KÖPPEN-GEIGER CLIMATE SYSTEM CLASSIFICATION AND FORECASTING IN THAILAND

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Abstract
Köppen-Geiger Climate Classification system (KGC) is one of well-known climate classification method with only rainfall and temperature values. This study aims 1) to update current total monthly rainfall, average monthly temperature and KGC map of 1987 – 2019 period and 2) to predict total monthly rainfall, average monthly temperature and KGC map of 2020 – 2060 and 2061 - 2100 period. The study was extracted by gathering total monthly rainfall and average monthly temperature from 104 meteorological stations over Thailand then cooperated with GIS process to classify and present climate type of 1987 – 2019. Moreover, Beijing Climate Center Climate System Model version 1.1 (BCC-CSM1.1) was used to forecast rainfall and temperature value to determine climate zone of Thailand of 2020 – 2060 and 2061 – 2100 period. The results of present period illustrated that Thailand climate was classified into three types: dry-winter characteristics (Aw) as a major climate, following by Tropical monsoon climate (Am) and Dry-winter humid subtropical climate (Cwa). In contrast, predicted values displayed only "Aw" and "Am" appearing in the mid and late twenty-first century, respectively. "Aw" climate covered the most area of Thailand with 90.14%, 91.85% and 96.37% while "Am" climate covered 8.77%, 8.15% and 3.63% for present, mid, and late twenty-first centuries period, respectively of a small area of Eastern part and almost half Southern region. Furthermore, "Am" climate was also predicted to appear in east side of Northeast region in 2020 - 2060 period whereas "Cwa" was appeared in small area of Northern region in 1987 – 2019 period. The up-to-date maps of rainfall, temperature value and KGC zone can be evidences to remind about climate change and support the future work.

Key words
Köppen-Geiger Climate Classification, Climate Change, Rainfall Variability, Equatorial Climate and Climate of Thailand

INTRODUCTION

Climate change is an important issue which all global sectors concern about. This problem is started to talk wildly after industrial revolution period due to an increasing of CO_2 and deforestation including an increasing of population. These major causes lead the land Surface Temperature and ocean temperature rising (Berila and Dushi, 2021). Moreover, these causes also lead the global temperature increasing

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more than 1 °C in 150 years past. (Jedlák, 2013; Neukom et al., 2019) In the same way, Thailand had to face with this issue, e.g., an increasing of air temperature in summer of Thailand and a longer drought period. (Phumkokrux and Rukveratham, 2020) Climate change issue also affects to agricultural activities, water reservation, health, ecosystems, social economy, and climate system, however; an intensity of the effects depended on variety of Thailand's topography. (Kisner, 2008)

The first global climate classification map has invented to define and discuss about climate system in each region in 1900 by a Russian-German geographer, meteorologist, climatologist, and botanist, named Wladimir Peter Köppen. (Köppen, 1900; Köppen, 1901) Moreover, Thornthwaite claimed in 1943 that Köppen got an inspiration from the theory of Swiss French botanist, named Augustin Pyramus de Candolle who has separated vegetation into 5 main groups by focusing on only temperature and precipitation (moisture). (Thornthwaite, 1943) These are the major factors which directly affect to variety of vegetation and ecosystems in the world thus these can be used to classify global climate into 5 major global climate groups (30 sub-types climate zone) (Sanderson, 1999; McConnell and Steer, 2015) Then, a German meteorologist and climatologist named Rudolf Oskar Robert Williams Geiger worked with Köppen to develop the climate classification in 1954 and 1961, called Köppen-Geiger Climate Classification system (KGC). (Geiger, 1954; Geiger, 1961) Therefore, the average monthly temperature, average seasonal temperature average monthly precipitation, total annual precipitation are simple statistical data which can define climate boundaries in any region for KGC (Chen and Chen, 2013)

Although there are many theories to classify climate zone by other climate experts, Köppen-Geiger Climate Classification system (KGC) is still widely present in many textbooks including in Thailand. Therefore, improvement of KGC maps is necessary to display and access easily in digital form. There are 3 famous recent versions of KGC maps which has published in 20th century period to present the updated world climate, produced by 1) Kottek et al. (2006) created a map based on CRU TS 2.1 and VASClimO V1.1 for monitoring air temperature and precipitation in monthly values, respectively at 0.5°-degree latitude/longitude grid with the factors data in 1951-2000 from about 7000–17,000 meteorological stations, 2) Peel et al. (2007) published a KGC map in global scale at 0.1 x 0.1 degree latitude/longitude grid, using climate parameters from 4279 observation stations then, the map is performed by raster interpolation technique (spline) and 3) Chen and Chen (2013) produced map at 0.5 x 0.5 latitude/longitude grid using average monthly temperature and precipitation data of 1901–2010 from Global Historical Climatology Network version 2 (GHCN2) and the Global Surface Summary of Day (GSOD). Moreover, there are 2 recent research groups, studied and published future KGC maps using various climate modelling, which are 1) Kriticos et al. (2012) presented the future KGC maps using air temperature, precipitation, and relative humidity datasets from CRU CL2.0 and WorldClim then, using IDW technique to analyse and present the maps. And 2) Beck et al. (2018) forecasted KGC map in the period of 2071–2100 using historical and future data of average monthly temperature and total monthly precipitation from Coupled Model Intercomparison Project Phase 5 (CMIP5) then, modelled with Representative Concentration Pathway 8.5 (RCP8.5). However, climate zone analysis in country scale may be difficult to identify and analyse climate change issue from previous KGC world map thus these following researchers tried to adapt KGC method to define climate zone and summarize climate issues in each small area. e.g., Diaz and Eischeid (2007) also applied KGC method to monitor climate zone in the western United States. Alvares et al. (2014) focused on updated KGC map in Brazil using climatological data from 2,950 stations. The rainfall and temperature maps were produced with resolution at 100 metres, cooperated with geographical coordinates and altitude. While the final climate map of Brazil was performed with a high spatial resolution at 1 hectare. and Sarfaraz et al. (2014) produced KGC map of Pakistan which has different climate types depending on different altitude to 8,611 metres from MSL, using air temperature, precipitation, and altitude datasets of 1981-2010 from 59 meteorological stations then, generated maps by IDW technique.

As all mentioned above inspired the author to study a climate zone by using KGC theory in country scale of Thailand thus, the objectives of the study are 1) to update current total monthly rainfall, average monthly temperature and KGC map of 1987 – 2019 (present period) by gathering climatological data from 104 meteorological stations and 2) to predict total monthly rainfall, average monthly temperature and KGC map of 2020 – 2060 and 2061 – 2100 (mid and late twenty-first century period) by gathering historical and future climate factors datasets from BCC-CSM1.1 (in CMIP5). The maps can be supported the future work to monitor and plan to cope with climate change issues in Thailand.

OBJECTIVES

1) To update current total monthly rainfall, average monthly temperature and KGC map of 1987 – 2019 (Present period).
2) To predict total monthly rainfall, average monthly temperature and KGC map of 2020 – 2060 and 2061 - 2100 (mid and late twenty-first century period).

KÖPPEN-GEIGER CLIMATE CLASSIFICATION SYSTEM (KGC)

The Köppen-Geiger Climate Classification system (KGC) is an easy method to determine world's climate zone without complex and expensive equipment. The KGC collects only near-surface air temperature and precipitation data in each area. (Kottek et al, 2006; de Sá Júnior et al., 2012) The KGC method use English alphabet and number as a climatic symbol in each region. The steps of KGC consideration are following: 1) the first letter is a capital English alphabet which is referred to the major climate in each region such as "A" defines to Equatorial or Tropical climates, "B" refers to Arid or Dry climates, "C" adverts to Warm or Mesothermal climates, "D" mentions to Cool or Microthermal climates, "E" adduced to Polar climates and "H" refers to Highland climates. 2) the second letter, it is small English alphabet which is referred to the volume of precipitation in each season. In case of "A", "C" and "D" types, "f" refers to constantly moist rainfall through months of a year, "m" mentions to monsoon rain and short dry period, "w" and "s" adverts to long dry period usually in winter and summer respectively but rarely found in any area for "s". However, the second letter in case of "B" and "E" is a capital English alphabet, refers to specific climates such as "S" refers to Steppe or Semiarid climate and "W" is True desert or Arid climate, "T" adduces to Tundra climate and "F" refers to Ice cap climate. And 3) the third letter can identify characteristic of temperature in summer in case of "C" and "D" such as "a", "b", "c" and "d" can represent that the temperature is hot, warm, mild, and cool in summer, respectively. However, the third letter for "B" is used to analyze the specific climate which are: "h" for hot and dry climate and "k" represents cold and dry climate. (Rohli and Vega, 2008) The detail of KGC can be described in the Tab. 1 and 2.

DATA AND METHODS

Study area and Meteorological data

This project focused on total area of Thailand, which is located at latitudes between 5° 37′ N - 20° 27′ N and longitudes between 97° 22′ E - 105° 37′ E, covered about 518,000 square kilometres in Southeast Asia. (Department of Mineral Resources, 2016). Thailand is separated to 5 meteorological regions by meteorological criterion, which are 1) Northern region consists of 15 provinces with high mountain ranges which are located from north to south direction, alternated with the valley. The highest peak of Thailand can be found in this region, up to 2,560 metres above mean sea level at Doi Inthanon. 2) Northeast region covers 20 provinces with plateau as a dominant topography (Slanting from west to east direction). There are three high mountains which are located as a barrier between northern, central, eastern part of Thailand and Cambodia with the peak at 400 – 1,300 metres above mean sea level which can block any humidity from the closest ocean. 3) Central region covers 18 provinces with large plain as a notable topography and the south side is located next to Gulf of Thailand. The small mountains can be found, however; the highest mountain also can be found around west side as a barrier of Thailand and Myanmar with the highest peak up to 1,600 metres above mean sea level. 4) Eastern region consists of 8 provinces, which is located next to Gulf of Thailand at west and south side. The outstanding topography is undulating plain. And 5) Southern region covers 16 provinces, which is flanked with Gulf of Thailand and Andaman Sea thus, so much humidity and rainfall can be found. There are high mountains which are located from north to south direction, are separated this region into two sides (West side next to Andaman Sea and East side closed to Gulf of Thailand). The topography of Thailand and study area maps are presented in Fig.1(a). Moreover, air temperature and precipitation value are so high through year with average annual temperature about 25-27 °C and total annual precipitation about 1,200 – 1,600 mm per year. (Meteorological Department of Thailand, 2016)

Data, Equipment and Methodology

The necessary data were separated into 2 types, which are: observation data and prediction data. Unfortunately, Unfortunately, there were difficut to collect perfect data of Average monthly temperature values (T_{am}) and total monthly precipitation or rainfall values which were used as observation data (P_{tm}) in long period (more than 40 year record) in many meteorological stations due to imperfect from recording and technical problems thus, T_{am} and P_{tm} of the present period were collected from just previous 33 years (1987 – 2019). The data were prepared by 104 meteorological stations under Meteorological Department of Thailand covering all 5 regions of Thailand. The detail of meteorological station is illustrated in Fig. 1(b) and Tab. 3

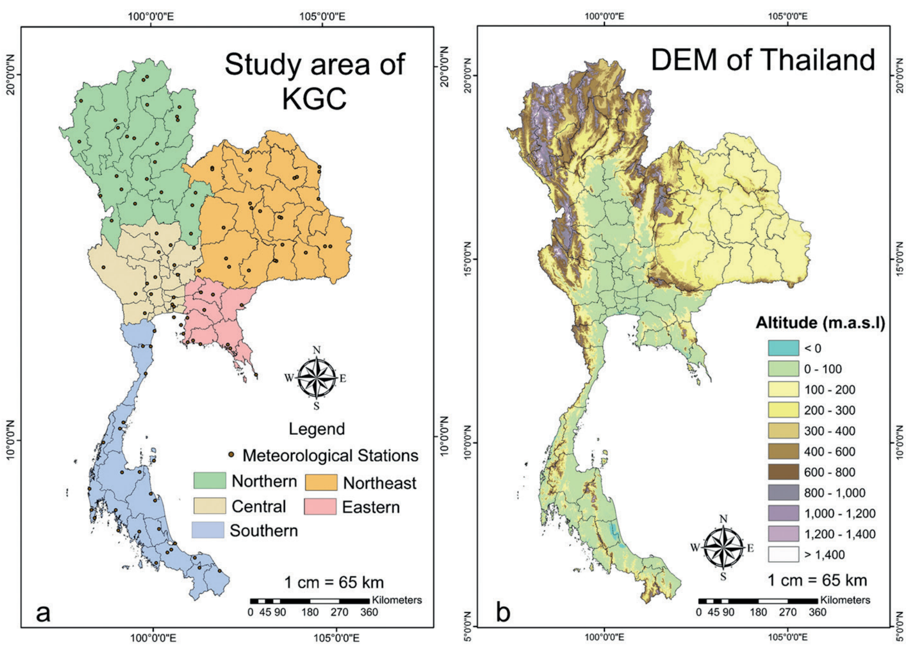

Fig. 1
(a) Study area and (b) Digital elevation model of Thailand
Source: Own creation

Tab. 1 Description of KGC major climate type for first letter

1^{st}	Climate description	Criteria Specifics
A	Equatorial or Tropical climates	- Coldest month (T_{am}) ≥ 18
B	Arid or Dry climates	- P_{aa} < 10 x $P_{thershold}$
C	Warm or Mesothermal climates	- 18 > Coldest month (T_{am}) ≥ 0 - Hottest month (T_{am}) ≥ 10
D	Cool or Microthermal climates	- Coldest month (T_{am}) < 0 - Hottest month (T_{am}) ≥ 10
E	Polar climates	- Hottest month (T_{am})< 10
H	Highland climates	- Climate characteristics changes by altitude

Source: Peel et al. 2007; Rohli and Vega 2008

Tab. 2 Description of KGC sub climate type for Second and Third letter

2^{nd}	3^{rd}	Criteria Specifics
f		- P_{am} ≥ 60 through year
m		- P_{am} < 60 short period in winter - Driest month (P_{am}) ≥ a = 100 – (P_{ta}/ 25)
w		- P_{am} < 60 short period in winter - Driest month (P_{am}) < a = 100 – (P_{ta} / 25)
s		- P_{am} < 60 short period in summer (rarely found)
	a	- Hottest month (T_{am}) ≥ 22
	b	- Hottest month (T_{am}) < 22
	c	- Fewer than 4 months (T_{am}) ≥ 10
	d	- Fewer than 4 months (T_{am}) ≥ 10 and Coldest month (T_{am}) < - 38
S		- P_{aa} < 5 x $P_{thershold}$
W		- P_{aa} ≥ 5 x $P_{thershold}$
	h	- Hot and dry (T_{aa}) ≥ 18
	k	- Cold and dry (T_{aa}) < 18
T		- 0 ≥ Hottest month (T_{am}) > 10
F		- Hottest month (T_{am}) < 0

Source: Peel et al. 2007; Rohli and Vega 2008

*Note: Temperature defines as °C, Precipitation determines as mm, Tam = average monthly temperature, Taa = average annual temperature, Pam = average monthly precipitation, Paa = average annual precipitation, Pta = total annual precipitation, Pthreshold = varies depending on the following rules (if 70% of Paa arises in winter then Pthreshold = 2 x Taa, if 70% of Paa arises in summer then Pthreshold = 2 x Taa + 28, otherwise Pthreshold = 2 x Taa + 14). Summer (Winter) in North hemisphere defines as April to September (October to March) for South hemisphere is adverse.

Tab. 3 Details of meteorological station in Thailand

Meteorological Regions	No. of Provinces	No. of Stations
Northern	15	24
Northeast	20	25
Central	18	16
Eastern	8	13
Southern	16	26
Overall	77	104

Source: Meteorological Department of Thailand, edited by the author

Prediction data was extracted by Beijing Climate Centre Climate System Model version 1.1 (BCC-CSM1.1) which is in the fifth phase (AR5) of Coupled Model Intercomparison Project Phase 5 (CMIP5), invented by Beijing Climate Centre (BCC) and China Meteorological Administration (CMA). The model provided physical, chemical, and biological values from the atmosphere, ocean, land, and sea-ice components (Gao et al., 2012; Wu, 2012; Xin et al., 2013a; Xin et al., 2013b; Zhang and Wu, 2012) thus, this model was used to predict the average monthly temperature and total monthly precipitation (rainfall) values of 2020 – 2100 period. Moreover, the SD GCM V 2.0 software (Statistical Downscaling of General Circulation Models Version 2.0) which is provided by Agricultural and Meteorological Software (2018), was used to extracted meteorological values from the model with 3 statistical downscaling methods (Gudmundsson et al., 2012) which are the Delta, the Quantile Mapping (QM) (Panofsky and Briar, 1968) and the Empirical Quantile Mapping (EQM) (Boe et al., 2007). BCC-CSM1.1 (historical) and BCC-CSM1.1 (RCP85) provided the data from 1850 - 2012 and 2006 – 2300, respectively. RCP85 was provided under the high emissions, no mitigation concept thus it would be modeled and gave a obviously point of view about danger climate change situation expectially if emissions such as CO_2 which can lead air temperature increaing and impact directly on human health could not be reduced. (Xin et al., 2013; Mihincău et al., 2019; Lyon et al., 2020)

However, the period of meteorological data for prediction process in this study was 1987 – 2019 and 2020 - 2100, extracted by "historical mon atmos Amon r1i1p1 v1 pr", "rcp85 mon atmos Amon r1i1p1 v20120705 pr" for precipitation and "historical mon atmos Amon r1i1p1 v1 tas" and "rcp85 mon atmos Amon r1i1p1 v20120705 tas" for air temperature. The data of this model can be accessed at The German Climate Computing Center (DKRZ: Deutsches Klimarechenzentrum GmbH) by http://cera-www.dkrz.de/WDCC/ui/Entry.jsp?acronym=BCB1hi for historical data and http://cera-www.dkrz.de/WDCC/ui/Entry.jsp?acronym=BCB1r8 for future data. However, Mean Absolute Error (MAE), Mean Absolute Percentage

Error (MAPE), Root Mean Square Error (RMSE), R-squared correlation (R2), Pearson coefficient and Index of Agreement are used to investigate the accuracy between observation data and prediction data from the model as presented in equation (1) – (6).

$$MAE = \frac{\sum_{i=1}^{n}|X_{exp,i}-X_{obs,i}|}{n} \quad (1)$$

$$MPAE = 100\,x\,\frac{1}{n}\sum_{i=1}^{n}\frac{X_{obs,i}-X_{exp,i}}{X_{obs,i}} \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{X_{exp,i}-X_{obs,i}}{X_{obs,i}}\right)^2} \quad (3)$$

$$\rho = \frac{\sum_{i=1}^{n}(X_{exp,i}-\bar{X}_{exp})(X_{obs,i}-\bar{X}_{obs})}{\sqrt{\sum_{i=1}^{n}(X_{exp,i}-\bar{X}_{exp})^2\sum_{i=1}^{n}(X_{obs,i}-\bar{X}_{obs})^2}} \quad (4)$$

$$r = \frac{n(\sum_{i=1}^{n}X_{exp,i}X_{obs,i})-(\sum_{i=1}^{n}X_{exp,i})(\sum_{i=1}^{n}X_{obs,i})}{\sqrt{[n\sum_{i=1}^{n}(X_{exp,i})^2-(\sum_{i=1}^{n}X_{exp,i})^2][n\sum_{i=1}^{n}(X_{obs,i})^2-(\sum_{i=1}^{n}X_{obs,i})^2]}} \quad (5)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(X_{exp,i}-X_{obs,i})^2}{\sum_{i=1}^{n}(|X_{exp,i}-\bar{X}_{obs}|+|X_{obs,i}-\bar{X}_{obs}|)^2} \quad (6)$$

Whereas; $X_{obs,i}$ refers to meteorological observation data, $X_{exp,i}$ refers to meteorological prediction data from the model, r is Pearson's correlation coefficient, ρ is Spearman's rank-order correlation, d is index of agreement. For MAE, MAPE and RMSE, the lowest values indicate that observation agree with prediction data, however; Pearson's correlation coefficient, Spearman's rank-order correlation and Index of Agreement focus on highest value (a range from 0 – 1). Moreover, administrative boundaries of Thailand (level 0 for country and level 1 for province) were composed and updated on 9 November 2019 by Information Technology Outreach Services (ITOS) with funding from USAID in vector shapefile format. (Retrieved from https://data.humdata.org/dataset/thailand-administrative-boundaries). Geographic Information System: GIS was cooperated with administrative boundaries of Thailand to analyse and present the results in form of maps. However, GIS programme calculated the area of Thailand around 516,085.376 square kilometres (different from the Thailand's area reference of Department of Mineral Resources (2016) about - 0.37%). Furthermore, the average monthly temperature and total monthly precipitation (rainfall) values of 1987 – 2019 and 2020 – 2100 period were gathered to classify climate types by following the rule of KGC in Table 1 and 2. Then, Raster interpolation is one of GIS methods, were used to distinguish and represent the results by using Inverse Distance Weight (IDW) for the total annual rainfall maps and Kriging for the average annual temperature maps and KGC classification maps of Thailand (with output cell size at 400 and Number of Point at 12). Furthermore, the trend of any changes is performed by excel programme with Simple Linear Regression Analysis method which was an easy method to model the relationship between independent and dependent variable, the objective is to predict the value of an output variable (or response) based on the value of an input (or predictor) variable as presented in equation (7). Although, Simple Linear Regression Analysis method still has a drawback like due to climate variables forecasting is too difficult to find an appropriate trend analysis method to work with fluctuate-data, this method was still used by many researchers in climatology field to analyse and discover a clear image of trend of climate variable changes including air temperature and precipitation. (Baltagi, 2002; Batima et al., 2005; Klamár et al., 2019; Ongoma et al., 2021).

$$y = \beta_0 + \beta_1 X + \varepsilon \quad (7)$$

Whereas y is the predicted value of the dependent variable (y) for any given value of the independent variable (X). β_0 is the intercept, the predicted value of y when the X is 0. β_1 is the regression coefficient – how much we expect y to change as X increases. X is the independent variable (the variable we expect is influencing y). ε is the error of the estimate, or how much variation there is in our estimate of the regression coefficient.

RESULTS AND DISCUSSION

Temperature and Precipitation Forecasting of Thailand for 2020-2061 and 2061-2100 period

Average monthly temperature (T_{am}) and total monthly precipitation (P_{tm}) of the mid twenty-first century (2020-2060), and the late twenty-first century (2061-2100) period were predicted by SD GCM V 2.0 software. Moerover, the programme cooperated with BCC-CSM1.1 (historical) for historical prediction and BCC-CSM1.1 (rcp85) for future prediction under high emissions and no mitigation concept, ran under three statistical downscaling methods (Delta, EQM, and QM). The result was presented that EQM was the appropriate method which could be used to forecast T_{am} and P_{tm} with lowest Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE) and highest R-squared correlation (R^2), Pearson coefficient and Index of Agreement as illustrated in Tab. 4. The accuracy values of T_{am} , predicted by EQM method at 0.86, 3.25, 1.17, 0.74, 0.86, and 0.89 for MAE, MPAE, RMSE, R2, Pearson coefficient and Index of Agreement86.76, 145.42, 0.30, 0.55 and 0.69, respectively. In addition, the values for P_{tm} prediction reported at 86.76, 145.42, 0.30, 0.55 and 0.69, respectively.

Tab. 4 Accuracy comparison of three statistical downscaling methods for average monthly temperature prediction from BCC-CSM1.1 model

Methods	MAE	MPAE	RMSE	R2	Pearson coefficient	Index of Agreement.
Average monthly temperature of Thailand						
Delta	1.23	4.71	1.66	0.45	0.67	0.36
EQM	**0.86**	**3.25**	**1.17**	**0.74**	**0.86**	**0.89**
QM	0.88	3.30	**1.17**	**0.74**	**0.86**	**0.89**
Total monthly rainfall of Thailand						
Delta	102.37	-	172.62	0.26	0.51	0.65
EQM	**86.76**	**-**	**145.42**	**0.30**	**0.55**	**0.69**
QM	93.79	-	156.94	0.27	0.52	0.67

Source: Own creation, cooperated with SD GCM V 2.0 software.

Temperature of Thailand in 1987-2019, 2020-2061 and 2061-2100 period

According to the Köppen-Geiger Climate Classification system, the first step of the theory focused on air temperature to determine the first letter as major climate zone (Capital English alphabet). Therefore, total monthly average temperature (T_{am}) of present period (1987 – 2019), the mid twenty-first century (2020-2060), and the late twenty-first century (2061-2100) period were collected from 104 meteorological stations over Thailand, predicted by BCC-CSM1.1 model, to analyse the changes and determine climate zone. The T_{am} of all stations was in range of 13.5 – 37.3 °C in present period. The most stations had the minimum T_{ma} equal or higher than 18 °C thus, the first letter was defined as "A" Equatorial or Tropical climates. However, some minimum T_{ma} which was lower than 18 °C and equal or higher than 0 °C appearing in some meteorological stations in Northern region especially, some stations in Chiang Rai, Phayao, and Tak provinces. Therefore, these could be classified as "C" Warm or Mesothermal climates. In contrast, T_{ma} of the mid twenty-first century, and the late twenty-first century period reported at 19.0 – 29.4 °C and 19.0 – 29.6 °C, respectively. Therefore, only "A" Equatorial or Tropical climates could be found in these periods. Specific detail of Thailand's temperature could be described by drawing the maps using Kriging technique, reported in °C Unit as presented in Fig. 2(a-c), the red tones refer to hotter temperature and yellow tones refer to cooler temperature. The highest average annual temperature (T_{aa}) of these three periods was found in Central part, gradually dropped in the next area which connected to Eastern part, Southern part, Northeast part, and Northern part, respectively. The supported reason of this phenomenon is the Central and Eastern of Thailand has so much urban activities than others, couples with the location of the regions is in low latitude and get much of an effect of sun ray. These configurations can lead the effect of heat rising. However, Southern of Thailand is different due to the location of area is between Andaman Sea and Gulf of Thailand, which can reduce the air temperature by a lot of humidity. Moreover, a different of T_{aa} of the mid twenty-first century and the late twenty-first century period was discovered by comparison with 1987 – 2019 data (based period), reported in °C Unit (+ value means the data of the year is higher than based period and - value refers in contrast) as presented in Fig. 2(d-e). Most of stations in both periods predicted gave higher T_{aa} values than based period; however, the magnitude of changes in the late twenty-first century (0.0 to +0.3 °C) was higher than the mid twenty-first century (-0.2 to +0.1 °C). The results indicated that the T_{aa} values tend to be warmer in near future due to CO_2 and other emission rising with no mitigation policy (according to RCP85 scenario output). Furthermore, the T_{am} trend of all regions in these three periods were similar by climbing at all but different in magnitude as illustrated in Tab. 5

Tab. 5 Linear regression analysis for average annual temperature of each region over Thailand

Region	Regression Equation		
	1987-2019	2020-2060	2061-2100
Northern	y = 0.0254x + 25.739 R^2 = 0.4163	y = 0.0032x + 25.59 R^2 = 0.142	y = 0.004x + 26.259 R^2 = 0.606
Northeast	y = 0.0217x + 26.469 R^2 = 0.2517	y = 0.0028x + 26.217 R^2 = 0.0906	y = 0.0035x + 26.934 R^2 = 0.5514
Central	y = 0.017x + 27.927 R^2 = 0.2307	y = 0.0035x + 27.738 R^2 = 0.1726	y = 0.0034x + 28.321 R^2 = 0.5748
Eastern	y = 0.0166x + 27.681 R^2 = 0.3182	y = 0.0039x + 27.578 R^2 = 0.2645	y = 0.0032x + 28.072 R^2 = 0.5773
Southern	y = 0.0132x + 27.271 R^2 = 0.3215	y = 0.0029x + 27.283 R^2 = 0.3884	y = 0.0032x + 27.586 R^2 = 0.7452

Source: Own creation

The Average monthly temperature graph of Thailand over these three periods were presented in red line graph form, read from y – left side axis as illustrated in Fig. 3 (a) 1987 – 2019, (b) 2020 – 2061, and (c) 2061 – 2100 period to explain the air temperature situation in each month. T_{ma} of present period was gradually increasing from January (in winter) and hit the peak in April (in summer) due to the sun ray is always perpendicular Thailand surface (Srivanit and Jareemit, 2020), lead so much heat concentration over the surface especially in the land. After that, the T_{am} was gently dropping and hit the lowest point in December (winter) due to winter solstice effect in north hemisphere (Jansri and Ketpichainarong, 2020). The temperature situation of the mid twenty-first century, and the late twenty-first century period resemble present period situation; however, the magnitude of change was lower than present period. This situation could be summarized that the air temperature would be high over the year and not be change so much in each month in the future.

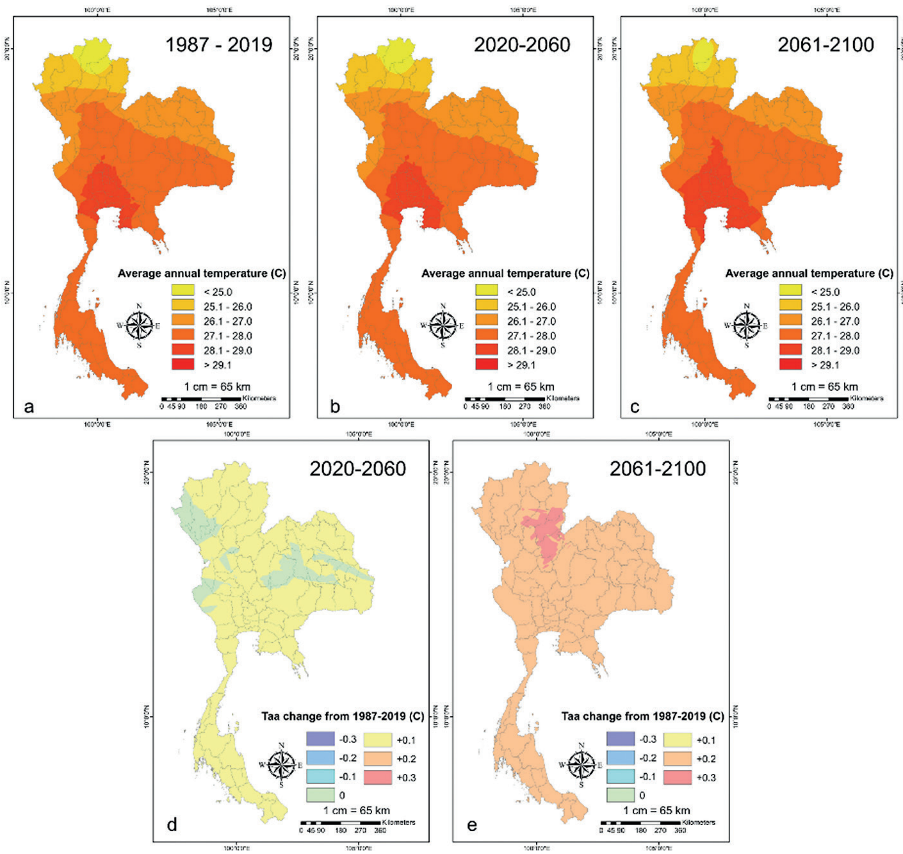

Fig. 2

Average annual temperature over Thailand maps of (a) 1987 – 2019, (b) 2020 – 2061, (c) 2061 – 2100 period, A change of Average annual temperature over Thailand compared with 1987 – 2019 period of (d) 2020 – 2060, and (e) 2061 – 2100

Source: Own creation

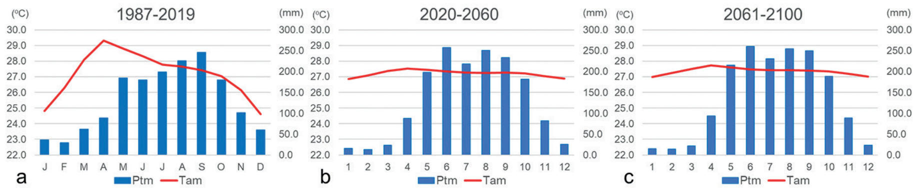

Fig. 3

Average monthly temperature and precipitation over Thailand of (a) 1987 – 2019, (b) 2020 – 2061, and (c) 2061 – 2100 period

Source: Own creation

Rainfall of Thailand in 1987-2019, 2020-2061 and 2061-2100 period

The rainfall mapping of present period (1987 – 2019), the mid twenty-first century (2020-2060), and the late twenty-first century (2061-2100) period was discussed in Fig. 4(a-c), were drawn by collecting total monthly rainfall in mm unit from 104 stations over Thailand, predicted by BCC-CSM1.1 model, cooperated with IDW technique. The blue tones refer to the less rainfall and the pink tones refer to the more rainfall. Moreover, Maximum, Minimum, and Mean values of total annual rainfall of each region over Thailand demonstrated in Tab.6. The pattern of rainfall distribution of these three periods were similar, the most rainfall distributed in Southern region with supported reason that the wet area of Southern of Thailand was affected from the location which is located next to two seas and get an influence from southwest monsoon in mid of May to mid of October then, northeast monsoon passes through until mid of February. The notable highest rainfall distributed around Sa Mui and Pha Ngan islands in Surat Thani province, and the bottom of the region in Songkla, Satun and Yala provinces. This was synonymous with the work of Limsakul, Singhruck, and Wang (2017). Eastern region also had the notable rainfall values with supported argument that the dominant wet area of eastern region appeared around the bottom area of the region which is in the front of Chanthaburi mountain range and next to gulf of Thailand, especially in Chanthaburi and Trat provinces because of humidity and affectation from southwest monsoon in mid of May to mid of October, the values of Chanthaburi and Trat provinces were significantly higher than Southern region (Thai Meteorological Department, 2015). Next is Northeast region, the rainfall always low in this area due to this area is far from the nearest sea. (Thai Meteorological Department, 2015) However, the outstanding moist area figured at the east side of region then gradually dryer to west side of region because of an effect from summer thunderstorm which happens around February to May and tropical cyclones which always pass through the area around May to October (Thai Meteorological Department, 2015). Following by Northern of Thailand, the distinctive moist area emerged at the small area of the upper of region (around Chiang Rai province) then, gentry dryer to lower of region. This phenomenon might be affected from 1-2 tropical cyclones which always pass through the upper area first then, this reason lead humidity sending to collect in forest to encourage producing of rainfall. Although, other area in this region got a little effect from tropical cyclone and the location of the area which is far from the sea lead the area has less chance to get the high rainfall, mountain topography also encourages humid air rising to the top of mountain, created clouds and rain falling to the area (Thai Meteorological Department, 2015; Komori et al., 2018). For the last region, the wet area of Central of Thailand was pointed out around upper side of region (around Chiang Rai province). Moreover, it was found in small area around north of Kanchanaburi province. The reason for this situation is the effect of southwest monsoon which always pass through the area in mid of May to mid of October and the location of Kanchanaburi province is not much far from nearest sea. Therefore, these can let much humidity pass through the area by gaps between mountains. However, inside area of region has less humidity, lead the area drier (Thai Meteorological Department, 2015; Limsakul, Singhruck, and Wang, 2017). Moreover, a different of P_{ta} of the mid twenty-first century and the late twenty-first century period was exploreed by comparison with 1987 – 2019 data (based period), reported in percentage value to make clearly understand (+ value means the data of the year is higher than based period and - value refers in contrast) as presented in Fig. 3(d-e). Both of changes were predicted that the most area of Thailand (except Northeast region) tend to have less rainfall value than based period (-17.7% to 16.3% for the mid twenty-first century and -15.9% to 25.0% for the late twenty-first century); however, the magnitude of changes were different. Rainfall value of the most area of Thailand in the late twenty-first century tends to have higher values than the mid twenty-first century except in the upper-Southern region. This situation was synonymous with a research study of Komori et al. (2018). The results indicated that total rainfall of Thailand tend to be higher in near future, but this cannot confirm that there is no chance to get more rainfall value in every month which is enough to change the climate type.

Tab. 6 Max, Min, and Mean of total annual rainfall of each region over Thailand

Region	1987-2019			2020-2060			2061-2100		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Northern	6.7	2287.5	1220.7	661.8	2304.1	1207.3	625.9	2739.3	1273.5
Northeast	574.1	2995.9	1372.4	652.0	4050.3	1518.0	749.6	4064.1	1594.3
Central	513.2	2675.8	1154.7	583.9	2249.3	1138.2	520.3	2668.6	1219.0
Eastern	419.6	6463.3	1463.2	717.7	6845.6	1363.1	569.7	6916.9	1512.8
Southern	585.6	5883.8	2077.1	586.8	5292.2	2023.2	453.3	5344.5	2026.8

Source: Own creation

The total monthly rainfall graph of these three periods were similar, the trends were rising from the beginning of the year and hit the peak around rainfall season (June to September) then, the trend gradually dropped down by end of year. The dry months appeared around winter as presented in Fig. 3(a-b). Furthermore, the P_{ta} trends of all regions in present and the late twenty-first century periods were similar by rising at all but different in magnitude; however, P_{ta} trends of all regions in the mid twenty-first century periods were increasing in Northern, Central and Eastern region whereas the trends tend to be decreased in Northeast and Southern region as illustrated in Tab. 7

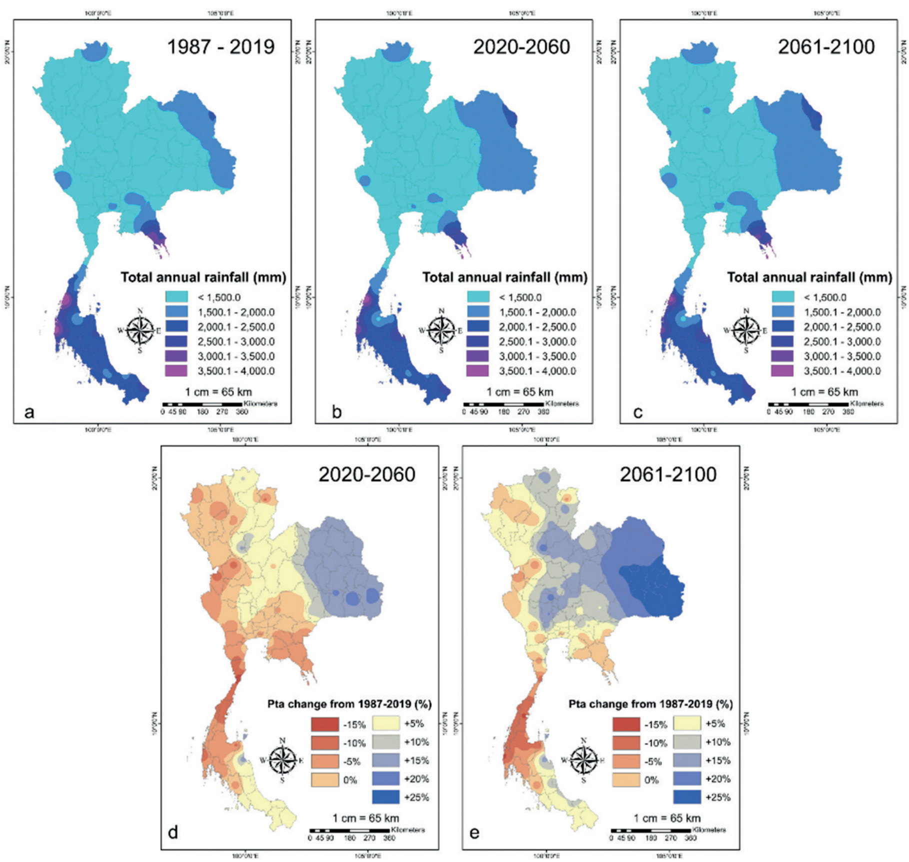

Fig. 4
Total annual rainfall over Thailand maps of (a) 1987 – 2019, (b) 2020 – 2061, (c) 2061 – 2100 period, A change of Total annual rainfall over Thailand compared with 1987 – 2019 period of (d) 2020 – 2060, and (e) 2061 – 2100
Source: Own creation

For the second step, total monthly rainfall of these three periods of each month in each station were analysed to determine the second English lowercase letter to get sub-climate type by following the rules in Tab. 2. The sub-climate type of "A" Equatorial or Tropical climates defined to two classes: Tropical savanna climate with dry-winter characteristics (Aw) and Tropical monsoon climate (Am) whereas sub-climate type of "C" Warm or Mesothermal climates could be classified as Dry – winter humid (Cw).

Tab. 7 Linear regression analysis for total annual rainfall of each region over Thailand

Region	Regression Equation		
	1987-2019	2020-2060	2061-2100
Northern	y = 2.2883x + 1220.1 R^2 = 0.0171	y = 0.1322x + 1242.6 R^2 = 8E-05	y = 1.4268x + 1290.3 R^2 = 0.0084
Northeast	y = 2.6853x + 1381.3 R^2 = 0.0296	y = -0.3865x + 1581.2 R^2 = 0.0003	y = 5.2434x + 1561.4 R^2 = 0.0665
Central	y = 2.8711x + 1160.5 R^2 = 0.0291	y = 1.714x + 1144.4 R^2 = 0.0119	y = 3.348x + 1202.6 R^2 = 0.0338
Eastern	y = 4.1023x + 1855.3 R^2 = 0.0491	y = 2.2231x + 1738.6 R^2 = 0.0085	y = 5.9654x + 1781.5 R^2 = 0.035
Southern	y = 9.0459x + 1980.8 R^2 = 0.0986	y = -0.8292x + 2087.2 R^2 = 0.0012	y = 1.8599x + 2039.8 R^2 = 0.0057

Source: Own creation

Köppen-Geiger Climate Classification system of Thailand in the present period (1987 – 2019)

Following the KGC rules as in Tab. 1 and 2, the KGC could be classified as Tropical savanna climate with dry-winter characteristics (Aw) and Tropical monsoon climate (Am) and Dry – winter humid (Cw) for present period (1987-2019). Therefore, characteristic of temperature in summer for Northeast region needed to be identified by operation as in Tab. 2. The results indicated that the most months of some station which were classified to "C" climate type, had T_{am} value equal or higher than 22 °C in the hottest month in each year. Therefore, the climate could be defined as "Cwa" or Dry-winter humid subtropical climate. Köppen-Geiger Climate Classification map of Thailand in present period was created by kriging method then illustrated in Fig. 5 (a). Pink, Brown, and Yellow scale refers to "Cwb", "Aw", and "Am" climate, respectively. However, there were just 8 years only in Phayao station (Phayao province) had T_{am} value lower than 22 °C in the hottest month in each year to classify the climate as "Cwb" or Dry-winter subtropical highland climate. This climate could not be classified as KGC climate in the area. "Aw" climate was the main sub-climate of the country which was appeared around

90.14% of Thailand with the evidence that all months had the T_{am} higher than 18 °C and P_{tm} were lower than 60 mm, was found around 4-5 months around November to March except in Southern region (P_{tm} were lower than 60 mm around 1 month) as presented in Fig. 6 (b-f). Proportion of Aw climate by KGC method in Thailand of present period were illustrated in Tab. 8(a). The results displayed that Aw was covered 100% of Northeast part (32.50% of Thailand), and Central part (13.76% of Thailand), respectively. However, it was overspread at 96.45% of Northern part (29.15% of Thailand) except Phayao Provinces, small-upper area of Lampang province and small-lower area of Chiang Rai province. Moreover, it also distributed in 80.04% of Eastern part (5.68% of Thailand) around the area behind Chanthaburi mountain range and 55.17% of Southern part (9.05% of Thailand).

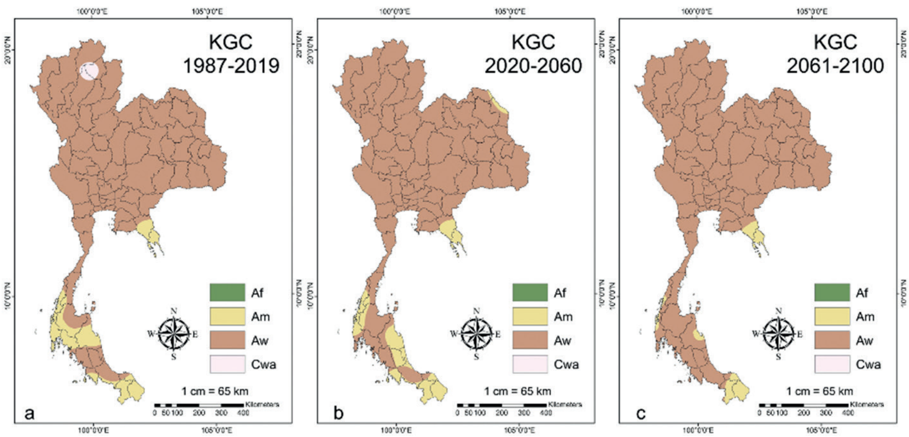

Fig. 5
Köppen-Geiger Climate Classification map of Thailand (a) 1987 – 2019,
(b) 2020 – 2061, and (c) 2061 – 2100 period
Source: Own creation

"Am" climate was found at 8.77% of Thailand territory with the evidence as presented in Fig. 6 (g-h) that T_{am} of each month was higher than 18 °C and P_{tm} of 1 – 2 months were lower than 60 mm. The results displayed that Aw was covered 19.96% of Eastern part (1.42% of Thailand) between front of Chanthaburi mountain range and next to Gulf of Thailand. Moreover, P_{tm} rapidly increased from the beginning of year and hit the peak around rainy season due to southwest monsoon which brings so much humidity to area. It also found 44.83% of Southern part (7.35% of Thailand) in alomost half area of region, respectively. P_{tm} was stably high all year due to southwest which allows humidity to area in rainy and winter season. However, northeast monsoon also brings humidity (rainfall) to the area, less than southwest monsoon. "Cwa" climate appeared at 3.55% of Northern region (1.07% of Thailand) as illustrated in Tab. 6(b) around Phayao Provinces, small-upper area of Lampang province and small-lower area of Chiang Rai province with the evidence as presented in Fig. 6 (a) that T_{am} of the coldest months were lower than 18 °C with the hottest months were higher than 22 °C and P_{tm} of 1 – 5 months were lower than 60 mm. The supported reason is the stations in these areas are located in high altitude above mean sea level, coupled with slope mountain ranges topography with forests which can collect humid and make the air temperature cooler, lead the air rising to the top thus, the air temperature would be lower than low altitude.

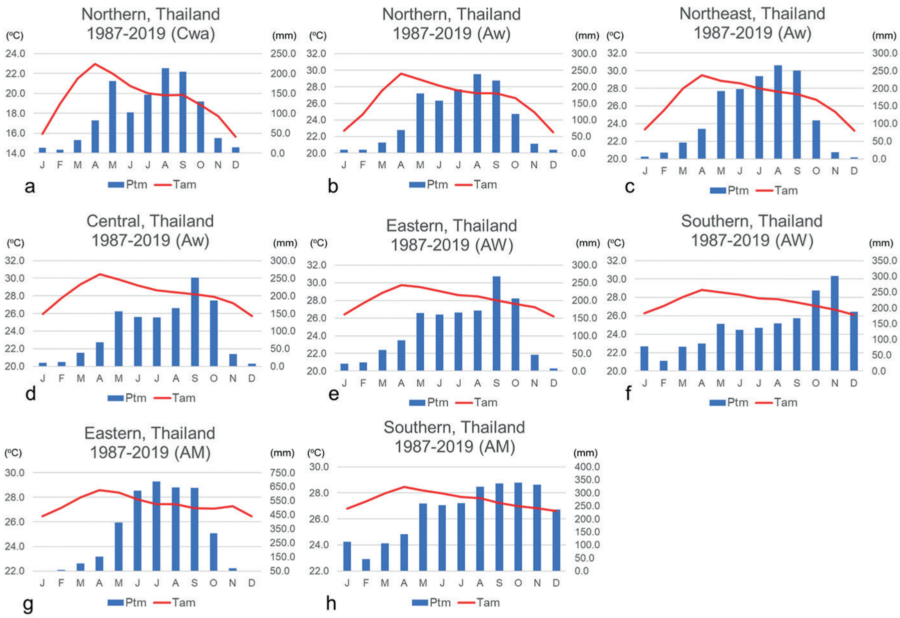

Fig. 6

Total monthly rainfall and Average monthly temperature values of Thailand in 1987 – 2019 period (a) Cwa in Northern region, (b) Aw in Northern region, (c) Aw in Northeast region, (d) Aw in Central region, (e) Aw in Eastern region, (f) Aw in Southern region, (g) Am in Eastern region, and (h) Am in Southern region

Source: Own creation

“Cwb” climate or Dry-winter subtropical highland climate and “Af” climate or Tropical rainforest climate were seldom discovered in some year of present period around the small-upper area of Northern of Thailand for “Cwb” and in the small-bottom area of Southern of Thailand. Unfornumately, these two sub climates could not be displayed when focusing on this through long study’s period. In summarisation, the results were coincident with the study of Beck et al. (2018) that Thailand had “Aw” as a main sub climate, following by “Am” in Eastern and Southern area of Thailand. Moreover, “Cwa” was still concurrently discovered in a small area of Northern of Thailand.

Tab. 8(a) Proportion of Aw and Am by KGC method in Thailand of 1987 – 2019

Regions	Area (km^2)	Aw			Am		
		Area (km^2)	Area (%) of region	Area (%) of Thailand	Area (km2)	Area (%) of region	Area (%) of Thailand
Northern	156,005.20	150,462.74	96.45	29.15	-	-	-
Northeast	167,740.60	167,740.60	100.00	32.50	-	-	-
Central	71,033.99	71,033.99	100.00	13.76	-	-	-
Eastern	36,654.54	29,337.92	80.04	5.68	7,316.62	19.96	1.42
Southern	84,651.05	46,698.17	55.17	9.05	37,952.88	44.83	7.35
Total of Thailand	516,085.38	465,273.43		90.14	45,269.50		8.77

Tab. 8(b) Proportion of Cma by KGC method in Thailand of 1987 – 2019

Regions	Area (km^2)	Cma		
		Area (km^2)	Area (%) of region	Area (%) of Thailand
Northern	156,005.20	5542.46	3.55	1.07
Northeast	167,740.60	-	-	-
Central	71,033.99	-	-	-
Eastern	36,654.54	-	-	-
Southern	84,651.05	-	-	-
Total of Thailand	516,085.38	5542.46		1.07

Source: Own creation

Köppen-Geiger Climate Classification system of Thailand in the mid and late twenty-first century period (2020 – 2060 and 2061 – 2100)

T_{am} and P_{tm} of mid and late twenty-first century period (2020 – 2060 and 2061 – 2100) were predicted by SD GCM V 2.0 software, cooperated with BCC-CSM1.1 (historical) for historical prediction and BCC-CSM1.1 (rcp85) for future prediction under high emissions and no mitigation concept to get climate classification change characteristics details if all emissions still high, ran under three statistical downscaling methods (Delta, EQM, and QM). After that, all data were run under KGC theory following as Tab.2 and 3. Then, KGC maps of mid and late twenty-first century period were created by kriging method, operated in GIS programme as presented in Fig. 5(b-c) with Brown and Yellow scale refers to "Aw", and "Am" climate, respectively. The KGC results of these two periods were similar predicted in term of "Cwa" was disappeared by air temperature rising in Northern part of Thailand. This can be awareness about

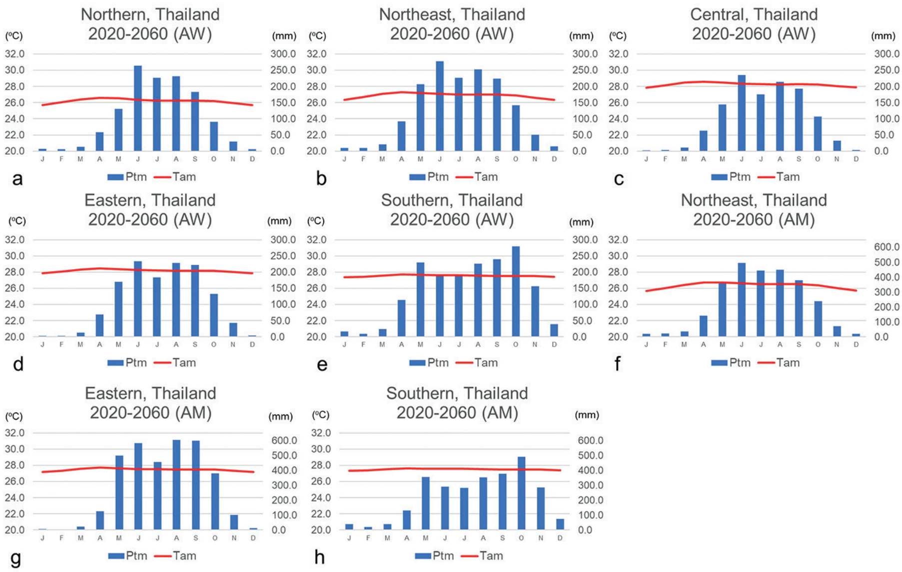

Fig. 7

Total monthly rainfall and Average monthly temperature values of Thailand in 2020-2060 period (a) Aw in Northern region, (b) Aw in Northeast region, (c) Aw in Central region, (d) Aw in Eastern region, (e) Aw in Southern region, (f) Am in Northeast region, (g) Am in Eastern region, and (h) Am in Southern region

Source: Own creation

global warming situation in this region. Therefore, only "Aw" and "Am" climates could be found in these two period but the extended area of each types were different. "Aw" Climate was still the major sub-climate type of Thailand according to mid and late twenty-first century period; however, it extended area more than mid twenty-first century period. The area of "Aw" were predicted around 91.85% and 96.37% of Thailand area for mid and late twenty-first century with the predicted evidence that all months had the T_{am} higher than 18 °C and P_{tm} were lower than 60 mm, was found around 4-5 months around November to March. Proportion of Aw climate by KGC method in Thailand of present period were illustrated in Tab. 9 and 10. The results represented that Aw was covered 100% of Northeast part (32.50% of Thailand), and Central part (13.76% of Thailand), respectively in mid and late twenty-first century period. However, it was overspread at 80.04% of Eastern part (5.68% of Thailand) and 82.89% (5.89% of Thailand) for mid and late twenty-first century period respectively, around the area behind Chanthaburi mountain range. Moreover, it also distributed around 61.35% of Southern part (10.06% of Thailand) and 85.35% of Southern part (13.99% of Thailand) for mid and late twenty-first century period respectively. It also appeared in Northeast of Thailand with 98.81% of area (32.12% of Thailand) for mid twenty-first century while

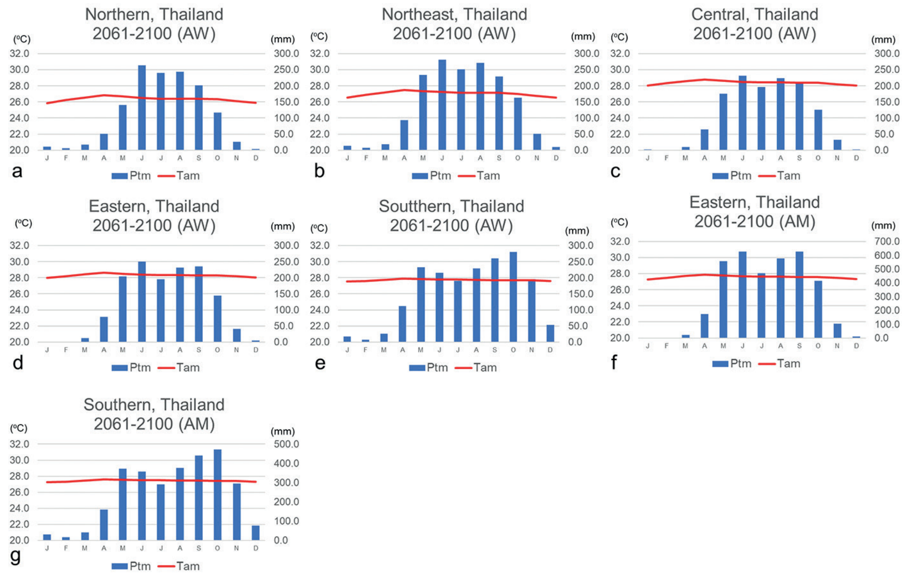

Fig. 8

Total monthly rainfall and Average monthly temperature values of Thailand in 2061-2100 period (a) Aw in Northern region, (b) Aw in Northeast region, (c) Aw in Central region, (d) Aw in Eastern region, (e) Aw in Southern region, (f) Am in Eastern region, and (g) Am in Southern region

Source: Own creation

it appeared at 100% of area (32.50% of Thailand) for late twenty-first century. Proportion of Am climate by KGC method in Thailand of present period were illustrated in Tab. 9 and 10. “Am” climate was still predicted to appear likely in almost same area of present period; however, the area tended to be smaller period by period. It covered about 8.15% and 3.63% of Thailand area for mid and late twenty-first century period, respectively with the predicted evidence that all months had the T_{am} higher than 18 °C and there were P_{tm} lower than 60 mm around 3-4 months around December to March. The results displayed that “Am” was covered 19.96% of Eastern part (1.42% of Thailand) for mid twenty-first century and 14.65% (2.40% of Thailand) for late twenty-first century period, between front of Chanthaburi mountain range and next to Gulf of Thailand. It also found at 38.65% of Southern part (6.34% of Thailand) in alomost half area of region for left, right, and bottom of area in mid twenty-first century whereas it was predicted to drcrease to 14.65% of region (2.40% of Thailand) around small area of right side and bottom of area in late twenty-first century period. Although rainfall values were stably high all year due to southwest and northeast monsoon effect which can lead more humidity and rainfall pass through the land, and even

In late twenty-first century had predicted rainfall values which were higher than mid twenty-first century, the dry months were still predicted and appeared in some months and some area. Therefore, this discontinuous highly rainfall would not enough to encourage the same climate type still appearing in the area.

In summarisation, the results were synonymous with the study of Kottek et al. (2006), Peel et al. (2007) and Chen and Chen (2013), represented that Thailand climate was compatibly classified into Equatorial or Tropical climates (A group) with two sub-climate types: Tropical savanna climate with "Aw" or dry-winter characteristics (major sub type) and "Am" Tropical monsoon climate (minor sub type).

Tab. 9 Proportion of Aw and Am by KGC method in Thailand of 2020 - 2060

Regions	Area (km²)	Aw			Am		
		Area (km²)	Area (%) of region	Area (%) of Thailand	Area (km2)	Area (%) of region	Area (%) of Thailand
Northern	156,005.20	156,005.20	100.00	30.23	-	-	-
Northeast	167,740.60	165,746.30	98.81	32.12	1,994.25	1.19	0.39
Central	71,033.99	71,033.99	100.00	13.76	-	-	-
Eastern	36,654.54	29,337.92	80.04	5.68	7,316.62	19.96	1.42
Southern	84,651.05	51,934.24	61.35	10.06	32,716.81	38.65	6.34
Total of Thailand	516,085.38	474,057.70		91.85	42,027.69		8.15

Source: Own creation

Tab. 10 Proportion of Aw and Am by KGC method in Thailand of 2061 - 2100

Regions	Area (km²)	Aw			Am		
		Area (km²)	Area (%) of region	Area (%) of Thailand	Area (km2)	Area (%) of region	Area (%) of Thailand
Northern	156,005.20	156,005.20	100.00	30.23	-	-	-
Northeast	167,740.60	167,740.60	100.00	32.50	-	-	-
Central	71,033.99	71,033.99	100.00	13.76	-	-	-
Eastern	36,654.54	30,382.09	82.89	5.89	6,272.45	17.11	1.21
Southern	84,651.05	72,250.92	85.35	13.99	12,400.13	14.65	2.40
Total of Thailand	516,085.38	497,412.80		96.37	18,672.58		3.63

Source: Own creation

SUMMARY AND CONCLUSIONS

Köppen-Geiger Climate Classification system (KGC) is an easy method to determine climate zone in Thailand by using observation data of 1987 – 2019 (the present period), coperated with BCC-CSM1.1 model to predict climate type in 2020 – 2060 (the mid twenty-first century period) and 2061 – 2100 (the late twenty-first century period). Moreover, RCP85 scenario of BCC-CSM1.1 model was selected to model the air temperature and precipitation under releasing of high emissions (easpecially CO_2) and no mitigation process concept to present the impacts under the worst situation. Futhermore, EQM was a appropriate statistical downscaling method to predict climate variables data, with the lowest MAE, MPAE, RMSE and the highest R^2, Pearson coefficient and Index of Agreement. GIS and Raster interpolation process were used to present climate zone with output cell size at 400 and Number of Point at 12. The results illustrated that high average monthly temperature (T_{am}) concentrated in the middle of Thailand then decreased in the next area thus, the lowest temperature always found in Northern of Thailand due to high altitude and forests effect for these three study periods. The predicted average monthly temperature (T_{am}) of the mid and late twenty – first century were higher than the present period due to an increasing of CO_2 and other emission with no any policy (according to RCP85 scenario work). The precipitation values were obviously high around the area which is located between front of Chanthaburi mountain range and the gulf of Thailand in Eastern region whereas in Southern region also had high rainfall due to monsoon effects. Moreover, upper side of Northeran and right side of Northeast region also had high rainfall due to tropical cyclone but the concentration was not steady in all months. Predicted P_{tm} values were increasing around half-right side of Thailand period by period. Unfortunately, this phenomenon was not enough to shift the climate type in the most area of Thailand. The summarization results of two periods were synonymous with the study of Kottek et al. (2006), Peel et al. (2007),Chen and Chen (2013), and Beck et al. (2018) indicated that Thailand climate was classified into Equatorial or Tropical climates (A group) with two sub-climate types: Tropical savanna climate with dry-winter characteristics (Aw) as a major sub climate, found in all regions and covered the most area of Thailand and Tropical monsoon climate (Am) as a minor sub climate in almost one – fifth of Eastern which was located next to the gulf of Thailand, and it dispersed in southern region. However, Dry-winter humid subtropical climate (Cwa) was discovered in small-upper area of Northern region, it would be predicted to dissappear in the mid and late twenty-century period. Moreover, Tropical rainforest climate (Af) and Dry-winter subtropical highland climate (Cwb) were seldom discovered in some year around the small area of the bottom of Southern of Thailand for Af and around in small – upper area of Northern region; however, this could not be classified as sub-climate type when focusing on long period.

Therefore, Thailand has just two classes of climate (Aw and Am climate). There was an interesting question asked by Sanderson (1999): *"Is it not time for modern atmospheric scientists to develop a "new" classification of world climate?"* the results from this study demonstrate that climate is changing all the time due to natural and human effects. Therefore, climate monitoring and prediction are essential to remind climate issues and support future research.

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REFERENCES

AGRICULTURAL AND METEOROLOGICAL SOFTWARE, 2018. SD-GCM Tool [Computer software]. Retrieved from: https://agrimetsoft.com/SD-GCM.aspx. Accessed on 18 October 2020.

ALVARES, C. C., STAPE, J. L., SENTELHAS, P. C., GONÇALVES, J. L., SPAROVEK, G. (2014). Köppen's climate Classification map for Brazil, *Meteorologische Zeitschrift*, 22, 6, 711-728.

BALTAGI, B., H. (2002). Simple Linear Regression. *Econometrics*, New York: Springer-Verlag Berlin Heidelberg New York, pp. 51-75.

BATIMA P., NATSAGDORJ L., GOMBLUUDEV P., ERDENETSETSEG B. (2005). Observed Climate Change in Mongolia. *AIACC Working Paper*. 12: 1 - 26

BECK, H. E., ZIMMERMANN, N. E., MCVICAR, T. R., VERGOPOLAN, N., BERG, A., WOOD, E. F. (2018). Present and future Köppen-Geiger climate classification maps at1-km resolution, *Scientific Data*, 5:180214, 1-12. DOI: 10.1038/sdata.2018.214DOI:10.1038/sdata.2018.214

BERILA, A. AND DUSHI, M. (2021). Measuring Surface Urban Heat Island in Response to Population Density Based on Remote Sensing Data and GIS Techniques: Application to Prishtina, Kosovo. *Folia Geographica*. 63(2)

BO'E, J., TERRAY, L., HABETS, F., AND MARTIN, E. (2007). Statistical and dynamical downscaling of the Seine basin climate for hydro-meteorological studies, International Journal of Climatology, 27, 1643–1655, DOI:10.1002/joc.1602

CHEN, D, CHEN, H. W. (2013). Using the Köppen classification to quantify climate variation and change: An example for 1901–2010, *Environmental Development*, 6, 669–79, DOI: http://dx.doi.org/10.1016/j.envdev.2013.03.007

DEPARTMENT OF MINERAL RESOURCES, 2016. Geology of Thailand. Retrieved from: http://www.dmr.go.th/main.php?filename=GeoThai_En Accessed on 29 May 2019,

DE SÁ JÚNIOR, A., DE CARVALHO, L.G., DA SILVA, F.F., DE CARVALHO ALVES, M. (2012). Application of the Köppen classification for climatic zoning in the state of Minas Gerais, Brazil. *Theoretical and Applied Climatology volume*, 108, 1–7. DOI: https://doi.org/10.1007/s00704-011-0507-8

DIAZ, H. F., EISCHEID, J. K. (2007). Disappearing "alpine tundra" Koppen climatic type in the western United States, *Geophysical Research Letters*, 34, L18707, 1-4, DOI:10.1029/2007GL031253

GAO F., XIN X., WU T. (2012) Study on the prediction of regional and global temperature in decadal time scale with BCC_CSM1.1 (in Chinese). *Chinese Journal of Atmospheric Sciences,* 1-26

GEIGER, R. (1954). Landolt-Börnstein – Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysikund Technik, alte Serie Vol.3, Ch. *Klassifikation der Klimate nach W. Köppen*. Berlin: Springer, pp. 603–607.

GUDMUNDSSON, L., BREMNES, J. B., HAUGEN, J. E., ENGEN SKAUGEN, T. (2012). Technical Note: Downscaling RCM precipitation to the station scale using quantile mapping – a comparison of Methods. *Hydrology and Earth System Sciences Discussions*, 9, 6185–6201, DOI:10.5194/hessd-9-6185-2012

JEDLÁK, M. (2013). Global Dimming as New Climate Phenomenon. *Folia Geographica*. 21: 38-47

JANSRI, S AND KETPICHAINARONG, W. (2020). Investigating In-service Science Teachers Conceptions of Astronomy, and Determine the Obstacles in Teaching Astronomy in Thailand. *International Journal of Educational Methodology*. 6(4): 745 - 758.

KISNER, C. (2008). Climate Change in Thailand: Impacts and Adaptation Strategies. In Electronic *Climate Institute [online]*. [accessed on 20 January 2020]. Retrieved from: https://climate.org/archive/topics/international-action/thailand.htm

KLAMÁR, R., MATLOVIČ, R., IVANOVÁ, M., IŠTOK, R. AND KOZOŇ, J. (2014). Local Action Group as A Tool of Inter-Municipal Cooperation: Case Study of Slovakia. *Folia Geographica*. 61(1): 36-67

KOMORIA, D., RANGSIWANICHPONGA, P., INOUEB, N., ONOC, K., WATANABED, S. AND KAZAMA, S. (2018). Distributed probability of slope failure in Thailand under climate change. *Climate Risk Management*, 20: 126-137

KÖPPEN, W. (1900). Versuch einer Klassifikation der Klimate, vorzugweise nach ihren Beziehungen zur Pflanzenwelt. *Geographische Zeitschrift*, 6, 657–679.

KÖPPEN, W. (1901). Versuch einer Klassifikation der Klimate, vorzugweise nach ihren Beziehungen zur Pflanzenwelt. *Meteorologische Zeitschrift*, 18, 106–120.

KOTTEK, M., GRIESER, J., BBECK, C., RUDOLF, B, RUBEL, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15, 3, 259-263. DOI:10.1127/0941-2948/2006/0130

KRITICOS, D. J., WEBBER, B. L., LERICHE, A., OTA, N., MACADAM, I., BATHOLS, J., SCOTT J. K. (2012). CliMond: global high-resolution historical and future scenario climate surfaces for bioclimatic Modelling. *Methods in Ecology and Evolution*, 3, 53-64, DOI: 10.1111/j.2041-210X.2011.00134.x

LIMSAKUL, A., SINGHRUCK, P., AND WANG, L. (2017). Climatology and Spatio-Temporal Variability of Wintertime Total and Extreme Rainfall in Thailand During 1970 – 2012. *Environment Asia*, 10(2): 162-176

LYON, C., BECKERMAN, A. P., MARCHANT, R., O'HIGGINS, P., DUNHILL, A., ALLEN, B., AZE, T., SAUPE, E., SMITH, C., HILL, D., STRINGER, L., RIEL-SALVATORE, J., MCKAY, J., AND BURKE, A. (2020). *Climate change research and action must look beyond 2100. 10.31223/X5QG7D.*

MCCONNELL, D. A., STEER, D. (2015). Earth's Climate System. *The Good Earth: Introduction to Earth Science*, New York: McGraw Hill Education, pp. 448-449.

MIHINCĂU, D., ILIEȘ, D., C., WENDT, J., LIEȘ, A., ATASOY, E., SZABO-ALEXI F, P., MARCU, F., ALBU, A., V., HERMAN, G., V. (2019). Investigations on Air Quality in A School. *Folia Geographica*, 61(2): 190–204

NEUKOM, R., STEIGER, N, GÓMEZ-NAVARRO, J.J., WANG, J., WERNER, J. P. (2019). No evidence for globally coherent warm and cold periods over the preindustrial Common Era, *Nature*, 571, 550–554, DOI: https://doi.org/10.1038/s41586-019-1401-2

ONGOMA, V., RAHMAN, M.A., AYUGI, B. NISHA, F., GALVIN, S., SHILENJE, Z. W., OGWANG, B. A. (2021) Variability of diurnal temperature range over Pacific Island countries, a case study of Fiji. Meteorol Atmos Phys. 133, 85–95. https://doi.org/10.1007/s00703-020-00743-4

PANOFSKY, H. W. AND BRIER, G. W. (1968). *Some Applications of Statistics to Meteorology*, Philadelphia: The Pennsyl-25vania State University Press.

PEEL, M. C., FINLAYSON, B. L., MCMAHON, T. A. (2007). Updated World Map of the Köppen-Geiger Climate Classification. *Hydrolody and Earth System Sciences*, 11, 1633-1644. DOI: https://doi.org/10.5194/hess-11-1633-2007

PHUMKOKRUX, N., RUKVERATHAM, S. (2020). Investigation of mean monthly maximum temperature of Thailand using mapping analysis method: A case study of summer 1987 to 2019. *E3S Web of Conferences*, 158, 1-5. DOI: https://doi.org/10.1051/e3sconf/202015801001

RUHLI, R., V., VEGA, A., J. (2008). Climate Across Space. *Climatology*, Massachusetts: Jones and Bartlett Publishers, pp.173 – 177.

SANDERSON, M. (1999). The classification of climates from Pythagoras to Koeppen. *Bulletin of the American Meteorological Society*, 80, 669–673. DOI: https://doi.org/10.1175/1520-0477(1999)080<0669:TCOCFP>2.0.CO;2

SARFARAZ, S., ARSALAN, M. H., FATIMA, H. (2014). Regionalizing the Climate of Pakistan using Köppen Classification System. *Pakistan Geographical Review*, 69, 2, 111-132.

SRIVANIT, M. AND JAREEMIT, D. (2020). Modeling the influences of layouts of residential townhouses and tree-planting patterns on outdoor thermal comfort in Bangkok suburb. *Journal of Building Engineering*. 30(101262): 1-12

THAI METEOROLOGICAL DEPARTMENT, 2015. The Climate of Thailand. Retrieved from: https://www.tmd.go.th/info/info.php?FileID=22 Accessed on 29 May 2018

THAI METEOROLOGICAL DEPARTMENT, 2016. Climate of Thailand. Retrieved from: https://www.tmd.go.th/en/archive/thailand_climate.pdf. Accessed on 29 May 2020

THORNTHWAITE, C. W. (1943). Problems in the classification of climates, *Geographical Review*, 33, 2, 233–255.

WU, T. (2012). A mass-flux cumulus parameterization scheme for large-scale models: description and test with observations. *Climate Dynamics*. 38, 725 – 744.
DOI 10.1007/s00382-011-0995-3

XIN, X., ZHANG, L., ZHANG, J., WU, T., AND FANG, Y. (2013). Climate change projections over East Asia with BCC_CSM1.1 climate model under RCP scenarios. *Journal of the Meteorological Society of Japan*. 91. 413-429. 10.2151/jmsj.2013-401.

XIN, X., WU, T., ZHANG, J. (2013a). Introduction of CMIP5 Experiments Carried out with the Climate System Models of Beijing Climate Center. *Advances in Climate Change Research,* 4, 1, 41-49. DOI:10.3724/SP.J.1248.2013.00041

XIN, X., WU, T., LI, J., WANG, Z., LI, W., WU, F. (2013b). How Well does BCC_CSM1.1 Reproduce the 20th Century Climate Change over China?. *Atmospheric and Oceanic Science Letters*, 6, 1, 21-26, DOI: 10.1080/16742834.2013.11447053

ZHANG, J., WU, T. (2012). The impact of external forcings on climate during the past millennium: Results from transient simulation with BCC_CSM1.1. *Geophysical Research Abstracts*, 14, EGU2012-448.