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Identification of Climate Trends and Patterns in South Sumatra

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ABSTRACT

South Sumatra is one of low-lying provinces in Indonesia with a vast area of peatland that is prone to peat fires and floods. Understanding climate patterns in South Sumatra is very important to anticipate the impacts of extreme weathers. This study identified the climate trends and patterns based on the daily data of temperature, rainfall and evapotranspiration obtained from 1975 to 2021 (46 years). Here, the trend and its significance were detected based on the linear regression and Mann-Kendall test approaches. Characteristics of wet/dry season (start, peak, end) were identified annually based on the 6th polynomial equation using rainfall and evapotranspiration data. The results show an increased trend of annual average temperature (0.04°C per year), rainfall (6.83 mm per year), and evapotranspiration (0.77 mm per year). Other findings reveal that the cyclic season in South Sumatra is wet season (starts from 1±30 to 163±79 Julian day), followed by dry season (from 172±152 to 273±90 Julian day), then wet season (until 244±90 Julian day). The mean excess of annual rainfall was 708 mm (593 mm and 114, respectively, for wet and dry season). Further, we found that South Sumatra experienced extreme dry season (8 times) with the longest in 2019 that lasted for 167 days in a row. As a precaution, extreme wet spells may occur in November-December, and March, whereas extreme dry seasons can be found in July-September each year.

KEYWORDS
climate, water balance, water availability, season, trend

INTRODUCTION

Climate change is one of the greatest ecological and social challenges in the world, especially for archipelago countries such as Indonesia (Dietz et al., 2020). In the context of climate change analysis, the climatic phenomenon must be studied from long-term observed data. Climate patterns can be identified through time series analysis, which provides information on trend patterns, cycles, or fluctuations around long-term average values. Constraints on the availability of long-term observed climate data are found widely especially for developing countries such as Indonesia. Therefore, the identification of climate change based on observed data is sometimes difficult to do. Climate change has an impact on the climatic season around the world (Manik, 2009; Susilokarti et al., 2015).

In Indonesia, the wet and dry season has been traditionally believed to occur between October to March, and from April to September, respectively (Adidarma et al., 2010). Yet Indonesia has three different rainfall patterns that impact the differences in the timing of the wet and dry seasons. Areas close to the equator, such as Samarinda (East Kalimantan), Sampali (North Sumatra), and Padang Marpoyan (Riau), have two peaks of rain (bimodal), which means they have a twice wet season, which is around March and October. Areas far from the equator and mostly in southern Indonesia, such as Ciomas (West Java), Naibonat (NTT), and Kendari (South East Sulawesi), have monsoonal type rainfall with one peak (unimodal) which indicates having one peak wet season in December. In addition, there is a type of local rain that only occurs in several regions of Indonesia, such as in Maluku, which has one peak of rain (unimodal), but its patterned opposite of the monsoonal type (Aldrian and Dwi Susanto, 2003; Salmayenti et al., 2017). This lack of information on precise climate patterns can cause many disadvantages, such as improper irrigation and drainage planning, cropping patterns of agricultural commodities that can be delayed due to unpredictable weather (Setiawan, 2020), and some inappropriate planning of infrastructure related to flooding and drought control.

The dry season or drought has received more attention because of its direct impact on vegetation. Forest fires are a common phenomenon in the dry season that often occur in equatorial rainforest areas, especially in Sumatra and Kalimantan, Indonesia. The danger of forest fires is often increased in the dry season, which is associated with a deficit of rainfall. When rainfall decreases, soil moisture decreases to compensate for evapotranspiration (Taufik et al., 2015). Land and forest fire disasters (*karhutla*) recorded 1,153 events (4.3 events per year per province) and drought 754 events (3.3 events per year per province). These two types of disasters have a frequency of more than twice a year in most of the provinces in Kalimantan and Sumatra (Suhardi, 2019). On the other hand, flooding is also another problem in Indonesia when rainfall increases. According to (Primadita et al., 2022) the distribution of rain tends to be 55% drier in 2016-2025, twice as wet in 2026-2035, and three times much drier in 2036-2045 compared to 2006-2015. In daily rainfall, the intensity of rain tends to be higher but with less rainfall. In Indonesia, the most frequent natural disasters are floods, with 7,363 incidents recorded, with an average frequency of 736 events per year or 21.6 events per year per province (Suhardi, 2019).

Climatic factors such as temperature, solar radiation, wind speed, relative humidity, duration and rainfall play an important role in the occurrence of drought (Mishra and Singh, 2010). Prolonged drought caused by climate is a strong trigger for forest fires in the tropics (Taufik et al., 2017). (Van Loon et al., 2016) stated that water deficits (or droughts) are the result of complex interactions between meteorological anomalies, land surface processes, changes in water storage, and human intervention. Challenges related to drought research and management should be addressed to improve management strategies to reduce severity and mitigate future drought impacts.

In addition to the increase in air temperature and drought, the increase in extreme climate events, floods, and shifts in the rainy season are also indications of climate change (Ruminta and Handoko, 2016; Ruminta et al., 2018). In South Sumatra, floods occur almost every year. When a high intensity of rainfall occurred in South Sumatra, water velocity in flood plain area is 0.97 m s^{-1} and maximum inundation depth reach 1.4 m in the flood plain area (Farid et al., 2017). This must be a serious concern in order to take mitigation actions by finding the appropriate method to see the pattern of the wet season.

A different method has been introduced to indicate the start of the wet and dry seasons (Irsyad et al., 2014; Setiawan, 2020). This method uses polynomial equations to interpolate daily cumulative rainfall data with high precision. The first derivation of the equation with respect to time can detect the beginning and end of the rainy season, and the second derivation can find its peak in each season. Those previous study have not included evapotranspiration parameters in their method so they cannot determine the water balance. In this study, this method was further developed by considering evapotranspiration which is an important factor for determining the dry season, so that it can estimate the availability of rainwater in each season.

The objective of this study was to identify the trends of rainfall and evapotranspiration (*ET*); the patterns of wet and dry seasons based on historical climate data using water balance model; and the start, end, peak, and available rainwater of wet and dry seasons. The results of this study are expected to be one of the methods of monitoring flooding when wet season or drought when dry season which has an impact on forest fires and increased carbon emissions which is one of the causes of climate change. Handling climate change is one aspect of the environmental development pillar in the national Sustainable Development Goals (SDGs) which aims to achieve sustainable management of natural resources and the environment as a support for all life.

RESEARCH METHODS

Research Site

The study area of this works is in South Sumatera, Indonesia. The data used in this study was daily climate data of Palembang City, collected for 46 years from 1976 to 2021 which was obtained from dataonline.bmkg.go.id. The use of longer data series will make the analysis results more accurate. The study area and point of BMKG station location used is shown in Figure 1. The climate data parameters collected were maximum air temperature, minimum air tempe-

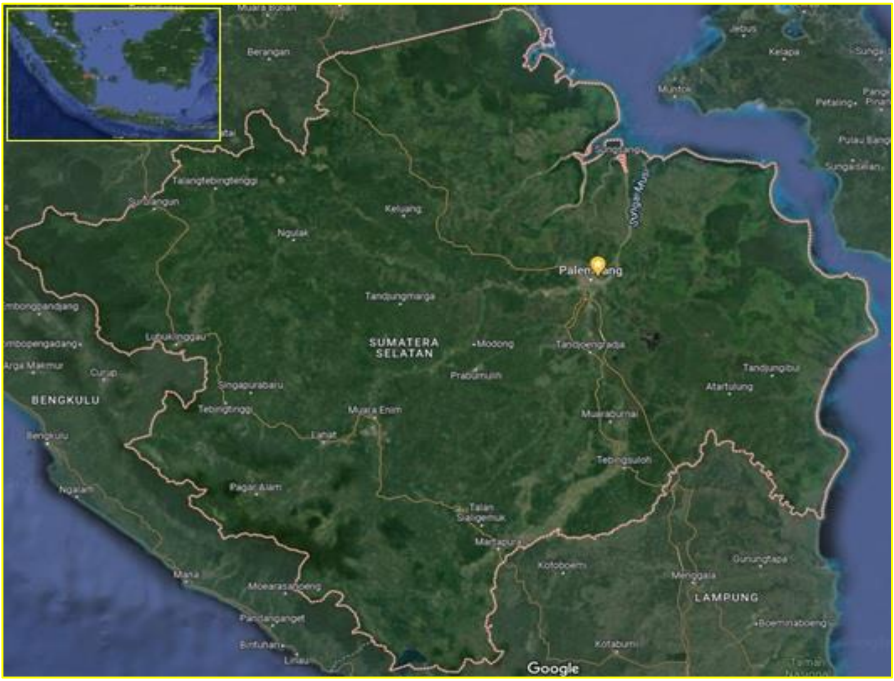

Figure 1 The Area of study, and the yellow dot is BMKG station locations used in this study

rature, average air temperature, average relative humidity, and rainfall.

Data Analysis

The value of potential evapotranspiration (*ETp*) that occurred in this study is a combination of evaporation and transpiration values. Evapotranspiration is difficult to measure and when measured its spatial variability is usually not taken into account (Gomariz-Castillo et al., 2018). The effects of the two processes are not separated in the calculation analysis because the two processes occur simultaneously and there is no easy way to tell them apart (Allen et al., 1998b). Therefore, the *ETp* value in this study was calculated using the Hargreaves model suggested by (Allen et al., 1998a). The calculation of *ETp* following the Hargreaves model is as follows:

$$ETp = 0.000939\ (Tave + 17.8)\ (Tmax - Tmin)0.5\ Ra \quad (1)$$

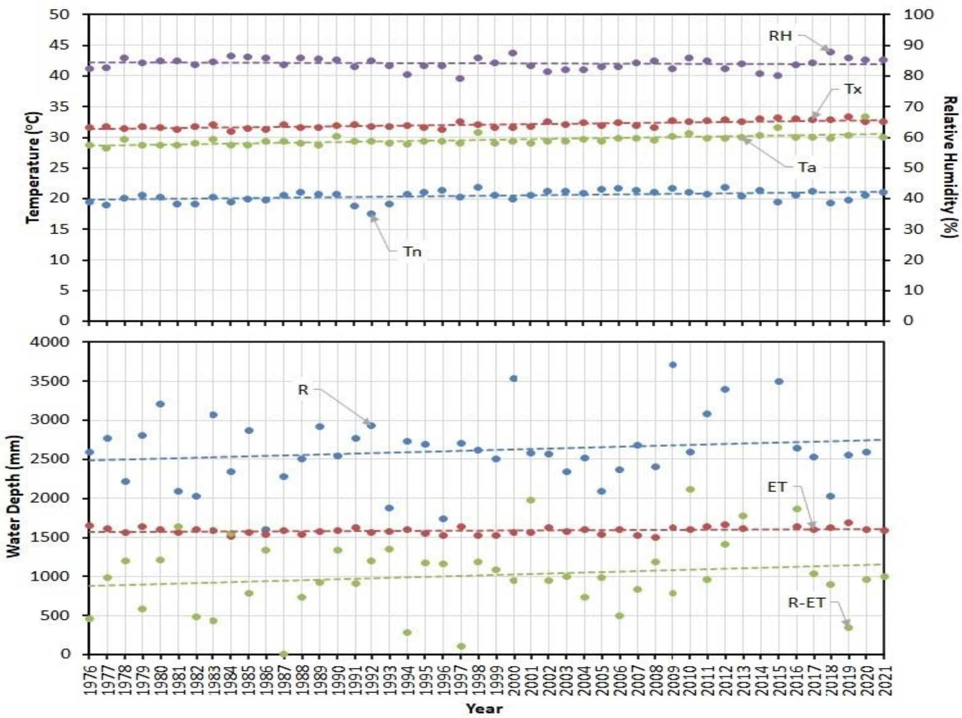

Figure 2 Climate variables and their trends from 1976 to 2021

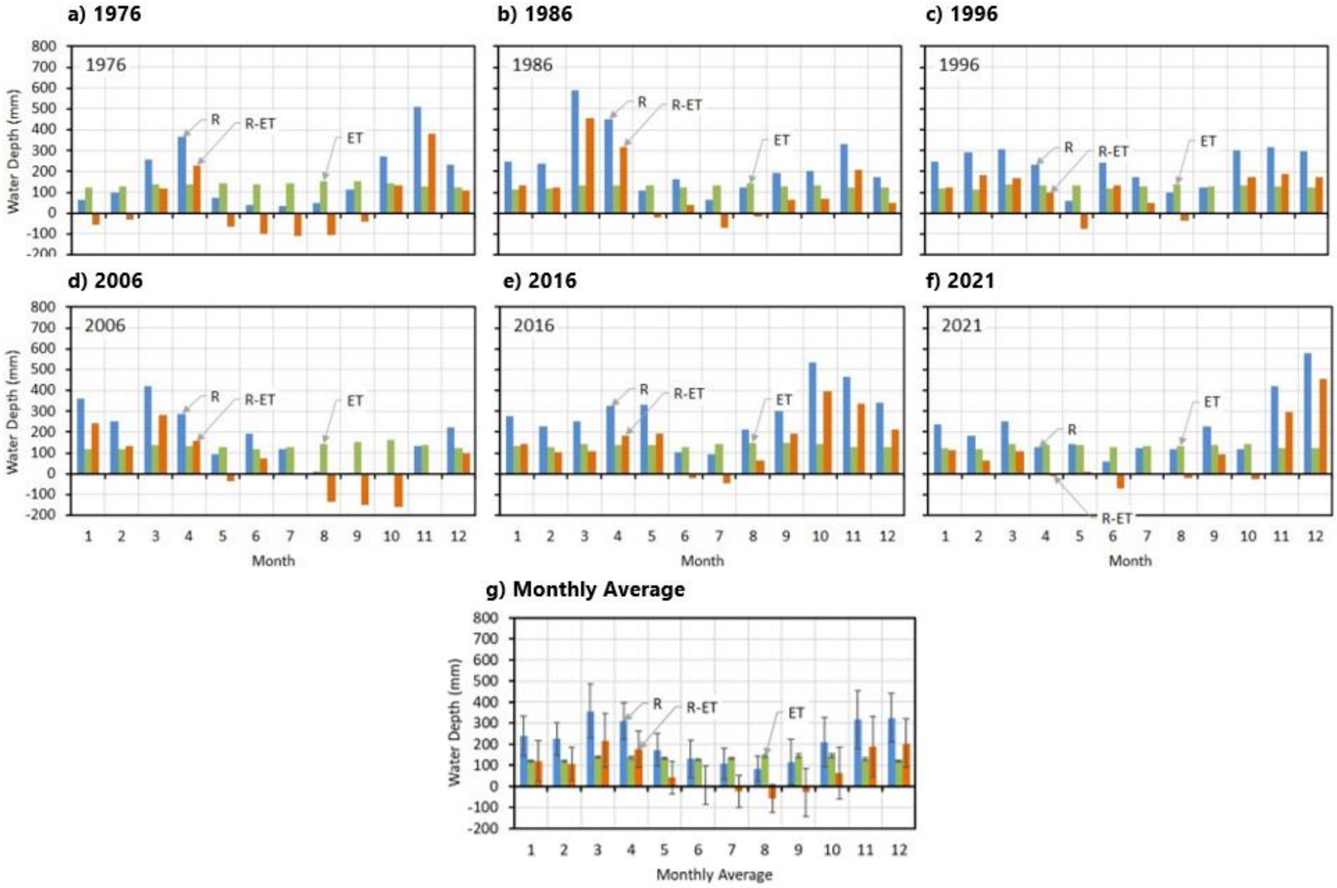

Figure 3 Monthly rainfall and evapotranspiration from 1976 to 2021.

ETp is potential evapotranspiration (mm d^{-1}), Ra is extra-terrestrial radiation (MJ m^{-2} d^{-1}), T_{max} is the maximum daily temperature (^{0}C), T_{min} is the minimum daily temperature (^{0}C), and T_{ave} is the average daily temperature (^{0}C). The value of *Ra* is obtained from the following equations:

$$Ra = 37.6\ dr\ [\omega s \sin(\phi)\sin(\delta)+\cos(\phi)\cos(\delta)\sin(\omega s)] \quad (2)$$

$$dr = 1+0.033 \cos(0.0172J) \quad (3)$$

$$\omega s = \arccos[-\tan(\phi)\tan(\delta)] \quad (4)$$

$$\phi = \frac{\pi L}{180} \quad (5)$$

$$\delta = 0.409 \sin(0.0172J-1.39) \quad (6)$$

Where, *J* is the order of days according to the Julian calendar, *L* is the latitude position (North latitude is given a positive sign and South Latitude is given a negative sign), *dr* is the relative distance of the earth and the sun, ωs is the sundial angle, φ is the position of latitude in radians, and δ is the angle of sun declination.

The accumulated daily *ETp* value was then derived to obtain the *ETp* rate. The derivation of the daily rainfall accumulation value is also carried out to obtain the rainfall rate. The polynomial method was used for the analysis of the beginning, end, and peak of the rainy and dry seasons. For the analysis of the probability of maximum rainfall, the Gumbel method is used. Furthermore, the Mann-Kendal method is used for annual climate trend analysis.

The relationship between the rate of rainfall and evapotranspiration can be expressed by the water balance model (Setiawan, 2020) in the form of:

$$\frac{dN}{dT} = \frac{dR}{dT} - \frac{dET}{dT} \quad (7)$$

Or it can also be written as follows:

$$Nt = Rt - ETt \quad (8)$$

Where *Nt* is the rates of the net of water balance (mm d^{-1}), *Rt* is rainfall (mm d^{-1}), and *ETt* is evapotranspiration (mm d^{-1}). *R(t)* and *ET(t)* are in forms of continuous functions that each represents cumulative rainfall and evapotranspiration over time, as follows:

$$R(t) \approx \sum_{i=1}^{i=t} R_i \quad (9)$$

$$ET(t) \approx \sum_{i=1}^{i=t} ET_i \quad (10)$$

Where *i* denotes the Julian calendar, which is equal to 1 for January 1 and so on until 365, or 366 for leap year. Thus, *Ri* and *ETi* are daily rainfall and evapotranspiration. The steps to identify the wet and dry periods can be written in the following 11-14 equation:

Wet period (*W*), dry period (*D*), and transition period (*T*) written as follows:

$$P = \begin{Bmatrix} W\ if\ N_t > 0 \\ D\ if\ N_t > 0 \\ T\ if\ N_t = 0 \end{Bmatrix} \quad (11)$$

Transition is Start (t_{Start}) of the wet period, and End (t_{End}) from the previous dry period, or vice versa.

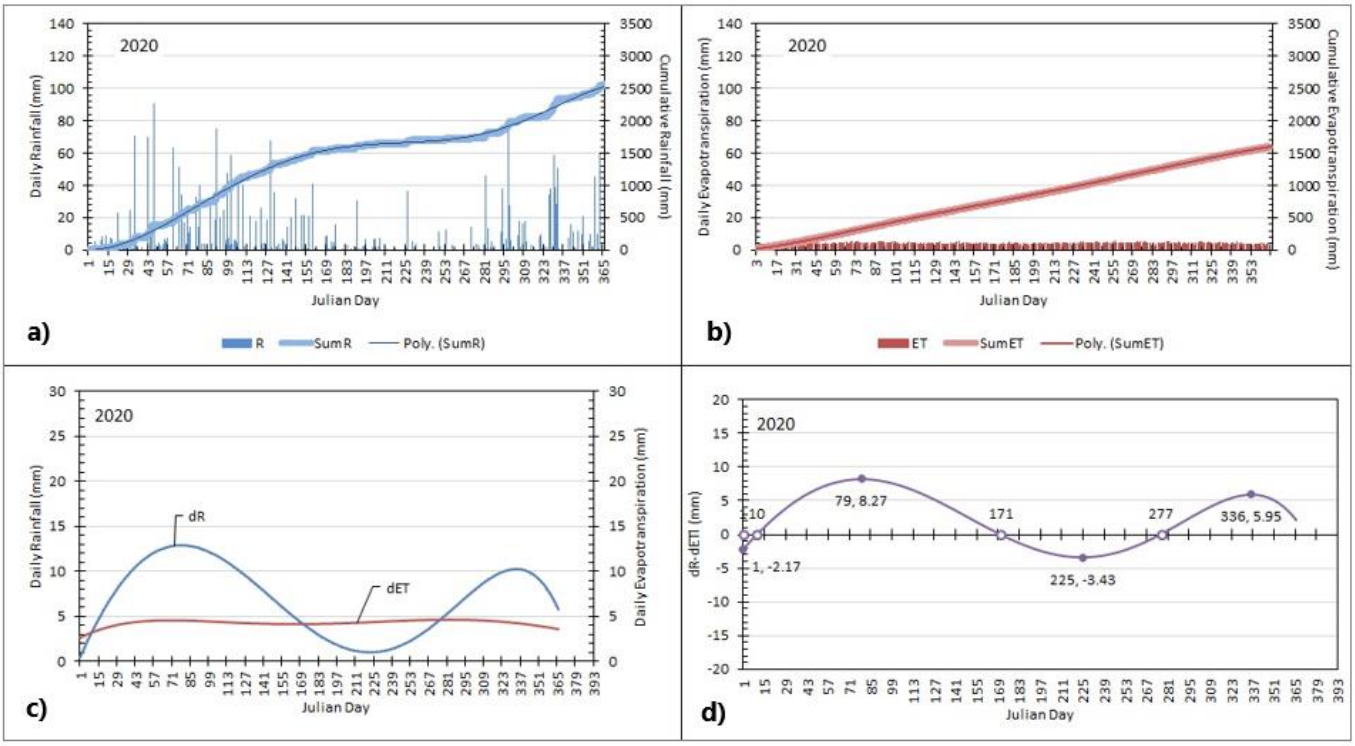

Figure 4 Process to determine wet and dry periods in a case for 2020. (a) daily rainfall; (b) daily evapotranspiration; (c) rates of rainfall and evapotranspiration; (d) rate of rainfall minus rate of evapotranspiration

Length (t_{Length}) of each period can be defined as follows:

$$t_{Length} = t_{End} - t_{Start} \quad (12)$$

Peak (t_{Peak}) of each period is the second derivative of $N(t)$ as follows:

$$Ntt|t_{Peak} = 0 \quad (13)$$

Available rainwater (ARW) of each period can be defined as follows (Setiawan, 2020):

$$ARW\,\Big|_{t_{Start}}^{t_{End}} = [R(t_{End})\text{-}R(t_{Start})]\text{-}[ET(t_{End})\text{-}ET(t_{Start})] \quad (14)$$

Data processing is done using MS Excel. Daily climate data every year is compiled in a different worksheet. Computer programs (functions) are developed and written in the Visual Basic Editor. The source codes of the main function to calculate the models in this method are built into the program algorithm to easily find the start, end, peak, season length, amount of available rainwater and peak rate in wet and dry season periods.

RESULTS AND DISCUSSION

Climate Conditions

Figure 2 shows annual climate and their trends from 1976 to 2021. The average and standard deviation (SD) for *Tn*, *Tx* and *Ta* was 20.43±0.93 °C, 32.08±0.60 °C, and 29.60±0.85 °C respectively, and for *RH* was 84.02±1.91 %. While *RH* was relatively stable from 1976 to 2021, *Tn* increased with time at 0.03 °C y^{-1}, and 0.04 °C y^{-1} for *Tx* and *Ta*. These trends indicated that the air was getting hotter. The annual rainfall (*R*) was 2597±458 mm, and evapotranspiration (*ET*) was 1588±43 mm. Both increased with time at 6.83 mm y^{-1} and 0.77 mm y^{-1}, respectively. The highest *R* was 3714 mm in 2010, whereas the lowest was 1606 mm in 1987. In general, the net of water balance (*WB*) fluctuated between surplus dan deficit but increased slightly with time at 6.06 mm y^{-1}, indicating the air became wetter. Increased temperatures, droughts, floods, and shifting of the rainy season are indications of climate change. The results of a previous study by (Ruminta et al., 2018) found that in several areas of South Sumatra had an increase in air temperature by 0.4–0.6°C, and rainfall decreased by 0–197 mm. An increase in air temperature and a decrease in rainfall causes a change in the region's climate which tends to be drier

Monthly Water Balance

The changes of monthly *R* and *ET* and *WB* from 1976 to 2021 showed in Figure 3(a) to Figure 3(f). In 1976, it can be seen that *WB* was a negative or rainwater deficit in January to February, and in May to September. However, from 1986 to 2021 there was a shift in the dry season pattern where the rainwater deficit occurred periodically from May to October. Overall, *WB* was a positive or rainwater surplus. Figure 3(g)**Error! Reference source not found.** shows the average monthly *R*, *ET*, and *N* over 46 years. While *ET* was relatively stable at 132±9 mm, *R* fluctuated widely from the lowest 85±60 mm in August to the highest 357±129 mm in March. In general, *WB* was a positive or rainwater surplus with the lowest water depth was

64 mm in October and the highest water depth was 218 in March, but from July

Table 1 Wet and dry periods and their occurrences

Period	Start (J-day)	Finish (J-day)	Length (days)	Peak value (mm day^{-1})	Peak day (day)	Net water (mm)
Dry1	1	9	9	-2.17	1	-18
Wet1	10	170	161	8.27	79	827
Dry2	171	276	106	-3.43	225	-269
Wet2	277	366	90	5.95	336	-539

to September was a deficit, which was the dry period with its peak in August with the water depth of -58 mm.

Daily Water Balance

The process to find continuous functions *dR(t)* and *dET(t)*, and to determine the Start, Finish, Net Water and Peak of Wet and Dry periods showed in Figure 4. As the example, we take the daily water balance in 2020. Figure 4(a) plots the daily rainfall (*Ri*) and its cumulative and continuous function *R(t)*. Figure 4(b) plots the daily evapotranspiration (*ETPi*) and its cumulative and continuous function *ETP(t)*. The first derivative for *R(t)*, and *ET(t)* showed in Figure 4(c). According to Equation (8), The results of the water balance rate model can be seen in Figure 4(d). The detail of the Start, Finish, Net Water and Peak of Wet and Dry periods from the Figure 4(d) can be seen in Table **1**.

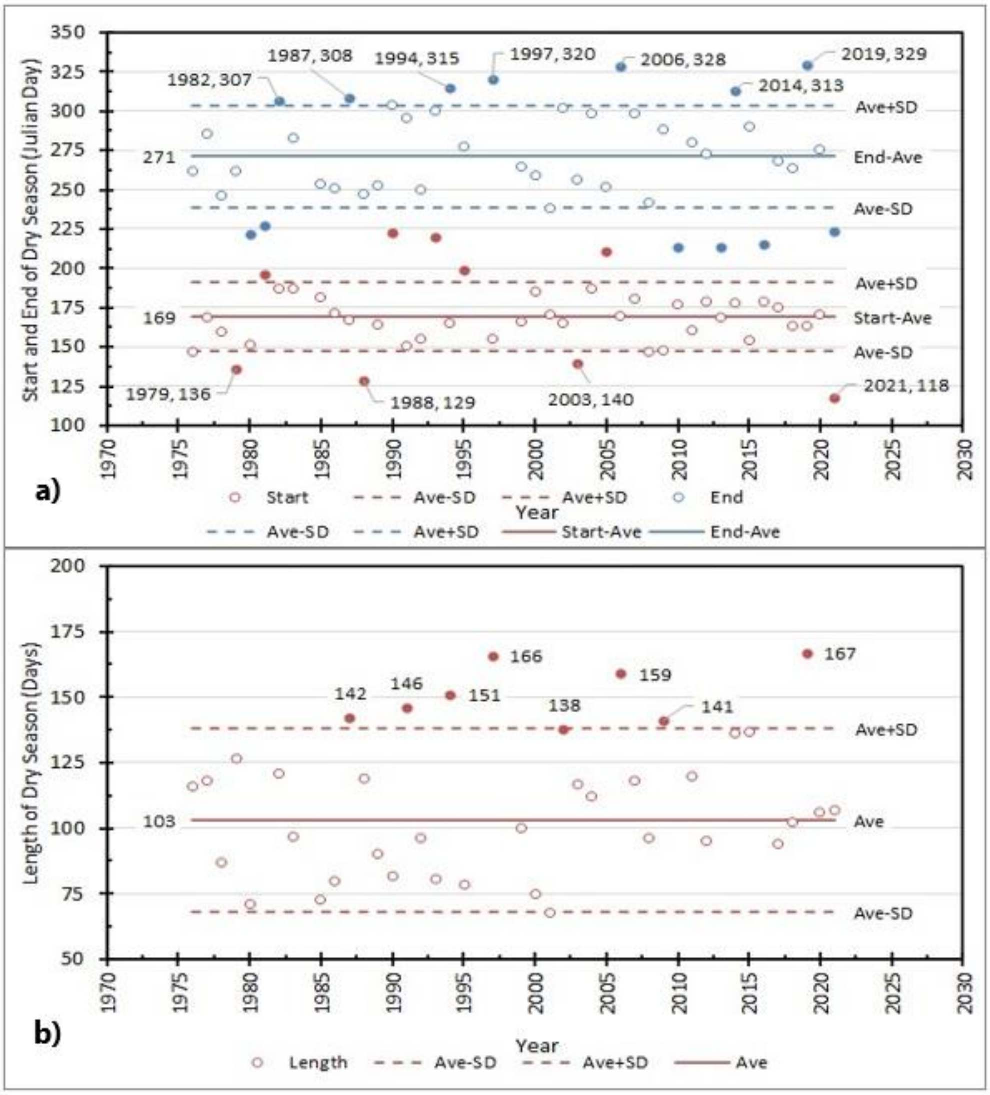

Figure 5 (a) Start and end of dry season from 1976 to 2021; (b) Length of dry season from 1979 to 2021

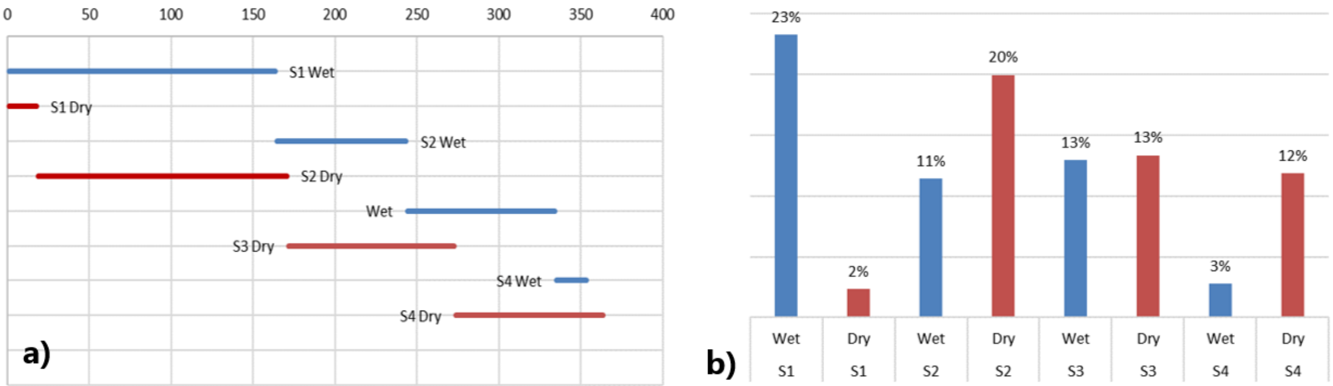

Figure 6 Seasonal a) segment and b) probability for 1 year

Dry Seasons

Based on Equation 11, Equation 8 and Equation 13, Figure 4(d) shows there are 2 points when net water (*Nt*) equals nil, which is on 171 J-day, and 276 J-day and the peak point on 225 J-day. This period was dry since between those two days; the *Nt* is negative. Another wet period started from 10 J-day to 170 J-day, and 277 J-day to the year of 2022. Based on Equation 14, the rainwater was deficit amounted to –269 mm, with the peak rate was –2.17 mm d-1 on 225 J-day.

For 1976 to 2021 or over 46 years, the start and end of dry season is shown in Figure 5(a). There are two colors of line and point in Figure 5(a). The red one is for the start of dry season, and the blue one is for the end of dry season. The average and SD of the start of dry season (the solid red line) was 169±22 J-day and the end of dry season (the solid blue line) was 271±32 J-day. The start days of dry season that were outside of the average start day–SD (the solid red points) are extreme start days which occurred several times over 46 years, were in 1979 on 136 J-day, 1988 on 129 J-day, 2003 on 140 J-day, and 2021 on 118 J-day. The end days of dry season that were outside of the average end day+SD (the solid blue points) are extreme end days which occurred in 1982 on 307 J-day, 1987 on 308 J-day, 1994 on 315 J-day, 1997 on 320 J-day, 2006 on 328 J-day, 2014 on 313 J-day, and 2019 on 329 J-day.

Figure 5(b) shows the length of dry season over 46 years from 1976 to 2021. The minimum length of dry season occurred was 37 days in 1981 and the maximal length of dry season was 167 days in 2019. The average and SD length of dry season was 103±35 days. The extreme length of dry season occurred eight times, were in 1987 for 142 days, 1991 for 146 days, 1994 for 151 days, 1997 for 166 days, 2002 for 138 days, 2006 for 159 days, 2009 for 141 days, and 2019 for 167 days.

The occurrence of the extreme length of dry season is caused by real climate change in those 8 years. There was drought throughout 1987, 1991, 1994, 1997, 2002, 2006, 2009 and 2019 and the lack of rainfall caused net water availability to become a deficit.

From the trend of data, it shows that apart from 2010, there was also a change in the pattern of the surrounding seasons in 2013. This could be caused by a very significant global warming in 2014 with a temperature increase of 0.65°C which was shown in a decrease in rainfall intensity in March 2014. According to BMKG (BMKG, 2015), since the end of 2014 the conditions in the Central Pacific Equator (Nino 3.4) have tended to be warm, this condition has continued until July 2015. At the end of July 2015, the Nino 3.4 index was already in El Nino Moderate conditions which then led to the 2015 rainy season in the Indonesian Territory experienced a decline of up to several months from normal (BMKG, 2015).

Season Patterns

Based on the summary climate data for 46 years that have been analyzed, the season pattern that occurred can be drawn. There were four wet periods (Wet1, Wet2, Wet 3, and Wet4) and four dry periods (Dry1, Dry2, Dry 3, and Dry4). Figure 6(a) shows the pattern of season clearly in sequence from the first of January (1 J-day):

- S1 Wet was from 1 J-day to 163 J-day with P = 23%; peak rate = 10.4 mm d^{-1}; and ARW = 601 mm;
- S1 Dry was from 1 J-day to 18 J-day with P = 2%; peak rate = -7.2 mm d^{-1}; and ARW = 35 mm;
- S2 Wet was from 164 J-day to 243 J-day with P = 11%; peak rate = -2.4 mm d^{-1}; and ARW = -223 mm;
- S2 Dry was from 19 J-day to 171 J-day with P = 20%; peak rate = 8.2 mm d^{-1}; and ARW = 679 mm;
- S3 Wet was from 244 J-day to 334 J-day with P = 13%; peak rate = 9.6 mm d^{-1}; and ARW = 195 mm;
- S3 Dry was from 172 J-day to 273 J-day with P = 13%; peak rate = -2.5 mm d^{-1}; and ARW = -272 mm;

- S4 Wet was from 335 J-day to 354 J-day with P = 3%; peak rate = 1.5 mm d^{-1}; and ARW = -459 mm;
- S4 Dry was from 274 J-day to 364 J-day with P = 12%; peak rate = 11.2 mm d^{-1}; and ARW = 152 mm.

From Figure 6(b), it can be deduced the probability of seasonal patterns that will occur in the following years. if divided into three segments throughout the year, at the beginning of the year it may start with a wet season from 1±30 J-day to 163±79 J-day, the dry season may start from 172±152 J-day to 273±90 J-day and followed by the wet season until 244±90 J-day. During the dry season, *ARW* was 114 mm (rainwater surplus). Whereas, during the wet season, *ARW* was 593 mm (rainwater surplus). And in the whole season, the rainwater is surplus 708 mm, which may be an early warning to anticipate flooding and rainwater management for the South Sumatra region.

The results of the study show that the Sumatera Selatan region has experienced climate change as indicated by changes in rainfall patterns and rainy days, as well as the trend of decreasing annual rainfall and rainfall distribution. These results are in line with those indicated by the research by (Rahayu and Anjasmara, 2020), and (Nugroho and Nuraini, 2016) that in several regions of Indonesia have experienced climate change. In some areas there are indications of rising air temperature, changes in monthly and annual rainfall distribution patterns, and season classification.

CONCLUSIONS

The study has been determined the patterns of wet and dry seasons based on the daily data of rainfall and evapotranspiration in Palembang City, South Sumatera Province, Indonesia from 1976 to 2021. Based on the climate data, the trends indicated that the air was getting hotter. The annual rainfall (R) was 2597±458 mm, and evapotranspiration (ET) was 1588±43 mm. Both increased with time at 6.83 mm y-1 and 0.77 mm y-1, respectively. There were four wet periods and four dry periods. On average, at the beginning of the year it may start with a wet season from 1±30 J-day to 163±79 J-day, then the dry season may start from 172±152 J-day to 273±90 J-day and followed by the wet season until 244±90 J-day. There were 8 extreme dry seasons with the longest was 167 days in 2019. As a precaution, extreme wet seasons may occur in Nov, Dec, and March while extreme dry seasons in Jul, Aug, and Sep. In the dry season, the rainwater was surplus about 114 mm. Whereas, in the wet season, rainwater was surplus about 593 mm. In the whole season, the rainwater was surplus up to 708 mm, which may be an early warning to anticipate flooding and rainwater management for the South Sumatra region.

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