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Agricultural Droughts Monitoring of Aceh Besar Regency Rice Production Center, Aceh, Indonesia – Application Vegetation Conditions Index using Sentinel-2 Image Data

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ABSTRACT

Monitoring the agricultural drought of paddy rice fields is a crucial aspect of preparing for proper action in maintaining food security in Indonesia. The Aceh Province is one of Indonesia's national rice production centers, especially Aceh Besar Regency; it includes three central districts; Indrapuri, Kuta Cot Glie, and Seulimeum. Satellite-Sentinel 2A data have been tested to monitor the drought levels of around 2,803 Ha in the three districts in this study. This study aimed to determine the drought level in Indrapuri, Kuta Cot Glie, and Seulimeum districts, Aceh Besar Regency's paddy rice fields using Sentinel-2A data imagery. The vegetation conditions index (VCI) of Sentinel-2 data was utilized to identify a vegetative drought level in the area for the 2018, 2019, 2020, 2021, and 2022 growing seasons. The vegetation inertia index is derived from the Normalized Difference Vegetation Index (NDVI). The results show that the VCI looked volatile, but the trendline increased by four percent, from 92.56 in July 2019 to 96.08 in July 2021. Most areas on the dates investigated found that the no drought category was still dominant. The designated data analyzed found that the June 2022 data tend to be distributed to the drought in extreme, severe, moderate, and mild increases compared to the previous data investigated. This figure shows an increasing drought in the study area, and the average drought index is in the category of mild drought. In addition, there has been a trendline decline in the value of NDVI in recent years, causing agricultural land for paddy rice fields to be slightly vulnerable to drought.

Keywords: drought monitoring, VCI, sentinel-2A, vegetation health index.

INTRODUCTION

Paddy rice production is a crucial aspect of food security in Indonesia. One of the treating factors that may affect production is agricultural drought in some paddy rice production centers. As the primary providers of the worldwide food supply chain, the agriculture practices of paddy rice In Indonesia are vital in safeguarding food security global (Accorsi and Manzini, 2019). Meanwhile, the spread of the COVID-19 pandemic has forced significant tasks to food production and consumption patterns, highlighting the vital need for reconsidering the sustainability of present approaches to agriculture and the food industry. One of the problems for maintaining food security is avoiding the drought on agricultural land during the growing season for paddy rice fields. The causes of droughts on agricultural land can be meteorological, agricultural, hydrological, and socioeconomic droughts (Wilhite, 2005). However, in recent years meteorological drought has been dominant in hampering agriculture practices (Bageshree et al., 2022; Guo et al., 2019).

Drought is a significant natural hazard, especially in agricultural practices for paddy-rice fields, and can cause significant losses to crop production and water supply (Surmaini et al., 2015). In recent years, droughts have been frequent due to the El Nino phenomenon and have had a tremendous impact on agricultural land (Syahrial et al., 2017). This phenomenon has further triggered several threats to Indonesian agriculture practices for paddy rice fields, especially in Indrapuri, Kuta Cot Glie, and Seulimeum Districts, Aceh Besar Regency, Aceh Province, Indonesia. These areas are among national rice production centers.

Identifying drought levels is essential for evaluating the likelihood of drought and its severity for national food security awareness (Gitz et al., 2016). The impact of drought can be well mitigated if detected earlier; this can be done through remote sensing data measures and monitoring regularly. However, monitoring regular based field visits is time-consuming and costly. Using remote sensing data, drought can be effectively monitored over large areas. Satellite-borne remote sensing data provide a synoptical interpretation of the Earth's surface and can therefore be used to monitor drought events spatially (Kogan, 1997, 1995; Liu and Kogan, 1996; Sholihah et al., 2016). Several remote sensing indices have been developed and applied to monitor the drought spatially (Huang et al., 2018). Among the indices, the NDVI as a vegetation health check has become one of the most commonly used for monitoring drought events (Akinyemi, 2021; Walter-shea, 2002). To improve the approach, combining vegetation index and temperature is recommended. Combined NDVI and ground surface temperature (ESG) provide a strong correlation and valuable information for identifying agricultural drought as an early warning system (Lee et al., 2021; Olii et al., 2022).

Some vegetation indices for drought monitoring using remote sensing data have been introduced. One of them, vegetation health index (VHI) has demonstrated outstanding capabilities (Sholihah et al., 2016). The result has shown better relevance in detecting drought (Akinyemi, 2021; Walter-shea, 2002). It considers vegetation conditions (VCI) and thermal vegetation conditions (TCI) in the observation period. Therefore, VHI further evaluates the dryness of vegetation affected by temperature (Lee et al., 2021; Olii et al., 2022). The parameters investigated can be derived from NDVI and ground surface temperature (ESG) data. Due to the relatively straightforward availability of high-resolution data, in this study, VHI was derived using temporal sequence from Sentinel-2A dry season and wet season data: July & December 2018, July & December 2019, July & December 2020, July & December 2021, and June 2022. During this period of growing seasons, July is considered the dry season; meanwhile, December represents the wet season.

Drought monitoring during the dry season is essential to see the possible adjustment for the growing season during this time. The dry season of paddy rice planting season is at the end raining season which ranges between April-September. Thus, June and July are critical months for paddy rice growing season in many parts of paddy rice growing in Indonesia rice production centre, including in Indrapuri, Kuta Cot Glie, and Seuleumun districts of Aceh Province Indonesia. In 2021, more than 600 hectares of paddy rice fields were experiencing drought in Kuta Cot Glie district (Indonesia, 2021). The harvest in the regency failed over an average area of 800 hectares. This data provides that drought is a serious matter. During this time of planting for the dry season, there were likely risks against the drought and a high risk of crop harvesting failures.

Obtaining data directly during the dry season is challenging; however, remote sensing data can be utilized to obtain data even though the harvest time has been done. One of the data freely available for evaluating drought is Sentinel-2 images data. Sentinel-2A images are considered in this paper because of the open access policy, good resolution, availability in a short period, and relatively good spatial range for drought monitoring. Ensuring the utilization of satellite image data can be used for drought monitoring for agriculture land, this study aimed to determine the drought level in the paddy rice fields of Indrapuri, Kuta Cot Glie, and Seulimeum Districts, Aceh Besar Regency, Aceh, Indonesia, by utilizing remote sensing data of Sentinel-2A to assess the drought in the regions by applying derived vegetation indices. In addition, a comparison was made between long-term droughts in 2018, 2019, 2020, 2021, and 2022 to determine drought-level conditions in the three districts as the rice production center in Aceh Besar Regency. As droughts are an unpredictable event in agricultural practices, and are recurrent as natural phenomena due to a deficiency in precipitation, and also water storage during the growing season, providing the information with rapid analysis using remote sensing data is an important aspect for continuing an area as production centre. This study tried to provide the information needed by both the government and farmers in a timely manner in making decisions in paddy rice planting activities.

Study area

The Indrapuri, Kuta Cot Glie, and Seulimeum districts of Aceh Besar Regency were selected as research areas (Figure 1). These areas are located in the northern part of Aceh Besar Regency, Aceh-Indonesia Province, which is geographically located between 5°10'–5°40'N and 95°20'–95°45'E. Administratively, the three districts bordering the Strait of Malacca to the North, the Seulawah Mountains to the East, the Bukit Barisan Mountains on the Southern border, and Banda Aceh City are located to the west. The landform in the study area is dominated by flat plains between 0–50 m above sea level. Almost 50 percent of the land use in the study area is paddy rice fields, about 184,486 ha of the total 397,104 ha in the three districts. These areas are one of the centers of national rice production in Indonesia.

MATERIALS AND METHODS

Data

The Sentinel-2A multispectral imager includes 13 spectral bands with a plot width of 290 km and a spatial resolution of 10 m (three visible and near-infrared bands), 20 m (6 red edge/shortwave infrared bands), and 60 m (3 red edge/shortwave infrared bands) were utilized. The objective of this study is intended to monitor the variability of ground surface conditions, its wide plot width, and high re-visit times (10 days with one satellite and five days in an entire constellation with the twin satellite Sentinel-2B) to support the monitoring of vegetation changes during the growing season. It also provides data and applications for operational land monitoring, emergency response, and security services.

The coverage boundary is approximately temporal sequences of the *Gadu*-dry and *Rendeng*-wet seasons of July & December 2018, July & December 2019, July & December 2020, and July & December 2021. June 2022 from Sentinel-2A data were collected in this study to monitor the drought levels in Indrapuri, Kuta Cot Glie, and

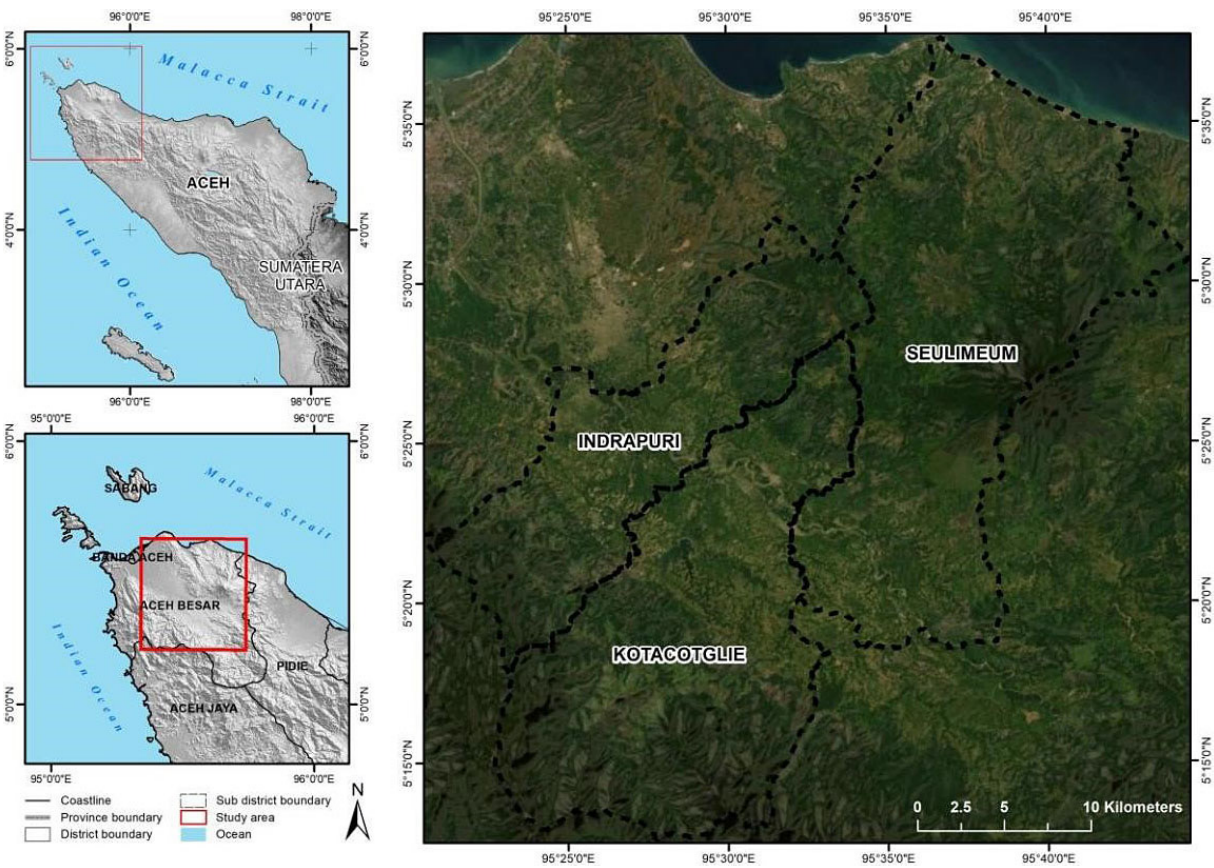

Figure 1. Location of study area

Seulimeum districts paddy rice field, Aceh Besar-Indonesia Regency. Scenes S2A of 100% cloud-free were selected and downloaded from the Copernicus Sentinels Scientific Data Center (https://scihub.copernicus.eu/dhus/). Orthorectified and radiometrically corrected images (level 1C processing) were used for the image analysis. Since the study area represents only a small part of the traces of each scene, it was assumed that constant atmospheric conditions and no atmospheric corrections were applied. Each scene contains 13 spectral bands with a native spatial resolution of 10 m (blue, green, red, and near-infrared bands), 20 m (red edge bands), or 60 m (shortwave infrared bands); all tape is re-sampled to a resolution of 10 m for further processing.

Drought-sensitive spectral indices

The available Sentinel-2 data is still at level 1C. To perform vegetation index calculations, it is required to use imagery that has been corrected by the atmosphere at least until *surface reflection (surface reflectance*) to avoid atmospheric effects. Therefore, in this study, atmospheric corrections were curried out to Sentinel-2 images using Sen-2Cor processing developed by Telespazio VEGA Deutschland GmbH in 2016 on behalf of the European Space Agency (Main-Knorn et al., 2017). Sen2Cor supports the atmospheric correction of Sentinel-2 imagery still at level-1C by producing imagery at level-2A corrected to bottom-of-atmosphere (BOA) reflections. Currently, Sen2Cor processing can be done through Anaconda programming-based processing (Louis et al., 2013; Mueller-Wilm, 2019).

The study used the Sentinel-2 imagery data provided by the European Space Agency (ESA), which covered the entire dry season in the study area. The Sentinel-2 satellite captures Earth's surface data with 13 spectral bands and three spatial resolutions of 10 m, 20 m, and 60 m. This is the processed data and only needs to be converted to reflectance values before calculating the drought index. With time-series data, a classification approach using Red and NIR bands of Sentinel-2 scenes has been used to view drought index results calculated from remote sensing data against drought in rice fields.

Drought was identified from multitemporal sentinel-2A satellite imagery of five different years; July and December 2018, July and December 2019, July and December 2020, July and December 2021, and June 2022. VCI was developed to monitor vegetation conditions (Kogan, 1995) to describe changes in the NDVI value due to weather conditions to monitor the effects of drought on vegetation. The NDVI layer was overlaid to notice differences in vegetation health throughout the dry seasons of 2018, 2019, 2020, 2021, and 2022. NDVI has become the primary tool for describing vegetation phenology, where high NDVI values indicate healthy and dense vegetation (Gómez-Mendoza et al., 2008; Sugianto et al., 2020). Meanwhile, VCI is the standard index for drought analysis for such measures (Liu and Kogan, 1996). VCI is based on the relative NDVI change concerning the minimum historical NDVI value. The VCI compares the current Vegetation Index (VI), such as NDVI or Enhanced Vegetation Index (EVI), to the values observed in the same period in previous years within a specific pixel. Thus, the VCI index can be derived from NDVI as in Equation 1. NDVI is calculated by band 4 and band 8 from Sentinel data.

$$VCI_j = \frac{NDVI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100 \qquad (1)$$

where: VCI_j – the value of the vegetation condition index for the *j*-date;
$NDVI_j$ – the NDVI value for the j-date;
$NDVI_{max}$ and $NDVI_{min}$ – the maximum and minimum NDVI values in the data set.

This study proposed the following classification scheme for drought monitoring (Table 1).

Table 1. A classification scheme for drought mapping

Drought Level	VCI Value range (%)
Extreme drought	<10
Severe drought	10–20
Medium drought	20–30
Light drought	30–40
No drought	>40

RESULTS AND DISCUSSIONS

NDVI value distribution

Drought patterns in the three districts as amongst the paddy rice production center of Aceh Besar regency over the period 2018–2022 were analyzed using the NDVI approach. The NDVI value is an index value that can be used as an indication of the vigor level of the plant during the growing season. It is acknowledged that Indonesia experiences two growing seasons, wet and dry seasons. The wet season starts in October and

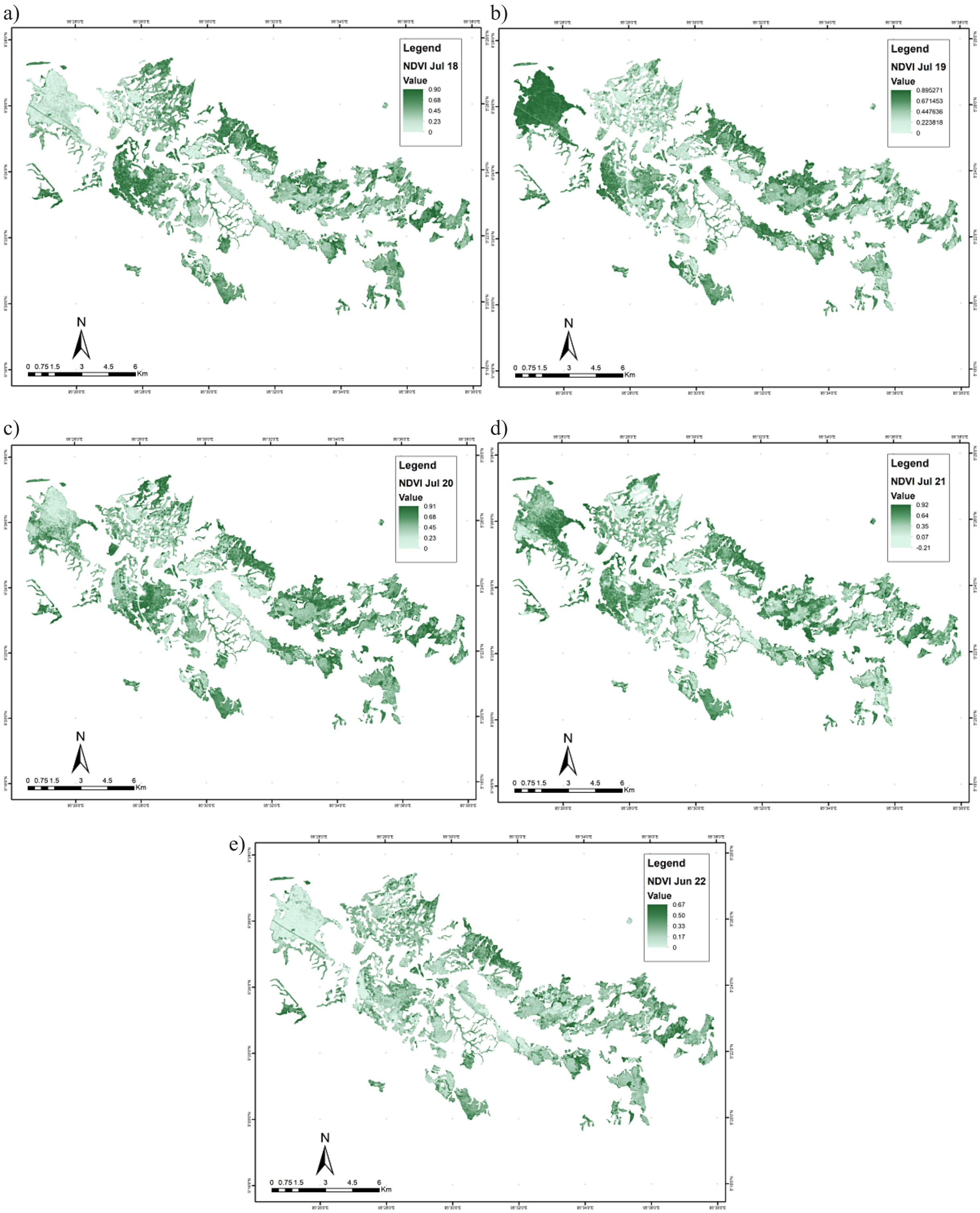

Figure 2. Spatial variations of NDVI value in the study area in the July/June growing season (a) 2018, (b) 2019, (c). 2020, (d) 2021, (e) 2022

ends in March, with the peak season in December/January. The dry season starts in April and ends in September, with the peak growing season in June/July. Thus, NDVI value distribution may reflect the health or drought experienced at the study site. The diversity of NDVI shows spatial variations in vegetation health in the study area and the dynamic values of NDVI annually, as shown in Figure 2. The figure depicts the spatial distribution of NDVI value of multitemporal data from July 2018 until 2022. July is considered a dry growing season. It shows there is a shift of NDVI value for different years investigated, the 2019 data of NDVI with high value concentrated

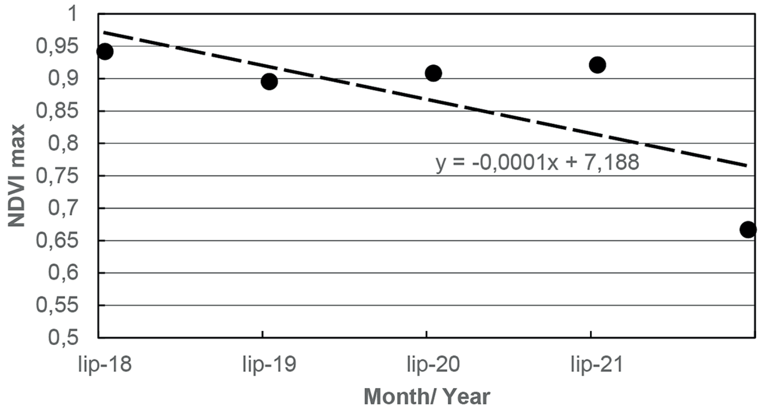

Figure 3. VCI changes of July-June growing season of 2018, 2019, 2020, and 2021

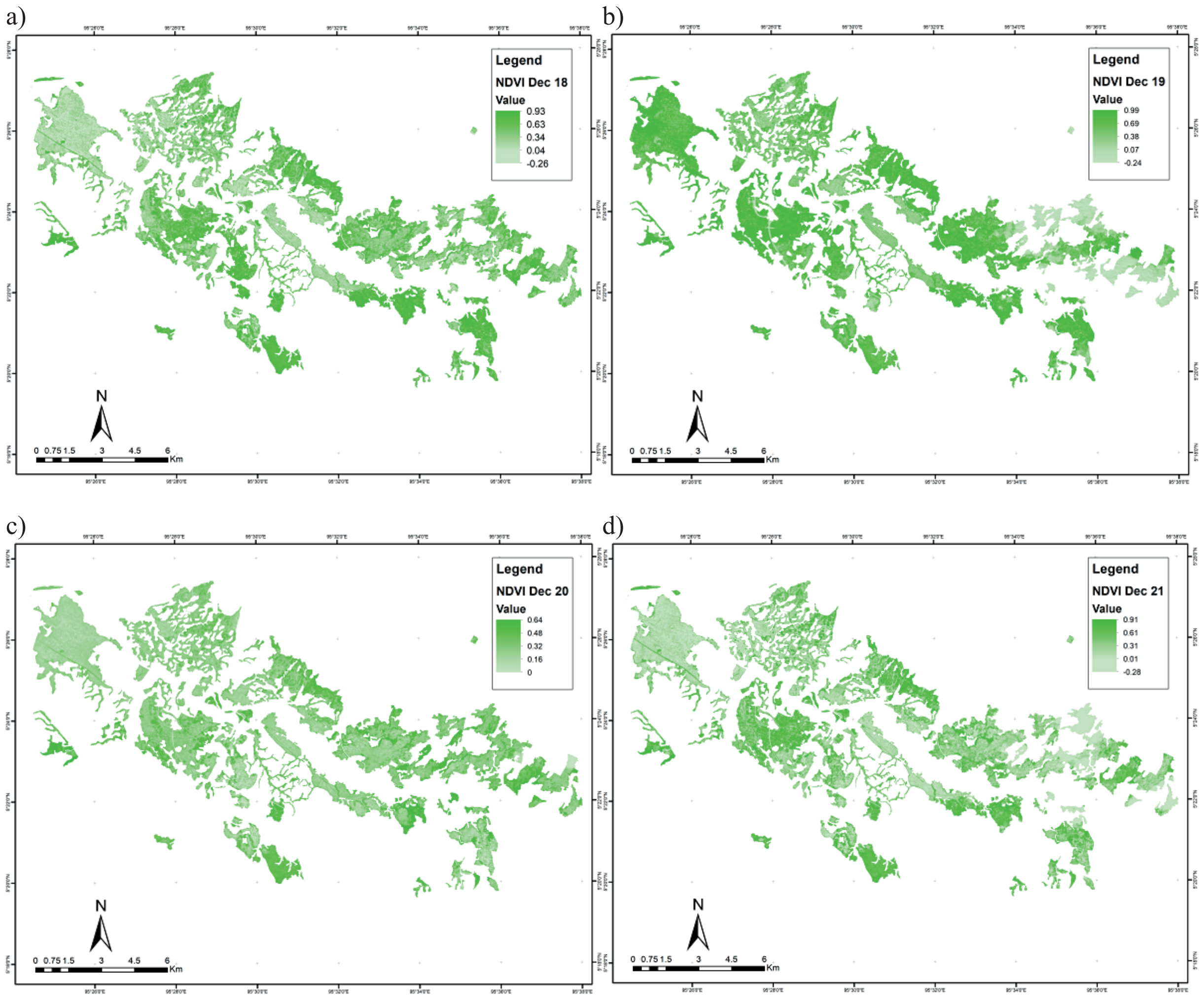

Figure 4. Spatial variations of temporal NDVI in the study area in the December growing season (a) 2018, (b) 2019, (c) 2021, (d) 2022

in the north-west of high value NDVI. Similarly, the 2021 data also show the same pattern of high NDVI value.

Even though there is a low correlation between the data observed between 2018 and 2021 (Figure 3) as considered dry season, the vegetation health index can be distributed spatially in the study area from the lowest on July 2021 with the value NVDI of approximate 0.67 and the highest NDVI value in July 2018 of approximately 0.95. This figure indicates that in July data, the health of vegetation index is still high, confirming that healthy paddy rice conditions still dominate the area. A similar result has been demonstrated by a study on the phenology of paddy rice in the area (Sugianto et al., 2020) and also similar studies in another part of Indonesia during the dry and wet season using the enhanced vegetation index (EVI), normalized difference vegetation index (NDVI), land surface water index (LSWI) and normalized difference water index (NDWI) of MODIS data series (Sari et al., 2010), showing variation growth stage during the dry season.

Figure 4 shows the spatial distribution of NDVI value of multitemporal data from December 2018 until 2022. December is considered a wet growing season. Figure 4 reflects the spatial distribution of NDVI values for different years from 2018 until 2022.

Similarly to the July data, there is a low correlation between the data observed between 2018 and 2021 (Figure 5). As the wet season is considered, the vegetation health index can be distributed spatially in the study area from the lowest on December 2020 with an NVDI of approximately 0.64 and the highest NDVI value in December 2019, approximately 1.0. This figure indicates that the shift of VCI in December data to observe the health of vegetation is high, confirming that healthy paddy rice conditions dominated the area.

Figure 5 shows that the NDVI value decreases during the observation period. Without a rice planting calendar at the test site, drought monitoring using NDVI alone as a critical parameter is not enough to evaluate the drought levels on a regional scale.

VCI value index distribution

The VCI value was obtained from the sentinal-2 imagery analysis of 5-multitemporal images data. It is acknowledged from the previous study that dry soils are usually visualized with low VCI. The 5-multitemporal images of the paddy rice field of the study area are depicted in Figure 6. Figure 6 shows that the VCI increased significantly from July 2019 to July 2021, but decreased slightly in June 2022. In general, dry conditions have high VCI and low NDVI. VCI spatial variations of July and December 2018, July and December 2019, July and December 2020, July and December 2021, and June 2022 from presented in Figures 6 and 7.

Figures 6 and 7 demonstrate the spatial distribution of VCI for different years of observation. The 2022 data is dominated by extreme and severe drought. Similarly, for 2018 and 2020, the data are dominated by severe drought. However, for 2019 and 2021, the data show mild and no drought spatially in the study area. As drought is considered a common phenomenon in agriculture, knowing the drought is essential for evaluating the growing season shift to reduce the potential loss of paddy rice production in the study area.

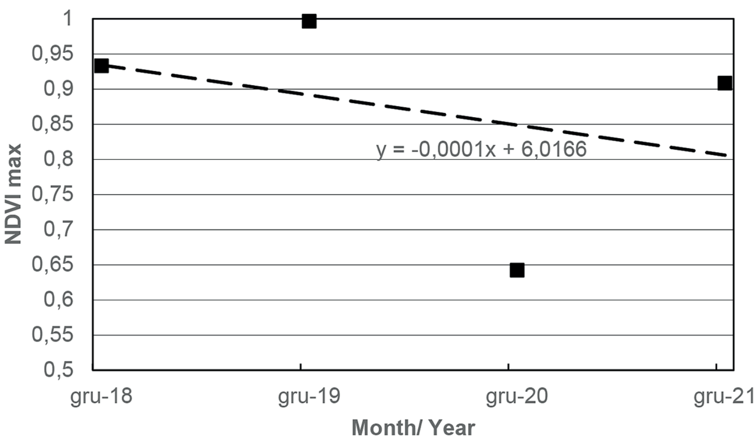

Figure 5. VCI Shift for December data of the study area

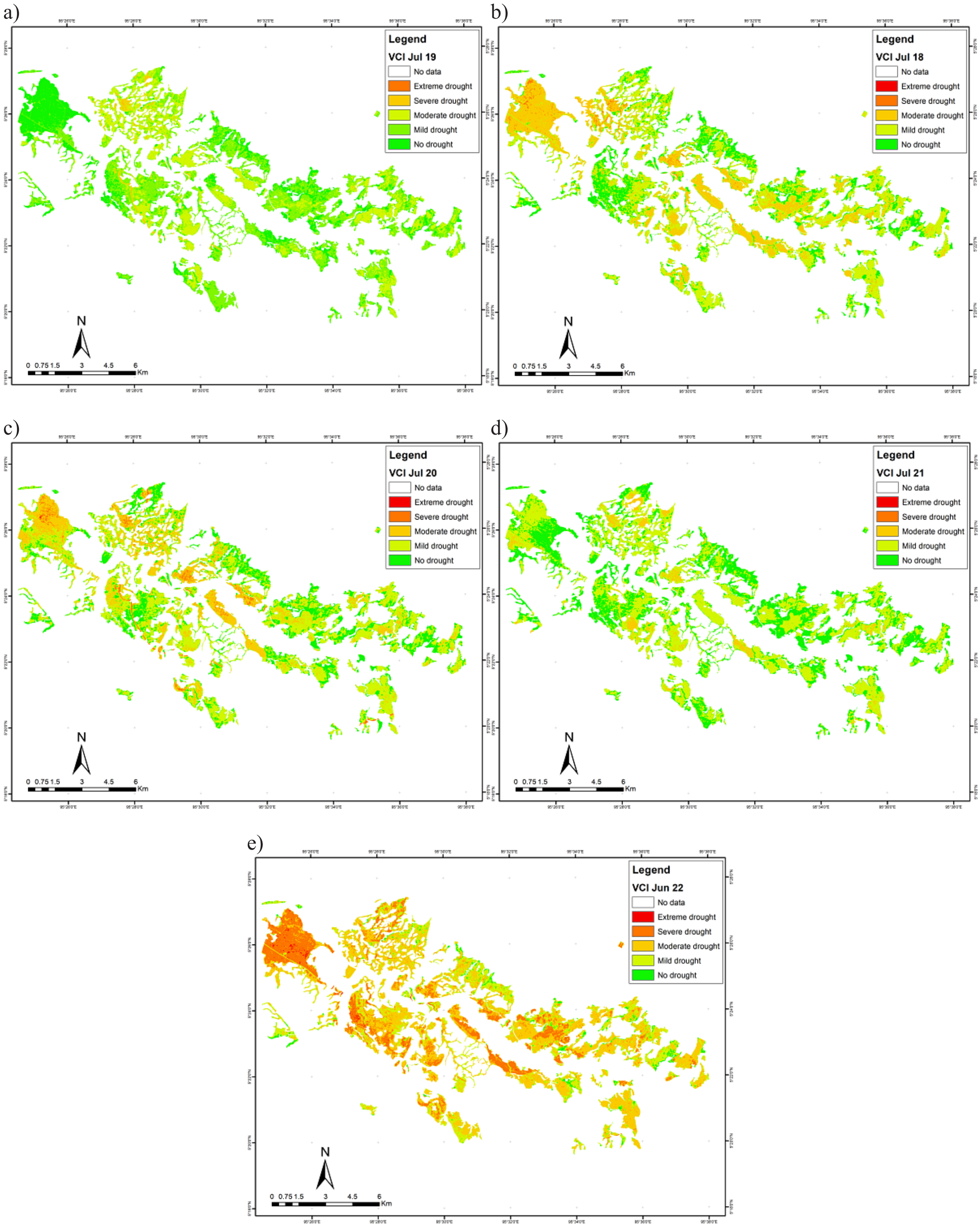

Figure 6. Spatial variations of temporal VCI in the study area in the July/June growing season (a) 2018, (b) 2019, (c) 2020, (d) 2021, (e) 2022 data

Figures 8 and 9 show that drought in the study area increased from December 2018 to December 2021. The drought rate from 2018 to 2021 increased significantly.

Figure 10 shows that extreme drought in November 2021 is eminent, even though other dates are not showing significantly, but it can represent that extreme drought happens in small areas. Severe drought was shown as well, with the total area approximately 32 hectares in November 2021, then increased total area to moderate drought and mild accounting for the highest in November

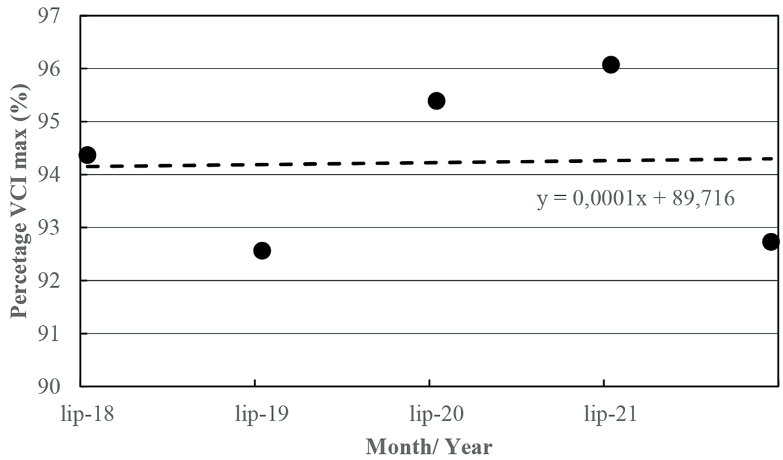

Figure 7. VCI Shift for the period July 2018 to July 2021

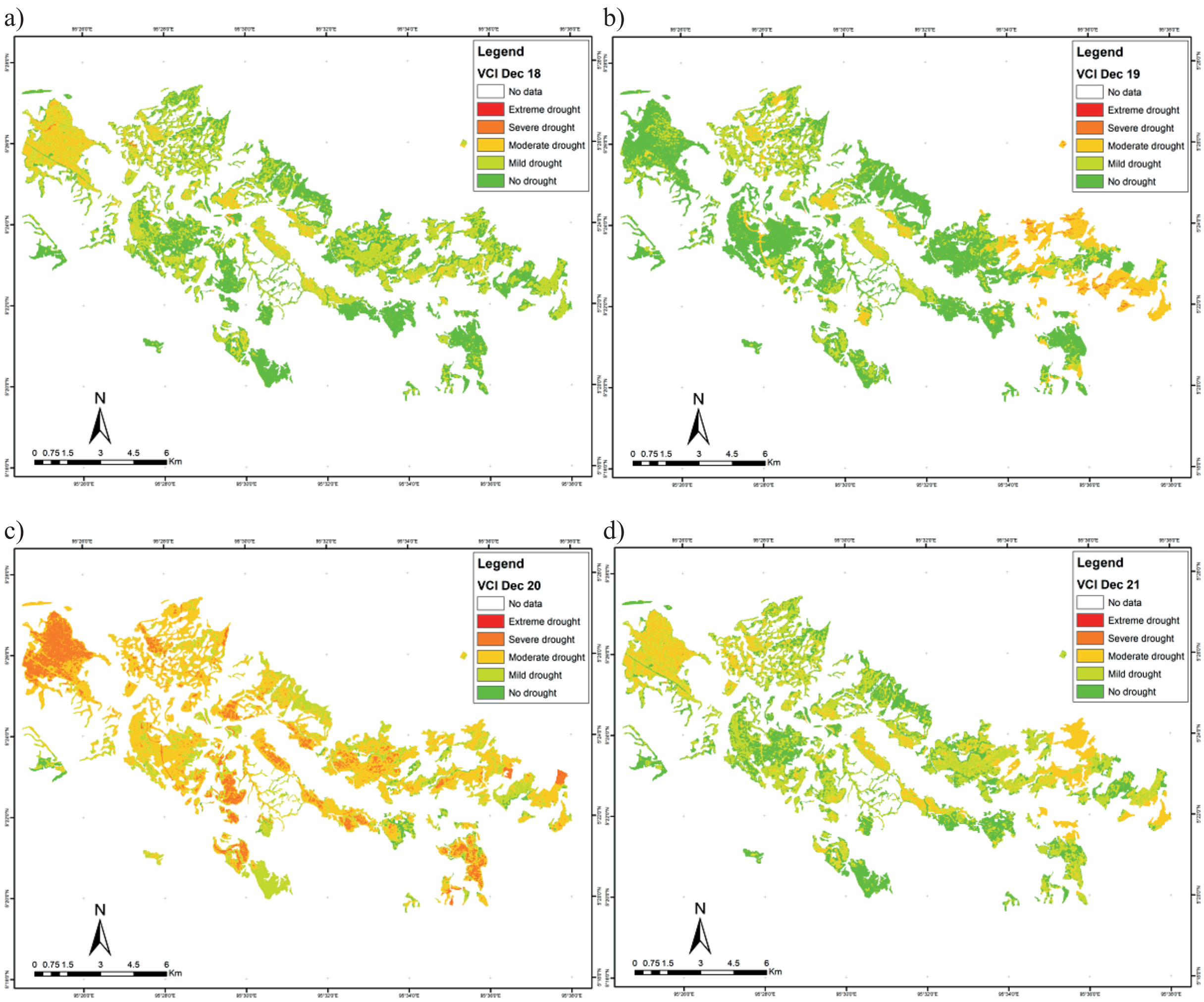

Figure 8. Spatial variations of multi-temporal VCI value of the study area in December

for 360 hectares and 1200 hectares, respectively. However, no drought is still dominant, accounting for an average of 8000 hectares from July to August 2020, then dropping to 6800 in January 2021, then increasing from June till November 2021. In April 2021, it also showed a decreased area with no drought. Table 2 shows the variation of the distribution of total area based on the class draught from extreme to no drought for 2018 until 2022 growing season; dry season (June-July) and wet season in December. Other research in Indonesia found that from 1992 to 2016 drought

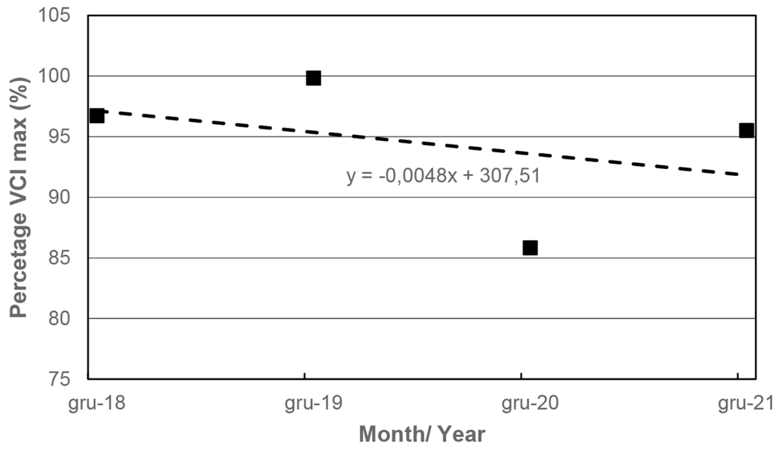

Figure 9. VCI shift in December growing season

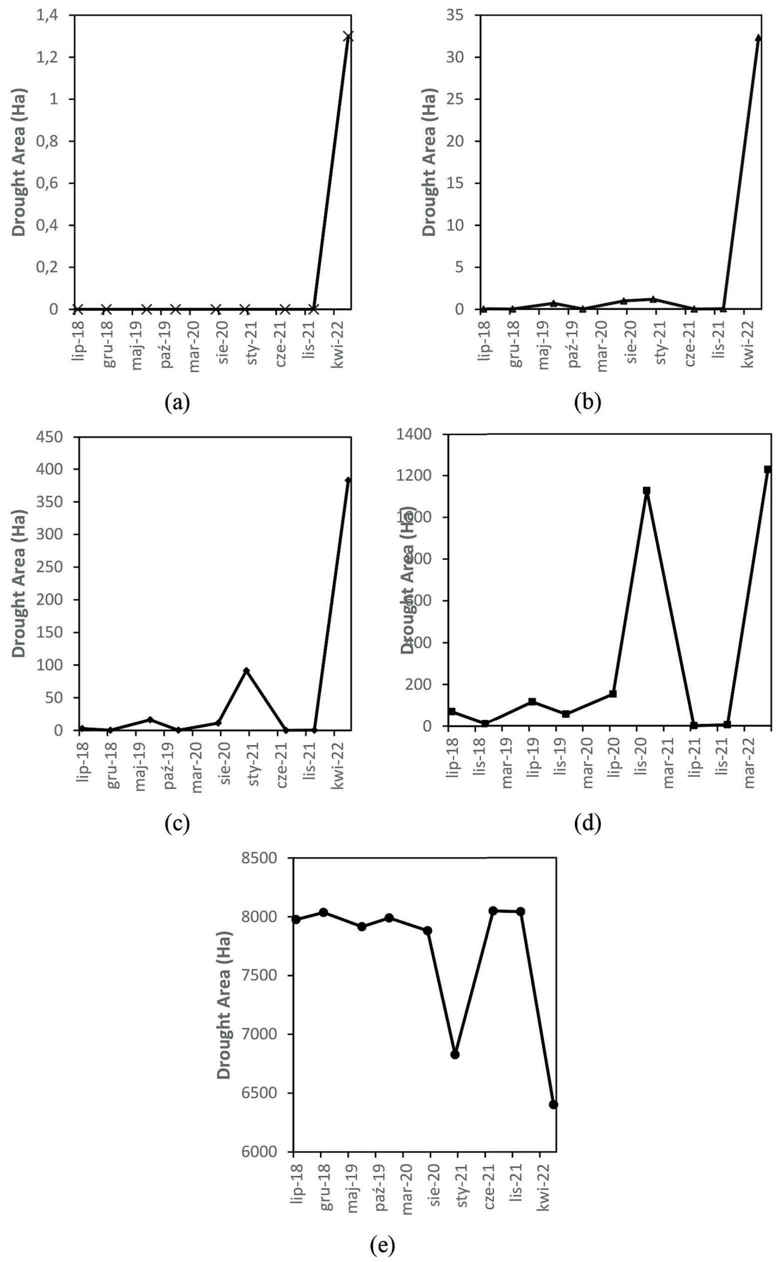

Figure 10. Different levels of VCI value represent the drought level of the rice field of the study area: (a) extreme, (b) severe, (c) moderate, (d) mild, (e) no drought

Table 2. The area of rice fields affected by drought in the different growing seasons

Drought Level	Jul-18	Dec-18	Jul-19	Dec-19	Jul-20	Dec-20	Jul-21	Dec-21	Jun-22
Extreme	-	-	-	-	-	-	-	-	1.3
Severe	0.04	-	0.67	-	0.96	1.15	-	0.04	32.34
Moderate	2.81	0.08	16.33	0.38	11.08	91.24	-	0.07	382.77
Mild	69.45	10.62	116.46	57.77	154.5	1128.11	0.02	4.18	1229.9
No drought	7975.14	8036.28	7914.38	7989.66	7881.29	6827.52	8047.93	8041.68	6400.92

was also experienced in Timor Island (Sabuna et al., 2022), and in Indonesia in general, despite the rainy season (Ferijal et al., 2021).

The distribution of drought from 2018 data until 2022 data indicated that only a tiny area in June 2022 had an extreme drought; the rest of the data investigated no extreme drought. Only a tiny area experienced severe drought in July 2019, July 2020, December 2021, and June 2022. Almost all dates investigated in the study area experienced moderate drought, with the highest in June 2022. The rest of the areas are experiencing mild drought. However, most of the areas on the dates investigated found no drought was still dominant.

Interestingly, the designated dates of data analyzed found that June 2022 data tend to be distributed to the drought in the extreme, severe, moderate, and mild increased compared to the previous data investigated. It was assumed that due to climate change, June 2022 will start with extreme weather. Further investigation will be conducted for the incoming year to see the trend of drought occurrence in the area.

The result of this study shows that during the dry season little or no extreme drought occurred in the paddy rice production center in the region. However, this finding may contribute to an early warning system of drought as part of the food security initiative (Shams Esfandabadi et al., 2022). Even though using Sentinel-2 data, which has 10-m bands, likely causes a severe salt-and-pepper effect (Xiao et al., 2021), this study has shown the promising result of vulnerability assessments of paddy rice field assessment of agricultural drought. Vulnerability assessment in the region for paddy rice fields is a crucial component of drought risk assessment, as they support the design of mitigation actions to target sectors or more sensitive populations (Wilhite, 2005). Drought is one of the causes of loss of production in agriculture practice (Ray et al., 2018). Moreover, drought occurrence may be avoided if potential drought data are provided an early warning.

CONCLUSIONS

This study has demonstrated the extent of Spatio-temporal analysis of drought for agriculture for paddy rice fields in five years of the growing season in the Indrapuri, Kuta Cot Glie, and Seulimeum Districts, Aceh Besar Regency by utilizing satellite-based remote sensing data. Severe drought was shown in November 2021, which then increased in terms of the total area to moderate drought and mild drought, accounting for the highest in November for 360 hectares and 1200 hectares, respectively. No drought category was still dominant from July to August 2020, dropping in January 2021, then increasing from June to November 2021. In April 2021, it also showed a decreased area with no drought category.

The distribution of drought from 2018 data until 2022 data indicated that only a tiny area in June 2022 had an extreme drought; the rest of the data investigated no extreme drought. Almost all dates investigated in the study area experienced moderate drought, with the highest in June 2022. The rest of the areas are experiencing mild drought. Most of the areas on the dates investigated found that no drought was still dominant. Interestingly, the designated data analyzed found that the June 2022 data tend to be distributed to the drought in extreme, severe, moderate, and mild increases compared to the previous data investigated. The index used in this study has successfully proven to identify the degree of the agriculture drought in the paddy rice production centers. This result can explain the drought severity in the study area by analyzing suitable vegetation. The results of VCI estimates can contribute to monitoring the occurrence of agricultural drought as an early warning system.

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REFERENCES

1. Accorsi, R., Manzini, R. (Eds.). 2019. Sustainable Food Supply Chains : Planning, Design, and Control through Interdisciplinary Methodologies, 1st ed. Academic Press, Bologna, Italy.
2. Akinyemi, F.O. 2021. Vegetation Trends, Drought Severity and Land Use-Land Cover Change during the Growing Season in Semi-Arid Contexts. Remote Sens, 13. https://doi.org/https://doi.org/10.3390/rs13050836
3. Bageshree, K., Abhishek, Kinouchi, T. 2022. A Multivariate Drought Index for Seasonal Agriculture Drought Classification in Semiarid Regions. Remote Sens, 14, 3891. https://doi.org/10.3390/rs14163891
4. Ferijal, T., Batelaan, O., Shanafield, M. 2021. Spatial and temporal variation in rainy season droughts in the Indonesian Maritime Continent. J Hydrol, 603, 126999. https://doi.org/10.1016/j.jhydrol.2021.126999
5. Gitz, V., Meybeck, A., Lipper, L., Young, C., Braatz, S. 2016. Climate change and food security: Risks and responses, Food and Agriculture Organization of the United Nations. https://doi.org/10.1080/14767058.2017.1347921
6. Gómez-Mendoza, L., Galicia., L., Cuevas-Fernández, M.L., Magaña, V., Gómez, G., Palacio-Prieto, J.L. 2008. Assessing onset and length of greening period in six vegetation types in Oaxaca, Mexico, using NDVI-precipitation relationships. Int J Bio, 52, 511–520. https://doi.org/10.1007/s00484-008-0147-6
7. Guo, M., Li, J., Wang, Y., Long, Q., Bai, P. 2019. Spatiotemporal variations of meteorological droughts and the assessments of agricultural drought risk in a typical agricultural province of China. Atmosphere (Basel), 10, 1–16. https://doi.org/10.3390/atmos10090542
8. Huang, J., Zhuo, W., Li, Y., Huang, R., Sedano, F., Su, W., Dong, J., Tian, L., Huang, Y., Zhu, D., Zhang, X. 2018. Comparison of three remotely sensed drought indices for assessing the impact of drought on winter wheat yield Comparison of three remotely sensed drought indices for assessing the impact of drought on winter wheat yield. Int J Digit Earth, 0, 1–23. https://doi.org/10.1080/17538947.2018.1542040
9. Indonesia, C. 2021. 800 Hektare Sawah di Aceh Besar Dilanda Kekeringan [WWW Document]. CNN Indones. URL https://www.cnnindonesia.com/nasional/20210227211900-20-611748/800-hektare-sawah-di-aceh-besar-dilanda-kekeringan (accessed 8.20.22).
10. Kogan, F.N. 1997. Global Drought Watch from Space. Bull Am Meteorol Soc 78, 621–636. https://doi.org/10.1175/1520-0477(1997)078<0621:GDWFS>2.0.CO;2
11. Kogan, F.N. 1995. Application of vegetation index and brightness temperature for drought detection. Adv Sp Res, 15, 91–100. https://doi.org/10.1016/0273-1177(95)00079-T
12. Lee, S., Kim, N., Lee, Y. 2021. Development of Integrated Crop Drought Index by Combining Rainfall, Land Surface Temperature, Evapotranspiration, Drought Monitoring. Remote Sens. https://doi.org/https://doi.org/10.3390/rs13091778
13. Liu, W.T., Kogan, F.N. 1996. Monitoring regional drought using the Vegetation Condition Index. Int J Remote Sens, 17, 2761–2782. https://doi.org/10.1080/01431169608949106
14. Louis, J., Gascon, F., Agency, E.S., Niezette, M. 2013. Sentinel-2 Level-2A Prototype Processor : Architecture, Algorithms and First Results SENTINEL-2 LEVEL 2A PROTOTYPE PROCESSOR : ARCHITECTURE, ALGORITHMS, in: ESA Living Planet Symposium 2013.
15. Main-Knorn, M., Pflug, B., Louis, J., Debaecker, V., Müller-Wilm, U., Gascon, F. 2017. Sen2Cor for Sentinel-2, in: Bruzzone, L., Bovolo, F., Benediktsson, J.A. (Eds.), Image and Signal Processing for Remote Sensing XXIII. SPIE, 3. https://doi.org/10.1117/12.2278218
16. Mueller-Wilm, U. 2019. S2 MPC, Sen2Cor Software Release Note.
17. Olii, M.R., Olii, A., Pakaya, R. 2022. Analysis of Spatial Distribution of the Drought Hazard Index (DHI) by Integration AHP-GIS-Remote Sensing in Gorontalo Regency. J Civ Eng Forum 8, 81–96. https://doi.org/10.22146/jcef.3595
18. Ray, R.L., Fares, A., Risch, E. 2018. Effects of Drought on Crop Production and Cropping Areas in Texas. Agric Environ Lett, 3, 170037. https://doi.org/10.2134/ael2017.11.0037
19. Sabuna, F.H., Hidayati, R., Santikayasa, I.P., Taufik, M. 2022. Drought Events in Western Part of Timor Island Indonesia, 36, 11–20. https://doi.org/10.29244/j.agromet.36.1.11-20
20. Sari, D.K., Ismullah, I.H., Sulasdi, W.N., Harto, A.B. 2010. Detecting rice phenology in paddy fields with complex cropping pattern using time series MODIS data: A case study of northern part of West Java-Indonesia. ITB J Sci, 42A, 91–106. https://doi.org/10.5614/itbj.sci.2010.42.2.2
21. Shams Esfandabadi, H., Ghamary Asl, M., Shams Esfandabadi, Z., Gautam, S., Ranjbari, M. 2022. Drought assessment in paddy rice fields using remote sensing technology towards achieving food security and SDG2. Br Food J ahead-of-p. https://doi.org/10.1108/BFJ-08-2021-0872
22. Sholihah, R.I., Trisasongko, B.H., Shiddiq, D., Iman, L.O.S., Kusdaryanto, S., Panuju, D.R. 2016. Identification of Agricultural Drought Extent Based on Vegetation Health Indices of Landsat Data : Case

of Subang and Karawang, Indonesia Identification of agricultural drought extent based on vegetation health indices of Landsat data : case of Subang an. Procedia Environ Sci, 13–20. https://doi.org/10.1016/j.proenv.2016.03.051

23. Sugianto, S., Adinda, R., Rusdi, M., Basri, H., Syakur, Iqbal, M. 2020. Rice crop phenology analysis during rendeng season using remote sensing data: An EVI-2 ratio approach of Aceh Besar regency rice field, in: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing. https://doi.org/10.1088/1755-1315/425/1/012017
24. Surmaini, E., Hadi, T.W., Subagyono, K. 2015. Early detection of drought impact on rice paddies in Indonesia by means of Niño 3. 4 index. Theor Appl Climatol, 21, 669–684. https://doi.org/10.1007/s00704-014-1258-0
25. Syahrial, A., Azmeri, Meilianda, E. 2017. Analisis Kekeringan Menggunakan Metode Theory of Run di DAS Krueng Aceh. J Tek Sipil, 24, 167–172. https://doi.org/10.5614/jts.2017.24.2.8
26. Walter-shea, E. 2002. Drought monitoring with NDVI-based Standardized Vegetation Index. Photogrametric Engeneringnering Remote Sens.
27. Wilhite, D.A. (Ed.). 2005. Drought and Water Crises, 1st ed. CRC Press, Boca Raton. https://doi.org/https://doi.org/10.1201/9781420028386
28. Xiao, W., Xu, S., He, T. 2021. Object-Based Algorithm – A Implementation in Hangjiahu Plain in China Using GEE Platform. Remote Sens, 13, 1–20.