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Drought Classification and Trend Analysis of Streamflow and Rainfall in the Northern Region of Peninsular Malaysia

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Abstract
Droughts can have a variety of negative effects, including decreased agricultural productivity, water scarcity, and health risks. Malaysia which receives constant annual rainfall also experienced drought. Hydrological drought commonly occurs from decreasing water supply availability from water sources whereas meteorological drought results from an absence of rainfall; these are two types of drought detected in Malaysia. Drought conditions that affect water systems are correlated with a lack of precipitation. Therefore, this study would analyse both drought situations in Perlis. Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) were chosen as drought index to evaluate both droughts. This study aims to a) evaluate the drought condition by the SDI and SPI value, b) analyze the trend of hydrological and meteorological drought by the Mann-Kendall Trend Test and c) examine the relationship between the SDI and the SPI. The 3-month reference period was applied to both indices due to its sensitivity on a smaller timescale. This study found that the SDI-3 and SPI-3 were able to observe the drought characteristics in Perlis. Perlis also experienced more hydrological drought than meteorological drought. The positive relationship between SDI-3 and SPI-3 suggests that the amount of rainfall and streamflow in Perlis are dependent on each other.
Keywords: Drought**;** Hydrological drought; Meteorological drought; Streamflow Drought Index; Standard Precipitation Index.

Introduction

Drought is a prolonged period of dryness mostly due to climate change. Drought can be inferred when there are obvious signs of decreased soil moisture or groundwater, diminished streamflow, crop damage, and general water scarcity since the starting point of drought is hard to identify (*Drought | National Geographic Society*, n.d.). The length of the drought, however, is difficult to determine because it can last for a week or be prolonged for more than a month. Drought is primarily brought on by several factors, including temperature shifts, irregularly distributed rain and snow, and a lack of precipitation (*What Causes a Drought?* n.d.).

Shifts in temperatures and weather patterns over a long period are commonly referred to as climate change (United Nations, n.d.). With the progression of a country's development, more greenhouse gas emissions (e.g., Carbon dioxide (CO2) and methane) were detected due to human activities. This gas emission would indirectly raise the surrounding temperature through the formation of a layer that would trap the sun's heat in the atmosphere. In the context of human activity, burning fossil fuels for energy, clearing forests, using fossil fuels for transportation, and cultivating food (e.g., uses of fertilisers and manure for growing crops) were some of the causes of climate change (United Nations, n.d.). The relationship between drought and climate change has been investigated before by several researchers (Gu et al., 2019; Lin et al., 2020; Danandeh et al., 2020). Páscoa et al. (2017) use data climatic data (e.g., precipitation, temperature, cloud cover, and vapour pressure, among others) to compute drought indices. They discovered a distinct pattern of increasing dryness severity, drought intensity, and a reduction in the period between consecutive droughts.

There are five main types of drought recorded which were meteorological drought, hydrological drought, agricultural drought, socioeconomic drought and ecological drought. Each drought has its occurrence factor and starting period. This study would only be focused on two types of drought which were hydrological and meteorological drought. Meteorological drought is determined by the level of dryness or the lack of rainfall as well as the length of the dry period. Meanwhile, hydrological drought is a drought state that mostly happens as a result of reduced water supply availability from water sources such as streamflow, and inflow to reservoirs, lakes, and ponds. Another factor contributing to this type of drought is also the reduced periods of precipitation including snowfalls. It is categorized under meteorological drought.

According to Asadi Zarch (2022); to quantify the effects of drought, drought indices are utilised. Some of the drought index usually used by the researcher in their study is the Standardized Precipitation Index (SPI) (Abeysingha & Rajapaksha, U. R, 2020), Streamflow Drought Index (Altın et al., 2020), Standardised Streamflow Index (SSI) (Zalokar et al., 2021) and Standardized Precipitation–Evapotranspiration Index (SPEI) (Li et al., 2020). To study the meteorological and hydrological drought in a region, two indices would be used. According to the World Meteorological Organization (WMO), SPI is a recommended tool to observe the amount of rainfall, drought negative index value, and wet positive index value (Pramudya & Onishi, 2018). Therefore, in order to assess the drought conditions brought on by the area's lack of precipitation, the SPI will be used. Other than that, SDI is a widely known drought index that was used mainly for evaluating the hydrological drought severity in an area (Nalbantis & Tsakiris, 2009). The index uses monthly streamflow data to categorise the drought severity of an area by its value. SDI uses the basis of the Standard Precipitation Index (SPI) (Mckee et al., 1993). By applying the same method of constructing SPI, a more flexible index was generated. Due to its purposes, both indices would be implemented in this study.

The trend of drought has been investigated alongside the severity as it helps to analyze its frequency. The increase or decrease trend of drought usually was studied by applying tests such as the Mann-Kendall (MK) test, the modified Mann-Kendall test and Spearman's rho test. The MK test is the most used measurement for drought trends because it does not require a specific sample distribution, which eliminates the possibility of outlier interference (Wang et al., 2017). Therefore, the MK analysis will be used in this study to analyze the hydrological and meteorological drought trend due to its advantages and suitability for the data used in this study area.

However, since each index had a distinct purpose in mind, it is also intriguing to see how the results of the two indexes correlated. Therefore, a correlation test would be applied to the result of the indices. The Spearman's rank correlation coefficients were chosen, given the possibility of a non-linear relationship between the drought indices, where the monotonic nature of the equation could benefit in calculating the correlation between the two variables (Cao et al., 2022). Other than that, it is also encouraging to discover a significant link between both the droughts and the factors examined in this study.

Malaysia located in the southeastern Asia of the world undoubtedly would receive a consistent amount of rainfall all year round with mean annual precipitation of 2000 to 4000 millimetres (mm). However, some severe and short terms drought has been reported in some areas of Malaysia. For instance, a severe drought has been documented in the past, where the 1998 Klang Valley water crisis when three of the reservoir dams in the Klang Valley—Gates Dam, Batu Dam, and Semenyih Dam—suffered a significant drop in water level due to the El Niño phenomenon ("Worst Water Shortage Occurred in 1998 with 150 Days of Rationing", 2014). Despite there being steady rains before the drought, the phenomenon of El Niño is to blame for the water shortage. Water rationing was implemented by the government of Malaysia at that time to overcome the drought. As this drought incident was so severe, a drought information website (*ABOUT US | INFO KEMARAU*, n.d.) was created to assist relevant agencies to make early preparation to face drought events. Other instances of drought included the 2016 drought, which saw heatwaves cause rivers and dams to dry up, ultimately leading to a fatal case of heatstroke. Hence, knowing the severity of the drought could help the responsible parties to make early precautions for upcoming drought events. It has been discovered that a drought that could affect the water supply is closely tied to a lack of precipitation. Therefore, to overcome the issues above and study the relation between the two factors, two drought index to investigate the severity of the drought in Malaysia is being proposed. The SDI and SPI will be used in this study due to their purposes. The SDI would be used to evaluate the hydrological drought that resulted from water shortages. Meanwhile, the SPI measures the meteorological drought that develops as a result of a lack of rainfall. Therefore, the objectives of this study would be:

1) To evaluate the drought condition by using the Streamflow Drought Index (SDI) and Standard Precipitation Index (SPI).
2) To analyze the trend of hydrological drought and meteorological drought by using a nonparametric Mann-Kendall Trend Test.
3) To examine the relationship between the Streamflow Drought Index (SDI) and the Standard Precipitation Index (SPI) based on correlation analysis.

Data and study area

The data set was obtained from Jabatan Pengairan dan Saliran Malaysia (Department of Irrigation and Drainage Malaysia). This data set includes monthly streamflow and rainfall data for the Sg. Jarum at Kg. Mesjid Perlis and Chuping station respectively. The state of Perlis located in the Northern region of Malaysia is considered eligible to be the case study since Perlis had experienced longer continuous hot weather than other states in Malaysia. The duration of this study would be from 2007 to 2019. Table 1 shows the details of the streamflow and rainfall station.

Table 1: Details of Sg. Jarum at Kg. Mesjid Perlis streamflow and Chuping rainfall station.

Basin name	**Basin area (km^2)**	**State**	**Station no.**	**Station name**	**Station latitude**	**Station longitude**	**Average monthly amount**
Sg. Perlis	310	Perlis	0010381SF	Sg. Jarum at Kg. Mesjid Perlis	6° 36' 55" N	100° 14' 43" E	27.19072 m^3/s
Chuping	26		48604	Chuping	6° 29' N	100° 16' E	112.76 mm

Methods

Streamflow Drought Index

The Streamflow Drought Index (SDI) was developed by Nalbantis and Tsakiris (2009). The way of producing the index is similar to the SPI and thus it also holds the same characteristics of simplicity and efficiency. However, the SDI was constructed specially for hydrological drought. The SDI used the monthly streamflow volumes at different time scales to determine the hydrological drought condition of a region. The calculations started with:

$$V_{i,k} = \sum_{j=1}^{3k} \mathrm{Q}_{i,j} \quad \text{for} \quad i = 1,2,\dots \quad j = 1,2,\dots,12 \quad k = 1,2,3,4 \tag{1}$$

where $V_{i,k}$ is the cumulative streamflow volume for the *i*-th hydrological year and the *k*-th reference period. Each *k*-th refers to different periods needed for the index. The Streamflow Drought Index (SDI), based on cumulative streamflow volumes $V_{i,k}$, is defined as follows for each reference period k of the i-th hydrological year:

$$\mathrm{SDI}_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \quad \text{for } i = 1,2,\dots, \quad k = 1,2,3,4 \tag{2}$$

Nalbantis and Tsakiris's (2009) description of the hydrological classification based on SDI values is as follows:

Table 2: Characteristics of hydrological drought from the SDI value.

Description	Criterion
Non-drought	SDI ≥ 0.0
Mild drought	-1.0 ≤ SDI < 0.0
Moderate drought	-1.5 ≤ SDI < -1.0
Severe drought	-2.0 ≤ SDI < -1.5
Extreme drought	SDI ≤ -2.0

Standard Precipitation Index

The formula for the Standard Precipitation Index (SPI) was proposed by McKee et al., (1993). McKee et al., (1993) started by utilising a cumulative gamma distribution as in Equation (3.14) to define the function of frequency or probability density function:

$$G(x_k) = \int_0^{x_k} g(x_k)dx_k = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^{x_k} t^{\alpha-1} e^{-\frac{x_k}{\beta}} dx_k \qquad (3)$$

α,β >0

where α and β are defined as shape parameters and as scale parameters respectively. Meanwhile, *x* is the amount of precipitation over the consecutive months *k* (selected time scale) in millimetres and must be also bigger than 0. The $\Gamma(\alpha)$ is a gamma function. To optimize α and β values, the maximum likelihood estimations of α and β are developed as such:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (4)$$

$$\hat{\beta} = \frac{x}{\alpha} \qquad (5)$$

where

$$A = \ln(x) - \frac{\sum \ln(x)}{n} \qquad (6)$$

n is the number of observation data for rainfall.

The cumulative probability of a recorded precipitation amount for the specified month and time period for the given location is then determined using the subsequent parameters. Due to the gamma function being undefined for $x_k = 0$ and a precipitation distribution may contain zeros, a cumulative probability H (x_k) is generated as follows:

$$H(x) = q + (1 - q)G(x) \qquad (7)$$

where *q* is the probability of zero precipitation by the following formula:

$$q = \frac{m}{n} \qquad (8)$$

where *m* is the number of occurrences of precipitation being zero and *n* is the precipitation observation number.

The cumulative probability $H(x)$ is then transformed to the standard normal random variable *z* with a mean of zero and variance of one, therefore the obtained value of *z* is the SPI value. The calculation of SPI could be obtained by using the approximation according to Abramowitz and Stegun (1964) by the equation as follows:

Calculation of SPI for 0 < $H(x_k)$ ≤ 5

$$SPI = -\left(t - \frac{c_o + c_1 + c_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3}\right) \qquad (9)$$

where

$$t = \sqrt{ln \frac{1}{(H(x_k))^2}} \qquad (10)$$

Calculation of SPI for 0 < $H(x_k)$ ≤ 1.0

$$SPI = -\left(t - \frac{c_o + c_1 + c_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3}\right) \tag{11}$$

where

$$t = \sqrt{ln\frac{1}{(1 - H(x_k))^2}} \tag{12}$$

where c_o = 2.515517, c_1 = 0.802853, c_2 =0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308.

The drought characterization table according to SPI (Mckee et al., 1993) is as follows:

Table 3: SPI value as proposed by Mckee et al., 1993.

Description	Criterion
Extremely wet	SPI ≥ 2.00
Severely wet	1.50 ≤ SPI < 2.00
Moderately wet	1.00 ≤ SPI < 1.50
Mildly wet	0.00 ≤ SPI < 1.00
Mild drought	-1.00 ≤ SPI < 0.00
Moderate drought	-1.50 ≤ SPI < -1.00
Severe drought	-2.00 ≤ SPI < -1.50
Extreme drought	SPI ≤ -2.00

Mann-Kendall Trend Test

The Mann-Kendall Test (MK) (Mann 1945; Kendall 1975), is a statistical test to identify the monotonic trends of data. The MK test is a non-parametric test, which means that no assumptions about the data that must be examined are necessary. The test statistic, Kendall's S, is described below:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} Sign(x_j - x_k) \tag{13}$$

in which

$$Sign(x_j - x_k) = \begin{cases} 1 & if\ x > 0 \\ 0 & if\ x = 0 \\ -1 & if\ x < 0 \end{cases} \tag{14}$$

where x_j and x_k are the sequential data values and *n* is the length of the dataset. It is noteworthy to note that the positive and negative values of S represent the upward and downward trends in the time series, respectively. Under the case of the null hypothesis, the statistics S is approximately normally distributed when the sample size $n \geq 10$, with the mean of S and variance given as follows:

$$E[S] = 0 \tag{15}$$

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_t^n t(t-1)(2t+5)}{18} \tag{16}$$

where *t* indicates the number of data of any given tie.

To determine the trend significance the standardized Z statistics test is computed by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (17)$$

As in Eq (17), the positive value of Z refers to the upward trend while the negative value refers to the downward trend.

Spearman's Rank Correlation Coefficient Test

The Spearman's Rank correlation coefficient test would be implemented on the SDI-3 and SPI-3 data to understand their relationship. Spearman (1961) produced this correlation test to find the association between two subjects. The formula for the correlation test is as follows:

$$p = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (18)$$

where p is the Spearman's rho correlation, d_i is the difference between the two ranks of each observation, and n is the number of observations.

Results and discussion

The result of the analysis of the Streamflow Drought Index (SDI) and Standard Precipitation Index (SPI) are as below:

Streamflow Drought Index

The annual Streamflow Drought Index (SDI) for Sg. Jarum at Kg. Mesjid Perlis is given in Table 4 and Figure 1. From the table and figure, it is observed that only one "extreme drought" occurrence which is in January 2007 among the 13 years case study. According to the Malaysian Meteorological Department website (2023), an increase in temperature was recorded in Peninsular Malaysia from 1998 to 2007 with a significant increase of 0.5°C to 1.5°C. Following the increase in temperature, Peninsular Malaysia also experienced less rainfall from 1998 to 2007 (Rahman, 2018). Nonetheless, the extreme drought was then shifted to the "moderate drought" phase in February 2007.

The "mild drought" and "moderate drought" incidents were also caught in some months in different years. A "mild drought" was identified by SDI-3 in the month of March 2016, this could happen due to a heat wave with temperature values above 37°C that have the potential to reach 39°C (Alias, 2016; "Heatwave-Hit Perlis, Kedah Likely to Finish Week at 39°c Again.", 2016). Other than that, the "mild drought" and "moderate drought" occurrence could have been brought on by Perlis's high temperature which may have had an impact on the streamflow volume. Thereafter, it is also viewed that Perlis experienced more "mild drought" incidences than "moderate drought".

Nonetheless, a quite good amount of "no-drought" conditions were also found. It is observed that from October 2014 to February 2015, the SDI-3 detected a continuous "no drought" condition in Perlis. It is possibly related to the flood in December 2014 faced by Perlis due to the northeast monsoon (OCHA (United Nations Office for the Coordination of Humanitarian Affairs), 2019). Other "no drought" conditions were also detected in most of the months from 2017 to 2019. In 2017, it was reported that Perlis and other parts of Peninsular Malaysia had significant flooding due to the overflowing water level (Zulkefli, 2017). However, there were no reported sightings of floods in 2018, therefore the "no-drought" occurrence observed may have been because of the slowly declining streamflow volume from the flood that happened a year before. Afterwards, the Malaysia Meteorological Department issued a 'yellow alert' warning for Perlis and the state nearby due to continuous heavy rainfall in May 2019 (Chern & Lim, 2019). As a result, Perlis eventually experienced floods and required residence evacuation in October 2019, a week after Malaysia had faced the inter-monsoon phase, which typically occurs from October to November ("Floods - more than 2,000 people in six states relocated.", 2019; *Laman Web Rasmi Jabatan Meteorologi Malaysia*, n.d.-b). Thereafter, it is concluded that the SDI-3 could prove not only the drought incident but also the flood incident that happened in Perlis. Furthermore, it was noted that the percentage of short-term and less severe hydrological droughts was higher than that of extreme and severe hydrological droughts. This finding is similar to that of Fung et al. (2020), who discovered that the likelihood of a short-term hydrological drought in the Northern Region is higher than the likelihood of a long-term hydrological drought.

Table 4: SPI value as proposed by Mckee et al., 1993.

Year/Month	January	February	March	April	May	June	July	August	September	October	November	December
2007	-2.04	-1.01	-0.20	-0.28	-0.33	-0.11	0.68	0.53	0.21	-1.18	-1.25	-0.40
2008	-0.60	-0.77	-0.42	-0.06	-0.13	0.06	-0.27	-0.36	-0.81	-0.97	-1.70	-0.36
2009	-0.72	-0.44	-0.28	0.31	0.23	-0.09	-0.55	-0.18	-0.26	-0.77	-0.68	-0.30
2010	-0.23	-1.20	-0.85	-1.06	-1.22	-1.02	-0.95	-0.77	-0.93	-1.36	-0.47	0.11
2011	0.23	-0.54	0.38	0.53	0.39	-0.53	-0.90	-0.90	0.10	-0.14	-0.59	-0.95
2012	0.16	0.54	0.91	-0.16	-0.39	-0.88	-1.10	-1.14	-0.92	-1.28	-0.58	-0.12
2013	-0.18	-0.89	-0.93	-0.90	0.01	0.30	0.22	-0.51	-0.89	-0.23	-0.62	-0.13
2014	-1.33	-1.10	-1.18	-0.91	-0.88	-0.68	-0.72	-0.68	-0.68	0.58	1.15	2.09
2015	2.06	1.89	-0.23	-0.48	-0.78	-0.80	0.39	0.89	1.45	1.44	1.66	0.56
2016	-0.03	-0.26	-0.09	0.20	0.69	0.83	0.97	0.73	0.69	0.51	0.57	0.85
2017	1.30	1.30	1.04	0.64	0.45	1.06	1.11	1.52	1.40	1.30	0.40	-0.21
2018	-0.02	0.99	1.70	1.88	1.85	1.74	1.46	1.29	1.16	1.03	0.98	0.62
2019	0.93	1.33	1.69	1.90	1.83	1.72	1.42	1.30	1.17	1.06	1.12	0.84

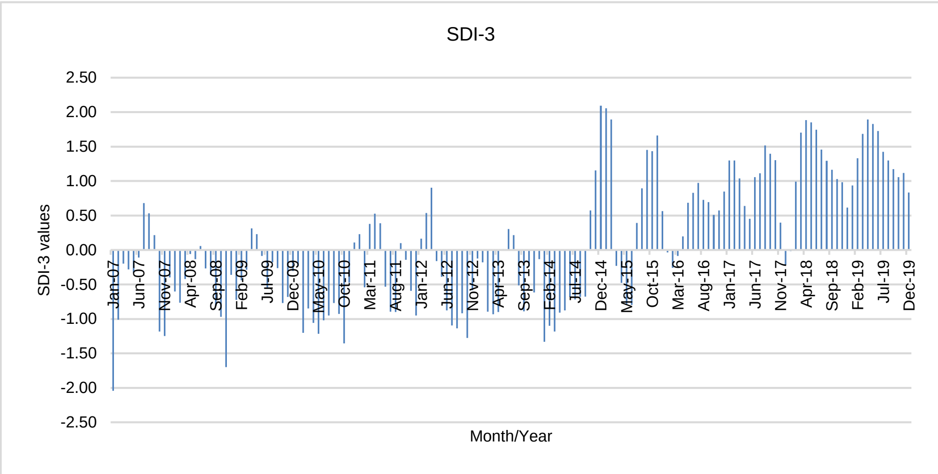

Figure 1 SDI-3 values of the Sg. Jarum at Kg. Mesjid Perlis streamflow station.

Standard Precipitation Index

The annual Standard Precipitation Index (SPI) for Chuping is as in Table 5 and Figure 2. Discerning the table and figure, it is found that four “extreme drought” occurrences happened with one of them in 2014 and three nonconsecutive “extreme drought” events happened in 2016. To analyse the “extreme drought” occurrences in 2014, it is worth viewing the consecutive drought incidence from September 2013 to June 2014. The temperature in Perlis was reported to be rising since June 2013 and a high temperature of 38.9°C was recorded in Chuping (Ibrahim, 2013). The continuous hot weather was then worsened by the 2014 El Niño phenomenon that started forming in May. With the deterioration of the drought condition as in Figure 5, it has been noticed that the phenomena may have affected Malaysia's temperature. Not only that, but the beginning of the southwest monsoon, which often exhibits drier conditions from late May to September, may also be one of the factors contributing to the severity of the drought. Nonetheless, the dry condition was getting better with the start of the intermonsoon phase in Malaysia in October. To dissect the nonconsecutive “extreme drought” events that happened in 2016, several occurrences that may have resulted in the events are explained. It is reported that since January 2016, Perlis has seen extremely hot weather with no presence of rainfall, with the greatest temperature being recorded at 39.2°C in Chuping (Ili Shazwani, 2016). Cloud seeding and water rationing were both several occurrences that may have resulted in the events being explained. It is reported that since January 2016, Perlis has seen extremely hot weather with no presence of rainfall, with the greatest temperature being recorded at 39.2°C in Chuping (Ili Shazwani, 2016). Cloud seeding and water rationing were both used to induce rainfall in Perlis indicating that the lack of rainfall incidence is worsen and had resulted in three extreme drought occurrences (Chow, 2016). Nonetheless, by November 2016, it is observed that Perlis's dry condition was shifted into a wet condition with the characteristics of "mildly wet". Warning of heavy rain and overflowing rivers was alerted to Perlis due to the northeast monsoon in November signalling the end of the dry spells to Perlis ("Alert over Heavy Rain and Overflowing Rivers Goes out in Kelantan, Terengganu, Johor and Perlis.", 2016).

Next, it is seen that the majority of the dry condition of the meteorological drought in Perlis were "mild drought" where in each year of the case study, at least one drought occurrence was recorded. This might be a result of the naturally hot environment of Perlis, where the average annual temperature is 28.45°C, 0.17% higher than the national average for Malaysia. Nevertheless, "mild drought" occurrences are thought to be transient and won't have a significant effect on Perlis. It is important to note that Perlis also had a string of consistently wet conditions by the value. Despite being considered the hottest state in Malaysia, Perlis was deemed capable of receiving heavy rainfall, with flooding incidents documented. The SPI-3 was nevertheless thought to be useful in testing the meteorological drought and differentiating the wet and dry conditions in Peninsular Malaysia's northern region. SPI-3 was also possible to identify both the short-term and long-term droughts, which are parallel to Malaysia's climate changes. This study concurs with Luhaim et al. (2021) that the SPI-3 can observe the drought occurrence in Peninsular Malaysia.

Table 5: SPI-3 values of the Chuping rainfall station.

Year/Month	January	February	March	April	May	June	July	August	September	October	November	December
2007	-0.17	0.16	0.11	0.26	-0.79	0.03	0.24	0.99	0.20	0.40	0.41	1.18
2008	0.28	0.38	0.63	0.85	0.17	-0.55	0.06	0.73	-0.13	-0.46	-1.52	-1.34
2009	-1.82	-0.64	0.51	1.02	1.47	-0.29	0.09	0.59	0.58	-0.70	0.40	0.44
2010	0.87	-0.21	0.47	0.28	-0.32	-0.47	-0.01	0.58	0.06	0.53	1.29	1.50
2011	0.73	0.85	1.59	1.46	0.93	-1.09	-0.80	0.78	0.61	0.31	-0.70	-0.94
2012	0.50	1.21	1.30	1.28	1.13	-0.07	-1.06	-1.54	-1.25	-1.62	-0.45	0.11
2013	0.21	0.41	-0.37	-0.07	-0.36	1.80	1.06	0.29	-1.05	-1.20	-1.08	-1.21
2014	-1.22	-1.61	-1.86	-0.52	-0.93	-0.50	-2.04	-1.72	-1.16	0.43	0.65	1.96
2015	1.06	1.06	-0.59	-0.22	0.66	0.47	0.95	1.10	2.15	1.57	0.87	-0.12
2016	-0.05	-1.12	-2.00	-2.22	-1.69	-1.80	-0.75	-2.07	-0.46	-0.26	0.35	0.33
2017	1.09	1.17	0.89	0.11	0.08	-0.40	-0.66	0.33	1.73	1.88	1.82	0.23
2018	1.07	0.42	0.17	-1.63	-0.83	0.81	1.59	-0.11	-0.30	-1.16	-0.76	-0.76
2019	-0.50	0.23	-0.24	-0.66	-1.15	-0.04	-0.23	0.35	-1.14	0.27	-1.28	-1.17

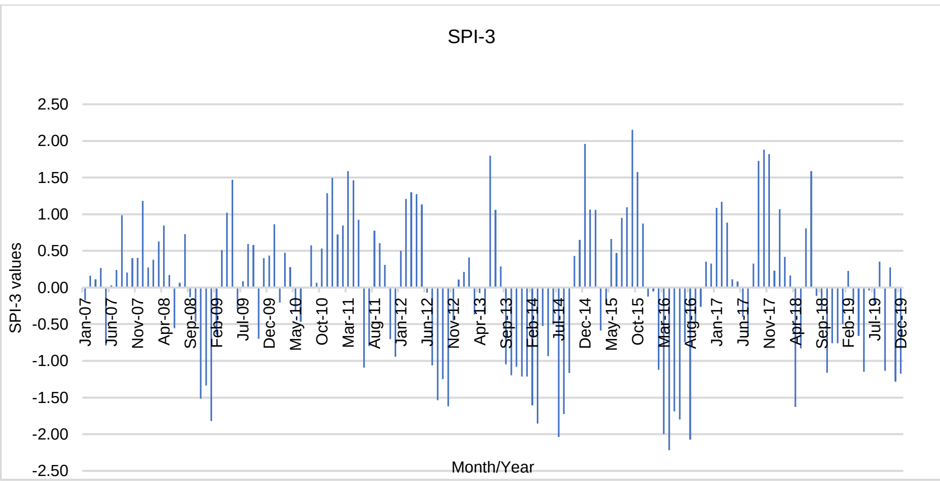

Figure 2 SPI-3 values of the Chuping rainfall station.

Mann-Kendall Trend Test

The Mann-Kendall Test was performed on SDI-3 and SPI-3 to observe the monthly trend of the hydrological drought and meteorological drought. The Mann-Kendall test results were interpreted at a *p*-value of 5% level of significance. The *z*-value and the *p*-value for SDI-3 and SPI-3 obtained by the test were as in Table 5 and 6 respectively. Analysing Table 5, it is found that six months (January, February, July, October, November and December) were found to have a *p*-value <0.05 indicating that there exists a trend during the month. Furthermore, it can be seen that all six months have substantial increasing trends due to the positive z-value. The remaining six months (March, April, May, June, August, and September) however, did not exhibit any significant trends due to a greater than 5% *p*-value. As a result, on an SDI-3 time frame, a positive trend for the hydrological drought was discovered. As for the streamflow volume, based on these findings, it is safe to conclude that the Sg. Jarum at Kg. Mesjid Perlis basin is generally also seeing an increase in streamflow volume.

Afterwards, for the SPI-3 trend, viewing Table 6, it is observed that five months (January, March, April, May and August) had obtained a *p*-value of less than 5%. However, positive and negative *z*-value was seen for the five months. Only the month of January had a positive *z*-value indicating January had a significant increasing trend. The other four months (March, April, May and August) nonetheless were found to have a negative trend due to the negative *z*-value obtained. The seven remaining months (February, June, July, September, October, November and December) were found to have no significant trend. As a result, it was discovered that the SPI-3 had an increasing and reducing trend, indicating that the Chuping region's precipitation also had an increasing and declining tendency.

The month of January was found to have a positive increasing trend for both of the indices. This may be due to the northeast monsoon that occurs from November to March. The heavy cumulative rainfall brought by the northeast monsoon may have resulted in the increasing trend observed in the month of January. Other than January, the SDI-3 and SPI-3 values identified different months that showed a trend. This may be due to the different upward and downward trends of streamflow volume and rainfall amount in the data set. Therefore, it is concluded that the Mann-Kendall Trend Test was able to detect the distinct trends of the SDI-3 and SPI-3, which are parallel to changes in Malaysia's monsoon.

Table 6: Results of Mann-Kendall Trend Test on SDI-3.

Month	January	February	March	April	May	June	July	August	September	October	November	December
z-value	2.2573	2.2573	1.7963	1.7693	1.8913	1.8913	2.1353	1.7693	1.8913	2.8674	2.6874	2.3793
p-value	0.0240	0.0240	0.0769	0.0769	0.0589	0.0589	0.0327	0.0769	0.05859	0.0041	0.0041	0.0173

Table 7: Results of Mann-Kendall Trend Test on SPI-3.

Month	January	February	March	April	May	June	July	August	September	October	November	December
z-value	0.7931	0.5491	-1.1592	-2.2573	-1.6472	0.5491	-0.1830	-1.6472	-0.4271	0.3050	-0.0610	-0.6711
p-value	0.4277	0.5830	0.2464	0.0240	0.0995	0.5830	0.8548	0.0995	0.6693	0.7603	0.9514	0.5022

Correlation of the Streamflow Drought Index (SDI) and Standard Precipitation Index (SPI)

The Spearman's rank correlation test with a significant *p*-value of 5% was tested on the SDI-3 and SPI-3 values. It is obtained that the *p*-value (r_s) of 0.0008 which is less than the 5% significant level. A correlation coefficient is considered significant if the *p*-value is less than 0.05. Therefore, there exists a relation between the SDI-3 and SPI-3 for this thesis case study. Other than that, as a result of the positive p-value (r_s), the SDI and SPI values are positively correlated. The study subconsciously concludes that there was a positive association between the hydrological and meteorological drought in Perlis based on the relationship between the SDI-3 and SPI-3 in this study. This is due to the fact that the SDI and SPI values were calculated to investigate the meteorological and hydrological drought conditions in Perlis. In addition, it was assumed that there would be a correlation between monthly precipitation and streamflow volume based on the SDI and SPI correlation in this study.

Conclusion

The SDI-3 and SPI-3 were discovered to be capable of observing the drought characteristics in Perlis. Thereafter, it was discovered that the region experienced more hydrological drought than meteorological drought. According to this study, Perlis recorded 46% of meteorological drought occurrences and 54% of hydrological droughts. This could be because the streamflow needed more time to recover after a severe hydrological drought incidence. Water sources are essential for the residents, thus it would be beneficial for the government to concentrate more on managing the diminishing water sources when a drought is occurring.

A significant trend was discovered by the Mann-Kendall Test on the SDI-3 and SPI-3 values for a portion of the month. The SDI-3 identified a trend with a *p*-value less than 0.05 in the months of January, February, July, October, November, and December. In the meantime, the SPI-3 identified a trend with a *p*-value of less than 0.05 in the months of January, March, April, May, and August. On both indices, the MK trend test revealed that January had a substantial positive trend. The Malaysian government should therefore pay closer attention to the drought occurrence in January.

Last but not least, a positive association between the SDI-3 and the SPI-3 was found using Spearman's rank correlation coefficient test with a *p*-value of 0.0008. It was determined that there was a positive relation from the *p*-value. This suggests that the amount of rainfall and streamflow in Perlis have a positive dependence on each other. Finally, it is concluded that Perlis would still be severely impacted by both droughts. Therefore, it is believed that the findings of this research can help the Malaysian government address the drought problem in Malaysia's northern region.

References

Abeysingha, N. S., & Rajapaksha, U. R. L. N. (2020). SPI-based spatiotemporal drought over Sri Lanka. *Advances in meteorology*, *2020*.

ABOUT US | *INFO KEMARAU*. (n.d.). http://infokemarau.water.gov.my/about.cfm.

Alias, D. N. H. (2016, March 30). Schools in Kedah, Perlis to close due to heatwave. Astro Awani. Retrieved May 13, 2023, from https://www.astroawani.com/berita-malaysia/schools-kedah-perlis-close-due-heatwave-100463.

Altın, T. B., Sarış, F., & Altın, B. N. (2020). Determination of drought intensity in Seyhan and Ceyhan River Basins, Turkey, by hydrological drought analysis. *Theoretical and Applied Climatology*, *139*(1), 95-107.

Alert over heavy rain and overflowing rivers goes out in Kelantan, Terengganu, Johor and Perlis. (2016, November 21). The Star. https://www.thestar.com.my/news/nation/2016/11/21/did-issues-warnings-infour-states-alert-over-heavy-rain-and-overflowing-rivers-goes-out-in-kelantan/.

Asadi Zarch, M. A. (2022). Past and future global drought assessment. *Water Resources Management*, *36*(13), 5259-5276.

Cao, S., Zhang, L., He, Y., Zhang, Y., Chen, Y., Yao, S., ... & Sun, Q. (2022). Effects and contributions of meteorological drought on agricultural drought under different climatic zones and vegetation types in Northwest China. *Science of the Total Environment*, *821*, 153270.

Chern, L. T., & Lim, R. (2019, July 29). Perlis, Kedah and Penang put on Yellow alert. *The Star*. https://www.thestar.com.my/news/nation/2019/05/08/perlis-kedah-and-penang-put-on-yellow-alert.

Chow, M. D. (2016, April 12). *Water rationing for Perlis if no rainfall in next four days*. New Straits Times. Retrieved May 26, 2023, from https://www.nst.com.my/news/2016/04/138747/water-rationing-perlis-if-no-rainfall-next-four-days?m=1.

Danandeh Mehr, A., Sorman, A. U., Kahya, E., & Hesami Afshar, M. (2020). Climate change impacts on meteorological drought using SPI and SPEI: case study of Ankara, Turkey. *Hydrological Sciences Journal*, *65*(2), 254-268.

Drought | National Geographic Society. (n.d.). https://education.nationalgeographic.org/resource/drought/.

Floods - more than 2,000 people in six states relocated. (2019, October 29). Malaysiakini. https://www.malaysiakini.com/news/497830.

Fung, K. F., Huang, Y. F., & Koo, C. H. (2020). Investigation of streamflow as a seasonal hydrological drought indicator for a tropical region. Water Supply, 20(2), 609-620.

Gu, L., Chen, J., Xu, C. Y., Kim, J. S., Chen, H., Xia, J., & Zhang, L. (2019). The contribution of internal climate variability to climate change impacts on droughts. Science of the Total Environment, 684, 229-246.

Heatwave-hit Perlis, Kedah likely to finish week at 39°C again. (2016, March 23). Today. https://www.todayonline.com/world/asia/heatwave-hit-perlis-kedahlikely-finish-week-39degc-again.

Ibrahim, Z. (2013, June 20). Many parts of Malaysia experiencing dry and hot spell. Borneo Post Online. https://www.theborneopost.com/2013/06/20/many-partsof-malaysia-experiencing-dry-and-hot-spell.

Ili Shazwani. (2016, March 22). Special prayers for rainfall in Perlis. New Straits Times. Retrieved May 26, 2023, from https://www.nst.com.my/news/2016/03/134396/special-prayers-rainfall-perlis?d=1.

Kendall, M. G. (1975): Rank Correlation Methods. – Charles Griffin, London, UK.

Laman Web Rasmi Jabatan Meteorologi Malaysia. (n.d.-b). https://www.met.gov.my/en/pendidikan/fenomena-cuaca/#Thunderstorms.

Li, L., She, D., Zheng, H., Lin, P., & Yang, Z. L. (2020). Elucidating diverse drought characteristics from two meteorological drought indices (SPI and SPEI) in China. Journal of Hydrometeorology, 21(7), 1513-1530.

Lin, H., Wang, J., Li, F., Xie, Y., Jiang, C., & Sun, L. (2020). Drought trends and the extreme drought frequency and characteristics under climate change based on SPI and HI in the upper and middle reaches of the Huai River Basin, China. *Water*, *12*(4), 1100.

Luhaim, Z. B., Tan, M. L., Tangang, F., Zulkafli, Z., Chun, K. P., Yusop, Z., & Yaseen, Z. M. (2021). Drought variability and characteristics in the Muda River Basin of Malaysia from 1985 to 2019. *Atmosphere*, *12*(9), 1210.

Mann, Henry B. "Nonparametric tests against trend." *Econometrica: Journal of the econometric society* (1945): 245-259.

Mckee TB, Doesken NY, Kleist Y (1993) The relationship of drought frequency and duration to time scales. 8th Conference on Applied Climatology, Anaheim, CA, 179–184.

Nalbantis, I., & Tsakiris, G. (2009). Assessment of hydrological drought revisited. *Water resources management*, *23*(5), 881-897.

OCHA (United Nations Office for the Coordination of Humanitarian Affairs). (2019, July 17). *Malaysia: Floods and landslides - Dec 2014*. ReliefWeb. https://reliefweb.int/disaster/fl-2014-000168-mys .

Páscoa, P., Gouveia, C. M., Russo, A., & Trigo, R. M. (2017). Drought trends in the Iberian Peninsula over the last 112 years. *Advances in Meteorology*, *2017*.

Pramudya, Y., & Onishi, T. (2018, March). Assessment of the standardized precipitation index (SPI) in Tegal City, Central Java, Indonesia. In *IOP conference series: earth and environmental science* (Vol. 129, No. 1, p. 012019). IOP Publishing.

Rahman, H. A. (2018). Climate change scenarios in Malaysia: Engaging the public. *International Journal of Malay-Nusantara Studies*, *1*(2), 55-77.

Spearman, C. (1961). The proof and measurement of association between two things.

United Nations. (n.d.). *Causes and Effects of Climate Change*. https://www.un.org/en/climatechange/science/causes-effects-climate-change.

Wang, Z., Li, J., Lai, C., Zeng, Z., Zhong, R., Chen, X., ... & Wang, M. (2017). Does drought in China show a significant decreasing trend from 1961 to 2009?. *Science of the Total Environment*, *579*, 314-324.

What Causes a Drought? (n.d.). NOAA SciJinks – All About Weather. https://scijinks.gov/what-causes-a-drought/.

Worst water shortage occurred in 1998 with 150 days of rationing | *The Star. (2014, February 26). Www.thestar.com.my; The Star. https://www.thestar.com.my/news/nation/2014/02/26/worst-water-shortage-occurred-in-1998-with-150-days-of-rationing/.*

Zalokar, L., Kobold, M., & Šraj, M. (2021). Investigation of Spatial and Temporal Variability of Hydrological Drought in Slovenia Using the Standardised Streamflow Index (SSI). Water, 13(22), 3197.

Zulkefli, A. S. (2017, January 9). Perlis on flood alert as two major rivers reach "warning" levels. New Straits Times. Retrieved January 23, 2023, from https://www.nst.com.my/news/2017/01/202944/perlis-flood-alert-two-major-rivers-reach-warning-levels.