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Tracing Trends in the Sequences of Dry and Wet Days over Peninsular Malaysia

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Abstract: This study attempts to trace changes in the dry and wet spells over Peninsular Malaysia based on the daily rainfall data from twenty rainfall stations which include four sub-regions, namely; northwest, west, south and east for the period of 1975 to 2004. Nine indices for each dry and wet spells comprising of the main characteristics for each spell, the persistency and the frequency of the various length of dry (wet) spells will be used to identify whether or not these indices have increased over Peninsular Malaysia. The Mann-Kendall (MK) trend test indicate that as the persistency of wet days is increased, the trend of the frequency of long wet spells is also found to be increased in most stations over the peninsula; however, decreasing trend is observed in the frequency of short spells in these stations. The frequency of long dry periods tends to be higher with a significant increase in the mean and variability of the length of the dry spells over the southern areas; whereas, all the indices of wet spells in these areas show a decreasing trend. Furthermore, over the western areas, all the indices of dry spells exhibit a negative trend and at the same time, the frequency of short wet spells exhibits a negative trend with an increase in the mean, variability and the persistency of the wet spells. Generally, no significant trend is found in most of the indices of dry (wet) spells in most stations over the northwestern and eastern areas for the period of 1975 to 2004.

Key words: Mann-Kendall trend test, dry and wet spells, persistency, variability, indices

INTRODUCTION

Due to the rapid growth in population as well as in the economic development, tracing trends in rainfall characteristics particularly on the sequences of dry and wet days is becoming an increasingly important component that needs to be taken into consideration in managing water resources not only in Malaysia but also throughout the world. Various types of rainfall indices have been used by previous researchers in determining the trends of climatic events. For example, Bai *et al*. (2007) studied the annual number of wet spells, annual precipitation amount and the mean daily precipitation in a wet spells in China for the period of 1951 to 2003. Schmidli and Frei (2005) examined the trends of heavy precipitation and wet and dry spells in Switzerland using fourteen rainfall indices which included the mean dry (wet) day persistence, the maximum number of consecutive dry (wet) days and the mean

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dry (wet) spells length. Moreover, several studies were emphasized on the dry (wet) spells since these variables greatly influenced agriculture and drought (Huth *et al*., 2000; Lana *et al*., 2003; Anagnostopoulou *et al*., 2003; Burgueno *et al*., 2005; Gong *et al*., 2005; Tolika and Maheras, 2005; Cislaghi *et al*., 2005; Serra *et al*., 2006; Su *et al*., 2006; Seleshi and Camberlin, 2006).

According to the Intergovernmental Panel on Climate Change (IPCC) (2007), it is very likely that hot extreme, heat waves and heavy precipitation events will contribute to become more frequent. Similarly, IPCC (2001) also reported that the overall global land precipitation has increased about 2% since the beginning of the 20th century. Karl and Knight (1998) reported that the number of rainy days has increased by 6% during the 20th century in the United States. Meanwhile, there are other studies that supported the findings of IPCC (2001) (Easterling *et al*., 2000; New *et al*., 2001; Groisman *et al*., 2005). The variations in meteorological droughts and wet spells during the period of 1900 to 1995 using the Palmer Drought Severity Index (PDSI) had been conducted by Dai *et al*. (1998). They reported that the excessive wetness and drought have increased in many parts of land areas such as the USA, mid-latitude Canada, Europe and S.E. Australia. However, Manton *et al*. (2001) reported that the number of rainy days had decreased significantly throughout Southeast Asia. In addition, Brunetti *et al*. (2004) reported that the number of wet days has shown a decreasing trend all over Italy for the last 120 years. The study on the trend of the frequency of short and long dry spells has been conducted by Gong *et al*. (2004, 2005). Gong *et al*. (2004) reported that a negative trend is found in the frequency of long wet spells with a linear trend of -5.6% per decade, whereas the occurrence of long dry spells showed an increasing trend at a rate of 7.2% per decade. In addition, Gong *et al*. (2005) studied the trend of summer dry spells over six sub-regions of China for the period of 1956 to 2000. They reported that three regions, namely; north, northeast and southwest of China exhibited a significant decreasing trend is observed in the frequency of short dry spells (≤ 10 days), whereas a significant positive trend in the frequency of long spells (≥ 10 days) is found over the north and northeast China.

Identifying changes in the trend of both dry and wet spells characteristics as well as the persistency will provide useful information in predicting future climate events since these variables are closely related to extreme weather events such as drought and flood. Most recently, the widespread flooding which occurred in the southern areas of Peninsular Malaysia from December 2006 until January 2007 caused by the extreme rainfall and prolonged wet spells contributed to RM 1.5 billion losses to the country. On the other hand, haze due to prolonged dry spells also has a negative impact to the environment. In August 2005, Malaysia announced a state of emergency in two towns, Port Klang and Kuala Selangor, after air pollution, which was caused by the haze, reached dangerous levels. Thus, it is very important to further investigate the changes in various types of rainfall indices in the climatic events specifically in the characteristics of dry and wet spells since these variables will contribute to drought and floods.

The study on tracing changes in the rainfall characteristics received less attention for the Malaysian data. Therefore, this present study is aimed to trace changes in the rainfall characteristics particularly on the sequences of dry and wet days which include the frequency of various lengths of dry (wet) spells, the persistency, the maximum duration, the mean length and the variability over Peninsular Malaysia in the last 30 years. The analysis of trend will be focused on the individual stations and on the regional basis for both wet and dry spells.

MATERIALS AND METHODS

Daily rainfall data for the selected 20 stations which comprise of four sub-regions, namely; northwest, west, south and east, over Peninsular Malaysia were obtained from the Malaysian Meteorology Services and Drainage and Irrigation Department for the period 1975 to 2004 (Table 1).

Table 1: List of the stations used in this present study

Station name	Code	Longitude	Latitude	Missing (%)
Bayan Lepas	N1	100.27	5.30	0.0
Bumbong Lima	N2	100.43	5.55	3.4
Alor Setar	N3	100.40	6.20	0.0
Padang Katong di Kangar	N4	100.18	6.43	3.5
Kg. Bahru	N5	100.17	6.50	0.3
Subang	W1	101.55	3.12	0.0
Rumah Pam JPS Bagan Terap	W2	101.07	3.72	9.3
Sitiawan	W3	100.70	4.22	0.0
Pusat Kesihatan Kecil Bt. Kurau	W4	100.80	4.97	8.0
Alor Pongsu	W5	100.58	5.03	0.8
Johor Bahru	S1	103.75	1.47	3.1
Senai	S2	103.67	1.63	0.0
Pintu Kawalan Tampok Batu Pahat	S3	103.20	1.62	9.0
Pintu Kawalan Sembrong	S4	103.05	1.87	3.1
Tangkak	S5	102.57	2.25	2.9
Pekan	E1	103.35	3.55	4.3
JPS Kemaman	E2	103.42	4.22	7.7
Kg. Menerong	E3	103.05	4.93	4.3
Stor JPS Kuala Terengganu	E4	103.13	5.32	6.3
Kota Bharu	E5	102.28	6.17	0.0

Table 2: List of the nine indices of dry (wet) spells used in this present study

Measurement	Index name (Dry)	Index name (Wet)
Maximum number of consecutive dry (Wet) days	MxD	MxW
Mean dry (Wet) spells length	MnD	MnW
Standard deviation dry (Wet) spells length	SdD	SdW
Probability of dry (Wet) days	P(D)	P(W)
Probability of two consecutive dry (Wet) days	P(D|D)	P(W|W)
Probability of three consecutive dry (Wet) days	P(D|DD)	P(W|WW)
Frequency of short spells (1-4 days)	SSD	SSW
Frequency of medium spells (5-9 days)	MSD	MSW
Frequency of long spells (at least 10 days)	LSD	LSW

The data used in this present study can be considered good quality data with less than 10% missing values throughout the 30-year period. The missing values in the data series for the period 1975 to 2004 were estimated using various types of weighting methods such as the inverse distance, the normal ratio and the correlation between the target and the neighboring stations (Eischeid *et al*., 2000; Sullivan and Unwin, 2003; Teegavarapu and Chandramouli, 2005; Xia *et al*., 1999). In addition, Fig. 1 shows the physical map indicating the locations of the selected rainfall stations that will be used in the analysis.

In this present study, a wet day is defined as a day with the rainfall amount of at least 0.1 mm and the wet spells is represented as a number of consecutive wet days which is followed and preceded by a dry day. On the other hand, a dry spell is defined as a number of consecutive days without rain. By considering various types of the rainfall indices used by previous researchers, Table 2 shows briefly the nine indices for each dry and wet spells characteristics including the maximum consecutive number of dry (wet) days, mean, standard deviation, the persistency of dry (wet) event and the frequency of various durations of dry (wet) spells length. The detailed analysis on the trend of these indices were very important to reduce the climate-induced flood risks as well as the impact of very long duration of dry (wet) days on society, agriculture and environment.

Each of the indices of dry (wet) spells will be computed annually for each station before further analysis could be conducted in identifying the trend for individual stations and also for regional basis. In order to identify the trend for regional basis, all the nine indices are computed annually for each station and then the all values are averaged according to the region in a way to get the annual regional means. The trend of the nine indices of dry (wet) spells for individual stations and also for the regional basis can be traced using a non-parametric Mann-Kendall (MK) test (Kendall and Gibbons, 1990). The slope of the linear trends for each of the indices is estimated using the ordinary least square method.

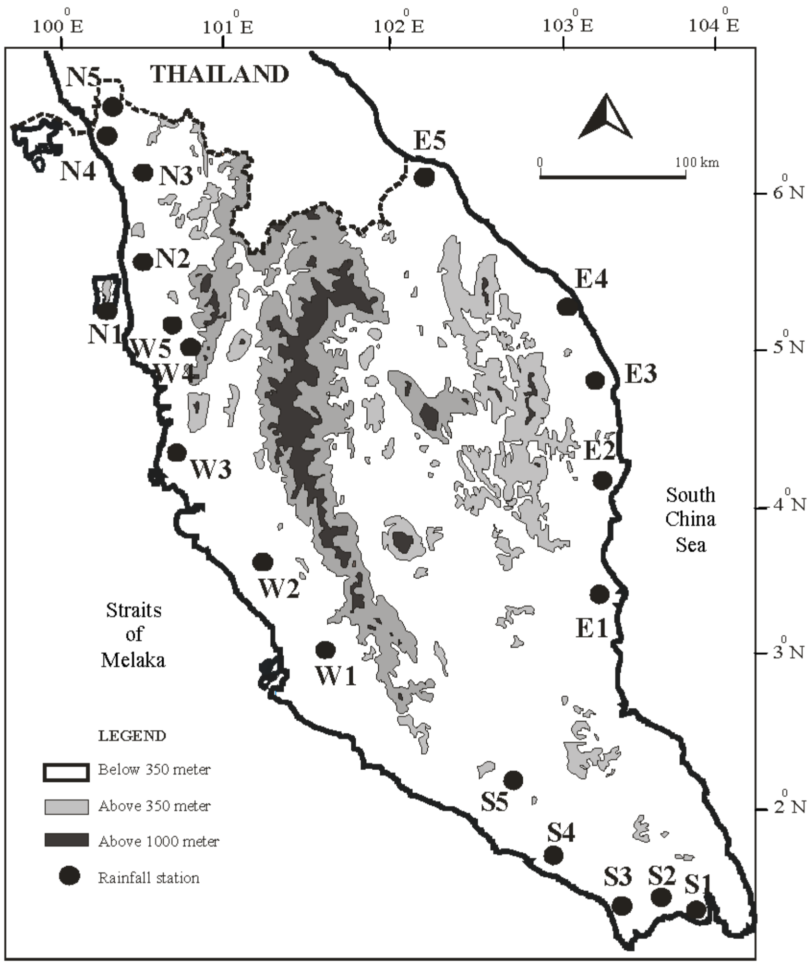

Fig. 1: The physical map indicating the twenty selected rainfall stations in Peninsular Malaysia

In the Mann-Kendall test, the indicator variable of interest, I, for each element x_i ($i = 1,\ldots, n$) of the series where ($i < j$), is denoted as follows:

$$I\,(x_i < x_j) = \begin{cases} 1 & x_i < x_j \\ 0 & \text{otherwise} \end{cases}$$

The test statistics τ is given by $\tau = \sum_{i=1}^{n} \sum_{j=i+1}^{n} I\,(x_i < x_j)$. In the case where no trend exists (null hypothesis), τ is asymptotically normal, independently from distribution of function and

$$u(\tau) = \frac{\tau - \overline{\tau}}{\sqrt{\mathrm{var}\,(\tau)}}$$

has the standard normal distribution, with $\overline{\tau}$ and var (τ) given by

$$\overline{\tau} = n(n-1)/4 \text{ and } \mathrm{var}\,(\tau) = n(n-1)(2n+5)/72$$

In this present study, the null hypothesis will be rejected at 5% level, i.e., $|u(\tau)|>1.96$.

RESULTS AND DISCUSSION

Mean Spatial Pattern of Dry (Wet) Spells

It can be seen that most of the stations located at the northwestern and the eastern areas of the peninsula have a slightly higher mean of the annual maximum of dry spells than at the other regions. Table 3 indicates that the mean of the annual maximum duration of dry days is found to vary from 13 to 30 days, whereas, for wet spells, Table 3 shows that the mean of the annual maximum duration of wet days varies from 10 to 24 days over the peninsula. It is remarkable that the S3 station can be classified as the driest station since all the dry spells indices at this station are higher than at the other stations. Without the S3 station, the mean and standard deviation of dry spells length are found to vary from 3 to 4 days and 2 to 5 days, respectively. For wet spells, the results indicate that the mean and standard deviation is slightly lower than the dry spells, which is found to vary from 2 to 4 days.

In this present study, the persistency of dry (wet) spells indicating the probability of dry (wet) occurrence on a given day is based on the previous event at most two consecutive dry (wet) days. The findings indicate that the persistency of three consecutive dry days is found higher than the persistency of two consecutive dry days as well as the probability of a dry day in all stations. This indication implies that the sequence of dry days tended to be a longer duration of consecutive dry days than the shorter period for the last 30 years. Similar findings are indicated for the persistency of wet spells. Furthermore, it can be seen that the mean of the frequency of short dry spells (1-4 days) over the eastern areas varied from 42 to 50 times which is slightly lower than at other regions. The highest mean of the frequency of short dry spells, 62 and 60 times, are observed in S3 and W1 stations, respectively. For the wet spells, two stations located in the southern areas, namely; S4 and S5, exhibit the highest mean of the frequency of short spells, 65 and 63 times, respectively. Moreover, the mean of the frequency of the medium dry and wet spells (5-9 days) is found varied from 6 to 11 times, whereas, for wet spells the chances of having the medium spells are slightly lower than the dry spells which varied from 3 to 11 times in the last 30 years. Over the study period, S3 station experienced having the most frequent long dry spells (at least 10 days) for 8 times, which is the highest mean frequency than at other stations. The rest of the stations which experienced having the longer dry spells for at least 10 days are found varied from 2 to 5 times. The chances of getting longer wet spells for at least 10 days is found slightly lower than the long dry spells, which varied from 1 to 4 times for the period of 1975 to 2004.

Trend of Dry (Wet) Spells

The trend of the individual stations in Table 4 indicated that the main characteristics of dry spells indices showed a slightly increased trend in most areas of the northwestern and southern areas, but a slightly decreased trend was observed over the eastern and the western areas of the peninsula. Meanwhile, a significant positive trend was found in almost all of the dry spells indices in most areas of the southern peninsula, except for the S5 station which was the only station located in the southern area which showed a decreasing trend in almost all the indices of dry spells. A decreasing trend in the persistency of dry spells is found over the western areas which resulted in a decreasing trend of the frequency of medium and long dry spells in these areas. Four out of the five stations over the western areas showed that the frequency of the medium dry spells (5 to 9 days) had significantly decreased to about 1 or 2 days or 10 to 20% per decade in the last 30 years.

The main characteristics of wet spells as shown in Table 4 indicated that a positive trend in the indices is found in most areas of the western and eastern part of the peninsula. Generally, a decreasing trend is observed in the indices of the main characteristics of wet spells in most stations over the southern and northwestern areas of the peninsula. It is observed that two stations which are located in the southern areas, namely; S3 and S4, show a decreasing trend in almost all the entire wet spells

Table 3: Descriptive summaries (mean±standard deviation) of the nine indices of the distribution of dry spells and wet spells over the four regions in Peninsular Malaysia

		Main characteristics			Persistency			Frequency of dry spells (times)		
Region	Code	MxD	MnD	SdD	P(D)	P(D|D)	P(D|DD)	SSD	MSD	LSD
Dry spells										
North west	N1	17.93±5.87	2.80±0.34	3.07±0.81	0.51±0.05	0.65±0.04	0.70±0.05	54.97±5.46	6.67±2.63	2.77±1.57
	N2	25.20±9.94	3.76±0.59	4.46±1.22	0.64±0.07	0.74±0.04	0.78±0.03	45.23±7.03	9.00±2.45	4.77±1.77
	N3	22.40±7.97	2.97±0.44	3.67±1.03	0.54±0.04	0.69±0.04	0.75±0.04	50.33±7.07	6.33±2.09	2.90±1.35
	N4	27.37±11.34	3.48±0.60	4.48±1.47	0.60±0.05	0.74±0.04	0.78±0.04	43.90±6.47	8.57±3.11	3.40±2.03
	N5	26.63±12.92	3.52±0.60	4.39±1.62	0.63±0.05	0.74±0.04	0.78±0.04	45.87±7.23	8.33±2.66	3.73±1.60
West	W1	12.40±3.53	2.38±0.31	2.17±0.51	0.45±0.04	0.57±0.05	0.62±0.07	60.87±7.26	6.90±2.64	1.37±0.96
	W2	17.83±5.81	3.24±0.61	3.39±0.93	0.54±0.09	0.68±0.05	0.72±0.06	48.73±11.98	8.73±3.06	3.40±1.94
	W3	15.90±4.79	2.79±0.35	2.78±0.64	0.53±0.05	0.64±0.05	0.68±0.05	57.33±7.27	9.17±2.48	2.33±1.45
	W4	13.73±4.47	2.52±0.28	2.53±0.71	0.43±0.07	0.60±0.05	0.66±0.07	53.53±9.08	6.27±2.65	1.80±1.37
	W5	17.87±6.12	3.03±0.37	3.20±0.72	0.56±0.06	0.67±0.04	0.71±0.04	54.20±5.37	8.70±2.69	3.27±1.51
South	S1	17.77±7.13	2.88±0.38	3.09±0.91	0.54±0.04	0.65±0.05	0.70±0.05	56.30±8.12	8.07±2.52	2.80±1.27
	S2	13.50±5.03	2.31±0.31	2.27±0.65	0.45±0.04	0.57±0.06	0.62±0.09	62.13±6.60	5.40±2.21	1.70±1.15
	S3	29.30±12.49	5.95±2.42	6.44±3.10	0.70±0.14	0.81±0.07	0.83±0.06	27.67±9.08	9.17±3.84	7.57±2.96
	S4	15.83±3.86	2.97±0.40	2.79±0.56	0.58±0.08	0.66±0.05	0.69±0.06	57.33±8.47	10.30±3.33	2.67±1.40
	S5	21.00±6.54	3.46±0.52	3.63±0.87	0.65±0.06	0.71±0.05	0.74±0.04	51.27±8.06	10.77±3.07	4.00±1.74
East	E1	22.73±9.28	3.51±0.61	4.04±1.32	0.60±0.04	0.71±0.05	0.74±0.05	49.30±9.35	8.93±2.60	4.07±1.70
	E2	20.40±8.94	3.45±0.61	3.74±1.12	0.53±0.10	0.70±0.05	0.74±0.04	43.97±11.65	8.77±3.18	3.57±1.41
	E3	18.73±6.83	2.75±0.46	3.29±1.19	0.44±0.06	0.63±0.07	0.70±0.06	49.77±6.78	6.57±2.54	2.13±1.14
	E4	25.00±11.15	3.84±0.72	4.64±1.73	0.58±0.06	0.73±0.05	0.77±0.05	41.73±8.14	9.10±2.73	4.40±1.43
	E5	20.47±7.53	3.34±0.62	3.74±1.09	0.56±0.05	0.69±0.05	0.74±0.05	48.73±8.30	8.77±2.34	3.80±1.85

		Main characteristics			Persistency			Frequency of wet spells (times)		
Region	Code	MxW	MnW	SdW	P(W)	P(W|W)	P(W|WW)	SSW	MSW	LSW
Wet spells										
North west	N1	12.37±4.11	2.73±0.26	2.35±0.47	0.49±0.05	0.63±0.03	0.65±0.04	54.03±4.58	9.03±2.43	1.73±1.46
	N2	10.33±8.77	2.23±0.63	1.98±1.54	0.36±0.07	0.53±0.09	0.57±0.10	54.40±7.74	4.53±2.19	0.57±1.22
	N3	12.13±3.53	2.79±0.36	2.38±0.51	0.46±0.04	0.64±0.04	0.66±0.04	50.17±7.38	8.60±2.50	1.50±1.28
	N4	11.07±3.94	2.60±0.34	2.18±0.59	0.40±0.05	0.61±0.05	0.63±0.07	48.33±6.21	7.07±2.03	1.10±1.30
	N5	9.57±2.90	2.30±0.29	1.86±0.43	0.37±0.05	0.56±0.06	0.58±0.06	52.23±5.78	5.90±2.52	0.53±0.73
West	W1	17.40±6.12	2.86±0.34	2.92±0.70	0.55±0.04	0.65±0.04	0.68±0.05	57.87±7.29	8.73±2.46	2.50±1.59
	W2	23.37±25.53	2.89±1.26	3.90±4.06	0.46±0.09	0.61±0.12	0.64±0.14	53.83±13.25	5.40±2.55	1.83±1.91
	W3	12.27±3.49	2.46±0.29	2.16±0.43	0.47±0.05	0.59±0.05	0.62±0.06	59.77±6.88	7.63±2.58	1.23±1.01
	W4	19.93±10.78	3.51±1.47	3.70±2.16	0.57±0.07	0.69±0.07	0.72±0.06	49.10±11.21	8.93±2.96	3.57±2.16
	W5	11.60±4.57	2.41±0.47	2.10±0.57	0.44±0.06	0.57±0.07	0.62±0.07	57.93±8.26	7.37±3.39	0.93±0.91

Table 3: Continued

Region	Code	Main characteristics			Persistency			Frequency of wet spells (times)		
		MxW	MnW	SdW	P(W)	P(W|W)	P(W|WW)	SSW	MSW	LSW
South	S1	11.50±7.69	2.49±0.46	2.15±1.27	0.46±0.04	0.59±0.06	0.60±0.07	59.60±8.67	6.93±2.38	0.87±1.17
	S2	13.43±3.85	2.87±0.25	2.50±0.40	0.55±0.04	0.65±0.03	0.67±0.04	57.10±5.74	10.37±2.98	1.97±1.25
	S3	13.47±9.87	2.42±1.11	2.56±2.02	0.30±0.14	0.53±0.15	0.57±0.19	40.63±10.16	2.60±2.30	1.50±2.05
	S4	11.37±8.06	2.18±0.62	1.98±1.23	0.42±0.08	0.51±0.13	0.55±0.14	64.53±10.36	5.00±3.13	0.90±1.09
	S5	10.00±5.77	1.91±0.30	1.66±0.73	0.35±0.06	0.47±0.07	0.53±0.09	62.67±7.10	3.27±1.55	0.57±1.04
East	E1	12.13±5.53	2.32±0.28	2.13±0.73	0.41±0.04	0.57±0.05	0.61±0.07	56.00±8.25	5.23±1.76	1.10±0.92
	E2	19.37±19.70	3.67±4.09	3.97±5.56	0.47±0.10	0.65±0.09	0.69±0.10	47.33±13.73	6.60±2.46	2.27±2.13
	E3	18.30±5.55	3.39±0.49	3.37±0.65	0.56±0.06	0.71±0.04	0.73±0.03	44.77±6.90	10.00±2.96	3.27±1.55
	E4	16.20±7.62	2.76±0.51	2.96±1.16	0.42±0.06	0.64±0.06	0.68±0.07	46.67±7.36	6.37±2.74	2.03±1.30
	E5	14.27±4.52	2.60±0.29	2.52±0.55	0.44±0.05	0.61±0.05	0.65±0.05	52.90±7.15	6.50±2.27	1.73±1.23

Table 4: Linear trend per decade (LT) for each of the dry spells and wet spells indices over the period 1975 to 2004

Region	Code	Main characteristics						Persistency						Frequency					
		MxD		MnD		SdD		P(D)		P(D|D)		P(D|DD)		SSD		MSD		LSD	
		LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Dry spells																			
North west	N1	-1.33	D	0.03	I	-0.06	D	-0.01	D	0.01	I	-0.01	D	-1.17	D	0.18	I	0.44	I
	N2	-2.77	D	0.19	I	-0.02	D	0.06	I	0.03	I	0.03	I	-1.83	D	-0.32	D	1.29	SI
	N3	0.80	I	0.03	I	0.15	I	-0.02	D	-0.02	SD	-0.01	D	-0.27	D	-0.36	D	0.44	I
	N4	2.28	I	-0.01	D	0.23	I	-0.07	SD	-0.04	D	-0.04	D	0.52	I	-0.23	D	-0.12	D
	N5	-3.39	D	0.06	I	-0.32	D	0.09	I	0.03	I	0.00	NT	0.22	I	0.31	I	0.41	I
West	W1	0.62	I	-0.07	D	-0.02	D	-0.07	SD	-0.06	D	-0.04	D	-0.48	D	-0.84	SD	-0.02	SD
	W2	-1.23	D	-0.10	D	-0.21	D	-0.07	D	-0.05	D	-0.06	D	0.57	I	-0.91	SD	-0.27	SD
	W3	-0.56	D	-0.13	D	-0.11	D	-0.07	SD	-0.07	SD	-0.08	SD	0.76	I	-1.63	SD	-0.02	D
	W4	1.15	I	-0.03	D	0.08	I	-0.16	D	-0.01	D	0.00	NT	-5.25	SD	-1.33	SD	0.06	I
	W5	-2.67	SD	-0.21	SD	-0.36	SD	-0.18	SD	-0.11	SD	-0.07	D	-0.12	D	-0.10	D	-0.58	SD
South	S1	1.23	I	0.08	I	0.26	I	-0.02	D	0.06	I	0.10	I	-2.86	D	-0.07	D	0.16	I
	S2	-0.13	D	0.04	I	0.02	I	0.01	I	0.03	I	0.01	I	-0.91	D	0.52	I	0.00	NT
	S3	6.07	SI	1.38	SI	1.68	SI	0.33	SI	0.26	SI	0.26	SI	-6.11	SD	-1.19	D	1.28	I
	S4	0.29	I	0.24	SI	0.20	I	0.27	SI	0.15	SI	0.12	I	0.59	I	1.74	I	0.75	I
	S5	-1.96	D	-0.28	SD	-0.34	D	-0.17	SD	-0.14	SD	-0.11	SD	2.78	I	-1.21	SD	-0.36	SD

Table 4: Continued

		Main characteristics						Persistency						Frequency					
		MxD		MnD		SdD		P(D)		$P(D \mid D)$		$P(D \mid DD)$		SSD		MSD		LSD	
Region	Code	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
East	E1	-0.23	D	0.06	I	0.08	I	0.00	NT	0.01	I	-0.01	D	-0.60	D	0.28	I	0.01	I
	E2	-1.52	D	-0.18	D	-0.16	D	0.12	I	-0.06	D	-0.04	D	4.39	I	-0.13	D	0.04	I
	E3	-2.48	SD	-0.17	D	-0.41	D	-0.06	SD	-0.11	SD	-0.12	SD	2.39	I	-0.08	D	-0.35	SD
	E4	-0.67	D	0.05	I	-0.05	D	-0.02	D	0.01	I	0.00	NT	-0.78	D	-0.36	D	-0.08	D
	E5	-0.56	D	-0.01	D	-0.15	D	-0.02	D	0.00	NT	-0.02	D	-0.67	D	0.57	I	-0.20	SD

		Main characteristics						Persistency						Frequency					
		MxW		MnW		SdW		P(W)		$P(W \mid W)$		$P(W \mid WW)$		SSW		MSW		LSW	
Region	Code	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Wet spells																			
North west	N1	0.34	I	0.04	I	0.06	I	0.01	I	0.03	I	0.05	I	-0.80	D	-0.03	D	0.00	NT
	N2	-2.79	SD	-0.11	D	-0.39	D	-0.06	D	-0.05	D	-0.05	D	-0.71	D	0.75	I	-0.46	SD
	N3	0.08	I	0.04	I	-0.03	D	0.02	I	0.01	I	-0.02	D	-0.16	D	0.14	I	0.14	I
	N4	1.94	SI	0.10	I	0.27	SI	0.07	I	0.05	I	0.12	I	-0.72	D	0.31	I	0.55	I
	N5	-0.73	D	-0.16	SD	-0.13	D	-0.09	D	-0.12	SD	-0.07	D	1.47	I	-0.73	SD	-0.26	SD
West	W1	1.94	I	0.12	I	0.26	I	0.07	I	0.07	I	0.05	I	-0.83	D	-0.22	D	0.52	I
	W2	-7.50	D	0.03	I	-0.80	D	0.07	I	0.07	I	0.03	I	-1.41	D	1.33	I	0.30	I
	W3	0.36	I	0.05	I	0.04	I	0.07	I	0.04	I	0.00	NT	0.00	NT	0.55	I	0.05	I
	W4	4.05	I	0.71	SI	1.04	I	0.16	I	0.20	SI	0.24	SI	-6.03	SD	-0.41	D	1.28	I
	W5	1.39	SI	0.30	SI	0.32	SI	0.18	SI	0.19	SI	0.18	SI	-3.08	D	1.52	I	0.72	I
South	S1	3.38	I	0.16	I	0.58	I	0.02	I	0.09	I	0.17	SI	-3.42	SD	0.03	I	0.53	I
	S2	-1.49	SD	0.04	I	-0.04	D	-0.01	D	0.02	I	0.04	I	-1.86	SD	1.07	I	-0.07	D
	S3	-3.88	SD	-0.23	D	-0.57	D	-0.33	SD	-0.19	D	-0.38	SD	-3.03	D	-1.07	SD	-0.56	SD
	S4	-0.58	SD	-0.32	SD	-0.22	SD	-0.27	SD	-0.38	SD	-0.40	SD	4.55	SI	-2.75	SD	-0.44	SD
	S5	1.08	I	0.16	SI	0.22	I	0.17	SI	0.14	I	0.04	I	1.66	I	0.41	I	0.37	SD
East	E1	0.98	I	0.03	I	0.15	I	0.00	NT	0.02	I	0.05	I	-0.35	D	-0.60	SD	0.33	I
	E2	-7.01	D	-1.31	D	-1.91	D	-0.12	D	-0.21	D	-0.16	D	4.07	I	0.34	I	-0.02	D
	E3	0.52	I	-0.03	D	0.05	I	0.06	I	-0.01	D	-0.03	D	1.66	I	-0.23	D	0.37	I
	E4	1.01	I	0.08	I	0.23	I	0.02	I	0.04	I	0.10	I	-1.28	D	-0.36	D	0.70	I
	E5	0.92	I	0.05	I	0.15	I	0.02	I	0.03	I	0.08	I	-1.16	D	0.61	I	-0.07	SD

The Mann-Kendall (MK) trend test results are indicated as NT for no trend, I for non-significant increased trend, SI for significant increased trend, D for non-significant decreased trend and SD for significant decreased trend at 5% level

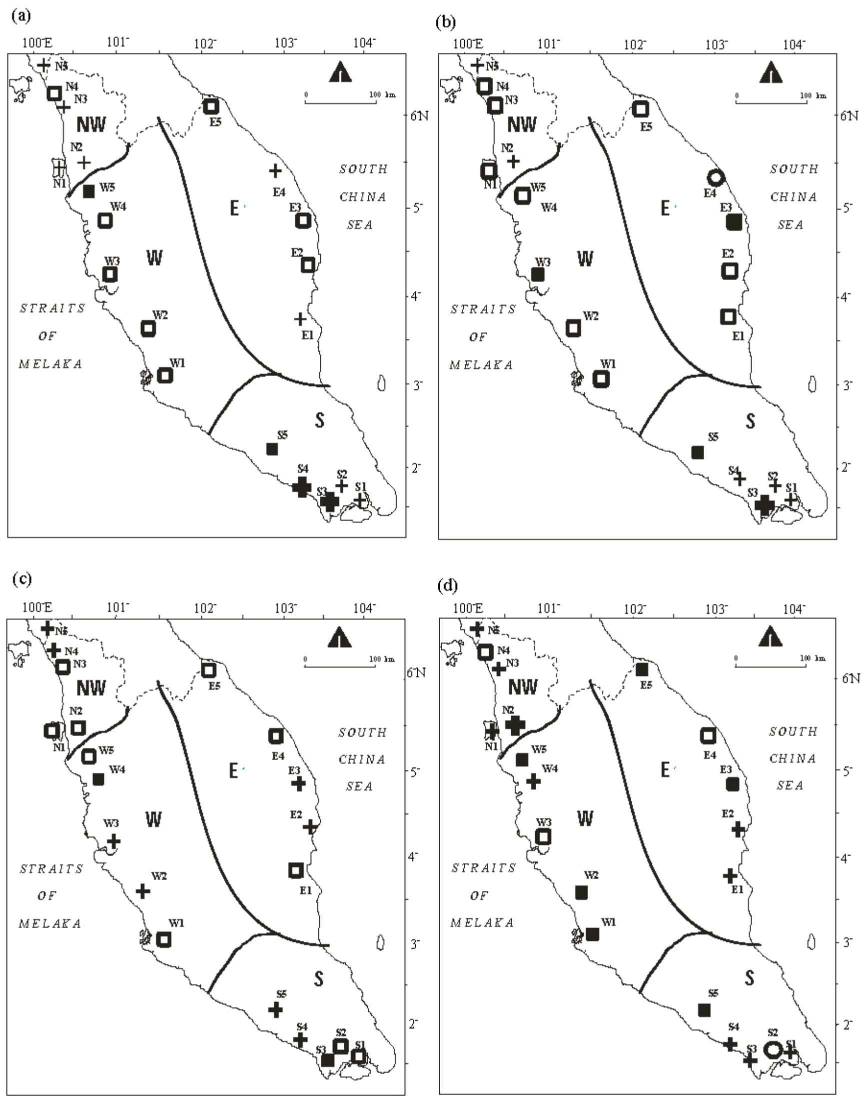

Fig. 2: The trend of the dry spells indices, a) the mean (MnD), b) the persistency (P(D|DD), the frequency of c) short spells (SSD) and d) long spells (LSD). (✚) significant positive trend, (+) positive trend, (■) significant negative trend, (□) negative trend and (○) no trend

indices. However, it is interesting to note that the frequency of short wet spells in S4 station exhibits a significant positive trend at the rate of 4.55 or 55% per decade, while the rest of wet spells indices in this station have shown a negative trend for the last 30 years.

In order to further investigate the effects of the trend of the persistency of dry (wet) events to the trend of the frequency of short and long dry (wet) spells, Fig. 2 and 3 shows these four indices for dry and wet spells for each of the stations, respectively, over the peninsula. Notice that the mean and the persistency of the dry spells exhibits negative trends, whereas for the wet spells the positive trends

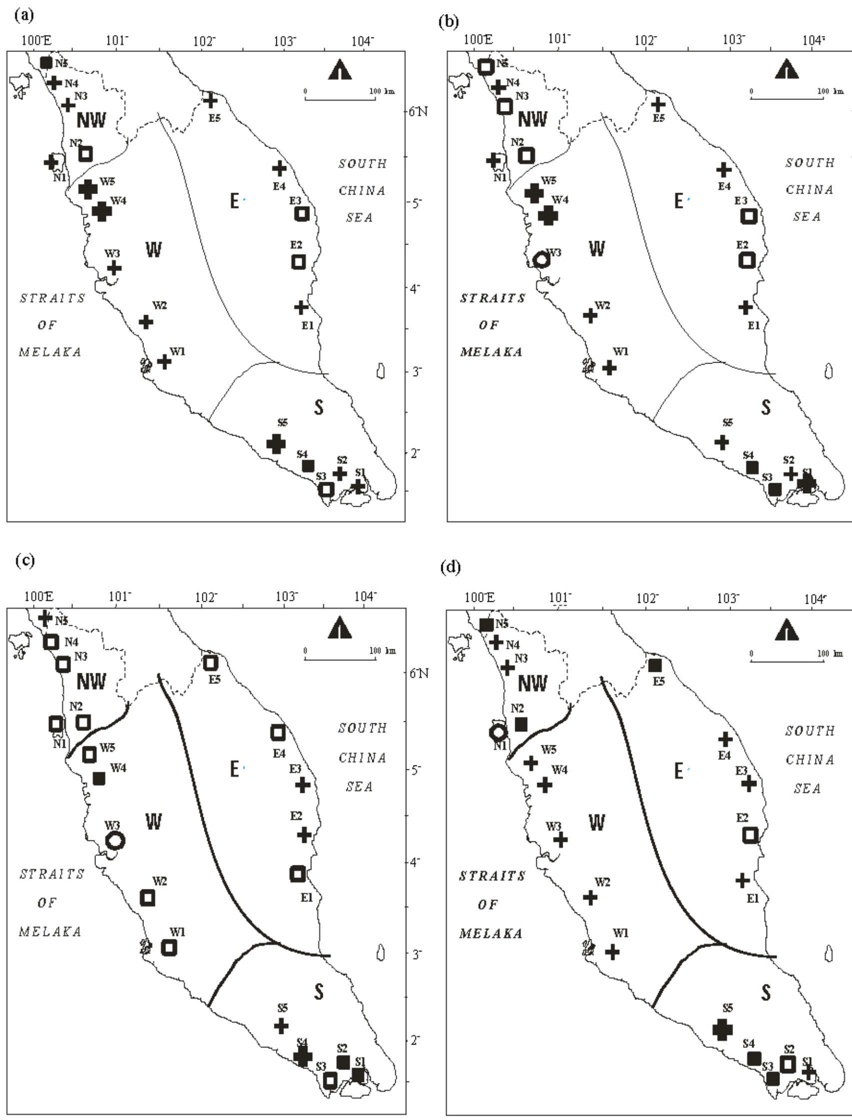

Fig. 3: The trend of the wet spells indices, a) the mean (MnW), b) the persistency (P(W|WW), the frequency of c) short spells (SSW) and d) long spells (LSW). (✚) significant positive trend, (+) positive trend, (■) significant negative trend, (□) negative trend and (○) no trend

is observed in most stations over the peninsula. Meanwhile, the frequency of long dry and wet spells indicated almost the same pattern, where a more increasing trend is observed in the frequency of long wet spells rather than in the frequency of long dry spells. On the contrary, the frequency of short wet and dry spells indicate a negative trend in most of the stations. It can be seen clearly here in Fig. 3 that as the mean and the persistency of wet spells increased, the frequency of long wet spells also increased, while a decreasing trend is observed in the frequency of short wet spells over the western areas of the peninsula.

Table 5: Linear trend per decade (LT) for annual regional means of the nine indices of the distribution of dry and wet spells over the four regions in Peninsular Malaysia

	Main characteristics						Persistency						Frequency					
	MxD		MnD		SdD		P(D)		P(D|D)		P(D|DD)		SSD		MSD		LSD	
Region	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Dry spells																		
North west	-0.88	D	0.05	I	-0.01	D	0.01	I	0.00	NT	0.02	I	-0.51	D	-0.09	D	0.49	I
West	-0.54	D	-0.10	SD	-0.12	D	-0.11	SD	-0.06	SD	-0.04	SD	-0.91	D	-0.96	SD	-0.17	D
South	1.10	I	0.28	SI	0.36	SI	0.09	I	0.07	I	0.08	I	-1.30	D	-0.04	D	0.37	I
East	-1.09	D	-0.05	D	-0.14	D	-0.01	D	-0.04	D	-0.04	D	0.95	I	0.06	I	-0.12	D
	Main characteristics						Persistency						Frequency					
	MxW		MnW		SdW		P(W)		P(W|W)		P(W|WW)		SSW		MSW		LSW	
Region	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Wet spells																		
North west	-0.23	D	0.00	I	-0.04	D	-0.01	D	-0.02	SD	0.00	NT	-0.18	D	0.09	I	-0.01	D
West	0.05	I	0.24	I	0.17	I	0.11	I	0.12	I	0.10	I	-2.27	SD	0.55	I	0.57	I
South	-0.30	D	-0.02	SD	0.00	NT	-0.09	SD	-0.06	SD	-0.10	SD	-0.42	D	-0.46	D	-0.03	D
East	-0.72	D	-0.22	D	-0.28	D	0.01	I	-0.02	D	0.01	I	0.59	I	-0.05	D	0.26	I

The Mann-Kendall (MK) trend test results are indicated as NT for no trend, I for non-significant increased trend, SI for significant increased trend, D for non-significant decreased trend and SD for significant decreased trend at 5% level

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Regional Trend of Dry (Wet) Spells

The results of the regional trends in Table 5 showed that no significant trend in the maximum number of consecutive dry (wet) days for both dry and wet spells is found over Peninsular Malaysia. In most cases, the findings of this present study revealed that the significant trends in the indices of dry (wet) spells are observed more frequently in the western and the southern areas than at the other regions. All the indices of dry spells as shown in Table 5 exhibited a decreasing trend and a significant negative trend is found in the mean dry spells, the persistency and the frequency of medium spells are observed, over the western peninsula. Meanwhile, for the wet spells, Table 5 showed that a positive trend was found in all the indices except the frequency of short wet spells in these areas. It can be seen that as the persistency of wet spells increased at the rate of 0.1 or 15% per decade, the frequency of long wet spells also showed an increasing trend at the rate of 0.58 day or 29% per decade; however, a significant negative trend at the rate of 2.27 or 4% per decade was found in the frequency of short wet spells over the western areas.

Regardless of the frequency of medium and short spells, all the indices for the regional means of dry spells as shown in Table 5, indicated an increasing trend with the mean (0.28 day or 8% per decade) and the variability (0.36 day or 10% per decade) of dry spells over the southern areas. It is observed that as the mean, variability and the persistency increased, the frequency of long dry spells also increased, while the frequency of short dry spells showed a decreasing trend over the southern areas. For the wet spells, Table 5 indicates that a decreasing trend is observed over the southern areas, while the western and the eastern areas show an increasing trend in almost all the indices. The findings of this present study seem to be in agreement with (Monton *et al*., 2001; Brunneti *et al*., 2004) who both reported that the trend of the number of wet days significantly decreased over Southeast Asia and Italy.

CONCLUSION

Tracing changes in the trend of both dry and wet spells characteristics as well as the persistency will provide useful information in predicting future climate events since these variables are closely related to extreme weather events such as droughts and floods. The findings of this present study indicated that most of the stations located at the northwestern and the eastern areas of the peninsula had a slightly higher mean of the annual maximum of dry spells than at the other regions. The findings are in agreement with the results of Deni *et al*. (2008) who found that dry spells were largely dependent on latitude and were longer and more frequent in the northern areas than in the southern areas. Moreover, it could be seen that the main characteristics of dry spells showed decreasing trends in most stations located in the western and eastern areas, but a slightly increasing trend was observed over the southern and northwestern areas of the peninsula. Meanwhile, a positive trend in the main characteristics of wet spells was found in most stations over western and eastern areas of the peninsula, except in the E2 stations which consistently showed a negative trend during the period of study.

Moreover, as the persistency of wet days increased, the trend of the frequency of long wet spells was also found to be increased in most stations over the peninsula, while a decreasing trend was observed in the frequency of short spells in those stations. On the contrary, the persistency of dry days showed a decreasing trend over many stations in the peninsula except at the four stations located in the southern areas. Due to the decreasing trends in the persistency of dry days, the trend of the frequency of long dry spells is also expected to decrease in these stations.

Finally, it can be concluded that in the southern areas, the frequency of long dry periods tended to be higher with a significant increase in the mean and variability of the length of the dry spells. However, for the western areas it could be seen that all the indices of dry spells exhibited a negative trend. For the wet spells, the frequency of short spells showed a significant negative trend with an increase in the mean, variability and the persistency of the wet spells over the western areas. Generally, no significant trends were found in most of the indices of dry (wet) spells in most stations over the northwestern and eastern areas for the period of 1975 to 2004. Manton *et al*. (2001) studied seven rainfall stations in Malaysia for the period of 1950s and 1960s to 1998, where three out of the seven stations were located in the Peninsular Malaysia. They reported that the number of wet days indicated a significant negative trend at all the stations except at that in Kuching. However, in this present study the trend of the probability of wet days was slightly opposed to the one of Manton *et al*. (2001) where the number of wet days significantly decreased over Malaysia except at the Kuching station. This discrepancy may be due to the fact that quite different periods were used in the two stations.

Future studies should address trace changes in the trend of other indices in the rainfall characteristics such as the precipitation amount and also the extreme rainfall events which include more regions over the peninsula. Further research is also suggested in detecting the trends on various rainfall indices during the monsoon seasons and the inter-monsoon period.

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