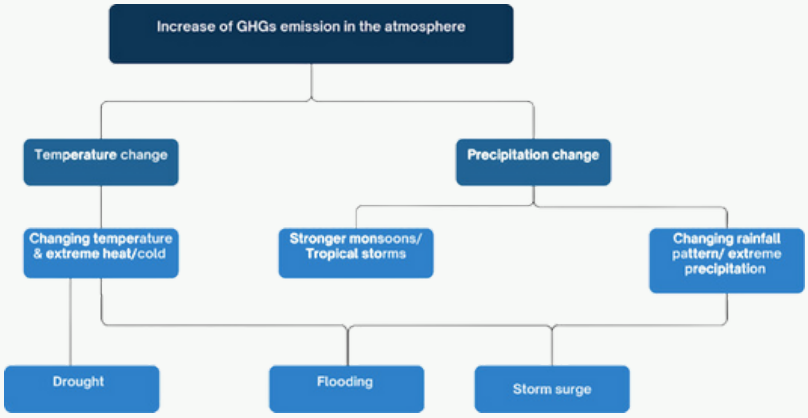


Fig. 16. Occurrence of floods, cyclone and drought due to climate change

Thailand ranks 16th globally in terms of vulnerability to climate-related hazards. Specifically, it is ranked 73rd for cyclones, 35th for drought, and 20th for floods [8]. Flooding poses a particularly significant risk to Thailand due to its geographic and climatic conditions, frequently resulting in severe events that impact infrastructure, agriculture, and communities. Floods can cause injuries and fatalities, disrupt healthcare services, and hinder access to medical care.

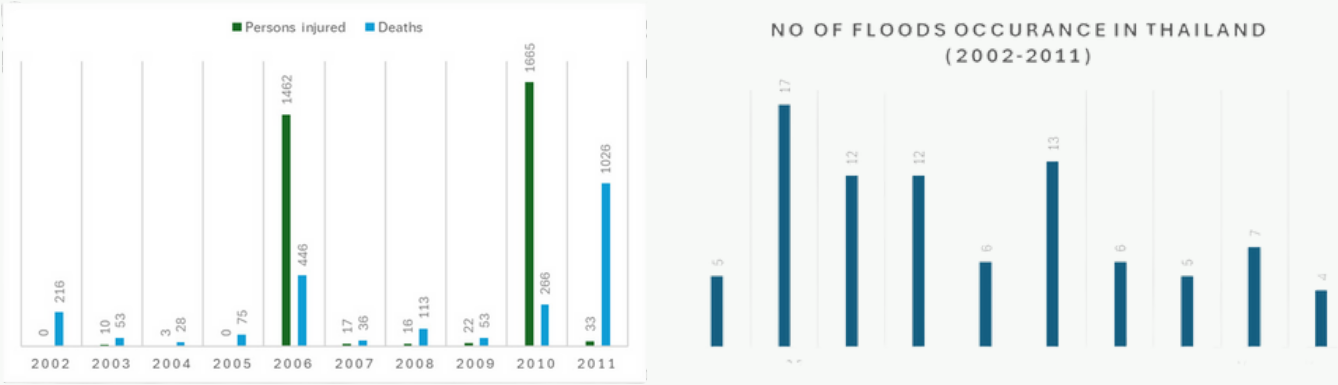


Fig. 17. Flooding statistics in Thailand from 2002 to 2011

National level climate modeling was carried out to list the number of several provinces in Thailand which are prone to floods and drought in the future (2016-2035) [5].

Risk areas to floods	**Bangkok, Nakhon Ratchasima, Ubon Ratchathani, Nakhon Sawan, Chiang Mai, Khon Kaen, Chiang Rai, Chaiyaphum, Buri Ram, and Phitsanulok**
Risk areas to drought	**Bangkok, Nakhon Ratchasima, Ubon Ratchathani, Khon Kaen, Buri Ram, Si Sa Ket, Roi Et, Surin, Maha Sarakham, and Chaiyaphum**

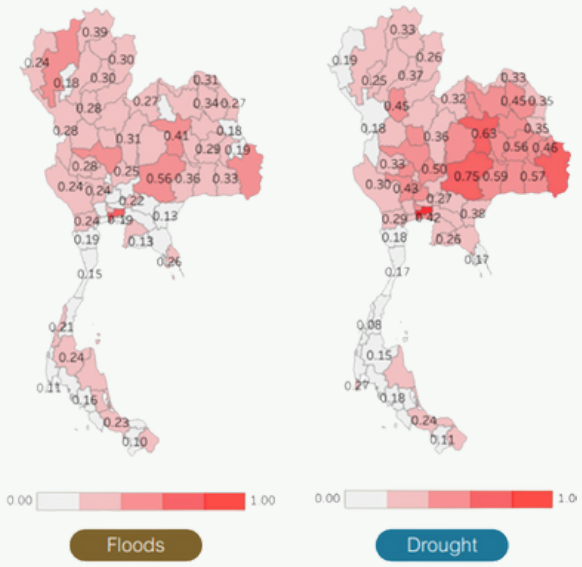


Fig. 18. Risk areas for public health sector due to floods and droughts during 2016 to 2035

(b) High and low ambient temperatures

The consequences of rising global temperatures and climate change include more frequent occurrences of heat stress, heat waves, and intensified urban heat islands (UHI) [17]. Over the decades, the annual mean temperature has shown an upward trend: between 1981-1990, temperatures increased by 0.33°C, followed by increments of 0.16°C per decade in 1991-2000 and 0.145°C in 2001-2010. From 2011 to 2021, Thailand experienced an average annual temperature rise of 0.09°C, with a peak of 44.2°C recorded in Lampang, nearing the national record of 44.6°C set the previous year [7].

These temperature increases have adverse effects on human health, ranging from reduced well-being to heightened occurrences of heat-related illnesses and fatalities. Heat stress significantly impacts daily human activities, with excessive heat exposure during routine tasks leading to health issues such as heat exhaustion, heat strokes, and heat cramps. Elevated ambient temperatures pose a dual health risk: increased morbidity and mortality across the general population due to extreme temperatures, and reduced productivity resulting from occupational heat exposure. Furthermore, heat stress affects mental health by inducing mood changes and physiological distress [17].

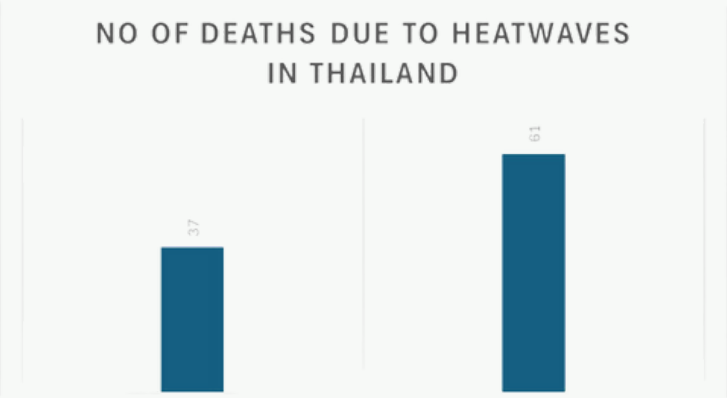


Fig. 19. Deaths due to heatwaves in Thailand.

According to projections, heat-related deaths are expected to rise by 14-29%, with the highest rates anticipated in the Central region. This increase is offset somewhat by a projected decrease in cold-related deaths, resulting in a net rise of 5-13% overall [8]. In 2024, the Ministry of Health reported 61 deaths attributed to heat stroke since the year began, a notable increase compared to the 37 deaths recorded throughout the entirety of 2023 [18].

(c) Air quality: respiratory diseases associated with air pollution

Climate change has the potential to influence local and regional air quality through various mechanisms, including altering chemical reaction rates, boundary layer heights affecting vertical mixing of pollutants, and synoptic airflow patterns that govern pollutant transport [19]. These changes can lead to fluctuations in pollutant concentrations, posing significant concerns for human health, especially given the already high levels of air pollution. Elevated levels of particulate matter (PM), specifically PM with diameters less than 10 $\mu g/m^3$ (PM10) and 2.5 $\mu g/m^3$ (PM2.5), as well as ozone (O3), are linked to numerous adverse health outcomes. Higher concentrations of PM2.5 are associated with an increased risk of lung cancer, cardiopulmonary diseases, and overall mortality. Similarly, elevated O3 levels correlate with a higher incidence of cardiovascular and respiratory issues, as well as increased overall mortality.

The health effects of air pollutants depend on the extent of exposure. Exposure refers to the amount of a chemical that enters the body through inhalation, dermal contact, or ingestion, crosses biological membranes (like the lung epithelium, skin, or gut epithelium), enters the bloodstream either in its original or metabolized form, reaches target tissues, and triggers early biological effects. If these effects are not mitigated, they can develop into diseases. According to the 2018 air quality assessment report for Thailand, data from monitoring stations in five representative provinces—Chiang Mai (north), Khon Kaen (northeast), Rayong (east), Saraburi (central), and Songkhla (south)—highlight the following pollutants of concern: PM2.5, PM10, and ozone. The following charts show the number of patients admitted due to PM 2.5, PM 10 and ozone in all district hospitals [13].

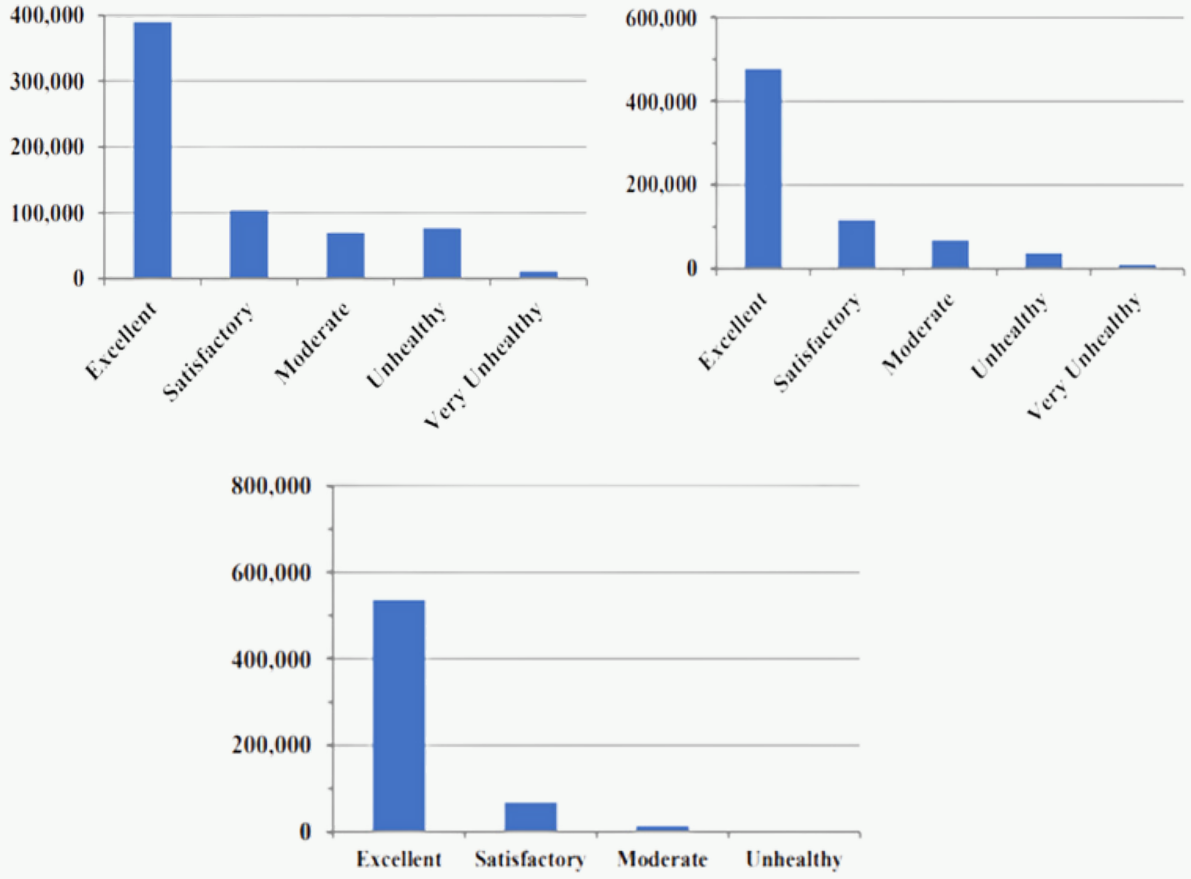


Fig. 20. Number of patients by PM and ozone classification in all districts

The number of days exceeding national PM2.5 standards was highest in Saraburi, followed closely by Chiang Mai, and lowest in Songkhla. Saraburi also had the highest number of days exceeding national PM10 standards, followed by Chiang Mai, with the fewest exceedances in Songkhla. The number of days exceeding national ozone standards was highest in Songkhla, while Chiang Mai and Saraburi did not exceed the national standards for ozone.

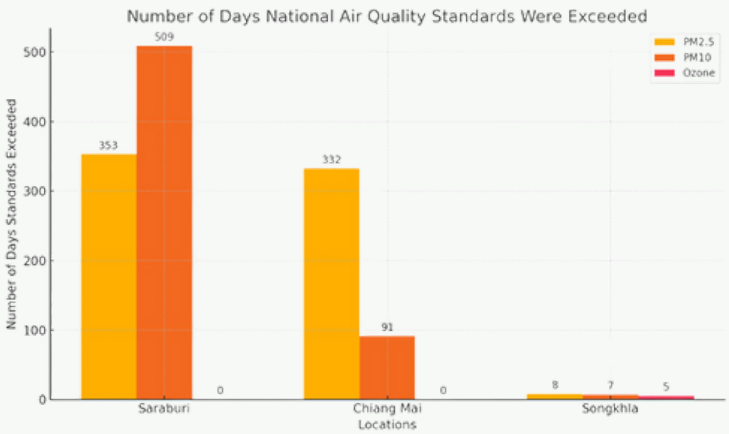


Figure 21– Number of days air quality has exceeded NAQS

(d) Infectious diseases

Climate change projections indicate an increase in infectious and vector-borne diseases in Thailand. Hydrological changes may also enhance disease transmission. Temperature, precipitation, and other weather variables influence the geographic range, seasonality, and intensity of many vector-borne diseases. The location and activity of vectors depend largely on temperature and the availability of water for breeding sites. Pathogen replication rates are generally temperature-dependent, though the relationship is typically nonlinear. Climate-sensitive vector-borne diseases important for Thailand include malaria and dengue.

From 2012 to 2021, data on vector-borne diseases in Thailand showed a decline in morbidity and mortality from dengue fever, peaking in 2013. The highest death toll from dengue fever was in the Northern region, followed by the Central Plain (excluding Bangkok), the Northeastern region, and the Southern region. Malaria morbidity and mortality also decreased over the same period. Most malaria cases were in the Northern region, followed by the Central Plain (excluding Bangkok), and the Southern region (Strategy and Planning Division, Ministry of Public Health, 2023) [5].

Thailand is now considered a malaria low-endemic country. Malaria transmission in the Central Plain areas has been eliminated, persisting only in forested regions, particularly along international borders. Climate change could influence malaria transmission by affecting temperature, precipitation, and humidity, which could alter seasonal patterns. Malaria transmission peaks during the rainy season and drops significantly during the dry season when temperatures are low. However, warmer temperatures during the dry season, given sufficient water for breeding, could extend the transmission season [8].

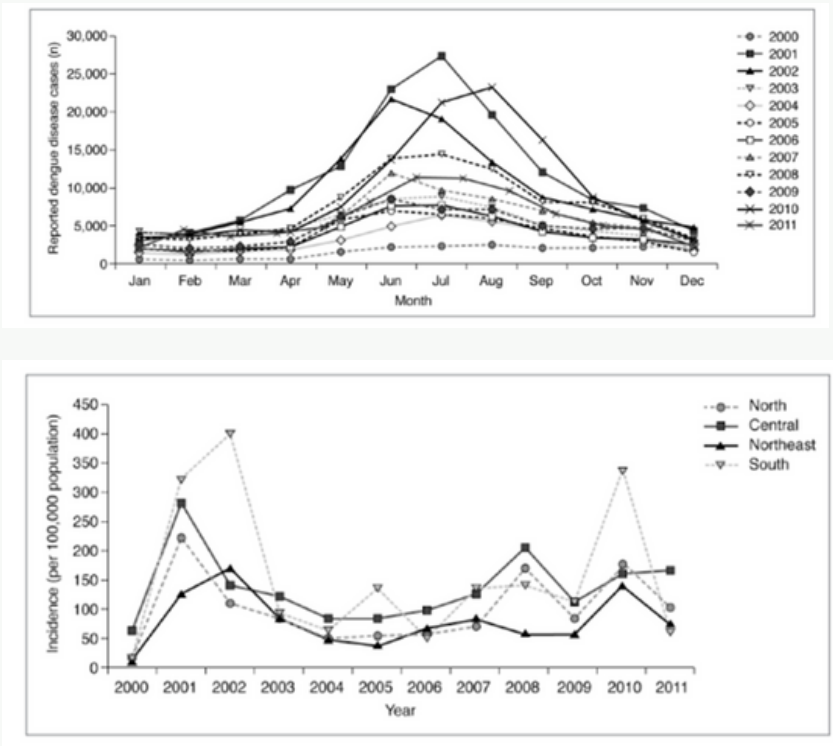


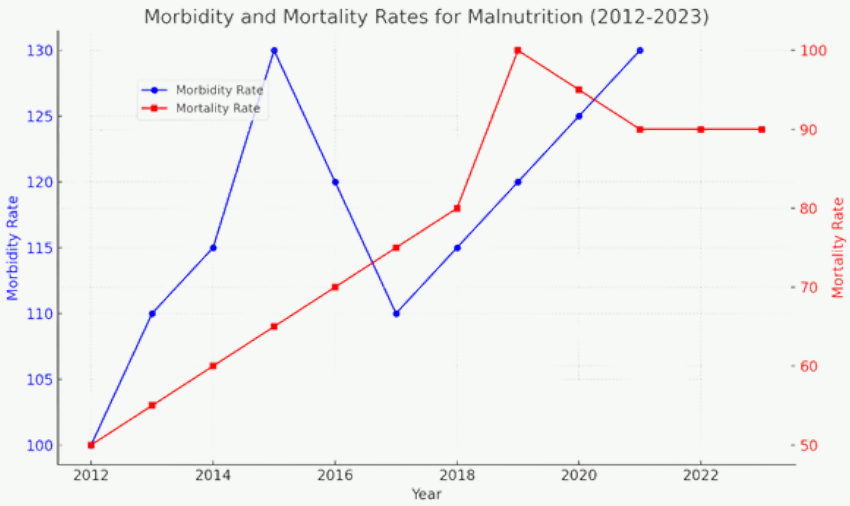
Fig. 22. Seasonality of dengue in Thailand and regional variations

Dengue is the fastest-spreading mosquito-borne viral disease, with a 30-fold increase in global incidence over the past 50 years (WHO 2013). Temperature and precipitation are critical for mosquito breeding and survival. Warm, humid conditions increase the survival and biting rates of Aedes aegypti, the primary vector. Both heavy rainfall and drought can increase dengue incidence if households store water in containers that serve as mosquito breeding sites. The following graphs in Figure 24 illustrate the clear seasonality of dengue in Thailand and regional variations [8].

(e) Malnutrition

Climate change is anticipated to adversely affect food security in numerous regions. The consequences of climate change are projected to be substantial for food security. Increasing temperatures, extreme weather events, and alterations in growing seasons can diminish agricultural productivity by stressing plants, damaging crops, and disrupting farming cycles. Variations in precipitation patterns can result in either water scarcity or excess, which in turn impacts both crop growth and livestock productivity. Soil erosion and changes in moisture levels further jeopardize soil health and crop yields.

Moreover, warmer temperatures may widen the habitat range of agricultural pests and diseases, heightening risks to crops and livestock. Extreme weather events can interfere with food supply chains, while higher temperatures may cause increased food spoilage and waste. Fisheries and aquaculture are also threatened by rising ocean temperatures and acidification, which affect marine ecosystems and fish stocks.

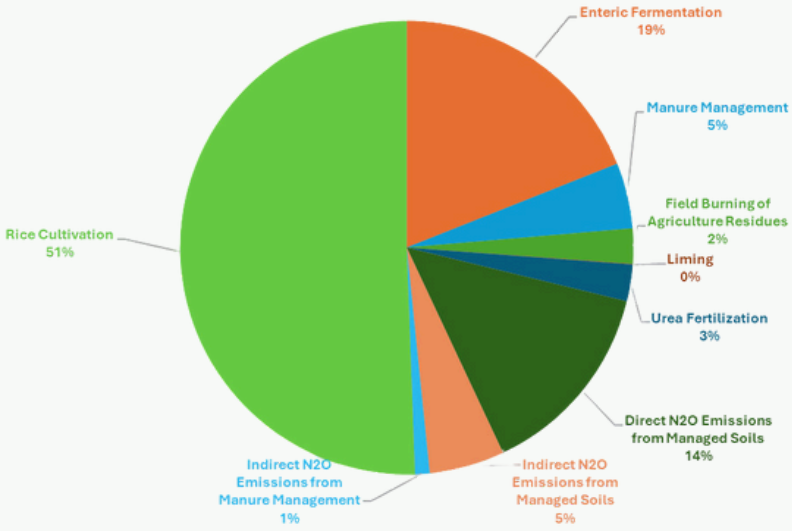


Regarding malnutrition in Thailand, the morbidity rate peaked in 2015 between 2012-2015, then declined during 2015-2018, and rose again from 2018-2021. Meanwhile, deaths due to malnutrition increased from 2012-2023, reaching a peak in 2019 and stabilizing between 2019 and 2021 (Strategy and Planning Division, Ministry of Public Health, 2023) [5].

5 Agriculture

Agriculture is potentially the most vulnerable economic sector to climate change due to its heavy reliance on climatic conditions. Climate change can affect food production both directly and indirectly. Direct impacts involve changes in carbon dioxide levels, precipitation patterns, and temperatures. Indirect impacts include effects on water resource availability and seasonal patterns, soil organic matter decomposition, soil erosion, changes in pest and disease dynamics, the introduction of invasive species, and the loss of arable land due to coastal flooding and desertification.

In Thailand, agriculture is a vital sector. It not only provides food for the population but also generates significant employment and revenue from agricultural exports. Agriculture occupies 47% of Thailand's land [3]. According to the Office of the National Economic and Social Development Board (NESDB), agricultural activities contributed about 10% of the GDP in 2016. The sector also plays a major role in the labor market, employing approximately 11.7 million people, or 30.7% of the workforce, in 2016. Additionally, about 5.9 million households were involved in agriculture in 2015 (Office of Agricultural Economics 2016) [20]. However, agriculture is also the second largest source of greenhouse gas emissions in Thailand, following the energy sector, with rice cultivation being the primary contributor to these emissions.



In 2022, around 1,178.91 square kilometers (km^2) or 0.49% of Thailand's total agricultural land of 238,803.92 km^2 were impacted by storms. In 2020, drought affected 2,848 km^2 (1.20%) of agricultural land, while floods in 2021 affected 9,120 km^2 (3.82%) and destroyed an additional 3,341.22 km^2 (1.40%). The total financial losses from storms, droughts, and floods between 2011 and 2019 were significant. Storms caused losses amounting to 17.49 million USD, droughts resulted in 119.39 million USD in damages, and floods led to 23.74 million USD in losses.

Additionally, national-level climate modeling has been conducted to predict which provinces will be affected by climate impacts on the agriculture sector between 2016 and 2050 [5].

Risk areas to heat stress	Nakhon Ratchasima, Ubon Ratchathani, Buri Ram, Si Sa Ket, Khon Kaen, Surin, Roi Et, Nakhon Si Thammarat, Udon Thani, and Nakhon Sawan.
Risk areas to flood	Nakhon Ratchasima, Khon Kaen, Nakhon Sawan, Chiang Rai, Ubon Ratchathani, Chiang Mai, Kamphaeng Phet, Phitsanulok, Sakhon Nakhon, and Phetchabun.
Risk areas to drought	Nakhon Ratchasima, Khon Kaen, Ubon Ratchathani, Si Sa Ket, Udon Thani, Chaiyaphum, Roi Et, Buri Ram, Surin, and Nakhon Sawan.

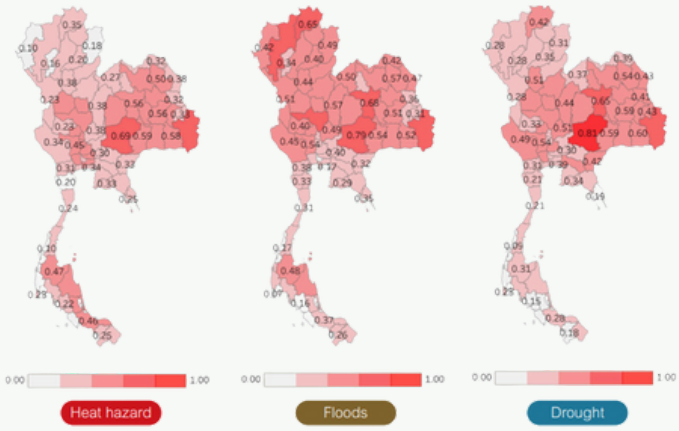


Fig. 23. Risk areas for agriculture sector due to heat, floods and droughts during 2016 to 2035

6 Tourism

Many industrial and service sectors in Thailand experience negative impacts from climate change, particularly due to supply chain and operational disruptions caused by extreme weather events. Tourism, a key economic driver contributing significantly to Thailand's GDP, is heavily influenced by the environment and climate [1]. Climate is a crucial factor in determining the suitability of locations for tourist activities and influences the seasonality of tourism demand. Thus, climate change can alter the duration and quality of climate-dependent tourist attractions. Key climate-related hazards affecting the tourism sector include drought, storm surges, coastal flooding, variations in the rainy season, flash floods, and landslides. For instance, Koh Tachai, one of Thailand's renowned islands, has been closed indefinitely due to environmental degradation, including coral bleaching linked to climate change and damage from tourism. Coral bleaching exacerbates the negative impacts of tourism on Thailand's coral reefs [1].

Extreme climate change trends may result in shorter, milder winters and longer, hotter summers, with the wet season featuring more frequent heavy rainfall. These changes can adversely affect tourism destinations, particularly those with fragile ecosystems. A decline in tourist numbers would increase the risk of revenue loss for the tourism industry, which currently employs 10.55% of Thailand's labor force (according to 2021 data from the International Labour Organization) [21].

High-risk areas identified by UNDP Thailand, such as Bangkok, Chiang Mai, and Phuket, generate the highest tourism revenues. Other at-risk provinces include Trat, Surat Thani, and Nakhon Ratchasima. These areas are particularly vulnerable to the adverse effects of climate change, which threatens the stability and profitability of Thailand's tourism sector [22].

A study has been carried out to forecast future climate risks and their impacts on Thailand's tourism sector, with a focus on natural and cultural attractions. The study classified risk areas into three categories: flood risk, drought risk, and landslide risk.

The analysis revealed that 736 tourist destinations fall within drought-prone areas, primarily located in the North, followed by the Central Plain, West, and East regions. Additionally, 169 tourist destinations are situated in flood-prone areas, mainly in the Central Plain and West, with a smaller number in the South and Northeast regions [5].

Environmental Hazards (Case Studies)

1 Haze pollution in Northern Area (2019)

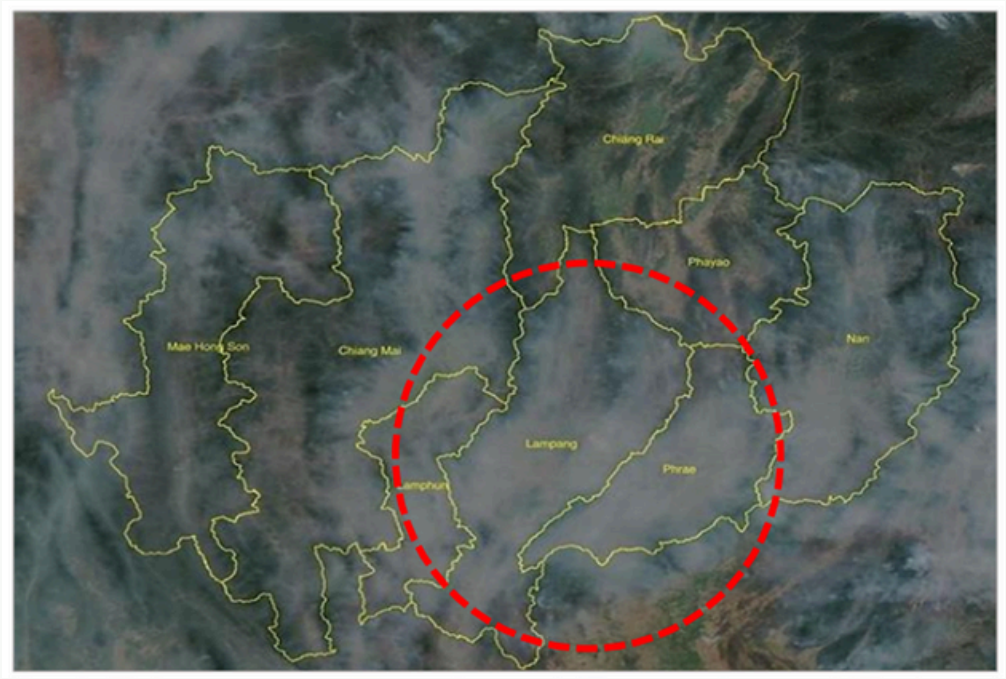
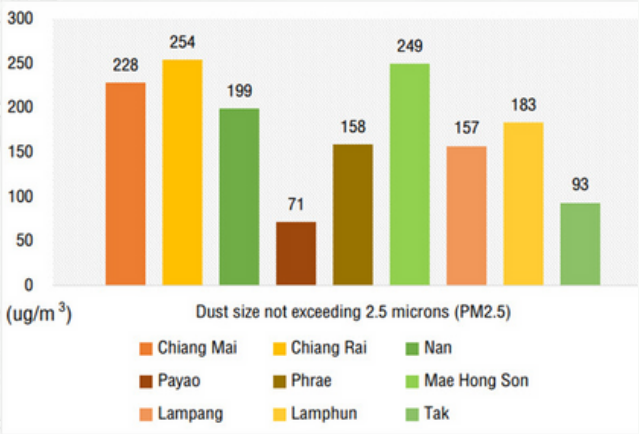


Fig. 24. Satellite images from NASA (March 11, 2019)
(Source: Geo informatics and Space Technology Centre Northern Region)

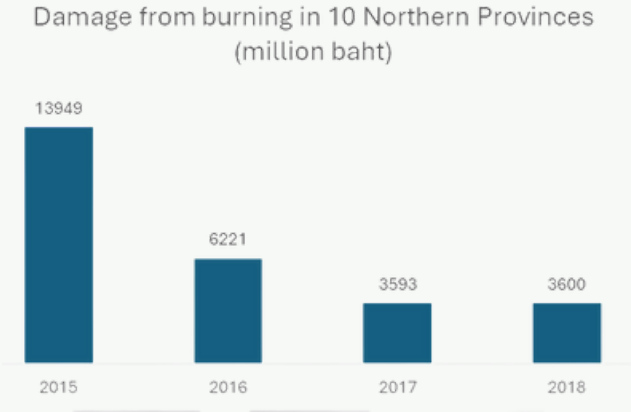
Chiang Mai, the largest city in Northern Thailand, is encircled by mountains which contribute to its unique climatic conditions. These geographical features cause temperature inversions and low wind speeds, particularly during the dry season from November to April, exacerbating haze problems. This period, characterized by minimal precipitation, is particularly prone to haze, peaking in severity during February and March. Haze has been a recurrent issue in Northern Thailand for over a decade, typically emerging from January to April, with the worst conditions in March due to extremely dry weather fueling forest fires [23]. In March 2019, Chiang Mai experienced unprecedented air pollution levels, with the US Air Quality Index (AQI) hitting a record high of 300, making it the most polluted city globally at that time [24]. This severe haze was primarily caused by forest fires and open burning practices, affecting air quality across nine provinces to levels deemed hazardous to health.

Fig. 25. Smog in Northern Thailand

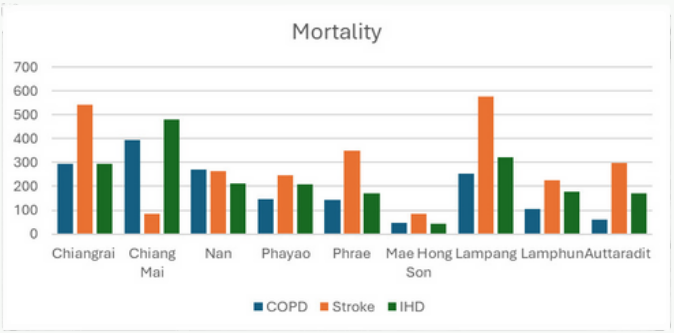
Data from the Pollution Control Department, gathered from 17 air quality monitoring stations across nine provinces, indicated that PM2.5 levels ranged between 70 and 250 micrograms per cubic meter [13]. These levels are significantly above the safe limit of 50 micrograms per cubic meter.

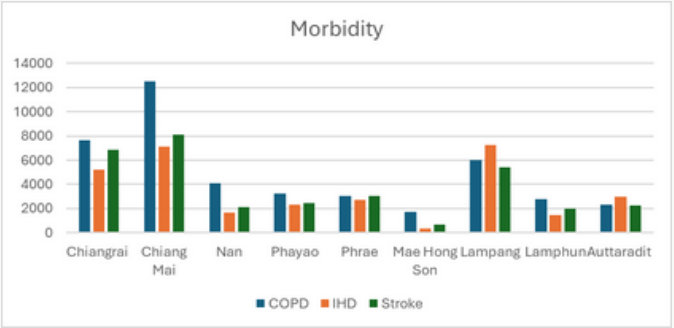


From 2015 to 2018, burning activities in ten northern provinces of Thailand caused significant economic damage, with the highest impact recorded in 2015 at 13,949 million baht. Over the years, there was a notable decline in damages, reaching 3,600 million baht by 2018. Despite this reduction, the region still faced considerable financial losses, averaging 6.6 billion baht annually [25]. These economic impacts include loss of income, damage to property, and increased health costs due to poor air quality.



In March 2019, Northern Thailand faced significant travel disruptions primarily due to haze, which led to a range of issues affecting both locals and tourists alike. One of the most pronounced impacts was on visibility, causing vision problems and resulting in flight delays for approximately 20% of flights operating in the region. The haze not only compromised air quality but also had severe implications for tourism and public health. The Northern region experienced a sharp decline in tourist numbers, with a notable 15% decrease compared to previous months. This decline was mirrored in the hospitality sector, where key cities such as Chiang Mai and Chiang Rai saw hotel occupancy rates plummet by more than 10-20%, as travelers opted to avoid the affected areas. The haze thus not only posed immediate health risks but also dealt a significant blow to the region's tourism industry, highlighting the vulnerability of Northern Thailand to environmental factors during certain times of the year. The records of individual mortality and morbidity, detailing the location and primary causes of death in 2019, were obtained from the Thailand Ministry of Public Health [26].





2 Flood (2011)

In 2011, Thailand experienced its worst flood in modern history. The disaster affected 9.1% of the country's land area, impacting over 13 million people and resulting in 680 fatalities. The flood caused extensive damage and losses amounting to USD 46.5 billion, and it immobilized Bangkok and its surrounding areas for two months. The floodwaters spread across 69 provinces nationwide, but the most severe damage occurred in industrial estates, residential areas in Bangkok, nearby northern and western provinces, and agricultural lands in the Lowver Northern region and Central Plains. The flooding started in late July 2011 and did not recede until mid-December 2011 [27].

Fig. 26. Floods in Thailand (Source: The Atlantic)

The primary cause of the 2011 floods in Thailand was record-breaking rainfall. That year, the country experienced its highest annual rainfall in 61 years. The southwest monsoon began early, bringing unprecedented rainfall in March and April, which persisted throughout the six-month summer monsoon season. Additionally, remnants of four tropical storms crossed the north, causing rivers to overflow [28].

Four main factors contributed to the severity of the 2011 floods:

1. The highest recorded rainfall and five consecutive tropical storms during the rainy season.
2. Excessive water runoff from major rivers.
3. Inappropriate land use in flood-prone areas.
4. Poor flood management practices.

The table lists the ten largest flood events in Thailand from 1985 to 2012, as recorded by the Dartmouth Flood Observatory. Although the 2011 flood ranks fifth in terms of magnitude, it ranks first in terms of duration [28].

Year	Dates	Flood Magnitude	Duration
1995	1 Aug- 9 Nov	7.9	101
2002	18 Aug- 26 Nov	7.9	101
2006	20 Aug- 13 Dec	7.7	116
2004	6 Aug- 3 Oct	7.6	59
2011/2012	5 Aug- 9 Jan	7.5	158
2007	5 Sep-10 Nov	7.3	67
1994	3 Sep- 18 Dec	7.1	107
2005	13 Aug- 26 Sep	7.1	45
2003	12 Sep- 12 Oct	7.0	31
1996	18 Jul- 21 Aug	7.0	35

In 2011, Thailand experienced a devastating flood that significantly impacted the country. The disaster affected 12.8 million people and resulted in 728 deaths. It also caused extensive damage to agricultural areas, with 10.417 million (16,668.55 square km) of farmland being affected, according to the Ministry of Agriculture's 2012 report. Additionally, 9,859 factories were damaged, and as of November 25, 2011, 660,000 jobs were impacted. The total damage and loss from the flood amounted to THB 1.43 trillion (USD 46.5 billion), with losses constituting 56% of this total. The financial impact was immense, reflecting the widespread devastation across various sectors. The World Bank estimated that the recovery and reconstruction efforts would require THB 1.49 trillion (USD 50 billion) over the next six months and beyond. The scale of the 2011 flood's impact is evident in the extensive damage to infrastructure, agriculture, and employment, highlighting the need for substantial recovery efforts. The combination of affected lives, economic loss, and the extensive area of damaged land underscores the severity of this natural disaster and the critical need for effective flood management and prevention strategies in the future [27].

3 Drought in Northeastern Thailand (2015-2016)

Thailand is among the countries in the Asia Pacific region most severely affected by drought. These droughts significantly disrupt the economy, causing extremely low precipitation and sharp drops in groundwater levels, leading to severe water shortages that affect the agro-food system, consumption, and ecosystem services. During the 2015-2016 drought, 14 provinces, 55 districts, 290 sub-districts, and 2,666 villages were impacted. This period marked one of the most severe droughts in recent history, characterized by prolonged below-average rainfall and high temperatures [29].

The northeastern part of Thailand, known as the Isan region, is particularly vulnerable to drought. This area, which includes provinces like Khon Kaen, Udon Thani, and Nakhon Ratchasima, is an upland plateau with shallow lakes that feed into the Mekong River. The region often suffers from arid conditions and drought.

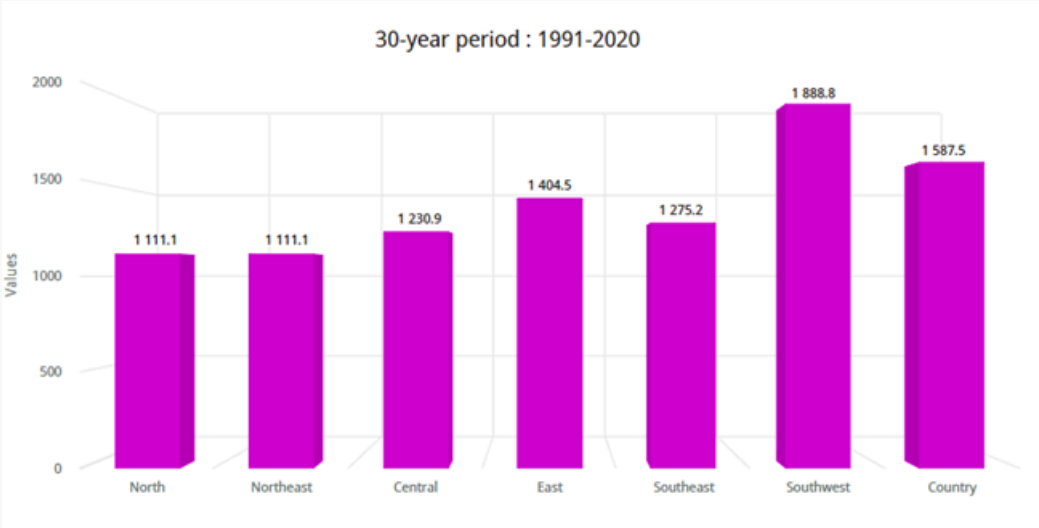


Fig. 27. Annual mean rainfall in Thailand from 1991 to 2020

The 2015-2016 drought, spanning from late 2014 to most of 2016 with peak severity during the 2015 rainy season and early 2016, drastically reduced water levels in reservoirs, rivers, and other water bodies. Agricultural areas faced severe water shortages, leading to diminished crop yields and, in some cases, total crop failures. The lack of water also stressed natural ecosystems, including forests and wetlands. Over 50% of the Mekong watershed area in northeastern Thailand was in critical drought status during this period. The economic losses across the 14 affected provinces amounted to $1.70 billion, with rice production losses alone exceeding $2.50 million [29]. The drought damaged crops and land in 13 provinces, causing rice production to fall by 27 million tonnes to its lowest level since 2000-2001. Farmers in the central plain irrigation areas suffered from severe droughts, impacting the quality and quantity of agricultural products. Those in rain-fed areas experienced water shortages and product damage. In the northeast, both irrigation and rain-fed areas were affected, with farmers in rain-fed areas also dealing with increased insect infestations due to the drought. Additionally, over 15 public health facilities in drought-affected areas faced water shortages, negatively impacting the services provided to the local population [30].

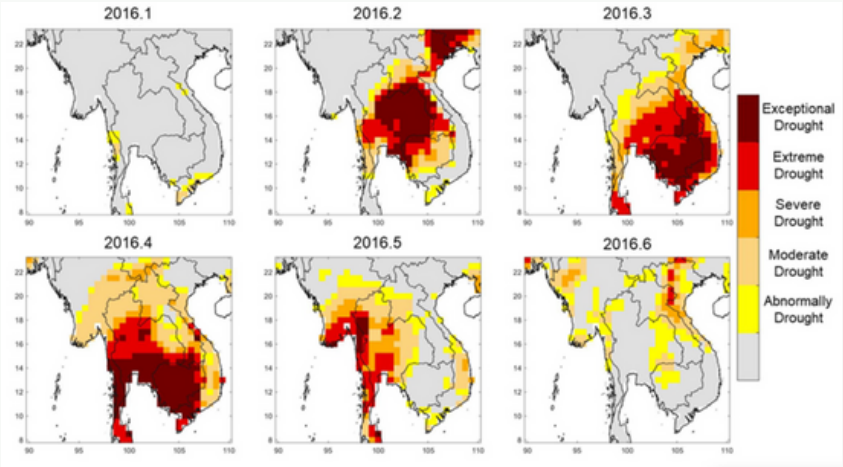


Fig. 28. Satellite-based image of drought events from January to June (2016)

The drought had profound human impacts, heavily affecting the livelihoods of farmers and rural communities who faced economic hardship due to crop losses. Water scarcity led to conflicts over resources and increased migration to urban areas in search of employment, exacerbating poverty and food insecurity in the affected regions. Infrastructure also suffered, with damaged irrigation systems and a decline in livestock health due to inadequate water supplies. The economic cost was substantial, particularly in the agricultural sector.

Fig. 29. A farmer walks on a dried out field in Suphanburi (2015) (Source: The Strait Times)

Mitigation Strategies

Thailand has implemented several strategies to reduce GHG emissions, focusing on various sectors such as energy, transportation, industry, agriculture, and waste management. Thailand is committed to mitigating climate change by integrating it into national policies to achieve carbon neutrality by 2050 and net-zero emissions by 2065 [31].

The 20-Year National Strategy (2018-2037)	**Long-term strategy guiding overall national development, including climate mitigation goals.** **1) Reducing greenhouse gas emissions and promoting a low-carbon society** • **Reduce greenhouse gas emissions.** • **Support agricultural practices that lower emissions.** • **Restore deteriorated forests and expand forest areas for carbon storage.** **2) Enhancing disaster management and adaptation** • **Improve the disaster management system.** • **Increase people's capacity to adapt to climate change impacts.** • **Develop systems for dealing with infectious diseases linked to climate change** **3) Strengthening National Competitiveness and Legal Frameworks** • **Create a robust database system.** • **Promote low-carbon products and services.** • **Implement economic incentives for climate-friendly investments.** • **Encourage businesses to plan for climate change.** • **Update laws to support climate change management**
The 12th National Economic and Social Development Plan (2017-2021)	**National plan focusing on economic and social development, incorporating climate change mitigation measures to reduce GHG emissions.** • **Develop and revise laws to align with global climate agreements.** • **Implement measures to cut greenhouse gases across sectors like electricity, transport, industry, households, and buildings.** • **Promote renewable energy and reduce fossil fuel use in power generation.** • **Improve transport systems and enhance the efficiency of engines and machinery.**
Climate Change Master Plan (2015-2050)	**Comprehensive plan outlining Thailand's approach to address climate change, with specific strategies for mitigation and adaptation.** • **Establish a national plan for climate adaptation and sustainable growth.** • **Develop policies and tools to address climate change at sectoral and national levels.** • **Create a common framework for government agencies and organizations to coordinate action plans efficiently.** • **Provide budgeting agencies with clear guidelines for allocating funds to support climate change initiatives.**
Nationally Appropriate Mitigation Action (NAMA) (2014-2020)	**Framework for voluntary GHG emission reduction efforts, targeting a 7-20% reduction from business-as-usual levels by 2020.** • **Advancing renewable and alternative energy sources.** • **Enhancing energy efficiency in power, industries, buildings, and transportation.** • **Using biofuels instead of fossil fuels in transportation.** • **Implementing Thailand's plan to improve transport infrastructure.**
Thailand's Nationally Determined Contribution (NDC) (2021-2030)	**Roadmap and action plan for GHG emission reduction efforts, targeting a 20-25% reduction by 2030.**

During 2013-2020, NAMA was implemented in power generation, industry and transport sectors to reduce GHG emissions. In 2020, Thailand reduced GHG emissions to 56.54 MtCO2 eq (15.40%) from 10 mitigation measures in the energy and transport sectors.

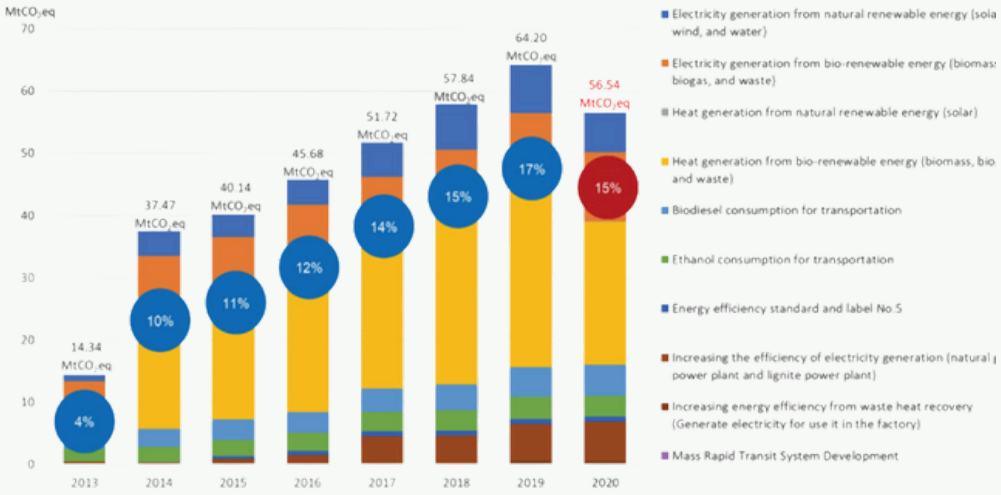


Fig. 30. Thailand's GHG emission reduction from NAMA Implementation

Mitigation measures are being implemented across various sectors as follows:

Energy Sector	**- Energy efficiency improvement** **- Renewable energy development** **- Alternative energy development plan**
Transportation Sector	**- Promotion of Electric Vehicles (EVs)** **- Public Transportation Enhancement** **- Biofuels**
Industrial Sector	**- Implementation of emission reduction technologies and energy efficiency programs** **- Substitution of raw materials in cement production and natural refrigerants replacement**
Waste Sector	**- Increasing 3R (Reduce, Reuse and Recycle) campaign** **- Methane recovery from industrial wastewater treatment** **- Improvement of municipal wastewater treatment** **- Promoting of clean technology** **- Developing waste-to-energy projects**
Agriculture Sector	**- Promoting biogas production from animal waste** **- Alternative wetting and drying in paddy of rice fields to mitigate CH4 emission, saving water and potentially increasing crop yields** **- No or avoid burning of crop residues in the field** **- Promoting utilization of crop residue for alternative energy purposes** **- Enhancing carbon sequestration in tree and soil**
Forest and Land Use Sector	**- Reducing deforestation** **- Improved forest management** **- Promoting wood products utilization** **- Reforestation and afforestation**

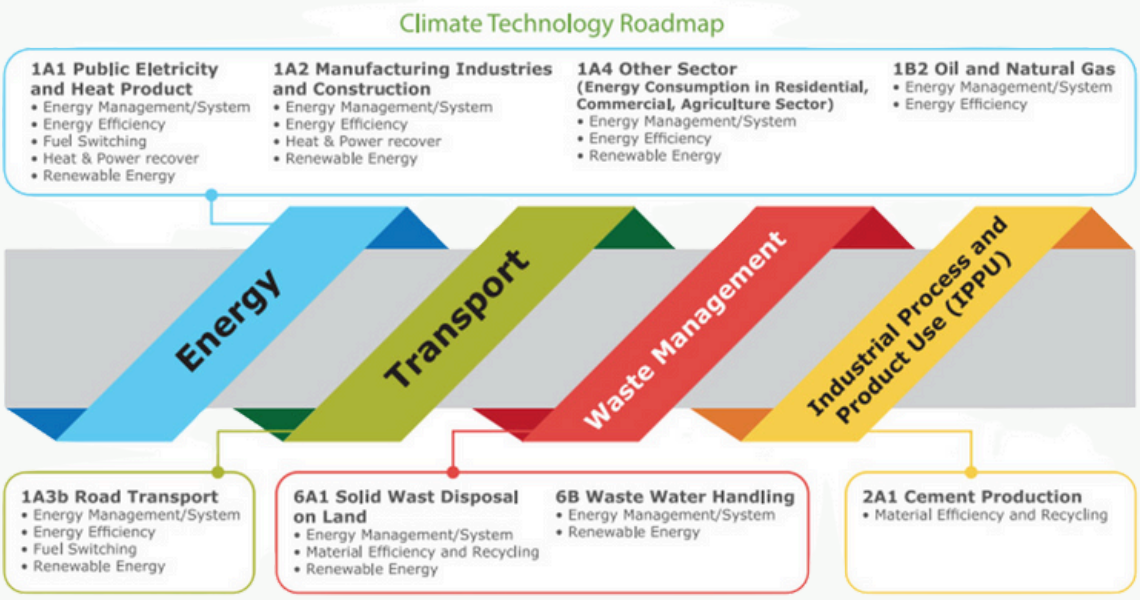
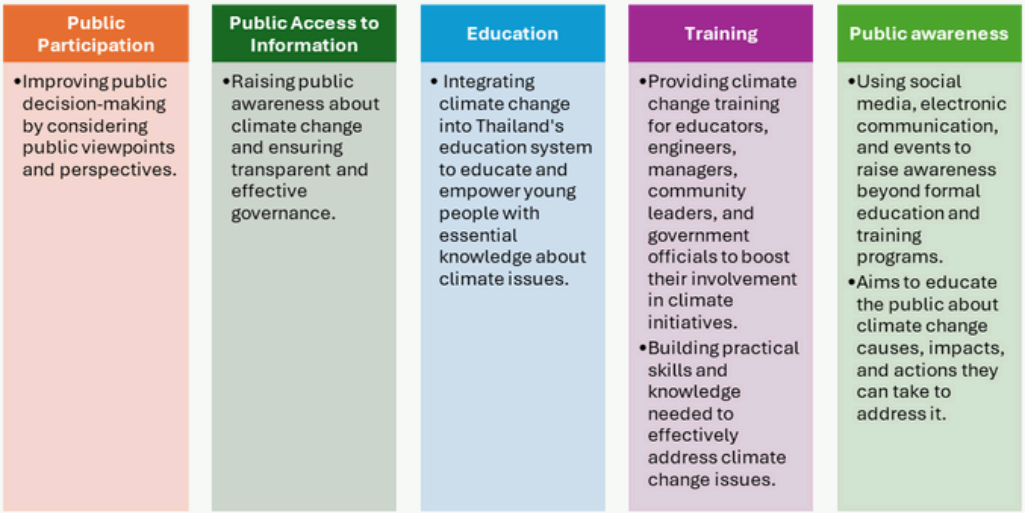


Fig. 31. Overview of climate mitigation technology roadmap

Technology development is crucial for supporting national climate efforts by aiding both emissions reduction and climate resilience. Thailand established the National Science and Technology Development Agency (NSTDA) and the Office of National Higher Education Science Research and Innovation Policy Council (NXPO) under the Ministry of Higher Education, Science, Research and Innovation (MHESI) to promote this goal. They have developed a climate technology database and roadmap aligned with Thailand's Nationally Determined Contributions (NDC) for 2021-2030 [31].



Furthermore, Article 6 of the Convention and Article 12 of the Paris Agreement highlight the importance of climate education, awareness, training, public participation, access to information, and international cooperation. These elements are essential for developing and implementing effective climate policies and actions [31].

Adaptation Strategies

Climate change significantly affects our environment, economies, and societies. To cope with these challenges, adaptation strategies are crucial. They aim to reduce vulnerabilities and enhance resilience to climate impacts. Effective adaptation requires planning, collaboration, and sustainable practices [5].

1. Water Resource Management

Upstream Management	- Protecting and restoring watershed forests to prevent soil erosion. - Engaging local administrative organizations (LAOs) and communities in upstream areas to develop land use plans. - Using economic incentives to encourage upstream communities to conserve the ecosystem.
Flood Management (Midstream and downstream management)	- Build flood response infrastructure tailored to local characteristics and communities. - Improve drainage efficiency. - Establish urban flood protection systems with comprehensive water and drainage plans at river basin, provincial, and city levels.
Drought Management (Midstream and downstream management)	- Build infrastructure to store rainwater and manage water in drought-prone areas, non-irrigated zones, and groundwater-dependent areas. - Establish a water grid system. - Create databases on water usage, budgets, and demand across Thailand's 22 major river basins.
Downstream water management	- Restore rivers and natural water sources nationwide with participation from all sectors. - Encourage the adoption of wastewater treatment technology to recycle water in homes and industries.

2. Health and Well-being

Preventing climate change health impacts	- Enhance healthcare for vulnerable groups. - Upgrade medical and public health services for climate change. - Educate and engage the public on health impacts of climate change and adaptation. - Improve health station infrastructure in high-risk areas. - Set standards for emergency responses to climate-related health issues. - Advance research and innovation to manage climate-related health risks.

3. Social and Economic Measures

Management of natural tourism destinations	- Align tourism schedules with shifting seasons. - Create tourism approaches that consider capacity changes due to climate in risk areas. - Prepare plans for natural disaster responses. - Secure extra water sources for drought-prone natural tourism spots using ecosystem-based methods.
Management of art and culture tourism destinations	- Improve tourism infrastructure and flood protection for cultural sites in vulnerable areas. - Implement measures to protect valuable art and architecture from climate impacts like temperature, humidity, and CO2. - Strengthen measures to safeguard art and architecture from climate-related damage and disasters.

4. Ecosystem-based Adaptation

Management of terrestrial ecosystems	- Enhance healthcare for vulnerable groups. - Upgrade medical and public health services for climate change. - Educate and engage the public on health impacts of climate change and adaptation. - Improve health station infrastructure in high-risk areas. - Set standards for emergency responses to climate-related health issues. - Advance research and innovation to manage climate-related health risks.	- Create biological indicators for all ecosystem risk areas nationwide. - Complete Thailand's Red List Index. - Expand protected areas for climate-vulnerable migratory species. - Support eco-villages to live sustainably and protect natural resources.
Management of wetlands	- Restore natural and man-made wetlands to prevent flooding without harming ecosystems. - Foster networks for sustainable wetland conservation and rehabilitation.	
Management of marine and coastal ecosystems	- Conserve marine and coastal resources, expanding mangroves with community involvement. - Protect endemic and endangered marine species from climate impacts and prevent invasive species. - Develop a national coastal management plan to combat erosion with community input. - Enhance coastal areas' ability to handle and prevent storm surge impacts.	

5. Infrastructure and Built Environment

Management of human settlements and security	- Develop emergency infrastructure and response plans for natural disasters, involving public participation and awareness. - Create interconnected green spaces in cities to mitigate climate impacts. - Prepare backup plans for essential systems during climate emergencies. - Establish guidelines to address urban heat island effects, especially in large cities. - Update building standards to include climate-resilient designs in the Building Control Act. - Promote climate-resilient and adaptable building designs for better disaster and climate change response, tailored to local contexts.

6. Agriculture and Food Security

Management of crop farmland	- Adjust agricultural practices for climate change. - Enhance water management in irrigated zones for flood and drought resilience. - Conserve soil and improve fertility in degraded agricultural land through techniques like cover cropping and contour tillage. - Improve water resources in non-irrigated areas to meet crop and livestock needs. - Promote integrated farming and crop rotation to mitigate climate risks. - Create a reliable early warning system for agriculture, accessible and linked with other systems. - Map local climate risks and impacts on agriculture for farmer access and application.
Management of livestock farmland	- Improve livestock management and products to adapt to climate change. - Develop systems to prevent and treat livestock diseases linked to climate impacts and epidemics from floods and droughts
Management of fisheries and aquaculture farmland	- Enhance fishery management to address climate change trends. - Restore fishery resources and aquatic habitats for biodiversity balance. - Develop systems for preventing and treating animal diseases.

References

[1] Government, R.T., Thailand's Third National Communication under the United Nations Framework Convention on Climate Change. (2018).
[2] Leknoi, U., A. Yiengthaisong, and S. Likitlersuang, Community engagement initiative amid climate change crisis: Empirical evidence from a survey across Bangkok Metropolis of Thailand. Cities, 2022. 131: p. 103995.
[3] Bank, A.D., Climate Risk Country Profile: Thailand.
[4] Thailand, G.o., Thailand's Second Biennial Update Report 2017.
[5] Government, R.T., Thailand's National Adaptation Plan 2024. 2023.
[6] Thailand, G.o., Thailand's Fourth Biennial Update Report 2022, United Nations Framework Convention on Climate Change (UNFCCC).
[7] Wikipedia, Climate change in Thailand. 2024.
[8] Health, T.M.o.P., Thailand Health Impact Assessment: Climate Change 2022, Thai Ministry of Public Health.
[9] Project, C.R. Sea Level Rise. 2023; Available from: https://cri.org/sea-level-rise/#:~:text=As%20the%20planet's%20mean%20temperature,an%20increasing%20rate%20every%20year.
[10] Sojisuporn, P., C. Sangmanee, and G. Wattayakorn, Recent estimate of sea-level rise in the Gulf of Thailand. Maejo International Journal of Science and Technology, 2013. 7: p. 106-113.
[11] Org, E. Sea Level Rise by the End of the Century: Bangkok. 2023; Available from: https://earth.org/data_visualization/sea-level-rise-by-the-end-of-the-century-bangkok/#:~:text=Earth.Org%20has%20modelled%20severe,population%20displacement%20indicated%20bottom%20right.
[12] Limsakul, A. and P. Singhruck, Long-term trends and variability of total and extreme precipitation in Thailand. Atmospheric Research, 2016. 169: p. 301-317.
[13] Department, P.C., Thailand State of Pollution Report 2020. 2021, Pollution Control Department, Ministry of Natural Resources and Environment
[14] Nguyen, N., et al., Evaluating Low-Cost Commercially Available Sensors for Air Quality Monitoring and Application of Sensor Calibration Methods for Improving Accuracy. Open Journal of Air Pollution, 2021. 10: p. 1-17.
[15] Ministry of Natural Resources and Environment, T., Thailand's Fifth National Report to the Convention on Biological Diversity 2020, Asean Centre for Biodiversity.
[16] Pomoim, N., et al., Vulnerability to climate change of species in protected areas in Thailand. Scientific Reports, 2022. 12: p. 5705.
[17] Arifwidodo, S.D. and O. Chandrasiri, Urban heat stress and human health in Bangkok, Thailand. Environmental Research, 2020. 185: p. 109398.
[18] Post, B. Heat stroke claims 61 lives this year. 2024; Available from: https://www.bangkokpost.com/thailand/general/2790690/heat-stroke-claims-61-lives-this-year.
[19] Ebi, K. and G. McGregor, Climate change, tropospheric ozone and particulate matter, and health impacts. Cien Saude Colet, 2009. 14(6): p. 2281-93.
[20] Office of the National Economic and Social Development Council, T., Thailand Economic and Social Development Report. 2023, NESDC.
[21] Share of Employment in the Tourism Sector in Thailand from 2011 to 2020. 2023; Available from:
[22] Programme, U.N.D. Climate Impact in Thailand. 2024; Available from: https://www.undp.org/stories/climate-impact-thailand.

References

[23] Mostafanezhad, M. and O. Evrard, Chronopolitics of crisis: A historical political ecology of seasonal air pollution in northern Thailand. Geoforum, 2021. 124: p. 400-408.

[24] Wipatayotin, A. Chiang Mai air pollution worst in the world. 2019; Available from: https://www.bangkokpost.com/thailand/general/1643388/chiang-mai-air-pollution-worst-in-the-world.

[25] University, U.T.R., PM 2.5 Levels and Health Impact in Northern Thailand 2023.

[26] Jomjunyong, A.P.D.S., Haze Pollution, Northern Region of Thailand.

[27] Poaponsakorn, N., P. Meethom, and K. Pantakua, The Impact of the 2011 Floods, and Flood Management on Thai Households. 2015. p. 75-104.

[28] Gale, E.L. and M.A. Saunders, The 2011 Thailand flood: climate causes and return periods. Weather, 2013. 68(9): p. 233-237.

[29] Capacity building for drought adaptation (Thailand case study). 2022.

[30] Wongsit, A., Analysis and Investigation on Spatio-Temporal Dyanmi Pattern Of Drought in Thailand 2021.

[31] Government, R.T., Thailand's Fourth National Communication under the United Nations Framework Convention on Climate Change. 2022.