Environment and Ecology Research 12(3): 223-231, 2024 http://www.hrpub.org
DOI: 10.13189/eer.2024.120301

Drought Monitoring due to Climate Change in Urban and Sub Urban Area

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Received May 17, 2023; Revised March 28, 2024; Accepted April 23, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Raja Muhammad Naufal Raja Azman, Nur Asmaliza Mohd Noor, Sharifah Abdullah, Marini Mohamad Ideris , "Drought Monitoring due to Climate Change in Urban and Sub Urban Area," Environment and Ecology Research, Vol. 12, No. 3, pp. 223 - 231, 2024. DOI: 10.13189/eer.2024.120301.*

(b): *Raja Muhammad Naufal Raja Azman, Nur Asmaliza Mohd Noor, Sharifah Abdullah, Marini Mohamad Ideris (2024). Drought Monitoring due to Climate Change in Urban and Sub Urban Area. Environment and Ecology Research, 12(3), 223 - 231. DOI: 10.13189/eer.2024.120301.*

Abstract Development and human activities have contributed to global warming and climate change, thus affecting water scarcity around the world. Due to this pattern, the establishment of knowledge on the drought index and drought event needs to be strengthened and enhanced, especially in Malaysia. Therefore, this study aims to assess the drought indices due to climate change impact on urban and sub-urban areas in Malaysia located at Langat River Basin and Pahang River Basin. The drought analysis using the Standardized Precipitation Evapotranspiration Index (SPEI) has been established for 3 months, 6 months and 12 months using the evaporation and rainfall data according to the identified station for 30 years that started from year 1988 until 2018 depending on the completeness of the data. The findings for urban areas indicated the significant values of the drought events compared to the sub-urban area which indicated the fluctuated values due to the land use and pattern of rainfall. Moreover, there were 2 and 1 severe drought event recorded by SPEI 3 and SPEI 12, respectively, for Langat River Basin whilst Pahang River Basin a total of 2 severe drought months by SPEI 3 were recorded, 1 severe drought by SPEI 6, and 6 severe drought events by SPEI12. Thus, findings from this study are very important to evaluate the condition of drought performance and deliver valuable information which is beneficial for the government and private agencies to plan mitigation strategies in the future.

Keywords Climate Change, Drought Index, SPEI, Water Scarcity

1. Introduction

Climate change has become a crucial issue recently due to rapid and improper human activities and development planning. The extreme event of drought is one of the consequences of climate change which led to a water deficit, and it became more frequent and longer. Drought can be influenced by various factors such as climate change, human activities, and land use. Alteration of the spatial and temporal distribution of precipitation and temperature, together with the raised-up in industrialization, urbanization, and land use, has contributed to climate change, thus the effect on the drought intensity and influencing the pattern of drought. Furthermore, human activities such as land use and construction can change drought evolution characteristics by changing the land use pattern, significantly impacting drought.

There are three common droughts: Meteorological, Agricultural, and Hydrological. The meteorological drought can be defined according to the dry period's dryness and duration by comparing it with the regular or average amount [1]. Meanwhile, the agricultural drought focuses on the precipitation storages, differences between actual and potential evaporation, soil water deficits, and reduced groundwater that can impact agriculture. Another definition of agricultural drought is a variable of crop susceptibility during the different stages of crop development from emergence to maturity. It involves various characteristics such as precipitation shortages, differences between actual and potential evapotranspiration, and soil moisture deficits [1]. The hydrological drought is an effect of periods of precipitation shortfall on the surface or subsurface water supply, and usually, it takes longer for precipitation deficiencies to show up in the hydrological components such as soil moisture, streamflow, and groundwater and reservoir levels [1]. Thus, the drought analysis usually focuses on the drought characteristics, duration, and severity of water resource management, improvement on the drought, and development of a drought warning system.

In order to determine the drought indices, a few methods have been adopted, such as Standard Precipitation Index (SPI), Standard Precipitation Evapotranspiration Index (SPEI), Palmer Drought Severity Index (PDSI), and Effective Drought Index (EDI). The SPI developed by McKee [2] was used to calculate the rainfall deficit by considering the precipitation in various time scales and normally using the 30 years of historical monthly precipitation. SPI was established to determine the precipitation deficit and effect of drought in different water sources and time scales [3];[4]. Meanwhile, the SPEI is determined according to the differences between precipitation and potential evapotranspiration. It is quite similar to the SPI; however a bit different from incorporating the temperature data [5]. The PDSI uses precipitation and temperature as required data to measure the moisture supply, which is more complicated than the SPI. The EDI was developed to calculate the drought index by considering the daily water accumulation with the weighting function for time passage [6]. It could accurately calculate daily drought severity and the current level of water resource availability [7]. However, the SPEI has been chosen to analyze the drought index in Urban and Suburban areas due to the availability of data, which is more useful in climate change studies through the combination of multi-timescale aspects of the SPI and evaporation. Besides, long-term analysis is available through more data required, around 30-50 years.

Malaysia has been blessed with abundant rainfall throughout the year. However, due to human activities and climate change, drought has become prevalent in Malaysia, contributing to the exceptional rainfall deficit and local water crisis events. In recent times, the scientist forecast that there is the possibility of three consecutive years of drought starting from 2019, which has led to several investigations on drought analysis. Moreover, in Malaysia, a series of drought events have been recorded starting from 1992, 1997, 1998, 2015, and 2016, thus leading to the significant drive to further study this to recommend the mitigation plan and lessen the effect of the drought event. The study on the drought in Malaysia began in early 2014 by looking at drought impacts on vegetation health by combining two types of drought assessment which are the meteorological part using SPI and the agricultural part using Normalized Differentiation Vegetation Index (NDVI) in Kedah in 2016, the application of SWSI and SIAP software to determine occurrences of drought in Langat River Catchment and trend analysis concerning the drought episode in 2018 and 2020 drought indices monitoring using SPI and Z index score for Gua Musang Kelantan [8];[9];[10]. Therefore, there are many opportunities to explore in terms of assessing drought indices in suburban and urban areas, which can contribute to the knowledge of the water scarcity in that area. The findings can help the government in terms of how to plan mitigation action to lessen the effect of drought.

Thus, this paper aims to assess the drought indices due to climate change impact on the urban focusing on Langat River Basin and sub urban area focusing on Pahang River Basin in Malaysia.

2. Materials and Methods

2.1. Site Description

Langat River Basin, laid in the urban area, is a trans-state river basin located in the mid-western of Peninsular Malaysia and has undergone rapid urbanization, industrialization, agriculture, and road networks [11]. It is located at latitude N 2° 40' 0'' and N 3° 20' 0'' and between longitude E 101° 20' 0'' and E 102° 0' 0'' as shown in Figure 1 [12].

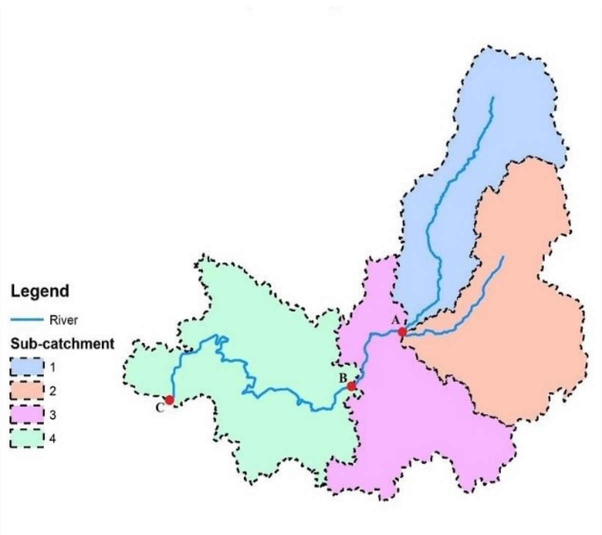

Figure 1. Map of Langat River Basin [12]

The calculation of the drought index using SPEI was involved with the monthly rainfall and monthly evaporation data obtained from DID Malaysia and MET

Malaysia for 30 years, from 1988 until 2018. Table 1 shows the list and location of rainfall stations for the Langat River Basin.

Table 1. List and location of rainfall station for Langat River Basin [12]

STATION	LATITUDE	LONGITUDE
Tadika Kemas Kg. Tg. Sepat	2° 40’ 53’’	101° 33’ 49’’
P/A Sg. Pelek Sepang	2° 37’ 58.9’’	101° 37’ 26.2’’
P/A Kg. Tali Air Morib	2° 44’ 39’’	101° 27’ 02’’
Kg. Salak Tinggi	2° 47’ 19.2’’	101° 44’ 31.1’’
P/A Kelanang	2° 48’ 44’’	101° 25’ 6’’
Pejabat JPS Sg. Manggis	2° 49’ 35’’	101° 32’ 30’’
Ldg. Brooklands	2° 49’ 40’’	101° 33’ 15’’
P/A Pekan Banting	2° 48’ 38’’	101° 30’ 30’’
P/A Sg. Sedu	2° 51’ 21.1’’	101° 30’ 53’’
Dengkil	2° 51’ 20.8’’	101° 40’ 53.1’’
KLIA	2° 48’ 17.5’’	101° 41’ 30.5’’
RTB Bukit Changgang	2° 48’ 41’’	101° 39’ 15’’
Bukit Changgang	2° 48’ 48.5’’	101° 38’ 30.9’’
Paya Indah	2° 52’ 44’’	101° 37’ 09’’
Kg Jenderam Hilir	2° 51’ 41’’	101° 44’ 7’’
Sek. Men. Bandar Tasik Kesuma	2°53’55.47’’	101° 52’ 13.3’’
P/A Bt. 9 Sijangkang	2° 57’ 23’’	101° 26’ 03’’
P/A Bt 7 Sijangkang	2° 57’ 23’’	101° 26’ 03’’
Ldg. Bkt. Cheeding	2° 54’ 40’’	101° 34’ 35’’
Puncak Niaga Putrajaya	2° 54’ 40’’	101° 41’ 50’’
RTM Kajang	2° 59’ 46’’	101° 47’ 8.9’’
Kolam Takungan Sg. Merab	2° 56’ 43’’	101° 44’ 60’’
Stor JPS Hulu Langat	2° 56’ 10’’	101° 45’ 49’’
Kajang	2° 59’ 33.7’’	101° 47’ 7.8’’
Sg. Rinching	2° 54’ 54.7’’	101° 49’ 18.9’’
Sg. Raya Bt.9 Hulu Langat	3° 04’ 04’’	101° 46’ 19’’
Sg. Serai Bt.12 Hulu Langat	3° 05’ 58’’	101° 47’ 51’’
Empangan Semenyih	3° 04’ 43’’	101° 52’ 50’’
Kg. Pasir	3° 00’ 48.4’’	101° 51’ 57.8’’
Ldg. Dominion	3° 00’ 13’’	101° 52’ 55’’
TNB Pansun	3° 12’ 34.7’’	101° 52’ 33.1’’

Pahang River Basin was laid in the suburban area located in the Eastern part of Peninsular Malaysia with latitude N 2° 48’ 45’’ and N 3° 40’ 24’’ and longitude E 101° 16’ 31’’ and E 103° 29’ 34’’ as shown in Figure 2 [13].

Monthly rainfall and evaporation data gained from the Meteorological Department Malaysia and Department of Irrigation and Drainage Malaysia for 30 years, from 1988 until 2018, has been used to calculate the drought index using the SPEI for the suburban area. Table 2 shows the list and location of rainfall stations for the Pahang River Basin.

Table 2. List and location of rainfall station for Pahang River Basin [12]

STATION	LATITUDE	LONGITUDE
Ladang Karmen	3° 20’ 20’’	102° 24’ 50’’
Kg. Batu Cek Mek	3° 19’ 40’’	102° 30’ 25’’
Kg. Kuala Bera	3° 23’ 25’’	102° 32’ 00’’
Temerloh (Lubuk Pasu)	3° 25’ 48’’	102° 25’ 12’’
Est. Kg. Awah	3° 30’ 00’’	102° 32’ 25’’
Paya Membang	3° 27’ 15’’	103° 02’ 25’’
Kg. Serambi	3° 29’ 50’’	103° 08’ 20’’
Paloh Inai (Serambi)	3° 28’ 48’’	103° 07’ 48’’
Permatang Pauh	3° 28’ 10’’	103° 23’ 00’’
Pekan	3° 29’ 24’’	103° 24’ 36’’
Empangan Repas	3° 33’ 36’’	101° 52’ 48’’
Lubok Paku	3° 31’ 10’’	102° 46’ 40’’
Kg. Temai Hilir	3° 32’ 10’’	103° 14’ 50’’
Rumah Pam Pahang Tua di Pekan	3° 33’ 40’’	103° 21’ 25’’
Kastam Kuala Pahang	3° 32’ 00’’	103° 27’ 55’’
Kuala Krau	3° 42’ 40’’	102° 22’ 05’’
Paya Gintong di Jerantut	3° 51’ 30’’	102° 26’ 40’’
Peri Jerantut	3° 57’ 45’’	102° 25’ 40’’
Rumah Pam Paya Kangsar	3° 54’ 15’’	102° 26’ 00’’
Kg. Sg. Yap	4° 01’ 55’’	102° 19’ 30’’

Figure 2. Map of Pahang River Basin [13]

2.2. Standard Precipitation Evapotranspiration Index (SPEI)

SPEI was calculated at the monthly resolution, and index values were fitted by maximum likelihood estimation and normalized using the two-parameter gamma distribution for SPI and generalized extreme value (GEV) distribution for SPEI. The computation of SPEI can be performed based on the (1) [5]. The data was analyzed in order to calculate SPEI using the Rstudio software.

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \qquad (1)$$

Where W= $[-2 \ln (P)]^{0.5}$ for $P \leq 0.5$; P=1-F(x); C_0 =2.515517, C_1=0.802853, C_2=0.010328; d_1=1.432788, d_2=0.189269 and d_3=0.001308 [5].

3. Results and Discussions

The SPEI was analyzed using the evapotranspiration data and monthly rainfall data for 30 years from 1988 to 2018 for the Langat and the Pahang River basin. The analysis has been conducted using the 3-month, 6-month and 12-month time scales, reflecting the moisture conditions in the short term and long term besides providing a seasonal precipitation estimation [14]. The trends of the 3, 6, and 12 months for both river basins are shown in Figures 3, 4, 5, 6, 7 and 8. The Langat River Basin clearly showed the significant condition of the drought event, whilst the Pahang River Basin indicated a fluctuating pattern of the drought event. As for the Langat River Basin, the rainfall deficiency clearly shows a significant condition from 1998 until 2007 for SPEI 3, SPEI 6, and SPEI 12, respectively. This pattern of condition indicated that the magnitude of drought events occurred during that time. The SPEI 3 was documented as the highest severe drought during August 1998 with a value of severity -1.6079, as shown in Figure 3, whilst SPEI 6 recorded the highest moderate drought occurred on August 2001 with a severity of -1.396, as depicted in Figure 5. The highest severity drought with -1.50 was found during June 1999, as shown in Figure 7 for SPEI 12. Many reasons influenced the severity and magnitude of the droughts, such as the location and the lower precipitation rate [15];[16].

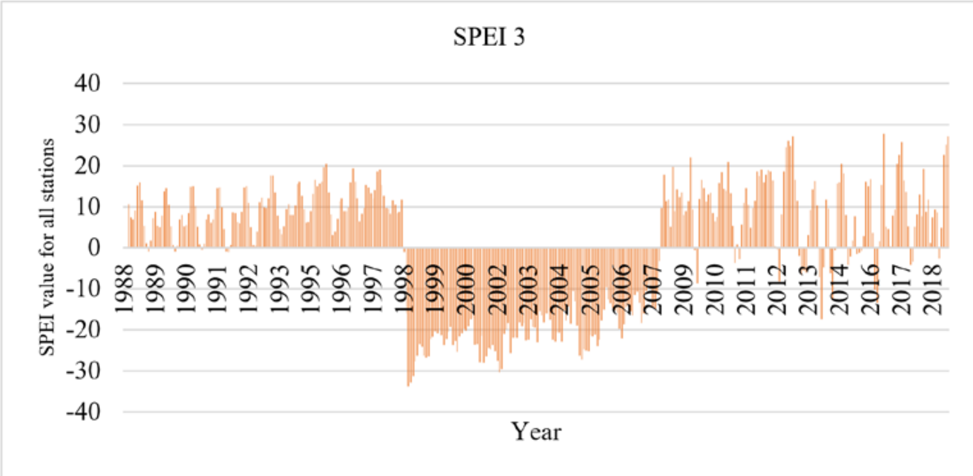

Figure 3. Trends of SPEI 3-months for Langat River Basin

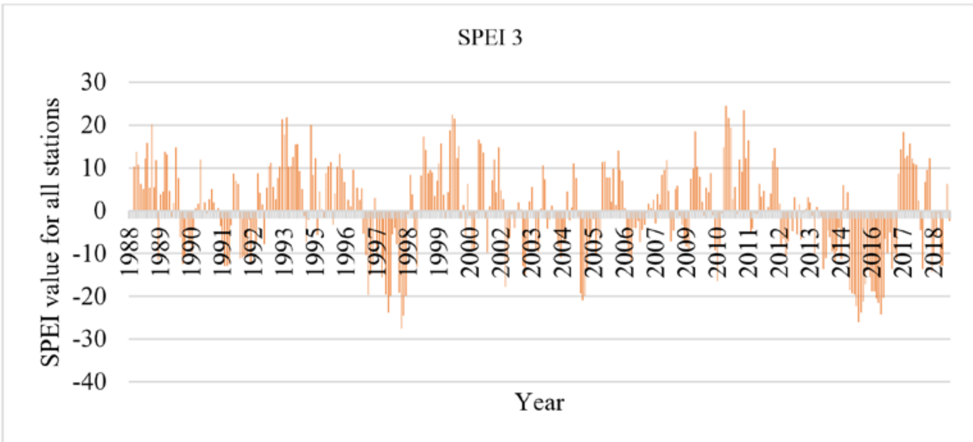

Figure 4. Trends of SPEI 3-months for Pahang River Basin

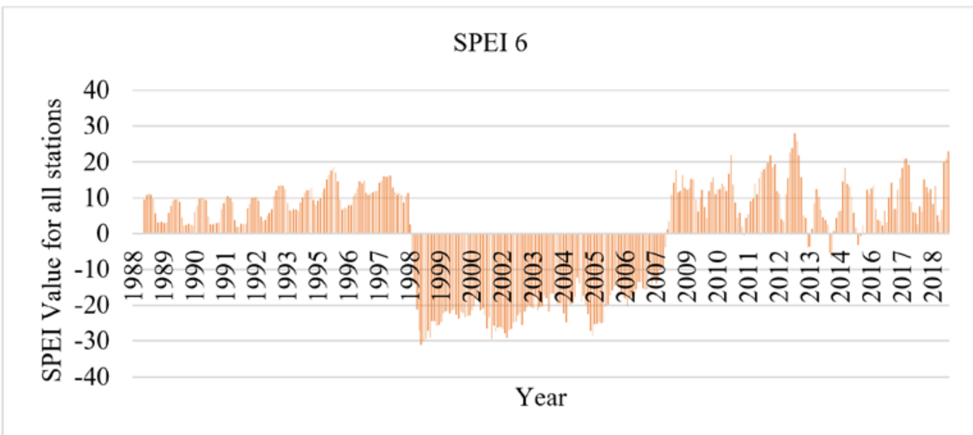

Figure 5. Trends of SPEI 6-months for Langat River Basin

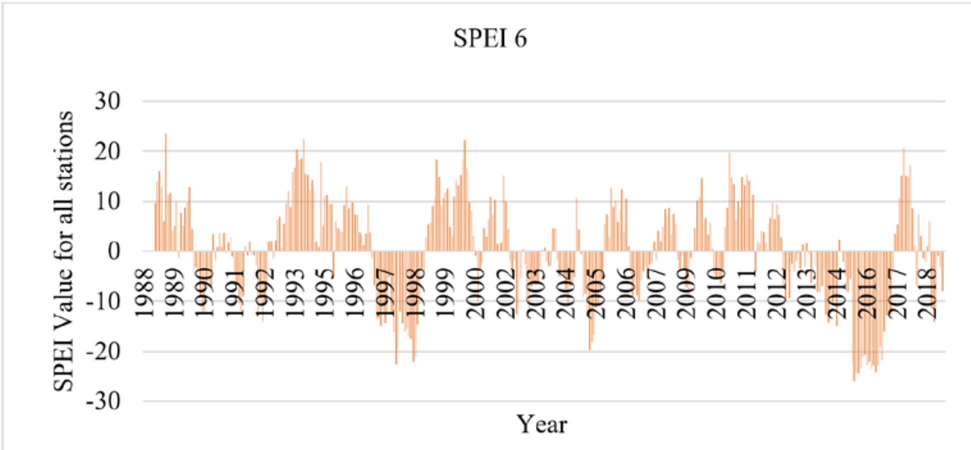

Figure 6. Trends of SPEI 6-months for Pahang River Basin

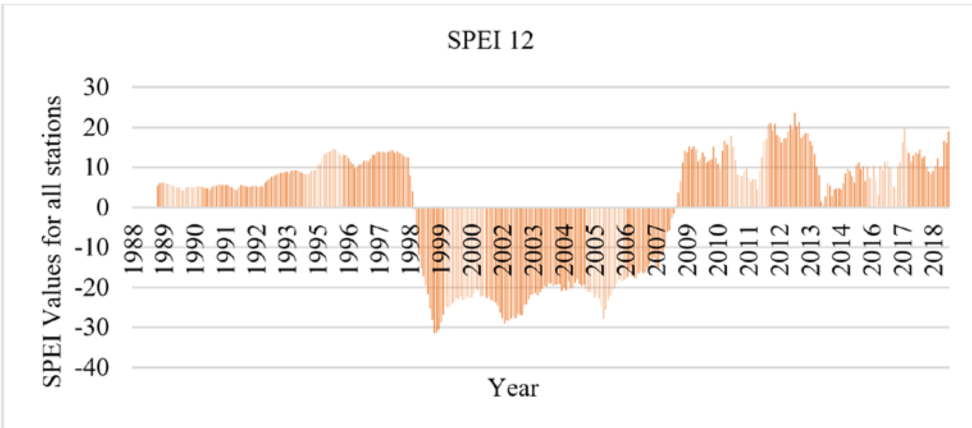

Figure 7. Trends of SPEI 12-months for Langat River Basin

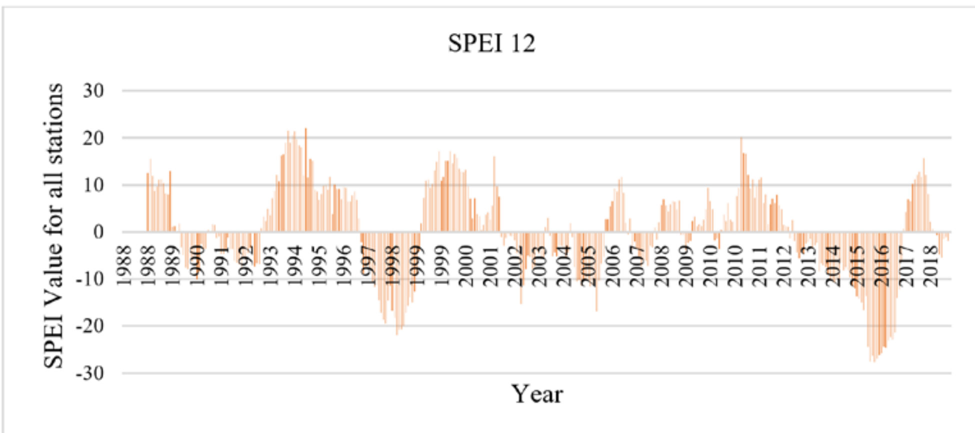

Figure 8. Trends of SPEI 12-months for Pahang River Basin

Fluctuation pattern between 30 years of data for the Pahang River Basin has been observed from 1990-1992, 1996-1998, 2002-2004 and 2015-2016. The highest severity drought of SPEI 3 occurred during April 1998 with a value of -1.612, as shown in Figure 4. Meanwhile, Figure 6 indicates the value of the severe drought during July 2015, with a value of -1.518 for SPEI 6. The SPEI 12 has been observed to have a severe drought with a value of -1.623 in March 2016, as shown in Figure 8. The SPEI 12 values are relatively rigorous, which may reveal the differences of inter-annual drought phase, and has clearly expressed the drought on a large spatial scale. However, the SPEI 3 reveals the variations in the drought situations over a short term, with small sensitivity to the inter-annual differences. Therefore, the SPEI value indicates more significant variations in the drought event with a smaller time-based scale and short duration due to over storage of rainfall, according to Kim et al. [7] thus the monthly SPEI value is contributed by the variations in monthly temperature and rainfall, therefore, it can redirect the content of soil water better [17].

Many factors affect the trend of drought patterns, such as rainfall amount or pattern of rainfall and land use characteristics. However, certain factors caused by climate change modify the form, intensity and timing of water demand, precipitation, and runoff. The availability of water becomes less predictable due to the contribution of the increased period of drought and higher temperatures. The irregular rainfall pattern can be observed over the last two decades, which affected the annual precipitation and daily temperature, thus prolonging dry periods for a few years in Malaysia [18]. Besides, the deterioration of water quality and groundwater also contributed to the degradation of the water supply. Instead, the increase on water demand due to the higher population growth, economic development, and changes in the rainfall pattern due to climate change has led to prolonged duration and magnitude of the drought events. According to Tan et al. [19], the greater increase in the warm index was found in the southern of peninsular Malaysia indirectly due to climate change, rapid urbanization, and industrialization, which has induced more warm days in the last decade.

Land use changes are basically involved with human use for example, terrestrial space for economic, residential, recreational conservation, and government purpose such as deforestation that has significantly increased the temperature. Furthermore, the changes in land use patterns and climate change are inter-relatable, where land use changes the concentration of greenhouse gasses, thus contributing to climate change [20]. The urban area, which already has the changes in the land use pattern, significantly impacts drought propagation, and this can be observed clearly by comparing between the Pahang River Basin and Langat River Basin. Zhou et al. [21] have conducted a study to investigate the relationship among drought indices and concluded that forest and cover types are significantly affected since climate change affects vegetation growth due to the conversion of forest land for economic development reasons.

In the statistical method, drought has been grouped into four classes: near normal, moderate, severe, and extreme drought, according to the SPEI Value as depicted in Table 3.

Table 3. Classification of SPEI

SPEI Values	Classification
2.00 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

There were 2 and 1 severe drought recorded for SPEI 3 and SPEI 12, respectively, for Langat River Basin, as shown in Table 4. Pahang River Basin recorded a total of 2 severe drought months by SPEI 3, 1 severe drought by SPEI 6, and 6 severe drought events by SPEI12, as shown in Table 5. This analysis is very important in order to extract the condition of drought performance and deliver valuable information on the option of drought differences, thus recognising the option of drought episodes with regard to their time and seriousness [22];[18].

The trend for SPEI3, SPEI6, and SPEI12 for Langat River Basin is slightly different from the Pahang River Basin due to the different areas, climate, development of the area, and many more. Furthermore, the temporal trends for SPEI did not specify a fixed shape and tend to vary occasionally because of the differences on temperature and total rainfall for a specific station [23]. Besides, the high sensitivity of SPEI depends on the complexity of the time series, which varies from one station to another station.

Table 4. Frequency of drought based on SPEI values for 30 years for Langat River Basin

SPEI Values	Condition	Frequency 3 Month	Frequency 6 Month	Frequency 12 Month
2.0 and more	Extremely Wet	0	0	0
1.50 to 1.99	Severely Wet	0	0	0
1.0 to 1.49	Moderately Wet	11	8	3
-0.99 to 0.99	Near Normal	304	301	304
-1.00 to -1.49	Moderately Drought	52	58	60
-1.50 to -1.99	Severe Drought	2	0	1
-2.00 or Less	Extremely Drought	0	0	0

Table 5. Frequency of drought based on SPEI values for 30 years for Pahang River Basin

SPEI Values	Condition	Frequency 3 Months	Frequency 6 Months	Frequency 12 Months
2.0 and more	Extremely Wet	0	0	0
1.50 to 1.99	Severely Wet	0	0	0
1.0 to 1.49	Moderately Wet	15	12	12
-0.99 to 0.99	Near Normal	331	337	337
-1.00 to -1.49	Moderately Drought	24	22	16
-1.50 to -1.99	Severe Drought	2	1	6
-2.00 or less	Extremely Drought	0	0	0

4. Conclusions

Findings from this study indicated that Langat River Basin recorded more events for moderately drought compared to the Pahang River Basin due to the situation of the basin, which is located in an urbanized area and has different conditions of rainfall patterns. As a result, it is believed that Langat River Basin will expose more on the condition of drought events. Thus, the concerted effort needs to be tackled and addressed to lessen this event's impact. The involved parties i.e. government or private agencies, to propose the reducing planning in the future.

Acknowledgements

This work was supported by the Ministry of Higher Education (MOHE) under the Fundamental Research Grant Scheme entitled Assessment of Water Scarcity-Related Drought Index for Water Security in Malaysia with the grant number 600-RMI/FRGS 5/3 (265/2019).

REFERENCES

[1] Brüntrup, M., Tsegai, D. (2017). Drought adaptation and resilience in developing countries. Briefing Paper, No. 23/2017, Deutsches Institut für Entwicklungspolitik (DIE), Bonn

[2] Mckee, T. B., Doesken, N. J., Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In: Proc. of the 8th Conference on Applied Climate, Anaheim, CA, USA, 179-184.

[3] Guenang, G. M., Mkankam Kamga, F. (2014). Computation of the standardized precipitation index (SPI) and its use to assess drought occurrences in Cameroon over recent decades. Journal of Applied Meteorology and Climatology, 53(10), 2310–2324. https://doi.org/10.1175/JAMC-D-14-0032.1

[4] Othman M., Ash'aari Z.H., Muharam F.M., Sulaiman W.N.A., Hamisan H., Mohamad N.D., Othman N.H. (2016). Assessment of drought impacts on vegetation health: A case study in Kedah. 8 th IGRSM International Conference and Exhibition on Remote Sensing & GIS (IGRSM 2016) IOP Pub IOP Conf. Series: Earth and Environmental Science 37, 1-13. https://doi.org/10.1088/1755-1315/37/1/01207

[5] Serrano S.M.V., Beguería, S., Moreno, J.L. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of Climate, Volume 23, 1696-1718. https://doi.org/10.1175/2009JCLI2909.1

[6] Byun, H. R.., Wilhite, D. A. (1999). Objective quantification of drought severity and duration. Journal of Climate, 12, 2747-2756. https://doi.org/10.1175/1520-0442(1999)012<2747:OQODSA>2.0.CO;2

[7] Kim, D. W., Byun, H. R., Choi, K. S. (2009). Evaluation, modification, and application of the effective drought index to 200-Year drought climatology of Seoul, Korea. Journal of Hydrology, 378(1–2), 1–12.

[8] Nor Adawiyah, A., Suhami, J., Abdul Rahman, K. (2014). Capacity development to support national drought management policy, Hanoi, May 2014, Country Report, 1 2.

[9] H Khan, M. M., Muhamad, N. S., El-Shafie, A. (2018). Wavelet-ANN vs ANN based model for hydro meteorological drought forecasting, Water 10, 1-21. https://doi.org/10.3390/w10080998

[10] Hui Mean, F., Yusof, Z., Yusof, F. (2018). Drought analysis and water resource availability using standardized precipitation evaporation index. Atmosphere Resources 201, 102-115.

[11] Toriman M. E., Mokhtar M.B., Hossain M.A.A., Aziz N.A.A., Mohamad S., Hashim N.M., Ahmad S., Ali N., Mohd Fuad M.J., Habibah A., Hamzah J., Er A.C., Hussain M.Y. (2012). Social learning approach in integrated river basin management-lessons from the Langat River Basin, Malaysia. Advances in Natural and Applied Sciences, 6(1), 42–5.

[12] Department of Irrigation and Drainage 2017 List and location of hydrological station for Malaysia. http://h2o.water.gov.my/v2/index.cfm. (Accessed 19 November 2020)

[13] Tachikawa,Y., James, R. A. K., M. N. bin M. D. (2004).

Pahang River. Malaysia-5, 170, 12. Retrieved October 5, 2022, from http://hywr.kuciv.kyoto-u.ac.jp/ihp/riverCatalogue/Vol_05/7_Malaysia-5.pdf

[14] Pingping, C.H.U., Yancheng, H.A.N., Shiyuan, F. (2019). Spatiotemporal characteristics of drought in Shanxi Province based on SPEI. IOP Conference Series: Earth and Environmental Science, 376(1), 1-6. https://doi.org/10.1088/1755-1315/376/1/012003

[15] Quang, C. N. X. Hoa, H. V., Giang, N. N. H., Hoa, N. T. (2021). Assessment of meteorological drought in the Vietnamese Mekong delta in period 1985-2018. IOP Conference Series: Earth and Environmental Science, 652(1), 1-8. https://doi.org/10.1088/1755-1315/652/1/012020

[16] Fung, K. F., Huang, Y. F., Koo, C. H. (2020). Spatiotemporal analysis of seasonal SPEI in Peninsular Malaysia. IOP Conference Series: Earth and Environmental Science, 476(1), 1-8. https://doi.org/10.1088/1755-1315/476/1/012113

[17] Wu H., Soh L.K., Samal A., Hong T., Marx D., Chen X. (2009). Upstream-downstream relationships in terms of annual streamflow discharges and drought events in Nebraska. Journal of Water Resource and Protection, 01(05), 299–315. https://doi.org/10.4236/jwarp.2009.15037

[18] Yusof, F., Hui-Mean, F., Suhaila, J., Yusof, Z. (2013). Characterisation of drought properties with bivariate copula analysis. Water Resources Management, 27(12), 4183–4207. https://doi.org/10.1007/s11269-013-0402-4

[19] Tan, M.L., Juneng, L., Tangang, F.T., Chung, J.X., Radin, F.R.B. (2021). Changes in temperature extremes and their relationship with ENSO in Malaysia from 1985 to 2018. International Journal of Climatology 41, 2564-2580. https://doi.org/10.1002/joc.6864

[20] Li, C., Zhang, X., Yin, G., Xu, Y., Hao, F. (2022). Evaluation of drought propagation characteristics and influencing factors in an arid region of Northeast Asia (ARNA). Remote Sensing 14(3307), 1-20.

[21] Zhou, K. Li, J., Zhang, T., Kang, A. (2021). The use of combined soil moisture data to characterize agricultural drought conditions and the relationship among different drought types in China. Agricultural Water Management, 243, 106479. https://doi.org/10.1016/j.agwat.2020.106479

[22] Society, T. E., Hu, Y., Yue, S., Wang, C. Y. (2016). Water tower of the Yellow River in a changing climate: Toward an integrated assessment. Water Resources Management, 13(3), 245–259.

[23] Mutsotso, R. B., Sichangi, A. W., Makokha, G. O. (2018). Spatial-temporal drought characterization in Kenya from 1987 to 2016. Advances in Remote Sensing, 07, 125-143. https://doi.org/10.4236/ars.2018.72009