Temporal Variation of MODIS NDVI in the North Coast Java During El Nino and La Nina

Novie Indriasari
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
novi012@brin.go.id

Orbita Roswintiarti
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
orbi001@brin.go.id

Fadillah Halim Rasyidy
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
fadi006@brin.go.id

Inggit Lolita Sari
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
inggit.lolita.sari@brin.go.id

Kustiyo
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
kust002@brin.go.id

Hengki Muradi
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
heng002@brin.go.id

Babag Purbantoro
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
babag.purbantoro@brin.go.id

Andy Indradjad
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
andy003@brin.go.id

Tatik Kartika
Research Center for Remote Sensing
National Research and Innovation Agency (BRIN)
Bogor, Indonesia
tati002@brin.go.id

Mokhamad Subehi
Center for Agriculture Data and Information System
Ministry of Agriculture)
Jakarta, Indonesia
subehi@pertanian.go.id

***Abstract*—El Niño/Southern Oscillation (ENSO) has been associated with drought and caused the agricultural sector in Indonesia to be vulnerable to climate change. Remote sensing data have been used for crop classification and monitoring for several decades. This study employed the temporal Terra MODIS NDVI imageries from 2001 to 2021 and the Oceanic Nino Index to identify El Niño and La Niña events to visually observed their impact on the paddy growth phase in several irrigated and non–irrigated paddy fields (dryland/rain-fed farming) on the north coast of Java, Indonesia. For the past 21 years, there were 7 El Niño and 11 La Niña events. These phenomena had a more significant impact on the non–irrigated paddy fields than on the irrigated paddy fields. Besides, they caused a shift period in the paddy vegetative phase and NDVI values. This study supports sustainable agricultural management to mitigate crop failure due to climate change.**

Keywords—Vegetation Index, Climate Change, Agriculture, Indonesia

I. INTRODUCTION

The global temperature has risen more than 1.1 degrees Celsius on average [1]. Subsequently, in the next 25 years, the Earth's temperature is anticipated to exceed the threshold of 1.5–4.5 degrees Celsius [2]. Indonesia has experienced increased land surface temperature, such as in Banten Province, with temperature rising 0.4 to 0.7 degrees Celsius per year [3]. Due to global warming, air temperature over Indonesia is expected to increase approximately from 0.2 to 0.3 C in the next five years up to 2030 [4].

As a tropical country, Indonesia is located between the Indian oceans and Pacific Oceans, and between Asia and Australia continents. The location caused Indonesia's climate to be strongly impacted by increased or decreased sea surface temperature due to regional air mass exchange and interactions between the atmosphere and the sea.

El Niño Southern Oscillation (ENSO) is one of the global climate phenomena of ocean-atmosphere interaction in the Pacific Ocean and influenced Indonesia's climate. El Niño and La Niña are the two distinct occurrences as a part of ENSO. The El Niño and La Niña have caused dry and rainy seasons in Indonesia to become drier and wetter, respectively.

The increase (El Niño) and decrease (La Niña) of sea surface temperature in the eastern Pacific Ocean will, furthermore, influence paddy productivity in Indonesia, into more vulnerable to climate [5]. Thus, adaptation strategies on irrigation, biotechnology, and selection of alternative crops are vital [5].

Remote sensing data have been used for several decades in the agriculture sector, such as crop classification, crop monitoring and yield assessment [6]. Several studies used the Normalized Difference Vegetation Index (NDVI) from optical imagery to assess variations in paddy growth and yield estimation. Moreover, information extracted from temporal NDVI can specifically characterize vegetation response to drought. Li, *et al.* [7] developed a real-time crop growth monitoring approach based on NDVI percentiles (pNDVI) to reduce NDVI fluctuations due to weather and field management. The pNDVI datasets were created by rearranging the data values from small to large and clustered into the percentile (P%) of the dataset [7]. Erasmi, *et al.* [8]

979-8-3503-4400-4/23/$31.00 ©2023 IEEE

2023 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES) | 979-8-3503-4400-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICARES60489.2023.10329802

showed variation NDVI has a significant correlation to ENSO warm phases (El Niño) in Indonesia.

This paper describes the use of high temporal NDVI of MODIS imagery to identify paddy growth response to climate change over 21 years from 2001 to 2021 in the irrigated and non-irrigated paddy fields (dryland/rain-fed paddy farming) on the north coast of Java. The study aims to support Indonesia's program on monitoring paddy productivity for developing sustainable agriculture and policy to mitigate climate change impact.

II. MATERIALS AND METHODS

A. Study Area

The study area is situated across three regencies in Java, namely Karawang, Subang, and Indramayu (107°3'33.56"E–108°34'48.14"E and 5°54'12.26"S–6°50'42.00"S) and covering an area of over 6,064 km^2 (Fig. 1). Several locations of dryland/rain-fed paddy farming (non-irrigated) and irrigated paddy fields were chosen for comparison the ENSO impact to paddy growth cycles and NDVI. The irrigated paddy fields are largely located in the lowlands in the study area.

B. Data

1) Terra MODIS imageries

The Terra MODIS (Moderate-resolution Imaging Spectroradiometer) imageries were used as the primary data set to produce the temporal Normalized Difference Vegetation Index (NDVI) dataset from 2001 to 2021. The Terra MODIS imageries were obtained from the USGS Earth Resources Observation and Science (EROS) Center (https://lpdaac.usgs.gov) and Remote Sensing Ground Station – National Research and Innovation Agency of Indonesia (BRIN).

The temporal Terra MODIS imageries were pre-processing using the LAPAN Advanced Image Processing System (LAIPS) software to produce geometric, radiometric, and topographic corrected data through the Top of Atmosphere (ToA) correction method, Bi-directional Reflectance Distribution Function (BRDF), and topographic correction. The dataset was provided at a 500-meter spatial resolution over the Indonesia area and available in the Analyzed Ready Data (ARD) product at a tile size of 5° × 5°. The next pre-processing of the imageries was to produce the cloud-free 8-day spectral reflectance images over Indonesia by applying linear interpolation to estimate unknown values caused by cloud [9]. The date of the imagery to produce the dataset in each year is shown in The date of Terra Modis to Produce 8-Day Ndvi.

2) Oceanic Nino Index (ONI)

The ENSO phenomena can be identified using several indices, such as Japan Meteorological Agency (JMA) index, Nino-4 indices including ONI and Southern Oscillation Index (SOI) [10]. The current study used ONI as an indicator of El Niño or La Niña events over the past two decades due to the long continuity of the data and available up to the present.

ONI was obtained from NOAA sea surface temperature (SST) observations in the Nino 3.4 zone. This region refers to the area in the Pacific Ocean where region 3 (in the eastern Pacific Ocean) intersects with region 4 (in the central Pacific Ocean), shown in Fig. 2. ONI was downloaded from https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. ONI values were classified from +0.5 or higher as El Niño indication, while ONI values from -0.5 or lower indicate La Niña events.

C. 8-day NDVI composite for 21 years

NDVI is widely used as an indicator of vegetation greenness. NDVI is the ratio between the Red and NIR radiation, resulting in an index of values between -1 and +1 (Equation 1). Index values greater than zero and closer to one indicate more actively growing healthy vegetation. Conversely, values below zero are non-vegetated areas such as water and bare soil.

The study used the 8-day mean NDVI dataset to smooth the datasets and reduce the influences of daily weather events, such as heat waves and rain. Equations 1 and 2 are used to create a temporal dataset of the 8-day NDVI.

$$NDVI = (NIR - R) / (NIR + R) \quad (1)$$

Where: R = Red band value; NIR = Near-Infrared band value.

$$\bar{X}_i = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

Where $\bar{X}_i$ is the 8-day of mean NDVI for data-i.

The final step of the data preparation in this study is to produce the 8-day mean NDVI dataset. The 8-day NDVI each year was used to extract information on the paddy growth phase. In this study, each year there were 46 scenes of the 8-day NDVI were acquired, as shown in Table I.

Fig. 1. Study area in the North Coast Java.

TABLE I. THE DATE OF TERRA MODIS TO PRODUCE 8-DAY NDVI

Day	Date	Day	Date	Day	Date	Day	Date
1.	1–8 Jan	13.	6–13 Apr	25.	10–17 Jul	37.	14–21 Oct
2.	9–16 Jan	14.	14–21 Apr	26.	18–25 Jul	38.	22–29 Oct
3.	17–24 Jan	15.	22–29 Apr	27.	26 Jul–2 Aug	39.	30 Oct–6 Nov
4.	24–31 Jan	16.	30 Apr–6 May	28.	3–10Aug	40.	7–14 Nov
5.	1–8 Feb	17.	7–14 May	29.	11–18Aug	41.	15–22 Nov
6.	9–16 Feb	18.	15–22 May	30.	19–26 Aug	42.	23–30 Nov
7.	17–24 Feb	19.	23–30 May	31.	27 Aug–3 Sep	43.	1–8 Dec
8.	25 Feb–3 Mar	20.	31 May–7 Jun	32.	4–11 Sep	44.	9–16 Dec
9.	4–11 Mar	21.	8–15 Jun	33.	12–19 Sep	45.	17–24 Dec
10..	12–19 Mar	22.	16–23 Jun	34.	20–27 Sep	46.	25–31 Dec
11.	20–27 Mar	23.	24 Jun–1 Jul	35.	28 Sep–5 Oct		
12.	28 Mar–5 Apr	24.	2–9 Jul	36.	6–13 Oct		

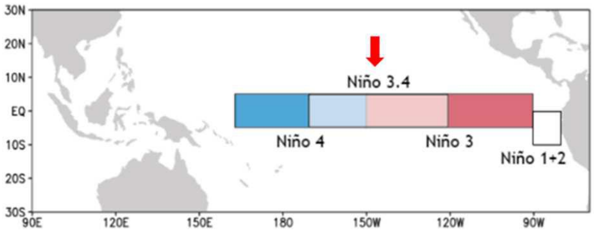


Fig. 2. Location of monitoring sea surface temperature to produce Oceanic Nino Index (light blue and pink box).

TABLE II. EL NIÑO AND LA NIÑA EVENTS BASED ON OCEANIC NINO INDEX FROM 2000 TO 2021

El Nino			La Nina		
Weak	Moderate	Strong	Weak	Moderate	Strong
2004-05	2002-03	2015-16	2000-01	2011-12	1999-00
2006-07	2009-10		2005-06	2020-21	2007-08
2014-15			2008-09	2021-22	2010-11
2018-19			2016-17		
			2017-18		

III. RESULTS AND DISCUSSION

Fig. 3 and Table II show the ENSO phenomena from 2001 to 2021 using ONI. ONI datasets showed Indonesia experienced 7 El Niño and 11 La Niña events over 21 years.

The El Niño events are classified into weak, moderate, and robust events based on their value. During the study period, Indonesia experienced four times weak El Niño with a peak value ranging from 0.5 to 1 in 2004–2005, 2006–2007, 2014–2015, and 2018–2019. Two moderate El Niño happened in 2002–2003 and 2009–2010, with peak values ranging from 1 to 1.5. The strong/extreme El Niño was detected in 2015–2016 with a peak value of more than 1.5.

From 2001 to 2021, La Niña events happened more often than El Niño. Four events of weak La Niña had values ranging from -0.5 to -1 occurred in 2000–2001, 2005–2006, 2008–2009, 2016–2017 and 2017–2018. The three moderate La Niña events happened in 2011–2012, 2020–2021, and 2021–2022, with a peak value ranging from -1 to -1.5. The strong/extreme La Niña events reached the highest and longest record in several past decades in 1999–2000, 2007–2008, and 2010–2011 with a peak value of more than -1.5.

The climate variation influenced by the ENSO phenomena impacted the paddy growth phase in Indonesia. Variations of the paddy phase over 21 years were observed using the composed NDVI every 8 days in the dryland paddy farming (non-irrigated) (Fig. 4). The interpretation of the paddy growth was analyzed using a three-pixel area of NDVI images (spatial resolution of 500 m). The NDVI values were calibrated from 16-bit to 8-bit (×200+50).

Fig. 4 shows the temporal of the 8-day NDVI over 21 years in the less irrigation field. Generally, paddy growth phase has two times cycles each year. The two paddy growth cycles consist of two optimum NDVI identified as paddy vegetative phase and two lowest NDVI identified in water/bare land.

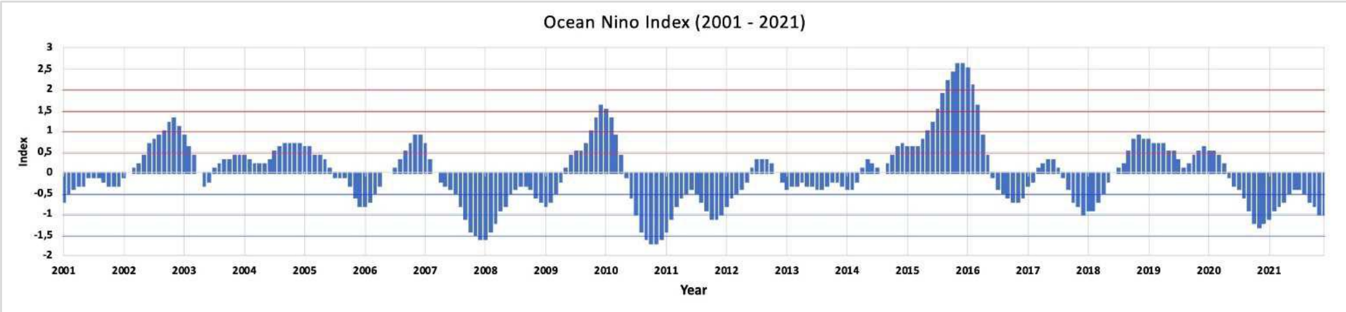


Fig. 3. Oceanic Nino Index from 2001 to 2021.

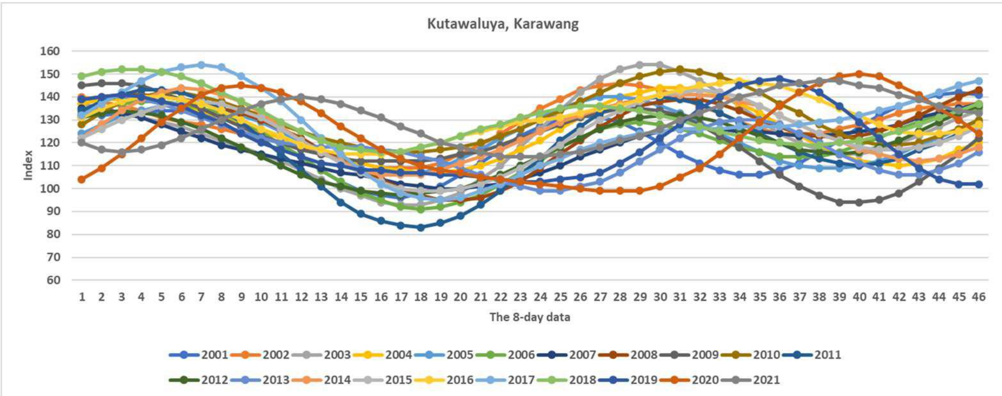


Fig. 4. Temporal variations of the 8-day NDVI from 2001 to 2021 in paddy fields with less irrigation, including dryland paddy/drain-fed system (Latitude: -6.18316, Longitude: 107.34481).

Analyses on climate variation impacted on paddy planting season and paddy growth over 21 years showed that the less irrigation paddy fields in north coast Java was significantly affected during El Niño and La Niña events (Fig. 4 and Fig. 5). The El Niño and La Niña events influenced the variation of the shift period of the paddy phase each year, including NDVI values.

Fig. 5 shows an example of the paddy planting season (includes vegetative phase dan generative phase) and their growth phase measured using NDVI in the less irrigation paddy fields in Patrol, Indramayu, during three conditions of normal or neutral climate (2001), La Niña (2010), and El Niño (2015). Paddy planting season in the non-irrigated field for the planting season 1 (rainy season) during the normal climate started from data-43 (1–8 Dec) to data-17 (7–14 May). The planting season 2 (dry season) started from data-18 (15–22 May) and data-42 (23–30 Nov). The NDVI values in this non-irrigated field range from 117 to 162.

El Niño events has significantly impacted the paddy planting season for the non-irrigated paddy field all year around. The extreme El Niño (which started in 2014), it indicated that the paddy's planting season 1 period has started from data-3 (17–24 Jan) to data-24 (2–9 Jul). while paddy planting season 2 (dry season) started from data-25 (10–17 Jul) to data-2 (9–16 Jan). The NDVI values has decreased with the values ranging from 90 to 150 in year 2015.

The extreme La Niña in 2010 has mainly impacted the paddy planting season 1 for the non-irrigated paddy field. Planting season 1 has shifted from data-40 (7–14 Nov) to data-18 (15–22 May). While the planting season 2 has less affected and has relatively similar pattern to the normal climate. The NDVI values ranged between 117 and 170.

Analyses on the paddy growth phase based on Fig. 5 and Table III, showed the extreme El Niño had caused the lowest NDVI values for all year round compared to other climate variations, including a shorter vegetative growth phase. Thus, this indicates that the NDVI variation during El Niño might cause an influence of paddy productivity in the non-irrigated paddy fields, including dryland/rain-fed paddy farming. During the La Niña, the NDVI had the highest values (approximately in day-7, and day-8) compared to other climate variations. Thus, the La Niña event has less impact on paddy productivity compared to El Niño (Fig. 5).

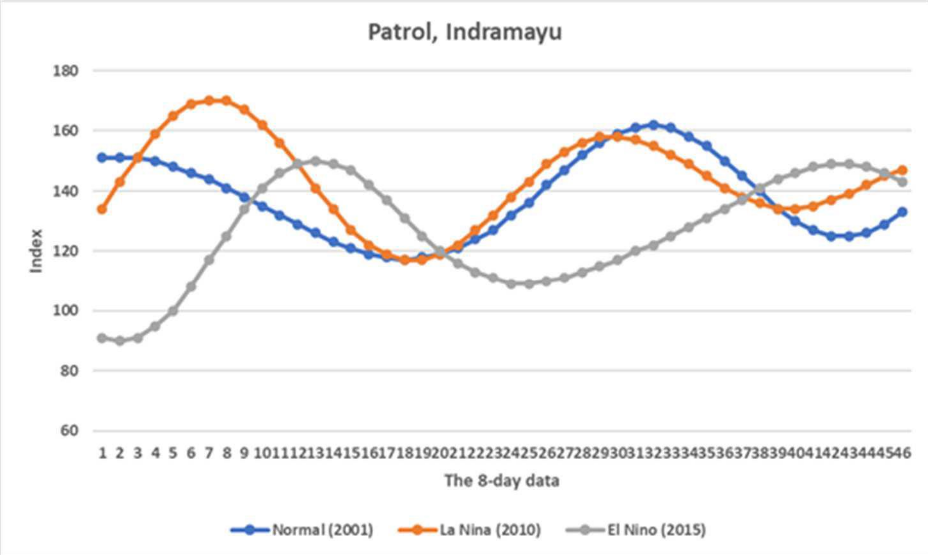


Fig. 5. NDVI trend of the paddy growth phase in non-irrigated paddy field during normal climate in 2001, El Niño in 2015, and La Niña in 2010 (Latitude: 6.31487, Longitude: -108.01862).

TABLE III. PADDY GROWTH PHASE (8-DAY) BASED ON NDVI IN AN AREA WITH FEWER IRRIGATION FIELDS DURING NORMAL, EL-NINO, AND LA NIÑA EVENTS

Trend	Optimal NDVI-1 (vegetative phase)	Lowest NDVI -1 (water/bare phase)	Optimal NDVI -2 (vegetative phase)	Lowest NDVI -2 (water/bare phase)	Explanation of NDVI
Normal	day-2, day-3 (9–24 Jan)	day-17, day-18 (7–22 May)	day-32, day-33 (4–19 Sep)	day-43, day-44 (1–16 Dec)	• Vegetative phase-1 > Vegetative phase-2 • Water/bare phase-1 < Water/bare phase-2
El Niño	day-13 (14 Mar–21 Mar)	day-25 (12 July–19 July)	day-41 (16 Nov–23 Nov)	day-2 (9 Jan–16 Jan)	• Vegetative phase-1 > Vegetative phase-2 • Water/bare phase-1 > Water/bare phase -2
La Niña	day-7, day-8 (18 Feb–5 Mar)	day-17, day-18 (7–22 May)	day-28 (3–10 Aug)	day-38 (22–29 Oct)	• Vegetative phase-1 > Vegetative phase-2 • Water/bare phase-1 < Water/bare phase-2

On the other hand, the ENSO phenomena have less impact on irrigated paddy farming. Fig. 6. shows the NDVI trend for three locations in Subang, Karawang, and Indramayu regencies which used irrigation systems for their fields with water supply from several dams such as Jatiluhur, Jatigede, Cipancuh, Walahar, and Sadawarna.

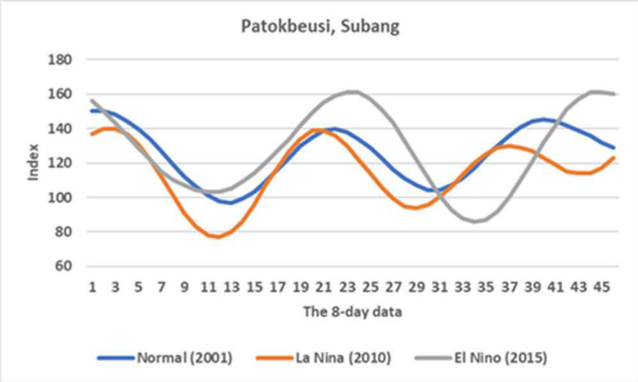
From Fig. 6, the paddy growth phase in the irrigated paddy fields had less impact on the ENSO phenomena over the past 21 years. During La Niña and El Niño, paddy growth cycles in the irrigated fields were consistent for approximately 3–4 months. The 8-day NDVI showed variation in paddy growth cycles, such as phase-1 was varied for each location. Moreover, during the El Niño event in year 2015, the NDVI value was also stable, and relatively higher than the normal climate. This can be seen in several regions that had higher paddy rice production during El Niño, such as Subang increased their rice production from 1,004,261 tons in 2015 to 1,269,869.51 tons in 2016 [11,12].

In several regions, ENSO events also influenced the shift period, yet in a relatively small difference. The shift planting season happened particularly in the second vegetative phase during La Niña.

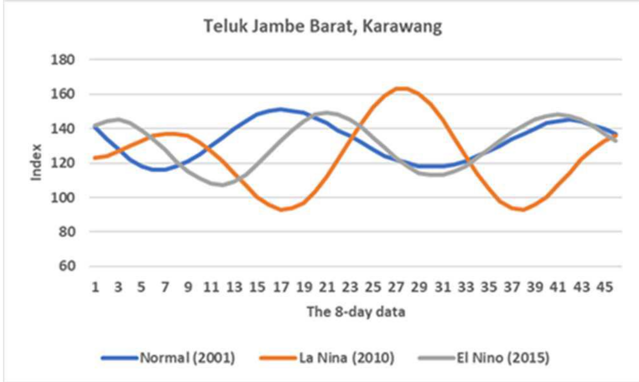
For example, the NDVI variation in Patokbeusi area in Subang Regency represented as the irrigated paddy fields shown in Fig. 6. During La Niña, the intensities of NDVI were higher than those during normal climate, particularly in planting season 2. There was a slight shift earlier in planting season 1. While during El Niño, the planting seasons 1 and 2 were shifted later than those during normal climate. The intensities of NDVI were lower in planting season 1.

From Fig. 6, the NDVI variation in irrigated paddy fields in Teluk Jambe Barat, Karawang Regency during La Niña, showed the planting seasons 1 and 2 were shifted later than those during normal climate. While during El Niño, the shift of planting later only in the planting season 1.

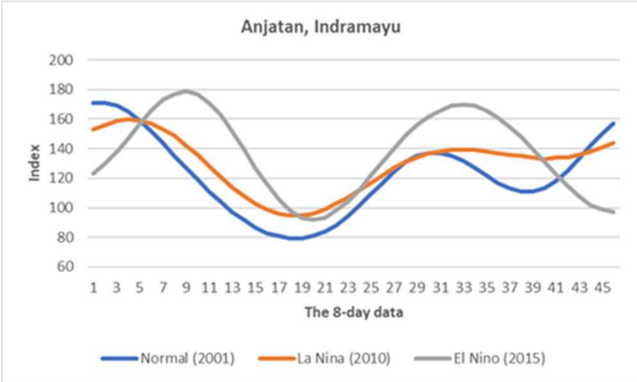
The higher NDVI values in the irrigated paddy field during the climate variation in the Normal, La Niña, and El Niño also shown in Anjatan area in Indramayu Regency (Fig. 6). Thus, paddy farming in Subang, Karawang, and Indramayu regencies experienced a slight shift in their vegetative period during the extreme El Niño event (2015), particularly in the second-period vegetative phase. While La Niña did not influence the vegetative phase in the first period in the study (rainy season).



(Latitude: -6.36129; Longitude: 107.63242)



(Latitude: -6.341526; Longitude: 107.238659)



(Latitude: --6.3656; Longitude: 107.957978)

Fig. 6. NDVI trend of the paddy growth phase in several irrigated paddy fields in Subang, Karawang, and Indramayu regencies during normal climate in 2001, El Niño in 2015, and La Niña in 2010.

In line with previous studies, the current study shows relationships between ENSO and drought in Java, which mainly affected dryland/rain-fed rice farming [13]. However, ENSO events have less influence on irrigated paddy fields. Future studies on the paddy growth phase related to ENSO phenomena using a robust method are important to be developed, including studies on modeling paddy's productivity to mitigate crop failure and to support policy on sustainable agricultural management.

IV. CONCLUSIONS

Temporal ONI datasets from 2001 to 2021 were used to identify ENSO phenomena. The current study showed that for 21 years, Indonesia, mainly on the north coast of Java experienced 7 El Niño and 11 La Niña events. The ENSO events influenced paddy growth cycles and their productivity.

The Analyzed Ready Data of Terra MODIS imageries were utilized to observe the impact of El Niño and La Niña on paddy phase and NDVI variations over the past two decades. There were a total of 46 datasets of 8-day NDVI each year to visually observe the paddy growth cycles in response to climate variations for irrigated and non–irrigated/rain-fed paddy farming.

El Niño events caused a shift in the paddy growth phase and lower NDVI values compared to normal conditions. While La Niña events affected the paddy vegetative cycles, their NDVI values were relatively steady and similar to normal conditions. However, ENSO phenomena have less impact in irrigated paddy fields. The current study supports sustainable agricultural management to mitigate crop failure due to climate variations.

REFERENCES

[1] S. Celik, The Effects of Climate Change on Human Behaviors. In Environment, Climate, Plant and Vegetation Growth, Eds. Springer International Publishing: Cham, 2020. 10.1007/978-3-030-49732-3_22pp. 577-589.

[2] P.M. Cox, C. Huntingford, M.S. Williamson, "Emergent constraint on equilibrium climate sensitivity from global temperature variability." Nature, 553, 319-322, 2018. https://doi.org/10.1038/nature25450.

[3] M. Munawar, T.A.E. Prasetya, R. McNeil, R. Jani, S. Buya, "Spatio and Temporal Analysis of Indonesia Land Surface Temperature Variation During 2001–2020." J. Indian Soc. Remote Sens. 2023, 51, 1393-1407. https://doi.org/10.1007/s12524-023-01713-0

[4] M. Case, F. Ardiansyah, E. Spector, "Climate change in Indonesia: implications for humans and nature." Climate change in Indonesia: implications for humans and nature. 2007.

[5] R. L. Naylor, D. S. Battisti, D.J. Vimont, W.P. Falcon, M. B. Burke, "Assessing risks of climate variability and climate change for Indonesian rice agriculture." Proceedings of the National Academy of Sciences 2007, 104, 7752-7757. https://doi.org/10.1073/pnas.0701825104

[6] Weiss, M.; Jacob, F.; Duveiller, G. "Remote sensing for agricultural applications: A meta-review." Remote Sens. Environ, 236, 111402, 2020. https://doi.org/10.1016/j.rse.2019.111402

[7] C. Li, H. Li, J. Li, Y. Lei, C. Li, K. Manevski, Y. Shen, "Using NDVI percentiles to monitor real-time crop growth." Comput. Electron. Agric., 162, 357-363, 2019. https://doi.org/10.1016/j.compag.2019.04.026.

[8] S. Erasmi, P. Propastin, M. Kappas, O. Panferov, "Spatial Patterns of NDVI Variation over Indonesia and Their Relationship to ENSO Warm Events during the Period 1982–2006." J. Clim., 22, 6612-6623, 2009. https://doi.org/10.1175/2009JCLI2460.1.

[9] Y. Setiawan, Kustiyo, A. Darmawan, "A simple method for developing near real-time nationwide forest monitoring for Indonesia using MODIS near- and shortwave infrared bands." Remote Sens. Lett., 7, 318-327, 2016. https://doi.org/10.1080/2150704X.2015.1137645

[10] D. E. Hanley, M. A. Bourassa, J. J. O'Brien, S. R. Smith, E. R. Spade, "A Quantitative Evaluation of ENSO Indices." J. Clim., 16, 1249-1258,

2003. https://doi.org/10.1175/1520-0442(2003)16<1249:AQEOEI>2.0.CO;2

[11] Badan Pusat Statistik. Kabupaten Subang Dalam Angka 2016 (Subang Regency in Figures 2016). BPS Subang, Indonesia, 2016.

[12] Badan Pusat Statistik. Kabupaten Subang Dalam Angka 2017 (Subang Regency in Figures 2017). BPS Subang, Indonesia, 2017.

[13] H. Mulyanti, H. A. Sudibyakto, M. P. Hadi, The Influence of Enso and IOD On Meteorological Drought To Develop Dryland Rice Crop Early Warning In Java Island. Universitas Gadjah Mada, 2015.