Data Analysis Project Report

The effect of Precipitation in the Years 2006 to 2020 on Dengue Infections in Thailand

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Content

1. Introduction

Dengue fever is an infectious disease caused by the RNA dengue virus family Flaviviridae. It is primarily transmitted through the bites of infected Aedes mosquitoes, particularly the female Aedes aegypti and Aedes albopictus mosquitoes (Gibbons and Vaughn, 2002; Khetarpal and Khanna, 2016). Dengue fever is one of the most rapidly propagating diseases worldwide. This is illustrated by the fact that in 1970 only 9 countries worldwide were affected by dengue fever, while nowadays its endemicity has been observed in 128 countries. There, it puts approximately 3.97 billion people at risk, causing 390 million infections each year (Khetarpal and Khanna, 2016; Li *et al.*, 2020).

Since the Aedes mosquitoes preferentially feed on humans, the mosquito-borne disease mostly causes infections among people. The dengue virus family include (entail) four serotypes. An infection with one serotype leads to lifelong immunity against this specific serotype. However, it only protects against the other serotypes for a few months (Gibbons and Vaughn, 2002). Depending on the severity and the symptoms, dengue is classified into three different clinical conditions. While the mild asymptomatic dengue fever is usually not that dangerous, the more severe dengue haemorrhagic fever and dengue shock syndrome can lead to life-threatening situations (Khetarpal and Khanna, 2016; Soneja *et al.*, 2021).

A major health issue lies in the tropical asia-pacific area, where over 75% of the dengue cases occur (Ibrahim Abdulsalam *et al.*, 2021). Thailand is known for its tropical climate, creating favourable conditions for the proliferation of the Aedes mosquitoes. The high mosquito densities cause dengue to remain a continuous threat to the public health (Ibrahim Abdulsalam *et al.*, 2021; Chumpu *et al.*, 2019).

The climate plays a crucial role in dengue transmission, as it heavily affects the presence of the mosquitoes and consequently dengue fever. A higher temperature increases the larvae development and decreases the incubation time of the dengue virus (Phanitchat *et al.*, 2019; Liu-Helmersson *et al.*, 2014). Furthermore, humidity influences the survival rate of the mosquitoes themselves. Another main factor for the dengue transmission is the precipitation. The Aedes mosquitoes have aquatic larvae, which makes water a necessity for proliferation. Therefore, the amount and frequency of rainfall determines the availability for Aedes habitats. While too little rain prevents reproduction, extreme rainfall can destroy breeding sites and kill the larvae. Frequent and light rain creates and preserves the habitat for the next generations of Aedes mosquitoes (Promprou *et al.*, 2005; Russell, 1998).

The most influential contributors to the precipitation in Thailand are the monsoons. There are two different monsoons: the southwest and the northeast monsoon. All of Thailand is affected by the southwest monsoon, which brings abundant rain during the summer months and is present from Mid-May to Mid-October. After the effect of the southwest monsoon weakens, the northeast monsoon prevails from Mid-October to Mid-February. It generally brings less rain for Upper Thailand, whereas it leads to rainfall on the eastern side of Southern Thailand bordering the Gulf of Thailand. On the contrary, the western side of Southern Thailand bordering the Andaman Sea experiences more rainfall during the southwest monsoon season (Khedari *et al.*, 2002; Promprou *et al.*, 2005). The time period between the two monsoons, from Mid-February to Mid-May, can be considered as a transition phase (Khedari *et al.*, 2002).

For an analysis on the relation of precipitation and dengue fever, it must be examined whether the two variables influence each other with a lag period in between. While precipitation is necessary for the mosquito survival and breeding, it may take some time for the rainfall to result in a change of infection rates. Other studies suggest that either the current-week precipitation or the three-week-lag precipitation have the most influence on dengue fever (Chumpu *et al.*, 2019). This must be taken into consideration as it heavily affects the analysis.

We analysed data on reported dengue cases in all provinces collected between 2006-2020 and determined the potential impact precipitation has on the dengue incidence. We predict the future impact of precipitation data on the dengue incidence and propose further non climatic factors affecting the dengue pattern.

Thailand is split up into 4 regions according to the general national consensus: The central region, the northeastern region, the northern region, the southern region (Figure A1).

2. Materials and Methods

2.1 Data

The precipitation data was obtained from the ERA5 reanalysis by the ECMWF. The data was obtained for each of the 77 provinces in Thailand, for every month of the time frame from 2006 to 2020. The dengue fever case data was obtained from the official Annual Epidemiological Surveillance Reports from 2006 to 2020, published by the Department of Disease Control, Bureau of Epidemiology of the Ministry of Public Health of Thailand. It contains monthly reported case data for each of the 77 provinces. This includes all clinical conditions of dengue fever. The population data for the provinces of Thailand were obtained from the Statistical Yearbooks, published by the National Statistical Office of the Ministry of

Digital Economy and Society of Thailand. For the areal data for each province of Thailand the Statistical Yearbook Thailand 2021 from the National Statistical Office of Thailand was used. To determine the effect on precipitation on dengue fever the monthly case data of dengue was divided by the population of the corresponding province and multiplied with 100,000. The resulting variable of cases per 100,000 citizens allows for an unbiased observation regardless of population. Since 2011, Nong Khai province split into two. This was dealt with by combining the two provinces back into one for 2011 to 2020, so that the 76 provinces from before 2011 and the 77 provinces from 2011 onwards could be analysed the same way.

2.2 Heatmaps

Heatmaps were created to visualize the distribution of the dengue incidences and precipitation over the months and the time period of 2006 to 2020 for each region. They were used to analyse seasonal patterns. The dengue incidences were summed up. The precipitation of each province was multiplied by the corresponding area, summed up and divided by the total area of the region. The coloured brackets of the heatmaps do not represent total values and cannot be directly compared with same colour brackets in other heatmaps. This is because of an inserted column-scaling, where the values of all months were scaled over one year. Therefore, the scaled heatmaps demonstrate in which months the precipitation or dengue incidence is high and in which they are low.

2.3 Generalized Additive Models

Generalized Additive Models (GAMs) are statistical models. GAMs illustrate non-linear and non-parametric relationships by incorporating a sum of smooth functions of features and elements of regression analysis. A GAM was computed to analyse the relationship between precipitation and dengue incidence in the monsoon season. The AIC value was minimised by choosing 5 degrees of freedom (k = 5) for our GAM. Degrees of freedom refer to the number of smoothing splines used to approximate the relationship between variables. An effective number of degrees of freedom (edf) close to 1 indicates a linear relationship. A better fitting GAM has a low GCV value.

A fitted GAM can be used to make predictions of our data. To compute GAM as a predictive model, the time series data must be stationary. Stationary data fluctuates around a constant mean and has a constant variance and covariance independent of time. The stationarity of our time series data is proven with the Dickey-Fuller test. The GAM was fit with the dengue incidence and precipitation time series data from 2006 to 2020 of the monsoon season. CORDEX precipitation data was used as the predictor variable. Predictions from the fitted GAM model were visualized in a spatial plot.

2.4 Temporal-Spatial Maps

Temporal-Spatial maps are used to visualize variables in a spatial plot. The multipolygon data (geometry) defining the area for each province is placed on a geographic coordinate system. The variables containing longitude and latitude values are combined in a data frame with the multipolygon data linked by the province names. The sf data frame is plotted onto a map using the geom_sf() and geom_point() functions. Multiple layers on the map for different variables, are used to find trends, patterns and relationships between different variables.

2.5 Pearson correlation and Spearman rank correlation

The Pearson and Spearman rank correlation are used to analyse if there is a relationship between two data samples of equal size. Pearson correlation is an indicator for linear relationship, while the Spearman correlation method is used to analyse monotonic relationships. However, a low correlation regardless of correlation method does not mean that there is no relation between the data samples. Although the Spearman correlation tests for monotonic relationships between variables, it is possible to run Spearman's correlation on a non-monotonic relationship to determine if there is a monotonic component to the association.

3. Results

3.1 No lag between Incidence of Dengue and Precipitation yields highest Correlation

The first step of the analysis was to find out whether a lag between the dengue incidence and precipitation could be detected. The outcome would influence the rest of the analysis. The lag must be incorporated into the data frames used to analyse the data. The Spearman correlation between the dengue incidence and precipitation of each province was calculated for every year separately and for all years combined. Next, the calculated correlation for each province was plotted (Figure A2).

No lag between the precipitation and incidence of dengue fever resulted in a higher correlation for most of the provinces, both when looking at the yearly correlation as well as the total correlation. This is especially the case in the northern and northeastern region, which have the highest correlation. However, there is also a non-negligible number of provinces where a 1-month lag provides a higher correlation in comparison to no lag. This is mostly the case for certain years in the southern and central region. Although a 1-month lag provides high correlations across the board, no lag yields higher correlations in most of the provinces and was established as the “lag of choice” for the heatmaps, temporal-spatial maps and traditional plotting (Figure A2).

3.2 Thailand´s Precipitation Pattern is split up into Three Seasons

To determine the effect of precipitation on dengue cases in Thailand, it is vital to understand the weather phenomenon and patterns dominating the regions North, Northeast, Central and South. The predefined seasons, as mentioned in the introduction, have been analysed and redefined according to visible precipitation patterns of our data. Using heatmap analysis, the time period with the highest rainfall could be distinguished for each region. Each heatmap in Figure A3 shows the column-scaled values for every month in 2006 to 2020.

In the northern, northeastern, and central region the precipitation period ranges from May to October. In the south however, precipitation additionally prevails in November, December and partly January as well. February, March and partly April experience little rainfall throughout Thailand. Consequently, the three dominating seasons in Thailand have been distinguished: The pre-monsoon season from February to April, the southwest monsoon dominating May to October and the northeast monsoon dominating November to January. To simplify measures, the southwest monsoon is referred to as the monsoon season.

To further examine the differences in precipitation seasons, the following Temporal-Spatial maps visualise the normalised precipitation of the three previously defined seasons from 2006 to 2020. In Figure 1 it is clearly visible that during the monsoon season from May to October, Thailand sees evenly high amounts of precipitation, as the southwest monsoon overall affects Thailand. In the pre-monsoon season from February to April, Thailand experiences low precipitation, although the South has slightly higher rainfall compared to the North. The northeast monsoon from November to January strongly affects the precipitation in the South, while leaving the North mostly dry. It is crucial to point out that the South experiences considerably less fluctuations in the amount of rainfall it gets throughout the year. It is visible that in the South, the northeast monsoon strongly effects the Gulf of Thailand coastal region, while the southwest monsoon strongly effects the Andaman Sea coastal region.

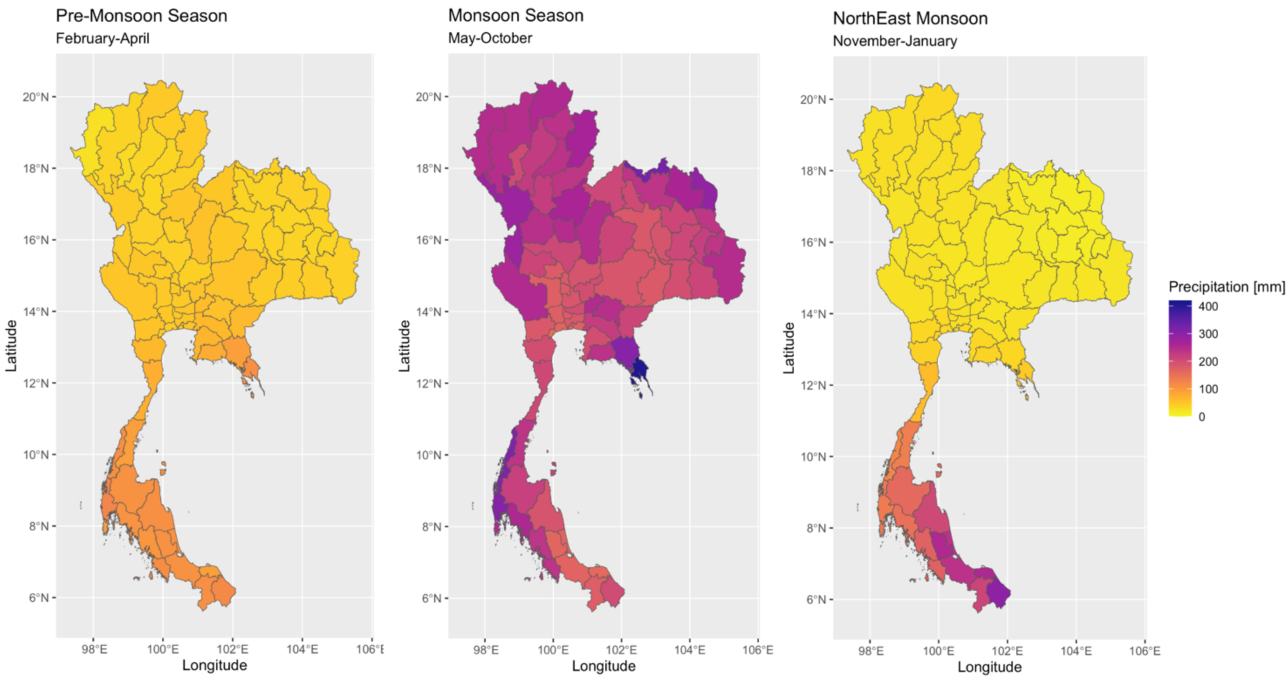

Figure 1: Temporal-Spatial maps visualising the precipitation for different seasons in Thailand. The precipitation is averaged over 15 years and normed for a month.

The Temporal-Spatial maps used averaged precipitation data across all 15 years to illustrate the geographic distribution of the precipitation patterns with a focus on seasonal changes. However, unique weather events are singled out using line charts depicting the precipitation in separate regions of Thailand over the 15 years. In all seasons, a seasonal progression, with precipitation peaking around the southwest monsoon season at 200 mm to 400 mm, is observed. However, compared to the other regions, the precipitation in the South is highest over a longer period of time. It is noticeable that outliers with precipitation values of up to 600 mm occur mainly in the South during the northeast monsoon (Figure A4).

3.3 The Incidence follows a similar Pattern to the Precipitation

The Temporal-Spatial maps depicting the incidence throughout the three seasons show a similar pattern. According to Figure 2, dengue cases are dominantly found during the monsoon season from May to October. The South and Central Region sees smaller fluctuations of dengue cases in comparison to the North (Figure 2).

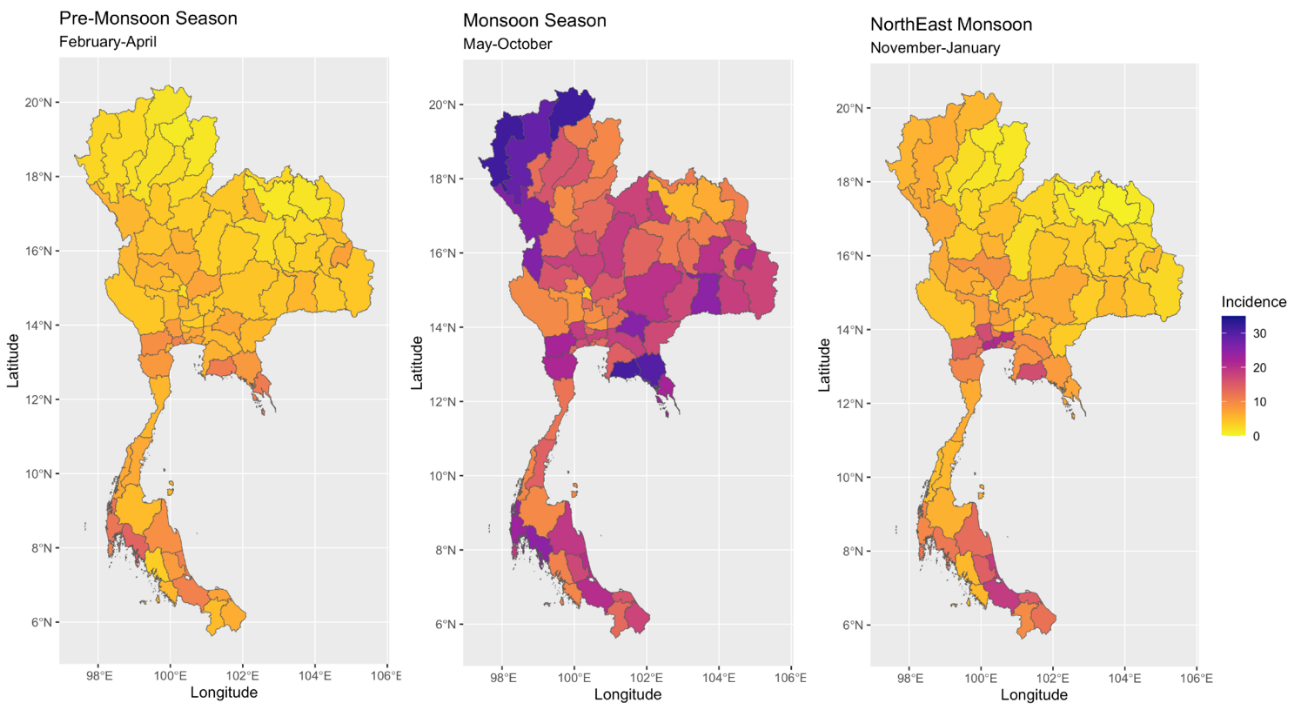

Figure 2: Temporal-Spatial maps visualising the incidence for different seasons in Thailand. The incidence was summed up over 15 years and normed for a month.

3.4 Incidence and Precipitation show a generally high Relationship

The heatmaps analyse the relationship between precipitation and incidence throughout the regions. In the northern and northeastern region, the precipitation period ranges from May to October. The dengue incidences peak in a similar manner from June to August, in the northern region even until September. In the South, high precipitation is almost present throughout the whole year, in particular from April to January. The high values for dengue incidences are scattered all over the year. However, the incidences still peak around June to August, while the precipitation peaks in October to December. The high precipitation and dengue cases from November to January occur during the northeast monsoon, while less dengue cases are observed during February to April. The incidences, however, are still higher than in the North and Northeast. The central region displays a similar precipitation pattern as the northern and northeastern region; however the dengue incidences are scattered from June to December. In individual years, high incidences occurred even in January, where the precipitation was minimal (Figure A3).

The Temporal-Spatial maps in Figure 3 provide an overview of patterns describing the relationship between precipitation and incidence. In the following, the Incidence and Precipitation are overlapped to compare the variables throughout the seasons: The exact same colourscience "Plasma" was used to compare the two variables. A stark contrast in circle colour, representing incidence, and the background fill, representing precipitation, would indicate independence between the two variables. To make the comparison fair, the highest intensity purple corresponds to the highest incidence/precipitation recorded; the highest intensity yellow corresponds to the minimal incidence/ precipitation recorded.

The pre-monsoon season displays generally similar colours, therefore indicating a close relationship between precipitation and incidence. In the monsoon season, the colours also resemble each other, indicating a relationship. The minor differences in hue might be due to the non-linear correlation between incidence and precipitation and the scale used. While the northeast monsoon season is generally coherent with the prior findings, the region around Bangkok displays a starker contrast between incidence and precipitation. Therefore, we can see a contrast in precipitation and incidence in Central Thailand both in the heatmaps and temporal-spatial maps. This required further investigation (Figure 3).

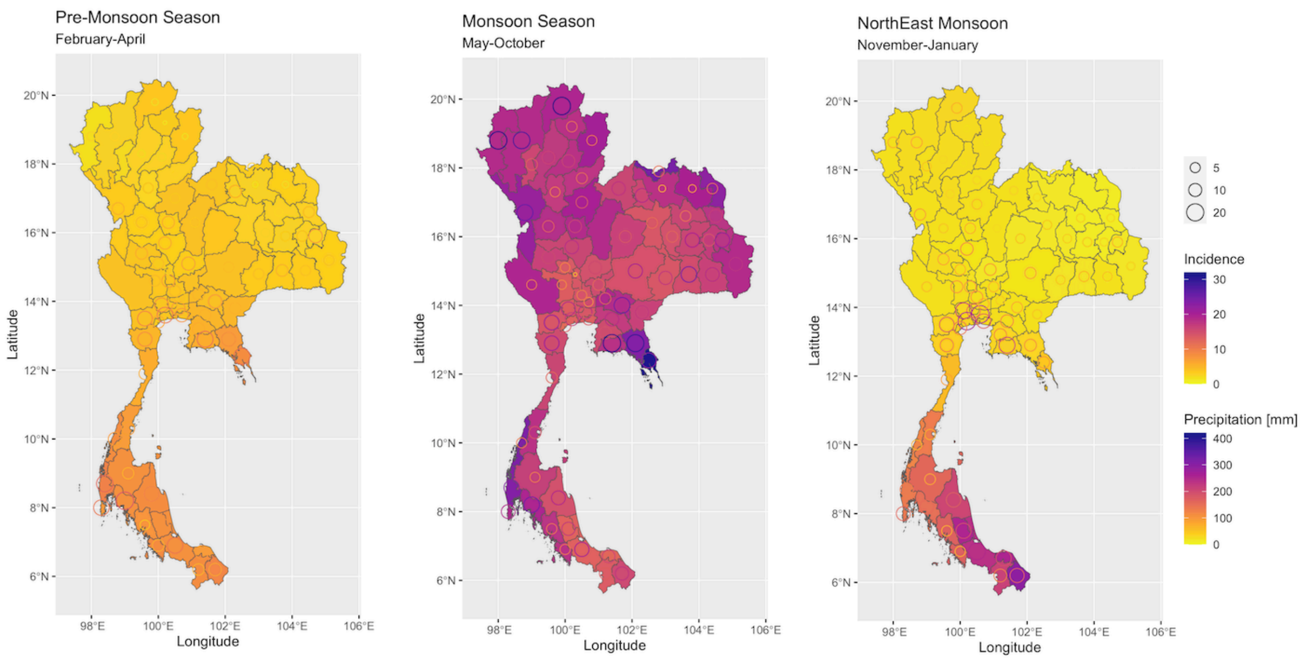

Figure 3: Temporal-Spatial maps visualising the precipitation and incidence. The size and colour of the circles represents the incidence while the background colour represents the precipitation.

3.5 Bangkok and Southern Central Region have high Incidence and low Precipitation.

The region around Bangkok seems to have a generally higher incidence throughout the year. The following Figure 4 zooms into the region around Bangkok and highlights the difference in incidence and precipitation.

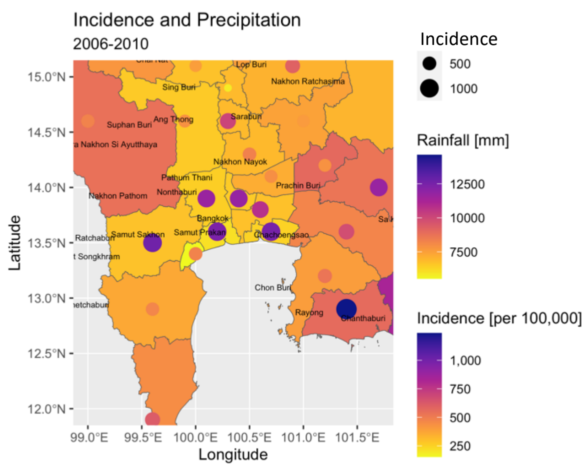

Figure 4: Temporal-Spatial map visualising the contrast between low precipitation and high incidence. The size and colour of the dots represents the incidence while the background colour represents the precipitation.

When comparing the total incidence and the total amount of precipitation in the years 2006-2010 in the provinces around Bangkok, we can see a clear contrast. Although the region surrounding Bangkok has experienced relatively little rain, the incidence is comparably high. Therefore, Bangkok and the surrounding area might have different factors contributing to the high incidence of dengue fever. Bangkok and the surrounding area are the centre point in which all rivers converge. This may be a factor contributing to high incidence in the area (Figure A5).

3.6 Spearman Correlation is high in the Northern and Northeastern Region and low in the Southern and Central Region

To further analyse the relationship between precipitation and dengue incidence, Spearman correlation was used. Both no lag and 1-month lag were taken into consideration since they have different effects on different regions. The northern and northeastern region have a high correlation in every province, both with no lag and 1-month lag (Figure5a,b) On the contrary, the provinces of the southern region have low no lag and 1-month lag correlations. The provinces of the central region, display a spread in their correlation coefficients. The highest correlations are on the same level as those from the northern and northeastern region and the lowest are on the same scale as the ones from the southern region. The correlation decreases from north to south (Figure 5c).

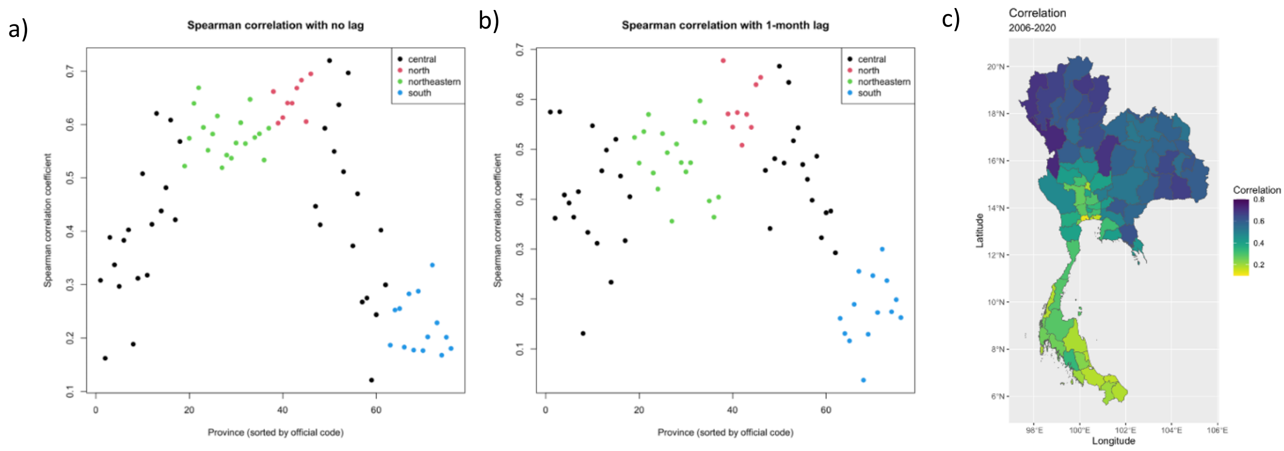

Figure 5: Spearman correlation between precipitation and incidences for every province. (a) Spearman correlation for every province with no lag. (b) Spearman correlation for every province with 1-month lag. (c) Spearman correlation for every province with no lag in a Temporal-Spatial map.

The Spearman correlation between precipitation and incidence in South Central Thailand appears to be significantly lower compared to the other regions. This perfectly matches with the stark contrast between high incidence and low precipitation seen in the same area. This further supports the theory that the precipitation might not have such a strong influence on the incidence in South Central Thailand.

3.7 The Predictive Chance of finding Dengue Incidence is equal across Thailand

The GAM analysis indicates weak linearity between incidence and precipitation according to the edf. The GCV-values are high suggesting a bad fit of our model. Predictions were made from the fitted GAM. The impact of precipitation on the distribution of dengue incidences during the monsoon season in Thailand was visualised in a spatial plot (Figure 6). Every region in Thailand has a high predictive chance of experiencing incidences between 18 and 19 dengue cases per 100,000 citizens. While the variance across Thailand is very low, the highest incidence is predicted to occur on the west coast of Northern and Southern Thailand and in the south of Central Thailand.

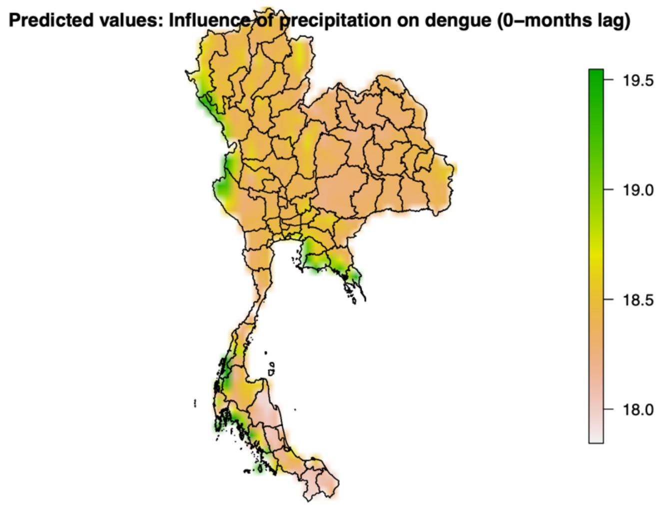

Figure 6: GAM spatial plot. The predictive chance of finding dengue incidence in Thailand.

3.8 Stationarity is highest in the South over a Year

In a year, the change in incidence follows a seasonal pattern, highest in the monsoon season while falling off in the other seasons. This is supported by the Dickey-Fuller test, which is computed for each year in a time frame from 2006-2020. This suggests non-stationarity for most years in all regions except for the south. The south displays generally lower p-values of the Dickey-Fuller test, indicating higher levels of stationarity. In 2006, 2011 and 2017, stationarity is observed in the south. Overall years, the relationship is non-stationary (Figure A6).

4. Discussion

4.1 Precipitation and Dengue have no Lag

The monthly precipitation and incidence had the highest Spearman correlation with no lag at all. Therefore, our analysis was performed with no lag. However, there could be a visible lag in combination with other factors such as temperature, humidity, and other variables. In another study, precipitation was linked with either no lag or a 3-week lag, confirming no lag as our "lag of choice" and simultaneously explaining why 1-month lag yielded a higher correlation in certain years. (Chumpu *et al.*, 2019). This results in a mix of both no lag and 1-month lag showing a relationship between precipitation and dengue, depending on the specific timing. However, the Spearman correlation as the method to determine the best lag may be misleading, as it measures monotonic relationships.

4.2 The Densely built Central Region Experiences a low Correlation between Precipitation and Incidence

The central region displays a decoupling of incidence and precipitation throughout the year. The precipitation is high during the southwest monsoon season from May to October, while elevated incidence is prominent from June to December. The total incidence from 2006-2020 is high compared to other regions, while the precipitation in the same time frame is comparably low. The weak relationship between dengue and precipitation is supported by the low Spearman correlations for the central region. This does not rule out a non-monotonous relationship between the variables, but it shows a more decoupled relation. The low correlation between precipitation and incidence is supported by various studies analysing dengue fever in urbanised environments such as Bangkok (Chumpu *et al.*, 2019).

Although rainfall generally increases the breeding sites for mosquitoes, its impacts on dengue transmissibility in the central region is moderate. A study indicates that the peak dengue incidence in Bangkok usually occurs outside the rainy season (Polwiang, 2020). Naturally, precipitation is not the only factor influencing dengue transmission rates. In Singapore, Struchiner *et al*. determined urbanization as the primary reason for rapid dengue growth in the past 40 years (Struchiner *et al.*, 2015). This is probably equally the case for Bangkok, as it is one of the most densely built capitals in the world (National Statistical Office of Thailand, 2021). In urban hubs like Bangkok, mosquitoes can breed in human-made water containers such as jars, pools, and discarded tires.

These sites are largely independent of rainfall and can contribute to high mosquito populations outside of the rainy season. Moreover, clogged-up drainage systems and the high amount of concrete in the city prevents percolation. Li *et* *al*. confirms the influence of urbanization on dengue incidence by observing an increase of mosquito survival in urban areas, leading to a rise in infections (Li *et al.,* 2014). Therefore, the deviation of the dengue incidence pattern from precipitation is caused by the densely built area of Bangkok and surrounding provinces.

Another factor to consider is that the area around Bangkok is the centre point of all rivers in Thailand. The river and its side channels are breeding grounds for mosquitoes. Although not being as attractive as standing water, the river system may contribute to the high dengue incidence in the central region.

4.3 The Rural Nature of North and Northeastern Thailand explains the close relationship between Dengue Incidence and Precipitation

The north and northeastern region confines the peak of its incidence inside the monsoon season from May to October. The number of incidences dramatically falls off before and after the monsoon season. This corresponds to the minimal amount of rainfall the region experiences outside of the monsoon season. They both follow a similar parabolic course. These patterns indicate a high relationship between the two variables in Northern and Northeastern Thailand. The high Spearman correlation coefficients further supports the notion that the two variables contain a monotonic component to their association. They grow and fall in a similar manner.

We have discussed the role of urbanization and large cities on the decoupling of dengue fever and precipitation. The North supports this notion by providing a contrast to the densely populated central region. The strong relationship between incidence and rainfall in the North may occur due to the geographical and urban conditions. Unlike the central region, the North and Northeast only contain a few smaller cities, all not surpassing 250,000 inhabitants (Worldpopulationreview, 2023). According to the National Statistical Office of Thailand, 66% of the population of the central region live in municipal areas. In the North and Northeast 22.6 % of the population live in municipal areas (Source NSO).

4.4 Abnormal Weather Phenomenons shape Southern Thailand´s Infection Rates

The southern region experiences high rainfall throughout the year due to its location between the Gulf of Thailand and the Andaman Sea. The South is subjected to both the northeast and southwest monsoon, increasing the duration of its rainy season up to January. The weather pattern in the South therefore differs strongly from the other regions. The dengue incidence is spread across the whole year, with its peak mostly during the southwest monsoon season. The incidence and precipitation in the South generally experience years with higher stationarity in comparison to the other regions. The incidence and precipitation are therefore more likely to fluctuate around a constant mean throughout the year, indicating lower seasonality. This suggests that incidence and the precipitation are more likely to stay the same over the year compared to the other regions. The Spearman correlation in the South is generally very low. A low correlation is expected if both the precipitation and the incidence follow a generally stationary course, which is suggested. However, the possibility of a non-monotonous relationship cannot be excluded.

Rainfall has been found to correlate with dengue in many southern provinces in Thailand, such as Prachuap Khiri Khan, Pattani, Phuket (Thammapalo *et al.*, 2005), and Nakhon Si Thammarat (Wongkoon *et al.*, 2013). This can be observed by looking at the higher incidence in the South during the northeast monsoon compared to other regions (Figure 3). But why do we experience low correlation values between incidence and rainfall?

The South experiences large amounts of abnormally high precipitation events in comparison to the other regions. Thammapalo *et al.* discovered that higher than the usual monthly levels of rainfall, mainly present in the south, had a negative correlation with the dengue incidence. Heavy rain may have an instantaneous negative effect on Mosquito populations due to the larvae being washed away during heavy downpours (Li *et al.*, 1985). The prevalence of a negative correlation between incidence and precipitation during extreme precipitation events may explain the low correlation values that were calculated in the South for the entire time frame of 15 years. The approach that is required to provide meaningful results is to factor out extreme precipitation events and to then recalculate the correlation. It would also be interesting to calculate a correlation measure for non-monotonous data and review correlations between smaller timeframes.

Another possible explanation for the low correlation between dengue incidence and precipitation lies in the large amounts of urbanization and construction in the region which may also contribute to dengue transmission (Wongkoon *et al.*, 2007). The south of Thailand has some of the highest foreign investments into the tourism sector and infrastructure, which increases labour mobility and the number of tourists. This increases the risk of importing dengue fever cases from other endemic areas and countries (Lie *et al.*, 2012).

4.5 Further Limitations in the Study

There are various limitations in the study. Firstly, the dengue infection are likely underestimated because people who are diagnosed with only mild or asymptotic systems are not registered in the local incidence do to not seeking medical attention. C.Chastel estimates the number of dengue infections to be 4-6 times the reported cases. However, these “uncounted” cases are less likely to contribute to drastically false results since the infection-to-case ratio changes equally with a change in precipitation.

Secondly, Bangkok being the centre of commerce and education in Thailand, experiences millions of day commuters coming from surrounding areas each day. These commuters might seek medical care elsewhere, while originally being infected in Bangkok. Therefore, it is vital to take the increased human mobility into consideration when analysing patterns in incidence and climate variables.

4.6 Making predictions for all provinces of Thailand simultaneously is a challenging Task

We can see consistently high dengue incidences during the monsoon season until 2040 across Thailand. This pattern is a direct continuation of what we currently see during the monsoon season. High risk clusters such as the west coast of the northern and southern region and the south coast of the central region predicted by the GAM match current high-risk clusters. It is questionable whether the results of our performed GAM are significant, particularly because of the poor GAM fit.

Making reliable predictions across the entirety of Thailand is a significant challenge due to the inherent complexity and diversity within the data set. A majority of existing prediction models are inadequate according to Leung *et al.*; Small amounts of variables, mostly climate variables, provide a limited accuracy of most prediction models (Leung *et al.*, 2023). Therefore Chumpu *et al.* highlights the necessity of modifying the climate variables used in a predictive model independently for separate provinces, because each province is affected by a certain set of variables. Each Province is subjected to a unique set of variables affecting its local dengue incidence (Chumpu *et al.*, 2019).

5. Appendix

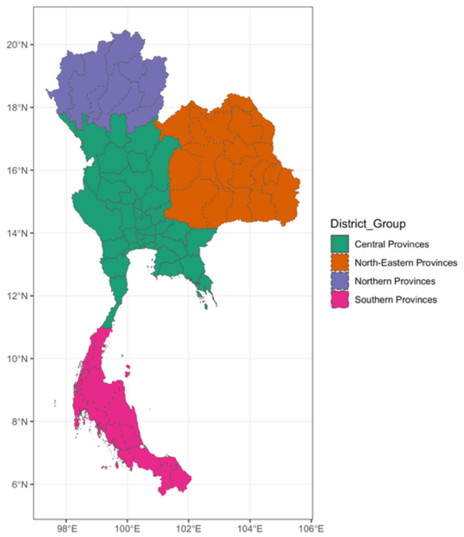

Figure A1: 4 Regions in Thailand. The central region, the northeastern region, northern region and southern region

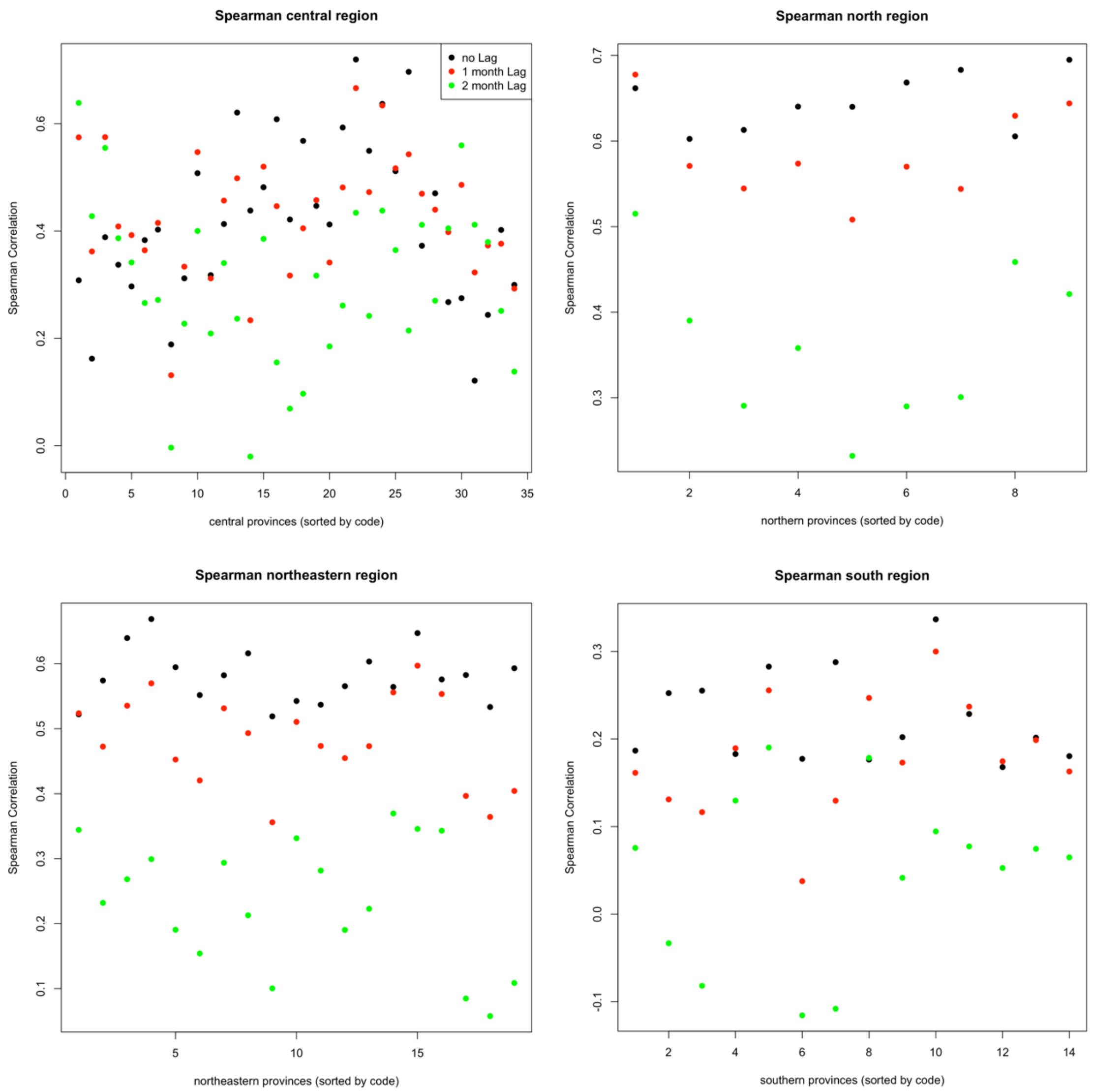

Figure A2: Spearman correlation for every province of Thailand with different lags between precipitation and dengue incidence. Plots for different regions: (a) central, (b) northern, (c) northeastern, (d) southern. Calculated for total time frame from 2006 to 2020. Calculated for no lag, 1-month lag and 2-month lag.

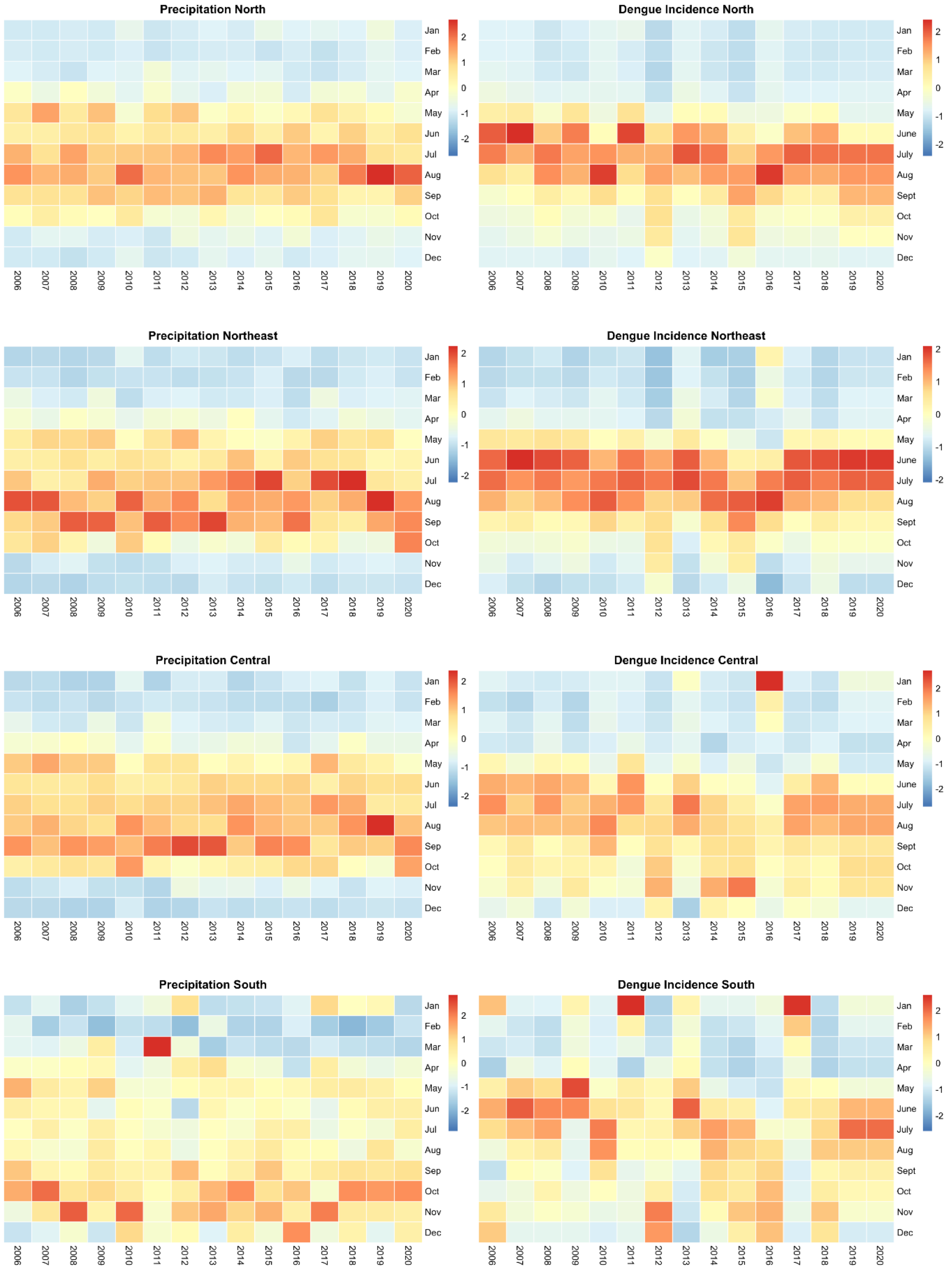

Figure A3: Precipitation and incidence heatmaps for every region. The heatmaps show either the precipitation or the dengue incidence. The rows show the months, while the columns show the years. It is scaled for every year (column-wise).

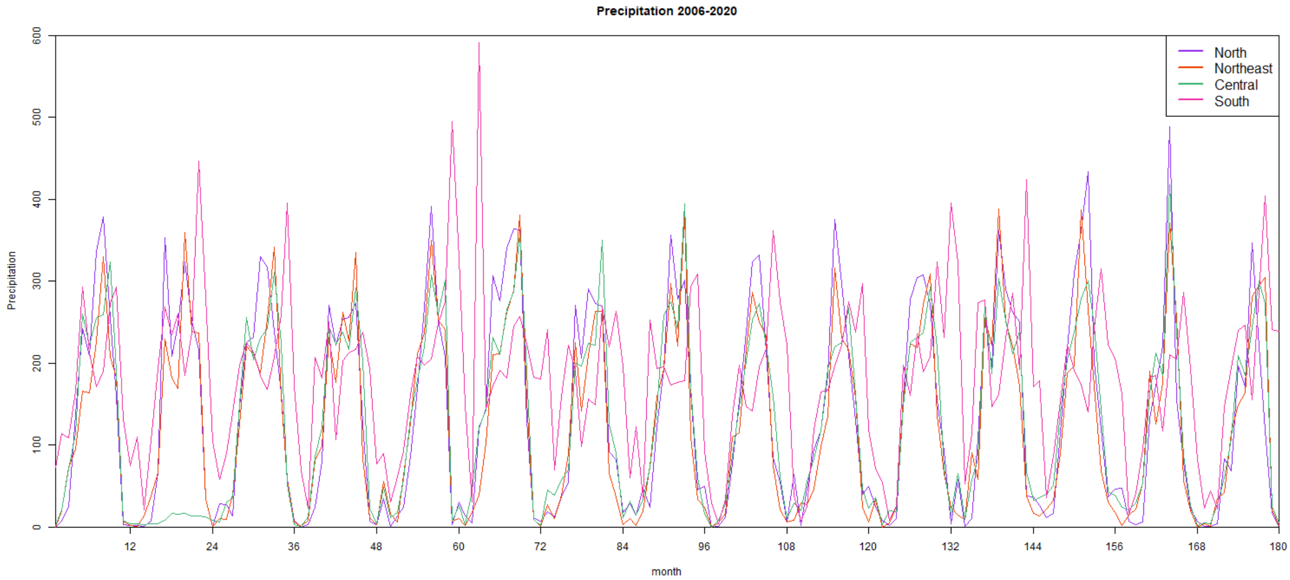

Figure A4: Precipitation time series from 2006-2020. Total precipitation for every region.

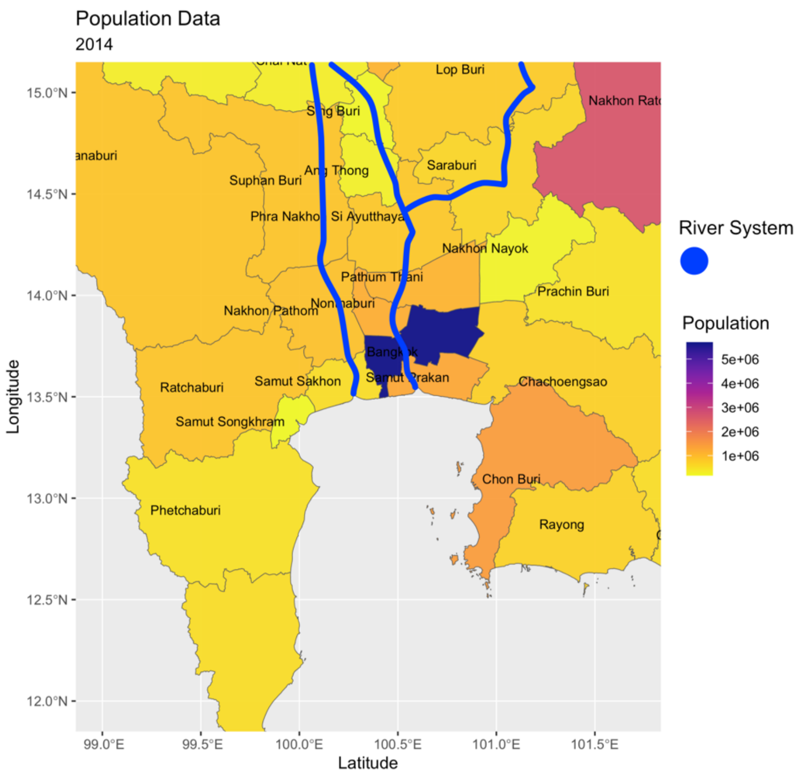

Figure A5: River system in central Thailand. Central Thailand is the centre point of all rivers in Thailand

Dickey-Fuller test: p-values										
Incidence						Precipitation				
years	North	Northeast	Central	South		years	North	Northeast	Central	South
2006	0,8506	0,956	0,9014	0,01		2006	0,9638	0,9702	0,99	0,8295
2007	0,8823	0,9048	0,9527	0,8606		2007	0,99	0,99	0,99	0,8021
2008	0,9766	0,9197	0,9571	0,9054		2008	0,9678	0,99	0,99	0,01
2009	0,79	0,8119	0,952	0,4625		2009	0,9837	0,99	0,99	0,7988
2010	0,9501	0,8942	0,9153	0,9303		2010	0,09138	0,5851	0,99	0,4486
2011	0,8142	0,9374	0,99	0,01378		2011	0,9661	0,99	0,99	0,06205
2012	0,9544	0,99	0,99	0,6082		2012	0,95	0,99	0,99	0,5359
2013	0,9626	0,0546	0,9847	0,6502		2013	0,4561	0,98	0,99	0,2171
2014	0,9766	0,9539	0,6665	0,9256		2014	0,99	0,6938	0,05577	0,1271
2015	0,2958	0,9073	0,4513	0,9706		2015	0,8831	0,9418	0,9735	0,9868
2016	0,9673	0,5795	0,01	0,2966		2016	0,9318	0,9816	0,9823	0,4208
2017	0,99	0,824	0,99	0,01		2017	0,99	0,9672	0,99	0,2211
2018	0,9702	0,9041	0,9668	0,9025		2018	0,5725	0,7447	0,8327	0,01634
2019	0,9088	0,9593	0,9854	0,9873		2019	0,9273	0,99	0,9724	0,8475
2020	0,9088	0,9593	0,9854	0,9873		2020	0,7968	0,5141	0,9798	0,7695
mean	0,87988667	0,83706667	0,7942875	0,59568		mean	0,830692	0,8879	0,91376467	0,47287933
2006-2020	0,01	0,01	0,01	0,01		2006-2020	0,01	0,01	0,01	0,01

Figure A6: p-values of Dickey-Fuller tests. Made for every year and region for both incidence and precipitation.

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