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Investigation of 37 years weather record and its relation to human health: A case study in Songkhla Province, Southern Thailand

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Abstract The weather data from the Thai Meteorological Department during 1982-2018 were analysed and identified the climate change situation in Songkhla Province, Thailand. Result indicated that temperature, humidity, rainfall, sunlight and heat index was statistic significantly increased at $p<0.05$, while the monthly maximum wind speed decreased in temperature change which 33% less than global temperature change. The increase in temperature consequently affected the other parameters such as humidity, rainfall and heat index. Moreover, the storm frequencies in Songkhla were not increased. Their frequencies of occurrence were slightly fluctuated. Another finding was the storm arrival date slightly shifted to the end of year. The characterization of relationship between climate change and health conditions were related to the diseases e.g. gastroenteritis, dengue fever, malaria, blood infection disease and upper respiratory infection from the year 2002 to 2018. The secondary data of crucial meteorological factors were recorded. The results revealed that the morbidity rates per 1,000 population for gastroenteritis, blood infection diseases, upper respiratory infection that had positive statical relationship with the average annual relative humidity with r^2 = 0.460, 0.461 and 0.486 (p <0.05) respectively, whereas dengue fever and malaria are not related to statistical relationship with all the investigated climatic variables including the average annual rainfall. Probably climatic change would increase the outbreaks of the gastroenteritis, blood infection, upper respiratory diseases, while it had not affected on the spread of dengue fever and malaria according to topographic factor in the study area.

Keywords: Climate change, Diseases, Rainfall, Temperature

The effects of climate on natural processes are fundamental components of living things to exist on the earth (Patz *et al*., 2000). Climate change has

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expanded as a high on the agenda of public health services worldwide.The health sector can use climate information effectively in epidemic early warning systems (Ghebreyesus *et al*., 2008). Although global warming may bring some localized benefits, such as fever winter deaths in temperate climates, the overall health effects of changing climate are overwhelmed. Climate change affects many of the social and environmental determinants of health – clean air, safe drinking water, sufficient food and secure shelter (WHO, 2018). Schwarz and Clore (1983) claimed that weather affects mood, which alter humans' judgement on their life satisfaction. The concepts of climate and weather are often confused. Weather is the state of the atmosphere at any given time and places. Weather patterns has greatly varied from year to year and region to region. Climate has averaged the weather conditions that persist over multiple decades or longer (Balbus *et al*., 2016). Since the industrial evolution, the greenhouse gas has been rapidly released. During the past 30 years, the global temperature has increased up to 0.2 ℃ per decade (Hansen *et al*., 2006). The rise of temperature consequently affected the global environment both in physical and biological views (Harley *et al*., 2006) such as ice melt, sea level rise, or storms (Hansen *et al*., 2016). Moreover, there are many reports showed that the number of hot days and their length in urban areas (Mishra *et al*., 2015; Opitz-Stapleton *et al*., 2016). Climate change also affects directly the outdoor workers including risk persons. . Heat index (HI) is a parameter to indicate the stage of heat risk. US Department of Labor suggested a guide for employers using HI for 4 stages (Occupational Safety and Health Administration, 2020) as follows: lower (<32.7 ℃), moderate (32.7-39.4 ℃), high (39.4-46.1 ℃), and very high to extreme (>46.1 ℃). HI is originally developed by multiple regression (Opitz-Stapleton *et al*., 2016). Rothfusz (1990) further adopted by assuming solar radiation, windiness, and human physiology, and reformulated the calculation based on temperature and relative humidity.

The Thai Meteorological Department classified the weather into 3 seasons (Climate center, 2019) based on monsoon; pre-monsoon (warm dry season), Southwest monsoon and Northeast monsoon. The Southwest monsoon (Asian summer monsoon; Jourdain *et al*., 2013) is occurred during May to October to cause the lower pressure in China called Tibetan low (Rohli and Vega, 2008) while the Northeast monsoon (Asian winter monsoon) is caused by the high pressure area from China during October-February. These two monsoons bring humid air from seas (Andaman sea and Gulf of Thailand) and generate rainfall in Southern Thailand. During Northeastern monsoon, the low pressure areas are situated at the same latitude to Southern Thailand. The low pressure area can further develop to be tropical depression, tropical storm, or typhoon. Most of storms arrived Southern Thailand during October to

December in Northeast monsoon (Climate center, 2019). Songkhla is a significant economic province in Eastern coast of Southern Thailand (Figure 1) which consists of the offshore petroleum production hubs, fisheries, tourism, and other industries. The livelihood has more than 1.9 million people of the 25 districts locate in the three provinces of Southern Thailand which rely on this fishery resource (Hue *et al*., 2018). Moreover, the wind power plants have been developed in Songkhla. In recent century, there have been faced several hazards which related to meteorological phenomena such as flooding, landslide, storm and storm surge. Moreover, in 2003-2013, the Ministry of Public Health of Thailand reported that 196 deaths due to heat stroke in Thailand. These disasters were related to the geographical location of Southern Thailand locates in the Malay Peninsula (tropical climate) which is warm and wet.

Figure 1. Location of Songkhla in Southern Thailand (top right). Dark circle indicates weather station in this study, dark area represents Koh Taeo studied area in Koh Taeo Sub-district (bottom middle left)

Analyzing the role of climate in determining human health outcomes will require interdisciplinary cooperation. Increased disease surveillance, integrated modeling and the using geographically based data systems would be afforded more anticipatory which measured by the medical community (Patz *et al.*, 2000). In order to understand how climate change creating or exacerbating health problems, assessments of climate change health impacts that must know about the current state and observed trends in a wide array of health conditions. In addition, because preexisting health conditions, socioeconomic status and life stage of all contribute to vulnerability to climate and weather-related health effects, assessments of climate change's health impacts should be informed by changing in these factors (Balbus *et al.*, 2016). This study aimed to identify the characteristics and changing of some climate parameters; temperature, humidity, rainfall, wind speed, heat index based on the weather station in Songkhla from 1982-2018, and to explain the storms trajected to Southern Thailand, and to examine the correlations between climate change and health conditions in Koh Taeo Sub-district, Muang Songkhla District, Songkhla Province between 2002-2018.

Materials and methods

Weather and climate section

The weather records were collected from Thai Meteorological Department (TMD) during 1982-2018. The station representing the study area is WMO Station ID 48568 located at 7.20 °N, 100.60 °E and +5 meter above mean sea level. The weather station was set up as the WMO standard. The monthly temperature, relative humidity, average maximum wind speed, and annually-accumulated rainfall and duration of sunshine including the storms (tropical depressions, tropical storms, and typhoons) since 1956 are obtained from TMD.

Heat index (HI) is calculated which based on US National Weather Service (NWS) Heat Index Method (Rothfusz, 1990) which is internationally used. The heat index is calculated on the basis of two parameters; temperature and relative humidity in the following equation:

$$\mathrm{HI} = -c_1 + c_2\mathrm{T} + c_3\mathrm{Rh} - c_4\mathrm{TRh} - c_5\mathrm{T}^2 - c_6\mathrm{Rh}^2 + c_7\mathrm{T}^2\mathrm{Rh} + c_8\mathrm{TRh}^2 - c_9\mathrm{T}^2\mathrm{Rh}^2 \quad (1)$$

where T is temperature in °F and Rh is relative humidity in per cent. For the constant values in equation are c_1= 42.379, c_2= 2.04901523, c_3= 10.14333127, c_4= 0.22475541, c_5= 6.83783×10^{-3}, c_6= 5.481717×10^{-2}, c_7= 1.22874×10^{-3}, c_8= 8.5282×10^{-4}, and c_9= 1.99×10^{-6}. This equation expresses HI in °F. This study, HI is further converted to °C.

The collected data were processed, analyzed and illustrated by R software (R Development Core Team, 2017). Climate trends were analyzed using simple linear regression to determine the rate (per year) of each parameter. The presented errors represented the standard error. Moreover, the statistical hypothesis was tested by the *p*-value.

Health section

This section characterized the relationships between climate change and health conditions in Koh Taeo Sub-district, Muang Songkhla District, Songkhla Province between 2002-2018. The four monitored meteorological factors (temperature (℃); relative humidity (%); rainfall (mm.); and sunshine duration (hr.)) and. the 5 investigated diseases (gastroenteritis, dengue fever, malaria, blood infection disease and upper respiratory infection) were investigated and analyzed.

Secondary data of the meteorological factors within the period of 2002-2018 were collected from the Thai Meteorological Department, Bang Na, Bangkok, Thailand, and calculated the temperature mean, relative humidity, rainfall and sunshine duration. The data of the health conditions and population were collected from the Songkhla Provincial Public Health Office and Ban Chum Por and Ban Bo It at Health Promoting Hospitals locates in Koh Taeo Sub-district, Muang Songkhla District, Songkhla Province from 2002-2018, and were computed the morbidity rates per 1,000 population. The obtained data was analyzed using statistical R software (open source) over the studied period by linear regression analysis. The independent variables were average annual temperature, annual relative humidity, annual rainfall and annual sunshine duration. The dependent variables were the morbidity rates per 1,000 population of gastroenteritis, dengue fever, malaria, blood infection disease and upper respiratory infection.

Results

Thirty-seven-year weather record and heat index

Plots of temperature from 1982-2018 are presented in Figure 2. Monthly averaged air temperatures were between 25.2 -30.2 ℃ with the average of 28.02 $\pm$0.05 ℃. It tended to increase by 0.0133 ℃ per year.

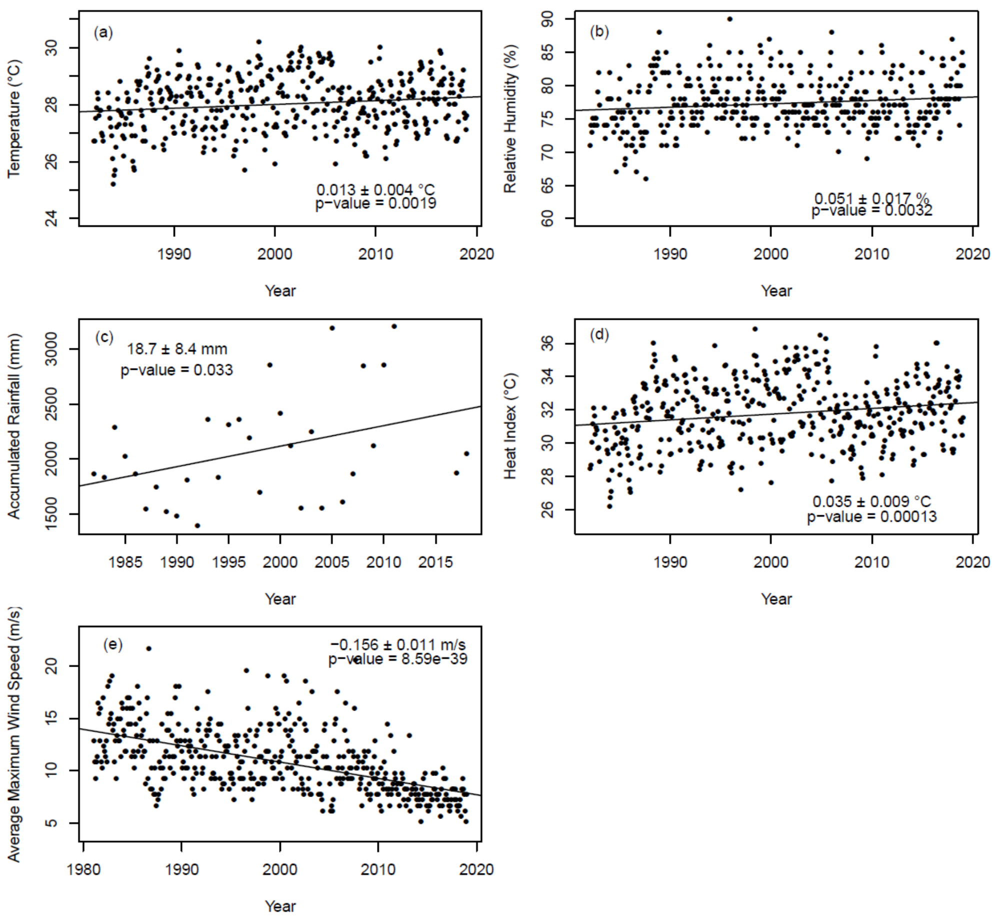

Figure 2. The tempurature (a), relative humidity (b), rainfall (c), heat index (d), and average maximum wind speed (e) in the past 37-years weather record

Table 1. Thirty seven year mean, rate, and *p*-value of temperature, rainfall, average maximum wind speed, relative humidity, and heat index

Parameter	Mean	Rate (per year)	*p*-value
Annual Temperature (℃)	28.0 ± 0.1	+ 0.0133 ± 0.0043	0.0019
Accumulate Rainfall (mm)	2076 ± 142	+ 18.7 ± 8.4	0.0332
Monthly-averaged maximum wind speed (m/s)	10.8 ± 0.1	- 0.156 ± 0.011	8.59×10^{-39}
Relative Humidity (%)	77.3 ± 0.2	+ 0.512 ± 0.173	0.0032
Heat index (℃)	31.8 ± 0.1	+ 0.0347 ± 0.009	0.00013

It found that not only temperature but also other weather parameters e.g. rainfall, and relative humidity, were increased which leading to raise the heat index. However, the average maximum wind speed decreased. The *p*-values from simple linear regression were less than 0.05. All the trends of each parameter are illustrated in Figure 2 and Table 1.

Statistical analysis of the 37-year weather records e.g. temperature and relative humidity), in Songkhla province gave the heat index (HI) between 26.1-36.9 ℃ .The 141 out of 437 data points in month showed HI at moderate risk level (32.7-39.4 ℃) (Occupational Safety and Health Administration, 2020) or 32 % of HI data. There were four months (April, May, June, and July) which the HI averaged =at moderate risk level. The HI showed the highest in May (34.2 ± 1.4 ℃). The average temperature and HI of each month are presented in Figure 3.

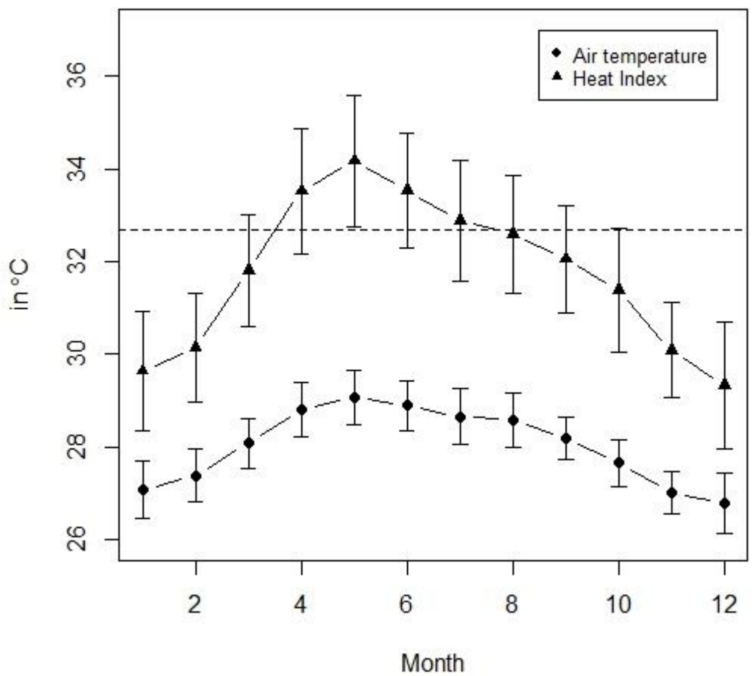

Figure 3. Temperature and heat index trend in a year (note that error bars express standard deviation)

Storm trend in Southern Thailand

Storms were recorded during monsoon from 1956 to early 2019. It noted that Tropical Storm namely Pabuk which arrived Southern Thailand on 3 January 2019 was counted as 368th day of 2018 because it was in 2018 monsoon season. The storm distribution is presented in Figure 4. The most frequent storms were observed in November. At the early of the record (1956-

1975), storms were dispersedly observed from beginning of October to late December. However, from 1975, there were only 5 from 21 storms observed in late October and one storm in early January.

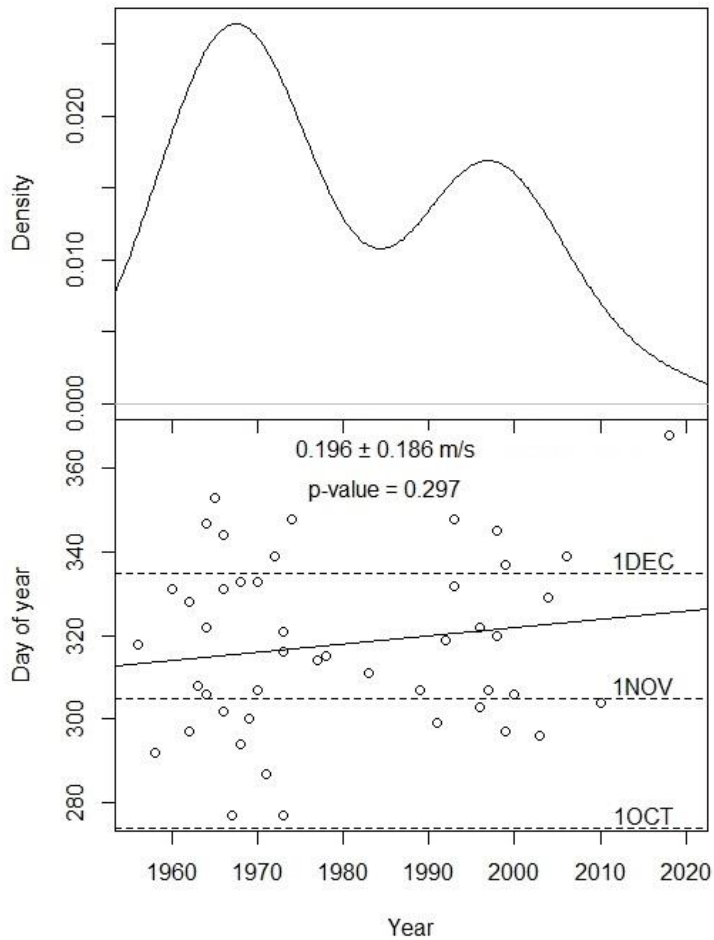

Figure 4. Distribution and day of year of storm in Southern Thailand

The linear regression analysis between year and day of year which faced the storm occurrence that was carried out. The result showed that the storms arrived Southern Thailand much late in approximately revealed at 0.196 ± 0.186 day/year with p-value of 0.297. The trend of storm frequency in Southern Thailand (1956-2019) decreased. Storms were much densed during 1956-1975, and less during 1976-1988 and became densed again during 1989-2000. The frequency of storms is presented in Table 2.

Table 2. Number and frequency of storm occurrence in Southern Thailand during 1956-2019

Period	No. of Storm	Frequency (per year)
1956-1975	27	1.42
1976-1988	3	0.25
1989-1999	12	1.20
2000-2019	6	0.31

Climate change and health impact

Linear regression analysis demonstrated that the morbidity rates per 1,000 population of gastroenteritis, blood infection disease and upper respiratory infection (URI) were positively related to average annual relative humidity (*p*-value <0.05), whereas dengue fever and malaria had no statistical relationship with average annual temperature, relative humidity, rainfall and sunshine durations (Table 3).

Table 3. Significant independent variables (*p* <0.05) and their influences on morbidity rate or symptoms of the investigated diseases related to climate change in Koh Taeo Sub-district

Health conditions	Equation	R-Square
Gastroenteritis	$Y = 0.833x - 64.086$	0.460
Blood infection disease	$Y = 0.994x - 76.531$	0.461
Upper respiratory infection (URI)	$Y = 0.509x - 39.122$	0.486

Remark: x = Average annual temperature

Comparing the morbidity rates per 1,000 population of the four aforementioned diseases which related to climate change among the 10 villages of Koh Taeo Sub-district, Muang Songkhla District, Songkhla Province, that were statistical compared through one-way ANOVA. The 10 investigated villages were conducted as follows: 1) Village No. 1 (Ban Laem Khian); 2) Village No. 2 (Ban Sam Kong); 3) Village No. 3 (Ban Chum Por); 4) Village No. 4 (Ban Dan Nuea); 5) Village No. 5 (Ban Dan Tai); 6) Village No. 6 (Ban Ko Taeo); 7) Village No.7 (Ban Ko Wa); 8) Village No.8 (Ban Bo It); 9) Village No.9 (Ban Chu Kiat); and 10) Village No.10 (Ban Dan Klang). Those were compared in each village that had a different distance from the coast, the morbidity rates per 1,000 population of the five aforementioned investigated diseases had not statistical differed in eacg village (*p*>0.05).

Discussion

In 2007-2009, temperatures were slightly lower than those of another period. This might relate to long La Niña effect. Average monthly temperature of each month was agreed with seasons (Climate center, 2019). During pre-monsoon, the temperature was high as compared to other seasons. At the beginning of the monsoon (ca. late of May), temperatures in June-August slightly decreased. From August – November, the temperature decreased more rapidly. This might relate to the earth rotation axis which leads the lower sun radiation (Exell, 1976) to Songkhla and monsoonal rain. Temperature continuously decreased until December and increased again due to end of monsoon and less solar radiation. All the analyzed weather parameter trends over 37 years in this study showed the p-value less than 0.05. This reflected the significance of the climate change in Songkhla. The past 37-year temperature record in Songkhla reflected the increase in temperature approximately 0.0133 ℃ per year. The increase of the temperature was similar to the global average. However, in Songkhla was ca. 33.5% less than that of the global. The increase of temperature might increase the evaporation rate due to Songkhla is located between Andaman and Gulf of Thailand. The higher vapor leaded the higher increase in relative humidity at 0.512 % per year. This allowed a good condition for forming cloud and resulted in the increase in accumulate rainfall approximately 18.7 mm/year. The increases in temperature and relative humidity consequently raised heat index (0.034 ℃ per year). The increase of the air temperature might relate to the global warming which greenhouse gas is dominant (Hansen *et al*., 2006). The greenhouse gas can reduce the temperature gradient (Coats and Karnauskas, 2017; Seager *et al.*, 2019) and decrease wind speed. The trend of average maximum wind speed in this study reduced at 0.156 m/s per year. This trend was similar to several studies such as (Yan *et al*., 2002; Rockel and Woth, 2007; Jiang *et al*., 2010).

Storm trend in Southern Thailand slightly changed with ca. 0.196 day per year and shifted to the late of the year. Even the p-value was greater than 0.05, the presence of storm during early October in 1950's -1970's and absence since 1980 could describe the trend of the later storms. For example, Tropical Storm Pabuk in early 2019 was a good evidence of the later storm. In future, the preparedness of storm season might be extended to the very end of the year or the beginning of the following year. Moreover, the delay of the monsoon was recently reported by Ashfaq *et al*. (2020). When the monsoon delays, the storm might be formed and arrive later. The increasing of both local and global temperature resulted in the decrease of ice volume, and rise of sea level. Trisirisatayawong *et al*. (2011) reported that sea level rise of Songkhla during

1993-2004 was 4.6 mm per year with satellite altimetry, while tidal gauge trend was 13.0 mm per year. They also reported the vertical land movement producing the land subsidence of 8.4 mm/year. With the higher rainfall (higher runoff) and rise of sea level , in the future, Songkhla Province might encounter more severe flooding events or storm surge as suggested by Ruckert *et al*. (2019).

As expectation, the relationship between all the investigated infection diseases showed the statistical positive relationship with the average annual relative humidity except dengue fever and malaria. It is well known that the increase in relative humidity will certainly enhance the abundance and activities of micro-organisms (bacteria, viruses and fungi) causing infection. Thus, the higher relative humidity is, the higher infection disease outbreak occurs. Surprisingly, the outbreaks of dengue fever and malaria had no statistical relationship with all the 5 investigated climatic variables especially the average annual rainfall since the high morbidity rates of dengue fever and malaria were normally observed during the rainy season due to the increase in the habitats of mosquitoes... This was probably caused by topographic factor of the study area. Our study site is located at the coastal area with the tiny saline peat swamp. Salinity of the surface and ground water in the swamp makes the peat swamp unfavorable for being the habitats of the mosquitoes carrying dengue viruses and malaria parasites. Hence, the trend of the increase in the average annual rainfall and average air temperature caused by global warming effects will not probably worsen the outbreak of dengue fever and malaria in the coastal areas with tiny saline peat swamp. However, the increase in relative humidity related to climate change do raise the spreading of the infectious diseases in the coastal areas. Our results are consistent with an earlier study reported that the higher rainfall, relative humidity and temperature might increase the tropical disease such as respiratory infectious illness (Pradit *et al*., 2020). Moreover, the increase of heat index might decrease the working hour of labor or outdoor activity for heat stoke protection (Opitz-Stapleton *et al*., 2016), while the care of patient in non-air conditioning room must be more careful (Kuehn and McCormick, 2017).

This study successfully established the trends of climate change in Songkhla Province via increasing of temperature, humidity, rainfall, and decreasing of wind speed. These parameters had trends concordant with the global scale, but appeared the lower strength. The temperature increase influenced the humidity, rainfall and heat index consequently. Surprisingly, the storms attacked Southern Thailand was not more frequent as they did in the past. Although the p-value of the day of year of storm occurrence was greater than 0.05, the absence of storm in early October and presence of storm in early

January can informed the later occurrence of storms in monsoon season. For the study of the relationship between meteorological factors (temperature, relative humidity, rainfall, and sunshine duration) affecting the rate of morbidity or symptoms related to climate change in Koh Taeo Sub district, Mueang District, Songkhla Province during 2002-2018, only 5 studied diseases out of 11 diseases had relationship with average sunshine duration with statistical significance (p <0.05). For other infection diseases were found to be related to both average sunshine duration and average rainfall at statistical significance level ($p < 0.05$). Furthermore, the stronger monsoon might cause more severe coastal erosion problems which would affect coastal ecosystems, fisheries and population settlements and tourism industries. The change of climate affected directly the disaster management, outdoor activities, patient care and the planning of these topics or issues need to be revised. In terms of climate change and health impacts, the morbidity rates per 1,000 population of blood infection diseases, upper respiratory infection diseases and gastroenteritis possessed statistical positive correlation with the mean annual relative humidity. Hence, the climate alteration probably affects the infection diseases. However, the spread of dengue fever and malaria in the coastal areas with tiny saline peat swamp showed no statistical relationship with all the 5 investigated climatic variables especially mean annual relative humidity. Thus, climate change will probably have no effect on their outbreaks according to the topographic factor of the study site. Based on the results recorded here, the present study underlines the climate change situation and the effects of climate change on morbidity risks in Songkhla Province, Thailand. Our data also justified the Thailand government in intending to instigate the prevention and adaptation strategies in order to diminish the costs and burden of climate changes.

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