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INVESTIGATING THE IMPACTS OF ENSO AND IOD ON RICE PRODUCTIVITY IN SOUTH SUMATRA, INDONESIA

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Abstract: Agriculture is a key sector in Indonesia, with rice being a staple crop and a major source of food for the country's population. However, climate variability, including El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events, can have significant impacts on agricultural productivity, particularly in lowland swamp areas where rice is cultivated. This research investigates the impact of both ENSO and IOD on rainfall and rice productivity in lowland swamp areas of South Sumatra, Indonesia, with a focus on food security. The study uses precipitation datasets generated by merging a satellite-gauge precipitation with precipitation observations from several rain-gauge stations located throughout South Sumatra for the period of 1983-2022. Historical data indicates that El Niño events combined with positive IOD phases lead to decreased rainfall in South Sumatra, often causing droughts. In contrast, La Niña phases with negative IOD increase precipitation, resulting in potential flooding and waterlogging issues. Rice cultivation analysis highlights Supron I as the predominant harvesting period, with 49.8% of the total harvested area. Following El Niño periods, there is a rise in harvested areas of Supron I, likely due to the transformation of dried swamps into farmable land. However, increased rainfall during La Niña adversely affects rice yields in this period. These observations highlight the importance of adaptive strategies in the face of climate variability to ensure food security in the region.

Keywords: ENSO, IOD, rice productivity, South Sumatra, lowland swamp area

Introduction

Climate change, characterized by escalating global temperatures, increased frequency and severity of extreme weather events, and altered precipitation patterns, presents substantial challenges to agricultural systems worldwide (Altieri & Nicholls, 2017; Mall et al., 2017; Thornton et al., 2014). Among the most affected is Indonesia, an economy heavily dependent on its agricultural sector (Butler et al., 2014). Agriculture in Indonesia, in addition to its pivotal role in securing the food supply, providing employment, and contributing to the Gross Domestic Product, bears significant social implications and directly impacts the wellbeing of the population (David & Ardiansyah, 2017; Pawlak & Kołodziejczak, 2020).

Rice cultivation, a critical component of agricultural activities in Indonesia, plays a significant role in the nation's food security (Neilson & Wright, 2017; Reardon et al., 2015; Thow et al., 2019). As the staple food in Indonesia, rice production is particularly susceptible to the adverse effects of climate

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change, including shifting weather patterns and climatic variations (Caruso et al., 2016; Hussain et al., 2020). Two key climate phenomena driving these shifts, the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), are known for their substantial influence on precipitation patterns in Indonesia (Agustina et al., 2021; Apriyana et al., 2019; Kurniadi et al., 2021). Consequently, the agricultural sector, particularly rice production, experiences consequential fluctuations due to changes in rainfall frequency, intensity, and duration, leading to considerable alterations in agricultural yields (Ansari et al., 2021; Jung et al., 2015; Merten et al., 2020; Surmaini et al., 2018). A comprehensive understanding of these climatic dynamics is thus critical to devising robust adaptive strategies that enhance agricultural resilience and secure food supply in the face of these climatic changes.

The ability to predict how ENSO may impact rice yields can serve as an invaluable asset for monitoring food security. As demonstrated by (Naylor et al., 2001), quantitative forecasts of ENSO's effects on Indonesian rice harvests can offer crucial insights for managing food security in one of the global major rice producers. While their study focused on national-level data, our research specifically for South Sumatra can similarly demonstrate the predictive capabilities of ENSO indices for rice cultivation.

Establishing region-specific models forecasting ENSO impacts will empower local governments to proactively implement adaptive measures that ensure adequate rice supply. Agricultural practices in South Sumatra appear to be evolving in response to climatic variations. As detailed in studies by Dulbari et al. (2020) and Khairullah et al. (2021), farmers seem to be capitalizing on drier conditions by utilizing previously swampy terrains for cultivation. However, the region faces its set of challenges during La Niña's wet periods, as waterlogged conditions can negatively impact rice yields.

South Sumatra, chosen as the study area due to its status as a major rice-growing region in lowland areas in Indonesia, provides a valuable case study for this research (Imanudin et al., 2021; Purbiyanti et al., 2021; Rumanti et al., 2018). While substantial research has explored the effects of ENSO and IOD events on global weather patterns (Gaughan et al., 2016; Khan et al., 2021; Yin et al., 2022), fewer studies have directly connected these climate phenomena to rice productivity in Indonesia. This study aims to bridge this knowledge gap, offering insights that can inform the development of effective adaptation strategies for lowland agriculture, ultimately bolstering regional food security.

With this context, this paper begins with a comprehensive overview of our research context and objectives, emphasizing the crucial role of agriculture, particularly rice cultivation, in food security and economy in Indonesia. It then discusses the impact of climate variability, highlighting the significant influence of ENSO and IOD phenomena on agricultural productivity. Given the urgent need to understand these climatic events' impacts on precipitation patterns, this research aims to provide valuable insights that enhance the resilience of lowland agriculture in the face of climate change and safeguard regional food security, given critical role of agriculture in Indonesia.

Materials and Methods

Research Location

The research was conducted in South Sumatra, a province located in the southern part of Sumatra Island, Indonesia (Figure 1). The province spans an area of approximately 91,592 square kilometers and is characterized by a tropical climate with significant rainfall throughout the year. South Sumatra is known for its extensive agricultural activities, with rice being the predominant crop cultivated in its lowland areas.

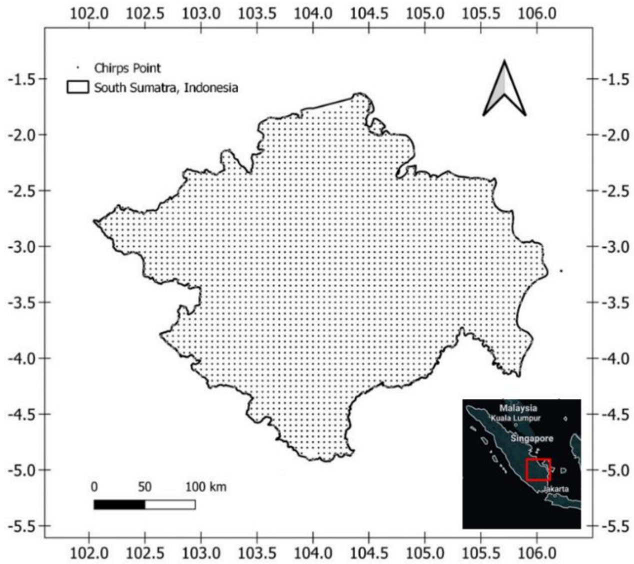

Figure 1: Spatial Distribution of CHIRPS Precipitation Data Grid over South Sumatra

South Sumatra was selected as the study area due to its considerable contribution to national rice production and its vulnerability to climate change, especially the impact of ENSO and IOD events. Moreover, diverse landscape in South Sumatra, characterized by coastal areas, plains, and mountains, offers a unique context to examine the interplay between climate variability and agricultural productivity.

Data

Our data collection process involved acquiring both climatological and agricultural datasets. The climatological dataset, we utilized monthly gridded precipitation datasets provided by the Agency for Meteorology, Climatology, and Geophysics (BMKG), Republic of Indonesia with a spatial resolution of 5 km (BMKG, 2022). This data compilation was the result of integrating the satellite-gauge precipitation measurements from the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) (Funk et al., 2015) with observational rainfall records from multiple rain-gauge stations dispersed throughout South Sumatra. The fusion of these datasets was carried out using the Kriging with External Drift interpolation method (Setiawan et al., 2018).

This data was supplemented by climatic oscillation indices data for ENSO and IOD events during the same period. These indices were obtained from the National Oceanic and Atmospheric Administration (NOAA), which hosts long-term, publicly accessible climate datasets. On the agricultural front, we focused on rice productivity data. The agricultural data were primarily sourced from the Statistics Indonesia (BPS), providing detailed information about rice production in South Sumatra, including yield rates, harvested areas, and planting seasons, over the studied timeframe.

With the aim of investigating the potential impacts of climatic oscillations on rice cultivation, we integrated these climatological and agricultural datasets. This integration allows for a comprehensive understanding of the complex interactions between the climate and agricultural productivity in South Sumatra.

Data Collection and Analysis

The data processing and analysis methodology integrates both climatological and agricultural datasets to investigate the impacts of ENSO and IOD on rice productivity across different harvesting periods in South Sumatra. Rainfall data were obtained from the CHIRPS database corresponding to historical ENSO and IOD episodes. These precipitation values were categorized and averaged according to the three rice harvesting seasons in South Sumatra, known as Suprons: Supron 1 from January to April, Supron 2 from May to August, and Supron 3 from September to December. By comparing the mean rainfall for each Supron during ENSO and IOD phases to the long-term normal precipitation for those months, anomaly values were derived. Mapping these anomalies in QGIS enabled spatial visualization of precipitation fluctuations across South Sumatra during different climate events for each distinct Supron.

In tandem, rice harvesting data from agricultural statistics were also categorized by Supron. The harvested area within a given Supron for a specific focal year was compared to the 5-year average harvested area for the same Supron in previous years. This reveals how rice cultivation during a particular Supron responded to climate variations compared to recent patterns.

Integrating the processed rainfall anomaly data with the rice harvesting statistics allows analysis of how ENSO- and IOD-driven precipitation fluctuations affect rice productivity in South Sumatra across the major planting and harvesting periods represented by the Suprons. The approach enables both spatial analysis of rainfall changes, and temporal analysis of rice area responses across distinct climatic phases for each Supron. Overall, this integrated data processing methodology provides the foundation to address the research objectives of assessing the relationships between climate variability and rice cultivation patterns across different seasons in this major agricultural region.

Combination of ENSO and IOD Events

To analyze the concurrent influences of ENSO and IOD events on climate and rice productivity in South Sumatra, the instances of overlapping ENSO and IOD phases were catalogued for each Supron. The integrated rainfall and rice harvesting datasets were used to compare precipitation patterns and productivity metrics during various concurrent ENSO-IOD phases for each Supron. Table 1 shows the combinations of ENSO and IOD events during the harvesting periods.

Examining these concurrent events provides deeper insight into the compounding effects of multiple climate drivers on agricultural outcomes across the Suprons in South Sumatra. Overall, cataloging and analyzing concurrent ENSO-IOD phases facilitates a nuanced understanding of how rice agriculture is impacted by the intersection of these two key modes of climate variability in South Sumatra.

Table 1: ENSO-IOD Phase Combinations by Supron

Year	Event	Periods		
		Jan-Apr	May-Aug	Sep-Dec
1997	ENSO	Neutral	El Niño Mod	El Niño Strong
	IOD	Neutral	(+)	(+)
1998	ENSO	El Niño Weak	La Niña Mod	La Niña Mod
	IOD	Neutral	(-)	(-)

1999	ENSO	La Niña Mod	La Niña Mod	La Niña Mod
	IOD	Neutral	Neutral	Neutral
2000	ENSO	La Niña Mod	La Niña Weak	La Niña Weak
	IOD	Neutral	Neutral	Neutral
2005	ENSO	Neutral	Neutral	Neutral
	IOD	Neutral	(-)	Neutral
2006	ENSO	Neutral	Neutral	El Niño Weak
	IOD	Neutral	Neutral	(+)
2009	ENSO	Neutral	El Niño Weak	El Niño Mod
	IOD	Neutral	Neutral	Neutral
2010	ENSO	El Niño Mod	La Niña Mod	La Niña Mod
	IOD	Neutral	(-)	Neutral
2015	ENSO	El Niño Weak	El Niño Mod	El Niño Strong
	IOD	Neutral	Neutral	(+)
2016	ENSO	El Niño Mod	Neutral	La Niña Mod
	IOD	Neutral	(-)	Neutral
2019	ENSO	El Niño Mod	Neutral	Neutral
	IOD	Neutral	(+)	(+)

Results and Discussion

In 1997, during a weak El Niño event, Supron I saw significant rainfall anomalies (115%-200%) in the eastern part of South Sumatra, while the southeast experienced below-average anomalies (below 85%-50%). In a moderate El Niño in the same year (Supron II), there were substantial reductions in rainfall anomalies (50%-0%) in the east and central areas, with minimal anomalies exceeding 115%. In Supron III, also during a strong El Niño in 1997, the southeastern and southwestern regions experienced a decrease in rainfall anomalies (50%-0%), with minimal anomalies exceeding 115%. In 2015, during a weak El Niño, Supron I observed widespread rainfall anomalies (115%-200%), except in sporadic regions in the east. In Supron II during a moderate El Niño in 2015, the southern part of South Sumatra saw significant rainfall reductions (50%-0%), while small parts in the west had anomalies between (115%-150%). In Supron III during a strong El Niño in 2015, the central region faced substantial decreases in rainfall anomalies (50%-0%), while some small areas in the south witnessed anomalies between (115%-150%) (see Figure 2).

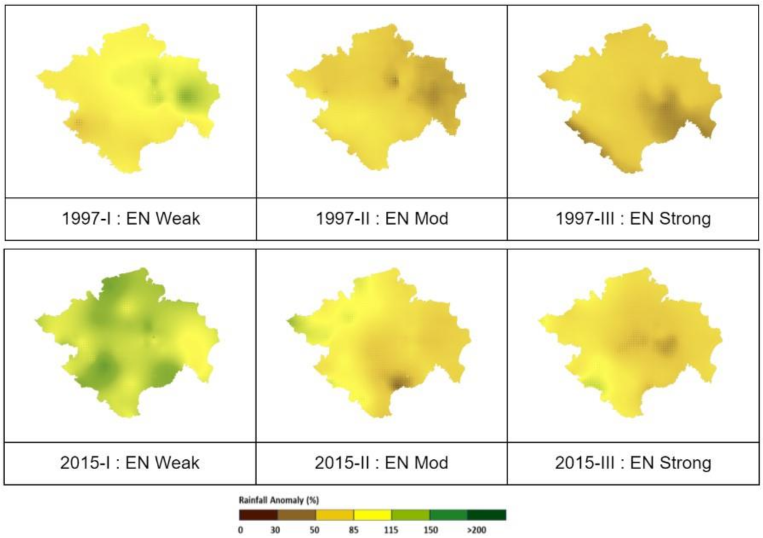

Figure 2: Rainfall Anomalies During El Niño Events in South Sumatra (1997 and 2015)

In contrast, during La Niña events, there were distinct rainfall patterns. In 1999, a moderate La Niña brought above-average rainfall anomalies (115%-200%) to Supron I, affecting almost all areas except small parts in the south and west. In Supron II, during the same La Niña event, there was a substantial increase in rainfall anomalies (115%-200%) in the west, while the east witnessed decreases (85%-50%). Supron III in the same period saw widespread above-average rainfall anomalies (115%-200%), except for small portions in the west. In 2000, during a moderate La Niña, Supron I encountered above-average rainfall anomalies (115%-200%), with some central areas exceeding 200%. Supron II witnessed a similar pattern during a weak La Niña, with above-average rainfall anomalies (115%-200%), and Supron III during the same weak La Niña in 2000 experienced widespread above-average rainfall anomalies (115%-200%), with some areas exceeding 200% (see Figure 3).

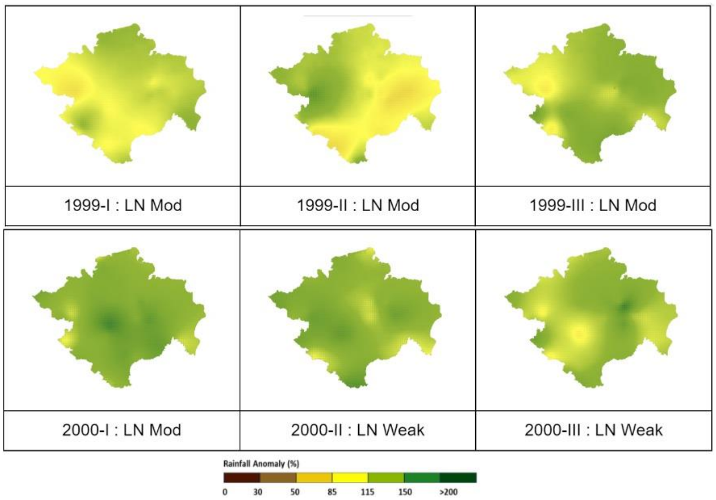

Figure 3: Rainfall Anomalies During La Niña Events in South Sumatra (1999 and 2000)

Figure 4 illustrates the variations in rainfall patterns during different phases of IOD in South Sumatra. In 2005, during an IOD-neutral phase, Supron I experienced rainfall anomalies ranging from 85% to almost 0% in the eastern part, while the western, central, and southern regions observed anomalies between 115% to under 200%. In the same year, during an IOD-negative phase, Supron II saw widespread rainfall anomalies, mostly ranging from almost 115% to under 200%, except for small areas in the east with anomalies exceeding 200% and in the southeast ranging from 85% to 115%. During the IOD-neutral phase in 2005, Supron III witnessed rainfall anomalies, predominantly ranging from almost 115% to under 200%, except for a small portion in the west with anomalies ranging from 85% to almost 30%, and in the central region with anomalies ranging from 85% to 115%.

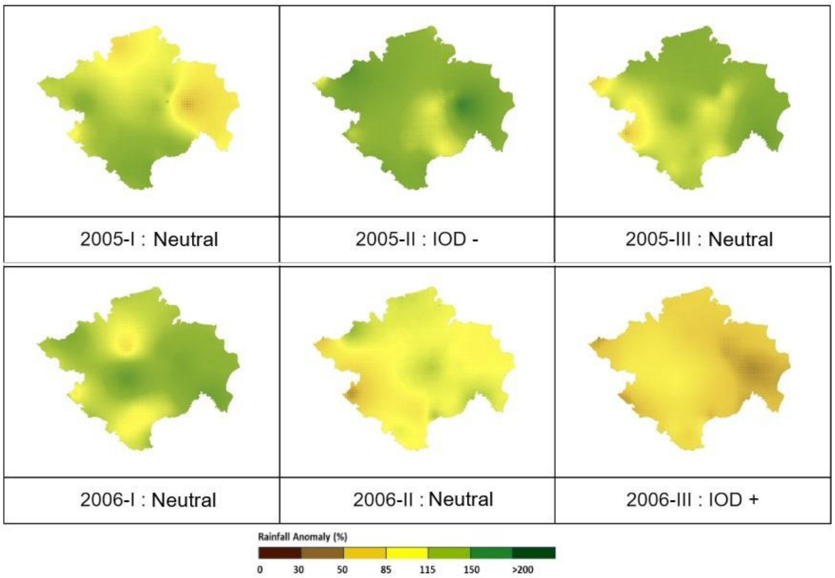

Figure 4: Rainfall Anomalies During Different Phases of the Indian Ocean Dipole (IOD) in South Sumatra (2005 and 2006)

In 2006, during another IOD-neutral phase, Supron I observed rainfall anomalies, mostly ranging from almost 115% to under 200%, except for some areas in the north and south where anomalies ranged from 85% to almost 115%. In Supron II, during the same IOD-neutral phase in 2006, rainfall anomalies were primarily between 85% and 115%, with a small area in the west experiencing anomalies ranging from 85% to almost 30%, and small parts in the center and northwest with anomalies ranging from 115% to under 200%. In Supron III, during an IOD-positive phase in 2006, the western region witnessed rainfall anomalies ranging from 85% to almost 30%, while the central area experienced anomalies ranging from 85% to 115%.

Harvested area versus paddy productivity in South Sumatra, as depicted in Figure 5. The cultivated area for rice has generally shown an increasing trend over the years, often correlating with higher production per hectare. However, it is important to note that specific years have witnessed a decrease in the harvested area. Notably, from 2018 to 2022, there is a notable decrease in harvested area. This decrease can be attributed to a change in the calculation method used by Statistics Indonesia (BPS). Since 2018, BPS has been using remote sensing data to determine harvested areas, whereas before that, they relied on estimation methods based on calculation for determining harvested areas.

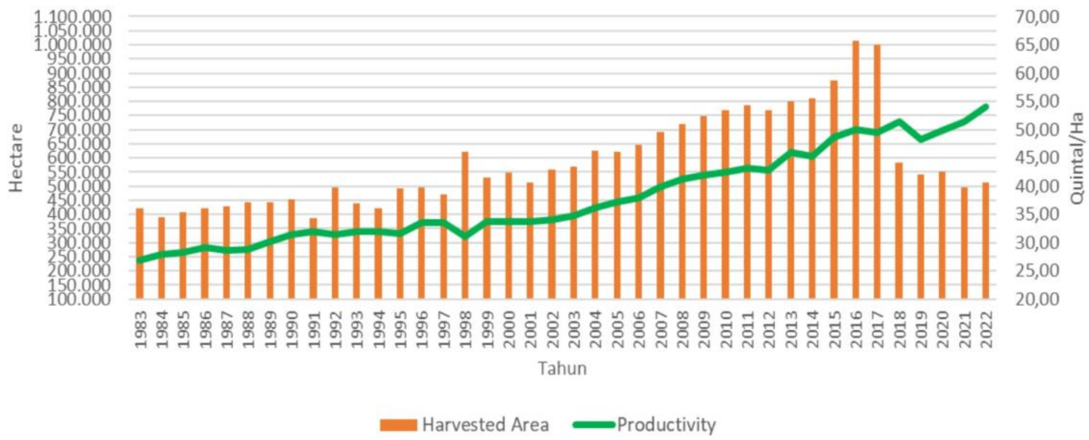

Figure 5: Trends in Rice Area and Productivity in South Sumatra for 1983 to 2022

The percentage of harvested area from 1983 to 2022 is illustrated in Figure 6. During this period, the distribution of harvested areas across the Supron periods is as follows: Supron I accounts for 49.8% of the total, Supron II represents 24.9%, and Supron III comprises 25.3% of the total harvested area. This distribution provides valuable insights into the seasonal variations in rice cultivation in South Sumatra over the decades.

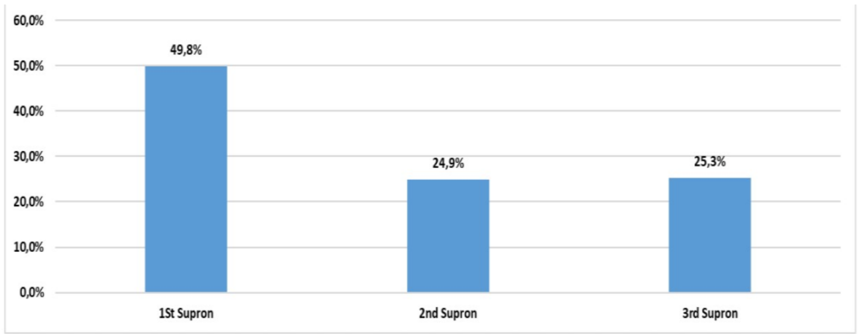

Figure 6: Percentage of Harvested Area by Supron in South Sumatra for 1983 to 2022

In general, as shown in Figure 7, the harvested area during Supron I consistently surpasses that of Supron II and III by approximately 150 to 200%. There are notable variations from the five-year averages in certain years. In 1998, Supron I exceeded its five-year average by approximately 325,000 hectares. Similarly, in 2006, Supron I was higher than its five-year average, reaching around 320,000 hectares. In contrast, in 2016, Supron I significantly exceeded its five-year average, reaching approximately 450,000 hectares. However, in 2001 and 2003, Supron I fell below its five-year average, with areas slightly below 250,000 hectares and around 240,000 hectares, respectively.

For Supron II, the variations are not significantly different from the average, except for the years 2015 and 2016, where the harvested area was around 260,000 hectares. In the case of Supron III, the variations are also not substantially different from the average, except in 2016, when the harvested area reached around 300,000 hectares.

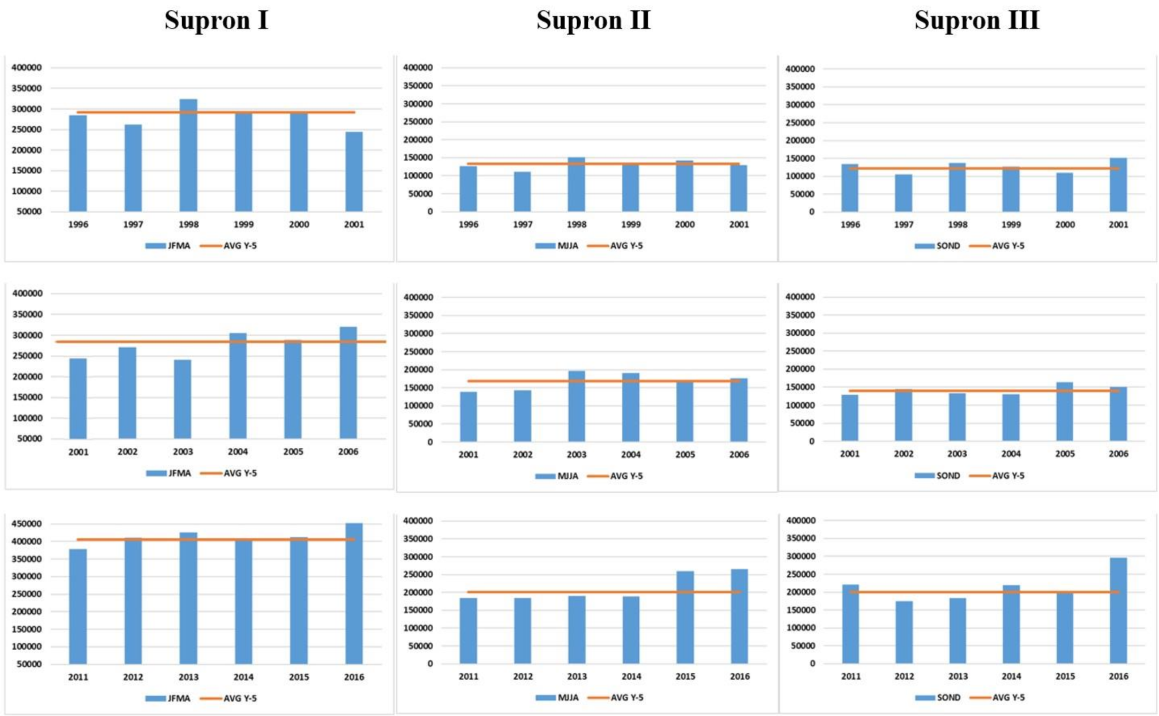

Figure 7: Harvested area by Supron (I, II, III) in South Sumatra in hectares

Discussion

The interplay between rainfall patterns South Sumatra and climatic phenomena, specifically the ENSO and the IOD, has accordance with previous studies studies ((Agustina et al., 2021; Apriyana et al., 2019; Kurniadi et al., 2021). The findings underscore that during El Niño events combined with positive IOD, South Sumatra experiences diminished rainfall. This observation aligns with drought conditions witnessed in the years 1997 and 2015. Such reductions in precipitation, especially when associated with both climatic factors, can create severe drought conditions, adversely affecting the agricultural and domestic sectors (Surmaini et al., 2018; Yin et al., 2022).

Conversely, La Niña events, when coupled with negative IOD phases, lead to increased precipitation in South Sumatra, as corroborated by (Agustina et al., 2021). Historical data from 1999 and 2000 provides a clear testament to this phenomenon. While increased rainfall can be beneficial, the implications are multifaceted. Elevated precipitation can lead to flooding and waterlogging, potentially wreaking havoc on agriculture, especially in regions prone to inundation (Merten et al., 2020; Surmaini et al., 2018).

When focusing on the rice cultivation landscape across the Supron periods, a prominent trend emerges from Supron I. Notably, this period claims 49.8% of the overall harvested area. The dominance of Supron I might be due to a combination of favourable climatic conditions and soil fertility optimal for rice growth. The data further suggests that post-El Niño dry phases lead to an expansion in harvested areas in Supron I. This can be interpreted as a shift in agricultural practices, where farmers possibly exploit drier, previously swampy terrains for cultivation as found in Dulbari et al. (2020) and Khairullah et al. (2021). Conversely, wet spells during La Niña present challenges, with waterlogged conditions potentially causing a dip in rice yield in Supron I. Drawing from these observations, it becomes evident that agrarian activities in South Sumatra, especially in Supron I, are intricately tied to broader climatic shifts.

Conclusion

The intricate relationship between rainfall patterns in South Sumatra and global climatic phenomena, particularly the ENSO and the IOD, has profound implications for the agrarian activities in that region. Our findings underline the pronounced effect these climatic events have on rainfall, which in turn significantly influences rice cultivation, especially during the dominant Supron I period.

During El Niño and positive IOD phases, South Sumatra grapples with reduced rainfall, inducing drought-like conditions that can adversely affect both agricultural and domestic sectors. In contrast, La Niña events combined with negative IOD phases herald increased precipitation, posing challenges of flooding and waterlogging, especially detrimental to rice cultivation.

The observed adaptability of farmers, especially in leveraging drier terrains post-El Niño events, showcases their resilience and the dynamism of agricultural practices in the region. However, with the increasing unpredictability of climatic events, However, given the growing unpredictability of climatic events, South Sumatra must stay vigilant and take proactive measures to protect its agricultural foundation.

In essence, understanding these climatic intricacies and their consequent impacts will be pivotal for future in South Sumatra, ensuring the region remains agriculturally robust and food secure amidst shifting global climate patterns.

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Declaration of Interest Statement

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All research procedures and data interpretations were conducted objectively and without bias. No external funding sources or affiliations influenced the findings or conclusions of this study.

References

Agustina, L., Virgianto, R., & Fitrianto, A. (2021). Utilization of remote sensing data for mapping the effect of Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) in Sumatra Island. IOP Conference Series: Earth and Environmental Science,

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, *140*, 33-45. https://doi.org/https://doi.org/https://doi.org/10.1007/s10584-013-0909-y

Ansari, A., Lin, Y.-P., & Lur, H.-S. (2021). Evaluating and adapting climate change impacts on rice production in Indonesia: a case study of the Keduang subwatershed, Central Java. *Environments*, *8*(11), 117. https://doi.org/https://doi.org/https://doi.org/10.3390/environments8110117

Apriyana, Y., Aldrian, E., & Koesmaryono, Y. (2019). The Dynamics of Rice Cropping Calendar and Its Relation with the ENSO (El Niño-Southern Oscillation) and IOD (Indian Ocean Dipole) in Monsoon and Equatorial Regions of Indonesia. IOP Conference Series: Earth and Environmental Science,

BMKG. (2022). *Report on the Average Rainfall Map and Number of Rainy Days in Indonesia for the Period 1991-2020 (Publication in Indonesian)*. Badan Meteorologi Klimatologi dan Geofisika. Retrieved 15 January from https://iklim.bmkg.go.id/id/detail-buletin/?tahun=2021&id=48

Butler, J., Suadnya, W., Puspadi, K., Sutaryono, Y., Wise, R., Skewes, T., Kirono, D., Bohensky, E., Handayani, T., & Habibi, P. (2014). Framing the application of adaptation pathways for rural livelihoods and global change in eastern Indonesian islands. *Global Environmental Change*, *28*, 368-382. https://doi.org/https://doi.org/https://doi.org/10.1016/j.gloenvcha.2013.12.004

Caruso, R., Petrarca, I., & Ricciuti, R. (2016). Climate change, rice crops, and violence: Evidence from Indonesia. *Journal of Peace Research*, *53*(1), 66-83. https://doi.org/https://doi.org/https://doi.org/10.1177/0022343315616061

David, W., & Ardiansyah. (2017). Organic agriculture in Indonesia: challenges and opportunities. *Organic Agriculture*, *7*, 329-338. https://doi.org/https://doi.org/https://doi.org/10.1007/s13165-016-0160-8

Dulbari, D., Santosa, E., Koesmaryono, Y., Sulistyono, E., Wahyudi, A., Agusta, H., & Guntoro, D. (2020). Local Adaptation to Extreme Weather and It's Implication on Sustainable Rice Production in Lampung, Indonesia. *AGRIVITA, Journal of Agricultural Science*, *43*(1), 125-136. https://doi.org/http://doi.org/10.17503/agrivita.v43i1.2338

Funk, C., Verdin, A., Michaelsen, J., Peterson, P., Pedreros, D., & Husak, G. (2015). A global satellite-assisted precipitation climatology. *Earth system science data*, *7*(2), 275-287. https://doi.org/https://doi.org/10.5194/essd-7-275-2015

Gaughan, A. E., Staub, C. G., Hoell, A., Weaver, A., & Waylen, P. R. (2016). Inter-and Intra-annual precipitation variability and associated relationships to ENSO and the IOD in southern Africa. *International Journal of Climatology*, *36*(4), 1643-1656. https://doi.org/https://doi.org/https://doi.org/10.1002/joc.4448

Hussain, S., Huang, J., Huang, J., Ahmad, S., Nanda, S., Anwar, S., Shakoor, A., Zhu, C., Zhu, L., & Cao, X. (2020). Rice production under climate change: adaptations and mitigating strategies. *Environment, climate, plant and vegetation growth*, 659-686. https://doi.org/https://doi.org/https://doi.org/10.1007/978-3-030-49732-3_26

Imanudin, M. S., Sulistiyani, P., Armanto, M. E., Madjid, A., & Saputra, A. (2021). Land suitability and agricultural technology for rice cultivation on tidal lowland reclamation in South Sumatra. *Jurnal Lahan Suboptimal: Journal of Suboptimal Lands*, *10*(1), 91-103. https://doi.org/https://doi.org/https://doi.org/10.36706/JLSO.10.1.2021.527

Jung, J.-W., Lim, S.-S., Kwak, J.-H., Park, H.-J., Yoon, K.-S., Kim, H.-Y., Baek, W.-J., & Choi, W.-J. (2015). Further understanding of the impacts of rainfall and agricultural management practices on nutrient loss from rice paddies in a monsoon area. *Water, Air, & Soil Pollution*, *226*, 1-11. https://doi.org/https://doi.org/https://doi.org/10.1007/s11270-015-2551-y

Khairullah, I., Alwi, M., & Annisa, W. (2021). The fluctuation of rice production of tidal swampland on climate change condition (Case of South Kalimantan Province in Indonesia). IOP Conference Series: Earth and Environmental Science,

Khan, S., Piao, S., Zheng, G., Khan, I. U., Bradley, D., Khan, S., & Song, Y. (2021). Sea surface temperature variability over the tropical Indian Ocean during the ENSO and IOD events in 2016 and 2017. *Atmosphere*, *12*(5), 587. https://doi.org/https://doi.org/https://doi.org/10.3390/atmos12050587

Kurniadi, A., Weller, E., Min, S. K., & Seong, M. G. (2021). Independent ENSO and IOD impacts on rainfall extremes over Indonesia. *International Journal of Climatology*, *41*(6), 3640-3656. https://doi.org/https://doi.org/https://doi.org/10.1002/joc.7040

Mall, R. K., Gupta, A., & Sonkar, G. (2017). Effect of climate change on agricultural crops. In *Current developments in biotechnology and bioengineering* (pp. 23-46). Elsevier. https://doi.org/https://doi.org/https://doi.org/10.1016/B978-0-444-63661-4.00002-5

Merten, J., Stiegler, C., Hennings, N., Purnama, E., Röll, A., Agusta, H., Dippold, M., Fehrmann, L., Gunawan, D., & Hölscher, D. (2020). Flooding and land use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry. *Ecology and Society*, *25*(3). https://doi.org/10.5751/ES-11678-250314

Naylor, R. L., Falcon, W. P., Rochberg, D., & Wada, N. (2001). Using El Nino/Southern Oscillation climate data to predict rice production in Indonesia. *Climatic Change*, *50*, 255-265. https://doi.org/https://doi.org/10.1023/A:1010662115348

Neilson, J., & Wright, J. (2017). The state and food security discourses of Indonesia: Feeding the bangsa. *Geographical Research*, *55*(2), 131-143. https://doi.org/https://doi.org/https://doi.org/10.1111/1745-5871.12210

Pawlak, K., & Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability*, *12*(13), 5488. https://doi.org/https://doi.org/https://doi.org/10.3390/su12135488

Purbiyanti, E., Sjarkowi, F., Adriani, D., Antoni, M., Alamsyah, I., Yudhistira, N., & Utami, G. (2021). Water-system changes in swampy rice agro-ecosystems area and their economic impacts on farmers in South Sumatra, Indonesia. IOP Conference Series: Earth and Environmental Science,

Reardon, T., Stringer, R., Timmer, C. P., Minot, N., & Daryanto, A. (2015). Transformation of the Indonesian agrifood system and the future beyond rice: A special issue. In (Vol. 51, pp. 369-373): Taylor & Francis.

Rumanti, I. A., Hairmansis, A., Nugraha, Y., Susanto, U., Wardana, P., Subandiono, R. E., Zaini, Z., Sembiring, H., Khan, N. I., & Singh, R. K. (2018). Development of tolerant rice varieties for stress-prone ecosystems in the coastal deltas of Indonesia. *Field Crops Research*, *223*, 75-82. https://doi.org/https://doi.org/https://doi.org/10.1016/j.fcr.2018.04.006

Setiawan, A. M., Koesmaryono, Y., Faqih, A., & Gunawan, D. (2018). Development of High Resolution Precipitation Extreme Dataset Using Spatial Interpolation Methods and Geostatistics in South Sulawesi Indonesia. *Int. J. Sci. Basic Appl. Res.*, *42*, 27-46.

Surmaini, E., Susanti, E., Sarvina, Y., & Syahputra, M. R. (2018). Development of Early Detection Method for Drought and Flood on Rice Paddy. *Agromet*, *32*(2), 81-92. https://doi.org/https://doi.org/https://doi.org/10.29244/j.agromet.32.2.81-92

Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: a review. *Global change biology*, *20*(11), 3313-3328. https://doi.org/https://doi.org/https://doi.org/10.1111/gcb.12581

Thow, A. M., Sharma, S. K., & Rachmi, C. N. (2019). An analysis of Indonesia's shrinking food security policy space under the WTO. *Food Security*, *11*, 1275-1287. https://doi.org/https://doi.org/https://doi.org/10.1007/s12571-019-00967-2

Yin, H., Wu, Z., Fowler, H. J., Blenkinsop, S., He, H., & Li, Y. (2022). The combined impacts of ENSO and IOD on global seasonal droughts. *Atmosphere*, *13*(10), 1673. https://doi.org/https://doi.org/https://doi.org/10.3390/atmos13101673