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STATISTICAL MODELLING FOR FORECASTING LAND SURFACE TEMPERATURE CHANGE IN THAILAND

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Abstract

It is anticipated that Thailand's climate will keep changing. Due to its increased sensitivity to natural hazards for example severe rainfall, floods, forest fires, deforestation, and vegetation fluctuation. It is extremely vulnerable to the effects of climate modification. However, the variations in the Land Surface Temperature (LST) are a major cause of climate change. The study aims are to explore the daytime LST yearly seasonal patterns and trends, and to forecast LST variation in sub-regions and regions in Thailand. The daytime LST time series data from 2000 to 2023 was downloaded from the Moderate Resolution Imaging Spectroradiometer (MODIS) website. To model the yearly seasonal patterns of LST in the daytime was applied the natural cubic spline method with eight knots. The linear regression model was used to demonstrate the LST trends. Moreover, to forecast LST trends over 23 years was applied a cubic spline with 2, 3, and 4 knots. Finally, to adjust spatial correlation and to estimate the increase in daytime LST was used the multivariate regression model. The results show that, there was an increasing LST trends in Thailand. The daytime LST by sub-regions were increased in the southern and central of Thailand. Furthermore, the southern and central regions demonstrate the increasing trends of the daytime LST. The eastern region shows the stable while the northern region was likely increase of LST trends. The mean increase of LST per decade was 0.115 °C. Therefore, by applying a cubic spline with three knots to forecast the daytime LST trends demonstrates the significant rise trends compared with other spline knots. Nevertheless, LST of the daytime in Thailand is steadily increasing. The increasing reasons is needed to be explored in future studies.

Introduction

Land Surface Temperature (LST) is the essential idea of monitoring the ground temperature or earth surface temperature using satellite and technologies of remote sensing. LST is a significant environmental parameter that was apply in various climatology, urban, meteorology, agriculture, planning, and environmental monitoring. In addition, LST is the surface temperature of the earth's ground resulting from land surface-atmosphere interactions and energy fluxes between the surface and the atmosphere (Khandelwwal et al., 2018). The ability to monitor local and global climate change to better understand environmental conditions and how they affect the sustainability of human life is one of the major advantages of LST. Additionally, it has the ability to significantly alter the phenology of the seasonal vegetation index, which affects both the local and global energy balance (Islam & Ma, 2018). Furthermore, it is a significant parameter in surface-atmosphere interactions and climate variation. LST has gone up in some parts of the globe (Mustafa et al., 2020; Prasetya et al., 2020; Fitra- hanjani et al., 2021; Abdulmana et al., 2024). Furthermore, Lean and Rind (2009) found that, human activities (for example, deforestation, solar irradiance, anthropogenic effect, and volcanic aerosols) was effect to the daytime LST in the universal and had gradually risen. Nevertheless, it is a instrument for exploring climate variation on the earth surface.

Thailand, nestled in Southeast Asia, boasts a rich tapestry of landscapes ranging from lush rainforests to expansive plains and rugged mountains. However, this natural beauty faces a growing threat from the escalating LST due to the effects of global climate change. Climate variation from the global, driven by human activities for instance deforestation and burning of fossil fuels. The presence of air pollutants, such as particulate matter and greenhouse gases, can contribute to warming. Certain pollutants, like black carbon, can absorb sunlight and contribute to local warming. Therefore, Thailand's distinct seasonal variations the hot season, the rainy season, and the cool season further compound the complexity of its temperature dynamics. Each season engenders unique climatic phenomena, influencing temperature fluctuations and precipitation patterns across the country. Navigating these seasonal nuances is pivotal for policymakers and stakeholders seeking to devise targeted interventions that address the multifaceted challenges posed by rising LST.

However, there were many previous analyses using diverse techniques by applying statistical modeling to predict and forecast the daytime LST variation. According to Kesavan et al. (2021) was used autoregressive integrated moving average (ARIMA) method to evaluate and predict the daytime LST in Tamil Nadu state of India. A linear regression model and four knots cubic spline were applied to illustrate the LST trends and to forecast LST increase in Taiwan (Abdulmana et al., 2024; Abdulmana et al., 2022). Spatial correlations were produced using factor analysis and a sixth-order polynomial regression model to predict the patterns and trends of LST (Wanishsakpong & McNeil, 2016). Therefore, there have been a few analyses concentrating on forecasting LST variations by using cubic spline with suitable spline knots. This stud aims to model the seasonal patterns and trends of LST and to forecast LST change using cubic spline with 2, 3 and 4 knots.

Theoretical Framework

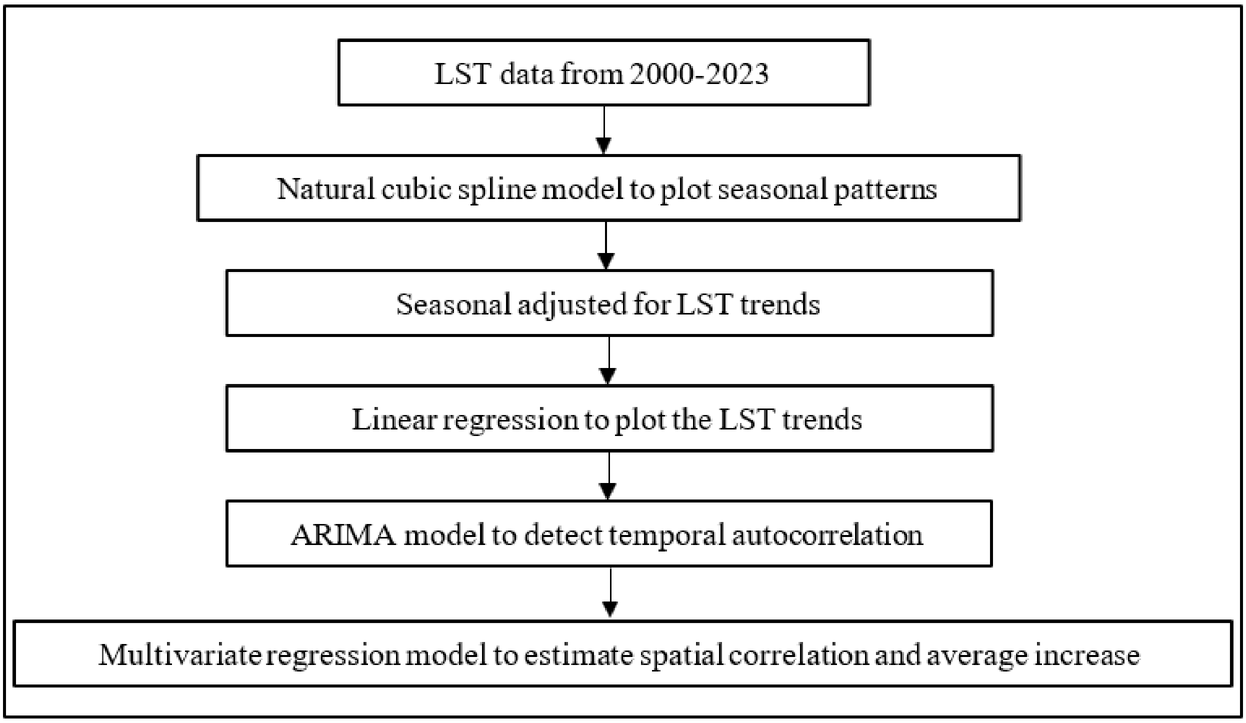

Figure 1: Theoretical framework of the study

Methodology

Study area

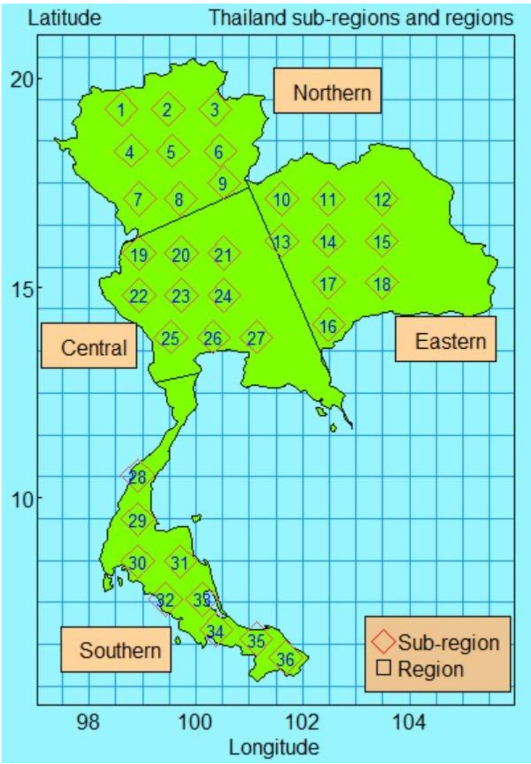

Figure 2: Study area

Thailand is the country that located in the center of mainland Southeast Asia. The main country body of Thailand is encompassed by Cambodia to the southeast, Laos to the north and east, Myanmar (Burma) to the west, and the Gulf of Thailand to the south. It is surrounding various ecosystems, consisting the rugged coasts along the narrow southern peninsula, the fertile rice fields of the central plains, the broad plateau of the northeast, and the hilly forested areas of the northern frontier.

In this analysis, Thailand area was separated into four regions which are the southern, central, eastern, and northern. In each region consist of nine sub-regions. There were 36 sub-regions including in this study, as demonstrated in Figure 2. To retrieve the coordinates of each sub-region was used the Google Earth program. The MODIS Land (MODLAND) tile calculator website was used to calculate and retrieve the tile horizontal and vertical coordinates, line number and sample in order to keep away from the overlap between sub-regions in allocating the latitude and longitude. Each sub-region area is 7×7 km2, which equals to 49 pixels in a 1×1 km2 grid.

Data used

The daytime LST data were obtained for every 1 km from the MODIS emissivity eight-day compound universal dataset, with daytime records spanning the period from March 2000 to November 2023. There was 45 observations in each year are made in each grid cell; hence, 1,035 observations over a period of 23 years total. The data product utilized in this research is called MODIS/Terra LST and Emissivity LST (MOD11A2).

Seasonal patterns of LST

The data of LST time series generally comprise seasonality as another time series data. Therefore, to illustrate LST patterns and trends over 23 years, the LST time series have to be adjusted for seasonality. The natural cubic spline function with definite boundary conditions was applied to ensure smoothness over the period of LST in each sub-region. This method was used by many previous analyses includingTaiwan (Abdulmana et al., 2024; Abdulmana et al., 2022), Peninsular Malaysia (Ismail et al., 2019), Central Sumatra (Prasetya et al., 2020), Nepal (Sharma et al., 2018), and Phuket Island, Thailand (Wongsai et al., 2017). The eight knots of a cubic spline were assigned and fit to the data in this model for the Julian days 10, 40, 80, 130, 240, 290, 330, and 360.

Seasonal adjusted of LST

Then, the seasonally adjusted time series were computed by placing the original values and subtracting them from the predicted patterns and adding the values of the mean to verify that the average daytime LST over the period of 23 years was unchanged. The formula takes the form:

$$y_{sa} = y - \hat{y}_t + \bar{y} \qquad [1]$$

where, y_sa is the seasonally adjusted daytime LST, y is the original value subtracted with yˆ_t which is the fitted value, plus the overall mean y¯of observed data.

Forecasting LST using 2, 3 and 4 knots cubic spline

However, for forecasting LST trends over 23 years, the study used 2, 3, and 4 knots of spline function to observe the suitable knot for forecasting. The knots cover the range of the data. Therefore, extreme knots correspond to the minimum and maximum time points, respectively. The natural spline, which is linear beyond the range of the data, was applied. With two boundary conditions needed to make the function linear outside the data range,

Therefore, to detect the temporal autocorrelation from the model was used Auto Regressive Integrated

Moving Average (ARIMA) model. The first (ARIMA) and second (ARIMA) order autoregressions were applied. The daytime LST trends from ARIMA models of each sub-region were demonstrated in a time series plot. Additionally, the increase of the daytime LST by regions was illustrated on the Thailand map to show 23 years of the daytime LST variations. Most of the time series variables are spatially correlated. To handle those spatial correlations, the average increases of daytime LST by regions were estimated by applying a multivariate regression model. The confidence interval of the increase of daytime LST and the acceleration increase of daytime LST per decade were illustrated using a forest plot.

Finding & Discussion

Seasonal pattern of LST

To model the seasonal pattern of daytime LST was fitted by using cubic spline function with eight knots as illustrated in Figure 3. Furthermore, eight knots were selected as they provide the highest r square. This analysis, the annual seasonal pattern plots of all sub-regions in Region 4 which is in southern of Thailand have been chosen to display the seasonal patterns. The X axis represents Daytime LST in degree Celsius (°C), and the Y axis shows the day of the year.

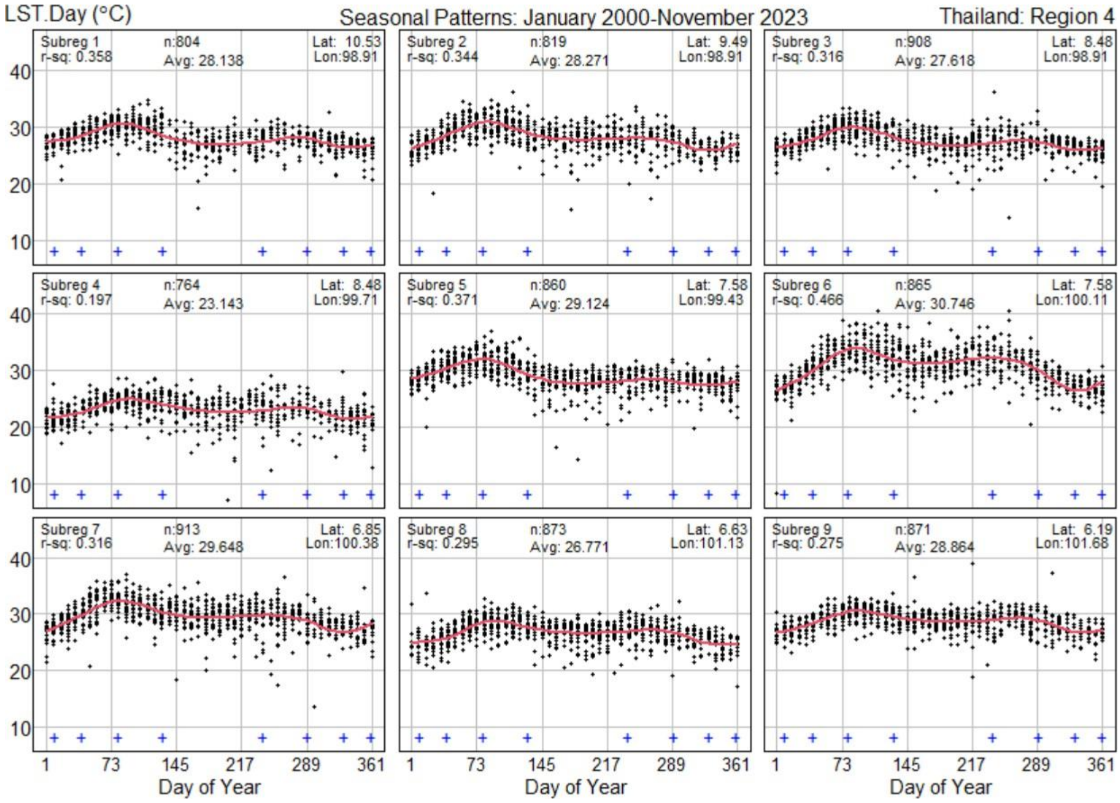

Figure 3: Seasonal pattern of Daytime LST

Figure 3 demonstrates the annual seasonal patterns that was fitted using eight knots of natural cubic spline function, represented by a blue plus sign. These nine plots illustrate the LST in the daytime of region 4 with nine sub-regions, which is in the southern of Thailand. Vertical stacks of points represent the mean ground surface temperatures for eight-day periods (the orbital period of the Terra satellite is eight days) recorded during 23 years from 01 January 2000 to 28 November 2023 based on 46 orbits per year. The n value shows the total number of observations. The result shows that there was a slightly rise of LST in daytime in February with a peak in March. From May there was a moderate reduce with the lowest point being achieved in cold from October to December. The annual seasonal patterns of daytime LST were a parallel with other sub-regions and regions.

Seasonal adjusted of time series and forecasting by using cubic spline with 2, 3 and 4 knots

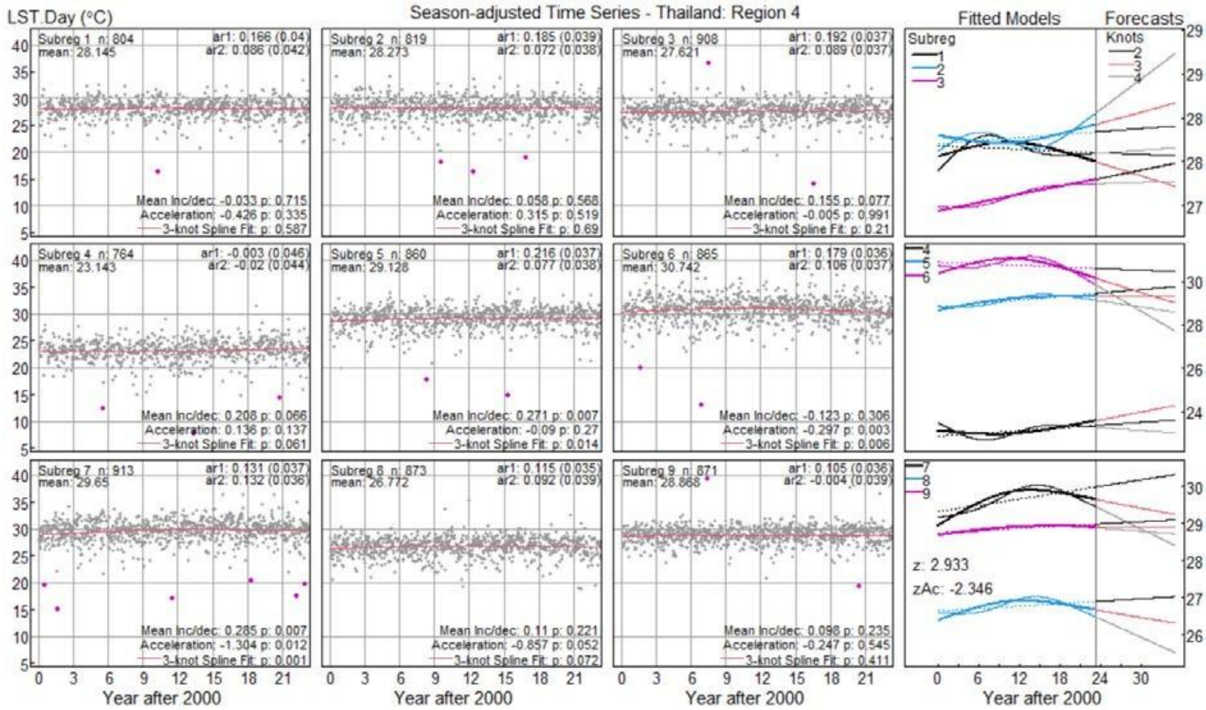

Figure 4: Seasonal adjusted of time series and forecasting by using cubic spline with 2, 3 & 4 knots

Figure 4 illustrates the LST trends from 2000 to 2023 by using ARIMA models based on cubic spline function in the Southern region of Thailand. Ar1 and ar2 denoted the first and second-order autoregressive values from using the ARIMA model, respectively. The right three plots show the curves of fitted models using 2, 3 and 4 spline knots to forecast LST increase or decrease of each three sub- regions in each row. The study found that sub-region 6 in Region 4 show the highest average of the daytime LST, which was 30.742 °C, whereas Sub-region 4 show the lowest average of the daytime LST with 23.143 °C. Therefore, there was a significant increasing daytime LST trends over 23 years by fitting the model for forecasting with three knots of cubic spline and high precise results comparing to other spline knots. To evaluate the daytime LST increase by sub-region were used the mean increases per decade and p-values as represent in Table 1.

Table 1: The mean increase/decade of the daytime LST with p-values for 36 sub-regions in Thailand from 2000 to 2023.

Variable	**LST**		**Variable**	**LST**	
Sub-region	**Increase**	**P-value**	**Sub-region**	**Increase**	**P-value**
1	0.142	0.073	19	0.186	0.052
2	0.037	0.713	20	0.406	0.001
3	0.015	0.847	21	0.179	0.215
4	0.138	0.228	22	0.378	0.001
5	-0.016	0.833	23	0.216	0.117
6	0.153	0.115	24	0.346	0.021
7	0.253	0.046	25	0.218	0.083
8	0.188	0.409	26	0.555	0
9	-0.087	0.436	27	0.195	0.113
10	0.219	0.109	28	-0.033	0.751
11	0.065	0.585	29	0.058	0.568
12	-0.478	0	30	0.155	0.077
13	0.026	0.82	31	0.208	0.066
14	0.085	0.489	32	0.271	0.007

15	-0.072	0.557	33	0.123	0.306
16	0.082	0.586	34	0.285	0.007
17	0.025	0.866	35	0.11	0.221
18	0.078	0.491	36	0.098	0.235

Variation by sub-region and region in Thailand

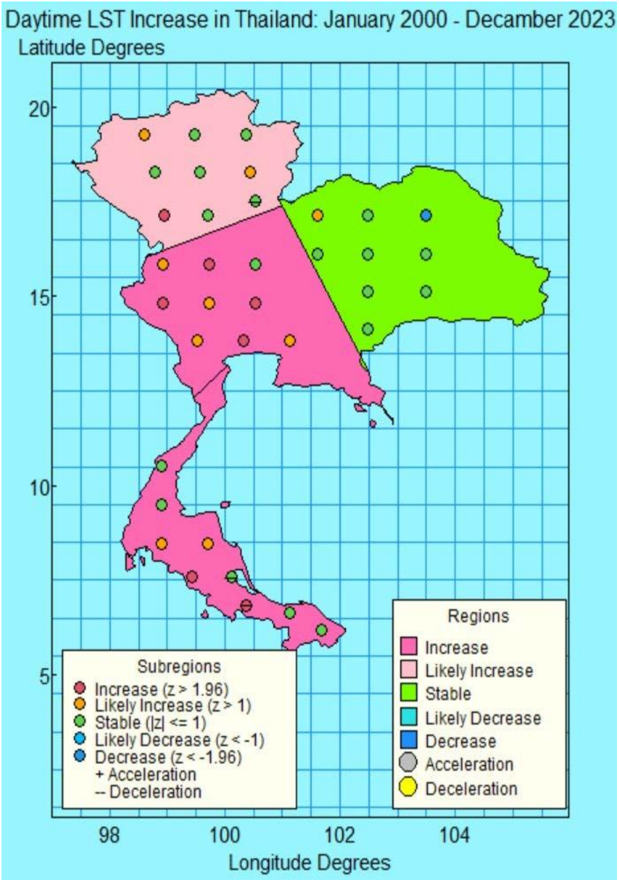

Figure 5: LST variation by sub-region and region in Thailand over 23 years

Figure 5 represents the regions and sub-regions of daytime LST variation. The legends at the bottom left and right show the variations of the daytime LST in different colours by sub-regions and regions overall 23 years. The value of decadal mean increase and p-values of each sub-region are retrieved from Table 1, and they were applied to define the increase and in daytime LST in sub-regions. If the p-value < 0.05 and increase value > 0, this was defined as increase (red); if the p-value < 0.159 and increase valued > 0, this was defined as likely increase (orange); if the p-value < 0.159 and increase < 0 was defined as likely decrease (light blue); if p-value < 0.05 and increase value < 0, this was defined as decrease (blue); and the remaining condition was defined as stable (green). The increasing and decreasing values of each region and z-value were retrieved from Figure 4. Z-values were used to define the increase and decrease levels. If the z-values of daytime LST > 1.96, this was defined as increase (red); if the values > 1 to 1.96, this was defined as likely increase (orange); if the values <= 1, this was defined as stable (green); if the values < -1 to -1.96, this was defined as likely decrease (light blue); and if the values < -1.96, this was defined as decrease (blue). The brown colour is defined as acceleration and the yellow defined is defined as a deceleration in the region. The analysis results illustrate that most of LST in the daytime by sub-regions were stable and increase of LST, except for the Sub-regions 12 was decrease of LST. The sub-region 1, 6, 10, 19, 20, 22, 23, 24, 25, 26, 27, 30, 31, 32, and 34, which had significantly increased of daytime LST. There was an increase in the daytime LST in all regions except in region 2 which is in the eastern of Thailand had stable of LST over 23 years.

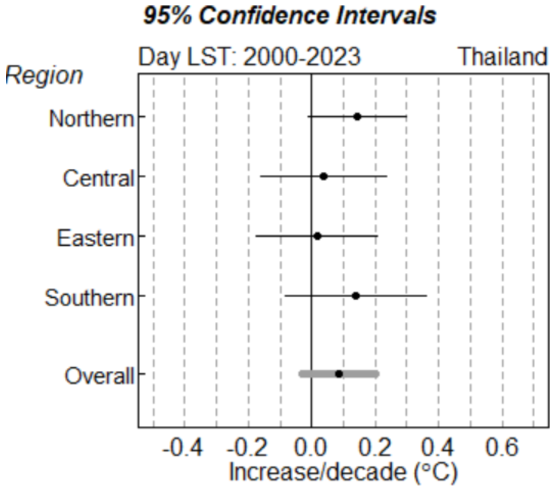

Figure 6: 95% confidence intervals of decadal daytime LST increases in Thailand from 2000 to 2023

Figure 6 illustrates a forest plot of the 95% confidence intervals range of LST increases in Thailand per decade. The specific region is denoted in the Y axis, which includes four regions: northern, central, eastern, and southern region. The X axis is representing the daytime LST increase per. The plot displays an increasing decadal of the daytime LST in all regions. The average increase per decade was 0.115 °C.

Discussion

Using a proper number of cubic spline knots and linear regression could effectively extract yearly daytime LST seasonal patterns and trends. This study used an eight knots of cubic spline method to model daytime LST seasonality, which was a similar method to many previous analyses (Prasetya et al., 2020; Abdulmana et al., 2024; Abdulmana et al., 2022; Wanishsakpong & McNeil, 2016; Ismail et al., 2019; Sharma et al., 2018). The average increase in daytime LST was 0.115 °C per decade, which indicates the rising trend of daytime LST and it was consistent with many previous studies (Islam & Ma, 2018; Mustafa et al., 2020; Fitra-hanjani et al., 2021; Sharma et al., 2018; Hamoodi et al., 2019). In addition, our study has parallel with the results that was study by the Rotjanakusol and Laosuwan (2018), Saelim et al. (2020) and Adulkongkaew et al. (2020) which reported that LST in Thailand has been increased.

However, for forecasting trends using three knots of cubic splines indicated that daytime LST in Thailand has been rising. Moreover, it is a suitable knot for forecasting daytime LST in this analysis with reasonably high accuracy. However, a cubic spline with three knots is appropriate for short-term forecasts. Therefore, the increasing trends in daytime LST are a result of the rapid population and urban growth in Thailand increases the need for vertical city development because of the limited territory, changes in radio solar reflectance, thermal emissivity, and heat capacity in built materials, subsequently leading to temperature increases in megacities of Thailand especially in Bangkok (Kachenchart et al., 2021).

Conclusion and Future Recommendation

This analysis illustrated a successful method for modelling and forecasting time series data with temporal and spatial variation of LST in the daytime. The analysis illustrated that there was rise and stable in the average of LST per decade in almost all sub-regions except for sub-regions 12 was decline. Moreover, the region level indicates an increasing trend in all regions except in eastern of Thailand. Daytime LST in Thailand has increased in the past two decades and continues to increase. The mean increase in daytime LST was 0.115 per decade. The increasing surface temperature is affected by urban expansion, deforestation, and farmers, especially in the central and southern region. This rise could be used to warn Thailand policymakers to better plan and deal with future global warming.

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