THE ANALYSIS OF FIRE HOTSPOT DISTRIBUTION IN KALIMANTAN AND ITS RELATIONSHIP WITH ENSO PHASES

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Manuscript received: July 25, 2022
Revised version: October 24, 2022

Zahra R.A., Nurjani E., Sekaranom A.B., 2022. The analysis of fire hotspot distribution in Kalimantan and its relationship with ENSO phases. *Quaestiones Geographicae* 42(1), Bogucki Wydawnictwo Naukowe, Poznań, pp. 75–86. 7 figs, 2 tables.

Abstract: Kalimantan experiences fire hazards almost every year, which threaten the largest tropical forest in Southeast Asia. Climatic conditions, such as increasing surface temperature and decreasing rainfall, become important especially when El Nino Southern Oscillation (ENSO) occurs. Studies on fire are commonly conducted based on the climatic condition such as the dry or wet season, but those which focused on analysis of fire occurrences with the specific ENSO phases are still limited. This study aims to identify the spatial and temporal distribution of rainfall, land surface temperature, and soil moisture and analyses the distribution of hotspots in Kalimantan from 2014 to 2020 during different ENSO phases. The data used are Moderate Resolution Imaging Spectroradiometer (MODIS) for hotspot analysis, Global Precipitation Measurement (GPM) for rainfall analysis, MODIS Land Surface Temperature (LST) for surface temperature analysis and Soil Moisture Active Passive (SMAP) for soil moisture analysis. The methods used were descriptive and spatial analyses based on each ENSO phase, which were then combined to analyse the temporal and spatial distribution of fire, rainfall, LST and soil moisture. The temporal distribution shows a positive relationship between ENSO, rainfall, LST, soil moisture and hotspots with a confidence level of 90% in the dry months of August–October. Fire occurred in most parts of West and Central Kalimantan, associated with low elevation, organic soil types and agricultural peatland. The average trend of increasing hotspots is 17.4% in the El Nino phase and decreasing hotspots by 84.7% in the La Nina phase during August–October in Kalimantan.

Key words: fire hotspot, ENSO, rainfall, land surface temperature, soil moisture

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Introduction

Climate change not only affects the atmosphere, but also affects ecosystems of the earth. One of the most noticeable adverse impacts of climate change is land and forest fires (Hurteau et al. 2019). Various studies over the past decade have demonstrated the significant effect of climate change on land and forest fires. Goss et al. (2020) show an increase in the forest fire risk as driven by climate change. The rise of global temperature by 0.3°C decade^{-1} has led to drier organic matter in tropical rain forests, dominated by peat material. The peat material becomes combustible and is the main factor that triggers forest fires in the tropics. Due to the above conditions, forest and land fires have become one of the most common disasters in Indonesia (Hatta 2008). Among the islands in Indonesia, Kalimantan has seen the highest number of forest fire cases:

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https://doi.org/10.14746/quageo-2023-0006
ISSN 2082-2103, eISSN 2081-6383

large-scale forest fires started in 1982, followed by fires in 1983, 1994, 1997, 1998, 2006 and 2015 (Arisman 2020). The occurrence of large forest fire in Kalimantan suggests the strong influence of climatic factors, particularly during the extremely dry period.

El Nino Southern Oscillation (ENSO) is one of the most significant tropical climate anomaly that influences weather variability in Indonesia. ENSO phases influence rainfall, surface temperature and soil moisture variability as indirect impacts (Bussberg 2021). The El Nino phase is often associated with drought in Indonesia (McPhaden et al., 2020), by decreasing precipitation and increasing land surface temperature. For example, the El Nino event triggered a long period of severe drought over parts of Indonesia in 1997 (Sudibyakto et al. 2021). The large forest fires in Kalimantan during mid-2015 were also often associated with the El Nino event (Arisman 2020). Forest fires cause major economic losses in Indonesia and the surrounding countries, particularly owing to health, land transportation and aviation problems.

Analysis of the spatial and temporal distribution of forest fire hotspots and various natural triggering factors is important to determine the spread of forest fires and their relationship to these atmospheric factors. Due to the lack of surface observation, remote sensing data is useful for providing rapid analysis of hotspots and its contributing factors in terms of weather and climate. Changes in precipitation, surface temperature and soil moisture that are easily retrieved by satellite sensor could be utilised in the forest fire early warning system. Furthermore, identification of the process related to the contributing factor can be used for fire hotspot prediction.

The differences of this study from other fire research studies lie on the ENSO-based analysis in the spatial and temporal distribution of climate factors and soil moisture in the driven parameters of fires in Kalimantan. Santika et al. (2020) analysed the spatial and temporal distribution of Moderate Resolution Imaging Spectroradiometer (MODIS) hotspot based on the interannual climate variation, land type, and village livelihood in Kalimantan. Sari et al. (2020) gave analysis of fire hotspot distribution in East Kalimantan and compared the analysis with the land use condition. Nurdiati et al. (2021) assessed the fire occurrences in Kalimantan and Sumatra based on El Nino conditions, comparing the weak, moderate and strong conditions. Najib et al. (2022) analysed the 2015 and 2019 extreme drought events and the ENSO effect on the joint distribution of drought indicators using copula. Yananto and Dewi (2016) also analysed the climatic anomaly on fire in Kalimantan based on NINO 3.4 SST Index, Southern Oscillation Index and Indian Ocean Dipole (IOD). Sloan et al. (2017) assessed the El Nino impacts on fire activity based on industrial land conversion and drought. Larasati et al. (2019) focused on Central Kalimantan for assessing the fire regime in peatland restoration by analysing sea surface temperature (SST), rainfall and hotspot.

Several studies have also contributed towards analysing Kalimantan's climatic condition on land surface temperature (LST). Chapman et al. (2020) assessed the impact of deforestation in Kalimantan by analysing the rainfall and temperature using data derived from Conformal Cubic Atmospheric Model (CCAM). McAlpine et al. (2018) used the LST MODIS data to analysed the impact of forest loss in Kalimantan on its temperature. Chen et al. (2016) used the SST data in analysing 2015 Borneo fires. The research gap in this study related to the meteorological aspect focused on ENSO phases by analysing fire occurrences across Kalimantan. The soil moisture identified in this study also was a different aspect from the previous studies, as this parameter contributed to the wetness of the peatland area across Kalimantan. The basic condition and analysis of soil moisture could be managed for further drought analysis, specifically in the peatland area where the fire was more likely to happen.

From previous studies, the spatial and temporal distribution of fire was limited for combining climate factors and soil moisture analysis based on ENSO. Therefore, this study aims to (1) identify the spatial and temporal distribution of hotspots in Kalimantan at different ENSO phases from 2014 to 2020, and (2) identify the rainfall, surface temperature and soil moisture distribution towards fire hotspots at different ENSO phases based on remote sensing data.

Materials and methods

Study area

The research was conducted in Kalimantan, a part of Borneo Island, which is administratively located in Indonesia. This region comprises an area of 743,330 km^2 and consists of four provinces, namely West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan and North Kalimantan.

Data collection

The data collection was carried out, particularly remote sensing data and Oceanic Nino Index

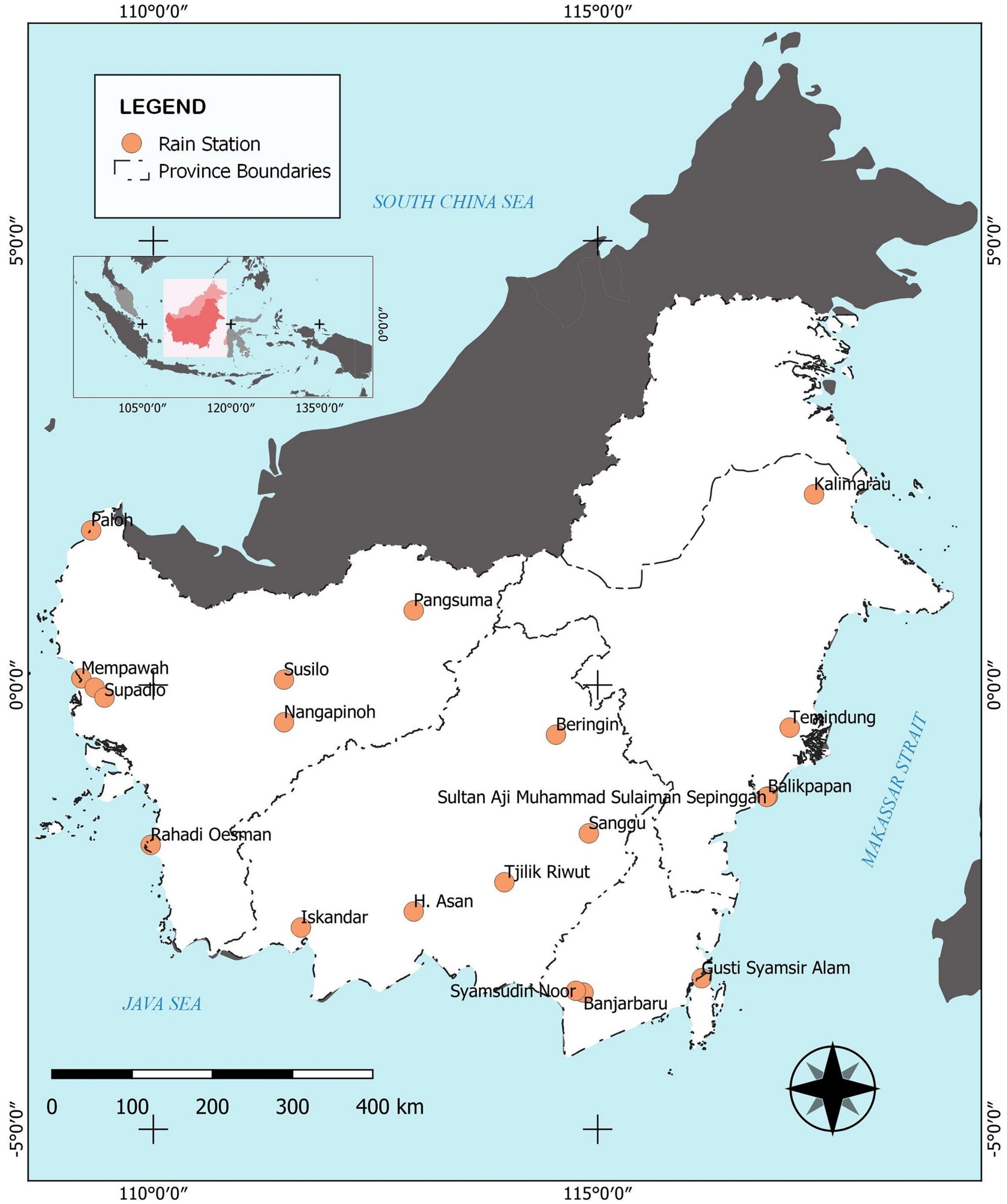

Fig. 1. Rain station in Kalimantan (BIG and BMKGs 2020). Base map obtained from Indonesian Geospatial Agency.

Table 1. List of data used in this study.

No.	Data	Source	Organisation	Access	Spatial resolution	Temporal resolution
1.	Hotspot	Moderate Resolution Imaging Spectroradiometer MODIS (MCD14ML) 2014–2020	The National Aeronautics and Space Administration (NASA)	lpdaac.usgs.gov/tools/appeears/	1 km	Daily
2.	Satellite precipitation data	Global Precipitation Measurement (GPM) 2014–2020	The National Aeronautics and Space Administration (JAXA)	giovanni.gsfc.nasa.gov/giovanni/	0.1°	Monthly
3.	Land Surface Temperature	Moderate Resolution Imaging Spectroradiometer MODIS (MOD11A1.006) 2014–2020	The National Aeronautics and Space Administration (NASA)	lpdaac.usgs.gov/tools/appeears/	1 km	Daily
4.	Soil Moisture	Soil Moisture Active Passive SMAP (SPL4SMAU) 2015–2020	The National Aeronautics and Space Administration (NASA)	lpdaac.usgs.gov/tools/appeears/	9 km	Daily
5.	Meteorological station data	Indonesian Bureau of Meteorology	Badan Meteorologi dan Klimatologi (BMKG)	dataonline.bmkg.go.id/	–	Daily
6.	Oceanic Nino Index (ONI)	ONI 2014–2020	The National Oceanic and Atmospheric Administration (NOAA)	origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php	–	Monthly

(ONI), as shown in Table 1. This study used datasets from 2014 to 2020 to analyse how the fire, rainfall, LST and soil moisture distribution occurred during this period and does not focus on climate variability in a long period of time.

Data processing

The ONI index from 2014 to 2020 was utilised as a proxy to the El Nino and La Nina events. The El Nino event occurs when ONI increases >0.5°C and La Nina occurs when ONI decreases below −0.5°C. While the ONI anomaly falls between −0.5°C and 0.5°C, it is considered as a neutral phase. Precipitation, land surface temperature and soil moisture were then compared for each phase. Global Precipitation Measurement (GPM) precipitation data was utilised to characterise rainfall anomalies between the El Nino, neutral and La Nina phases. Validation was conducted by comparing rainfall data on GPM images with data on 20 meteorological station data (Fig. 1) from the Indonesian Bureau of Meteorology (Badan Meteorologi dan Klimatologi - BMKG). The meteorological station located nearest to the grid centroid of the GPM data were used for Pearson correlation analysis. The result indicates that rainfall data from GPM image processing correlates strongly (Schober et al. 2018) with station rainfall data by *r* Pearson = 0.81 (Fig. 2). This value indicates that the condition of the rain data from the GPM measurement are of good quality to be utilised in this analysis.

Information about LST was obtained from the MODIS LST product (MOD11A1.006). This satellite imagery product is vulnerable to cloud disturbances because it has a spatial resolution of 5 km. Due to the cloud sizes being <5 km,

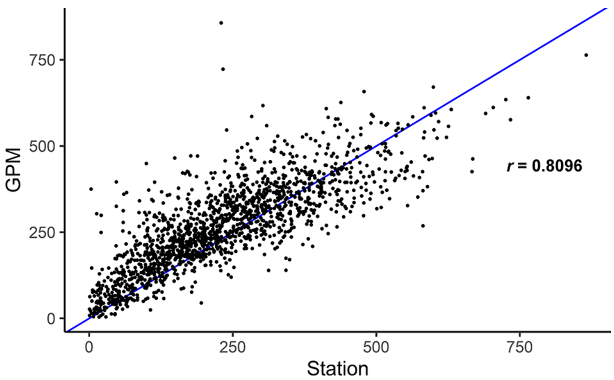

Fig. 2. The 1-1 plot and correlation of global precipitation measurement and meteorological station measurements.

aerosols can interfere with the grid values in LST. Inappropriate LST grid could be removed by identifying the Quality Control channel (QC band). Grids considered inappropriate are removed from the analysis by a clip raster process with an LST raster. The QC band has several values: '0,' '1,' '2' and '3' flags and are associated with the average errors <1, 1–2, 2–3, and >3 K, respectively. LSTs with average errors of 2–3 and >3 K (QC flag = 2 and 3) were removed in RStudio by using the 'raster' package to stack the images and clip them. Then, MODIS LST grid value was scaled into a specific temperature value (in Celsius) as shown in the equation below:

$$\text{Temp} = (\text{Grid Value} \times 0.02) - 273.$$

The hotspot data was obtained through MODIS MCD14ML images containing the location, date and time of recording, and confidence level. Fire hotspot data processing was carried out by identifying the confidence level of >50%, 75% and 90% in August–October, as this period was considered to have a reasonable correlation with ENSO. Furthermore, data analysis was carried out using fire density, assessed as the number of hotspots per unit area of 0.1° or 100 × 100 km. To overcome the different spatial resolution of the data, the LST, soil moisture and fire density were then processed to obtain the 0.1° spatial resolution as the GPM rainfall images.

Data analysis was carried out by descriptive and spatial analysis. Descriptive analysis described the data and research results in tables, diagrams and graphs. Spatial analysis was conducted to identify the distribution of rainfall, surface temperature and soil moisture from satellite images. Data in each grid based on its classification (El Nino, neutral or La Nina) was processed to obtain average fire density, precipitation, surface temperature and soil moisture at different ENSO phases.

Results

Different influences of ENSO phases during the wet months and dry months

Figure 3 shows the variation of rainfall in each ENSO phase based on 3-months' period. The grouping of month's period was based on a previous study by Santika et al. (2020) regarding the climatic condition of Kalimantan and its relation to fire and land-use changes. The February–April period experienced El Nino in 2015, 2016 and 2019, with an average of 270–344 mm month^{-1} (Fig. 3, top-left). Meanwhile, La Nina only occurred in February–April 2018 with an average rainfall of 326 mm/month^{-1}. The neutral phase occurred in February–April 2014, 2017 and 2020 with average rainfall between 221 mm–304 mm month^{-1}. The May–July period had a predominance of El Nino phases in 2015 and 2019, with rainfall values of 184-mm month^{-1} and 201 mm month^{-1}, respectively (Fig. 3. top-right). Meanwhile, the La Nina phase was not found in May–July in these years. Other years were dominated by a neutral stage with an average monthly rainfall of 208–285 mm month^{-1}.

The August–October period had the driest conditions (Santika et al. 2020), with a high relationship between rainfall and ENSO (Fig. 3, bottom left). El Nino has a negative correlation with rainfall as when El Nino occurs, there is a tendency of decrease in precipitation (Sekaranom et al. 2020). The effect of El Nino to rainfall was more visible in the dry months (Sekaranom, Nurjani 2019). During El Nino, August–October experienced average monthly rainfall by 100 mm/month^{-1} in 2015 and 180 mm month^{-1} in 2018. Meanwhile during La Nina, rain tended to be higher than in the other phases as reached 270 mm month^{-1} (in 2016) and 273 mm month^{-1} (in 2020). The rainfall in the neutral phase

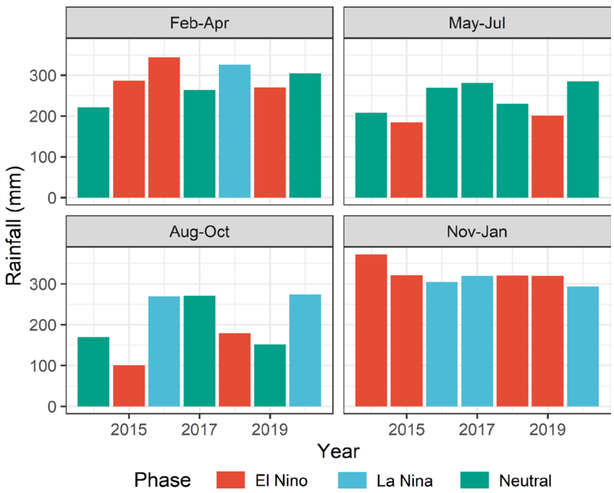

Fig. 3. Average monthly rainfall in Kalimantan 2014–2020.

tended to be higher than El Nino but lower than La Nina. Years with neutral phase occurred in August–October 2014, 2017 and 2019 with average rainfall of 169 mm month^{-1}, 270 mm month^{-1}, and 152 mm · month^{-1}, respectively.

November–January period in 2014, 2015, 2018, and 2019 were dominated by the El Nino phase (Fig. 3, bottom-right). However, the average rainfall on this period was not much different from the average rainfall, particularly compared with the La Nina in November–January 2015–2017 and 2020. In 2014, the average rainfall in the El Nino phase was higher. This indicates a less significant relationship between ENSO and rainfall in November–January period.

From the graph, ENSO was more correlated with rainfall during the August–October period. Correlation of rainfall in August–October for each ENSO phase was grouped to moderate correlation value (r = 0.65) according to Schober et al. (2018). Previous studies have also analysed the existence of a higher correlation of rainfall with ENSO in the dry month than in the wet month with a moderate correlation value ($0.33 < r < 0.66$) for the dry month and a weak correlation ($r < 0.33$) for the wet month (Susilo et al. 2013, Safril 2021). As the highest correlation was found in the dry months, further analysis in this study focused on the dry months only (August–October). Besides its significance on rainfall distribution as analysed before, this period for analysis has been implemented by a previous study related to climate analysis in Kalimantan by Santika (2020).

LST distribution during the dry months

Analysis of LST distribution during the August–October period in Kalimantan shows differences in each ENSO phase (Fig. 4). The average LST of Kalimantan in neutral, El Nino and La Nina was 27.75°C, 29.03°C and 27.48°C, respectively. These values indicate a significant change in El Nino, increasing up to 4.6% from normal conditions in August–October in Kalimantan. Meanwhile in the La Nina, the difference in LST was not much significant to normal conditions. The decrease was only 0.99% in the La Nina phase compared with the neutral phase.

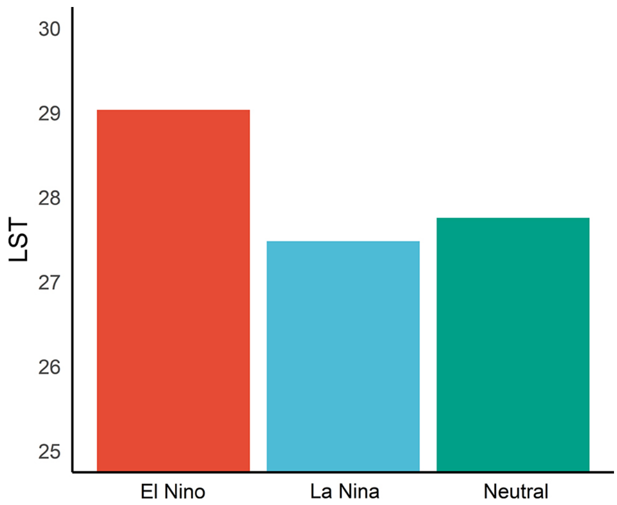

Fig. 4. Average land surface temperature in August–October based on El Nino Southern Oscillation in Kalimantan.

Soil moisture distribution during the dry months

Soil moisture data processed in the RStudio contained 9 km spatial resolution in m^3 · m^{-3} unit (NASA, n.d). The average soil moisture of Kalimantan tended to be lower in the El Nino and higher in the La Nina, corresponded to the rainfall pattern (Fig. 5). The average soil moisture of Kalimantan was 1.91 m^3 · m^{-3} in the neutral phase. In August to October period, 22% of decrease happened in Kalimantan's average soil moisture during the El Nino to 1.48 m^3 · m^{-3}. Meanwhile, there was an increase of 30% during La Nina with average soil moisture of 2.48 m^3 · m^{-3}.

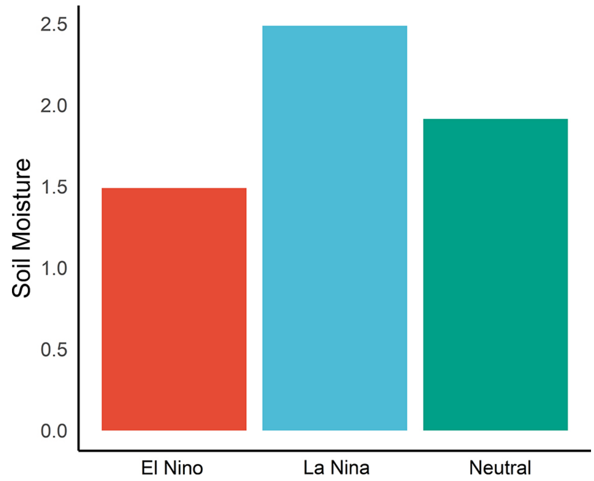

Fig. 5. Average soil moisture in August–October based on El Nino Southern Oscillation in Kalimantan.

Fire hotspot distribution during the dry months

The analysis of rainfall, surface temperature and soil moisture conditions described above was compared with the distribution of hotspots at each ENSO phase. Figure 6 shows the accumulation of hotspots from August to October at each ENSO phase. The analysis results show an increase in hotspots in the El Nino phase and a decrease in the La Nina phase in Kalimantan for hotspots with a confidence level of 50%, 75% or 90%.

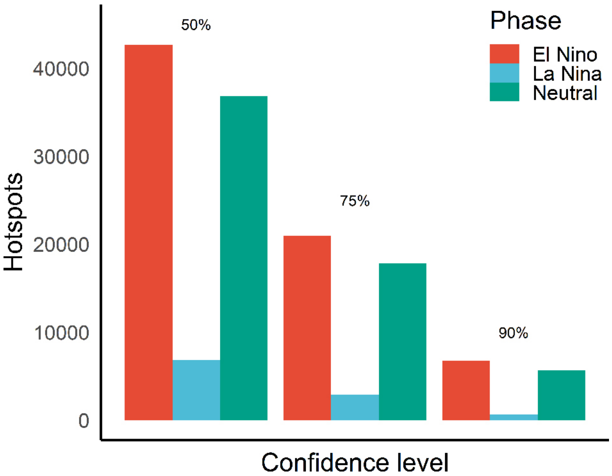

Fig. 6. Average number of fire hotspots in August–October based on El Nino Southern Oscillation in Kalimantan.

The different number of hotspots during El Nino and La Nina is represented by percentages shown in Table 2. These changes were analysed based on the number of hotspots accumulated in August, September and October for each ENSO phase. The analysis shows that hotspots increased 17.4% in average during El Nino. The trend of increasing hotspots was influenced by El Nino and soil moisture conditions in Kalimantan, which tended to decrease during this period (Fatkhuroyan et al. 2021). Meanwhile in La Nina, hotspots decreased by 84.7% in average, compared to normal conditions.

Spatial distribution of fire hotspot, rainfall, LST and soil moisture during different ENSO phases

The differences of the number and spatial distribution of hotspots are presented in Figure 7. The analysis show that hotspots were higher in El Nino and lower in La Nina from August to October. The spatial distribution of hotspots was higher in the south and west part of Kalimantan and fewer in the north. Rainfall decreased during El Nino and increased during La Nina, and the accumulation in the south tended to be lower than in the northern area. LST distribution was higher in the southern Kalimantan in El Nino and its number decreased during La Nina. Soil moisture decreased in several areas in the south and central parts of Kalimantan during El Nino. In contrast, there was a less significant increase in the central part of Kalimantan during La Nina.

Discussion

ENSO influence to fire hotspots during the neutral phase

The hotspot in the neutral phase from August to October had a clustered distribution from the south to the western region of Kalimantan with an average number of 5677 hotspots. Hotspots with density >70 per 100 km^2 were found on the south and western Kalimantan, associated with elevation and agricultural land use. Both areas have a lower elevation than the central part of Kalimantan. This is following the analysis of Singh and Yan (2021), as hotspots were generally found at a lower topography with more human activities.

Table 2. Comparison of hotspots from different levels of confidence during El Nino Southern Oscillation phases.

Level of confidence	Average monthly hotspots			Trend		Trend	
	Neutral	El Nino	La Nina	El Nino	Average	La Nina	Average
	[–]			[%]			
50%	36 834	42 666	6 838	15.83	17.40	−81.44	−84.70
75%	17 842	20 986	2 893	17.62		−83.79	
90%	5 677	6 741	632	18.74		−88.87	

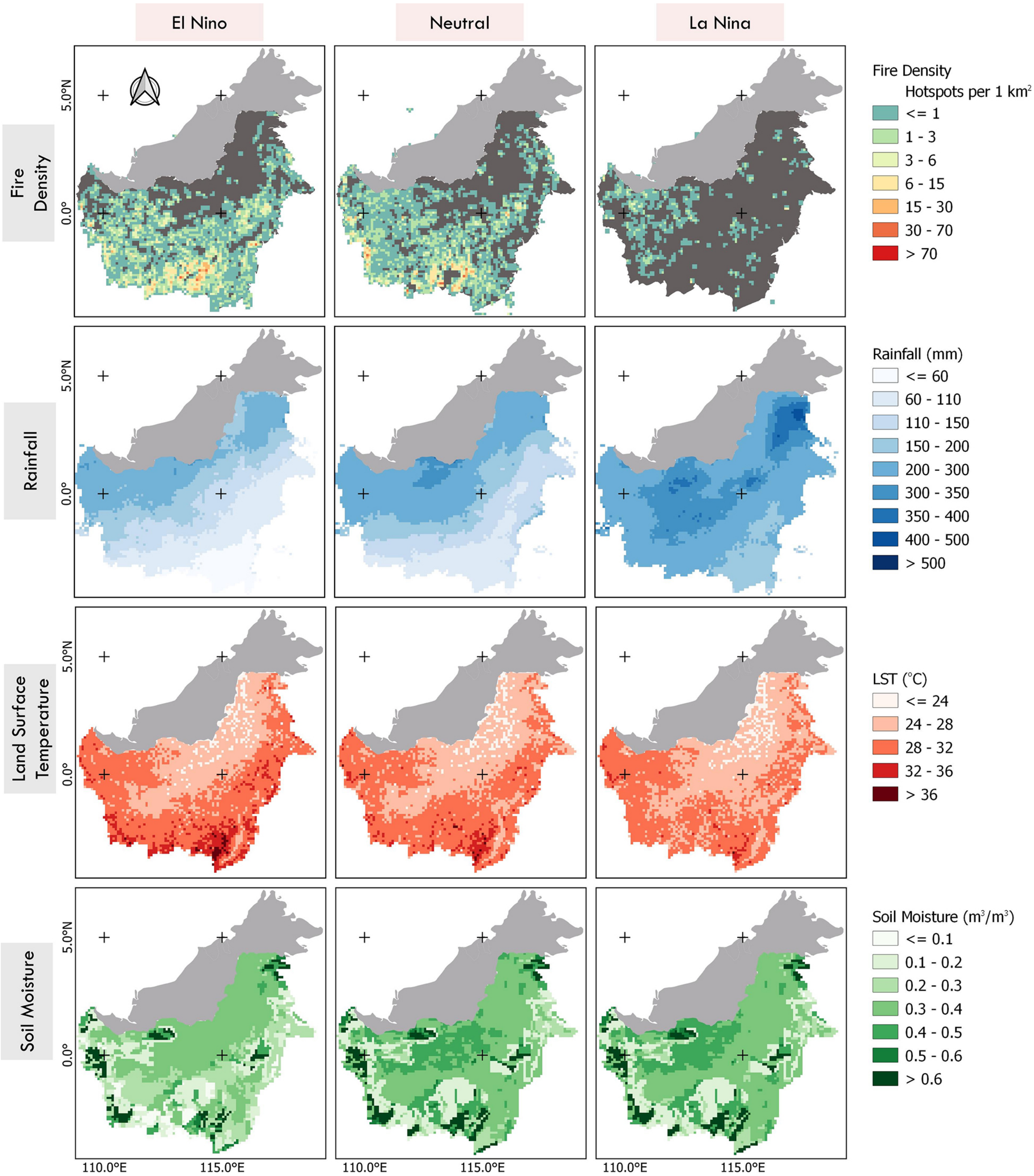

Fig. 7. Spatial distribution of average fire density, rainfall, land surface temperature and soil moisture during El Nino Southern Oscillation.

Meanwhile, hotspots were typically associated with the type of agricultural land use. High hotspot density in the southern and western parts of Kalimantan in agricultural land associated with peatland. In addition to a large amount of agricultural land, western Kalimantan had many transmigrants that impact land-use pressures (Singh, Yan 2021). In addition to the west and south sides, eastern Kalimantan also has a high vulnerability to fires due to deforestation.

The magnitude of the hotspots on the neutral phase from 2014 to 2020 tended to be dominated by the average value of the fire hotspots in 2019. The ONI value showed a neutral phase this year, yet a positive IOD phenomenon affected the number of hotspots. IOD events in 2019 had a peak of 1.9 in October and concluded as the one of the strongest IODs of the decade (Ratna et al. 2021).

The spatial distribution of rainfall from August to October during the neutral phase was found to be associated with elevation. The south and east sides were areas with plain morphology and basin due to intensive fluvial processes in Kalimantan. The upstream of various watersheds in the region was the central part of Kalimantan which had a higher elevation. This condition is associated with higher rainfall due to orographic influences. On the neutral phase, rainfall from August to October in the southern part had a range of 60–100 mm, while it was dominated by rainfall of 300–350 mm in the northern region.

The spatial distribution of LST in the neutral phase was also associated with elevation and land use with a pattern inversely proportional to rainfall. This was indicated by the distribution of higher LST at lower elevations in Kalimantan. The average value of LST in the neutral phase from August to October was 27.75°C. The northern and central sides of Kalimantan which were still dominated by tropical rainforests had a value of <24°C in LST. The distribution of the highest LST reaching >36°C was found on the south and west sides of Kalimantan, associated with the coastal and agricultural land-use dominated by human activities. The higher LST value in this area was also influenced by deforestation. In contrast, according to McAlpine et al. (2018), there was a correlation between forest decline and daily LST increase and precipitation reduction in Kalimantan.

From August to October, the spatial distribution of soil moisture in Kalimantan in the neutral phase indicated differences in soil moisture in various areas related with elevation and land-use. Most of the soil moisture values >0.6 $m^3 \cdot m^{-3}$ were on the south and west sides of Kalimantan, associated with lower elevations and peatland distribution. The presence of several areas on the eastern side of Kalimantan with high soil moisture was also related to peatlands in the Mahakam watershed. Meanwhile, increased soil moisture in the north was related to peatlands in the Kapuas watershed. Most of the central side of Kalimantan had a soil moisture distribution between 0.2 $m^3 \cdot m^{-3}$ and 0.4 $m^3 \cdot m^{-3}$, which was influenced by the higher elevation and acrisols soil type. This soil is yellowish red with a predominantly clay texture due to massive pedogenesis (Food and Agriculture Organization of the United Nations 2014). This soil is also known as ultisols soil, which is associated with wood stands scattered on the central side of Kalimantan. Meanwhile, soil types associated with high soil moisture are fluvisols and histosols. Fluvisols are soil-related to fluvial activity and have a lot of water content. In contrast, histosols are organic soil found on peatlands on the south and west sides and in a small part of the Mahakam and Kapuas watersheds.

ENSO influence to fire hotspots during El Nino

The hotspot distribution during El Nino tended to be more spread out and increasing than normal conditions from August to October. Hotspots were concentrated in the south and in the area between Central Kalimantan and South Kalimantan (Yananto, Dewi 2016, Fanin, Van Der Werf 2017). The increasing hotspot during El Nino associated with decreasing rainfall, increasing LST and decreasing soil moisture. The figure shows that the distribution of hotspots with an average density of >70 hotspots per 100 km^2 was increasing in low elevation areas with peatland use. The rise density of hotspots was generally influenced by the decrease in water content in peatlands due to dry conditions. This triggered the amount of carbon released due to the dryness of the organic land.

The lack of rainfall input generally influenced the decreasing water content in peatlands during the El Nino period. El Nino impacted rainfall in most areas (Sekaranom et al. 2020). In general, Kalimantan's rainfall decreased by 29% in August–October. One of the most affected areas was in the south to southeast part of Kalimantan had 60–100 mm of rainfall per month during neutral phase, but it became <60 $mm \cdot month^{-1}$ during El Nino.

The decrease in average monthly rainfall from August to October correlated with the increase in hotspots. Santika et al. (2020) stated that rainfall with fire events per month coupled with $r = 0.91$, while the decrease in rainfall with fire intensity was associated with $r = 0.89$. This value indicated a significant influence of rain on the incidence of fires in Kalimantan, especially during El

Nino conditions. There was an increased fire risk from the incidence and intensity of hotspots in Kalimantan. In addition, El Nino events can trigger positive IOD in the Indian Ocean (Sekaranom et al. 2020), thereby increasing the intensity of fires like those in 2015.

The rise in LST during El Nino generally occurs in south-eastern Kalimantan, which is associated with peatlands and high-intensity agricultural activities. LST rose to 4.5% in the El Nino event from August to October. Due to El Nino, this risen LST significantly affected the duration of the fire intensity, which could contribute to the increasing density of hotspots in areas associated with peatlands. Figure 6 shows an increase in area with a surface temperature of >36°C, which was the high density of hotspots in the southeast, south and parts of the west coast of Kalimantan.

El Nino and La Nina events that affected rainfall and LST also impacted soil moisture (Bussberg 2021). The decrease in soil moisture in Kalimantan during El Nino generally occurs in the central and southern parts of Kalimantan. Areas associated with tropical rainforests experienced decreasing soil moisture from 0.2 $m^3 \cdot m^{-3}$ to 0.3 $m^3 \cdot m^{-3}$. Meanwhile, the area with the soil moisture average >0.6 $m^3 \cdot m^{-3}$ decreased on the southern side of Kalimantan. This indicated a significant reduction in groundwater moisture during El Nino. Based on the results, there was a decrease in mean soil moisture in the El Nino phase by 22% from normal conditions. This correlated with the rising number of fire and lower rainfall.

El Nino implication to decreasing rainfall lowers peat's groundwater level and hydrological characteristics (Astiani et al. 2015). This reduced soil moisture increased CO_2 respiration in organic land as previous studies found that soil CO_2 respiration can increase by up to 67% during the dry season (Dariah et al. 2013, Astiani et al. 2015). Related to land use, previous research had shown that conversion of agricultural land can increase CO_2 emissions (Astiani et al. 2015, Ishikura et al. 2017). Focusing on the southern side of Kalimantan whose high soil moisture levels, it also has high intensity and density of hotspots. This area experienced significant soil moisture loss due to deforestation and conversion of agricultural land (Spessa et al. 2015). Conversion of peat swamp forests by human activities reduces the organic soil carbon content (soil organic C) due to changes from anaerobic to aerobic conditions (Nusantara et al. 2020). The carbon content stored on land with commonly histosol soil types released and became one of the causes of high fire susceptibility.

ENSO influence to fire hotspots during La Nina

The hotspots in La Nina had fewer numbers than other ENSO phases. The fire incidence with the highest density was six hotspots per 100 km^2 in the western part of Kalimantan. This area was covered by the type of dryland agriculture. Meanwhile, most areas of Kalimantan had a fire density value of <1 hotspot per 100 km^2. This number of hotspots decreased to up to 84.7% from normal conditions in August–October.

The less number and distribution of hotspots in La Nina was generally influenced by the amount of rainfall that occurred. The spatial distribution of rainfall shows increasing rainfall in almost all areas of Kalimantan during La Nina. The south and southeast sides experienced average rainfall of about 60–100 mm in neutral and 150–200 mm $\cdot$ $month^{-1}$ during La Nina, respectively. The La Nina event also affected the declining average LST of Kalimantan by 0.99%.

The rise in average soil moisture in the La Nina phase was 29.88% compared with the neutral phase. The most significant increase in soil moisture occurs in the middle part with land-use covered commonly by tropical rain forests. Meanwhile, there was no increase in soil moisture in areas with peatland use compared with normal conditions. This can be caused by the groundwater level, which has a stable state of groundwater saturation conditions, while the excess water was channeled into surface runoff.

The relationship between the distribution of hotspots and physical parameters such as rainfall, surface temperature and soil moisture in Kalimantan in 2014–2020 generally had a close spatial and temporal relationship in the El Nino, La Nina and neutral phases. The distribution of hotspots was associated with agricultural land use that had been affected by human activities. This follows previous research (Fanin, Van Der Werf 2017, Ishikura et al. 2017, Santika et al. 2020) which analysed a closer relationship between agricultural land and forest fires in Kalimantan. In addition, the increasing hotspots in the region generally occurred in August–October and had a pattern that corresponds to the El Nino, La Nina and neutral phases.

This study analyse about the condition of climate interaction with the physical attributes on land. Climate condition was analysed by ENSO index, rainfall and LST, while land surface parameters analysed were soil moisture and fire occurrences. This study also tried to obtain the percentages of increasing and decreasing number of each parameter during the ENSO phases. This study could benefit the management of climatic hazards, especially to obtain the prioritised time and location in Kalimantan. However, lack of field measurement data affected the result in a more specific way. In the future, it is important to analyse more field data and conduct the forecast analysis to obtain the trend of climate condition and its impact on soil moisture and fire occurrences. In the future development, this study can also contribute to not only fire hazard mitigation, but also the regional planning and food security in Kalimantan.

Conclusion

The influence of ENSO on hotspots, rainfall, temperature and soil moisture in Kalimantan significantly occurred mostly from August to October. Temporal analysis shows decreased rainfall, increased surface temperature, and decreased soil moisture in the El Nino phase, especially during a strong El Nino in 2015. This condition contrasted with La Nina conditions, as inverse condition occurred during this period. Spatial analysis shows that the most significant change areas are the southern and western parts of Kalimantan.

In general, spatial and temporal distribution of hotspots was closely related to rainfall, surface temperature and soil moisture. This was indicated by the correlation value and the distribution of hotspots by the trend of those parameters. Fire, rainfall, LST and soil moisture changes were mainly distributed in southern and western Kalimantan and in other areas associated with low elevation, agricultural land and peatland that have experienced interactions with human activities.

Acknowledgements

This research was not affiliated with any grants. The authors thank anonymous reviewers for improving the quality of the paper.

Author's contribution

The authors confirm contribution to the paper as follows: study conception and design: Rahma Aulia Zahra, Andung Bayu Sekaranom, Emilya Nurjani; data collection: Rahma Aulia Zahra; analysis and interpretation of results: Rahma Aulia Zahra, Andung Bayu Sekaranom; draft manuscript preparation: Rahma Aulia Zahra; critical revision of manuscript: Emilya Nurjani, Andung Bayu Sekaranom. All authors reviewed the results and approved the final version of the manuscript.

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