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Effects of climate anomaly on rainfall, groundwater depth, and soil moisture on peatlands in South Sumatra, Indonesia

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Abstract: Climate anomalies can cause natural disasters such as severe fires and floods on peatlands in South Sumatra. Factors that affect the natural disasters on peatlands include rainfall, groundwater level, and soil moisture. This paper aims to study the effect of the climate anomalies in 2019 and 2020 and effects of these influencing factors on peatlands in South Sumatra. The data used in this study was derived from in-situ measurement at two SESAME's measurement stations in the study area. The results indicate that in the 2019 dry season, the rainfall was minimal, the lowest groundwater table depth was −1.14 m and the lowest soil moisture was 3.4%. In the 2020 dry season, rainfall was above the monthly average of 100 mm, the lowest groundwater level was −0.44 m, and the lowest soil moisture was 26.64%. There is also a strong correlation between soil moisture and groundwater table depth. The correlation between the two is stronger when there is less rainfall.

Keywords: IOD; ENSO; Dry season; Correlation; Peatlands

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Introduction

South Sumatra is one of the provinces of the Republic of Indonesia and has 1.73 million hectares of peatland. During the extreme dry season, the peatland is often burnt massively, while during the extreme rainy season, it is often flooded (Hugron et al. 2020; Irfan et al. 2022; Irfan et al. 2019; Yuwati et al. 2021). Extreme dry and wet seasons occur due to climate anomalies which are usually associated with the natural phenomena of El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). ENSO occurs in the Pacific Ocean, while IOD occurs in the Indian Ocean. Indonesia is located between the two oceans and if an ENSO or IOD phenomenon occurs, there will be a direct effect on climate conditions in Indonesia (Hasudungan et al. 2021; Hendrawan et al. 2019; Wijaya et al. 2020).

ENSO consists of El Niño and La Niña, while IOD consists of IOD+ and IOD-. El Niño can cause extreme dry weather and La Niña can cause extreme rainy one. IOD+ can cause extreme dry season and IOD- can cause extreme rainy season. In 2019, the IOD+ occurred which caused the peatlands in Sumatra to dry out and massive wide fires. Meanwhile, in 2020 there was a medium-level La Niña that caused the average rainfall in Indonesia to be above normal level (Cai et al. 2022; Cao et al. 2022; Zheng et al. 2022).

The dry season in Indonesia generally occurs in July, August, September, and October (JASO). During the dry season, monthly rainfall is usually quite low, ranging from 50 mm to 100 mm per month (Irfan et al. 2022).

This research focuses on the effect of peatland hydro-climatological factors in dry season, particularly with the intention of assessing the impact of IOD+ 2019 and La Niña 2019 on rainfall and the other parameters such as groundwater level and soil moister related to rainfall. The effects of IOD+ 2019 and La Niña 2020 on these three parameters will be analyzed to find the correlation between the three during parameters the dry season in South

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Sumatra. Furthermore, several researches on the dynamics of hydro-climatological parameters on peatlands in Indonesia has been carried out (Irfan et al. 2022; Irfan et al. 2021; Irfan Muhammad et al. 2019; Irfan Muhammad et al. 2020). However, previous researches that specifically analyze and compare the effects of the 2019 IOD+ and La Niña 2020 phenomena on the parameters of rainfall, groundwater table depth, and soil moisture over the peatlands in South Sumatra has never been done. The current study is hence expected to gain a number of new findings which may result in a better understanding about the influence of the climate anomalies on the factors of rainfall, groundwater level, and soil moisture that in turn impact on the peatland landscapes in South Sumatra.

1 Study area

This research was conducted with the data derived from measurements in 2 research stations located in the peatlands of South Sumatra, namely stations OKI-1 and OKI-2. The coordinates of the stations are 104.9651°E and 3.478628°S for OKI-1, and 104.9775°E and 3.392495°S for OKI-2. Fig. 1 illustrates the locations of the study area, where the yellow and pink colors indicate peatland areas, and specifically the pink color is peatland domes. The blue boxes are canals in peatlands. It appears that OKI-1 station is closer to the canals than OKI-2 station.

The station was set up on the peatland to measure the hydro-climatological parameters in situ. Peatlands in the both locations have a medium level of maturity (hemic) in accordance with the characteristics of peatlands in Indonesia in general. This peatland has a fiber content of 33%–66%, a density of 0.1–0.19 g·cm^{-3}, and a water content of 450%–850%, appearing to be in dark brown color (Kirana et al. 2016; Purnamayani et al. 2022; Turmudi et al. 2019; Yulnafatmawita et al. 2021). In general, the water drains in a peatland faster in horizontal direction than in vertical (upward) direction. As a result, the top layer of peat is often dry and flammable, even though the bottom layer is wet. The same thing happened at the location of this study area, so that in the 2019 extreme dry season the area around this station experienced massive fires.

This research was conducted during the dry seasons of 2019 and 2020 because in 2019 the IOD+ phenomenon occurred and in 2020 the La Niña phenomenon occurred. The IOD+ phenomenon occurs due to the interaction between the sea and the atmosphere in the Indian Ocean which causes temperature anomalies in seawater. This temperature anomaly is used as a reference to determine the IOD+ level that occurs, as the higher the anomaly that occurs and the higher the IOD+ level. In this event, areas in the southeastern part of the Indian Ocean such as Indonesia experienced a lack of rain, while in the west it experienced an excess of rain. La Niña occurs because of the interaction between the ocean and the atmosphere in the Pacific Ocean. In this event, there was also an anomaly in seawater temperature in the Pacific Ocean which was used as a reference to determine the level of La Niña that occurred (Cao et al. 2022; Hendrawan et al. 2019; Huang et al. 2019; Puryajati et al. 2021; Reddy et al. 2022; Sankar et al. 2019; Shi & Wang, 2021). In the La Niña event, the amount of rainfall in Indonesia was above average.

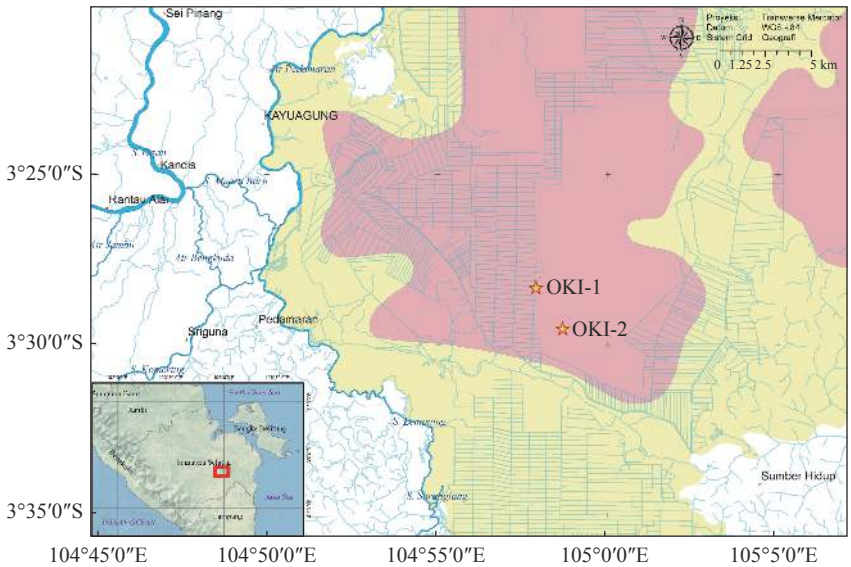

Fig. 1 Map of study area

2 Data

The research data is derived from the measurement results of the SESAME station in South Sumatra, namely the OKI-1 Station and OKI-2 Station. SESAME is a hydro-climatological measurement station that manages and performs in situ measurements on several peatlands in Indonesia, including in South Sumatra. The SESAME station was established in collaboration with the Indonesian government and the Japanese government to mitigate natural disasters, especially fires and floods on peatlands in Indonesia. This station was first established in mid-2018 on the islands of Sumatra and Kalimantan (Irfan Muhammad et al. 2019; Irfan Muhammad et al. 2020; Mandailing et al. 2020). The data from the measurement results of the SESAME station is displayed on the SESAME website, namely https://web.sesame-system.com.

3 Method

The data measured by the SESAME system is hourly data which we then convert into daily data and monthly data. The focus for this research period is during the dry season in Indonesia with the assumption that there are significant differences in the data as a result of the IOD+ and La Niña phenomena. The dry season in Indonesia usually occurs in the July to October (JASO), so the data we use is data for the JASO period. The data was processed and analyzed using statistical methods to obtain graphs, relationships, correlations, and correlation significance between the parameters of rainfall, groundwater level, and soil moisture.

4 Results and discussion

4.1 Rainfall

Table 1 shows that in the dry season period from July to October (JASO) in 2019, rainfall (RF) at the two research sites was very minimal. Rainfall is far below the long-termmonthly rainfall of 100 mm in the area, and even in August 2019 there was no rain at all. This happened because the IOD+ occurred in 2019 is classified as a high level IOD+, so that rainfall is very minimal. As a result, the peatlands become very dry and easily burnt. In 2019 the peatland area with wild fire in South Sumatra was 428 365 ha (Putra et al. 2021; Putra et al. 2019).

Table 1 also shows that the monthly rainfall in the JASO 2020 period is above the normal amount

Table 1 Monthly rainfall in the period July to October 2019-2020

	OKI-1 RF (mm/month)		OKI-2 RF (mm/month)	
	2019	**2020**	**2019**	**2020**
July	9	153.4	4.6	107.4
August	0	95	0	100.6
September	4.5	278.2	3.3	102
October	14.8	262.8	19	108.5
Total	28.3	789.4	26.9	418.5

of rainfall. However, the La Niña that occurred in 2020 is classified as a medium-level La Niña and the rainfall was not so extreme, it is still below 300 mm/month. In extreme La Niña conditions, rainfall can reach above 500 mm/month (Hayashi et al. 2020; Muhammad et al. 2019; Puryajati et al. 2021).

4.2 Groundwater depth

In the 2019 extreme dry season, groundwater depth level (GWD) generally decreased from July to September at both research sites. The lowest groundwater depth was 1.147 m below surface at the OKI-1 and 0.875 m below the surface at the OKI-2 as shown in Fig. 2. The decline in groundwater level in October 2019 was not very smooth because October was the end of the dry season when it started to rain. At the OKI-2 (Fig. 2b), it appears that in October the groundwater level experienced fluctuations due to the influence of rainfall.

The decline in groundwater level at the OKI-1 is sharper (maximum −1.147 m), compared to that at the OKI-2 (maximum −0.875 m). This happens because the OKI-1 is located closer to the canal, comparing to the location of the OKI-2 (Fig. 1). The canal system drains the water from peatlands and thus affect the groundwater near the canals, so that the groundwater level at the OKI-1 becomes lower (Ivan et al. 2020; Lu et al. 2021; Suryadi et al. 2021; Sutikno et al. 2020).

The Indonesian government has determined that the peatland with a maximum groundwater level depth of 0.4 m below surface is not easily flammable. As shown in Fig. 2, during the 2019 dry season the groundwater level exceeded the safe threshold, causing peatlands to catch fire easily. It is not surprising that in 2019 there have been massive fires on peatlands in Indonesia. In South Sumatra in 2019 there was a fire that scorched 967.25 hectares of peatland (Irfan et al. 2021; Putra et al. 2021).

During La Niña 2020, it appears that the ground-

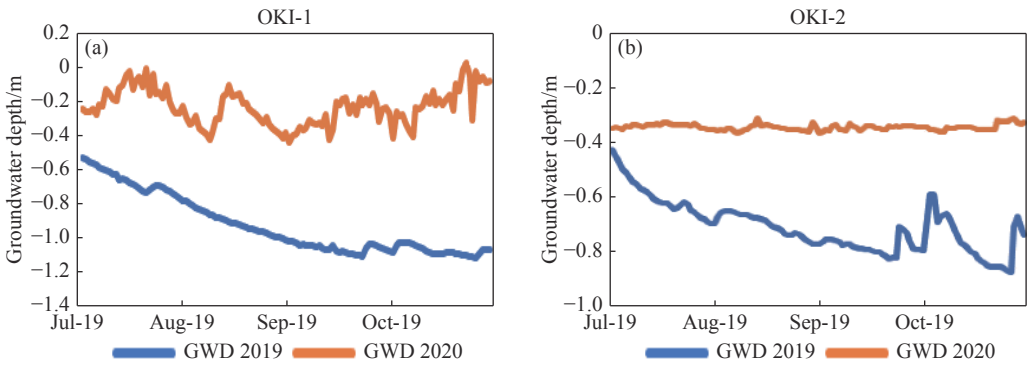

Fig. 2 Graph of groundwater level time series at OKI-1 (a) and OKI-2 (b) locations

water level is in the range from 0.01 m to 0.464 m deep (Fig. 2a). This data shows that the La Niña 2020 did not cause flooding in the 2020 dry season because the La Niña level was medium. The groundwater level at the OKI-1 is more volatile when compared to the OKI-2 because the rainfall at the OKI-1 is higher than that at the OKI-2.

The relationship between groundwater level and rainfall in the form of a time series graph is shown in Fig. 3. The graph shows that the groundwater level is strongly influenced by rainfall. When there is rainfall, the groundwater level will rise and vice versa. The higher the rainfall is, the higher the groundwater level, and vice versa.

4.3 Soil moisture

The measured soil moisture is referred to that measured on the peat soil surface. Soil moisture measuring sensors are installed at a depth of 5 cm below the surface of the peat soil. As shown in Fig. 4, during the 2019 dry season, soil moisture at the OKI-1 was very low as lower that 10%, while at the OKI-2 the soil moisture ranged from 10%–30%. It appears that the soil moisture at the OKI-1 is lower than that at the OKI-2. This is closely related to the presence of canals near the OKI-1 where the groundwater level is lower than that at the OKI-2. Lower groundwater level depth causes the surface soil to be drier and subsequently lower soil moisture. The low soil moisture or the dry topsoil has caused the peatlands to be very easily burnt in a natural or intentionally manner. During the 2020 dry season, soil moisture at the OKI-1 ranged from 30% to 50%; and at the OKI-2, it ranged from 30% to 65%. The high soil moisture

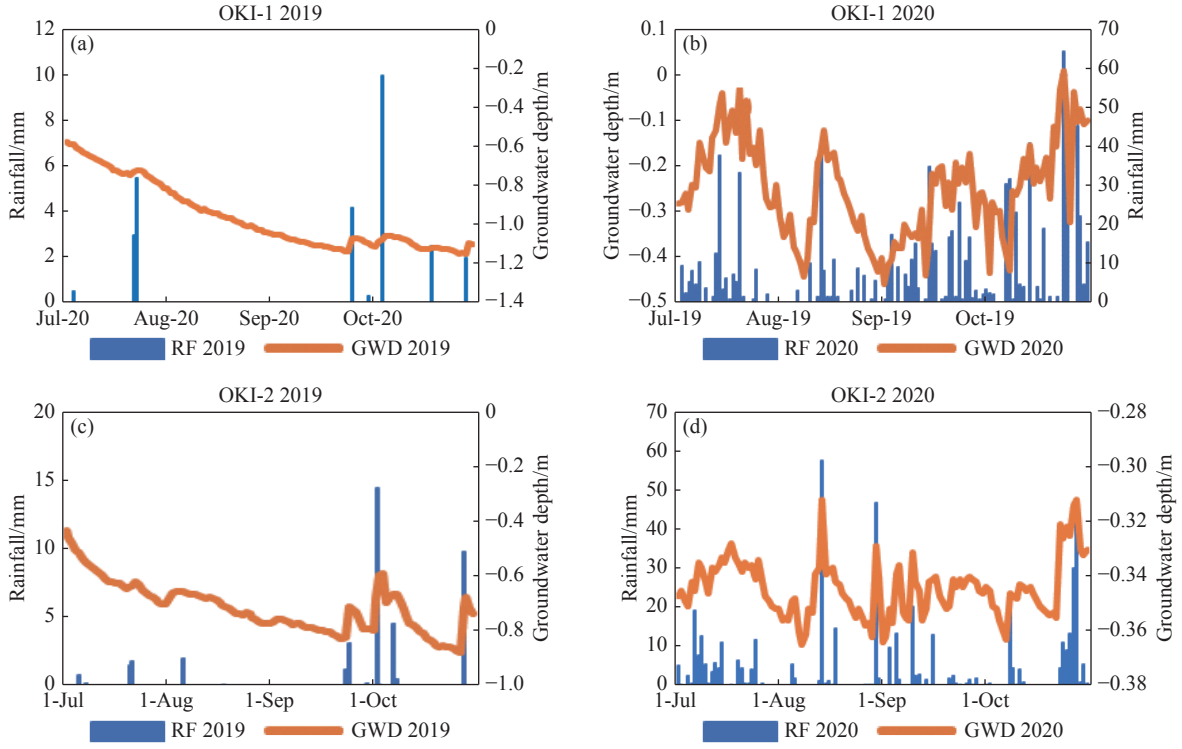

Fig. 3 The relationships between groundwater level and rainfall

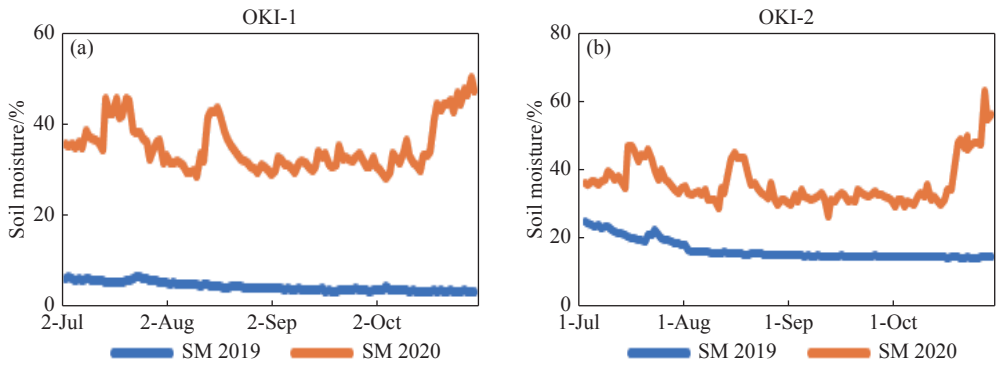

Fig. 4 Soil moisture time series at OKI-1 (a) and OKI-2 (b) locations

on the peat topsoil suggests that the peat soil surface is difficult to be burnt (Adinugroho et al. 2021; Millard et al. 2018; Wang et al. 2018; Widiarso et al. 2020).

To determine the degree of the correlation between soil moisture and groundwater level depth, a statistical test was carried out. The correlation graph, empirical equation, and coefficient of determination are shown in Fig. 5. The correlation coefficient (r) values obtained are all above 0.70 (Table 2), so it can be concluded that the correlation degree between soil moisture and groundwater level is high. Fig. 5 shows that the correlation coefficients for the 2019 dry season at the two monitoring sites are greater than those of the 2020 rainy season. This indicates that the lower the rainfall occurs, the better the correlation between soil moisture and groundwater level. The results of the detailed statistical expressions are shown in Table 2.

To analyze a relationship between soil moisture and rainfall, a time series for soil moisture and rainfall is plot in Fig. 6. Fig. 6 shows that soil moisture on the surface of peatlands is strongly influenced by rainfall. Fig. 6 (b) and Fig. 6 (d) show that if there is continuous rainfall, the topsoil on peatlands remains a high soil moisture level. Fig. 6 (a) and Fig. 6 (c) show that if there is infrequent rainfall, the soil moisture tends to decrease.

The low soil moisture is very critical for a fire

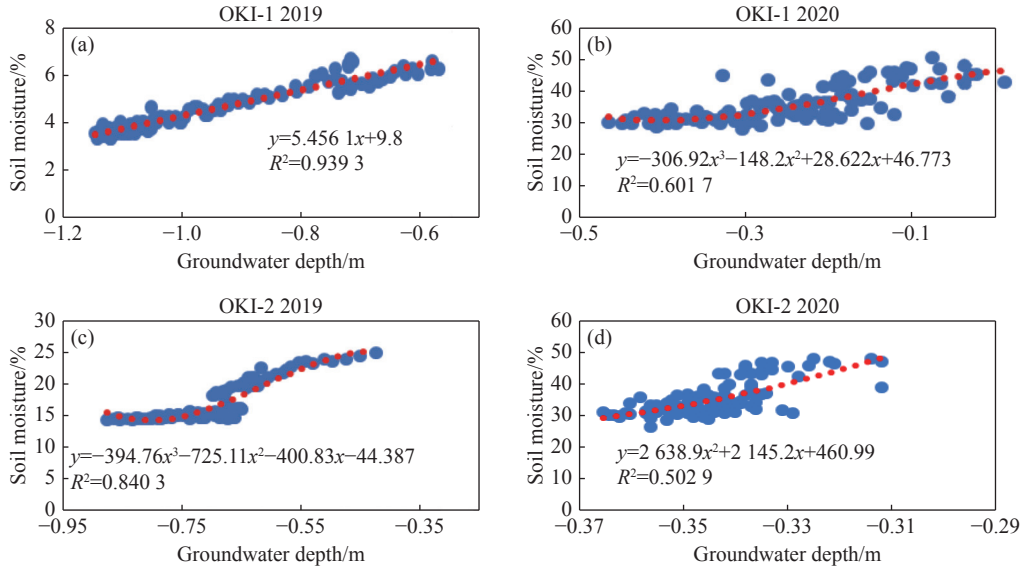

Fig. 5 Correlation between soil moisture and groundwater level

Table 2 Result of statistical calculation of correlation between soil moisture and groundwater level

Station	Year	Correlation Equation of GWL (x) vs SM (y)	Coefficient correlation (r)
OKI-1	2019	$y = 5.456\,1x + 9.8$	0.97
	2020	$y = -306.92x^3 - 148.2x^2 + 28.622x + 46.773$	0.78
OKI-2	2019	$y = -394.76x^3 - 725.11x^2 - 400.83x - 44.387$	0.92
	2020	$y = 2\,638.9x^2 + 2\,145.2x + 460.99$	0.71

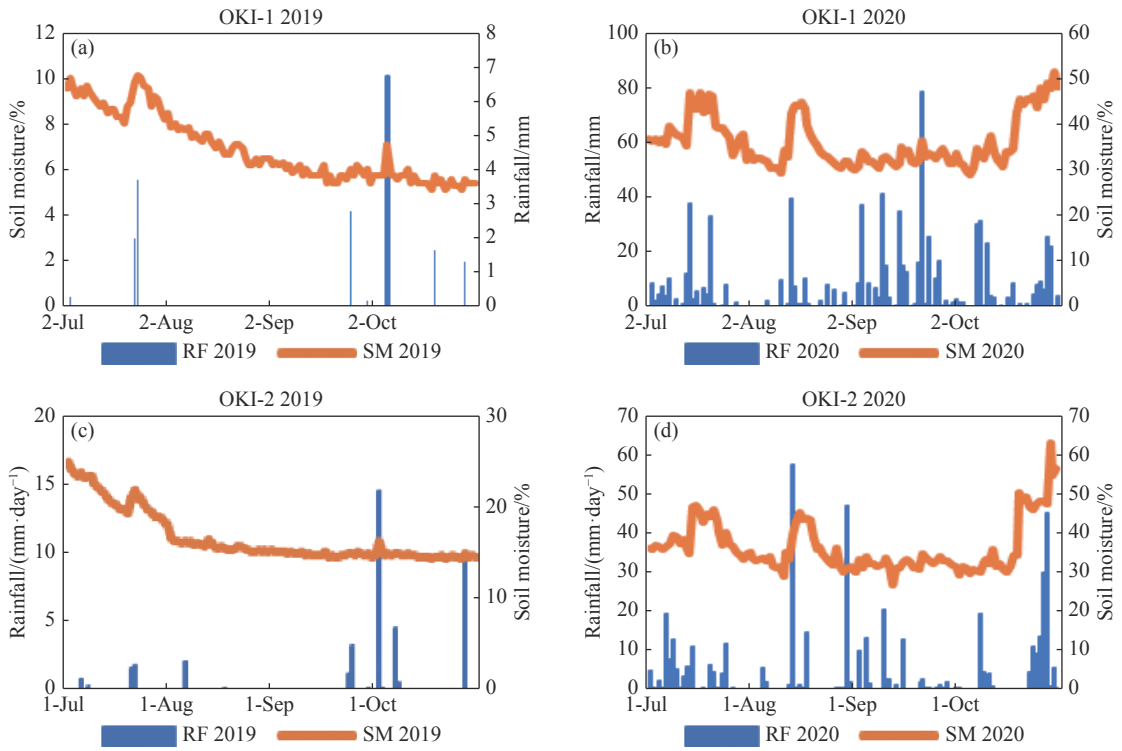

Fig. 6 Graph of the relationship between soil moisture and rainfall

incident on the peatland surface. The low soil moisture or dry peatland surface is caused by the low groundwater level and the lack of rainfall. The decline of groundwater level is caused by the lack of rainfall and the presence of canals near the peatlands. To prevent fires on the peatlands during the extreme dry season, the groundwater level must be maintained at a high level so that soil moisture can be maintained as well. Efforts are needed so that the water reserves in peatlands do not quickly decrease. Canals that drain water from peatlands must be closed. It is also necessary to build water reservoirs on peatlands where the water comes from rivers near the peatlands.

5 Conclusion

Climatic anomalies due to ENSO and IOD phenomena greatly affect the factors as rainfall, groundwater level, and soil moisture on peatlands in South Sumatra. The climate anomaly in 2019 that occurred due to the high level of IOD+ has caused rainfall, groundwater level, and soil moisture to drop to very low levels. Meanwhile, the climate anomaly in 2020 due to the mid-level La Niña caused the rainfall, groundwater level, and soil moisture to be well above average values. Results of this study show that there is a strong correlation between soil moisture and groundwater level, with a higher correlation coefficient when the rainfall is less. In the extreme dry season with minimal rainfall, the groundwater level drops drastically so that the soil moisture drops drastically. As a result, peatlands become very dry and easily burnt.

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