An analysis of heat wave trends using heat index in East Malaysia

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Abstract. This paper aimed to investigate the heat wave trends in East Malaysia based on the National Weather Services (NWS) Heat Index. The heat index was calculated by using mean temperature and mean relative humidity on monthly basis for 5 meteorological stations in East Malaysia during the period 2008 to 2010. The trends for heat wave were estimated from Heat Index based on the least square regression analysis at each station level. Results showed that the heat wave trends are increasing at all stations. The highest heat index was occurred in Sandakan on July 2010 with heat index 35°C while the lowest heat index happened at Kuching in January 2009 with 27.3°C. From the heat wave observed, East Malaysia is still in caution categories or normal condition (27°C – 32°C) and the extreme caution (32°C – 41°C) was observed during southwest monsoon (May-July). The safety condition of heat waves in East Malaysia is possibly due to weak to moderate El Nino occurred during the period of observation.

1. Introduction
A heat wave event is a prolonged period of abnormally hot weather and anticipated to become more frequent, longer, and severe with a warming of the Earth’s climate. There are many studies discuss about the effects of climate change on global temperatures and their distribution in space and time [1]. The rising in global mean temperatures because of climate change has high impact for the earth’s ecosystems and other natural systems such as extreme climate events, including heat waves.

An extreme heat wave can affect to serious health concern, especially heat stress and heat stroke among the sick and the elderly. There were 200 cases have been reported by the Ministry of Health Malaysia (MOH) related to hot weather which is 52 cases of heat cramps (hyperthermia, spasms of large muscle), 126 cases of heat exhaustion (fatigue, collapse) and 22 cases of heat stroke (hot red or flushed dry skin, nausea or vomiting, coma) includes two (2) deaths reported as a result of heat stroke [2]. The heat waves event for long period not only gives an impact on human health but also can cause severe damage to the environment, vegetation and production. For example, the exceptional weather patterns of hot and dry conditions from El Nino phenomena had affected the Fresh Fruit Bunch (FFB) yield and Oil Extraction Rate (OER) and contributed to decreasing crude palm oil yield in 2009[3].

East Malaysia is located in the equatorial region, and the seasonal variation of the climate is usually described as dry and wet seasons throughout the year. The average of rainfall is 250 centimeters a year and the temperature ranges between 26°C to 29°C on an average while the average relative humidity from 70% to 80%. In this region, wet season (northeast monsoon) spans from the months of October to March and dry season (southwest monsoon) spans from the months of April to September are...
Typically influencing, East Malaysia is also bare to the El Niño impact, which decreases rainfall during dry season. The climate shows noticeable impact on Malaysia by increasing sea levels and rainfall, flooding risks, severe droughts and extreme heat wave [4].

Recently, the heat wave trend and characteristic in Malaysia has not been extensively investigated. Until now, there is no standard acceptable definition of heat waves, but the heat wave vary relying on the length of consecutive days, the type of data temperature (minimum, average, maximum), the thresholds used to determine an extreme temperature, and whether humidity is taken into account [5]. Steadman [6, 7] defined the Heat Index (Hi) or known as the apparent temperature (Ta) might also be considered when studying the heat wave event. Steadman also translated combinations of air moisture and temperature and other factors such as wind speed and sun radiation into a single scale, calculated in the same units as air temperature [6]. Hi originally was developed to measure thermal comfort [8] but it has become a famous metric in environmental health since the U.S. National Weather Service (NWS) has associated different Hi ranges to environmental health threats [9]. Hi generated from temperature and relative humidity is more important than temperature for the human health because Hi shows how hot it exactly feels when relative humidity is combined with the actual air temperature. For example, if the air temperature is 34°C and the relative humidity is 75%, Hi is felt hot as 49°C [9] and the same effect is reached at just 32°C when the relative humidity is 90%.

In line with significant effects of Hi to our life and environment, this research focuses on the investigation of heat wave trends in East Malaysia based on the Hi defined from NWS for the period 2008-2010. This study is very important to further determining the occurrence of heat wave event in the future as an early warnings system especially during extreme weather in Malaysia.

2. Methodology

2.1. Data and location

The monthly mean temperature (°C) and mean relative humidity (%) was collected from Malaysian Meteorological Department (MetMalaysia) for the period 2008-2010 in order to calculate the heat index. In this study, we focused on East Malaysia because the beaches in East Malaysia are one of the most popular in Malaysia and become the tourist attraction every year. Economic strength and ecosystem stability by the evaporation of sea surface to inland in this coastal area is very important for the future sustainability. In addition, the selected station is close to the South China Sea and possible influence by the climate variability such as El Niño. Five (5) stations were chosen across East Malaysia and the details of the each station and locations are presented in Table 1 and Figure 1.

### Table 1. Five selected stations in East Malaysia

| No. | Station          | Longitude      | Latitude      |
|-----|------------------|----------------|---------------|
| 1   | Kota Kinabalu (urban) | 5° 55’ 58.800” N | 116° 02’ 60.00” E |
| 2   | Sandakan (sub-urban) | 5° 54’ 0.000” N  | 118° 04’ 1.200” E |
| 3   | Tawau (urban)     | 4° 16’ 01.200” N | 117°52’ 59.60” E |
| 4   | Kuching (industrial) | 1° 28’ 58.800” N | 110°19’ 58.80” E |
| 5   | Bintulu (urban)   | 3° 12’ 0.00” N  | 113°01’ 58.70” E |

2.2. Data Processing

This study chose the NWS method, which was developed by Rothfusz [10] based on the Steadman [6] for calculating Hi. The method was widely used in order to produce of weather warnings in real-life situations. NWS has modified this index for operational purposes such as specific ranges to health effects [14] and extreme heat warnings when needed. The calculation of Hi in this research is performed in agreement with equation:

$$ Hi = -42.379 + 2.049(1.8C +32) + 10.14R - 0.224(1.8C +32)R - 6.83 \times 10^{-3} (1.8C +32)^2 - 5.48 \times 10^{-2} R^2 + 1.22 \times 10^{-3} (1.8C +32)^2R + 8.52 \times 10^{-4} (1.8C +32)R^2 - 1.99 \times 10^{-6} (1.8C +32)^2R^2 $$
where \( R \) stands for the relative humidity (\%) and \( C \) is the temperature (\(^{\circ}C\)). The original equation was used Fahrenheit (\(^{\circ}F\)) [11] for temperature but in this study it was converted into Celsius (\(^{\circ}C\)) unit. Based on this equation, it is can be used only when air temperature and humidity is higher than 26\(^{\circ}C\) and 39\%, respectively [9]. Then, the trends for each station were calculated using a least square regression analysis. The significance of trend was tested using \( t \)-test at 95\% confidence level. The linear least square was applied to find the best fitting through the set of data. The linear least square fitting considers the deviation of a dependent variable, \( y \), from its expected value.

\[
y = (b_0 + b_1 x) + e
\]

where \( x \) is the predictor variable while \( b_0 \) and \( b_1 \) are unknown parameters, representing the intercept and trend coefficient of the fitted straight line. From this equation, the observed trend was heat index value \((y)\) with respect to time (annual basis) (the predictor variable, \( x \)). The values of \( b_0 \) and \( b_1 \) are estimated by minimizing the function of \( e \). The least squares regression line aim to minimize these prediction errors. The error of prediction associated with \( x \) be \( e \), which is

\[
e = y - y_1
\]

A positive value of the trend coefficient indicates an increasing trend and negative value indicates otherwise. Then, the \( Hi \) value that obtained from this equation later will be classified into 4 categories based on the health risk defined in Table 2, while Figure 2 shows the overall methodology that has been conducted in this study.

**Table 2. Health risks to various heat index categories adapted from NOAA (2009)**

| Heat Index (\( Hi \)) | Description |
|-----------------------|-------------|
| 27 – 32\(^{\circ}C\)  | Caution: fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps. |
| 32 – 41\(^{\circ}C\)  | Extreme caution: heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke. |
| 41 – 54\(^{\circ}C\)  | Danger: heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity. |
| > 54\(^{\circ}C\)     | Extreme danger: heat stroke is imminent. |
3. Result and Discussion

The variation of mean temperature, mean relative humidity, and the Hi value calculated using NWS model for all stations are presented in Figure 3. Based on the figure, overall temperature at all stations is still within normal range which is 26°C to 28°C [12]. The mean minimum temperature (25.8°C) was recorded at Kuching in January 2009 while the mean maximum temperature (29.4°C) was recorded at Kota Kinabalu in May 2010. From the figure, there is no slight difference in temperature recorded for the urban, suburban, and industrial area and no extreme temperature (>35°C) recorded during this period. The variation of mean temperature is slightly higher in the year 2009 and 2010 due to moderate El Nino event. El Nino events normally will change the climate patterns around the globe but the outcomes of each event are never exactly the same [13].

For the mean relative humidity, it showed in the range 68.2% to 91.2% with the minimum value was recorded at Kota Kinabalu in February 2008 and the maximum value was recorded at Bintulu in July 2010. For the Hi value, the minimum (27.3°C) are observed at Kuching in January 2009 while the maximum (35.0°C) has occurred at Sandakan in July 2010.

Based on the figure, the temperature at each station is in normal condition but the present of relative humidity have increased the heat index than the normal temperature [11]. The result shows that the heat index is increased due to the increment of the relative humidity. The high of relative humidity makes moist air feels hotter than dry air because it evaporates process less efficient. From the comparison results suggested that the peak values of the heat index mostly rising during May to July which has occurred during dry season (southwest monsoon). During this season, most areas experience monthly minimum rainfall and become drier or hotter climate conditions. From our analysis, it is interesting to note that all the stations showed increasing trends in heat index with the largest positive trends found in Sandakan followed by Kuching, Kota Kinabalu, Bintulu, and Tawau. This trend at the 95% confidence level is obtained from the linear equation as depicted in each figure. The highest trends magnitude happened in suburban area compared to another area is due to the effective difference between temperature and relative humidity.
Figure 3. Variation of mean temperature, mean relative humidity, heat index and their trends for (a) Kota Kinabalu, (b) Sandakan, (c) Tawau, (d) Kuching, and (e) Bintulu

Figure 4 shows the minimum and maximum heat index for each station during the study period. Based on the figure, Sandakan experiences the highest value of heat index in the month of July 2010 when it crosses 35°C followed by Kuching 34.8°C in July 2009, Bintulu in June 2009 and Tawau in May 2010 with 34.6°C and last but not least is Kota Kinabalu with 34.4°C. The entire maximum heat index occurred from June 2009 till July 2010 which is during El Nino event. For minimum heat index, the lowest was recorded at Kuching in January 2009 with 27.3°C. Sandakan recorded 27.8°C in February 2009 while Kota Kinabalu recorded 28.0°C in February 2008 and Bintulu with 28.6°C in January 2009. Tawau showed the highest for minimum heat index in February 2009 with 29.4°C.

Table 3 showed the heat wave categories where temperature during this period are in caution categories (27°C-32°C) but it becomes an extreme caution categories (32°C-41°C). During the period 2008 until 2010, the heat wave in East Malaysia is not in the crucial condition except during dry season (southwest monsoon). This condition could be changed once temperature increases due to climate change. The combination of temperature and relative humidity is important to understand local heat wave exposure and its effect on human health directly. Fountain et al. [14] found few differences in human response to air relative humidity exposure between 60% and 90% of the temperature range 20°C-26°C. The relationship between heat waves and their effects on human health also depends on the exposure time to high temperatures, the rate of temperature increase, and people’s climate adaptation capacity.
Figure 4. Minimum and maximum of heat index

Table 3. Categories of heat wave event

| Station    | Temperature (°C) | Humidity (%) | Heat Index (°C) | Time   | Categories          |
|------------|------------------|--------------|-----------------|--------|---------------------|
| K.Kinabalu | 28.9             | 81.3         | 34.4            | May-09 | Extreme caution     |
|            | 26.6             | 68.9         | 28.0            | Feb-08 | Caution             |
| Sandakan   | 28.2             | 80.1         | 35.0            | Jul-10 | Extreme caution     |
|            | 26.2             | 78.0         | 27.8            | Feb-08 | Caution             |
| Tawau      | 29.0             | 80.5         | 34.6            | Mac-10 | Extreme caution     |
|            | 26.8             | 82.5         | 29.4            | Feb-09 | Caution             |
| Kuching    | 28.5             | 88.2         | 34.8            | Jul-09 | Extreme caution     |
|            | 25.8             | 87.3         | 27.3            | Jan-09 | Caution             |
| Bintulu    | 28.7             | 84.7         | 34.6            | Jun-09 | Extreme caution     |
|            | 26.5             | 81.8         | 28.6            | Jan-09 | Caution             |

4. Conclusion

This paper successfully presents the analysis of heat wave trends in East Malaysia based on the heat index value calculated using the mean surface temperature and mean relative humidity for the period 2008-2010. The mean temperature was observed with a normal condition in the range 26°C to 28°C and no extreme temperature was recorded during the study period for all stations. The results showed the lowest heat index was occurred at Kuching in January with 27.3°C and the highest index was occurred at Sandakan in July 2010 with 35.0°C. The maximum heat index happened during March-July which is during the dry season. The heat index was in caution category with the lowest (27°C–32°C) but it becomes extreme caution (32°C–41°C) during March-July. We can assume that the heat wave still in safe condition due to moderate El Nino event occurred during the study period. From our analysis, the frequency trend of the heat wave is found significantly increased over time due to global climate change events. The increased trend of heat waves needs to be anticipated to prevent illness and death happen. Thus, further research needs to be conducted to find exact definition and status of heat waves for the preparation of an accurate early warning system in Malaysia. The use of
daily temperature and relative humidity and another parameter would possible to give more accurate information about the occurrence of heat wave events.

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