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Exploring El Nino effects on agricultural area using Landsat images analysis: A case study in Bondowoso Regency, Indonesia

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ABSTRACT

El Nino, which hit Indonesia in 2023, poses severe food security threats due to the high dry season with no rainfall and minimal cloud cover and can trigger serious drought problems if it happen for a long time. This study aimed to explore the impact on agricultural land in Bondowoso Regency during El Nino events. The analysis in this study primarily uses land surface temperature (LST) and normalized difference vegetative index (NDVI) map distribution. The Landsat data from USGS are collected and processed to become LST and NDVI distribution maps. Data analysis focused on the agricultural area layers based on data from the Indonesia geospatial portal. Referring to the LST and NDVI map distribution, the notable rise of LST starts in August 2023, and the peak is in October 2023. Around 46% of areas in the Bondowoso regency are detected as hotspot areas, which had LST above 30°C in October 2023. El Nino affects the irrigated lands and rain-fed fields more than the plantations. The NDVI alteration data does not show that the Bondowoso Regency is experiencing extraordinary drought due to the short-term impact of El Nino. However, the emergence of numerous areas in the moderate NDVI category warns that stress affecting vegetation is starting to occur. Mitigation plans should be prepared for the long-term impact of El Nino, particularly in the hotspot areas. This study could be a comprehension tool for the government and farmers to prepare mitigation plans.

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1. INTRODUCTION

Bondowoso Regency is located in East Java Province, Indonesia, which has sizeable agricultural land, with around 45% of the population working in agriculture. Bondowoso has various altitudes from 50 to 1130 meters above sea level and is surrounded by highlands and mountains (BPS Bondowoso, 2023). Bondowoso is flanked by the Argopuro Mountains on the west side and the Ijen Mountains on the east side, and it is surrounded by Penataran highlands on the north side. The agriculture area is divided into irrigated and rain-fed fields, primarily in lowland areas. Irrigated fields cover approximately 20%, and rain-fed fields cover about 35% of the total area of Bondowoso Regency (Suud et al., 2023). The area of Bondowoso Regency consists of mountains and hills covering 44.4%, the highlands covering 24.9%, and the lowlands 30.7%. The soil types are dominated by Regosol and Mediterranean, indicating a low ability to save water reserves (Ardiansyah et al., 2021). Based on the disaster index map published by BNPB, The National Board for Disaster Management, Bondowoso was included in drought-prone areas (BNPB, 2023). The El Nino wave that hit Indonesia in 2023 significantly impacted the Bondowoso Regency. The extreme drought threatened food security in the Regency (Radar Jember, 2023).

El Nino surrounded Indonesia in 2023 and will continue to do so in 2024. The effect of EL Nino in Indonesia will be low to moderate in early 2024 and become neutral in mid-2024 (CNN Indonesia, 2024). The EL-Nino is atmospheric and ocean dynamics that influence the weather and climate around the Pacific Ocean. El Nino is identified by an unusually cold sea surface temperature (SST) in the western tropical Pacific Ocean and a warmer in the eastern Pacific. Although some types of El Nino events occur, they all lead to rainfall anomalies in Indonesia (Iskandar et al., 2019). El Nino causes a strong rainfall season in the East Pacific but leads to an arid season in the West Pacific, like in Indonesia. The EL-Nino in Indonesia strongly affects agricultural land due to a lack of rainfall, leading to a strong drought and late monsoon seasons (Safitri, 2015).

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The effects of El Nino are also felt in Indonesia. El Nino impacts the primary irrigation network to Jatiluhur and potentially exacerbates agricultural drought, mainly in the downstream Citarum watershed (Dimyati et al., 2024). Even El Nino can cause deterioration of respiratory health since El Nino triggers the increase of severe drought and decrease in forest vegetation (Santika et al., 2023). This paper explores the effects of El Nino that are currently happening in 2023, especially on the agricultural land in Bondowoso Regency. The analysis is based on Landsat image data during the El Nino event in 2023, mainly land surface temperature data (LST) and normalized difference vegetation index (NDVI) data. By analysing LST and NDVI, this research wanted to investigate the extent to which El Nino effect the regency, where the most affected areas are, and when the peak of impact was detected. Land surface temperature (LST) serves as an indicator of the temperature at the Earth's surface and has been extensively employed in research areas such as global climate change studies, urban land use, land cover analysis, geo-biophysical studies, and as a key input for climate models (Jeevalakshmi et al., 2017). NDVI is a standard formula that gives information related to vegetation production. The vegetation-dense detection can be used to monitor the dynamics of the ecosystem (Zaitunah et al., 2018). LST and NDVI could have correlations and can be tools for drought assessment as the effects of climatic elements (Almouctar et al., 2024; Meshesha et al., 2024).

Understanding the El Nino effect is crucial to plan the next mitigation step. The LST can indicate the temperature alteration on the earth's surface as the impact of extreme heating during El Nino. The LST data, retrieved from Modis or Landsat, correlate reasonably with Oceanic Nino Index (ONI) data and monthly temperature data from meteorology stations and can be presented with linear regression models. This result confirms that LST data can be used to analyze the temperature distribution and pattern in Kuching, Malaysia, during El Nino (Kemarau & Eboy, 2023). NDVI can reflect the significant interannual variability of rainfall and temperature. However, many factors, like human activity and location characteristics, can affect the correlation between NDVI and climate, and the monthly lag correlation between NDVI and rainfall may emerge (Moses et al., 2022). This study analyzed the LST and NDVI, particularly agricultural land, to determine the short-term impact of El Nino in Bondowoso during 2023. These short-term impacts include discussing the growth of hotspot areas and the NDVI response in agricultural land. Furthermore, this study also discusses the correlation between the rise of LST and the NDVI alteration that represented vegetation dynamics in the Bondowoso Regency. Hopefully, it will provide new insight into regional resilience facing El Nio and can be a basis for developing mitigation policy, especially in the Bondowoso regency.

2. MATERIAL AND METHODS

The area of Bondowoso Regency involves a longitude of 113°48′10″ E to 113°48′26″ E, and a latitude of 7°50′10″ S to 7°56′41″ S. The Landsat data used in this study is Landsat 8 OLI/TIRS, collected from the US Geological Survey (USGS) database. Landsat data was taken on a specific date from March 2023 to December 2023, representing conditions in each month. The Landsat data representing the condition from January 2023 to February 2023 is not included due to the peak of the rainy season and no Landsat images that are clear from cloud cover. The date in each month is chosen while the date has minimum cloud shade, and three previous days in a row, there was no rain, as shown in Table 1.

The Landsat data are processed using Q-GIS software to generate land surface temperature (LST) and normalized difference vegetation index (NDVI). The data processing method to get LST and NDVI follows the USGS guidance (Kashkimbayeva et al., 2020; USGS, 2018). The Landsat data of Band 10, meanwhile Band 4, and Band 5 is converted from raw image (digital number) to top of atmosphere (TOA) radiance using the radiance rescaling factors in the metadata file. This act is called a radiometric correction. Radiometric correction is requisite for generating high-quality scientific data to produce more precise information, such as land cover maps (Muchsin et al., 2021). The Landsat data of Band 4 and Band 5 generates NDVI distribution maps using the NDVI formula (Kashkimbayeva et al., 2020). The Band 10 data was transformed to generate brightness temperature and then converted to LST.

The geospatial maps of Bondowoso are downloaded from The Indonesia Geospatial Portal, which contains area administration, contour, and land cover classification data (BIG, 2021). Landsat images were clipped using the geospatial map of Bondowoso based on administration and land cover classifications. The NDVI and LST maps are classified based on the agricultural land types to analyze the distribution of LST and NDVI in each land classification. The complete stage is shown in Figure 1. The additional data used is crop water availability, which has been processed based on data from the Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG). This water availability for crop data from March 2023 to December 2023 was collected and processed from the BMKG database (BMKG, 2023a).

3. RESULTS

The LST and NDVI maps have been generated from the Landsat data, which represents the monthly situation. The highest average NDVI value is in March 2023, and the lowest is in October 2023.

Table 1. The Landsat data specification in from March to December 2023

	Month									
	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nop.	Dec.
Date	11	20	22	15	17	26	27	21	6	24
Cloud cover (%)	3.42	19.38	8.05	7.59	10.92	10.62	3.93	0.43	7.17	6.18

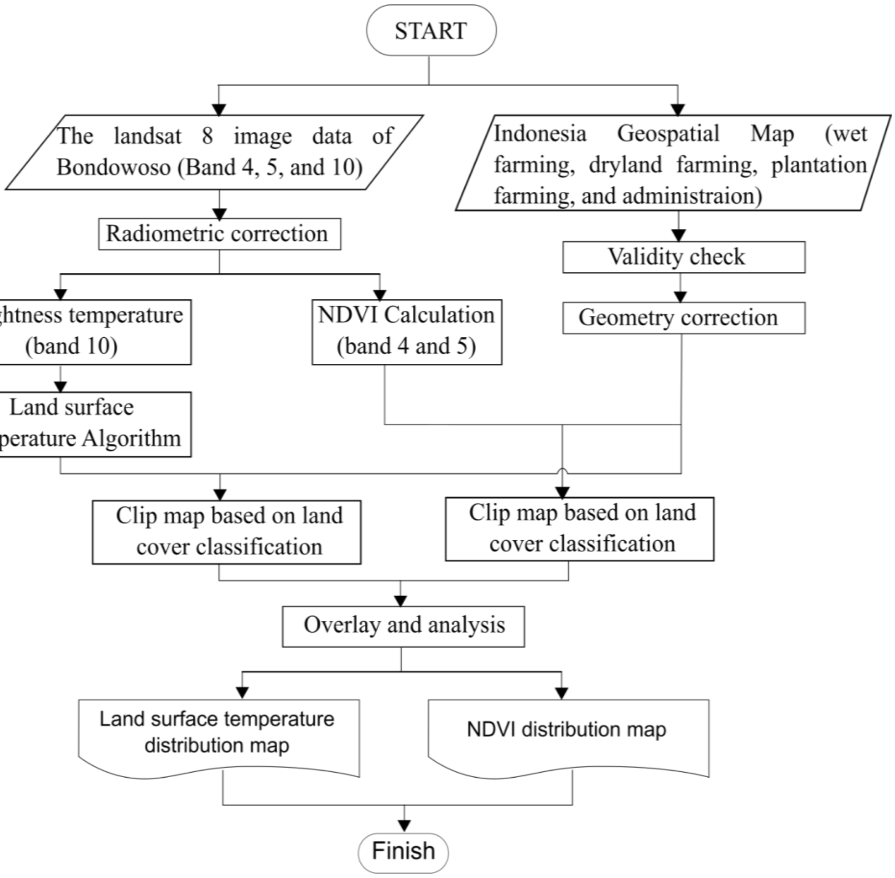

Figure 1. Landsat data processing stage

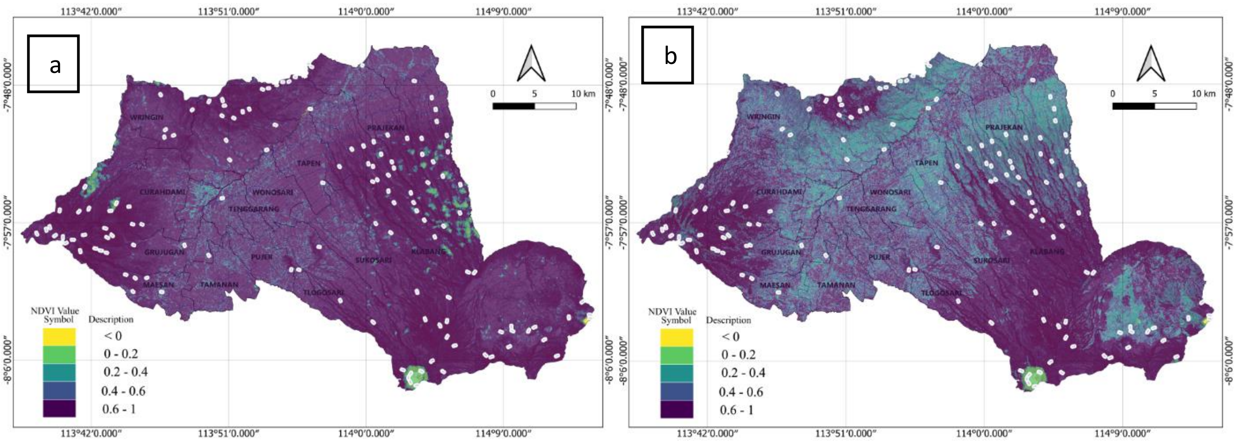

Figure 2. NDVI distribution maps in Bondowoso Regency on (a) 11 March 2023 and (b) 21 October 2023

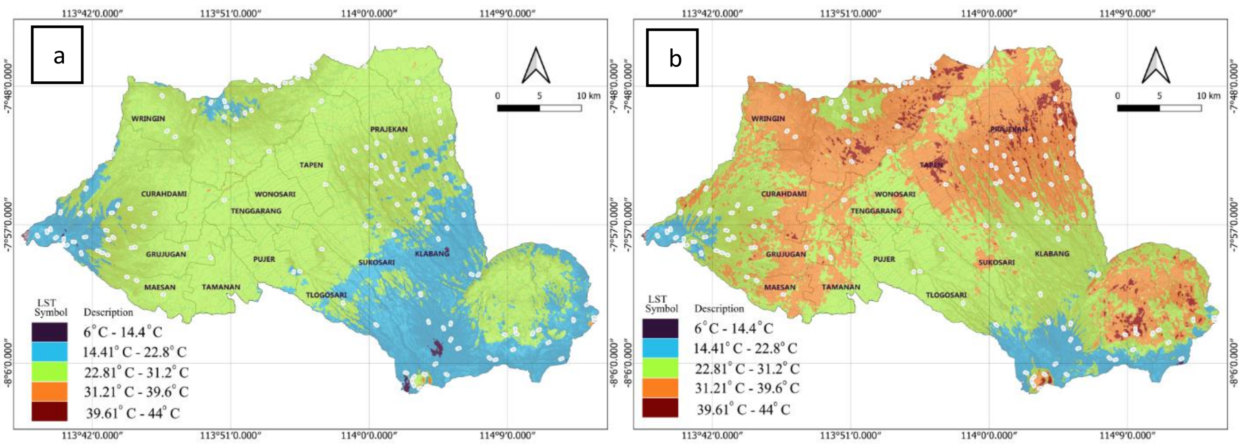

Figure 3. LST Distribution maps in Bondowoso Regency on (a) 11 March 2023 and (b) 21 October 2023

The comparison between the distribution map of NDVI in March 2023 and October 2023 has been presented in Figure 2. Meanwhile, the difference between the distribution map of LST in March 2023 and October 2023 has been presented in Figure 3. There are 23 subdistricts in Bondowoso. Based on the data in Figure 3, the areas of Bondowoso Regency in the northern and southeastern areas have many hotspot areas, with LST above 30°C in October 2023. Five subdistricts have LST above 40°C that is categorized as extremely hot: Tegalampel subdistrict, Tapen subdistrict, Klabang subdistrict, Prajekan subdistrict, and Cerme subdistrict. The highest average LST and the lowest average NDVI was reached in October.

Figure 4 shows the percentage area of Bondowoso regency with various LST, NDVI, and WAC levels. Grouping data of LST in this study is based on equal intervals of the lowest and highest temperatures on the LST distribution map. The grouping of NDVI values in this study is based on the classification used by Aziz et al. (2018). The percentage areas per LST group are calculated and presented in Figure 4(a), and the percentage areas per LST group are shown in Figure 4(b). The data in Figure 4(c) is collected from resumed data on water availability for crops (WAC) provided by BMKG (2023a). The WAC calculated the water balance based on the Thornthwaite and Mather method. The calculation assumes the water source is only from rainfall and that the soil depth is one meter, with homogenous soil conditions. The hotspots, namely areas with LST above 30°C, emerge from July 2023 to December 2023. Table 2 shows the average LST and NDVI in 2022 and 2023 to compare the situation with the previous year when the hotspot appeared.

The graphs in Figure 7 and Figure 8 were generated based on LST and NDVI distribution maps that were layered with agricultural land classification based on the classification from the Indonesia Geospatial map. The deployment of agricultural land classification can be seen in Figure 6. Based on the Indonesia Geospatial Map, the total area of agricultural land in Bondowoso is 929.04 km^2, which is 61% of the total area of Bondowoso Regency. The graphs are focused on analyzing agricultural land in Bondowoso Regency during El Nino, which consists of 52% irrigated land, 33% rain-fed fields, and 16% plantation areas. The data presents changes in agricultural regions with various levels of LST and NDVI each month. The agricultural area alteration per LST group is shown in Figure 7, while the agricultural area alteration per NDVI group is shown in Figure 7.

The correlation between the average LST and NDVI in the Regency and the specific agricultural land from March to December is shown in Table 2. Irrigated land, rain-fed fields, and plantations were classified as specific agricultural land based on Indonesia Geospatial maps. Irrigated land refers to flooded agricultural land, such as paddy rice fields. Rain-fed fields are dry land planted with tobacco, corn, or secondary crops. In comparison, the plantation relates to the area used for perennial plantation crops such as coffee, rubber, or pine plantations. The LST and NDVI data in this research have negative correlations, which indicates that the LST and NDVI data in this research have identical data patterns in opposite directions.

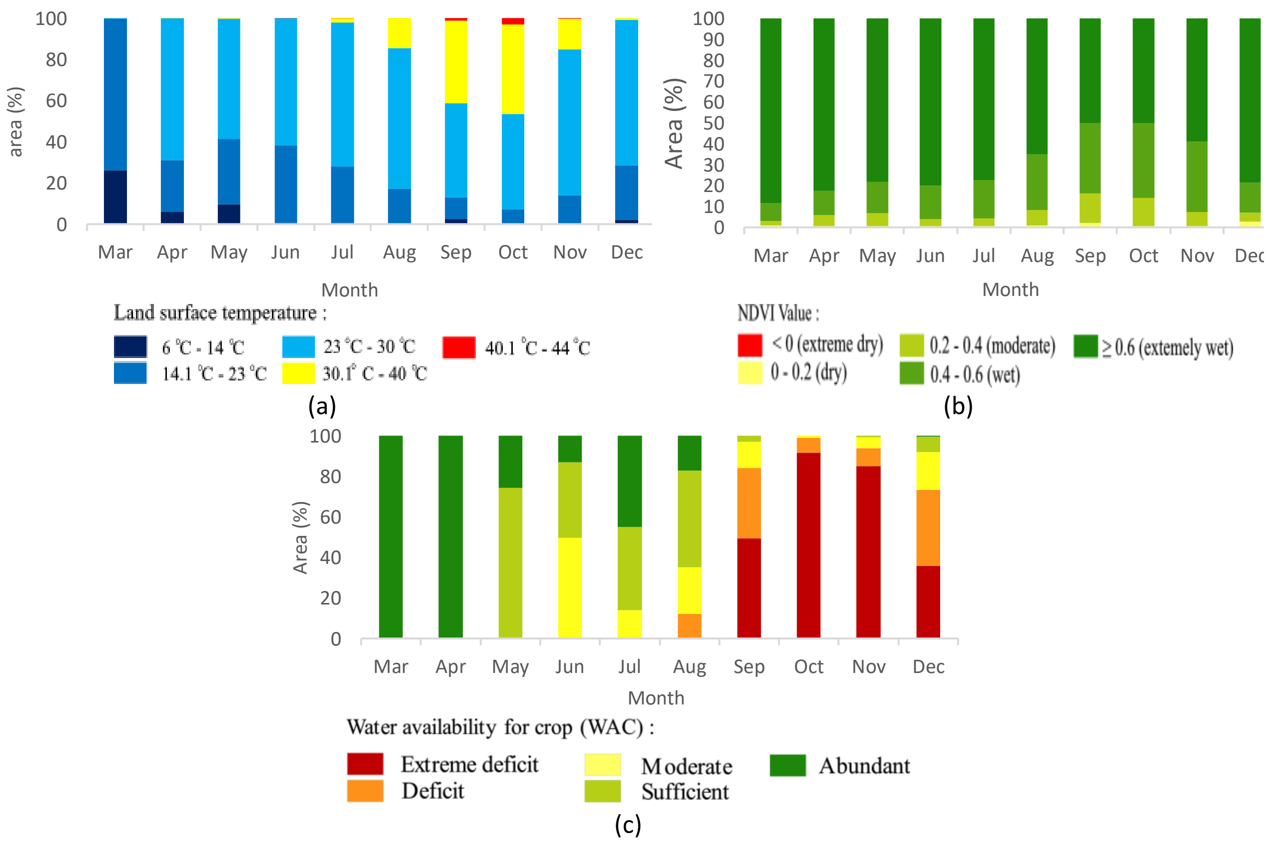

Figure 4. The alteration of percentage areas with an average of (a) LST, (b) NDVI, and (c) WAC from March to December 2023 in Bondowoso Regency

Table 2. The average LST and NDVI value in Bondowoso Regency from July to December in 2022 and 2023

Month	Average LST		Hotspot area		Average NDVI	
	2022	2023	2022	2023	2022	2023
July	24.6	16.5	0%	2.1%	0.7	0.6
August	21.0	26.9	0.1%	14.5%	0.5	0.6
September	12.6	29.5	0%	41.3%	0.5	0.6
October	10.4	30.8	0%	46.5%	0.5	0.6
November	*ND*	27.3	*ND*	15.1%	*ND*	0.6
December	11.6	24.3	0%	1%	0.4	0.7

Remarks: *ND* = not detected due to the image Landsat 8/9 without cloud clover is not available in USGS

4. DISCUSSION

Based on this study, the peak of El Nino in Bondowoso during 2023 happened in October, indicated by the highest average LST among other months. The data from the Banyuwangi Meteorology Station indicate that the highest maximum air temperature in October 2023 can reach 34°C with an average monthly temperature of 32°C. Moreover, no rainfall during October 2023 amplifies the hot weather (BMKG, 2023b). The weather temperature and land surface temperature have a strong correlation. Its coefficient correlation can reach 0.97 (Eboy & Kemarau, 2023b). The El Nino events assist in scorching weather in Southeast Asian countries like Malaysia and Indonesia and can trigger prolonged droughts. The extremely hot weather also has detrimental effects on humans and leads to a shortage of water and food resources (Kemarau & Eboy, 2021).

There are six subdistricts in Bondowoso regency whose areas have LST above 30°C or hotspots in October 2023. The hotspots started to rise in August 2023 and grew widely in October 2023, then shrunk in November 2023. There is an indication that the rise of LST and the decline of NDVI value happened in areas with lower elevation, as seen in Figures 2 and 3. The LST tends to rise in areas with altitudes under 550 MASL, primarily in residential areas. This result strengthens the previous findings that the hotspots existed during El Nino, primarily developed in town and industrial zones. The cold concentration areas are developed near water bodies and plants, contributing to lower temperatures (Eboy & Kemarau, 2023a).

Around 46% of Bondowoso regency areas were detected as hotspot areas, with LST above 30°C, and over 2% had LST above 40°C in October 2023, as shown in Figure 4(a). The LST above 30°C often happens during El Nino events (Kemarau & Eboy, 2023). Temperature above 30°C can make humans uncomfortable. The effect of high temperature on the plants can vary depending on the type of the plants. Temperatures above 40°C can induce stress, while a 30°C - 40°C temperature range may lead to reversible metabolic inhibition (Angus et al., 2018).

Based on data collected from the Meteorology Station of Banyuwangi, the rainfall was lessened from March 2023 and dropped significantly to almost 0 mm from July 2023 to October 2023 (BMKG, 2023b). The rainfall is still lower after October than the previous year, indicating a longer drought, as shown in Figure 5. This condition leads to hotter and drier climatic conditions in Bondowoso Regency. The percentage areas with LST above 30°C, NDVI value below 0.4, and deficit category of water availability for crop (WAC) rose significantly

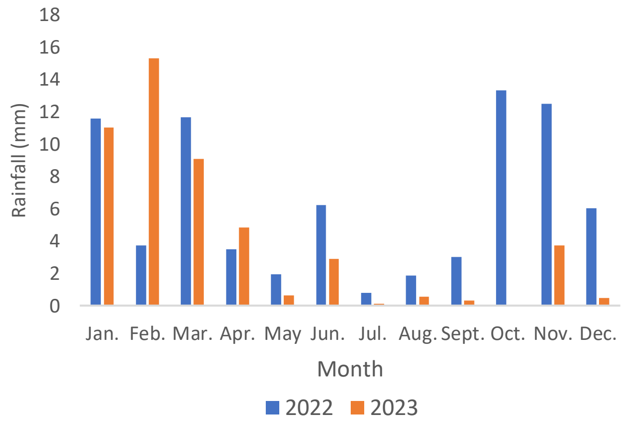

Figure 5. Comparison of Rainfall (mm) in 2022 and 2023 (BMKG, 2023b)

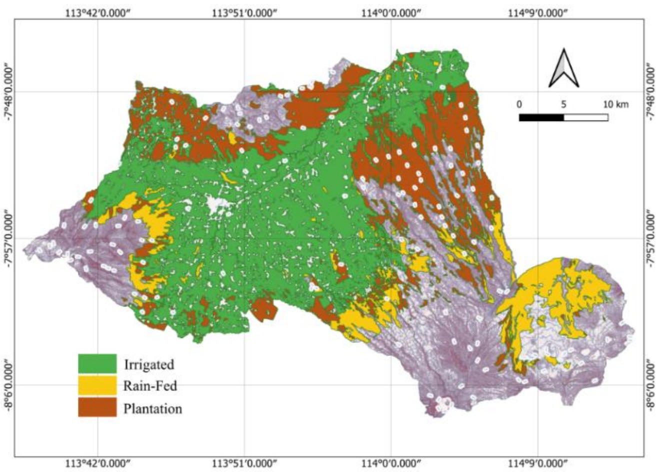

Figure 6. Distribution of agricultural land based on land classification from Indonesia Geospatial Spatial database

since August 2023, the graph in Figure 4(b) shows the distribution of NDVI and reflects the impact of the El Nino-induced dry season, which began in August 2023 and peaked in October 2023. During the peak period, over 14% of the area in Bondowoso Regency experienced moderate or drier NDVI categories. Moderate NDVI indicates sparse vegetation such as grasslands, shrubs, or senescing crops due to moisture availability and canopy resistance. This implies vegetation or soil water stress (Karnieli et al., 2010).

In the peak of LST, in October 2023, only 14% of Bondowoso Residence is classified as moderate or drier based on NDVI values, while the rest are categorized as wet or extremely wet. The recapitulation of WAC indicated that 91% of the area was classified as extreme deficit in October 2023,

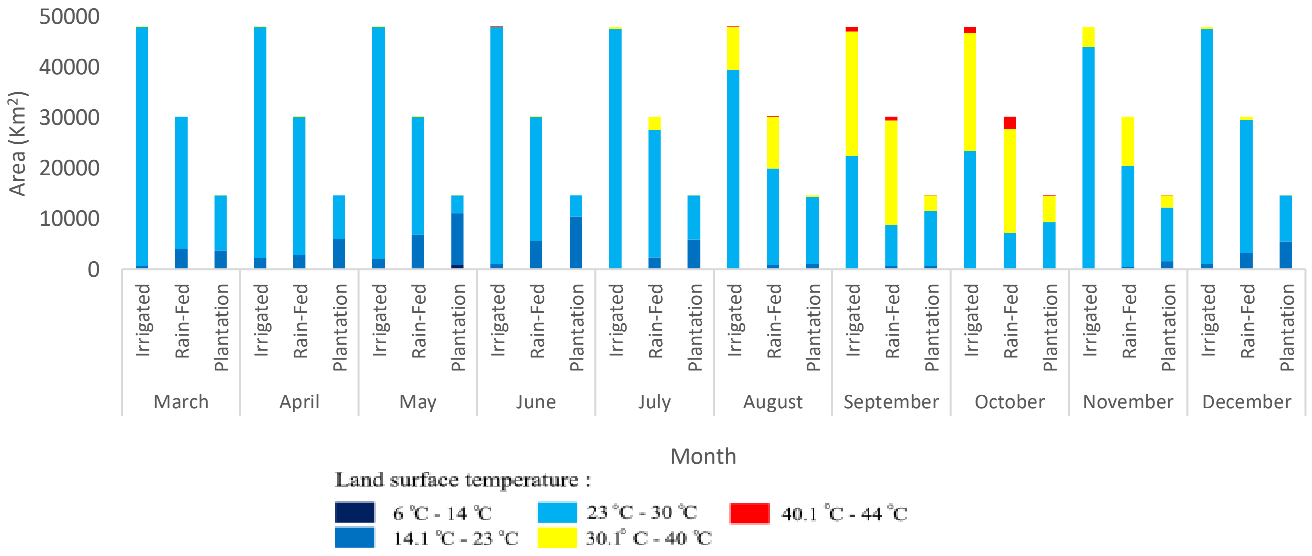

Figure 7. Changes in LST distribution on agricultural land from March 2023 to December 2023

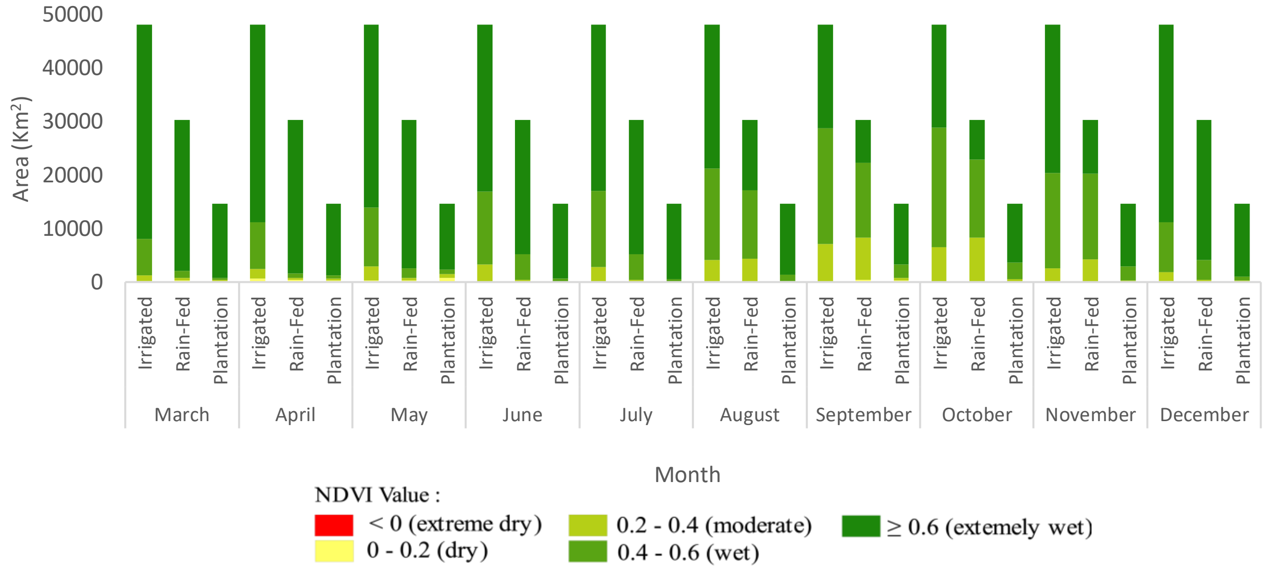

Figure 8. Changes in NDVI distribution on agricultural land from March 2023 to December 2023

Table 3. Correlation coefficient and coefficient of determination between the average of LST and NDVI value in Bondowoso regency with various classifications of agricultural land

	Regency	Irrigated lands	Rain-fed fields	Plantations
Correlation coefficient	-0.81	-0.87	-0.96	-0.82
Coefficient of determination (r^2)	0.66	0.76	0.92	0.66

as shown in Figure 4(c). However, the NDVI distribution area in Figure 4(b) did not indicate the severe drought in Bondowoso during El Nino. The maximum significant severity is moderate and dry category in less coverage areas. This mismatch is due to the WAC only indicating excess or lack of water for crop calculation, not actual condition, since the water balance calculation only considers rainfall as water supply. Meanwhile, the NDVI is the reflection of actual vegetation conditions. Naturally, additional efforts were conducted in real conditions to maintain available water capacities, such as pump irrigation, well utilization, and adjusting the type of plants cultivated.

The agricultural land with significant hotspots, with LST above 30°C, especially from July to November 2023, is the Rain-Fed area, followed by irrigated land and plantation area, as shown in Figure 7. In the plantation areas, which are primarily located in high altitudes and usually planted with perennial plants, the LST changes are not too significant. The rise of areas with various levels of NDVI seems significant in September and October 2023. The area classified as extremely wet in Rain-Fed fields decreased significantly in September and October 2023. The Rain-fed area experienced the most significant changes in NDVI during the El Nino peak. According to Figure 8, the NDVI distribution has changed most from the extreme wet to wet category since September 2023, with a peak in October 2023 Despite a notable increase in LST between August and October 2023, the impact on NDVI appears to be less severe, with most of the alteration from extreme wet to wet NDVI category. The LST increase is more noticeable in irrigated lands and rain-fed fields in lowlands, while plantations mostly located in highlands experience slight LST alteration.

The hotspots emerged from July to December 2023; meanwhile, in 2022, almost no hotspots were detected during the same period, as shown in Table 2. The average LST also rose month on month between 22% and 66% in 2023 compared to 2022 from July to December. The biggest rise month on month is in October, with a 66% rise. The average LST generally rose month-on-month significantly in 2023 compared to 2022, but the average NDVI month-on-month is almost stable except in December. The average NDVI month-on-month rose 38% in December. It indicates that the vegetation response in Bondowoso to the average LST rise was resilient for the short-term El-Nino strike, but it does not give long-term trajectories to the response. There is socio-ecological resilience against El Nino, which is influenced by many factors. The ecosystem response depends on the type and quality of its ecosystem (Whitfield et al., 2019).

All correlation coefficients between average LST and NDVI in this study are negative in each agricultural land classification, as shown in Table 3. This study reports a coefficient of determination (R^2) ranging from 0.66 to 0.92 to signify the correlation strength between LST and NDVI, as shown in Table 3. The strongest R^2 was found in the Rain-Fed area, and the weakest was in the plantation area. This result indicates that the rain-fed field areas are more sensitive to LST alteration than others. However, The R^2 between LST and NDVI can be influenced by many factors. The previous investigation shows that the R^2 of LST and NDVI can vary from 0.51 to 0.78 depending on the land cover classification (Ghobadi et al., 2015). Moreover, the study from Pande et al. (2024) denotes that the R2 between LST and NDVI is only 0.31. The biophysical, geographical variables, and solar radiation factors may vary the correlation between LST and NDVI. It is well-established that solar radiation is the primary driver of the relationship between LST and NDVI from the initial to the end of the growing season. The correlation between LST and NDVI can be positive or negative. If solar energy is the limiting factor for vegetation growth, it could be a positive correlation. On the contrary, it could be negative if solar energy is abundant and other factors play more roles in determining LST and NDVI correlation (Karnieli et al., 2010). The correlation between LST and NDVI becomes weaker in the NDVI values less than -0.2 and more than 0.4. It is nearly impossible to establish a correlation when the NDVI value is less than -0.2 (Guha & Govil, 2021). The NDVI is more correlated to the evapotranspiration (ET) factor than with LST (Pande et al., 2024). However, NDVI has the highest R^2 to LST than other vegetative indices such as the Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Triangular Vegetation Index (TVI), Enhanced Vegetation Index (EVI), and Soil-Adjusted Vegetation Index (SAVI) (Hussain et al., 2023).

5. CONCLUSION

The peak of El Nino in Bondowoso regency occurred from September to October 2023 based on the LST and NDVI maps analysis. The growth of hotspots reached 46%, and above 2% of the areas indicated hot extremes during the peak of El Nino spread in five subdistricts. The average LST has a convincing correlation with the average NDVI, with the coefficient of determination (R^2) ranging from 0.66 to 0.92. The significant rise of LST indicates the short-term impact of El Nino, but the NDVI remains stable, signifying short-term resilience. NDVI alteration does not show that Bondowoso Regency is experiencing extraordinary drought due to increased LST temperatures. However, the emergence of numerous areas in the moderate NDVI category warns that stress affecting vegetation is starting to occur. The irrigated lands and rain-fed fields are agricultural lands, mostly located in the lowlands, and are most affected by the LST rise based on the shifting of NDVI. Even though the study result indicated that the condition in Bondowoso is safe from extreme drought, significant efforts are needed to safeguard agricultural conditions to anticipate the long-term impact of El Nino.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests may appear and influence the work reported in this paper.

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