Research Article

Recent Trends in Temperature and Precipitation in the Langat River Basin, Malaysia

Mahdi Amirabadizadeh,¹ Yuk Feng Huang,² and Teang Shui Lee¹

¹*Faculty of Engineering, Universiti Putra Malaysia, 43300 Serdang, Selangor, Malaysia*

²*Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, 53300 Kuala Lumpur, Malaysia*

Correspondence should be addressed to Mahdi Amirabadizadeh; mamir692@gmail.com

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A study was undertaken to detect long-term trends in the annual and seasonal series of maximum and minimum temperatures. Measurements were taken at 11 meteorological stations located in the Langat River Basin in Malaysia. The rainfall and maximum and minimum temperature data were obtained from the Malaysia Meteorological Department (MMD) and the Department of Irrigation and Drainage (DID) Malaysia. The procedures used included the Mann-Kendall test, the Mann-Kendall rank statistic test, and the Theil-Sen's slope method. The analytical results indicated that when there were increasing and decreasing trends in the annual and seasonal precipitation and temperature, only the increasing trends were significant at the 95% confidence level. The Theil-Sen's slope method showed that the rate of increment in the annual precipitation is greater than the seasonal precipitation. A bootstrap technique was applied to explore uncertainty about significant slope values for rainfall, as well as the maximum and minimum temperatures. The Mann-Kendall rank statistics test indicated that most of the trends in the annual and seasonal time series started in the year 2000. All of the annual and seasonal significant trends were obtained at the stations located in the north, east, and northeast portions of the Langat River Basin.

1. Introduction

Quantitatively speaking, climate change refers to the statistically significant variations of the mean state of the climate or that of its variability for decades or even over a longer period [1]. Although climate change happens globally, its effects, however, can be deterministic, dependent on the region of study. Temperature and precipitation variables are the most important measures that indicate the signs of climate change. The Intergovernmental Panel on Climate Change (IPCC) AR4 specified that the average global surface temperature has increased by 0.074°C per year from 1906 to 2000 [2]. Furthermore, the IPCC AR5 report indicated that increases in mean temperature will continue for the 2016–2035 period [1]. The reports from IPCC also indicated that the frequency of extreme rainfall events have increased over most land areas, consistent with growing temperatures and atmospheric water vapour [3]. An analysis of the long-term changes in climate variables is very crucial for water resource planning

and management, as well as to put things into their proper perspective and context [4].

Many trend analyses have been carried out on climate variables, especially with temperature and precipitation. Many of researchers applied the nonparametric Mann-Kendall method in the detection of trend in hydrologic variables [5, 6]. The Mann-Kendall rank statistics test and Theil-Sen's slope method are other methods that are widely used to declare trends and magnitude changes in the climate variables in annual and seasonal time scales [7, 8].

The comparison between the trend detection methods is the main subject of many studies. Yue et al. [9] compared the power of the Mann-Kendall and Spearman tests for detecting the monotonic trend in time series. They stated that the power of the test depends on the slope of trend, level of significance, sample size, and properties of the datasets, such as skewness and variation. The test results also demonstrated that both of the tests provided the same consequences in the absence of autocorrelation.

FIGURE 1: Geographic location and spatial distribution of stations in the Langat River Basin.

While there were interests in the examination of the existence of trends for many climatic variables in Malaysia, a limited number of studies have been done in this country. Meng et al. [10] investigated the trend of regional warming in Malaysia using a mean annual temperature time series of approximately 50 years. Their findings showed complete agreement with the temperature increments reported by the IPCC for Malaysia, which are 0.99 to 3.44°C per 100 years. Tangang et al. [11] applied the Mann-Kendall test for 32 stations over whole peninsula of Malaysia for the period of 1974–2004. The MK test for mean, variability, and persistence of wet spells revealed positive and negative trends in the stations east of the peninsula during the northeast monsoon and southwest monsoon seasons, respectively. They also concluded that there is a wide gap in the knowledge of climate change throughout Malaysia.

Suhaila et al. [12] investigated the existing trends in daily rainfall in peninsular Malaysia based on seasonal rainfall during 1975–2004. The results of the Mann-Kendall test indicated a decreasing trend in the total amount of rainfall and frequency of wet days, as well as the increasing trend in rainfall intensity during the southwest monsoon. On the contrary, the results of the test showed reverse trends in the parameters for northeast monsoon flow.

The comparison associated with preceding studies in climate change in Malaysia indicated that there is a gap in many climate parameters such as maximum temperature, minimum temperature, and annual precipitation—one of the most important factor. Furthermore the beginning of trend is actually another concern that was not addressed in the past researches.

In this study, we analysed and examined the signs of change in the annual precipitation, as well as the maximum and minimum temperature regime, specific to Langat River Basin (a strategic basin), located in Malaysia (Figure 1). The Langat River Basin is the most urbanised river basin in Malaysia, located in the southern part of Klang Valley. During the last decade, this watershed has experienced rapid development in urbanisation, agriculture, and industrialisation. This watershed supplies water to two-thirds of the state of Selangor for its domestic, hydroelectric plant, industry, and agricultural consumption. As Selangor State is currently facing a water shortage problem, especially during the southwest monsoon season, analysing the trends of rainfall and the maximum and minimum temperatures is a vital activity in management of the water resources for the future. The objectives of this research were achieved using the Mann-Kendall and Mann-Kendal rank statistic methods. The rates of changes in these variables were then determined using the Theil-Sen's slope method.

2. Materials and Methods

2.1. Study Area. The total area of the Langat River Basin is approximately 2352 km². It lies between latitudes 2°40'15" to 3°16'15" N and longitudes 101°17'20" to 101°55'10" E in the southern part of the Klang Valley region. The northern part of the basin is a mountainous area, while its southern part consists of a flat area. The mean areal annual rainfall of the Langat River Basin is 1994.1 mm. The highest recorded monthly rainfall is about 327.1 mm, occurring in November, while the lowest is 97.6 mm in June. These two maximum and

TABLE 1: Geographic characteristics of stations for recorded precipitation data.

Station ID	Number	Longitude (E)	Latitude (N)	Altitude (m)	Period
2815001	1	101° 32'	2° 49'	3	1971–2011
2818110	2	101° 52'	2° 53'	36	1971–2011
2917001	3	101° 47'	2° 59'	39	1976–2011
3118102	4	101° 52'	3° 10'	91	1971–2011
2913001	5	101° 23'	2° 55'	3	1974–2011
2719001	6	101° 56'	2° 45'	93	1971–2011
44256	7	101° 30'	2° 49'	8	1974–2011
45241	8	101° 56'	2° 43'	64.1	1974–2011
Ampangan	9	101° 53'	3° 13'	233.3	1985–2011
Hospital Seremban	10	101° 56' 37"	2° 42' 33"	64.1	1971–2011
Petaling Jaya	11	101° 39'	3° 6'	60.8	1974–2011

minimum precipitations occurred in the northeast monsoon and the southwest monsoon periods, respectively.

Besides global warming, the climate of Malaysia is associated with many global and regional phenomena, such as monsoons, El Nino/La Nina, and the Indian Ocean Dipole (IOD). These phenomena could affect the severity of extreme events in the country. Scientists state that global warming will directly affect systems, such as hydrological cycles, and extreme events, such as El Nino/La Nina [13].

In the seasonal time scale, the surface climate in Malaysia is affected by two monsoon regimes, namely, the southwest (SW) monsoon and northeast (NE) monsoon patterns. The SW monsoon season that is dominated by the low level southwesterly winds begins in May and lasts through August. On the other hand, the NE monsoon season that is controlled by the northeast wind commences in November and ends in February of the following year [14].

The recorded data for rainfall (subdaily measurements) and maximum and minimum temperature (daily measurements) were obtained from the Malaysia Meteorological Department (MMD) and Department of Irrigation and Drainage (DID). The daily data for precipitation was extracted from subdaily data at each station. The series of annual and monsoon seasonal recorded data, which included the maximum temperature (T_{Max}), the minimum temperature (T_{Min}), and total precipitation (P), were analysed for the existence of monotonic trends.

The seasonal and annual values of T_{Max} and T_{Min} were computed as the average values over the season and year, respectively. The study periods were matched to all the available records at each station, which varied between 27 and 41 years. The recorded daily data were available at three temperature stations and eight precipitation stations. Monthly values were averaged to obtain the NE monsoon (winter) and SW monsoon (summer) temperature for each of the three stations. Spatial distribution and geographic characteristics of the precipitation and temperature stations are shown in Figure 1 and Table 1, respectively.

These stations were chosen as the database due to the good quality datasets, suitable length (close to 30 years) of data recorded, which is considered to be long enough for studying the changes in climate, and good spatiality

distribution in the mountainous and flat regions to cover the whole area of the river basin.

In the analysis of climate variables, it is primarily important to investigate the quality of the recorded climatic data, such as looking for missing values, analysing the outliers, and also administering the consistency test. In the case of missing observations, the daily missed values were repaired using the Ameliaview1.1 package in R software [15], which is based on the bootstrap method. Also, for the longer missed observations, the recorded values in neighbouring stations that had high correlations were used to complete the temperature and precipitation time series.

Outliers in the data sets can lead to false trend results and inaccurate statistical properties [16]. Bremer [17] found that the interquartile ratio (IQR) method reduces biases in the dataset caused by outliers, while also keeping the information for extreme events as well. In the IQR method, the higher and lower thresholds are described by $Q75\% + 5 \cdot \text{IQR}$ and $Q25\% - 5 \cdot \text{IQR}$, respectively [18]. Then, each value greater or smaller than the higher and lower bands, respectively, is set as an outlier and eliminated from the data sets.

The homogeneity of the time series has been investigated by many researchers [19]. In this study, the double-mass curve procedure [20] was applied to test the consistency of climate variables. The double-mass curve method is a graphical procedure to identify the inconsistency of station records by comparing the time trend in one station with other relatively stable records at other stations or the average of several nearby stations [6]. Results of the double mass-curves for all of the stations are straight lines, and no apparent breakpoints are detected in the time series.

The mean value of precipitation (P) at the observed stations varied between 1658.3 in Station 1 and 2351.6 mm in Station 8, which are located in the flat and mountainous areas, respectively. This pattern was repeated for the mean of the seasonal precipitation in the SW monsoon and NE monsoon seasons. This is shown in Table 2 and Figure 2.

As shown in Figure 2, the ranges of variation at Stations 9 and 11 are the smallest and greatest values in the temperature time series, respectively. These differences in T_{Max} and T_{Min} between stations were more related to the land use and altitude of gauging stations. Station 9, located in forest and

TABLE 2: Statistical properties of annual and seasonal rainfall and temperature in the Langat River Basin.

Station	Variable	Annual			Seasonal					
		Mean	S.D.	Skew	Mean	S.D.	Skew	Mean	S.D.	Skew
1	Precipitation	1658.3	304.9	-0.14	583.5	182.37	0.03	468.8	143.64	0.06
2		1883.8	366.3	0.35	594.5	181.72	0.73	517.5	144.83	0.68
3		2191.2	417.3	-0.31	773.3	245.15	0.13	562.8	175.61	0.15
4		2128.7	379.5	0.36	662.1	198.53	-0.14	638.0	178.20	0.39
5		1750.3	396.6	-0.16	687.9	219.40	0.45	460.4	122.03	0.68
6		1951.9	363.1	0.01	620.5	188.53	0.24	539.7	141.00	0.1
7		1965.6	470.9	2.43	677.2	206.92	1.35	606.7	188.01	1.45
8		2351.6	345.4	-0.38	786.1	224.75	-0.09	648.6	140.17	0.58
9	T_{Max}	31.7	0.46	0.07	31.1	0.62	-0.08	32.0	0.42	0.67
	T_{Min}	21.6	0.47	-0.88	21.5	0.44	-0.79	21.7	0.50	-1.23
10	T_{Max}	31.9	0.36	0.48	31.9	0.54	0.61	31.8	0.28	0.52
	T_{Min}	23.5	0.55	-0.18	23.4	0.58	-1.08	23.6	0.55	-0.08
11	T_{Max}	32.8	0.42	0.04	32.4	0.66	0.49	32.9	0.4	0.13
	T_{Min}	24.0	0.57	0.31	23.7	0.61	0.27	24.2	0.58	0.23

mountainous regions, demonstrated less variation in the maximum and minimum temperatures than did the two other stations near the urban area and lower altitudes. The 5-year moving average indicated an approximate monotonic increasing trend for the annual maximum temperature in Station 9 and the annual minimum temperature in Stations 10 and 11.

As shown in Figure 3(b), the stations that are located north and east of the Langat River Basin receive more rainfall than do those stations west of the basin during the study period. These results are consistent with those obtained by Deni et al. [21]. The mean annual T_{Max} and T_{Min} range from 31.6 to 33°C and 21.6 to 24.2°C respectively.

2.2. Trend Analysis. There are two main ways to declare the significant trends in the climatic data sets: parametric and nonparametric trend methods. In the parametric trend analysis, data should be independent and normally distributed, while in the nonparametric method, the only requirement is to be independent. In this study, the nonparametric Mann-Kendall was used for the detection of significant trends, the Mann-Kendall rank statistic test was used for determining the beginning of trend, and the Theil-Sen's slope procedure was applied to measure the quantity of change in the climatologic time series.

2.2.1. Mann-Kendal Test. The Mann-Kendall (MK) test is a robust method of detecting a monotonic trend in hydroclimatic data. The MK method is a rank-based procedure, with a strength being the application in skewed data. Another suitable property of this test is that it has a low sensitivity to abrupt breaks, which may be caused by inhomogeneous data.

For an observed time series $x = x_1, x_2, x_n$, the trend test statistic S is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{Sgn}(x_j - x_i), \quad (1)$$

FIGURE 2: Annual maximum and minimum temperatures and their 5-year moving average in the Langat River Basin.

where

$$\text{Sgn}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0. \end{cases} \quad (2)$$

And i and j are the rank of observation of the x_i, x_j of time series.

FIGURE 3: Spatial characteristics of the Langat River Basin include (a) land use map, (b) annual precipitation, (c) minimum temperature, and (d) maximum temperature.

The variance is computed as

$$V = \frac{n(n-1)(2n+5)}{18} - \sum_{i=1}^g \frac{t_i(t_i-1)(2t_i+5)}{18}, \quad (3)$$

where g is the number of groups of tied rank and t_i is number of ties in group i . For a sample size of 30 or larger, the S statistic is normally distributed and the value of the standard deviation is computed by

$$Z = \begin{cases} \frac{s-1}{\sqrt{0.5}} & S > 0 \\ 0 & S = 0 \\ \frac{s+1}{\sqrt{0.5}} & S < 0. \end{cases} \quad (4)$$

When $|Z| > Z_{1-\alpha/2}$ or the P value is smaller than the significance level (α), the null hypothesis is rejected and there is a significance trend in the time series. The $Z_{1-\alpha/2}$ and P value are obtained from the standard normal distribution table. In this study, the significance level is $\alpha = 0.05$ and therefore the null hypothesis of no trend is rejected while $|Z| > 1.96$.

The MK test analysis technique was widely used in detecting trends in climate variables [5, 8, 22–26]. The prewhitening procedure was carried out before completing the MK test to eliminate the influence of autocorrelation on the results of the test. The prewhitening procedure is described in Section 2.3.

2.2.2. Mann-Kendall Rank Statistic Test. According to Sneyers [27], the Mann-Kendall rank statistic (MKRS) test is used to determine the approximate beginning year of significant trends (e.g., [6, 14, 28]). Two sequential values, U_t and U'_t , are determined from progressive and backward time series, respectively. This method uses relative values of each element in the time series ($x_1, x_2, \dots, x_n$). The following steps are utilised in four sequences.

- (1) The magnitudes of x_i annual or seasonal time series ($i = 1, \dots, n$) are compared with x_j ($j = 1, \dots, i-1$). At each comparison, the number of cases $x_i > x_j$ is counted and indicated by n_i .
- (2) The test statistic t_i variable is computed using

$$t_i = \sum_{j=1}^i n_j. \quad (5)$$

- (3) As the t_i distribution is asymptotically normal, the mean and variance of t_i are calculated as follows:

$$E(t) = \frac{n(n-1)}{4}, \quad (6)$$

$$\text{Var}(t_i) = \frac{1}{72} [i(i-1)(2j+5)].$$

- (4) Finally, the sequential values of the U_t are computed by

$$U_t = \frac{t_i - E(t)}{\sqrt{\text{Var}(t_i)}}. \quad (7)$$

Similarly, these four steps are followed to compute the U'_t in backward direction, from the end of the time series. If the time series of U_t and U'_t intersect each other and at least one of them is greater than a chosen level of significance, then there is a statistically significant trend. The point where the U_t and U'_t cross each other indicates the approximate beginning year of a developing trend within the time series. In this study, as the level of significance $\alpha = 0.05$, then the absolute values of calculating U_t and U'_t are compared with the Gaussian distribution value 1.96.

2.2.3. Theil-Sen's Slope Method. The Theil-Sen's slope method [29] is used to estimate the rate of change the rate of change:

$$\beta = \text{Median} \left(\frac{x_j - x_i}{j - i} \right) \quad i < j, \quad (8)$$

where x_j and x_i are the data values in times j and i , respectively. The β sign represents the direction of change and its value indicates the steepness of change [7, 25]. According to Yue et al. [9], the slope estimated by Theil-Sen's slope (TSS) estimator is a robust estimation of the magnitude of the trend. In order to determine the magnitude of TSS, an algorithm in R programme that corresponds to an extension of original TSS test was applied. This technique is frequently used in determining the slope of trend in climate variable time series (e.g., [5, 30–33]).

2.3. Influence of Serial Correlation. In time series analysis, it is essential that the data sets used for trend analysis be free of serial correlation in the time series. von Storch and Navarra [34] found that the presence of serial correlation in the time series can complicate the results of the identification of the trend detection for the Mann-Kendall test since the positive first-order autocorrelation can increase the expected number of false positive outcomes. In this study, the trend-free prewhitening (TFPW) approach that was modified by Burn et al. [35] was used prior to the application of the Mann-Kendall and Theil-Sen's slope procedures to remove the significant serial correlation from the time series. This procedure can be followed in five steps.

- (1) Compute the TSS, β , using (8).
- (2) Remove the monotonic trend from the original data sets using

$$Y_t = X_t - \beta t, \quad (9)$$

where X_t is the time series value at time t and Y_t is the detrended series.

- (3) Compute r_1 , the lag-1 serial correlation of the new series. If the value of r_1 is not statistically significant at the 5% level, the estimated β is accepted. Otherwise, the detrended series is prewhitened through

$$Y'_t = Y_t - r_1 Y_{t-1}, \quad (10)$$

where Y'_t is the prewhitened series.

FIGURE 4: The plot of significant trends for annual and seasonal precipitation in the Langat River Basin at the 95% confidence level.

- (4) Add the monotonic trend to the prewhitened series through

$$Y_t'' = Y_t' + \beta t, \quad (11)$$

where Y_t'' is the trend-free prewhitened series.

- (5) Calculate the MK statistic on Y_t'' series and examine the local significance of the calculated statistics.

3. Results and Discussion

3.1. Analyses of Lag-1 Autocorrelation and the Prewhitening Process. The results of lag-1 autocorrelations and the prewhitening process of the annual and seasonal precipitation and temperature in the related situations are shown in Tables 3 and 4. As shown, while the serial correlations for the annual P , T_{Min} , T_{Max} before the TFPW process were all positive, positive and negative serial correlations were obtained at the seasonal time series of precipitation and temperature. While the temperature variables required

the TFPW process before the MK test, the majority of the precipitation variables did not require any prewhitening procedure. The strongest and weakest autocorrelation were found in the annual T_{Min} (Station 9) and SW monsoon T_{Min} (Station 11), respectively. Generally, the temperature variables have a higher autocorrelation than did the precipitation variables. The majority of the seasonal precipitation time series is free of significant lag-1 serial correlation.

3.2. Trend in Precipitation and Temperature Variables. The results of the MK test, the TSS estimator, and MKRS test for P , T_{Max} , and T_{Min} are presented in Tables 5, 6, and 7. The results of the MK test for the annual and seasonal time series are also presented in Figures 3 and 4.

3.2.1. Analysis of Precipitation. The results of the MK test of the annual and seasonal precipitation time series are shown in Table 5 and the significant trends at the 95% confidence level are illustrated in Figure 4. The results of the MK test

TABLE 3: Lag-1 serial correlation values for temperature variables before and after prewhitening.

Station	Critical r_1	T_{Max}		T_{Min}		NE T_{Max}		SW T_{Max}		NE T_{Min}		SW T_{Min}	
		r_1	r_1'	r_1	r_1'	r_1	r_1'	r_1	r_1'	r_1	r_1'	r_1	r_1'
9	0.37	0.48*	-0.01	0.58*	-0.02	0.36	—	-0.03	—	0.55*	-0.05	0.45*	0.34
10	0.31	0.37*	0.08	0.02	—	0.12	—	0.17	—	-0.09	—	0.42*	0.04
11	0.30	0.39*	0.02	0.75*	0.07	0.15	—	0.16	—	0.16	—	0.02	—

*Significant at the 5% significance level.

—No need to follow TFPW process.

TABLE 4: Lag-1 serial correlation values for annual and seasonal precipitation before and after TFPW process (r_1').

Station	Critical r_1	P (mm)		NE monsoon		SW monsoon	
		r_1	r_1'	r_1	r_1'	r_1	r_1'
1	0.31	0.11	—	-0.18	—	-0.05	—
2	0.31	0.06	—	-0.07	—	0.1	—
3	0.33	0.27	—	0.06	—	-0.03	—
4	0.31	0.36*	0.05	-0.03	—	0.2	—
5	0.32	0.21	—	-0.16	—	0.09	—
6	0.31	0.29	—	-0.13	—	-0.23	—
7	0.32	0.15	—	0.07	—	0.03	—
8	0.32	0.36*	0.27	-0.08	—	0.10	—

*Significant at the 5% level of significance.

—No need to follow TFPW process.

TABLE 5: The results of the MK and TSS methods for annual and seasonal precipitation in the Langat River Basin.

Site	Annual P (mm)				NE monsoon				SW monsoon			
	S	Z	P value	β (mm/yr)	S	Z	P value	β (mm/yr)	S	Z	P	β (mm/yr)
1	110	1.22	0.22	+4.5	28	0.30	0.76	+0.8	104	1.16	0.24	+2.5
2	59	0.65	0.54	+3.0	72	0.80	0.43	+1.7	-44	-0.48	0.63	-1.1
3	146	2.03	0.04*	+12.6	110	1.43	0.14	+5.8	26	0.33	0.73	+1.0
4	252	2.92	0.004*	+15.3	138	1.54	0.12	+5.4	122	1.36	0.17	+3.2
5	-83	-1.0	0.30	-5.8	-37	-0.45	0.65	-1.5	-83	-1.03	0.30	-1.6
6	280	3.13	0.002*	+17.1	136	1.52	0.13	+4.1	198	2.21	0.02*	+4.8
7	73	0.91	0.37	+4.5	43	0.53	0.59	+0.7	89	1.11	0.27	+2.5
8	188	2.45	0.014*	+13.4	91	1.13	0.26	+3.9	77	0.96	0.34	+2.2

*Statistically significant at the 95% confidence level.

TABLE 6: Results of the MK and TSS methods for annual temperature variables in the Langat River Basin.

Station	T_{Max} (°C)				T_{Min} (°C)			
	S	Z	P value	β (°C/yr)	S	Z	P value	β (°C/yr)
9	145	3.00	0.003*	+0.035	52	1.06	0.287	+0.01
10	135	1.68	0.09	+0.008	370	4.83	0.000*	+0.03
11	-29	-0.34	0.75	-0.002	401	4.84	0.000*	+0.04

*Statistically significant at 95% confidence level.

TABLE 7: The results of the MK and TSS methods for seasonal temperature variables in the Langat River Basin.

Station	Variable	NE Monsoon				SW Monsoon			
		S	Z	P value	β (°C/yr)	S	Z	P value	β (°C/yr)
9	T_{Max}	117	2.42	0.015*	+0.04	149	3.09	0.002*	+0.03
	T_{Min}	-3	-0.04	0.98	+0.0001	-29	-0.62	0.54	-0.007
10	T_{Max}	71	0.88	0.38	+0.007	87	1.08	0.28	+0.005
	T_{Min}	411	5.15	0.000*	+0.046	420	5.48	0.000*	+0.04
11	T_{Max}	-114	-1.27	0.204	-0.012	12	0.12	0.902	+0.001
	T_{Min}	558	6.26	0.000*	+0.043	568	6.39	0.000*	+0.041

*Statistically significant at the 95% confidence level.

for prewhitened annual precipitation showed that there are significant positive trends at Stations 3, 4, 6, and 8, which represents 50% of the precipitation stations. As shown in Figure 3(b), by considering the spatiality of these stations, the significance trends were obtained in these stations, which are located east and north of the basin. In addition, as illustrated by the altitude and DEM (Table 1 and Figure 1) of these stations, the positive significant trends are obtained in higher altitude areas. The land use of the area around Stations 3 and 4 are urban and forest, respectively.

The score values of this variable conformed to the P values at these stations. In addition, the largest S value obtained at Station 6 adapted to the most powerful significance trend test at that station. On the contrary, among these four stations with significant trends, Station 3 has the smallest S value and the largest P value. This indicates the smallest rate of change at this station. Nevertheless, the majority of trends for the seasonal precipitation time series were insignificant at the 95% confidence level. The only significant trend at the 95% confidence level was detected at Station 6 for SW monsoon precipitation.

The results of Theil-Sen's test of annual and seasonal precipitation time series are shown in Table 5 and significance trends at the 95% confidence level are illustrated in Figure 4. As indicated in Table 5, the largest increasing slope of significant annual precipitation occurred at Station 6, while the smallest rates were obtained at Station 3, which were 17.1 and 12.6 mm/year, respectively. Based on the results of the MK test for the annual and seasonal precipitations, the test could not detect any significant negative trends in the time series.

The consequences of the MKRS test for significant annual and seasonal precipitation and temperatures are shown in Figure 5. The sequential values of the $U(t)$, $U'(t)$, and the confidence limits are depicted by solid red, blue, and dashed lines, respectively. As shown in Figure 5(a), the intersection point of the $U(t)$ and $U'(t)$ curves has changed the regime of the downward trend to the increasing trend around year 1990, which became significant in the year 2002. In spite of the existence of significant positive trends at Stations 4, 6, and 8, the MKRS test was not capable of determining the approximate beginning year of the trends. During the study period of these stations, the $U(t)$ and $U'(t)$ have become significant, especially around the year 2000 and after.

3.2.2. Analysis of T_{Max} . The outputs of the trend detection analysis for annual and seasonal maximum temperature in the Langat River Basin are presented in Tables 6 and 7 and also in Figures 5 and 6.

Concerning the annual and seasonal analysis of T_{Max} , there were downward and upward trends at the stations. Three out of seven upward trends were statistically significant and none of the decreasing trends were significant at the 5% significance level. All of the significant trends are related to Station 9, located in the mountainous area, and forest land use category. The findings also indicate that the largest S value for the annual T_{Max} was found at Station 9. The strongest warming trend in T_{Max} was conformed to the lowest P value at this station. The slope estimator test indicated an increase

of 3.5°C per century in the maximum temperature at this station, which is close to the highest rate of temperature increments, 0.99–3.44°C, in a century, reported by the IPCC in Malaysia. The rates of significant seasonal changes in SW monsoon and NE monsoon seasons for T_{Max} were 3 and 4°C per century, respectively. Thus, the warming slope of T_{Max} in the annual period is higher than the SW monsoon season and lower than NE monsoon season. These results indicate that the monsoons' winds are active regional phenomena, which influence the observed maximum temperature during these seasons.

Regarding the annual significant trend at Station 9, the MKRS test was not able to indicate any mutation point for this powerful upward trend, as shown in Figure 5(c). The series of $U(t)$ passed the 95% confidence level in 1990, while the MKRS test detected the beginning years of trend for the annual T_{Max} at Stations 10 and 11 in 1998 and 2003, respectively. However, none of these trends are significant at the 95% confidence level. As illustrated in Figure 5(e), the warming trend for the NE monsoon T_{Max} at Station 9 began in 1997 and became significant during the same year. The MKRS test detected other intersections between $U(t)$ and $U'(t)$ series in the NE monsoon and SW monsoon seasons at Stations 10 and 11 after 1990, and none of them were significant at the 95% significance level.

3.2.3. Analysis of T_{Min} . The trend analyses for annual and seasonal T_{Min} in the three stations, Stations 9, 10, and 11, of the Langat River Basin obtained by the MK, MKRS, and TSS methods are given in Tables 6 and 7 and Figures 6 and 7. The annual MK trend test results identified the maximum S value at Station 11 and the smallest one at Station 9. Therefore, Station 9, which had the most powerful trend in T_{Max} , was replaced by Station 11 for T_{Min} . The increasing significant trend of the annual T_{Min} at Stations 10 and 11 were significant at the 95% confidence level, while it was not as strong as the annual increment in T_{Max} at Station 9.

According to the results, the highest value of the slope for the annual minimum temperature was identified at Station 11 (0.4°C/decade), while the lowest value was obtained at Station 9 (0.1°C/decade). As shown in Table 6, the probability of this trend being obtained randomly is close to zero, and thus the test results are significant at the 95% confidence level. The MK trend test for the SW monsoon and NW monsoon seasons indicated significant trends at Stations 10 and 11. The MK trend analysis of the seasonal T_{Min} showed a strong significant increasing trend at Stations 10 and 11 in the seasonal time periods. The altitudes of Stations 10 and 11 are less than the altitude of Station 9. The rates of seasonal increasing in T_{Min} at these two stations are about 4°C per century, which is near the NE monsoon trend in T_{Max} at Station 9.

The sequential MK test could not detect any beginning point for significant seasonal and annual positive trends. The result of this test showed a mutation point only at Station 9 for annual and seasonal trends in 2001 that passed the significant confidence levels in this year.

Therefore, the results of the present study indicated a climate change signal for annual rainfall, as well as the

FIGURE 5: Graphical example of $U(t)$ and backward series $U'(t)$ of the MKRS test for annual analysis ((a), (b), and (c)), NE monsoon season ((d), and (e)), and SW monsoon (f) for precipitation and temperature at the stations with significant trends at the 95% confidence level.

FIGURE 6: Results of significant MK trends for annual and seasonal temperature variables in the Langat River Basin at the 95% confidence level.

FIGURE 7: The spatial distribution of significant and insignificant trends for annual and seasonal temperatures along with corresponding Sen's slope values per year.

maximum and minimum temperatures in the Langat River Basin. These findings reflect other researchers that looked for signs of climate change for discrete climate parameters in Malaysia [10, 36, 37]. As far as we are aware, the present study is the only one that simultaneously focused on the slope of the trend in P , T_{Max} , and T_{Min} besides the beginning time of change in climate parameters in the Langat River Basin.

3.3. Uncertainty in Trends. A bootstrap method was applied herein on the database to assess the uncertainty in the estimated significant slopes associated with the slope estimator method in significant trends for the annual and seasonal

precipitation and maximum and minimum temperatures by using 1000 resampling times. The bootstrap histogram, box plot, confidence intervals, and other useful statistics of the bootstrapped slope values at these stations are shown in Table 8 and Figures 8 and 9. The 95% confidence intervals of the median bootstrapped slopes were computed using the percentile method. As shown in Table 7, all of the measured Theil-Sen's slope values are placed at the 95% confidence intervals. The box-plot figure also illustrated more nonnormality in the slopes' distribution for temperature than with the precipitation in the significant stations.

FIGURE 8: Examples of histogram of bootstrap slopes in significant trend for annual and seasonal temperatures (T_{Max} , T_{Min}) and precipitation.

4. Conclusions

Changes in the climate variables due to global warming and regional systems, such as monsoon phenomena, were investigated at the Langat River Basin to precisely determine the rate of changes in this strategic river basin. The main objective of this study was the annual and seasonal trend analysis for P , T_{Max} , and T_{Min} at the 11 selected stations in this river basin to support the water management policymakers for planning for the future. Three nonparametric methods, the MK, MKRS test, and TSS, were applied to complete the

detection of trends for the variables. The analyses of the MK and TSS were performed after eliminating the influence of significant lag-1 serial correlations from the time series using the TFPW technique. The results of these trend tests showed significant increasing trends at four stations (Stations 3, 4, 6, and 8) for annual precipitation, one station for the SW monsoon season (Station 6), one station for the seasonal and annual T_{Max} , and two stations for the annual and seasonal T_{Min} , at the 95% confidence level. The rate of changes in this river basin showed that north and east of basin have faced a moderate change in the maximum and minimum

FIGURE 9: Boxplot of slope obtained from bootstrap method for the significant trends of annual and seasonal rainfall and temperatures (a: S9 (T_{Max}), b: S10 (T_{Min}), c: S11 (T_{Min}), d: S9 (T_{Max} NE monsoon), e: S10 (T_{Min} NE monsoon), f: S11 (T_{Min} NE monsoon), g: S9 (T_{Max} SW monsoon), h: S10 (T_{Min} SW monsoon), i: S11 (T_{Min} SW monsoon)).

TABLE 8: The bootstrap results for slopes in significant trends for rainfall and maximum and minimum temperatures in the Langat River Basin.

Station	Parameter	Estimated Theil-Sen's slope	Bootstrap results of slope			
			The 95% confidence intervals		Mean	Standard deviation
S3	Precipitation	12.6	8.369	15.738	12.01	1.95
S4		15.3	12.732	18.293	15.34	1.11
S6		17.1	15.244	18.748	16.89	0.91
S8		13.4	10.172	15.516	13.25	1.46
S6 (SW monsoon)		4.8	3.477	6.051	4.77	0.67
S9 (T_{Max})	Temperature	0.035	0.023	0.042	0.034	0.005
S10 (T_{Min})		0.03	0.029	0.037	0.032	0.002
S11 (T_{Min})		0.04	0.036	0.046	0.041	0.002
S9 (T_{Max} NE monsoon)		0.04	0.033	0.052	0.04	0.005
S10 (T_{Min} NE Monsoon)		0.046	0.042	0.05	0.047	0.002
S11 (T_{Min} NE monsoon)		0.043	0.040	0.046	0.044	0.001
S9 (T_{Max} SW monsoon)		0.03	0.025	0.038	0.03	0.003
S10 (T_{Min} SW monsoon)		0.04	0.038	0.045	0.041	0.002
S11 (T_{Min} SW monsoon)		0.04	0.039	0.043	0.041	0.001

temperatures and rainfall during the past four decades. In other words, the weather north and east of basin became warmer and wetter during the study period.

While the rates of upward significant changes for annual precipitation ranged from 12.6 to 17.1 mm per year, for the rate of change in SW monsoon, a significant trend was found to be about one-third (4.8 mm per year). The TSS test determined the slope of an upward trend for the annual and seasonal T_{Max} in a range of 3.5 to 4°C per century. It is the same for the annual and seasonal significant trends for the T_{Min} variable. Also, all of the significant trends were found at the stations located in the north, east, and northeast parts of the basin. Their elevations are higher than those stations in the west region of the river basin. The land use of these stations is forest or urban area. The other important result is that all of the significant long-term trends in precipitation and temperature gradually increased during the study period.

Also, it showed that the monsoon system is a powerful phenomenon among all other active systems in the region. This rate of change in the annual and seasonal rainfall, T_{Max} and T_{Min} temperature may drive some changes in land cover/land use of the basin therefore increasing the flood frequency in this region, especially during the NE monsoon season. Furthermore, changes in the water demand pattern for all type of usage in the region is another consequence, due to the alterations in climate parameters. Future studies in trend analysis for extreme rainfall events and other indices of precipitation in the Langat River Basin would be very useful for future water resource planning.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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