Meteorol Atmos Phys
DOI 10.1007/s00703-017-0537-6

ORIGINAL PAPER

Trend analysis and change point detection of annual and seasonal temperature series in Peninsular Malaysia

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Received: 24 August 2016 / Accepted: 29 May 2017
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Abstract Most of the trend analysis that has been conducted has not considered the existence of a change point in the time series analysis. If these occurred, then the trend analysis will not be able to detect an obvious increasing or decreasing trend over certain parts of the time series. Furthermore, the lack of discussion on the possible factors that influenced either the decreasing or the increasing trend in the series needs to be addressed in any trend analysis. Hence, this study proposes to investigate the trends, and change point detection of mean, maximum and minimum temperature series, both annually and seasonally in Peninsular Malaysia and determine the possible factors that could contribute to the significance trends. In this study, Pettitt and sequential Mann–Kendall (SQ–MK) tests were used to examine the occurrence of any abrupt climate changes in the independent series. The analyses of the abrupt changes in temperature series suggested that most of the change points in Peninsular Malaysia were detected during the years 1996, 1997 and 1998. These detection points captured by Pettitt and SQ–MK tests are possibly related to climatic factors, such as El Niño and La Niña events. The findings also showed that the majority of the significant change points that exist in the series are related to the significant trend of the stations. Significant increasing trends of annual and seasonal mean, maximum and minimum temperatures in Peninsular Malaysia were found with a range of 2–5 °C/100 years during the last 32 years. It was observed that the magnitudes of the increasing trend in minimum temperatures were larger than the maximum temperatures for most of the studied stations, particularly at the urban stations. These increases are suspected to be linked with the effect of urban heat island other than El Niño event.

1 Introduction

The world's climate is getting warmer. According to the Intergovernmental Panel on Climate Change (IPCC) (2013), the atmosphere and oceans have warmed up, snow and ice have diminished, the sea level has risen, and the concentrations of greenhouse gases have increased. It is acknowledged that there will be more frequent hot temperature extremes and fewer cold ones over most land areas on daily and seasonal timescales as the global mean temperature increases. Increases in temperature may result in higher evaporation rates and decreased snowfall and also early snowmelt events in winter, causing shifts in runoff. Even a global change of 1° is significant because it takes a vast amount of heat to warm all the oceans and the atmosphere and land by that much. These evidences of global warming and their impacts on human society have increased concerns among academics, the public and governments. Although global temperature is the main concern, local and regional temperatures are also important on a small spatial scale. Hence, it is very important to understand the changes and behaviours of temperature series over time locally and regionally.

Responsible Editor: J. T. Fasullo.

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Published online: 07 June 2017

Over the past decades, many researchers have analysed the changes in temperature series from various climate change perspectives on both temporal and spatial scales (Cayan and Douglas 1984; Michaels et al. 1998; Schaefer and Domroes 2009; Mohsin and Gough 2010; Feng et al. 2011; Choudhury et al. 2012; Jain et al. 2013). These studies have resulted in several significant findings. For example, a rising trend in maximum, minimum, mean and diurnal temperature range has been observed in North-East India by Jain et al. (2013). They predict that the rise in temperature in the future may be much larger than that observed in the current situation, and may be more pronounced. Additionally, other findings by Mohsin and Gough (2010) showed that urbanisation in the Greater Toronto area has significantly contributed to the increase of annual mean temperatures since the 1980s. On the other hand, a study by Schaefer and Domroes (2009) showed that climate warming was evident in Japan throughout all periods of observation (1901–2000, 1951–2000, and 1976–2000). The mean annual temperatures have increased at all stations over Japan from 0.35 to 2.95 °C/100 years, and they are suspected to be related to the urban heat island (UHI) effect. The majority of studies indicate a rising trend in the temperature series, such as North-East India (Choudhury et al. 2012; Jain et al. 2013; Jeganathan and Andimuthu 2013), Canada (Mohsin and Gough 2010), Turkey (Karabulut et al. 2008), China (Feng et al. 2011; Wang and Zhang 2012); Saudi Arabia (Almazroui et al. 2013), and the USA (Capparelli et al. 2013). The results all suggest that the global climate is getting warmer.

Trend detection in climate data and hydrological data series has been an important topic for both hydrology and climatology in the past decades. In trend analysis, the assumptions of stationarity and time-invariant characteristics are invalid as a result of the natural variability of the climate system (Xu et al. 2003). Time series data are said to be stationary if they are free of trends, shifts or periodicity. Either gradual change (trend) or abrupt change (jump) is evidence of non-stationarity in hydrological time series data (Koutsoyiannis 2006; Li et al. 2014). Trend analysis and change point detection in hydrological and climate data series have been investigated by many researchers throughout the world (Xu et al. 2003; Wang and Zhang 2012; Li et al. 2014; Zarenistanak et al. 2014). In most studies, trend analysis was performed before change point analysis. According to Villarini et al. (2009), this approach may lead to misleading results since the information derived from change point analysis is not taken into account in the trend analysis. Li et al. (2014) recommended conducting change point detection first followed by trend analysis, since the results are more reliable and reasonable. They suggested that if change points are not considered in the time series analysis, the trend analysis will not be able to detect an obvious increasing or decreasing trend over certain parts of the time series.

Temperature analysis in Malaysia has been conducted successfully by several researchers (Wai et al. 2005; Griffiths et al. 2005; Tangang et al. 2007; Amirabadizadeh et al. 2015; Tan et al. 2015). Wai et al. (2005) investigated 50 years of temperature data from 1950 to 2005 from six selected stations in Malaysia. The result indicated a significant increase in the mean annual temperature, which was consistent with the increase in the global warming trend for the past 30 years. On the other hand, Griffiths et al. (2005) showed that daily maximum and minimum temperatures, extremes, and variance were spatially coherent across the Asia–Pacific region, where the majority of studied stations exhibited significant trends with an increase in the mean, maximum and minimum temperatures, a decrease in cold nights and cool days, and an increase in warm nights.

It was also found that surface temperatures in most regions of Malaysia showed significant warming trends of between 2.7 and 4.0 °C/100 years based on temperature data from 1961 to 2002 (Tangang et al. 2007). Tangang et al. (2007) also showed that the interannual variability of the Malaysian temperature is largely dominated by the El Niño Southern Oscillation (ENSO). Recent analysis on precipitation and temperature was carried out by Amirabadizadeh et al. (2015) for the Langat River Basin, Malaysia using the method of Mann–Kendall, the Mann–Kendall rank statistic and the Theil–Sen’s slope. General results show that significant increasing trends were detected in annual and seasonal maximum and minimum temperatures. Similar methods were also applied by Tan et al. (2015) in detecting the trends in precipitation, temperature and streamflow for the Johor River Basin in the Southern Peninsular Malaysia. Significant increasing trends resulted for precipitation and temperature in their study.

In most of the past researches, the change points representing the year or period in which a particular change was likely to occur were not considered and the test for serial correlation in a sequential time series was not performed. Therefore, the aim of this study is to conduct a trend analysis with the focus on the changes and behaviours of temperature series over time locally and regionally, which address these issues. Furthermore, it is also our aim to analyse the possible factors that contribute to the changes in the temperature series, specifically factors that associated with the increasing trend. Furthermore, the climatic parameters used in this study such as mean, maximum and minimum temperatures were analysed both annually and seasonally to provide details on the changes and impact of these climate variables to the climate phenomenon in Malaysia. The findings from this study are expected to assist policy makers in terms of future planning in preparing suitable adaptation strategies in the face of uncertain changing climate.

2 Study area and data

Peninsular Malaysia is situated in the tropics between the latitudes of 1°N and 7°N and longitudes of 100°E–103°E. Peninsular Malaysia has an equatorial climate with uniformly high temperatures, high humidity, relatively light winds and abundant rainfall throughout the year. The climate variations within Peninsular Malaysia are caused by differences in altitude and the exposure of the coastal lowlands to the alternating southwest and northeast monsoon winds. During the year, the region experiences two rainy seasons associated with the Southwest Monsoon (SWM) from May to August and the Northeast Monsoon (NEM) from November to February. The coasts exposed to the NEM tend to be wetter than those areas exposed to the SWM during the NEM season and the eastern areas normally suffer a series of floods. The coasts normally have a sunny climate with temperatures ranging from 23 to 32 °C, and the lowlands have almost similar temperatures, whereas the highlands are cooler and wetter. However, Malaysia has recently experienced erratic weather conditions. The occurrence of El Niño episodes, including the extreme one between 1997 and 1998, brought some unusual weather conditions such as prolonged droughts with extremely long spells of dry days, which had negative impacts in terms of a deterioration in the quality of life and in crop production in Malaysia (Juneng and Tangang 2005; Yusof et al. 2013). Othman et al. (2016) reported a prolonged drought in the early part of 2014 has caused Malaysia to experience shortage of water supply, which directly affected both health and growth of vegetation. In their study, they found the northwest Peninsular Malaysia to be impacted more by the dry event during the northeast monsoon season compared to other regions. Recent drought events were also reported in March 2016, which was caused by the El Niño phenomenon (ECHO Daily Flash, 20 March 2016). Temperatures in Malaysia have been found almost 5° higher than the normal situation. It has been reported that the Malaysian government had to close more than 250 schools to protect the students from being exposed to effect of high temperatures. These events in 2016 have been compared to the one in 1997/1998. It was reported that Sabah and northern Sarawak in East Malaysia were the most affected areas. Hundred hectares of crops have been destroyed by fires in Sabah and ten villages were affected. The drought is likely to cause water pollution and water scarcity.

The temperature datasets used in this study were the daily mean temperature, daily maximum and minimum temperatures from ten stations across Peninsular Malaysia. The datasets were obtained from the Malaysian Meteorological Department, and the record mostly covers a period of 32 years from 1980 to 2011. These stations were chosen based on the completeness of the dataset and suitable length of records. Table 1 provides the longitude and latitude coordinates of the stations and their elevations above mean sea level, and Fig. 1 maps the stations.

3 Methodology

Annual and seasonal analyses of the temperature series were conducted in this study. The annual mean temperature series were computed for each year, and the seasonal mean temperatures were classified according to the NEM and SWM seasons of the year. There are many statistical techniques available, which detect trends within a time series, such as the moving average, linear regression and Mann–Kendall trend test. Non-parametric methods are often used since they are less sensitive to outliers and do not require the assumption of normality; therefore, they are highly recommended for general use by the World Meteorological Organisation (Zhang et al. 2009).

Three statistical methods are used in this study to analyse the temporal trend in the temperature series. The first method was the non-parametric Mann–Kendall (MK) test, also known as Kendall's tau test. The method has been applied in many studies to identify whether monotonic trends exist in hydro-meteorological data, such as temperature, rainfall and streamflow (Deka et al. 2013; Liu et al. 2013). This test is often used because it does not require any assumption about the data that need to be tested. Trend magnitude of the slope of the trend then can be estimated using a simple non-parametric procedure known as the Theil–Sen estimate, which is given by

$$\beta = \text{Median}\left[\frac{(x_j - x_k)}{j - k}\right]. \tag{1}$$

For all $j > k$ where x_j and x_k are the sequential data values at times j and k, respectively. Apart from the Theil–Sen estimator, linear regression can also be used to estimate significant trends with the slope of the regression line (e.g. Tangang et al. 2007; Schaefer and Domroes 2009).

The existence of serial correlation in time series data affects the ability of the test to assess the significance of trends. The presence of positive serial correlation could increase the possibility of rejecting a null hypothesis of no significant trends when it may actually be true (von Storch 1995; Douglas et al. 2000; Suhaila et al. 2010). This could, therefore, affect the results of the trend tests, thus reducing the effective sample size for the station of interest and possibly leading to wrong conclusions. To check for the existence of serial correlation in the time series, the following equation was employed:

Table 1 List of the meteorological stations with their geographical coordinates

Stations	Latitude	Longitude	Altitude (m)	Period of record
Alor Star	6°12′N	100°24′E	3.9	1980–2011
Bayan Lepas	5°18′N	100°16′E	2.8	1980–2011
Ipoh	4°34′N	101°06′E	40.1	1980–2011
Cameron Highlands	4°28′N	101°22′E	1545.0	1984–2011
Batu Embun	3°58′N	102°21′E	59.5	1983–2011
Subang	3°08′N	101°33′E	16.6	1980–2011
Muadzam	3°03′N	103°05′E	33.3	1985–2011
Mersing	2°27′N	103°50′E	43.6	1980–2011
Kluang	2°01′N	103°19′E	88.1	1980–2011
Senai	1°38′N	103°40′E	37.8	1980–2011

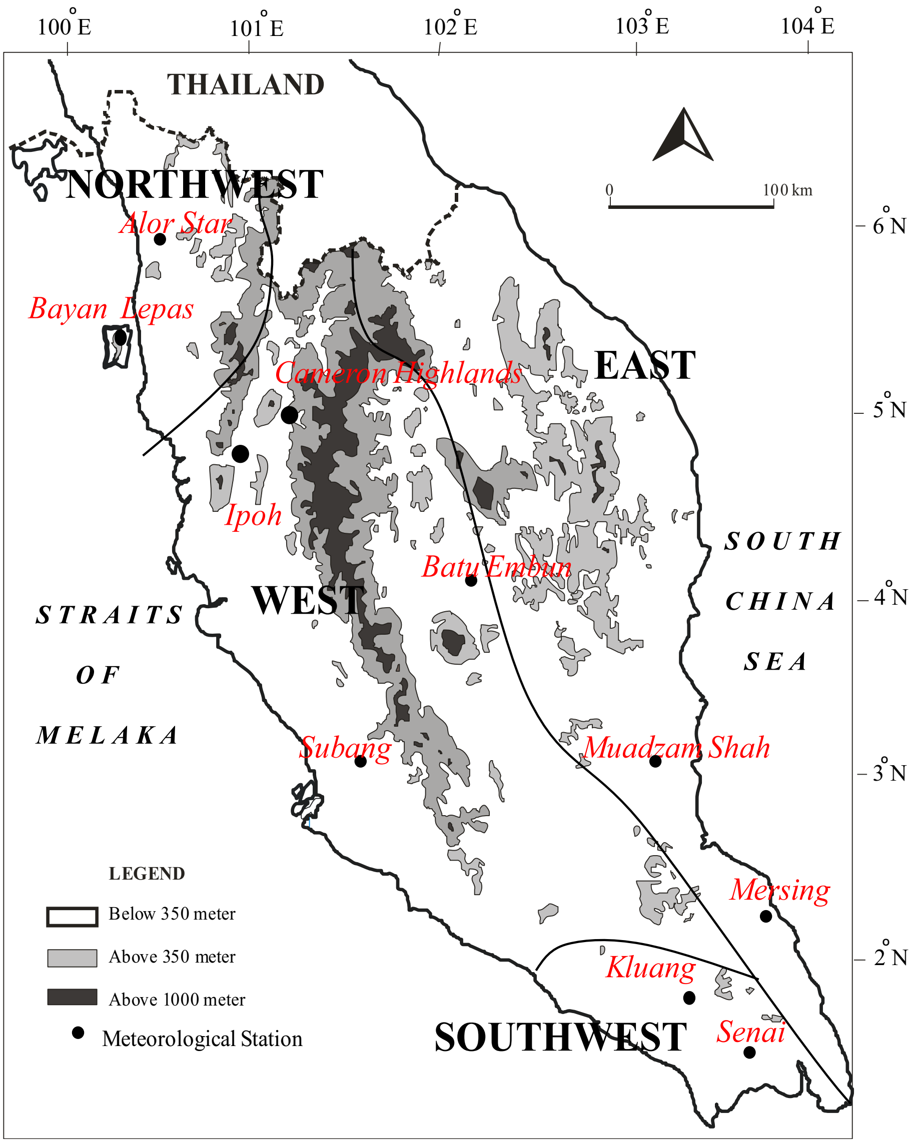

Fig. 1 Map showing the location of 10 meteorological stations

$$\frac{-1-1.645\sqrt{n-2}}{n-1} \leq r_1 \leq \frac{-1+1.645\sqrt{n-2}}{n-1}, \qquad (2)$$

where r_1 is the lag-1 autocorrelation coefficient and n is the number of observations in the data (Salas et al. 1980). A modified version of the trend free pre-whitening (TFPW) procedure proposed by Yue et al. (2002) is applied prior to the MK test if the value of r_1 is significant. This method involves estimating the slope of the monotonic trend for any series that is serially correlated, removing this trend prior to series pre-whitening and, finally, adding the calculated monotonic trend to the pre-whitened data series.

A field significance trend was employed in this study to support the results of local trend analysis. The results could be more relevant than at individual site for detecting the impacts of global phenomena such as climate change. Field significance is assessed when a statistical test is repeated on several distinct data series through the bootstrapping procedure. The method in this study was adopted from the study of Yue et al. (2003). The field significance trends can be assessed by comparing the observed number of significant trends from the original data with the number of significant decrease and increase trends, which were estimated by bootstrapping procedure. A detailed explanation on the method can be found in Yue et al. (2003).

In the statistical literature, analysis of change points in a time series fits well with homogeneity testing (Alexandersson and Moberg 1997). Several tests, such as the standard normal homogeneity test (SNHT), Buishand range test and the Pettitt test, have been described, which can be applied to climate data sets to detect non-homogeneities. As mentioned in Wijngaard et al. (2003), these three tests are location specific and capable of locating the year where breaks or a change point occurs. The SNHT can easily detect breaks near the beginning and at the end of a series, whereas the Buishand range and Pettitt tests are sensitive to breaks in the middle of a time series (Suhaila et al. 2008). However, in order for SNHT and the Buishand range test to be conducted, normality assumptions are required and, as an additional constraint regarding SNHT, a good reference site is required (Alexandersson 1986; Alexandersson and Moberg 1997). In the case of the Pettitt test, no normality assumption is required since it is based on the ranks of the data series. Moreover, it is also less sensitive to outliers than are the other tests (Wijngaard et al. 2003). Therefore, the Pettitt method was employed in this study rather than the others discussed.

Suppose that $Y_i, i = 1, 2, \ldots, n$ is independent and identically distributed. Under the null hypothesis H_0,, it is usually assumed that the Y_i's have the same mean, and the series is homogeneous (no change point). Under the alternative hypothesis, the Pettitt test (Pettitt 1979) assumes that a break or shift in the mean is present and the series is inhomogeneous (a change point exists).

The test is based on the ranking order of the Y_i values. The equation statistic is given as follows:

$$X_d = 2\sum_{i=1}^{d} r_i - d(n+1), \quad d = 1, 2, \ldots, n, \tag{3}$$

where r_i is refer to the rank of the Y_i values. The break is detected near year m given that

$$X_m = \max_{1 \le d \le n} |X_d|. \tag{4}$$

When X_d attains a maximum value of d in a series, then a change point will occur in the series. The critical value is obtained by

$$K_\alpha = \left[-\ln \alpha\left(n^3 + n^2\right)/6\right]^{1/2}, \tag{5}$$

where n is the number of observations, and α is the level of significance, which determines the critical value. The significance probability of the test can be computed approximately by

$$p \text{ value} \cong 2e^{\frac{-6X_m^2}{n^3+n^2}}. \tag{6}$$

The change point is said to be significant when the p value is less than 0.05.

The last method, the sequential MK test, is also applied to temperature series to detect any significant trend and to identify any abrupt change in the data. The test is an extension of the Mann–Kendall test, which is normally used as an effective way of locating the beginning year of a trend (Zarenistanak et al. 2014, Amirabadizadeh et al. 2015) and identifies any abrupt change in the time series data (Mohsin and Gough 2010; Wang and Zhang 2012; Almazroui et al. 2013). The intersection between two resulting trend lines derived from this test can be considered as evidence of an abrupt change in the time series.

4 Results and discussion

4.1 Summary statistics of annual and seasonal temperature series

The basic statistics for annual temperature, such as the mean, standard deviation, coefficient of variation and maximum temperature, are listed in Table 2. The mean annual temperature was in the range of 26–27 °C. The lowest temperature was observed at the Cameron Highlands station, where it had a value below 18 °C, and the highest temperature was recorded at Bayan Lepas station, located in the inland area of Peninsular Malaysia. The annual mean temperatures are higher in the west and northwest due to their locations, which are blocked by the Titiwangsa range as shown in Fig. 1. This range prevents the NEM, which associated with heavy rainfall winds, from reaching the western and north-western areas of the peninsula. Consequently, it caused these areas to become drier than the eastern part, particularly during the northeast monsoon season. A study done on the spatial distribution of

Table 2 Statistics of annual mean temperature series for ten studied stations in Peninsular Malaysia

Stations	Mean (°C)	Standard deviation (°C)	Coefficient of variation, CV (100%)	Max mean temp (°C) (year)
Alor Star	27.41	0.33	1.20	28.13 (2010)
Bayan Lepas	27.51	0.40	1.46	28.35 (2002)
Ipoh	27.17	0.34	1.25	28.05 (1998)
Cameron Highlands	17.91	0.22	1.21	18.47 (1998)
Batu Embun	26.48	0.32	1.20	27.30 (1998)
Subang	27.37	0.57	2.07	28.50 (2010)
Muadzam	26.46	0.30	1.12	27.22 (1998)
Mersing	26.43	0.34	1.28	27.23 (1998)
Kluang	26.24	0.35	1.33	26.93 (1998)
Senai	26.18	0.31	1.18	27.08 (1998)

wet and dry spells in Peninsular Malaysia by Deni et al. (2010) also concluded that dry spells were more frequent in northern areas compared to the southern areas. In terms of coefficient of variation, which was computed as the standard deviation to its mean, the largest variability in the temperature series was computed for Subang station, where it was nearly 2.0%, followed by Bayan Lepas station, where it was approximately 1.5%. As shown in Table 2, the maximum mean temperature at most of the studied stations occurred in the year 1998 as Malaysia experienced a major El Niño event in 1997 and 1998. An effect of the ENSO phenomenon was the shifting of rainfall patterns over different regions of the world. This phenomenon caused much of the Southeast Asian region, such as Thailand, Vietnam, Indonesia, Singapore and Malaysia to experience dry conditions, which led to drought in many areas (Juneng and Tangang 2005).

Table 3 displays the mean temperature in two seasons, SWM and NEM, with their coefficient of variations. It was clear that the high mean temperature was dominant during the SWM. Again, the lowest mean temperature was recorded by the Cameron Highlands station during both seasons, due to its location on the Titiwangsa Range at nearly 1545 m.a.s.l. During both seasons, stations located in the west and northwest of Peninsular Malaysia recorded higher temperatures than did other stations. In terms of variation in the temperature series, Subang station recorded the largest variability in both seasons of 2.2% and nearly 2% during SWM and NEM, respectively. Batu Embun, Muadzam and Senai were among the studied stations that recorded a low variability in the seasonal mean series. According to the Wilcoxon signed-rank test, the difference between the two seasons was statistically significant for each station since all probability values listed in Table 3 were below the 5% significance level.

4.2 Testing for the serial correlation effect

Testing for serial correlation effects was implemented before other tests took place. The dataset was tested at the 5% significance level for serial correlation effects. Most series were found to be serially correlated. As shown in Table 4, the annual minimum temperature series at all stations were serially correlated. According to the test results, both annual and seasonal mean and maximum temperature series at Ipoh, Cameron Highland and Batu Embun stations were found to be serially independent, whereas the rest of the series at other stations showed signs of being serially correlated. The temperature series that showed a serial correlation effect were then subjected to Yue et al.'s (2002) pre-whitening procedures before the Pettitt, SQ–MK and MK tests were applied.

4.3 Change point analysis via Pettitt and SQ–MK tests

It is suggested in this study that change point detection should be performed before trend analysis, as proposed by Villarini et al. (2009) and Li et al. (2014). If some change points exist in the series, the trend must be analysed with the non-parametric MK test for each of the sub-series divided by these change points. Otherwise, if no significant change points are detected, the MK test should be performed on all records. The assumption of Pettitt and SQ–MK tests is that the series is serially independent. Thus, for those series that were found to be serially correlated, the original temperature series were whitened first before the Pettitt and SQ–MK tests were applied. The values of the test statistics and the detection point for both tests are presented in Tables 5, 6 and 7 with their probability values. Significant change points exist if the *p* values are below the 5% significance level.

Table 3 Statistics of seasonal mean temperature series for ten studied stations in Peninsular Malaysia

Stations	Southwest Monsoon (SWM)		Wilcoxon sign rank test (p value)	Northeast Monsoon (NEM)	
	Mean (°C)	Coefficient of variation, CV (%)		Mean (°C)	Coefficient of variation, CV (%)
Alor Star	27.57	1.20	0.00	27.11	1.60
Bayan Lepas	27.70	1.55	0.00	27.36	1.55
Ipoh	27.55	1.29	0.00	26.79	1.53
Cameron Highlands	18.20	1.33	0.00	17.48	1.74
Batu Embun	26.92	1.12	0.00	25.72	1.40
Subang	27.74	2.20	0.00	26.92	1.99
Muadzam	26.88	1.18	0.00	25.86	1.30
Mersing	26.52	1.44	0.00	26.18	1.42
Kluang	26.53	1.29	0.00	25.80	1.63
Senai	26.43	1.15	0.00	25.82	1.35

With regard to Table 5, no change points in annual and seasonal mean temperatures were detected at Ipoh and Cameron Highlands stations. However, it was observed that significant abrupt changes occurred at other stations during the middle and at the end of the 1990s. The change points captured by the Pettitt test involved the years from 1994 to 2000 while change points that were detected by the SQ–MK test mostly occurred in 1997 and 1998. The detection years listed in Table 5, such as 1994/1995, 1995/1996, 1997/1998, 1999/2000 and 2000/2001, were found to be related to the El Niño (warm) and La Niña (cool) years based on the information published by the National Oceanic and Atmospheric Administration (NOAA) (Golden Gate Weather Services 2017).

Change points for both annual and seasonal maximum temperature series are displayed in Table 6. The results indicated that both Pettitt and SQ–MK tests failed to capture any change points at Batu Embun station in both annual and seasonal series. Similarly, no change points were detected by the Pettitt test in the annual and seasonal maximum series at the Ipoh station. However, interestingly, a change point was detected in 1995 by the SQ–MK test during the SWM. Again, the SQ–MK test successfully located a change point in 1997 at Subang station, but the Pettitt test failed to locate any point in the annual maximum series. The Pettitt test once again was unable to locate any significant change point at the Cameron Highlands station during the SWM, but its change point was successfully detected by the SQ–MK test. During the NEM season, there was no indication of change points in the maximum series for the Alor Star, Bayan Lepas, Ipoh, Batu Embun and Subang stations. Both Pettitt and SQ–MK tests failed to detect any change points for these stations. In general, most of the change points detected by both tests in maximum temperatures again occurred at the middle and at the end of the 1990s, with these most frequently observed in the years 1996–1998.

For a minimum temperature series, no change points were detected at all, either annually or seasonally, at the Cameron Highlands station as shown in Table 7. In contrast, significant change points in the annual and seasonal minimum temperatures were observed at other stations, and most of them were located at the middle and at the end of the 1990s. During the SWM season, there was an abrupt change in the minimum series for Alor Star, Bayan Lepas, Ipoh, Kluang and Senai stations during the year 1994 while change points were observed at year 2001 for Batu Embun and Muadzam stations. In general, the years 1996–1998 were once again denoted as the most frequently detected years for an abrupt change in the minimum series.

Since this study did not have sufficient metadata, there was no strong evidence to relate the cause of the break points to non-climatic factors, such as the relocation of the stations, changes in measurement methods or changes in the surrounding environment. However, if these stations did not undergo any changes caused by non-climatic factors, the detection points may have been caused by climatic factors. The analyses of the abrupt changes in the temperature series suggested that most of the change points in Peninsular Malaysia frequently occurred in years 1996–1998. Considering the values of the Oceanic Niño Index, 1995/1996 are considered weak La Niña years while 1997/1998 are referred to as strong El Niño years. With reference to the studies by Tangang et al. (2012) and Wan Zin et al. (2010), during 1997 and 1998, Malaysia experienced episodes of El Niño events, and these phenomena were confirmed by the findings from this study, which revealed 1997 and 1998 as a change point. These results seem to be consistent with other studies conducted around the world. For example, Almazroui et al. (2013) indicated that the majority of the stations in Saudi Arabia had a change point in the surface annual temperature in 1997. Similarly, Fischer et al.

Table 4 Serial correlation effect on mean, maximum and minimum temperature for annual and seasonal series

Stations	Mean		Maximum		Minimum	
	lagl-r	Result	lag l-r	Result	lag l-r	Result
Annual						
Alor Star	0.4984	Y	0.3241	Y	0.7434	Y
Bayan Lcpas	0.5902	Y	0.3291	Y	0.7904	Y
Ipoh	0.2381	N	−0.1294	N	0.5770	Y
Cameron Highlands	0.0069	N	0.6043	Y	0.3412	Y
Batu Embim	0.1551	N	−0.1724	N	0.6287	Y
Siibang	0.6894	Y	0.4093	Y	0.7863	Y
Muadzam	0.5119	Y	0.6331	Y	0.6247	Y
Khiang	0.6086	Y	0.7094	Y	0.6282	Y
Mersing	0.4203	Y	0.4866	Y	0.5345	Y
Senai	0.4786	Y	0.7210	Y	0.6978	Y
Southwest Monsoon						
Alor Star	0.5350	Y	0.4252	Y	0.6648	Y
Bayan Lcpas	0.6949	Y	0.4307	Y	0.8021	Y
Ipoh	0.1516	N	−0.0059	N	0.4691	Y
Cameron Highlands	−0.0566	N	0.4880	Y	0.2154	N
Batu Embun	0.2054	N	−0.0192	N	0.4895	Y
Siibang	0.7700	Y	0.3893	Y	0.2276	N
Muadzam	0.5178	Y	0.6839	Y	0.4723	Y
Khiang	0.6913	Y	0.8180	Y	0.6348	Y
Mersing	0.3681	Y	0.4706	Y	0.4947	Y
Senai	0.3942	Y	0.6153	Y	0.5673	Y
Northeast Monsoon						
Alor Star	0.1962	N	−0.0041	N	0.5750	Y
Bayan Lcpas	0.3447	Y	0.1075	N	0.6728	Y
Ipoh	0.1352	N	−0.0260	N	0.4663	Y
Cameron Highlands	0.0156	N	0.5366	Y	0.2166	N
BatuEmbun	0.2717	N	−0.1530	N	0.3663	Y
Subang	0.5849	Y	0.0512	N	0.7116	Y
Muadzam	0.3584	Y	0.4265	Y	0.3747	Y
Khiang	0.4762	Y	0.4381	Y	0.5092	Y
Mersing	0.2154	N	0.4000	Y	0.2655	Y
Senai	0.3978	Y	0.6128	Y	0.6229	Y

Y serially correlated, *N* serially independent

(2012) found that 71% of all stations in southern China had a change point in the annual mean temperature around 1997–1998. Generally, it could be said that there are high possibilities that all the detection points captured by the Pettitt and SQ–MK tests are related to climatic factors such as El Niño and La Niña events.

4.4 Trend analysis of annual temperature series

Three variables, namely the mean, maximum and minimum temperature series, were analysed for annual trends. Based on the change point analysis in Tables 5, 6 and 7, the temperature series were split into two sub-series for those stations where the change points were found to be significant. The results of trend analysis for annual and seasonal mean sub-series divided by the change points are shown in Table 8.

The MK tested for the presence of possible trends at each of the sub-series and in the entire record series. The statistics values of MK test and the p values are given in Table 8. Significant trends exist with the p values are below than 5% significance level. As displayed in Table 8, the results revealed that all stations except Ipoh and Cameron Highlands exhibited statistically significant increasing trends in mean temperature in the entire record series. However, only a few stations showed significant

Table 5 Detection or change points via Pettitt test and sequential Mann–Kendall test for annual and seasonal mean temperature series

Stations	Annual				Southwest Monsoon				Northeast Monsoon			
	Pettitt test			SQ–MK	Pettitt test			SQ–MK	Pettitt test			SQ–MK
	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point
Alor Star	211	0.001	1996	1996	208	0.000	1994	1997	150	0.025	2000	1996
Bayan Lepas	233	0.000	1994	1997	222	0.000	1994	1997	166	0.005	1999	1997
Ipoh	113	0.207	No	No	110	0.233	No	No	94	0.357	No	No
Cameron Highlands	61	0.749	No	No	42	1.000	No	No	106	0.074	No	No
Batu Embun	146	0.013	1996	1998	111	0.100	1996	1998	159	0.003	1996	1999
Subang	234	0.000	1994	1997	234	0.000	1993	1997	200	0.000	1994	1997
Muadzam	185	0.000	1996	1998	150	0.003	1996	1997	134	0.005	1997	1998
Kluang	240	0.000	1996	1997	210	0.000	1996	1997	197	0.000	1996	1996
Mersing	185	0.005	1996	1997	170	0.007	1996	1997	146	0.031	1996	1997
Senai	162	0.019	1995	1997	148	0.028	1995	1996	143	0.025	1996	1997

Table 6 Detection or change points via Pettitt test and sequential Mann–Kendall test for annual and seasonal maximum temperature series

Stations	Annual				Southwest Monsoon				Northeast Monsoon			
	Pettitt test			SQ–MK	Pettitt test			SQ–MK	Pettitt test			SQ–MK
	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point
Alor Star	145	0.048	1996	1997	194	0.001	1996	1997	92	0.384	No	No
Bayan Lepas	181	0.006	1996	1997	158	0.015	1996	1997	120	0.120	No	No
Ipoh	135	0.079	No	No	123	0.136	No	1995	58	1.000	No	No
Cameron Highlands	146	0.007	1991	1998	94	0.149	No	1998	133	0.006	1996	1999
Batu Embun	42	1.000	No	No	50	1.000	No	No	83	0.325	No	No
Subang	150	0.037	1989	1997	160	0.014	1995	1997	94	0.357	No	No
Muadzam	161	0.002	1996	1998	128	0.016	1996	1997	121	0.016	1996	1998
Mersing	227	0.000	1996	1997	176	0.005	1994	1997	177	0.002	1996	1996
Kluang	208	0.001	1996	1997	222	0.000	1995	1997	195	0.001	1996	1996
Senai	220	0.000	1995	1997	206	0.001	1995	1997	167	0.005	1996	1996

positive trends in the first sub-series (before the change point), and no significant trends were observed in the second sub-series (after the change point) or vice versa. For the annual maximum series, the Pettitt test failed to detect any significant change points at Ipoh, Batu Embun and Subang during the period considered. There is no indication of significant trends at Ipoh and Batu Embun at the 5% significance level, but a significant trend exists in the series for Subang as indicated by the SQ–MK test that was able to locate the year 1997 as the change point. In addition, significant increasing trends exist in the maximum series for other stations. Generally, it seems that no decreasing trends were detected in the entire record series; decreasing trends were only found when the series were split into sub-series. For example, Muadzam and Subang stations displayed a significant increasing trend before the change point and a decreasing trend after the change point, but the series as a whole showed an

Table 7 Detection or change points via Pettitt test and sequential Mann–Kendall test for annual and seasonal minimum temperature series

Stations	Annual				Southwest Monsoon				Northeast Monsoon			
	Pettitt test			SQ–MK	Pettitt test			SQ–MK	Pettitt test			SQ–MK
	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point	Statistics value	*p* value	Change point	Change point
Alor Star	206	0.001	1996	1997	211	0.001	1994	1997	200	0.000	1997	1997
Bayan Lepas	224	0.000	1994	1997	222	0.000	1994	1997	223	0.000	1997	1997
Ipoh	166	0.009	1993	1997	154	0.020	1994	1997	180	0.002	1992	1996
Cameron Highlands	62	0.646	No	No	97	0.167	No	No	104	0.083	No	No
Batu Embun	196	0.000	1997	1999	158	0.003	2001	1998	156	0.002	1997	1998
Subang	230	0.000	1994	1997	255	0.000	1995	1997	232	0.000	1994	1997
Muadzam	168	0.000	1997	1998	150	0.003	2001	1997	144	0.002	1997	1999
Mersing	201	0.000	1996	1997	192	0.002	1996	1997	144	0.023	1997	1997
Kluang	219	0.000	1996	1997	194	0.001	1994	1997	203	0.000	1996	1997
Senai	228	0.000	1996	1997	184	0.003	1994	1997	214	0.000	1997	1997

increasing trend. These findings support the suggestion of Li et al. (2014) that if change points are not considered in the time series analysis, the trend analysis will not be able to detect an obvious increasing or decreasing trend over certain parts of the time series.

In the case of the minimum temperature series, no indication of change points in the minimum temperature series and no significant trends were detected at the Cameron Highlands station as displayed in Table 8. However, significant increasing trends were observed in the minimum temperature series for the nine other stations. An increasing trend in the minimum series before and after the change point was observed at the majority of the stations. The numbers of significant increasing trends in the minimum series are larger than those that were found in the maximum series, which indicates that the minimum temperatures are increasing rapidly. Therefore, the increasing trend in the annual mean temperature can be attributed to a large number of increasing trends in the annual minimum temperature.

Further analysis on the field significant trend was carried out to strengthen the results obtained at the individual stations by examining whether trends of temperature series at individual stations occurred by chance. Table 9 summarises the overall results of the field significant trend over Peninsular Malaysia. Based on the results, it can be concluded that Peninsular Malaysia experienced a field significant increasing trend in mean, maximum and minimum temperature series in both annual and seasonal. There was no sign of field significant decreasing trends obtained over Peninsular Malaysia based on the *p* value computed in Table 9.

4.5 Trend analysis of seasonal temperature series

Testing for the serial correlation effect was again implemented on the seasonal series before the MK test was applied. The results of the MK test for the seasonal temperature series, SWM and NEM are shown in Figs. 2 and 3, respectively. As shown in the results, the climate of Peninsular Malaysia during both seasons warmed during the last 30 years. All stations except Ipoh and Cameron Highlands showed an increasing trend in mean temperature during the SWM and NEM. There are more meteorological stations with statistically significant increasing trends in the maximum temperature during the SWM as displayed in Fig. 2b than during the NEM. As shown in Fig. 3b, no significant trends were detected in the maximum series at Alor Star, Bayan Lepas, Ipoh and Subang stations during the NEM, in contrast to the patterns obtained during the SWM, where all these stations showed significant trends. During both seasons, Ipoh showed a decreasing trend in maximum temperature, which was significant during the SWM. In the case of the minimum series, all stations except Cameron Highlands display a significant increasing trend during both monsoon seasons. It was found that based on Figs. 2 and 3, the number of significant increasing trends in minimum series is larger than that in maximum series in both seasons.

Compared to other countries such as Vietnam and Thailand, it was found that Vietnam's mean temperature as a whole has increased since 1970s with both maximum and minimum temperatures having increased significantly in winter monsoon (NEM) in comparison with the summer (SWM) (Nguyen et al. 2014). This differs with our

Table 8 Statistical trend analysis for annual mean, maximum and minimum temperature series for each sub-series and the entire records

Stations	Annual mean		Annual maximum		Annual minimum	
	Segmentation year	MK test	Segmentation year	MK test	Segmentation year	MK test
Alor Star	1980–1999	1.91 (**0.03**)	1980–1999	0.88 (0.19)	1980–1995	2.57 (**0.01**)
	2000–2011	0.62 (0.27)	2000–2011	0.34 (0.37)	1996–2011	2.57 (**0.01**)
	1980–2011	4.32 (**0.00**)	1980–2011	2.75 (**0.00**)	1980–2011	5.23 (**0.00**)
Bayan Lepas	1980–1993	1.53 (0.06)	1980–1995	0.05 (0.48)	1980–1993	2.62 (**0.00**)
	1994–2011	1.14 (0.13)	1996–2011	−0.05 (0.48)	1994–2011	1.59 (0.06)
	1980–2011	4.18 (**0.00**)	1980–2011	2.37 (**0.01**)	1980–2011	5.37 (**0.00**)
Ipoh	1980–2011	1.51 (0.07)	1980–2011	−1.38 (0.08)	1980–1992	1.65 (**0.05**)
					1993–2011	−0.38 (0.35)
					1980–2011	3.20 (**0.00**)
Cameron Highlands	1984–2011	0.50 (0.31)	1984–1993	2.61 (**0.01**)	1984–2011	0.33 (0.37)
			1994–2011	−1.52 (0.06)		
			1984–2011	2.33 (**0.01**)		
Batu Embun	1983–1995	−0.06 (0.48)	1983–2011	0.28 (0.39)	1983–1996	1.31 (0.09)
	1996–2011	1.76 (**0.04**)			1997–2011	1.88 (**0.03**)
	1983–2011	3.06 (**0.00**)			1983–2011	5.35 (**0.00**)
Subang	1980–1993	2.38 (**0.01**)	1980–1996	2.35 (**0.01**)	1980–1993	1.75 (**0.04**)
	1994–2011	0.68 (0.25)	1997–2011	−1.78 (**0.04**)	1994–2011	−0.08 (0.50)
	1980–2011	5.13 (**0.00**)	1980–2011	2.14 (**0.02**)	1980–2011	4.69 (**0.00**)
Muadzam	1984–1995	1.03 (0.15)	1984−1995	2.81 (**0.00**)	1984–1996	1.53 (0.06)
	1996–2011	0.41 (0.34)	1996–2011	−2.87 ((**0.00**)	1997–2011	1.78 (**0.04**)
	1984–2011	3.42 (**0.00**)	1984–2011	2.71 (**0.00**)	1984–2011	4.71 (**0.00**)
Mersing	1980–1995	1.04 (0.15)	1980–1994	0.54 (0.29)	1980–1995	0.59 (0.30)
	1996–2011	0.00 (0.50)	1995–2011	−0.29 (0.39)	1996–2011	0.72 (0.24)
	1980–2011	2.62 (**0.00**)	1980–2011	3.13 (**0.00**)	1980–2011	3.72 (**0.00**)
Kluang	1980–1995	0.69 (0.24)	1980–1995	−0.80 (0.21)	1980–1995	1.48 (0.07)
	1996–2011	1.36 (0.09)	1996–2011	−0.05 (0.48)	1996–2011	0.37 (0.36)
	1980–2011	4.35 (**0.00**)	1980–2011	3.26 (**0.00**)	1980–2011	4.16 (**0.00**)
Senai	1980–1993	1.64 (**0.05**)	1980–1994	2.18 (**0.01**)	1980–1995	2.84 (**0.00**)
	1994–2011	−0.04 (0.48)	1995–2011	1.44 (0.07)	1996–2011	2.28 (**0.01**)
	1980–2011	2.72 (**0.00**)	1980–2011	4.66 (**0.00**)	1980–2011	5.57 (**0.00**)

The bold cell indicates the *p* value which shows the significant trend at 0.05 level

Table 9 The results of field significant trends via the permutation test

Temperature series	Annual		Southwest Monsoon		Northeast Monsoon	
	SI (*p* value)	SD (*p* value)	SI (*p* value)	SD (*p* value)	SI (*p* value)	SD (*p* value)
Mean	**0.003**	0.423	**0.004**	0.383	**0.003**	0.376
Maximum	**0.006**	0.386	**0.001**	0.367	**0.019**	0.370
Minimum	**0.001**	0.407	**0.002**	0.392	**0.005**	0.388

The bold cells indicate the *p* value for the field significant trends at the significance level of 0.05

findings, where the number of significant increasing trends in maximum temperatures was found to be higher in SWM than NEM but no difference in terms of minimum temperatures series in both seasons. In Northern Thailand, increasing trends of temperature were experienced in the observed period of 1960 to 2010 where both maximum and

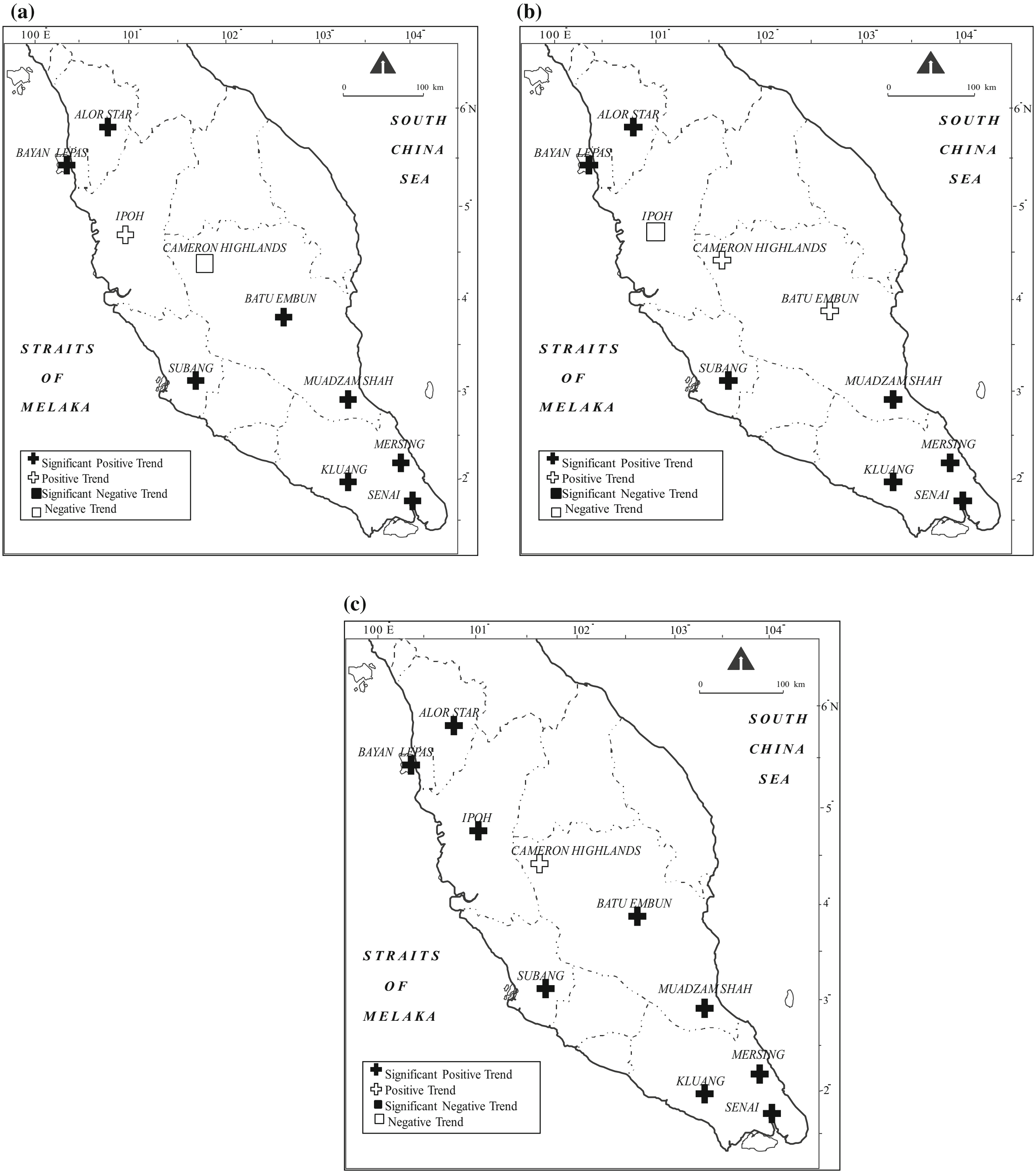

Fig. 2 The trend of **a** mean, **b** maximum and **c** minimum temperatures during the Southwest Monsoon

minimum temperatures increased significantly during all seasons (Masud et al. 2016). Masud et al. (2016) had also shown that minimum temperature had a number of increasing trends more than maximum temperature, which is similar to our current findings. Recent analysis done by Beule et al. (2016) in Thailand also demonstrated that both maximum and minimum temperatures are increasing, with the minimum temperatures increasing at a faster rate than maximum temperatures, which are similar to our findings as shown in the next subsection.

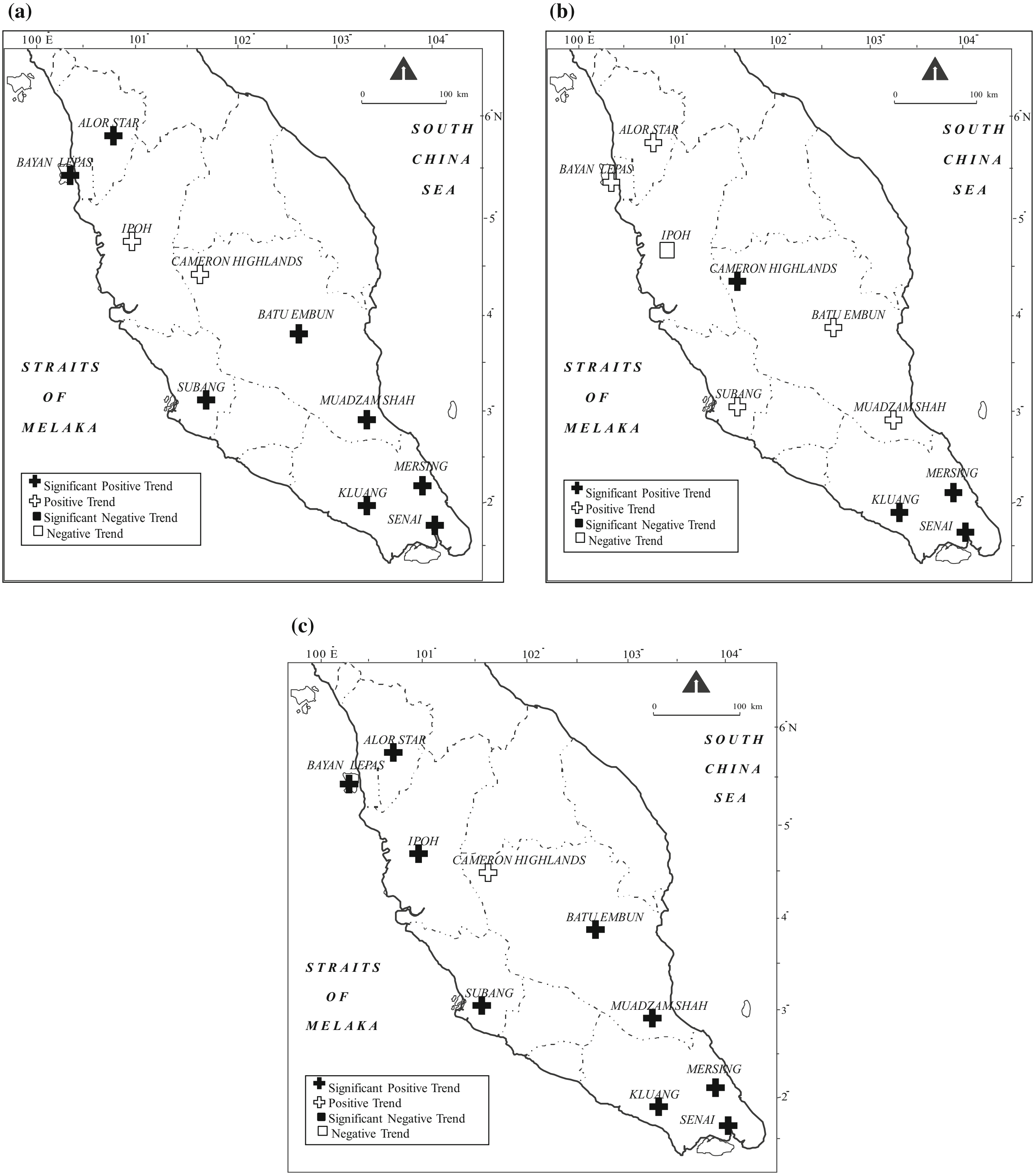

Fig. 3 The trend of **a** mean, **b** maximum and **c** minimum temperatures during the Northeast Monsoon

4.6 Estimated trends in annual and seasonal temperature series

The magnitude of estimated trends was computed, based on the entire records, with a Theil–Sen estimator and the linear regression method in units of °C/100 years. The results are displayed in Table 10. In general, results computed from both methods are consistent in both annual and seasonal series. The estimated trends of annual mean temperature increased between 2 and 5 °C/100 years, which showed that most stations in Malaysia have experienced warming trends over the last three decades. Subang, a station situated near the capital city of Kuala Lumpur, yielded the largest increase in mean temperature with a warming rate of between 4 and 6 °C/100 years. The highest warming rate recorded at Subang station occurred during the SWM season (May–August). Other stations that showed higher warming rates during the last three decades were Bayan Lepas (2.4–3.6 °C/100 years) and Kluang (2.6–3.4 °C/100 years). For the last three decades, the warming rates in the mean temperature series at Batu Embun (1.6–2.5 °C/100 years) and Senai (1.8–2 °C/100 years) stations have been lower than those at other stations in Peninsular Malaysia.

The estimated trend of maximum temperature in Peninsular Malaysia is in the range of 1.4 and 5.8 °C/100 years. Senai, a transit town situated in the southwest of Peninsular Malaysia, exhibited the highest warming rates in the maximum series of between 4.2 and 5.8 °C/100 years during the last three decades. Of all the stations, Ipoh showed a decreasing trend of 0.4 and 1.4 °C/100 years in the maximum series with a significant decrease during the SWM season. In comparison, the estimated warming rates in the minimum series were larger than those in the maximum series for most stations in Peninsular Malaysia. Subang, Bayan Lepas and Senai are among the stations that produced higher warming rates in the minimum series (i.e. 4.5–5.6 °C/100 years).

The IPCC (2013) observed that each of the last three decades has been successively warmer at the Earth's surface than any decade has been since 1850. It also reported that, in the Northern Hemisphere, the 1983–2012 periods were probably the warmest 30-year period of the last 1400 years. For Malaysia as a whole, climate warming over the last three decades is evident, which is consistent with the mean global temperature reported by the IPCC (2013). However, the estimates of warming rates produced in our study, which were calculated during the 30 years, are much higher than the globally averaged combined land and ocean surface temperature data of 0.85 °C (0.65–1.06 °C) over the period 1880–2012 reported by the IPCC (2013). These higher estimates are possibly due to the short length of records considered in the current study since some studies have reported higher warming rates based on a shorter data record as mentioned in Tangang et al. (2007).

It was reported in a previous study by Tangang et al. (2007) that the mean surface temperatures in most regions in Malaysia (Peninsular and West Malaysia) showed a significant warming trend from 1961 to 2002 with warming rates of between 2.7 and 4 °C/100 years. Similar patterns are also revealed in the current study in which there were significant increasing trends in mean temperatures during

Table 10 Estimated trends (in °C/100 years) using Theil–Sen estimator and fitted linear regression lines for annual and seasonal of mean, maximum and minimum temperature series

Stations	Annual			Southwest Monson			Northeast Monsoon		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Alor Star	**2.25 (2.45)**	**2.00 (2.10)**	**3.80 (3.80)**	**2.59 (2.70)**	**2.72 (2.60)**	**3.16 (3.40)**	**2.45 (2.60)**	1.68 (1.90)	**4.33 (4.30)**
Bayan Lepas	**3.20 (3.20)**	**1.40 (1.80)**	**5.10 (5.10)**	**3.57 (3.60)**	**1.62 (1.80)**	**5.55 (5.60)**	**2.39 (2.80)**	1.23 (1.65)	**4.97 (4.80)**
Ipoh	0.95 (0.80)	−0.93 (−0.90)	**2.91 (2.30)**	1.16 (0.90)	**−1.13 (−1.40)**	**2.68 (2.30)**	0.95 (0.90)	−0.40 (−0.40)	**3.10 (2.65)**
Cameron Higlands	0.23 (0.10)	**4.08 (3.20)**	0.43 (0.90)	−0.24 (−0.30)	**3.43 (2.40)**	0.23 (0.40)	0.93 (1.00)	**4.36 (4.19)**	1.40 (1.50)
Batu Embun	**1.79 (1.70)**	0.16 (0.50)	**3.15 (3.00)**	**1.81 (1.60)**	0.33 (0.00)	**2.94 (3.00)**	**2.31 (2.50)**	1.47 (2.00)	**3.64 (3.41)**
Subang	**5.20 (4.60)**	**2.25 (1.65)**	**4.55 (4.50)**	**6.08 (5.30)**	**2.29 (2.00)**	**5.43 (8.40)**	**4.51 (4.00)**	1.43 (1.70)	**5.10 (4.80)**
Muadzam	**2.50 (2.40)**	**3.48 (2.70)**	**3.20 (3.10)**	**2.51 (2.40)**	**3.55 (2.80)**	**3.40 (3.45)**	**2.47 (2.12)**	**2.77 (2.75)**	**3.45 (3.01)**
Mersing	**1.90 (1.90)**	**3.09 (2.76)**	**2.00 (1.90)**	**2.44 (2.30)**	**3.67 (3.20)**	**2.29 (2.20)**	**1.86 (1.60)**	**2.99 (3.19)**	**1.78 (1.65)**
Kluang	**2.55 (2.60)**	**3.33 (3.10)**	**2.49 (2.40)**	**2.59 (2.60)**	**3.35 (3.20)**	**2.47 (2.40)**	**3.36 (3.00)**	**4.50 (4.40)**	**3.13 (2.71)**
Senai	**1.85 (1.80)**	**4.18 (4.45)**	**4.20 (4.80)**	**1.95 (1.80)**	**4.52 (4.50)**	**4.33 (4.70)**	**1.93 (1.80)**	**5.26 (5.75)**	**4.85 (5.10)**

The bold values indicate significant estimates at 5% significance level for Theil–Sen and regression methods. The values in bracket refer to the estimated values by regression method the last 32 years from 1980 to 2011. Our current results are based on annual and seasonal (NEM and SWM) bases while the results published by Tangang et al. (2007) were based on seasonal average temperature over three-month periods, such as January–February–March (JFM) and April–May–June (AMJ). To investigate how the trends differ between the previous and current studies, the results for common stations, namely Subang, Mersing and Bayan Lepas, are compared on the annual basis. As mentioned before, the estimated trends in this study were computed based on the entire records not on each sub-series divided by the change points. Based on the entire records, the estimated trends in our current study are slightly higher than those recorded in Tangang et al. (2007) by between 0.1 and 1.0 °C. For example, Subang exhibits the highest warming rates of 4.6 °C/100 years, followed by Bayan Lepas station with warming rates of 3.2 °C/100 years, compared to 3.8 °C/100 years and 2.3 °C/100 years in the previous study for Subang and Bayan Lepas, respectively. The increase in warming rates may be due to several factors other than the short length of records, 30 years compared to 40 years in the previous study.

4.7 Possible factors that contribute to the higher warming rates

One of the factors that may contribute to the higher warming rates in some stations in Peninsular Malaysia is the number of El Niño events that occurred in the last three decades. Ten such events were reported during the study period of 1980–2011, and those for 1982/1983 and 1997/1998 were considered as major. In Sect. 4.3, the years 1996–1998 were considered as the changing point for most of the studied stations. However, no detection points were observed in the 1982/1983 year by either the Pettitt or SQ–MK tests. The failure of the tests to recognise any change point for that year may be due to insufficient data prior to that year. This seems to suggest that the trends during the studied period were probably more affected by the higher temperatures in 1997–1998 than in 1982–1983. The result here is consistent with the IPCC (2001), which concluded that the 1990s were the warmest decade and 1998 was the warmest year on record.

An additional factor that may accelerate warming in Peninsular Malaysia and could be considered in this study is the effect of urban heat islands (UHI). An urban heat island is a city or metropolitan area that is significantly warmer than its surrounding rural areas because of human activities and interference with the natural ecosystem (Xu et al. 2012). Studies have shown the emergence of the UHI phenomenon in the past few decades at stations located in cities (Fujibe 2009, 2011; Mohan et al. 2012; Zhang et al. 2014). The UHI effect enhanced the warming rate by 3 °C/100 years in the city of Tokyo as reported by Fujibe (2011), and Mohan et al. (2012) reported a maximum UHI of 8.3 °C for the city of New Delhi. As mentioned in the Southwest Climate Change Network (2008), the general characteristics of the UHI are that the average minimum temperature increases more than maximum temperatures and the average nighttime temperatures increase more than the average daytime temperatures. In the study done by Hamdi (2010), he estimated the urban heat island effects on the temperature series of Brussels, Belgium using remote sensing method. His study revealed that the urban warming on minimum temperature is higher with nearly 2.5 times more than on maximum temperature. Similarly, the study done by Sajjad et al. (2015) in Lahore city, Pakistan, also suggested that minimum temperature increased more than maximum temperature at urban stations. These findings suggest that the maximum temperature is substantially less affected by urbanisation than the minimum temperature.

In the case of Malaysia, the country has undergone a rapid development process since independence in 1957. At the beginning of the twenty-first century, many cities experienced rapid industrialisation. Kuala Lumpur in the Klang Valley area is the largest urban area as well as the largest metropolitan area in Malaysia, followed by Penang, the second largest city. Large urbanised cities, such as the locations of Subang station near Kuala Lumpur and the Bayan Lepas station in Penang, have played a significant role in changing the urban air temperature pattern. The higher warming rates that were observed in these stations were expected to be related to the effect of UHI. The results were comparable to the study conducted by Yusuf et al. (2014), which confirmed that the UHI effect exists in the Kuala Lumpur metropolitan area. On the other hand, stations such as Batu Embun and Muadzam, which are not considered as being in a metropolitan area, showed lower warming rates. Estimated warming rate as discussed in Sect. 4.6 already indicated that the estimated trend for urban stations such as Subang and Bayan Lepas showed the highest rates compared to others. Additionally, the minimum temperatures increase more than the maximum temperatures at these two stations.

5 Conclusions

Trend analysis and change point detections of annual and seasonal mean, maximum and minimum temperature series were carried out for ten meteorological stations located in Peninsular Malaysia. It was proposed that the change point detection should be performed before the trend analysis. Change point analysis via the non-parametric Pettitt and the sequential Mann–Kendall tests revealed that most of the detection points at the stations in both annual and seasonal analyses occurred in the years 1996–1998. These change points are suspected of being related to the occurrence of El Niño and La Niña events. The series were divided into two sub-series separated by the change point and were then assessed using the Mann–Kendall test. Some decreasing and increasing trends were observed at each sub-series (before or after change points) of the selected stations. The results derived from this study suggest that the existence of change points in the series is mostly associated with significant trends.

A general pattern of warming temperatures from 1980 to 2011 in Peninsular Malaysia is observed in this study. Both annual and seasonal mean, maximum, and minimum temperatures experienced a significant increasing trend. The local mean temperatures have increased during the last 32 years in a range between 2 and 5 °C/100 years. It was also shown that there were larger increases in the minimum temperatures than in the maximum temperatures at the majority of the stations. In comparison to the increase in the mean global temperature for the last three decades as reported by the IPCC (2013), the higher trends in temperature series in Malaysia are possibly due to the short length of records, which was calculated during 30 years or so. There are other possibilities, including that the observed warming in Malaysia may be accelerated by the occurrence of the El Niño events in the year 1997/1998 (Tangang et al. 2007, 2012) and other factors like the urban heat island (Salleh et al. 2013; Shaharuddin et al. 2014). The results of UHI effect highlighted that minimum temperature increased more than maximum temperature at urban stations such as Bayan Lepas and Subang due to rapid urbanisation. Future research is essential to analyse the changes in temperature extremes by adding more temperature indices such as the frequency of hot days, warm nights, cool days, and cold nights, and investigate their anomalies over topography using a large number of stations. Other than that, the study on the effect of UHI on minimum and maximum temperatures by considering the urban and rural stations is needed for a better understanding of climate change in Malaysia.

Acknowledgements The authors are indebted to the anonymous reviewers for comments that have greatly improved the paper. We would like to extend our sincere gratitude to the Ministry of Education Malaysia and Universiti Teknologi Malaysia for the financial support given to this work under the post doctoral scheme and Research Grant FRGS 4F845.

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