Eco. Env. & Cons. 27 (November Suppl. Issue) : 2021; pp. (S94-S102)

ISSN 0971–765X

Long-term rainfall trend and distribution in the Western region of the Peninsular Malaysia

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(Received 5 April, 2021; Accepted 4 June, 2021)

ABSTRACT

Rainfall trend and intensity are essential guides in understanding long-term changes in rainfall. This study aims to identify the trend and intensity of long-term rainfall at the main stations in the western region of Peninsular Malaysia between 1960 and 2010. Rainfall data were collected from 133 stations under the purview of the Department of Drainage and Irrigation of Malaysia. The analytical techniques used were descriptive analysis and the Mann-Kendall Trend Test. The results showed that from 1960 to 2010 the rainfall for all stations were in upward trend. However, Mann-Kendall Test (P=1), showed that the trend was not significant. The average annual rainfall in the western region were classified as moderately wet having to decrease from a range of 1936 mm to 2635 mm, whereas, Dale's average annual rainfall were in the range of 2540 mm to 2794 mm. The average rainfall variability for the western region during the study period was 699 mm,in contrary; Dale's average rainfall variability from 1950 to 1959 was 254 mm. The maximum rainfall average for the western region (moderately wet) also lowered by 155 mm (6 per cent) from 1960 to 2010. The rainfall distribution showed that not all areas of the western province in Dale's study received between 2540 mm and 2794 mm of rainfall annually. The implications of this study is in improving water management, especially in managing and planning the water supply more efficiently.

Key words : *Rainfall trend, Rainfall intensity, Western region, Mann-Kendall test, Peninsular Malaysia.*

Introduction

Rainfall is a fundamental aspect of the hydrological cycle and changes in rainfall patterns can directly affect water resources (Islam *et al.*, 2012). Recently, climate change has significantly influenced the pattern and distribution of rainfall in local and global scales. For instance, in 2007 the Intergovernmental Panel on Climate Change (IPCC) reported an increase in the amount of rainfall in areas located at 30º N latitude between 1900 and 2005, alongside a decrease in the amount of rainfall in the tropics since the 1970s. The changes in the amount and distribution of rainfall are mainly due to the increase in land and vegetation clearing for various development purposes (Trenberth *et al.,* 2007). Rainfall in the northern subtropical region (20-40º N) did not show a significant trend. However, there were various rainfall pattern in different decades (New *et al.*, 2006). Manton *et al.* (2001) reported that the amount of annual rainfall in the Southeast Asian region decreased between 1961 and 1998 and the number of rainy days also decreased significantly in most Southeast Asian countries. Furthermore, annual rainfall data and the monsoons in the Ganga valley (India) during the period 1901–1989 indicated a declining trend (Kothyari and Singh, 1996). Moreover, study in the central mountainous region of Sri Lanka has shown that annual rainfall decreased between 1964 and 1993, with the highest drop in rainfall recorded in March-April (Herath and Ratnayake, 2004).

Malaysia too is experiencing similar trend, where areas previously categorised as dry had received exceptional rainfall and consequently unexpected floods and rendered a change in the pattern and distribution of rainfall. According to Dale (1959), during the northeast monsoon windyseason, the East Coast of Peninsula Malaysia, West Sarawak and Northeast Sabah experienced heavy rainfall. Average monthly rainfall in these areas ranged from 230 mm to 760 mm. concurrently, land areas or areas protected by mountain ranges were very often free from the effect of high precipitation. With the exception of heavy rainfall in the southern region of Peninsular Malaysia for several days at the end of December 2006 and in mid-January 2007 that caused massive flooding (Malaysian Meteorological Department, 2007). According to Xia *et al.* (2004), rainfall trends over long periods of time is particularly relevant in hydrological studies as a tool for detecting and identifying rainfall changes as well as for the diverse planning and management of water resources. In addition, long-term analysis renders it possible to examine the effects of climate change and diversity on water resources (Chen *et al.*, 2006) as well as human activities, in particular the agricultural activities. Awareness of the variety and amount of precipitation is essential for engineers in designingthe urban irrigation structures (Desa and Rakhecha, 2004). Information on rainfall trends can be used as a forecast indicator in planning for flood mitigation or minimizing precipitation associated with drought. Therefore, this study seeks to review the long-term trend and intensity of rainfall in the western region of Peninsular Malaysia between 1960 and 2010.

The Rainfall Region in Peninsular Malaysia Based on Dale (1959)

Dale (1959) created a rain region for Peninsular Malaysia via the isohyet method (Figure 1),using the amount of rain collected at 21 rainfall stations (Alor Setar, Baling, Penang, Taiping, Sitiawan, Kampar, Kuala Selangor, Kuala Lumpur, Jelebu, Melaka, BatuPahat, Kluang, Johor Bahru, Mersing, Pekan, Temerloh, Bukit Fraser, Kuala Lipis, Dungun, Kuala Krai, and Kota Bharu) to describe

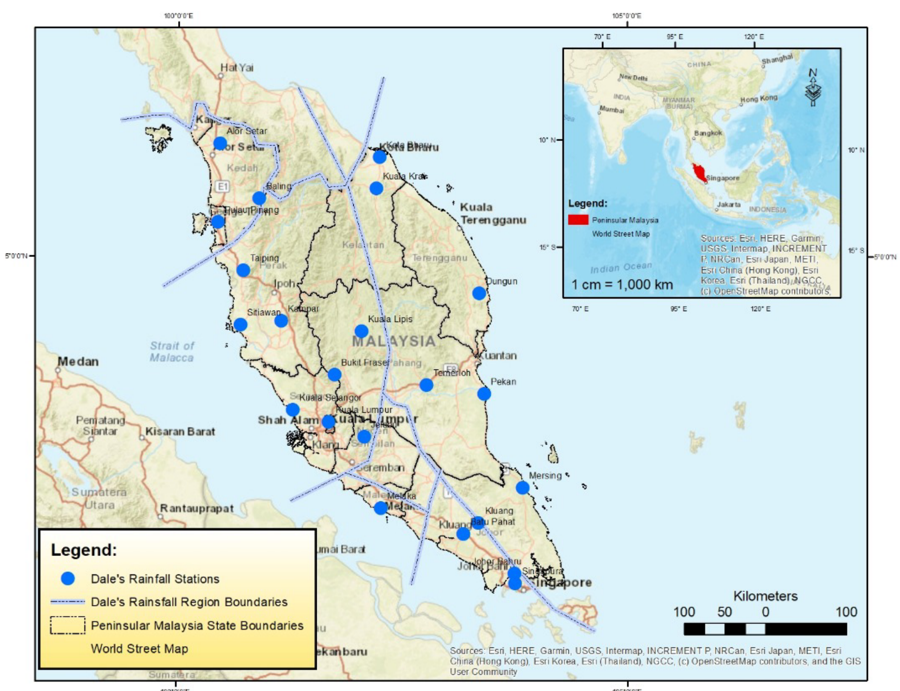

Fig. 1. The Rainfall Region in Peninsular Malaysia (Dale, 1959)

the rainfall areas in Peninsular Malaysia. This method is often utilised to describe the rainfall conditions at a location by combining points that have the same value to form the desired size, such as 100 inches. The value of a point is calculated based on the estimated value between two observation points.

Dale (1959) divided Peninsular Malaysia into five rain regions: northwest, west, east, southwest and the Port-Dickson-Muar coast. The northwest rain region collected less than 2540 mm of rainfall, while the west received > 2540 mm, the east > 2794 mm and the Port Dickson-Muar coast 2032–2540 mm. Meanwhile, the southwest region was considered as dry area (less than 2286 mm of rainfall per year). The rainfall region has been used as a guide by the Malaysian Meteorological Department and the Department of Irrigation and Drainage to classify rainfall areas as well as for water resource planning for irrigation and other domestic purposes.

Subsequently, Dale (1959) placed Peninsular Malaysia in the Inter Convergence Zone, i.e., usually seeing convectional rainfall in the evening and as a result less heavy rainfall. Typically, the amount of rainfall in Malaysia was found to be high, with most areas receiving at least 2,000 mm of rain per year and some areas receiving up to 3,500 mm. Dale (1959) also noted that during the northeast monsoon windyseason, the exposed East Coast Peninsula, West Sarawak and Northeast Sabah all experienced high precipitation events. Average monthly rainfall in the area fall within the range of 230 mm to 760 mm. Meanwhile, land areas or areas protected by mountain ranges were unaffected by the heavy rainfall.

Methodology

Study Area

For present investigation, the western region of Peninsular Malaysia was chosen as the study area as it often suffers from water shortages. Dale (1959) explained that thisregion received more than 2540 mm of rainfall per year, the second highest in the country. Therefore, Dale's classification of rainfall regions from 1959 is outdated and does not reflect the current situation; as a result, it should be re-examined. According to Dale (1959), the boundaries of the western rainfall region arecomposed of five states: Perak, Selangor, Negeri Sembilan, Kelantan and Pahang. However, only specific districts that bordering the states of Perak, Selangor and Negeri Sembilan with the state of Kelantan and Pahang are

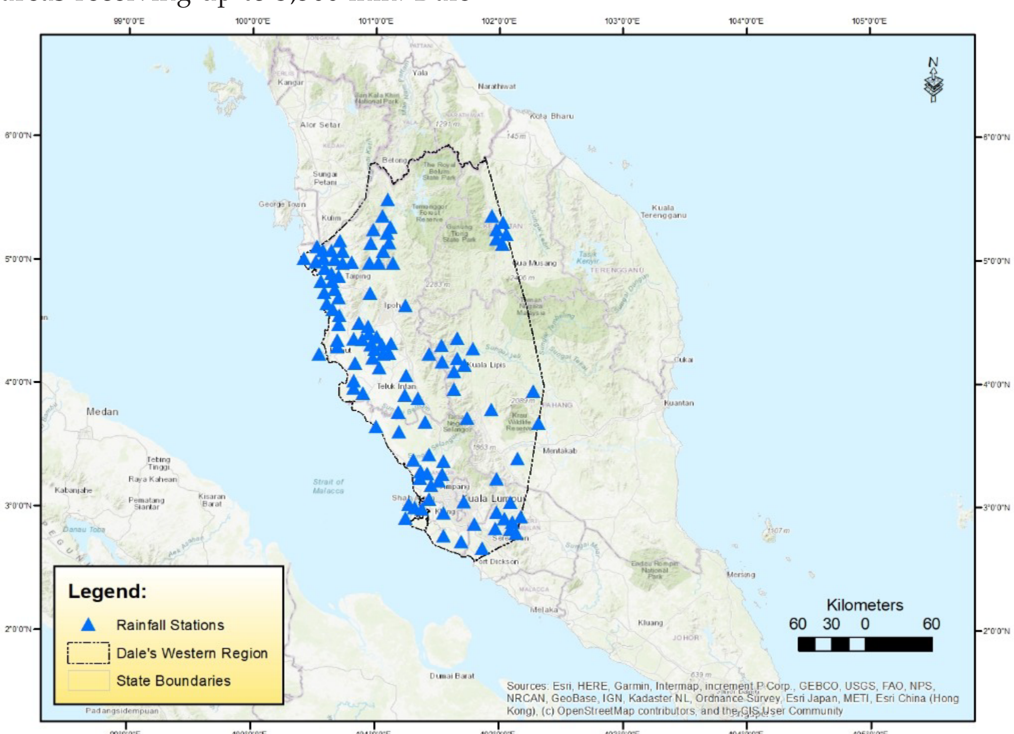

Fig. 2. Study areas and rainfall stations

involved in this study. 133 rainfall stations were monitored in this study. Figure 2 shows the study area and the locations of each station in the western region of Peninsular Malaysia.

Data Collection and Analysis

This study also examined secondary data (rainfall) from all of the stations in the western region from 1960 to 2010. These data were obtained from the Department of Drainage and Irrigation of Malaysia. The Mann-Kendall (MK) Trend Test was used to identify rainfall trends in the western region of Peninsular Malaysia. The MK test is a non-parametric test that can be used to detect the inclination of rainfall and represents one of the most frequently employed global methods for trend tracking in hydrology, climatology and meteorology (Batisani and Yarnal, 2010; Du and Shi, 2012; Praveen *et al.,* 2020; Singh *et al.,* 2008; Tabari *et al.,* 2011; Wang *et al.,* 2012). According to Mondal *et al.* (2015), MK test is widely utilised because it can be used for free time-series data and is not very sensitive to outliers. Researchers who have used this test to study patterns of rainfall distribution include Weldegerima *et al.* (2018) for Africa, Anand and Karunanidhi (2020) and Praveen *et al.* (2020) for India and Khalil (2020) in Thailand.

The MK test is commonly applied to validate trends in time series data, especially environmental data such as rainfall, temperature, discharge, sediment expression and water quality (Burn and Elnur, 2002; Mohmadisa *et al.,* 2010; Nasir *et al.,* 2009; Shaharuddin and Noorazuan, 2006; Yue *et al.,* 2003). It is also utilised to identify whether a trend is significant or not. Mann-Kendall statistical (S) analysis attempts to state that a null hypothesis (Ho) is expressed as no trend, while the alternative hypothesis (HA) expresses the existence of a trend, as shown in the equation below:

Ho : Prob [xj> xi] = 0.5, where j >i
HA : Prob [xj> xi] ≠ 0.5

The S analysis produces value to indicate the direction and magnitude of trend significance of a series of data (Shaharuddin and Noorazuan, 2006). Either an increasing, decreasing or a stable trend in rainfall is attained via this analysis. The following formula is used for this test statistic S:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\ (x_j - x_i)$$

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if} \quad x_j - x_i > 0 \\ 0 & \text{if} \quad x_j - x_i = 0 \\ -1 & \text{if} \quad x_j - x_i < 0 \end{cases}$$

If the statistical test S shows a positive value, it implies an increasing trend; if it shows a negative value, it indicates a declining trend. Based on the conclusion presented in the S analysis, if the value of S is greater than 0, it indicates an increasing trend, whereas if the value of S is less than 0, it shows a downward trend. Descriptive analyses such as minimum, maximum, average and standard deviation (SD)are also calculated.

Results and Discussion

Rainfall Trend

Based on the rainfall data collected from 133 stations between 1960 and 2010, the MK test for the average annual rainfall showed a positive or increasing rainfall trend with P-value of 0.8838. The S value was positive (19) and the value of Z was 0.146. The MK test was also conducted on the average annual rainfall of 133 rain stations in the western region, revealing values of P=1, S=1 and Z=0.000. Moreover, the average variability in annual rainfall as compared to the average annual rainfall by Dale (1959) concluded a different pattern in decrease and increase during specific years. There was only a slight improvement which resulted in the Mann-Kendall Trend Test (P=1).

Average Annual Rainfall

Figure 3 illustrates the average annual rainfall of 133 stations in the western region during 1960 to 2010. The minimum annual rainfall recorded was 1936 mmin 2005, while the maximum was 2635 mm in 1966. The average annual rainfall across the period was 2279 mm and the Standard Deviation (SD) was 200 mm, indicating huge variability in rainfall across the period. Furthermore, 88 per cent of the years (44 years) the rainfall was exceeded 2000 mm per year, with the exceptions for 1974 (1979 mm), 1977 (1954 mm), 1978 (1999 mm), 1992 (1963 mm), 1998 (18967 mm) and 2005 (1936 mm). In no specific year within the study period was the amount of rainfall heavy or extreme. The average annual rainfall in the western region was found to be lower than the average annual rainfall in Peninsular Malaysia of 2400 mm (Mohamad Suhaily Yusri, 2007).

Differences between Dale's Average Rainfall and Annual Rainfall

From 1960 to 2010, the average annual rainfall for the 133 study stations was lower than the average rainfall for the western region recorded in Dale's (1959). Dale determined that rainfall in the western region ranged from 2540 mm to 2794 mm, whereas this study showed a decrease for rainfall in the western region from 1936 mm to 2645 mm, with an average of 2279 mm. About 12 per cent (6 years) of the annual average with a minimum increase of more than 2540 mm in 1966 (95 mm), 1973 (43 mm), 1984 (33 mm), 1993 (72 mm), 2000 (70 mm) and 2008 (76 mm). This scenario revealed that the amount of rainfall received in the western region were decreasing and was uneven from year to year, as shown in Figure 4. It would give the impression that modifications to Dale's classification of rainforests need to be repeated, as it would have a significant impact on surface water resources and the effect of changing global rainfall trends would affect the study area. Regional climate classifications aim to divide reions into several homogeneous groups based on long-term climatic properties (Meher-Homji, 1980). According to Chan (1995), each classification is different and none can be considered universal, meeting the needs of all fields and proving suitable for all purposes.

Variations between Dale's (1959) and the Present Study's

The difference between Dale's maximum rainfall (2794 mm) and minimum rainfall (2540 mm) was 254 mm. By contrast, the results in this study showed a maximum of 2635 mm and a minimum of 1936 mm, with a difference of 699 mm. Maximum rainfall in Dale's western province was 2794 mm while total rainfall in the western region of the present study was 2636 mm, a difference of 159 mm (6 per cent). Meanwhile, the minimum amount of rainfall in the western region classified by Dale (2540 mm) and the amount of rainfall in this study (1936 mm) showed a difference of 604 mm (23.8 per cent). This situation indicates the variability in the rainfall as can be seen for rainfall.

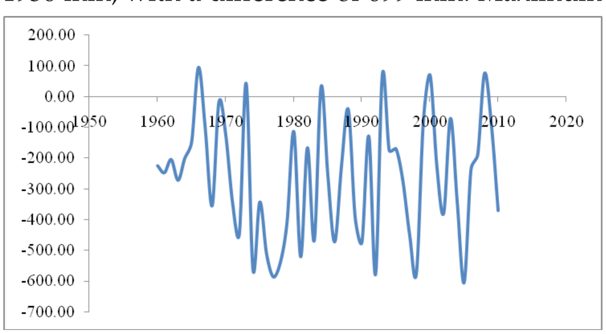

Fig. 3. Average annual rainfall in the Western Region from 1960 to 2010

Differences between Average Rainfall and Average Rainfall Variabilities Every Ten Years

The results revealed that the average rainfall and the average rainfall variability every ten years between 1996 and 2010 were insignificant and difficult to unravel. Based on the MK test, the rainfall trend increased (P=1), but comparing the average rainfall and the average rainfall variability for every ten years, the increases and decreases in the rainfall period could be identified, occurring as a result of the influence of ElNiño Southern Oscillation (ENSO) and LaNiña as well as changes in active land use. Balling and Brazel (1987) have stated that temperature pattern and local-scale rainfall, especially in urban areas, can be affected by urban climate change. Changes in a city's climate are the result of changes in land use activities and the morphology of the city itself. Moreover, the occurrence of the ENSO every three to seven years leads to changes in land and ocean temperature trends. The ENSO results in unusually dry conditions in Malaysia and surrounding countries (Fedorov and Philander, 2000).

The average rainfall between 1961 and 1970 was 2382.75 mm and later, decreased to 2158.93 mm from 1971 to 1980. However, it increased to 2242.06

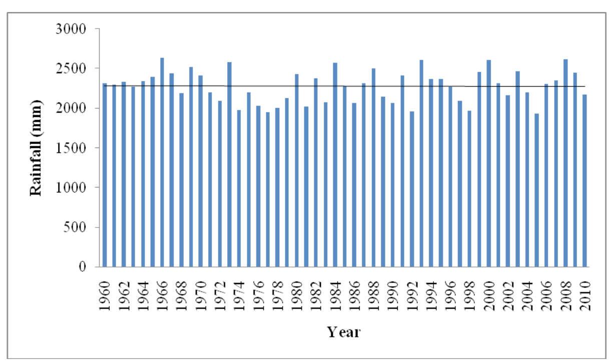

Fig. 4. Differences between Dale's average rainfall and annual rainfall in the Western Region from 1960 to 2010

mm and 2311.21 mm from 1981 to 1990 and from 1991 to 2000, respectively. In ten years duration, from 2001 to 2010, the average rainfall decreased to 2296.45 mm. This trend may be attributed to the spatial and temporal diversity in the distribution of tropical rainfall, being affected by global changes such as the ENSO and LaNiña.

The above trend can be influenced by the extreme climate and weather changes (temperature fluctuation) that significantly affected both global and local trend and distribution of rainfall over the longer duration. The most recent IPCC report discovered that the intensity and frequency of extreme weather events have increased over the last 50 years. Among the weather indicators considered to have changed significantly are the frequency of storms exceeding 30 mm/ hour, increased daily rainfall intensity and prolonged drought conditions (IPCC, 2007). Local studies around the world have shown both increases and decreases in the amount and the intensity of rainfall caused by global warming (Noorazuan, 2003).

In short, the results of this study showed that all of the stations experienced an annual rainfall trend that increased from 1960 to 2010, although not significantly, according to the MK test (P=1). The average rainfall in the western region was also lower (2279 mm) than the average annual rainfall in Malaysia (2400 mm). Furthermore, the average annual rainfall for the western region (the wetland area) decreased from 1936 mm to 2635 mm compared to Dale's average yearly rainfall range of 2540 mm to 2794 mm. The average rainfall variability in the western region during the study period was 699 mm, compared to Dale's figure of 254 mm between 1950 and 1959. The maximum rainfall average for the western region (moderately wet) also declined

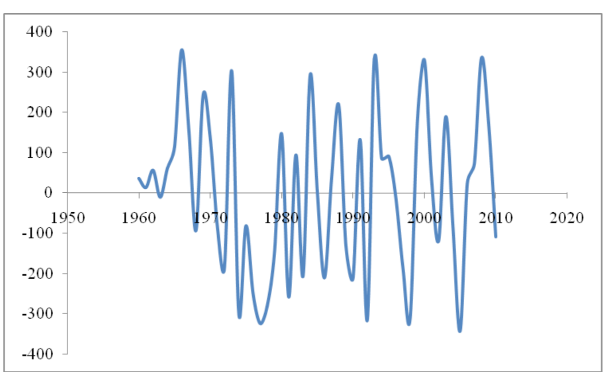

Fig. 5. Differences between average rainfall and average rainfall variability for every 10 years

by 155 mm (6%) between 1960 and 2010. According to Chan (1995), the nature and characteristics of climate of one area'smay differ from others due to spatiality, elevation, distance from the sea and local properties. Time also affects the characteristics of the climate of an area. Moreover, although the distance between two regions may be close, the climate's features may differ due to local variations in factors such as vegetation, soil, topography and slope. Figure 5 presents the differences in average rainfall and average rainfall variability every ten years.

Overall, the results revealed that all of the stations experienced an increasing annual rainfall trend from 1960 to 2010, although not significantly, according to the MK test (P=1). This study showed similarities with Khalil's (2020), which trend analysis identified an increase in rainfall on a seasonal and annual scale in Thailand, but contradictedto Cannarozzo *et al.*(2006), that reported an overall negative trend across the entire region of Sicily, Italy. A significanty decreasing trend in annual rainfall was also reported by Kaiwart *et al.* (2020), for Chhattisgarh, India.

Furthermore, the present study's revealed that the average rainfall received by the western region was lower (2279 mm) than the average annual rainfall in Malaysia (2400 mm). The average annual rainfall range for the western region which classified as the second wet area decreased to a range of 1936 mm to 2635 mm, compared to Dale's average annual rainfall, which ranged between 2540 mm and 2794 mm. Decreased rainfall intensity in western region can be related to Manton *et al.*'s (2001)which state that the annual rainfall levels in the Southeast Asian region decreased between 1961 and 1998 and the number of rainy days also diminished significantly in most Southeast Asian countries. Furthermore, according to the IPCC (2007), the continuous increase in carbon dioxide levels in the atmosphere over the last five decades has caused global warming. This phenomenon has increased the global surface temperature by 0.6°C, leading to greater extreme weather conditions, particularly in the distribution of rainfall and thunderstorm patterns.

The average rainfall variability in the western region during the study period was 699 mm, compared to Dale's estimation of 254 mm between 1950 and 1959. The maximum average rainfall for the western region (moderately wet) also fell by 155 mm (6%) between 1960 and 2010. Certain areas in the western region were subject to extreme rainfall (including Bukit Larut, Selama and Batu Kurau)or light rainfall (such as Lawin, Tanjung Karang and Sungai Besar). The differences in rainfall intensity in these areas can be attributed to local factors such as the topography of the area and the distance from the coast. Khalil (2020) has clarified that any increase or decrease in rainfall in any region affects the quantity of overflow produced and may affect water resources planning and the allocation of water to various sectors of water consumption. Thus, understanding rainfall trends can provide useful information on water planning, developmentand management in a district or region (Weldegerima *et al.,* 2018).

Conclusion

This study found that all of the stations experienced an increasing annual rainfall trend from 1960 to 2010, although not significantly, following the MK test (S=1). The average annual rainfall for the western regionis classified as the second wetland area that decreased to a range of 1936 mm to 2635 mm, compared to Dale's average annual rainfall, which ranged between 2540 mm and 2794 mm. Meanwhile, the average rainfall variability for the western region during the study period was 699 mm, compared to Dale's average rainfall variability of 254 mm. The maximum average rainfall for the western region (moderately wet) fell by 155 mm (6%) from 1960 to 2010. Some western region areas were subject to extreme rainfall (Bukit Larut, Selama, and Batu Kurau) or light rainfall (Lawin *et al.,*).

The rainfall pattern between 1960 and 2010 showed a variation due to not all of the areas in the western region determined by Dale experiencing rainfall between 2540 mm and 2794 mm per year. There were also areas in the western region that did not getting between 2540 mm and 2794 mm of rainfall per year. As a result, new western rainfall regions can be discerned based on 51 years of rainfall data. Specifically, the area of Dale's original western region were narrowed and shifted to the southwestern region. Dale's original western region, which is the second-most humid area after the eastern region (with rainfall above 2794 mm), has become a dry area (southwest region), with an average area of less than 2284 mm of rainfall. Overall, the new western region that covers 4,6413.6 km², making it 10 per cent smaller than the area of the western region identified by Dale, covering 5,1596.2 km². It showed that the nature and characteristics of the climate differed across areas due to spatial variations. Moreover, the time aspect affected the nature and the climatic characteristics of an area associated with global change and human actions.

Meanwhile, the disturbance aspect of the water supply around the Klang Valley did not owe to rainfall distribution changes, but because this area was one of the western territories that experiencing rainfall of between 2540 mm and 2794 mm. By contrast, the clean water supply crisis in the Klang Valley region owed to population increase,intensifying demand and leading to problems related in reducing water resources. Furthermore, the increase in surface runoff due to rapid development reduced the availability of water. In addition, severe river pollution will affected the clean water supply capacity. With this study, water management could be improved efficiently. Moreover, floods and the management of natural disasters especially in development areas such as the western region of Peninsular Malaysia could be effectively managed.

Aknowledgements

This research has been carried out under Fundamental Research Grants Scheme (2011-0072-106-02) provided by the Ministry of Education of Malaysia. The authors would like to extend their gratitude to Universiti Pendidikan Sultan Idris (UPSI) that helped manage the grants.

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