Climate change risk reduction through readiness: An assessment of extreme temperature indices for Peninsular Malaysia

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Abstract

Over the next century, people in many parts of the world will increasingly be confronted with the impacts of extreme climatic events. Such risks of extreme events can, fortunately, be reduced through readiness. Therefore, it is important to provide society and stakeholders in vulnerable sectors and regions with indicators and early warning information which will allow them to prepare properly and adequately. To improve readiness or preparedness for extreme temperature events in Peninsular Malaysia, twelve extreme temperature indices at ten selected states were developed and the significant trends of the indices using least square method analysed. The analysis results indicated that there were significant increasing and decreasing trends of extreme temperatures in some of the indices. The extreme temperatures affecting the northern, central and southern areas of Peninsular Malaysia were distinctly different from those of the eastern region, indicating that different levels of preparedness were in order.

Keywords: climate change trends, early warning, extreme temperature indices, preparedness, readiness, risk reduction

Introduction

Nowadays, people are suffering from the impact of extreme events. They are being forced to adapt urgently to the effects such as drought, flood and heat wave. According to Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (Intergovernmental Panel on Climate Change, 2008), year 1995 to 2006 were ranked among the twelve warmest years in the instrumental record of global surface temperature which the land regions were reported to warm faster than the oceans. The warming events affect negatively on human and natural environment, for examples disturbance in agricultural planning and management (Tao et al., 2006) and disruption of terrestrial ecology (Meehl et al., 2000).

Thus, there is a need for the societies to respond better to the impact of extreme events through readiness. Readiness includes elements such as early warning systems, monitoring policies, forecasting strategies and scenario identifications (Centre for Global Sustainability, 2013). From these four elements, our main concern is the development of early warning system. Early warning system provides evidence on an emergence of dangerous event. The evidence can enable action to be taken in advance to reduce the risks involved.

Different hazards pose greater risks. Sufficient early warning system benefits the communities by providing them ample time to prepare for the impacts of hazards caused by extreme events. In Africa, Malaria Early Warning System (MEWS) have been developed using several key indicators including seasonal climate forecasts and weather monitoring (Thomson & Connor, 2001). These indicators might be used to extend possible epidemic warning times from several months to a year. Recognizing the essential need of climate information to understand and predict flood, National Directorate of Water, together with the National Institute of Meteorology and the National Disaster Management Institute facilitate the preparedness for flood in Mozambique by coordinating flood early warning system (Hellmuth et al., 2007). The system detects and monitors flood and also provides a flood risk forecast.

An index can be used in developing early warning system. The index which is easy to interpret and comparable among countries and across time is important to build early warning system for individual country (Yang & Kim, 2014). Several types of indices have been developed and evaluated for early warning system including National Food Security Index to measure the sufficiency of the national food supply (Yang & Kim, 2014), Standardized Precipitation Index (SPI) for detecting the early onset (and end) of drought (Donald et al., 2000) and extreme temperature and precipitation indices to clarify the changes in frequency of rainfall and temperature extremes (Ozer & Mahamoud, 2013).

With this thematic focus, we aim to develop extreme temperature indices to integrate with early warning system for disasters. The development of the indices is a part of risk reduction plan through readiness. The indices we obtained do not only act as statistical indicators in monitoring extreme temperature but also elevate public awareness among societies. In this study, we assess extreme temperature indices at ten studied area in north Peninsular Malaysia.

Malaysia is located in Southeast Asia with latitude and longitude 2° 30' N and 112° 30' E, respectively. The country is generally free from natural disasters such as volcanoes and earthquakes. Nevertheless, drought is one of the significant hazards that affecting this country. Drought which is caused by increasing of land and sea surface temperatures has affected certain areas in the eastern regions of Malaysia (Centre for Hazards and Risk Research at Columbia University, 2005). Several studies focusing on forecasting and modeling the temperature in Malaysia have been conducted. Forecast based on Global Climate Models shows that Malaysia could experience changes in temperature from 0.7 to 2.6 degree Celsius (Ministry of Science, Technology and the Environment 2000). Studies on extreme temperature in Malaysia indicated the existence of warming trend at certain meteorological stations in Malaysia (Hasan et al. 2013a, 2013b, 2014). As a result, the changes of the extreme temperature would increase the air surface and sea level temperature and also reduce crop yields in Malaysia.

Materials and methods

Data description

Daily maximum and minimum temperature data from ten meteorological stations are obtained from Malaysian Meteorological Department. Table 1 shows the stations with their geographical coordinates. Chuping (CP), Alor Setar (AS) and Bayan Lepas (BL) stations are located at the northern (N) part of

Table 1. The geographical coordinates of meteorological stations

No	Station Name	Zone	Region	State	Longitude	Latitude
1	CP	1	N	Perlis	100° 16' E	6° 29' N
2	AS	1	N	Kedah	100° 24' E	6° 12' N
3	BL	1	N	Penang	100° 16' E	5° 18' N
4	KB	1	E	Kelantan	102° 18' E	6° 10' N
5	KT	1	E	Terengganu	103° 206' E	5° 23' N
6	KLIA	2	C	Kuala Lumpur	101° 42' E	2° 43' N
7	MC	2	S	Malacca	102° 15' E	2° 16' N
8	MR	2	S	Johor	103° 50' E	2° 27' N
9	MS	2	S	Pahang	103° 05' E	3° 03' N
10	SN	2	S	Johor	103° 40' E	1° 38' N

Peninsular Malaysia while Kota Bharu (KB) and Kuala Terengganu (KT) stations are located at the eastern (E) region of Peninsular Malaysia. Four stations which are Malacca (MC), Mersing (MR), Muadzam Shah (MS) and Senai (SN) are located at southern (S) part of Peninsular Malaysia. Only one station is located at central (C) part of Peninsular Malaysia which is KLIA station.

The locations are divided into two zones distinguished by the latitude. Zone 1 lies between 5° N to 6° N while Zone 2 lies between 1° N to 3° N latitude lines .The data for all stations are recorded from 1st January 1994 to 31st December 2013 except for KLIA which is observed from 1st July 1998 to 31st December 2013. The data are measured in Degree Celsius (°C).

Quality control process

A prerequisite for indices calculation is a data quality control. In this study, we use RClimDex (1.0) which is a R based program to perform simple data quality control. The RClimDex (1.0) is a user friendly interface developed and maintained by Xuebin Zhang and Feng Yang at the Climate Research Branch of Meteorological Service of Canada. The quality control procedures performed by the RClimDex (1.0) identify unreasonable values (i.e. daily maximum temperature less than daily minimum temperature) and also outliers in daily maximum and minimum temperature.

Homogeneity testing

A homogeneity testing is a preliminary procedure before conducting any climatic analysis. The test is applied to detect the variability of the data. Homogeneous data are the data taken at a time within the same environments and using the same instruments (Kang & Yusof, 2012). Any inhomogeneous series detected should be adjusted or removed from the analysis. For this reason, we use RHTestV4 to identify step changes in station temperature time series. RHtestV4 is based on a two-phase regression model with a linear trend for the entire series (Wang, 2003).

Extreme temperature indices

Extreme temperature indices are the statistical indicators which are derived from daily observations of maximum and minimum temperature. Constructing extreme temperature indices is important for monitoring and detecting changes in temperature at the studied area. Expert Team on Climate Change Detection and Indices (ETCCDI) has developed a set of extreme temperature indices that are statistically robust to measure daily variability easily and provide useful understanding to the society (Politano, 2008).

Table 2. Extreme temperature indices

Indices Categories	ID (units)	Indices
Absolute Indices	TXx (°C)	Highest maximum temperature
	TXn (°C)	Lowest maximum temperature
	TNx (°C)	Highest minimum temperature
	TNn (°C)	Lowest minimum temperature
Threshold Indices	SU28 (days)	Summer days
	SU30 (days)	Hot days
	SU34 (days)	Extreme hot days
Percentile-based Indices	TN10P (%)	Cold nights
	TN90P (%)	Warm nights
	TX10P (%)	Cold days
	TX90P (%)	Warm days
Other Indices	DTR (°C)	Diurnal temperature range

There are different categories of extreme temperature indices recommended by ETCCDI and the indices can be calculated in term of monthly or annual basis. However, in this study, we only develop twelve extreme temperature indices which are appropriate for the climate of Malaysia and focus on the annual basis. The details of each temperature index are listed in Table 2.

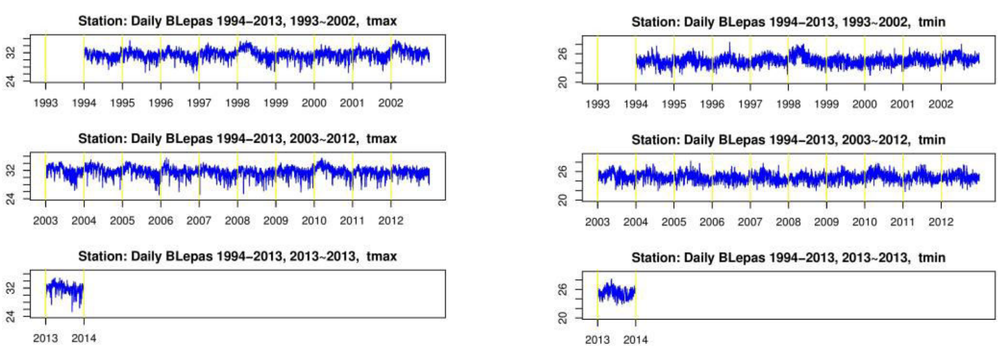
The computation of the indices is performed using R software with climdex.pcic package. For each meteorological station, a linear trend of each index is computed using linear least square method with p-value less than 0.10 is considered as statistically significant. The positive value of the index coefficient indicates an increasing trend and vice versa.

Results and discussion

Homogeneity testing and quality control process

The homogeneity testing is conducted to identify abrupt changes in data series. However, the result obtained from the RHtestV4 indicates that there is no artificial step change identified in station temperature time series. Moving on, the quality control procedures performed using RClimDex (1.0) show that there is no unreasonable value and outlier detected in the daily maximum and minimum temperatures.

After the quality control procedures have been performed, time series plots (with missing values are plotted as red dots) of daily maximum and minimum temperatures are produced by RClimDex (1.0) for an easy visualization. As an example, the time series plot of daily maximum and minimum temperatures at Bayan Lepas station are shown in Figure 1. From the plots, there is no missing value identified in the datasets.

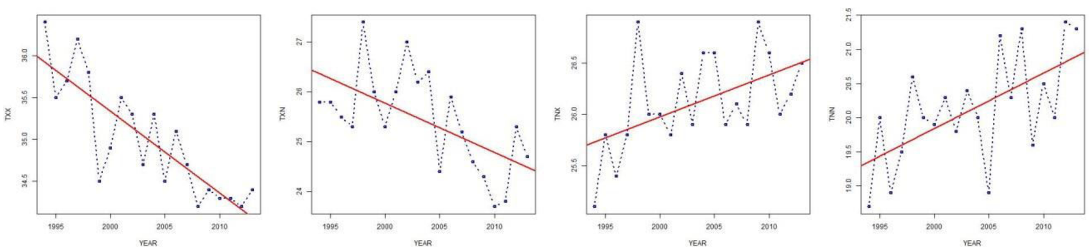


Daily maximum temperature | Daily minimum temperature

Figure 1. *Time series plot of daily maximum and minimum temperatures at Bayan Lepas Station*

Absolute temperature indices

Generally, there are significant increasing and decreasing trends for the absolute temperature indices as illustrated in Figure 2 and Table 3. Both TXx and TXn indices exhibit significant decreasing trends at the eastern (Kota Bharu and Kuala Terengganu stations), northern (Bayan Lepas and Chuping stations), central and southern (Malacca, Muadzam Shah and Senai stations) regions of Peninsular Malaysia, respectively. In contrast, the significant increasing trends are identified for both TNx and TNn indices for all all stations except for Kota Bharu and KLIA stations. The significant increasing trend of TNx index is noticed at Alor Setar and Malacca stations. Besides, the trend of TNn index increases significantly at all stations except for Kota Bharu, KLIA and Malacca stations.



TXx-KB TXn-CP TNx-MC TNn-MS

Figure 2. *Significant trends of annual absolute temperature indices at selected stations*

Table 3. Absolute temperature indices

Station	TXx Coef. (p -value)	TXn Coef. (p -value)	TNx Coef. (p -value)	TNn Coef. (p -value)
AS	-0.010 (0.803)	-0.041 (0.308)	**0.038 (0.044)**	**0.110 (0.006)**
BL	-0.013 (0.651)	**-0.059 (0.084)**	0.009 (0.645)	**0.042 (0.002)**
CP	-0.037 (0.360)	**-0.099 (0.006)**	-0.021 (0.340)	**0.075 (0.058)**
KB	**-0.097 (0.000)**	-0.035 (0.184)	-0.015 (0.471)	0.019 (0.520)
KT	**-0.057 (0.014)**	-0.027 (0.350)	0.015 (0.515)	**0.055 (0.085)**
KLIA	-0.043 (0.372)	**-0.174 (0.027)**	0.001 (0.970)	0.020 (0.529)
MC	-0.037 (0.354)	**-0.072 (0.084)**	**0.041 (0.020)**	0.020 (0.317)
MR	0.023 (0.391)	-0.033 (0.311)	-0.016 (0.472)	**0.041 (0.091)**
MS	**-0.037 (0.092)**	-0.023 (0.430)	0.016 (0.259)	**0.081 (0.005)**
SN	-0.040 (0.125)	-0.041 (0.038)	0.025 (0.146)	**0.057 (0.023)**

Coef. = coefficient

Threshold temperature indices

There are several threshold temperature indices suggested by ETCCDI including frost days (FD0), summer days (SU25) and tropical nights (TR20). However, those suggested indices cannot be applied in this study due to the climate of Malaysia. Since Malaysia has tropical rainforest climate, this country is always hot and humid throughout the year. Hence, the new temperature thresholds are introduced and fixed correspond to the Malaysia's climate as mentioned in Table 2.

The first threshold temperature index (daily maximum temperature above 28°C) is fixed as summer days index (SU28) because it exceeds the value of annual mean surface temperature for this country which ranged from 26°C to 28°C (Malaysia's Second National Communication, 2000). For hot days index (SU30), the threshold (daily maximum temperature above 30°C) is chosen by considering the relationship of temperature with the agriculture product. Higher temperature should lead to decrease in yields. Therefore, the optimum annual temperature for major economic crop in Malaysia (Malaysia's Second National Communication, 2000) is assessed (Table 4) before fixing the second threshold temperature index. Comparing the upper range of the optimum annual temperature, rubber production has the lowest value which is 30°C.

Table 4. Optimum annual temperature of major economic crop in Malaysia

Crop	Optimum Annual Temperature
Oil Palm	22°C - 32°C
Rice	24°C - 34°C
Rubber	23°C - 30°C
Cocoa	25°C - 32°C

Coef. = coefficient

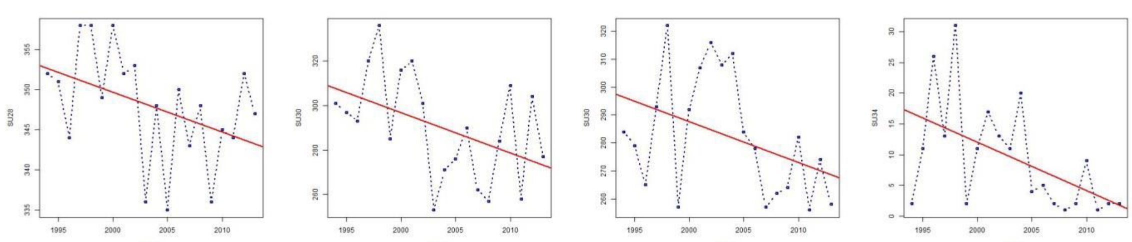
Moving on, the extreme hot days index (SU34) is built based on human thermal comfort level in outdoor spaces. Study done by Makerami et al. (2012) regarding human thermal comfort in outdoor spaces of hot and humid climate of Malaysia concluded that the acceptable condition for human is when the temperature less than 34°C. This condition is normally occurred during the early hours (9-10 am) and late afternoon (4-5 pm). Consequently, the temperature value greater than 34°C is fixed as the threshold temperature for extreme hot days index.

The analysis results of threshold temperature indices are presented in Table 5. Overall, there are significant decreasing trends for the indices. Bayan Lepas and KLIA stations show a strong evidence of a significant negative trend for SU28 index while Senai station exhibits significant decreasing trend for SU30. As displayed in Figure 3, Kuala Terengganu station demonstrates a clear tendency to decrease for both SU28 and SU30 indices while at Kota Bharu station, the significant negative trends exist for SU30 and SU34 indices. However, there is no significant trend for the threshold temperature indices exhibit at northern (Alor Setar and Chuping stations) and southern (Malacca, Mersing and Muadzam Shah stations) parts of Peninsular Malaysia respectively.

Table 5. Threshold temperature indices

Station	SU28 Coef. (p -value)	SU30 Coef. (p -value)	SU34 Coef. (p -value)
AS	-0.198 (0.234)	0.453 (0.164)	0.440 (0.734)
BL	**-0.207 (0.072)**	0.453 (0.293)	-0.041 (0.931)
CP	-0.253 (0.120)	-0.318 (0.309)	-1.057 (0.359)
KB	-0.342 (0.182)	**-1.453 (0.081)**	**-0.789 (0.016)**
KT	**-0.493 (0.065)**	**-1.815 (0.043)**	-1.367 (0.084)
KLIA	**-0.396 (0.077)**	-0.825 (0.343)	-1.000 (0.478)
MC	-0.165 (0.205)	-0.486 (0.186)	-1.083 (0.292)
MR	-0.263 (0.519)	-0.135 (0.886)	0.270 (0.460)
MS	-0.205 (0.364)	-0.298 (0.534)	-1.662 (0.191)
SN	-0.343 (0.245)	**-1.390 (0.043)**	-0.909 (0.342)

Coef. = coefficient



SU28-KT SU30-KT SU30-KB SU34-KB

Figure 3. *Significant trends of annual threshold temperature indices at selected stations*

Percentile-based temperature indices

Considering the analysis result of four percentile-based indices as in Table 6, the cold nights index, TN10P (percentage of days when daily minimum temperature less than 10th percentile) appeared to decrease significantly over the years at all stations except KLIA. Conversely, the trend of warm nights index, TN90P (percentage of days when daily minimum temperature greater than 90th percentile) increases significantly at half of the stations (Alor Setar, Kuala Terengganu, Malacca, Muadzam Shah and Senai stations) as presented in Figure 4.

Table 6. Percentile-based temperature indices

Station	TN10P Coef. (p -value)	TN90P Coef. (p -value)	TX10P Coef. (p -value)	TX90P Coef. (p -value)
AS	**-0.930 (0.000)**	**0.859 (0.001)**	**-0.227 (0.092)**	0.373 (0.278)
BL	**-0.596 (0.002)**	0.523 (0.110)	-0.187 (0.201)	0.144 (0.664)
CP	**-0.319 (0.056)**	-0.014 (0.966)	0.129 (0.389)	-0.201 (0.582)
KB	**-0.510 (0.018)**	0.061 (0.763)	**0.324 (0.047)**	**-0.708 (0.008)**
KT	**-0.577 (0.003)**	**0.834 (0.000)**	**0.475 (0.011)**	**-1.153 (0.032)**
KLIA	0.040 (0.280)	-0.036 (0.937)	0.368 (0.238)	-0.571 (0.230)
MC	**-1.040 (0.000)**	**0.576 (0.055)**	0.158 (0.206)	-0.381 (0.280)
MR	**-0.522 (0.003)**	0.184 (0.419)	-0.050 (0.781)	0.051 (0.883)
MS	**-0.829 (0.000)**	**0.545 (0.001)**	0.162 (0.181)	-0.337 (0.259)
SN	**-0.754 (0.001)**	**1.044 (0.005)**	0.273 (0.112)	-0.450 (0.212)

Coef. = coefficient

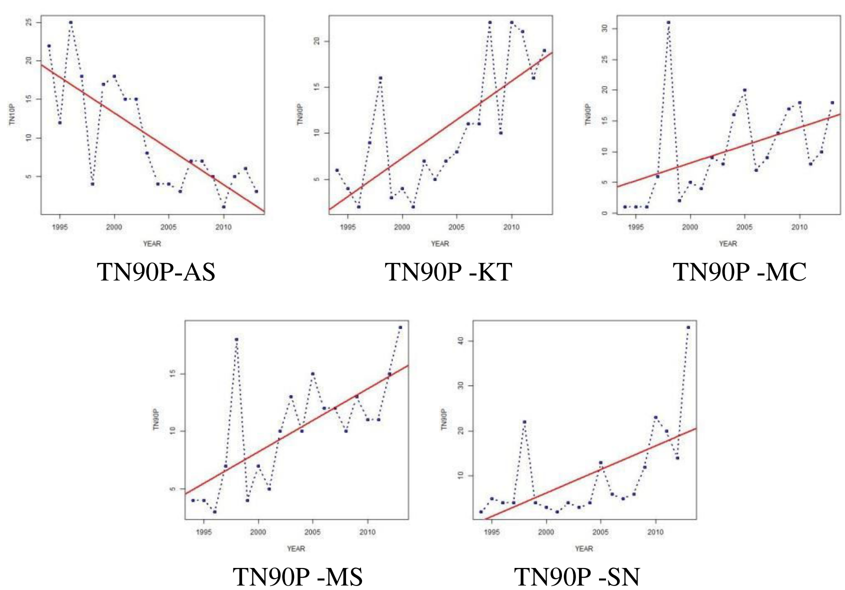


Figure 4. *Significant trend of annual cold (TN90P) index at five stations*

For the cold days index, TX10P (percentage of days when daily maximum temperature less than 10th percentile), the negative trend is detected at Alor Setar station while the positive trends are noticed at Kota Bharu and Kuala Terengganu stations. Contradict to the warm nights index, trend of warm days index, TX90P (percentage of days when daily maximum temperature less than 10th percentile) decrease significantly at Kota Bharu and Kuala Terengganu stations.

Diurnal temperature range indices

The diurnal temperature range (DTR) index calculated from the annual mean difference between maximum temperature (TX) and minimum temperature (TN) demonstrates a significant downward trend at all stations except Mersing (Figure 5). As stated in Table 7, the decrement values range from 0.17°C to 0.86°C per decade. These changes indicate that the daily maximum temperature decreases while daily minimum temperature increases.

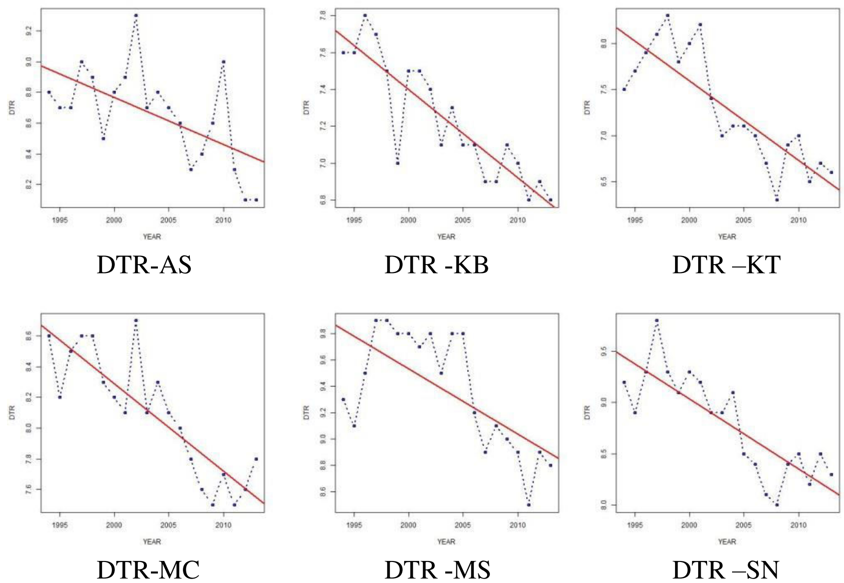


Figure 5. *Trend of annual DTR index at selected stations*

Table 7. Diurnal temperature range indices

Stations	DTR Coef. (p -value)
AS	**-0.030 (0.007)**
BL	**-0.017 (0.031)**
CP	**-0.022 (0.039)**
KB	**-0.048 (0.000)**
KT	**-0.086 (0.000)**
KLIA	**-0.029 (0.030)**
MC	**-0.057 (0.000)**
MR	-0.009 (0.449)
MS	**-0.049 (0.001)**
SN	**-0.068 (0.000)**

Coef. = coefficient

Summary result

Over the 20 years period of study, the extreme temperature indices demonstrate significant increasing and decreasing trends. It is noticed that the trends of absolute temperature indices decrease in maximum temperature and conversely increase in minimum temperature (Table 8). The significant increasing trends apparent in minimum temperature reveal that the studied area has become less cold rather than hotter.

Table 8. Stations with significant trend

Temperature Indices	Significant Increasing Trend	Significant Decreasing Trend
TXx	-	KB, KT, MS
TXn	-	BL, CP, KLIA, MC
TNx	AS, MC	-
TNn	AS, BL, CP, KT, MR, MS, SN	-
TN10P	-	AS, BL, CP, KB, KT, MC, MR, MS, SN
TN90P	AS, KT	AS, MC, MS, SN
TX10P	KB, KT	AS
TX90P	-	KB, KT
SU28	-	BL, KT, KLIA
SU30	-	KB, KT, SN
SU34	-	KB
DTR	-	AS, BL, CP, KB, KT, KLIA, MC, MS, SN

This result is the same as the percentile-based temperature indices result which the number of warm nights appears to increase while the number of warm days decreases over the year. The same result was also reported by Mohammed Al-Habsi et al. (2014) in their study done at Salahah, Oman. The contrary trends in minimum and maximum temperatures indicate that, in long-term, diurnal temperature range has decreased in the studied area (Mohammed Al-Habsi et al., 2014).

By evaluating the threshold temperature indices, the result indicates that minority of the stations exhibit significant decreasing trends on number of days exceeding 28°C, 30°C and 34°C. Comparing with the result presented in our previous study on analyzing changes in temperature extremes based on daily average temperature (Mohd Salleh, et al., 2015) different results were produced in that study. The investigation on daily average temperature that were above defined threshold values showed that majority of the stations have significant increasing trends on number of days exceeding 82.4°F (28°C) and some of the stations exhibited significant increasing trends on number of days exceeding 86.0°F (30°C).

By analyzing the temperature indices trend at each station, Alor Setar, Bayan Lepas and Chuping, KLIA, Malacca, Mersing, Muadzam Shah and Senai stations show a reasonably strong evidence of getting less cold. On the other hand, a colder trend is observed at Kota Bharu and Kuala Terengganu stations during the studied period. Comparing the trend analysis in both zones, this study identified that the number of the significant trends in Zone 1 is higher than in Zone 2.

Risk reduction through readiness

Climate change is expected to come with warmer temperature condition. Increase in temperature has its predictable risk in varied ways. In Malaysia, agriculture's contribution to gross domestic product has been on the decline from 37% in 1960 to 7.3% in 2010 (Devendra, 2012). Soil moisture declines with higher temperature leading to drought condition in some areas. Study conducted by Chua (2012) indicated that a temperature increase arising from the global climate change affect the epidemiology of malaria in Malaysia. Increase in temperature has significant effect in increasing the malaria risk.

Implementing adaptation and readiness strategies to reduce the risks will decrease vulnerability in food and health security. One of the strategies is the development of early warning system. For this purpose, it is hoped that the extreme temperature indices analysis conducted in this study will provide useful and appropriate information in developing the early warning system.

Conclusion and recommendation

This research paper presents the analysis of extreme temperature indices at ten stations located at the northern, eastern, central and southern part of Peninsular Malaysia. Twelve extreme temperature indices are assessed based on daily maximum and minimum temperature data obtained from Malaysian Meteorological Department. In general, between 1994 and 2013, significant positive trends of the indices related to minimum temperature are identified compared to significant negative trends of the maximum temperature indices. These results indicate that the studied area has become less cold rather than hotter. Comparing all four regions, the less cold trend is observed at the stations located at the northern, central and southern parts of Peninsular Malaysia while colder trend is detected at the eastern region. The possible causes of the observed trends in extremes are not investigated in this study. Nevertheless, it is believed that the trends may be influenced by natural and human factors. The biggest obstacle to quantify whether the extreme temperature events have changed in Malaysia is lack of long-term temperature data. The relatively short-term temperature data is likely to produce trends that are sensitive to the sampling period. Therefore, future studies should include longer period of data with wider studied area and also consider the possible causes affecting the extreme temperature trends.

Acknowledgement

This research was supported by School of Mathematical Sciences, Universiti Sains Malaysia.

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