Drought and climate change assessment using Standardized Precipitation Index (SPI) for Sarawak River Basin

C. H. J. Bong and J. Richard

ABSTRACT

Severe droughts in the year 1998 and 2014 in Sarawak due to the strong El Nino has impacted the water supply and irrigated agriculture. In this study, the Standardized Precipitation Index (SPI) was used for drought identification and monitoring in Sarawak River Basin. Using monthly precipitation data between the year 1975 and 2016 for 15 rainfall stations in the basin, the drought index values were obtained for the time scale of three, six and nine months. Rainfall trend for the years in study was also assessed using the Mann–Kendall test and Sen's slope estimator and compared with the drought index. Findings showed that generally there was a decreasing trend for the SPI values for the three time scales, indicating a higher tendency of increased drought event throughout the basin. Furthermore, it was observed that there was an increase in the numbers of dry months in the recent decade for most of the rainfall stations as compared to the previous 30 to 40 years, which could be due to climate change. Findings from this study are valuable for the planning and formulating of drought strategies to reduce and mitigate the adverse effects of drought.

Key words | agriculture, climate change, drought index, precipitation, Standardized Precipitation Index (SPI)

C. H. J. Bong (corresponding author)
J. Richard
Department of Civil Engineering, Faculty of Engineering,
Universiti Malaysia Sarawak,
94300, Kota Samarahan, Sarawak,
Malaysia
E-mail: *bhjcharles@unimas.my*

INTRODUCTION

Drought is a natural hazard with large impacts on regular human activities, reduction of crop production and water shortages. Drought is linked to precipitation intensity, amount of precipitation occurrences and time scale between two wet seasons. The severe drought in 1998 was connected to the strong El Nino Southern Oscillation event, which affected millions of residents in Sarawak, Malaysia, caused high global temperatures, disrupted water supply in regional areas, caused forest fires and impacted irrigated agriculture. According to the World Meteorological Organization (WMO), six drought periods in Sarawak were during the periods 1982–1983, 1986–1988, 1991–1992, 1997–1998, 2009–2010 and 2014–2016 due to the strong El Nino.

There are several established scientific methods to identify and forecast drought occurrence, such as Standardized Precipitation Index (SPI), Palmer Severity Index, Crop Moisture Index and Reclamation Drought Index, which are commonly used to determine the drought indices. These drought index values incorporate thousands of data on rainfall, stream flow and other water resources indicators into an understandable large representation. Some indices are more suitable than others for certain uses, even though none of the main indices is essentially superior to the rest in all circumstances. Each of the indices works in a different way depending on the need that arises (Othman *et al.* 2016a).

Drought indices such as the SPI can be used to evaluate the impact of climate change on short- and medium-term

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drought in a region (Lee *et al.* 2017). This can be done either by determining the changes in frequency of extreme events that might accompany climate change (Loukas *et al.* 2008), analysis of severity, duration and intensity of time series SPI (Lee *et al.* 2017) and trends projection of SPI using possible future climate change scenarios (Huang *et al.* 2016; Osuch *et al.* 2016). For the case of Peninsular Malaysia, a study conducted by Yusof *et al.* (2012) using SPI based on 33 years of daily precipitation data for 69 stations has shown upward trend values for drought events, especially in eastern and western parts. This finding concurs with the latest study by Tang (2019), where increasing hot years are evident from the temperature surges under the influence of El Nino and the co-occurrence of dry spells and heavy rainfall within the same year is an emerging weather pattern in Malaysia.

This study aims to understand the trend of annual monthly precipitation and whether climate change has increased the frequency of drought events in recent years in Sarawak River Basin. The trend of annual monthly precipitation for the selected rainfall stations in Sarawak River Basin was investigated by using Mann–Kendall (MK) test and Sen's slope estimator and compares the outcome with drought index. The SPI was chosen as the tool to analyse and monitor drought events in this study. This study will provide insights into drought assessment and also the impact from climate change for Sarawak River Basin which is lacking in the existing literature.

METHODOLOGY

The location of the selected rainfall stations in this study are as shown in Figure 1. Sarawak River Basin is one of the major river basins that is situated at the southern part of Sarawak, Malaysia, with a catchment area of approximately 2,456 km^2 and river length approximately 120 km. According to Hii *et al.* (2011), Sarawak River Basin mainly experiences two main monsoon seasons: northeast monsoon season (November–March) whereby the wet season is recorded and southwest monsoon season (June–September) whereby dry months are recorded. The climate of the river basin is classified as tropical rain forest that consists of high temperature and high annual total precipitation of about 3,830 mm (Abdillah *et al.* 2013). An earlier preliminary study by Bong *et al.* (2009) has shown that, generally, the mean annual rainfall, annual mean temperature and annual mean daily evaporation rate for Sarawak River Basin have an upward trend for the past three to four decades. However, limited studies on drought were found in the literature for the basin.

Rainfall data

Rainfall data and periods obtained for this study are shown in Table 1. The monthly rainfall data were collected from Drainage and Irrigation Department (DID), Sarawak. The selection of rainfall stations was based on sufficient rainfall record that was at least 30 years of data (in this case between the years 1975 and 2016). There are only 15 rainfall stations out of a total of 49 which meet the criteria as outlined, and these were used in this study.

Estimation of missing data

Estimation of missing data up to the year 2016 were made in this study to preserve the continuity of monthly precipitation data for SPI calculation and data consistency check to increase the accuracy of the SPI results. The percentages of missing data were calculated for all the selected precipitation stations. Only the precipitation stations with missing data less than 10% within the study period were selected for SPI analysis. Normal ratio method was applied to compute the missing value of the selected station by selecting the rainfall data of the three closest neighbouring stations.

Mann–Kendall (MK) test

The annual monthly rainfall trend for this study was determined by using two non-parametric tests, namely, Mann–Kendall (MK) test and Sen's slope estimator. The MK test and Sen's slope estimator have been commonly used to analyse trends for extreme rainfall events, such as the previous work done by Othman *et al.* (2016b) for the Pahang and Kelantan river basins in Malaysia. The MK test (Mann 1945; Kendall 1975; Gilbert 1987) is a non-parametric (distribution-free) numerical test usually proposed to investigate the trend within hydrological time

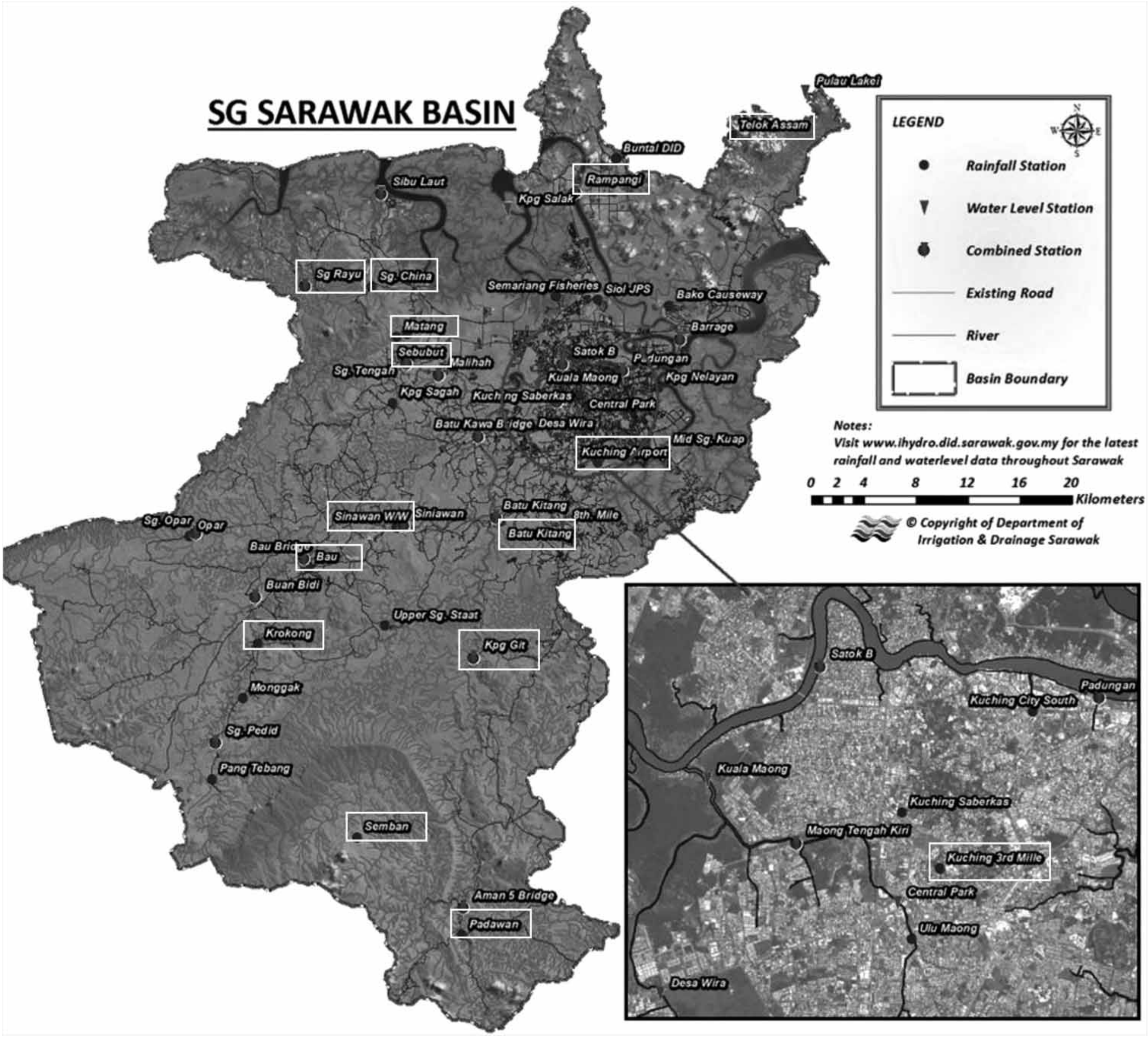

Figure 1 | Location of selected rainfall stations in Sarawak River Basin (DID 2019).

scales. The function of the MK test is to statistically evaluate whether there is a monotonic increasing or decreasing trend of the variable of interest over time.

The Mann–Kendall statistic, S, is incremented by 1 if data value from a later time period is higher than data value sampled from an earlier time period. If no trend presents at first, the S value is assumed to be 0 and is increased by 1 if the later time period data are higher than the earlier time period. The S value decreases by 1 if the earlier time period data are higher than later time period data. After the net result of all the increments and decrements of data have been computed, the final S value will be produced. The S value will be a positive value if the trend present is an upward trend and a downward trend will be a negative value.

Hypothesis testing is applied to determine the significance of the trend. For the test interpretation, the null hypothesis (H_o) indicates that there is no significant trend in the data series while the alternative hypothesis (H_a) indicates a significant trend present in the data series. If the Z

Table 1 | Details for the selected rainfall stations in Sarawak River Basin

		Location		
Station ID	**Station name**	**Latitude (°N)**	**Longitude (°E)**	**Data period**
1102019	Padawan	01°09°48	110°15°19	1975–2016
1201076	Semban	01°13°52	110°10°58	1975–2016
1301074	Krokong	01°21°55	110°06°52	1980–2016
1302078	Kampung Git	01°21°22	110°15°47	1986–2016
1401005	Bau	01°25°06	110°08°58	1975–2016
1402001	Siniawan W/W	01°26°46	110°12°37	1984–2016
1402047	Batu Kitang	01°27°01	110°16°55	1980–2016
1403001	Kuching Airport	01°29°27	110°20°57	1975–2016
1502001	Sebubut	01°34°49	110°13°03	1980–2016
1502026	Matang	01°34°39	110°12°29	1981–2016
1503083	Kuching Third Mile	01°31°46	110°20°32	1981–2016
1601001	Sungai Rayu	01°36°48	110°08°49	1986–2016
1601003	Sungai China	01°36°47	110°11°35	1981–2016
1603058	Rampangi	01°40°43	110°20°01	1985–2016
1704013	Telok Assam	01°43°04	110°16°29	1981–2015

value is smaller than the selected significance level or confidence level, the null hypothesis is accepted.

Sen's slope estimator

Sen's slope estimator is a non-parametric test applied to estimate the magnitude of the trend in time series data (Mayowa *et al.* 2015). The true slope (change per unit time) can be approximated by conducting a straightforward non-parametric procedure developed by Sen (1968) if a linear trend is shown in a time series.

Sen's slope estimator is tested by a probability value (p-value) two-tailed test at a certain confidence level. A positive magnitude value shows increasing trend with time while negative magnitude value shows decreasing trend with time. Sen's slope estimator is commonly used with the MK test and the statistic S value of the MK test is consistent with Sen's slope value. If the MK test statistic presents an upward trend, a similar positive slope magnitude can be obtained.

SPI methodology using Gamma probability distribution

SPI is a simple index and straight forward to be computed and statistically related depending on the probability of rainfall for any time period. SPI can help to assess drought severity for any location and any period because of its normal distribution (McKee *et al.* 1993) and the frequencies are consistent. According to Hayes *et al.* (2011), the WMO suggested SPI as the main meteorological drought index that countries are supposed to use to monitor and investigate drought situations.

McKee *et al.* (1993) proposed the categorization system for the SPI value which is classified into seven categories, as in Table 2, to identify drought severity. A drought occurs at any time, as the SPI is continuously negative until it achieves a value of -1.0 or more. Drought ends when the SPI value becomes positive.

McKee *et al.* (1993) recommended using the Gamma probability distribution in SPI calculation and it has been used in Mishra & Desai (2006), Belayneh & Adamowski (2013) and Lloyd-Hughes & Saunders (2002). For this study, the SPI values were calculated by using SPI software program (SPI_SL_6.exe) which can be downloaded for free from the National Drought Mitigation Center, University of Nebraska Lincoln site (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx).

Theoretically, the SPI represents the number of standard deviations, above or below that an event is from the mean.

Table 2 | SPI classification (McKee *et al.* 1993)

SPI value	Class	Cumulative probability	Probability of event (%)
SPI ≥ 2.00	Extreme wet	0.977–1.000	2.3%
1.50 ≤ SPI < 2.00	Very wet	0.933–0.977	4.4%
1.00 ≤ SPI < 1.50	Moderately wet	0.841–0.933	9.2%
−1.00 ≤ SPI < 1.00	Near normal	0.159–0.841	68.2%
−1.50 ≤ SPI < −1.00	Moderate dry	0.067–0.159	9.2%
−2.00 ≤ SPI < −1.50	Severe dry	0.023–0.067	4.4%
SPI < −2.00	Extreme dry	0.000–0.023	2.3%

The SPI will have a standard normal distribution with an expected value of 0 and a variance of 1 during the base period when the gamma parameters are estimated. After the SPI values are determined for the different time scales, the frequency/number of occurrences for drought for each decade can be determined by using the SPI value below −1.0 as the threshold value for drought condition (Loukas *et al.* 2008; Lee *et al.* 2017).

RESULTS AND DISCUSSION

Rainfall trend analysis

The missing values for stations Semban, Kampung Git and Sungai Rayu were determined to be more than 10% and were therefore excluded from this study. The estimation for missing values was done by using normal ratio method for the other 12 rainfall stations by interpolating the data of the selected station with the three neighbouring stations to obtain a complete dataset. Addinsoft's XLSTAT 2018 software package was applied for the non-parametric tests. The MK test and Sen's slope estimator with 95% confidence level were used to investigate the trend significance and magnitude, respectively. Table 3 shows the results of the trend analysis.

No significant trend was shown in the series among the 12 stations with p-value more than α value (0.05). Eight stations presented decreasing trend and four stations presented increasing trend in the series. The analysis results revealed that most of the rainfall stations had a decreasing trend in annual monthly rainfall. Hence, there was a symptom of rainfall decreases over this minimum 30-years study period. Reduction of rainfall trend might lead to severe drought in the future.

Table 3 | Trend analysis results

		Total monthly rainfall		
Station ID	Station name	*S*	*p*-value (two-tailed)	Sen's slope (mm/year)
1102019	Padawan	874	0.816	0.009
1301074	Krokong	−2,214	0.477	−0.042
1401005	Bau	−1,228	0.744	−0.015
1402001	Siniawan W/W	−2,555	0.330	−0.057
1402047	Batu Kitang	−5,495	0.078	−0.094
1403001	Kuching Airport	511	0.892	0.006
1502001	Sebubut	−2,029	0.513	−0.035
1502026	Matang	−4,816	0.107	−0.108
1503083	Kuching Third Mile	3,711	0.214	0.069
1601001	Sungai Rayu	−3,068	0.220	−0.101
1603058	Rampangi	383	0.873	0.011
1704013	Telok Assam	−2,086	0.466	−0.048

Variability of SPI time series

Drought studies are normally focused on the three- to nine-month time scales. Different time scales of the SPI presented differences in magnitude and duration of droughts. For short- and medium-term time scale, three-month SPI was used to analyse moisture conditions and hence available to provide a seasonal estimation of precipitation. The three-month SPI compares the rainfall for a specific three-month period with the total rainfalls from the same three-month period for all the years chosen in the historical record. The six-month SPI compares the rainfall for the selected period with the same six-month period over the historical report. Six-month SPI specifies medium-term trends in rainfall and is very effective in showing the precipitation over distinct seasons. Nine-month SPI is considered a hydrological drought index and becomes useful for monitoring the surface water resources. A downward trend of SPI value indicates a higher tendency of increased drought occurrence throughout the basin.

Most of the rainfall stations with the same time scales presented a downward trendline in the series. For the three-month SPI time scale, there were three rainfall stations showing an upward trendline but only two rainfall stations for six-month SPI and one rainfall station for nine-month SPI. The tendency of fewer but longer droughts was found in the six- and nine-month SPI averaging periods as compared to three-month SPI. This concurs with the findings of Naumann *et al.* (2018), where global median drought length is projected to slowly increase with global warming and climate change. A downward trend of SPI values indicates a higher possibility of increased drought happening throughout the basin, as shown in Figure 2 for Matang station. Similar trends were observed by Yusof *et al.* (2012) for daily rainfall data between the periods of November 1975 and October 2008 where most of Peninsular Malaysia experiences drier drought event. Table 4 summarizes the SPI values for the selected rainfall stations in Sarawak River Basin with the year the peak intensity of drought occurs for each of the time scales.

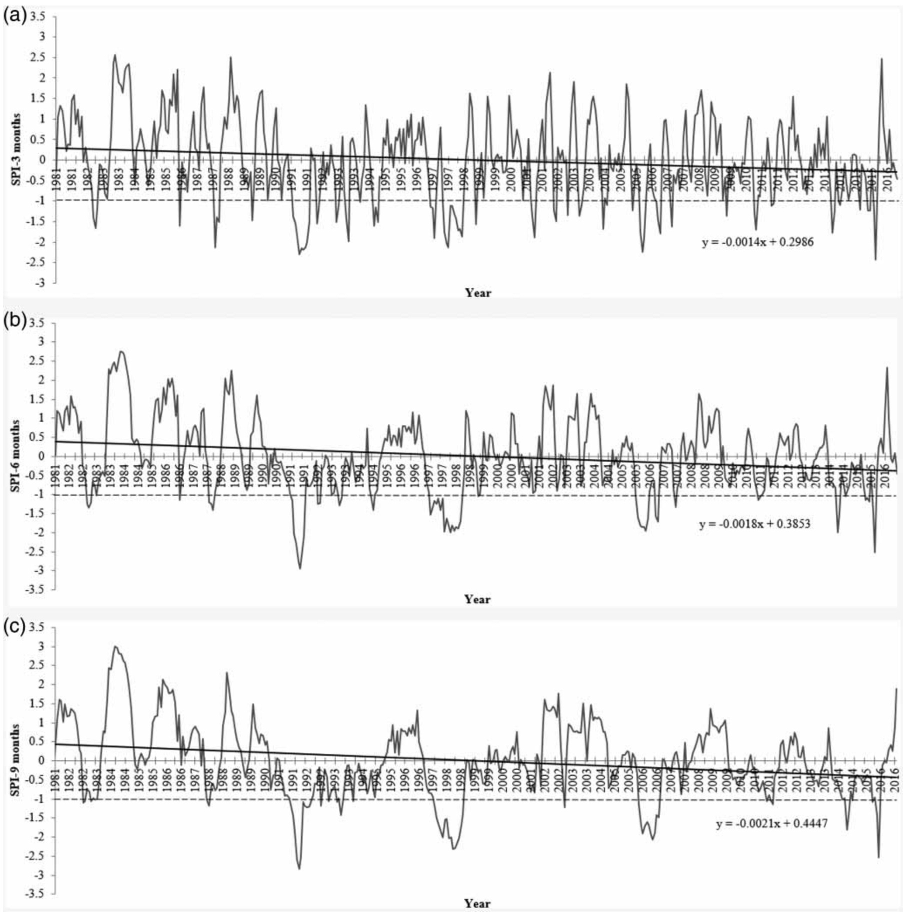

Figure 2 | SPI for Matang station: (a) three months; (b) six months; (c) nine months.

Table 4 | Summary of drought occurrences for the selected rainfall stations in Sarawak River Basin

Rainfall station	SPI interval (months)	Duration (months)	Mean intensity	Peak intensity SPI value	Peak intensity Year
Padawan	3	504	−0.01	−2.86	1982
	6	504	−0.01	−2.63	1975
	9	504	−0.01	−2.85	1975
Krokong	3	444	−0.01	−3.21	2014
	6	444	−0.01	−3.1	2014
	9	444	−0.01	−2.91	2014
Bau	3	504	−0.02	−2.81	1996
	6	504	−0.02	−2.64	1996
	9	504	−0.02	−3.12	1996
SiniawanW/W	3	384	−0.01	−3.16	2014
	6	384	−0.01	−3.15	1998
	9	384	−0.01	−3.31	1998
Batu Kitang	3	444	−0.02	−2.72	2016
	6	444	−0.01	−3.01	2006
	9	444	−0.01	−2.47	1991
Kuching Airport	3	504	−0.01	−3.22	1997
	6	504	−0.01	−3.6	1997
	9	504	−0.01	−3.0	1998
Sebubut	3	444	−0.01	−2.32	1983
	6	444	−0.02	−2.44	1991
	9	444	−0.01	−2.31	2006
Matang	3	432	−0.01	−2.42	2016
	6	432	−0.01	−2.94	1991
	9	432	−0.01	−2.83	1991
Kuching Third Mile	3	432	−0.01	−2.96	1996
	6	432	−0.01	−3.05	1998
	9	432	−0.01	−3.24	1998
Rampangi	3	372	−0.01	−3.61	1997
	6	372	−0.01	−3.13	1997
	9	372	−0.01	−3.14	1997
Sungai Rayu	3	384	−0.01	−2.51	2001
	6	384	−0.02	−2.25	2009
	9	384	−0.01	−2.18	2001
Telok Assam	3	432	−0.01	−2.87	1997
	6	432	−0.01	−3.08	1998
	9	432	−0.01	−3.53	1998

Application of the SPI in drought monitoring

Water supply shortage happened in 2014 in Malaysia due to the strong El Nino phenomenon causing extensive drought and absence of rains that affected agriculture and food production. For short- and medium-term time scale, three-month SPI was used to analyse moisture conditions and hence available to provide a seasonal estimation of precipitation. In the year 2014, the driest region in Sarawak River Basin was around Siniawan W/W rainfall station with the lowest SPI value of −3.21 and the wettest region was Padawan with the highest SPI value of 1.74, as shown in Table 5. SPI values of more than 1.0, mostly from August to October which is considered as wet season, indicates heavy rains and recurrent localized floods occur while the SPI values less than −1.0 from January to April were classified as dry. The most suitable period for growing crops is from December to March with SPI values between 1 and −1 as the growing season begins. As mentioned in Table 2, SPI values of −1 to 1 are considered near normal weather condition, that is, not too wet or too dry and suitable for planting. The most suitable harvesting season is from April to June with SPI values of less than 1. The SPI values continue to drop to −3 in July and illustrate that the weather is extreme dry and drought may occur. Tables 6 and 7 show the monthly values for six-month and nine-month SPI, respectively, for Sarawak River Basin in the year 2014. As the time scale increases, the SPI responds more slowly to short-term variation of rainfall and the cycles of negative SPI values become more visible for the year 2014 due to the El Nino phenomenon. However, the severity of the drought (based on the SPI values) seems to reduce slightly as the time scale increases.

Impact of climate change on drought frequency

Table 8 shows the total number of dry months for different decades for each of the time scales in the current study. Generally, most stations in Sarawak River Basin showed that the decade between the years 1997 and 2006 has the highest numbers of dry months with SPI values less than −1 (except for Padawan) as compared to the other decades. This higher number of dry months during the period 1997–2006 could be due to the super El Nino phenomenon that happened in 1997–1998. However, looking at a longer period, the most recent decade period of 2007–2016 tends to have higher numbers of dry months for most of the stations (except for Bau, Matang, Teluk Assam and Kuching Third Mile) as compared to the period 1977–1986 and 1987–1996. This could be due to the impact of climate

Table 5 | The monthly values for three-month SPI in 2014

Mth	Padawan	Bau	Kuching Airport	Third Mile	Matang	Batu Kitang	Krokong	Rampangi	Sebubut	Sungai Rayu	Telok Assam	Siniawan W/W
Jan	−0.9	0.05	−0.65	−0.18	−0.01	−0.65	0.03	−2.27	−0.16	−0.6	−1.54	−0.26
Feb	−2.07	−1.2	−1.52	−0.66	−0.9	−1.68	−1.37	−2.95	−1.23	−1.64	−1.57	−0.99
Mar	−1.85	−2.32	−2.91	−1.57	−1.77	−2.1	−2.79	−2.29	−1.83	−2.3	−2.32	−1.7
Apr	−0.89	−1.67	−1.26	−0.56	−1.23	−0.96	−1.37	−2.12	−0.94	−1.36	−1.97	−0.74
May	0.4	−0.91	−0.58	−0.14	−0.05	−0.7	−1.19	−1.16	0.4	0.09	−1.62	−0.22
Jun	−0.56	−1.88	0.48	0.68	−1	−1.18	−1.89	−1.39	−0.33	−0.54	−2.32	−0.92
Jul	−0.38	−2.72	−0.55	0.09	−1.1	−2.55	−3.21	−0.81	−0.89	−1.59	−1.75	−3.21
Aug	0.25	−0.67	1.4	0.76	−0.71	−0.12	−0.92	0.13	−0.17	−0.53	0.18	−1.03
Sep	0.98	−0.21	1.54	0.4	−0.09	0.58	−0.6	0.39	0.34	−0.21	0.28	0.34
Oct	1.74	0.71	0.99	0.64	−0.56	0.62	0.98	0.85	0.09	0.16	0.44	1
Nov	0.48	−0.16	−0.58	0.16	−0.97	−0.36	−0.11	0.03	−0.31	−0.46	−0.68	−0.61
Dec	0.02	−0.15	−0.59	−0.47	−0.78	−1	0.39	−0.5	−0.67	−0.82	−0.48	−1.23

Table 6 | The monthly values for six-month SPI in 2014

Mth	Padawan	Bau	Kuching Airport	Third Mile	Matang	Batu Kitang	Krokong	Rampangi	Sebubut	Sungai Rayu	Telok Assam	Siniawan W/W
Jan	−0.99	−0.18	−0.24	0.1	0.13	−0.89	−0.21	−2	0.12	−0.55	−1.63	−0.58
Feb	−1.8	−0.97	−1.46	−0.61	−0.76	−1.68	−1	−2.42	−0.98	−1.37	−1.89	−1.1
Mar	−1.54	−1.1	−1.73	−0.71	−0.66	−1.75	−0.94	−2.47	−0.72	−1.36	−2.03	−0.97
Apr	−1.4	−0.99	−1.61	−0.55	−0.77	−1.22	−1.05	−2.73	−0.74	−1.24	−2.25	−0.74
May	−1.47	−1.5	−1.67	−0.58	−0.82	−1.78	−1.83	−2.86	−0.84	−1.38	−2.11	−1.05
Jun	−1.71	−2.63	−2.12	−1.04	−1.99	−2.15	−3.1	−2.48	−1.85	−2.19	−2.82	−1.81
Jul	−0.97	−2.58	−1.37	−0.47	−1.5	−1.79	−2.57	−1.97	−1.38	−1.82	−2.39	−1.79
Aug	0.44	−1.03	0.5	0.26	−0.43	−0.49	−1.28	−0.78	0.23	−0.28	−1.09	−0.66
Sep	0.28	−1.39	1.34	0.61	−0.64	−0.02	−1.69	−0.54	−0.04	−0.55	−0.77	−0.5
Oct	1.11	−0.99	0.56	0.49	−1.05	−0.53	−0.84	0.15	−0.46	−0.78	−0.35	−1
Nov	0.48	−0.49	0.43	0.5	−0.92	−0.22	−0.69	0.05	−0.32	−0.65	−0.4	−1.01
Dec	0.65	−0.26	0.42	−0.13	−0.76	−0.31	−0.07	−0.3	−0.37	−0.75	−0.26	−0.78

Table 7 | The monthly values for nine-month SPI in 2014

Mth	Padawan	Bau	Kuching Airport	Third Mile	Matang	Batu Kitang	Krokong	Rampangi	Sebubut	Sungai Rayu	Telok Assam	Siniawan W/W
Jan	−1.12	−0.34	−0.33	0.21	0.05	−0.7	−0.55	−2.19	0.13	−0.78	−1.78	−0.78
Feb	−1.92	−1.11	−1.14	−0.32	−0.48	−1.3	−1.27	−2.5	−0.63	−1.4	−1.81	−1.29
Mar	−1.2	−1.01	−1.58	−0.41	−0.53	−1.43	−1	−2.35	−0.58	−1.17	−1.98	−1.19
Apr	−1.44	−1.14	−1.24	−0.28	−0.5	−1.35	−1.08	−2.48	−0.47	−1.13	−2.36	−0.98
May	−1.34	−1.26	−1.64	−0.56	−0.68	−1.73	−1.41	−2.54	−0.65	−1.18	−2.43	−1.15
Jun	−1.65	−1.59	−1.34	−0.43	−0.87	−1.89	−1.58	−2.67	−0.8	−1.47	−2.55	−1.26
Jul	−1.43	−1.68	−1.71	−0.49	−1.01	−1.77	−2.01	−2.69	−1	−1.55	−2.51	−1.59
Aug	−1.29	−1.51	−0.72	−0.28	−0.97	−1.48	−1.85	−2.42	−0.89	−1.4	−1.85	−1.26
Sep	−1.02	−2.39	−1.14	−0.76	−1.8	−1.51	−2.91	−1.94	−1.59	−2.05	−2.15	−1.65
Oct	0.08	−1.75	−0.5	−0.09	−1.46	−1.07	−1.59	−1.26	−1.04	−1.3	−1.38	−1.11
Nov	0.6	−0.91	0.02	0.24	−0.8	−0.56	−1.13	−0.57	−0.07	−0.5	−1.07	−0.85
Dec	0.21	−1.06	0.52	0.13	−1.03	−0.61	−1.03	−0.69	−0.53	−0.91	−0.76	−1.2

Table 8 | Total numbers of dry months (SPI < −1) for different decades

Sub-basin	Period	SPI 3	SPI 6	SPI 9
Padawan	1977–1986	17	19	15
	1987–1996	12	13	13
	1997–2006	18	17	18
	2007–2016	13	23	26
Bau	1977–1986	15	18	25
	1987–1996	10	11	11
	1997–2006	20	30	29
	2007–2016	15	15	15
Krokong	1987–1996	13	12	17
	1997–2006	29	31	30
	2007–2016	16	14	20
Kuching Airport	1977–1986	17	17	15
	1987–1996	12	8	11
	1997–2006	24	22	28
	2007–2016	12	17	20
Siniawan	1987–1996	14	17	13
	1997–2006	22	26	31
	2007–2016	20	17	19
Matang	1987–1996	23	18	18
	1997–2006	30	27	27
	2007–2016	14	12	10
Sebubut	1987–1996	13	8	5
	1997–2006	31	28	29
	2007–2016	16	17	14
Batu Kitang	1987–1996	17	14	16
	1997–2006	19	17	19
	2007–2016	26	23	23
Sungai Rayu	1987–1996	13	11	13
	1997–2006	18	21	20
	2007–2016	20	28	23
Rampangi	1987–1996	16	9	8
	1997–2006	21	13	13
	2007–2016	16	7	10
Teluk Assam	1987–1996	20	20	21
	1997–2006	17	21	23
	2007–2016	13	16	12
Kuching Third Mile	1987–1996	18	17	15
	1997–2006	21	25	28
	2007–2016	5	5	1

change, although more detailed study is needed to ascertain this hypothesis.

CONCLUSIONS

The analysis results generally showed decreasing trend for the SPI values for the three time scales which indicates a higher tendency of increased drought events throughout the basin. Also, an analysis on the numbers of dry months for the past decades has shown there is a tendency of increased drought events in the recent decade with more prolonged periods. Hence, it is predicted that drought will hit harder and for more prolonged periods in the future for the Sarawak River Basin. These findings indicated that climate change could affect the drought severity and subsequently the planning of water resources projects and drought management in the basin. Future work involving spatial mapping of SPI is suggested for the investigation of temporal and spatial variability of drought occurrences in the basin and their connection with possible hazards such as forest fires and floods.

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