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Comparative study of meteorological and hydrological drought characteristics in the Pekalen River basin, East Java, Indonesia

Donny HARISUSENO ✉

University of Brawijaya, Faculty of Engineering, Water Resources Engineering Department, MT. Haryono Street No. 167, 65145, Malang, Indonesia

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Abstract

Drought is known as a normal part of climate and including in a slow-onset natural hazard which may have several impacts on hydrology, agriculture, and socioeconomic. Drought monitoring, including its severity, spatial and duration is required and becomes an essential input for establishing drought risk management and mitigation plan. Many drought indices have been introduced and applied in regions with different climate characteristics in the last decades. This paper aims to compare standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) along with standardized streamflow index (*SSI*) in Pekalen River Basin, East Java, Indonesia. The statistical association analyses, included the Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s) were performed to examine the degree of consistency between monthly and annual drought index of *SPI* and *RAI*. Additionally, the comparative analysis was performed by overlapping both monthly and annual drought index from the *SPI* and *RAI* with the *SSI* at hydrological years. The study revealed that the characteristic of the annual drought index between the *SPI* and *RAI* exhibits pattern similarity which indicated by the high correlation coefficient between them. Further, the comparative analysis on each hydrological year showed that the *SPI* and *RAI* were very well correlated and exhibited a similar pattern with the *SSI*. Overall, the *SPI* shows better performance than the *RAI* for estimating drought characteristic either monthly or annual basis. Hence, the *SPI* is considered as a reliable and effective tool for analyzing drought characteristic in the study area.

Key words: *drought index, rainfall anomaly index, standardized precipitation index, standardized streamflow index*

INTRODUCTION

Drought has a close relationship with weather condition and commonly is defined as a meteorological event which is indicated by lack of precipitation over an extended period of time compared with normal precipitation or mean of precipitation from at least 30 years of precipitation data [MORID *et al.* 2006]. Due to a slow evolution or developing in time, drought is hard to detect and becoming a recurring phenomenon that affects a wide variety of sectors. Some researches attempt to associate the influence of climate change and deforestation on drought occurrence, such as [BAGLEY *et al.* 2014; PANDAY *et al.* 2015]. The influence of climate change is commonly associated with ENSO/El-Nino events that have close relationship with drought occurrence [ALDRIAN, DJAMIL 2008]. SISWANTO and SUPARI [2015] confirmed that the ENSO event could be probably associated with the decreasing of rainfall trend in the rainfall stations located at some regencies in island Java, including Probolinggo Regency. The similar result was shown by HAMADA *et al.* [2002] who stated that the interannual variations of rainfall on the rainy and dry season in East Java influenced with ENSO events. PRASETYO *et al.* [2009] had been confirmed that most of the forest conversion into agricultural expansion such as for paddy field, upland agriculture, cash crops plantation, and small area for settlement development was occurred in East Java, including the Pekalen River basin, Probolinggo Regency. The high rate of deforestation along with urbanization, and improper agricultural practices was presumed have a large impacts on water balance [DOUGLAS 1999]. LESTARI *et al.* [2015] stated that actual land use in 2009 at Probolinggo Regency was dominated by bare land (37.81%), paddy field (27.77%), and nature forest (23.08%). However, during period 2010–2015, it was reported that there was a significant decreasing of area of nature forest approximately 11.82% due to conversion into plantation and farming land. The decreasing of area of nature forest directly impact the water availability particularly in dry periods due to less amount of rainfall that infiltrated into soil and contribute to groundwater recharging. Moreover, the high rate of urbanization and improper agricultural practices in the study area enhance worst condition regarding water availability and water demand in the study area as well [WICAKSONO *et al.* 2010].

Drought duration along with its areal extent and severity become the important information which must be well provided in order to support better management and planning [JAIN *et al.* 2015]. Monitoring of drought becomes most activity, which used to obtain information regarding drought aspects, including its severity, spatial and duration. Method of drought indices is normally carried out to conduct activity for monitoring a drought event. Information on monitoring of drought events could be used as a guideline for decision makers in order to make plans for drought mitigation and adaptation even contingency as well [DOGAN *et al.* 2012].

Former studies had been conducted to increase knowledge of drought characteristic either temporally and spatially. YUAN *et al.* [2016] employed the standardized precipitation index (*SPI*) and the standardized evapotranspiration index (*SPEI*) methods in the United States and concluded that the *SPEI* method is more suitable due to its smaller errors on mean average error (*MAE*). HAIED *et al.* [2017] performed drought analysis in the Wadi Djelfa--Hadjia River basin, Algeria using *SPI* method and the reconnaissance drought index (*RDI*) and confirmed that both indices had good performance in the different time scales. The *SPI* which has been well proposed by World Meteorological Organization (WMO) is more frequently applied to drought analysis in regard with owing effortless calculation, consider only precipitation data and accommodate multiple scale of time [JEMAI *et al.* 2016]. MISHRA and SINGH [2010] found that the Palmer drought severity index (*PDSI*) has a drawback in estimating drought intensity because of its fixed timescale considering that drought phenomenon is a multi-scalar phenomenon, which was included in series and prolonged event. ŁABĘDZKI and BĄK [2017] studied concerning relationship between the *SPI* and crop drought index (*CDI*) to examine the effect of meteorological drought on crop water deficit. LI *et al.* [2015] utilized the *SPEI* which mainly based on temperature and precipitation data and confirmed that evapotranspiration provide significant influence on predicting drought, yet further research should be conducted to affirm the results.

Some researchers examine scope of drought analyses in a perspective of water volume shortage, which generally defined as hydrological drought. Hydrological drought is defined as decrease of available water in all its forms or deficiency in water supply [MA *et al.* 2015]. Information regarding hydrological drought plays a significant role in water resources management where most of our daily activities depend on either surface water resources or ground water resources [WENG *et al.* 2015]. SHUKLA and WOOD [2008] assessed hydrological drought by developing the standardized runoff index (*SRI*) by assuming that the streamflow data follow a certain probability distribution. In addition, VICENTE-SERRANO *et al.* [2011] examined the standardized streamflow index (*SSI*) which utilizing streamflow data to analyse the hydrological drought index. The *SSI* method has been frequently implemented in hydrological research [BARKER *et al.* 2016]. PATHAK *et al.* [2016] carried out comparative study to assess hydrological drought by standardized runoff index (*SRI*) and streamflow drought index (*SDI*) in Ghataprabha River basin and showed that there is no significant different between *SRI* and *SDI* particularly for long-term drought analysis. TSAKIRIS AND NALBANTIS [2009] developed *SDI* which similar to *SPI* concept. The *SDI* has been widely proposed in hydrological drought due to its capability to accommodate drought analysis in time varying of streamflow data [YEH 2019]. Comparative study among the *SDI* and the *SSI* was carried out by KERMEN and GÜL [2018], and the result revealed that no significant difference between *SDI* and *SSI* particularly for long term drought analysis. ZOU *et al.* [2018] developed the *SSI* by including non-stationary characteristic in streamflow series data and proved that the method was feasible for drought forecast.

Most of the aforementioned studies solely discuss concerning the analysis of drought separately or individually between meteorological and hydrological drought. It was explained previously that meteorological drought is analyzed based on precipitation data while streamflow data used as main variable to estimate hydrological drought. Studies concerning relationship between meteorological drought and hydrological drought was carried out by BĄK and KUBIAK-WÓJCICKA [2017] and BARTCZAK *et al.* [2014]. Meteorological droughts seem to only describe drought characteristic in large scale and long term regional drought, however less explain the condition of water supply [YEH 2019]. By integrating meteorological and hydrological drought, the assessment of drought can be performed more comprehensive and realistic. However, thus far the studies concerning analysis of the relationship between meteorological and hydrological droughts are less conducted. Therefore, the purpose of the present study is to compare the performance and evaluate the applicability of meteorological drought indices by the standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) and examine the appropriateness of both indices in relate to hydrological drought (*SSI*).

MATERIALS AND METHODS

STUDY AREA

The study area was located in the Pekalen River basin, Probolinggo regency, East Java Province, Indonesia. The Pekalen River basin encompasses an area of 207.92 km^2 and having main river length of 35.1 km and average width

5–25 m. The basin area lies between latitude 7°40’ and 8°10’ S and longitude 111°50’ and 113°30’ E and includes in dry climate or typical monsoon climate, generally characterized by a relatively sharp dry season of 3–5 months [TAN 2008]. The annual rainfall varies from 800 mm in the northern parts to 1500 mm in the southern parts where rainy season take place from November to April and dry season from May to October. The study area has an immensely irregular rainfall pattern, which makes it susceptible to experience widespread droughts. During last three years (2016–2018), data recording showed that there were 40 villages distributed over eight districts having high potential to experience severe droughts in the study area. The Pekalen River has a wide range of topographic elevations ranging from 5 m at the Pajarakan sub-districts to over 1500 m at the top of Argopuro Mountain and extends across three sub-districts namely Tiris, Maron, and Gending, respectively. Based on the flow data recording during period 1999–2018, the minimum monthly mean river discharge was 6.35 $m^3 \cdot s^{-1}$ and normally took place over July to October.

Figure 1 displays the study area along with location of the rain gauge and hydrometric station. Station Pajarakan and Jatiampuh are located in the downstream part of Pekalen River basin, and mostly consist of urbanized area, agriculture, and irrigation. Station Pekalen, Condong, and Jurangjero are located in the middle part of the basin area, which is dominated by agriculture and irrigation. Station Segaran, Tiris, Kartosuko, and Bermi are located in the upstream part of the basin area, which is mostly consist of plantation and forest area. Due to the wide topographical differences presenting in the Pekalen River basin area, the selected stations are assumed to represent climatic variation among the downstream, middle, and upstream part of the study area. In case of station Bermi and Jurangjero, despite their location that situate beyond boundary of the basin study area, however result of Thiessen polygon analyses showed that both stations have a high value of weighting factor that indicate a significant of influential rainfall area in the Pekalen River basin. Hence, both Bermi and Jurangjero stations remain considered to be used in the further analysis.

STUDY METHODS

From Figure 1, there are two hydrometric stations shown in the map of study area, namely Condong and Jurangjero hydrometric stations. However, considering that the Jurangjero hydrometric station is located beyond boundary of the basin study area, thus the present study uses the Condong hydrometric station for further analysis. The Condong station is selected due to its location that situate in the main river of Pekalen River basin, thus it is assumed that streamflow data at the hydrometric station relate with the rainfall at the upstream part of river basin area referring to the concept of rainfall-runoff relationship. Hence, it is suitable for the necessity of comparison analysis between meteorological and hydrological drought indices.

The record length of monthly rainfall in 20 years from 1999 to 2018 were selected from nine manual rain gauges. The recorded rainfall data were used to analyze meteorological drought index while streamflow data length in 20 years from 1999 to 2018 collected from Condong hydrometric station was used to hydrological drought analysis.

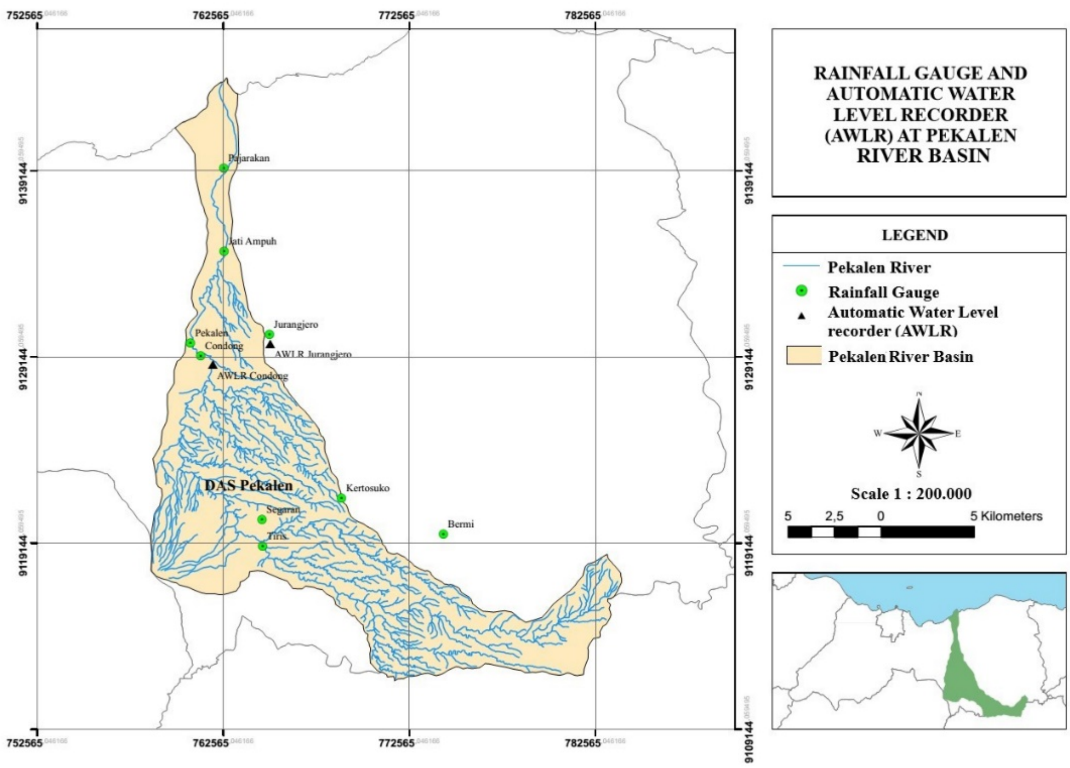

Fig. 1. Rain gauges and hydrometric station map at the study area; source: own elaboration

In order to assure quality of data input in drought analysis, some statistical tests were performed in the entire rainfall and streamflow data, including data normality test, homogeneity test, stationary test, trend detect test, and persistence test. The data stationary test was performed by examining mean and variance stability test using *F*-test and *t*-test, respectively. Shapiro–Wilk test was applied to examine normality of data [SEYAM, OTHMAN 2014] while Spearman rank test was used to detect trend signs [BEIGHLEY, MOGLEN 2002]. The persistence test was performed by Spearman serial correlation test. The Levene's test was employed to examine homogeneity of rainfall and streamflow data in the study area [WANG *et al*. 2008].

The meteorological drought index analysis was performed monthly basis during 20 years (1999–2018). The standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) were selected for assessing meteorological drought in this study considering their practicability and simplicity in drought assessment under various climatic condition. It is noted that the *SPI* is established in the Document of Indonesia National Standard, Ministry of Public Works and Housing as a standard method recommended for drought analysis in Indonesia as well. The standardized streamflow index (*SSI*) developed by MODARRES [2006] was chosen for assessing hydrological drought based on streamflow data length in 20 years from 1999 to 2018 considering its ability to be implemented easily at any timescale.

The drought analysis using the *SPI* and *RAI* were implemented in monthly and annual period. Subsequently, the resulting drought indices were evaluated and compared each other by means of statistical analyses, including Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s). Similar with the meteorological drought analysis, the hydrological drought analysis using the *SSI* was carried out based on monthly and annual period as well. Further, the monthly and annual drought index from the *SPI* and *RAI* methods were overlapped with monthly and annually periods of the *SSI* hydrological drought index.

In the present study, the overlapped of drought indices was considered within hydrological year which classified into five groups in order to obtain better understanding regarding drought indices comparison in a short term annual period, namely 1999–2002, 2003–2006, 2007–2010, 2011–2014, and 2015–2018, respectively. In order to obtain further description regarding the overlapped of hydrological and meteorological drought index, the Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s) were used as well. Subsequently, the method of meteorological drought index, which statistically display a good agreement with the *SSI* is considered as the appropriate method for estimating meteorological drought in the study area.

- **Standardized precipitation index (*SPI*)**

The standardized precipitation index (*SPI*) method has become a popular drought tool considering its simplicity and practicability in drought assessment under various climatic condition and multiple time scales [KAZEMZADEH, MALEKIAN 2015]. The method measures the shortage of rainfall or rainfall deficit at various periods based on normal conditions of rainfall. The *SPI* is designed to compute rainfall deficits for different time scales, including 3 months, 6 months, 9 months, 12 months or 24 months of cumulative precipitation, respectively. The *SPI* adopts an assumption that the distribution of rainfall series data in particular period is approached by a probability density function (PDF). Thus the fitting process is carried out to find which probability distribution function has best suitability with the distribution of the rainfall series data. The gamma distribution is considered as the probability density function which has relatively good for describing the rainfall series data [KEYANTASH, DRACUP 2002; MISHRA, SINGH 2010]. However, it is possible to apply other probability distribution function for the rainfall series data due to the fitting accuracy of the probability distribution shows good fitting with the rainfall series data. MISHRA and SINGH [2010] mentioned some of probability distributions shows suitability with the rainfall series data, including Pearson type III distribution and log normal, extreme value, and exponential distributions have been widely applied to simulations of precipitation distributions [LLOYD--HUGHES, SAUNDERS 2002]. *SPI* value calculation based on gamma distribution that is defined as a function of frequency or probability, as the following [LOUKAS, VASILIADES 2004]: $G(P) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} P^{\alpha-1} e^{-P/\beta}$ for monthly rainfall (P) > 0, where α and β values are the shape and scale parameters, P is the monthly rainfall and $\Gamma(\alpha)$ is the gamma function. The value of α and β is optimally calculated using maximum likelihood as displayed in the following: $\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$, $\beta = \frac{\bar{P}}{\alpha}$ where $A = \ln(\bar{P}) - \frac{\sum \ln(P)}{n}$, and n is the number of observation.

The parameters obtained are subsequently applied to find the cumulative probability of an observed rainfall event for the given month and time scale for the desired rain gauge. For zero magnitude monthly rainfall (P = 0), the gamma distribution $G(P)$ could not be defined, hence the cumulative probability changes into:

$$H(P) = q + (1 - q)\, G(P) \tag{1}$$

Where q is the probability of a zero magnitude rainfall event and $G(P)$ the cumulative probability of the incomplete gamma function.

Based on the theory of probability, if m is the number of zeros in a rainfall time series, n is the total number of rainfall events, then the probability of zero rainfall (q) can be estimated by m:n. By applying Equation (1), errors are eventually introduced to parameters α and β of the Gamma distribution. The *SPI* magnitude is derived from the transformation of the cumulative probability, $H(P)$ to the standard normal distribution z with average equal to zero and variance of one. The equation used for transforming gamma to standard normal distribution depends on the magnitude of $H(P)$ where for: $0 < H(P) \le 0.5$, the Equation (2) is used whereas Equation (3) is applied for $0.5 < H(P) \le 1.0$.

$$Z = SPI = -\left(t - \frac{c_0 + c_1 + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{2}$$

$$Z = SPI = \left(t - \frac{c_0 + c_1 + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{3}$$

Where: c_0, c_1, c_2 are 2.516, 0.803, and 0,010 while d_1, d_2, d_3 are 1.433, 0.189, and 0.001 respectively. Positive *SPI* values indicate greater than mean precipitation (or rainfall surplus), negative *SPI* values represent less than mean precipitation (or deficit rainfall) [PATEL *et al*. 2007] and the magnitude of *SPI* values represent the intensity of drought and wet events.

The Equation (4) is used to calculate *t* value for range $0 < H(P) \leq 0.5$ while for $0 < H(P) \leq 1.0$, the *t* value is computed with Equation (5).

$$t = \sqrt{\ln\left(\frac{1}{(H(P))^2}\right)} \tag{4}$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0-H(P))^2}\right)} \tag{5}$$

- **Rainfall anomaly index (*RAI*)**

The rainfall anomaly index (*RAI*) incorporates a ranking procedure to assign magnitudes to positive and negative precipitation anomalies [KEYANTASH, DRACUP 2002]. Due to its simplicity and practicability to address drought at multiple time steps for varying climatic regions, the method has been frequently used in drought estimating problems [MISHRA, SINGH 2010; MONTASERI *et al*. 2017]. Basically, the *RAI* index attempt to compute the rainfall deviation from the normal magnitude of rainfall or average rainfall and subsequently examines monthly or annual rainfall on a linear scale resulting from a data series [MONTASERI *et al*. 2017]. This method has the advantage of being able to analyze drought index only with single input, namely rainfall and the results of the analysis can be presented in the form of monthly, seasonal and annual drought indices.

The rainfall anomaly index (*RAI*) is developed according the following procedure:

1) computing long-term average of rainfall at the desired rain gauge ($\bar{P}$);
2) extracting average of 10 cases from among biggest rainfall during the period of analysis (*m*);
3) extracting average of 10 cases from among lowest rainfall during the period of analysis (*x*);
4) comparing rainfall data (*P*) with long-term average rainfall data ($\bar{P}$); if $P > \bar{P}$, anomaly is positive and drought index can be computed using the following equation:

$$RAI = 3\left(\frac{P-\bar{P}}{m-\bar{P}}\right) \tag{6}$$

5) if $P < \bar{P}$, anomaly is negative and droughts index can be determined using the following equation:

$$RAI = -3\left(\frac{P-\bar{P}}{m-\bar{P}}\right) \tag{7}$$

In this study, the resulted indices of *RAI* were transformed to standard normal distribution *z* in order to be used in the same numerical format with the *SPI* index. Thus, the comparison analyses of both indices could be performed in the same numerical format. The standardized of *RAI* is carried out by using the following Equation:

$$z_{RAI} = \frac{RAI_{\text{index}} - \overline{RAI_{\text{index}}}}{s} \tag{8}$$

Where z_{RAI} is standardized *RAI*, while $\overline{RAI_{\text{index}}}$, s are average of RAI_{index} and standard of deviation of RAI_{index}, respectively.

- **Standardized streamflow index (*SSI*)**

Hydrological drought is defined as a lack of water and groundwater supply in the form of lake water and reservoirs, river flows, and groundwater levels. Hydrological drought is measured from the water level of rivers, reservoirs, lakes and ground water. In this study, hydrological drought analysis was performed by the standardized streamflow index (*SSI*), which adopt similar concept with the standardized precipitation index (*SPI*). The probability fitting process based on Anderson–Darling test was conducted to obtain which probability distribution function has best appropriateness with the distribution of the streamflow series data. The result showed that the Weibull distribution was the chosen probability density function, which agree with the streamflow series data in the study area. This is consistent with TELESCA *et al*. [2012] who found that the Weibull distribution could be used to describe the streamflow series data.

The *SSI* value was computed based on equation of the Weibull probability distribution, which could be presented as follows:
$F(S) = \frac{\alpha}{\beta^{\alpha}} S^{\alpha-1} e^{-(S/\beta)^{\alpha}}$ where S is monthly streamflow data, where α and β values are the shape and scale parameters, respectively. The value of α and β is optimally calculated using extensive numerical iterations in maximum likelihood as displayed in the following [MOHAMMADI *et al*. 2016]:

$$\alpha = \left(\frac{\sum_{i=1}^{n} S_i^{\alpha} \ln(S_i)}{\sum_{i=1}^{n} S_i^{\alpha}} - \frac{\sum_{i=1}^{n} \ln(S_i)}{n}\right)^{-1} \tag{9}$$

$$\beta = \left(\frac{\sum_{i=1}^{n} S_i^{\alpha}}{n}\right)^{\frac{1}{\alpha}} \tag{10}$$

The *SSI* value resulted from the Weibull distribution, subsequently transformed to the standard normal distribution *z* in order to be used in the same numerical format with the *SPI* and *RAI* indices. The transformation of the *SSI* into the standard normal distribution was carried out by using the similar Equation (8).

RESULTS AND DISCUSSION

TESTING OF RAINFALL DATA QUALITY

Table 1 displays general characteristic of annual rainfall data for each rain gauge in study area during 20 years observation from 1999 to 2018, while Figure 2 demonstrates mean annual areal rainfall displayed along with normal rainfall (i.e. average of mean annual rainfall for 20 years). According to Figure 2, there are 13 years of observation period found owing magnitude of mean annual rainfall below the normal rainfall, specifically 2001, 2002, 2004, 2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, and 2015 respectively. A year with a magnitude of

Table 1. Summary of annual rainfall characteristics in the study area

Station no.	Rain gauge	Elevation (m)	Latitude (N)	Longitude (E)	Annual mean (mm)	Coefficient of variation	Skewness
1	Condong	130	7°58’13”	113°22’14”	1 887	0.26	0.94
2	Segaran	350	7°57’41”	113°23’11”	3 260	0.34	0.41
3	Pajarakan	015	7°46’55”	122°22’51”	1 082	0.21	0.02
4	Tiris	480	7°58’23”	113°24’00”	3 616	0.29	0.93
5	Kertosuko	795	7°57’51”	113°26’21”	3 061	0.19	0.71
6	Jurangjero	145	7°42’57”	113°24’12”	1 735	0.24	0.89
7	Pekalen	095	7°52’31”	113°21’54”	1 769	0.30	0.53
8	Jatiampuh	025	7°49’44”	113°25’39”	1 407	0.23	0.62
9	Bermi	1060	7°57’29”	113°29’20”	2 924	0.19	0.02

Source: own study.

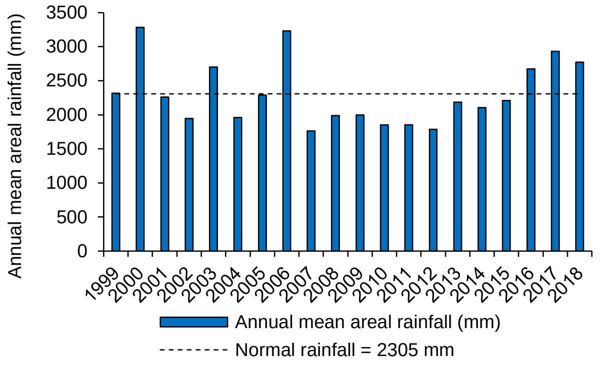

Fig. 2. Annual mean areal rainfall displayed along with normal rainfall for 1999–2018; source: own study

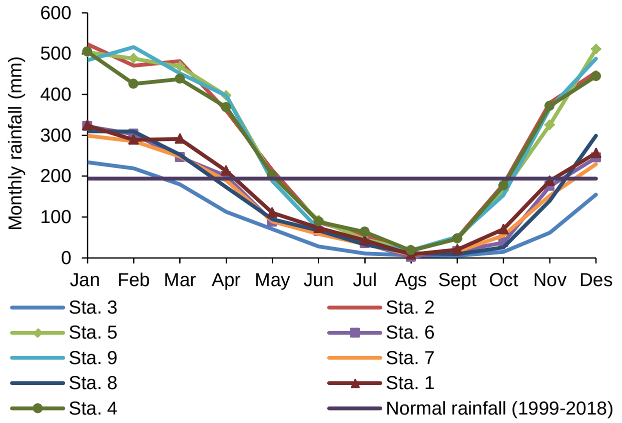

Fig. 3. Mean monthly rainfall along with normal rainfall for each rain gauge during years 1999–2018; stations numbers as in Table 1; source: own study

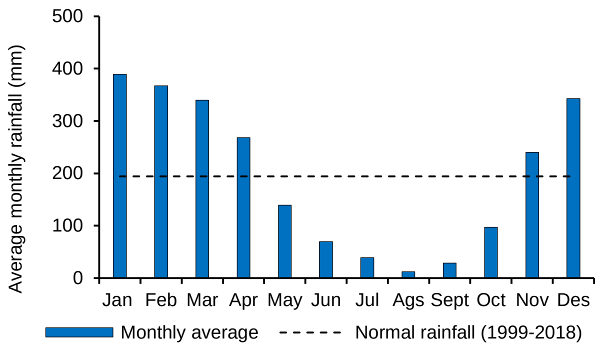

Fig. 4. Mean monthly areal rainfall along with normal rainfall; source: own study

mean annual rainfall below the normal rainfall is classified as “dry year”, otherwise stated as “wet or normal year”. The present study revealed that from the total 20 years of entire observation, there are 13 years (65%) are classified as “dry year”, thus hydrologically, the study area is potentially supposed to have experience in drought problem. The analyses of rainfall characteristic were also conducted in a monthly period in order to obtain well description regarding rainfall attribute in the study area. Figure 3 exhibits description concerning mean monthly rainfall along with normal rainfall (i.e. average of mean monthly rainfall for 20 years) for each rain gauge during years 1999–2018 while Figure 4 depicts mean monthly areal rainfall derived from simple arithmetic method along with normal rainfall which represent the monthly period for the entire years of observation in the basin.

From Figure 3, the series of mean monthly of rainfall data for each rain gauge were compared each other and the normal rainfall was used to investigate which months own magnitude below the normal rainfall. Months which magnitude below the normal rainfall is admitted as “dry month”, otherwise stated as “wet month”. According to the series pattern of monthly rainfall shown in the Figure 3, two groups of rain gauge were appeared based on the scattered position of their data in the graphic. The first group was identified in the top layer, which consist of stations 2, 4, 5, and 9, while the second group was displayed in the down layer which included in stations 1, 3, 6, 7, and 8.

Additional result was also achieved from Figure 3, where dry months persisted from May to October and wet months lasted from November to April, respectively. The results were asserted on the Figure 4, where during the observation period (1999–2018), most of dry season stayed for six months from May to October (previously classified as dry months), while rainy season took place from November to April (wet months) in the study area. Table 2 presents preliminary statistical testing of rainfall data for each rain gauge in the study area, including homogeneity, normality, stationary, and randomness tests.

As displayed in Table 2, the Levene’s test for homogeneity shows p-values > 0.05 for all rain gauges except stations 6 and 8, thus they are not used in the further analysis. The same analyses regarding statistical testing for data quality were conducted for streamflow data. The homogeneity test for streamflow data was done using the Levene’s test, while the Shapiro–Wilk test was applied to examine normality data. The result of analyses demonstrated that

Table 2. Summary of statistical testing of rainfall data for each rain gauge

Station no.	Levene's test[1)] *p*-values	Shapiro–Wilk test[2)] *p*-values	Stationary test[3)] F_{calc}	Spearman rank test[4)] t_{calc}	Spearman serial correlation test[5)] t_{calc}
1	0.27	0.06	0.36	–1.07	–0.07
2	0.25	0.57	1.08	0.42	1.72
3	0.87	0.79	0.88	0.61	–1.67
4	0.50	0.07	0.91	0.14	1.73
5	0.57	0.16	1.30	0.42	1.34
6	0.04	0.14	0.20	0.42	–0.62
7	0.33	0.55	0.23	–1.29	–0.59
8	0.02	0.34	0.26	–1.20	–0.82
9	0.62	0.08	1.02	0.36	1.61

1) Homogeneity test at 0.05 sig. level, *p*-value > 0.05 indicate acceptance of null hypothesis, which means rainfall data are homogen. All rain gauges were homogen except stations 6 and 8. Accordingly, they were not used in drought analysis.
2) Normality test at 0.05 sig. level, *p*-value > 0.05 indicate acceptance of null hypothesis, which means rainfall data follow normal distribution. All rain gauges owned *p*-value > 0.05, thus rainfall data follow normal distribution.
3) Stationary test using Fisher test (*F*-test) at 0.05 sig. level, $F_{calc} < F_{cr}$ indicate acceptance of null hypothesis which means rainfall data were stationary. All rain gauges had $F_{calc} < F_{cr\ =\ 3.18}$, thus rainfall data were stationary.
4) Trend detect test at 0.05 sig. level, two tailed test, $-t_{cr} < t_{calc} < t_{cr}$ indicate acceptance of null hypothesis which means rainfall data have no trend. All rain gauges had $-t_{cr\ =\ -2.10} < t_{calc} < t_{cr\ =\ 2.10}$, thus rainfall data have no trend.
5) Persistence test at 0.05 sig. level, two tailed test, $-t_{cr} < t_{calc} < t_{cr}$ indicate acceptance of null hypothesis which means randomness in rainfall data. All rain gauges had $-t_{cr\ =-\ 1.74} < t_{calc} < t_{cr\ =\ 1.74}$, thus rainfall data have a randomness.
Source: own study.

the streamflow data fulfilled the assumption of homogeneity and normality data. Figure 5 displays result of normality test plot for annual streamflow in the study area. The figure showed that the data scatter plot of rank based normal distribution (*z*-score) and annual streamflow lied on a straight line.

Figure 5 confirmed that the streamflow data fulfilled the assumption of normal distribution, which means the streamflow data are consistent without any outlier data in it. Accordingly, the streamflow data could be used for drought analysis.

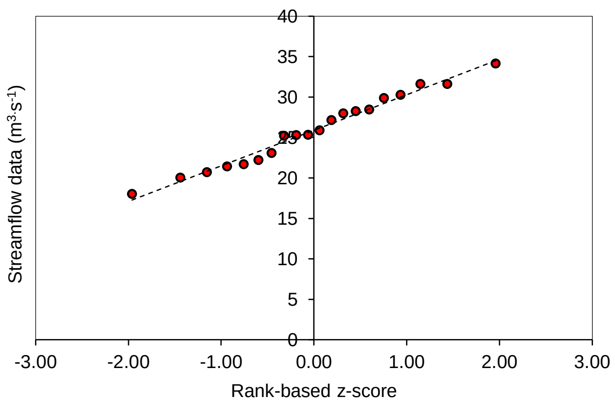

Fig. 5. Normality test plot for annual streamflow; source: own study

METEOROLOGICAL DROUGHT INDEX

The meteorological drought based on rainfall data series provided an overlook and understanding of drought attribute across the study area. The present study estimated droughtevents based on rainfall data as a single input during period 1999–2018. The drought assessment was computed from monthly rainfall data, considering that monthly basis is common period that used in water resources practices in the study area. In addition, the monthly period provide rainfall, which is relatively consistent and stable, thus more appropriate for drought analyses.

The result of Levene's test showed 0.788 and 0.789 for the *SPI* and *RAI*, respectively. This implies that the null hypothesis of Levene's test is accepted, it suggests that the variances of the two groups are equal, hence the homogeneity of variances assumption is accepted. The normality test using Shapiro–Wilk test at 0.05 significant level showed that *p*-value is 0.373 > 0.05, thus the drought index of *SPI* followed normality assumption. The normality test was derived for drought index of *RAI* where Shapiro-Wilk test *p*-value showed 0.292 > 0.05, it means that the normality assumption was accepted for the drought index of *RAI*.

Figure 6 displays the normality plot of annual drought index of *SPI* and *RAI*. From Figure 6, it could be identified that the data scatter plot of rank based normal distribution (*z-score*) and annual drought index of *SPI* and *RAI* lied on a straight line. Accordingly, normality assumption was accepted for both *SPI* and *RAI* drought index data. Figure 7 displays annual mean areal drought index for the *SPI* and (*RAI*). The figure shows that the annual pattern of mean areal drought index between the *SPI* and *RAI* has similarity. From the drought index appearance in Figure 7, it could be identified that the drought index of *SPI* tends to have negative and positive index higher than *RAI* index. Moreover, the result of statistical tests showed for Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s) were 0.983, 0.839, and 0.952 respectively. Accordingly, the results of the statistical association analysis confirmed that there was a good agreement between the drought index of *SPI* and *RAI*, which means that the two index methods could be well applied in drought assessment in the study area. This result was consistent with AL-TIMIMI and OSAMAH [2016] who found that the *SPI* and *RAI* has a quite similar tendency in drought assessment which was indicated by a linear trend with correlation coefficient 0.97. Moreover, the result of present study was in line with HÄNSEL *et al*. [2015] who stated that the *SPI* and *RAI* was well correlated for monthly time scale where the Pearson product moment correlation coefficients above 0.96.

Figure 8 exhibits annual drought index of *SPI* and *RAI* along with annual mean areal rainfall in the study area. The figure showed a similar trend between annual mean areal rainfall and annual mean areal drought index of *SPI* and *RAI*. The high magnitude of drought index corresponds to high magnitude of annual rainfall, conversely the low drought index relates with less rainfall. Quantitatively, the Pearson correlation (r) applied to examine the relationship between the annual mean areal rainfall and drought index of *SPI* and *RAI* where the result showed values of 0.63 for

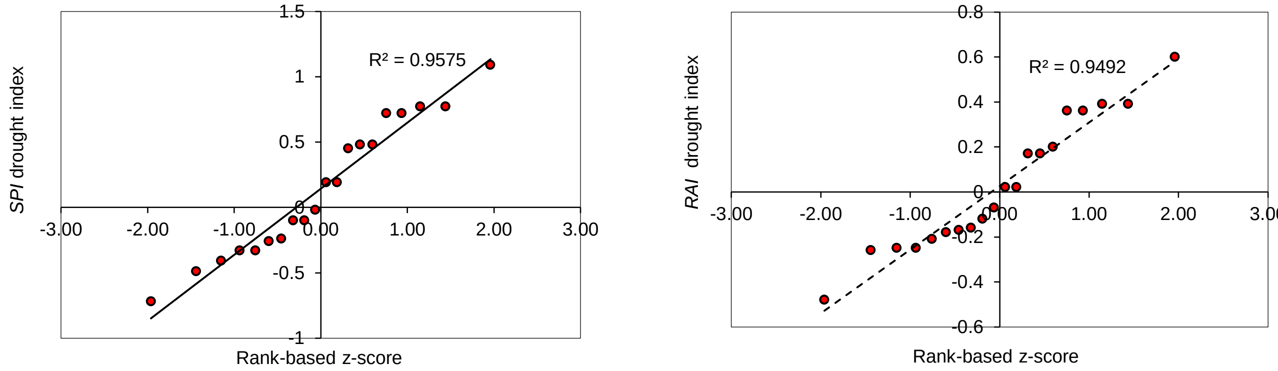

Fig. 6. Normality plot of annual drought index of standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*); source: own study

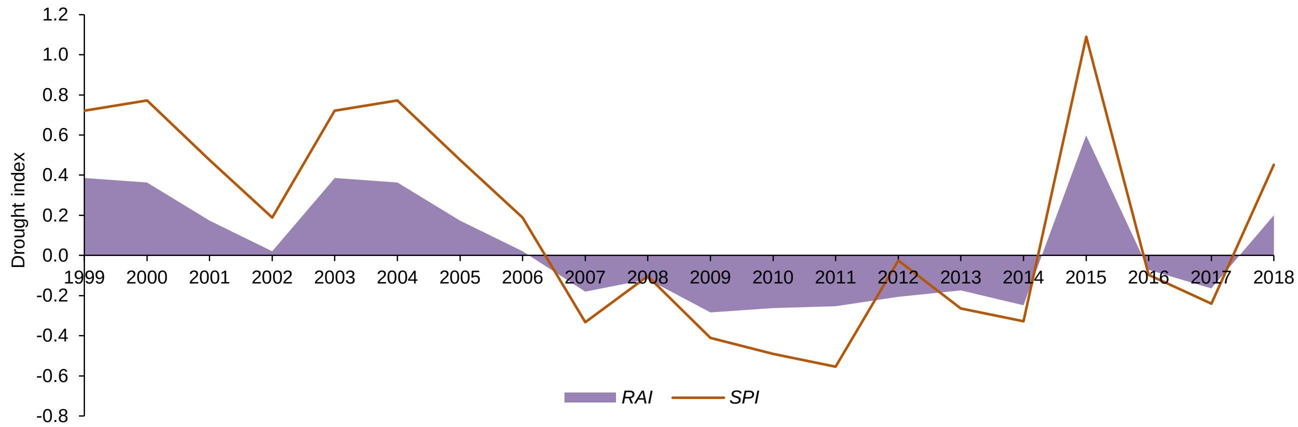

Fig. 7. Annual mean areal drought index for the standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*); source: own study

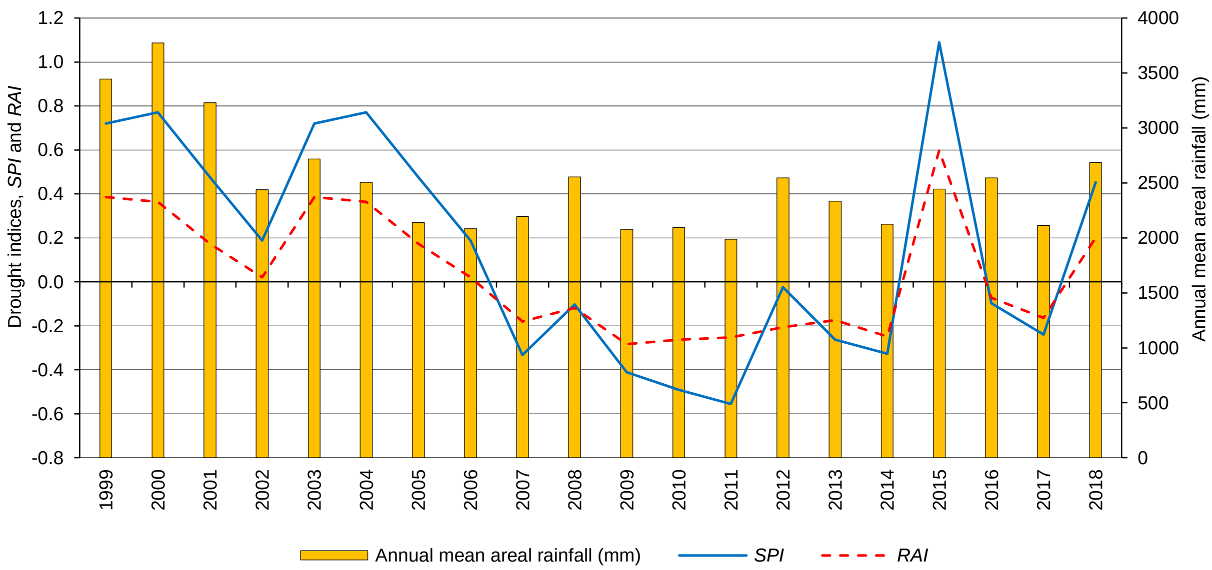

Fig. 8. Annual drought index of standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) along with annual mean areal rainfall; source: own study

SPI and 0.61 for *RAI*, respectively. Accordingly, there was a good relationship among annual mean areal rainfall, drought index of *SPI*, and *RAI*. It could be known that there is no significant difference concerning the degree of association among *SPI* and *RAI* relate to annual mean areal rainfall.

HYDROLOGICAL DROUGHT INDEX

The basic concept of standardized streamflow index (*SSI*) was similar to that of the *SPI* where series of stream-flow data were assumed to follow distribution of certain probability density function. The Anderson–Darling test was used to find the probability density function, which has a good agreement with the streamflow data. The result showed that the Weibull distribution was the chosen probability density function, which agree with the streamflow series data in the study area. The result was consistent with TELESCA *et al*. [2012] who found that the Weibull distribution could be used to describe the streamflow series data.

Same with the meteorological drought analysis, the hydrological drought analysis using the *SSI* was conducted based on monthly and annually period of streamflow data from 1999 to 2018 as well. The *SSI* value was computed based on equation of the Weibull probability distribution, which could be presented in Equation (8). The *SSI* indices resulted from the Weibull distribution, subsequently transformed to standard normal distribution z in order to be used in the same numerical format with the *SPI* and *RAI* indices.

The high magnitude of a negative value of the *SSI* index indicates a high degree in drought severity, conversely, the low negative value of the *SSI* index denotes a low degree of drought severity. Prior used in further analyses, the results of *SSI* were examined for testing of homogeneity and normality of drought index data using the Levene's test and Shapiro–Wilk test, respectively. The result of Levene's test at 0.05 significance level showed that p-value 0.425 > 0.05 which indicates that the null hypothesis of Levene's test is accepted, hence the homogeneity of variances assumption is accepted. The normality test using Shapiro–Wilk test at 0.05 significance level showed that p-value is 0.265 > 0.05, thus the drought index of *SSI* followed normality assumption. Figure 9 presents the *SSI* along with the mean annual streamflow during period 1999–2018 in the study area. The negative indices increased in conjunction with the decreasing of streamflow and occurred over the years in 2007 to 2012. Conversely, the index decreased accompanying with the increasing of streamflow. The highest negative value of the *SSI* index appeared in 2016, which correspond to the lowest streamflow, whereas the lowest negative value of the *SSI* index was presented in 2017, which associate with the highest streamflow. Overall, the pattern seems relatively similar between the *SSI* index and annual streamflow, which lead to a good relationship among them. Accordingly, the *SSI* could be used in drought assessment, particularly in context of hydrological drought analysis.

COMPARISON BETWEEN METEOROLOGICAL AND HYDROLOGICAL DROUGHT

The meteorological drought characteristics were extracted from *SPI* and *RAI*, while the hydrological drought characteristic was derived from the *SSI* in the study area. In this study, comparative analysis was carried out in order to obtain a better description regarding relationship between meteorological and hydrological drought. Procedure of comparative analysis was performed by overlapping drought index from the *SPI* and *RAI* with the *SSI* at same hydrological year. The present study used the annual mean areal drought index of *SPI* and *RAI* which derived from the Thiessen polygon method. The annual mean areal drought index represents weighing average value of drought index from the seven rain gauges in the study area.

Figure 10 displays comparison between *SSI*, *SPI* and *RAI* based on annual drought index during period 1999–2018. From the figure, it could be appeared that dry years lasted from 2007–2012, while 1999–2006 seems to be included in wet years. Both the *SPI* and *RAI* showed a similar pattern with the *SSI*, which implies a good agreement among the three drought indices. The increasing of *SSI* drought index accompanied with the increasing of *SPI* and *RAI*, conversely when the *SSI* decreases, the drought index of *SPI* and *RAI* tend to decrease as well.

Table 3 exhibits summary of statistical association analyses between the *SSI*, *SPI* and *RAI*. From Table 3, it could be known that the magnitude of the three correlation tests was greater than 0.6 which confirmed that that there was a good agreement between the drought index of *SPI* and *RAI* with the *SSI*. The magnitude of each correlation test did not show significant difference between *SSI* against *SPI* and *SSI* against *RAI*. Thus, it could be pronounced that the *SPI* and *RAI* provide nearly same performance as a tool for analyzing of meteorological drought in the study area. The two index methods are very well correlated with the *SSI* which means that the two index methods could be well applied in drought assessment in the study area.

Nevertheless, the result of statistical association analyses displayed in the Table 3 showed that the *SPI* give better performance compared with the *RAI*. The result was consistent with BARKER *et al*. [2016] who stated that the *SSI* was strongly correlated with *SPI* with short time scale.

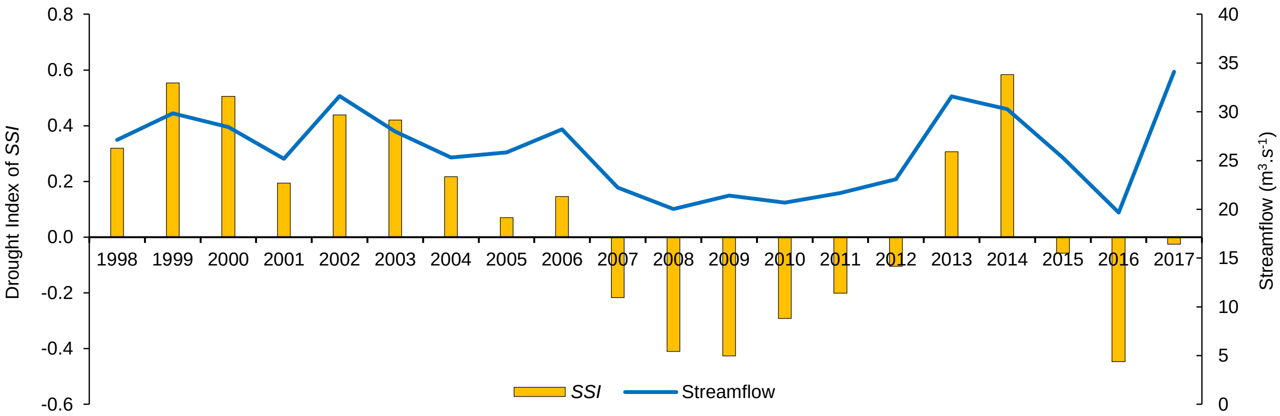

Fig. 9. Standardized streamflow index (*SSI*) along with mean annual streamflow 1999–2018; source: own study

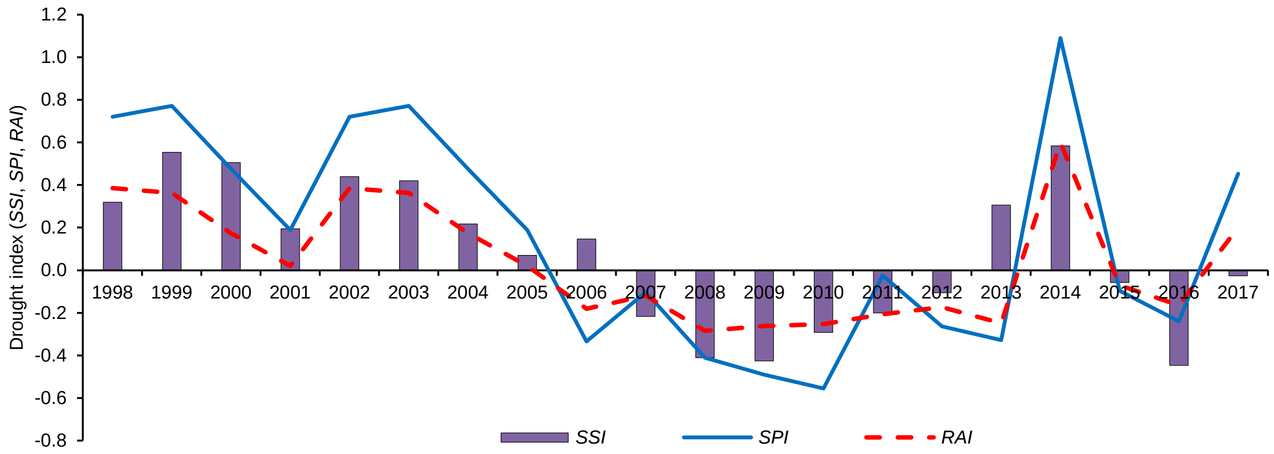

Fig. 10. Comparison between annual drought index of standardized streamflow index (*SSI*), standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) during period 1999–2018; source: own study

Table 3. Summary of statistical association analyses between the standardized streamflow index (*SSI*), standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*)

Test	*SSI* vs *SPI*	*SSI* vs *RAI*
Pearson correlation	0.83	0.81
Kendall tau	0.66	0.63
Spearman rho	0.82	0.79

Source: own study.

The result was also concordant with SOĽÁKOVÁ *et al.* [2013] who stated that both *SSI* and *SPI* had a good relationship in terms of drought duration, recurrence time, and drought severity, respectively. Figure 11 displays scatter plot between *SSI* and *SPI* in monthly basis, while for *SSI* and *RAI* is presented in Figure 12. From both figures, it could be known that both *SPI* and *RAI* exhibit relatively good result which is indicated with the magnitude of coefficient of determination (R^2) exceed 60% for each drought index. However, the result of *SPI* demonstrate more satisfy performance which is confirmed with the value of coefficient of determination (R^2) = 88.8%.

Further analyses were conducted to know better regarding the degree of relationship between the *SSI*, *SPI* and *RAI* in monthly basis. The overlapping of monthly drought indices was considered within five groups of hydrological year from 1999–2018, namely 1999–2002, 2003–2006, 2007–2010, 2011–2014, and 2015–2018, respectively. Table 4 summarizes the statistical correlation test for the *SPI* and *RAI* against the *SSI* for each hydrological year. The magnitude of the three statistical correlation tests as denoted in Table 4 indicate that the *SPI* has a good relationship with the *SSI*. Accordingly, it could be revealed that the *SPI* show better performance compared with the *RAI* in respect to explaining degree of relationship with the *SSI*. The Pearson correlation (for the *SSI* against *SPI* displayed in range

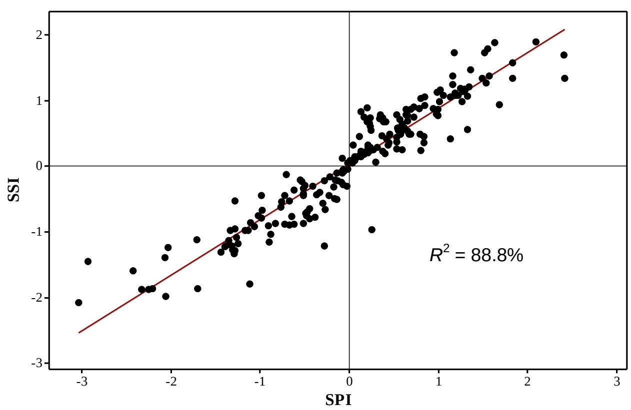

Fig. 11. Scatter plot of standardized streamflow index (*SSI*), standardized precipitation index (*SPI*) in monthly during 1999–2018; source: own study

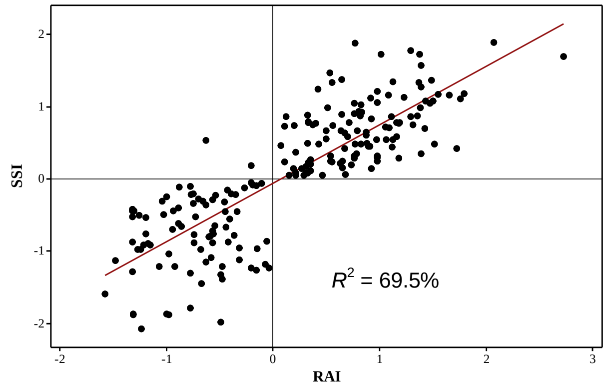

Fig. 12. Scatter plot of standardized streamflow index (*SSI*) and rainfall anomaly index (*RAI*) in monthly during 1999–2018; source: own study

Table 4. Summary the statistical correlation test for the standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) against the standardized streamflow index (*SSI*) for each hydrological year

Specification	Hydrological year				
	1999–2002	2003–2006	2007–2010	2011–2014	2015–2018
SSI vs *SPI*	0.472[1)]	0.500[1)]	0.321[1)]	0.488[1)]	0.504[1)]
	0.303[2)]	0.273[2)]	0.242[2)]	0.394[2)]	0.364[2)]
	0.469[3)]	0.378[3)]	0.343[3)]	0.434[3)]	0.462[3)]
SSI vs *RAI*	–0.143[1)]	–0.155[1)]	–0.211[1)]	0.340[1)]	0.245[1)]
	–0.061[2)]	–0.182[2)]	–0.091[2)]	0.303[2)]	0.091[2)]
	–0.014[3)]	–0.28[3)]	–0.161[3)]	0.413[3)]	0.098[3)]

[1)] Pearson correlation test (r); [2)] Kendall tau test (τ); [3)] Spearman rho test (r_s).
Source: own study.

within 0.321–0.504, while the Kendall tau test showed 0.242–0.394.

In regard with the Spearman rho test, the magnitude exhibited 0.343–0.469. Despite of the low coefficient of correlation as shown in Table 4, the results confirm that the *SPI* is feasible tool for analyzing meteorological drought in the study area. Overall assessment, the *SPI* shows better performance than the *RAI* for estimating drought characteristic either monthly or annual basis in the study area.

In order to increase further understanding, the comparison between the *SSI*, *SPI* and *RAI* was performed with regard to drought intensity. The drought intensity was classified into four classes, namely normal, moderately dry, severely dry, and extremely dry, respectively. Statistic percentile 25%, 50%, and 75% were computed from the series of drought index of the *SSI*, *SPI*, and *RAI*, which subsequently used to determine upper and lower limits of class interval of drought intensity for each method. Afterward, each series of drought index was individually classified into which class interval they fit, then the number of drought index in each class interval were counted to derive frequency of each class interval. Total number of drought index which fit in each class, then divided by the total number of drought index series to derive percentage frequency of each class of drought intensity. Figure 13 demonstrates comparison of percentage frequency of normal, moderately, severely, and extremely dry classes of the *SSI*, *SPI* and *RAI* for each hydrological year. From Figure 13, it could be known that all of the drought indices show same percentage frequency of extremely dry class, while slightly different to normal, moderately, and severely dry classes, respectively. The *SPI* seems to agree with the *SSI* for severely dry class, while the *RAI* appears to coincide with the *SSI* for moderately dry class. In respect to the normal class, both the *SPI* and *RAI* exhibit similar performance. Accordingly, the *SPI* and *RAI* were confirmed as a reliable tool for assessing meteorological drought in the study area. Overall assessment, the standardized precipitation index (*SPI*) shows better performance than the rainfall anomaly index (*RAI*) for estimating drought characteristic either monthly or annual basis in the study area.

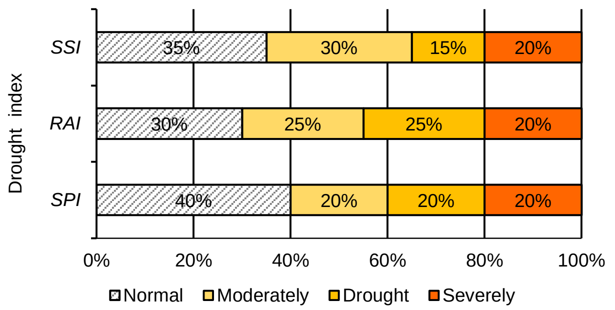

Fig. 13. Comparison of percentage frequency of drought intensity period 1999–2018; source: own study

CONCLUSIONS

The present study applied the standardized precipitation index (*SPI*) and rainfall anomaly index (*RAI*) to assess drought attribute in terms of meteorological drought, while the standardized streamflow index (*SSI*) employed to assess hydrological drought. Comparison analysis was performed to examine the relationship between the monthly and annual drought index of *SPI*, *RAI*, and *SSI* in order to identify which meteorological drought index (*SPI* and *RAI*) have a good agreement with the *SSI*. The present study revealed that the characteristic of the annual drought index between the *SPI* and *RAI* exhibits pattern similarity which indicated by the high correlation coefficient of Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s), respectively. Moreover, both *SPI* and *RAI* displayed a good result concerning the degree of association among *SPI* and *RAI* relate to annual mean areal rainfall. Accordingly, the two meteorological drought index methods could be well applied in drought assessment in the study area. Further result was also shown that the *SSI* could be used in drought assessment based on streamflow data record in the study area, instead of the *SPI* and *RAI*. The comparison of the annual drought index of *SSI*, *SPI* and *RAI* showed that both the *SPI* and *RAI* display a similar pattern with the *SSI*, which implies a good agreement among the three drought indices. In addition, overlapping of the annual drought of *SSI*, *SPI*, and *RAI* in each hydrological year demonstrated that the *SPI* and *RAI* methods are very well correlated with the *SSI* which was shown by the magnitude of correlation coefficient of Pearson correlation (r), Kendal tau (τ), and Spearman rho (r_s) are higher than 0.6, respectively. Nevertheless, refer to the magnitude of each correlation coefficient, the *SPI* give better performance compared with the *RAI*. In regard to drought intensity, both meteorological drought methods display a good conformity with the drought intensity pattern of *SSI*, thus the *SPI* and *RAI* could be as a tool for estimating drought characteristic in the study area. Based on the overall comparison analyses between the meteorological and hydrological drought index, the *SPI* shows better performance than the *RAI* for estimating drought characteristic either monthly or annual basis in the study area. Accordingly, the *SPI* was considered as a reliable and effective tool for analyzing drought characteristic in the study area. The results of present study could be considered as reference in preparation of masterplan of water resources management document particularly on drought mitigation planning through a program of clean water supply and water distribution to the villages that experiencing drought at the study area.

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