Agricultural Land Dryness Distribution Using the Normalized Difference Drought Index (NDDI) Algorithm on Landsat 8 Imagery in Eromoko, Indonesia

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ARTICLE INFO

Received: 28 Apr 2022
Received in revised: 22 Sep 2022
Accepted: 26 Sep 2022
Published online: 30 Jan 2023
DOI: 10.32526/ennrj/21/202200157

Keywords:
Estimation model/ Land drought category/ Soil evaporation/ Soil moisture

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ABSTRACT

The study area, Eromoko, has agricultural land covering 79.76% of the area, which experiences drought every year, causing a decrease in crop yields. Information on agricultural land dryness is needed to reduce the impact of dryness conditions on the agricultural sector. The effect of drought can be minimized using the transformation of the Normalized Difference Drought Index (NDDI) algorithm on Landsat 8 Imagery because it is considered capable of being used for land drought analysis that is accurate and efficient in time and cost. This study created a model for estimating soil moisture with actual soil moisture as the dependent variable and NDDI as the independent variable in several agricultural land uses in Eromoko. The results showed that the estimation model could estimate soil moisture with accuracy in plantations at 85.31%, irrigated paddy fields at 75.99%, rainfed paddy fields at 76.62%, and moors at 88.48%. The dryness category in the study area is 3,314.82 ha (35% of the total area). The variability of land use greatly affects the drying conditions. Dryness conditions can be reduced by controlling the dryness factors. Mitigation efforts to maintain soil moisture include irrigation planning based on the estimation model, applying bio-mulch and organic mulch, organic fertilization, and meeting water requirements in the harvesting period.

1. INTRODUCTION

Drought causes insufficient soil moisture for plant needs due to a lack of long-term rainfall (Liu et al., 2021). Drought in Indonesia is related to the El-Nino Southern Oscillation (ENSO) phenomenon, where rainfall has decreased sharply compared to normal conditions during the dry season. Central Java Province is one of the regions in Indonesia that is affected by the ENSO phenomenon. The impact is a decrease in rainfall in September-October-November (Hidayat et al., 2018), and drought may become a major disaster in areas with low rainfall intensity (Wild, 1993).

Drought is characterized by a water shortage for domestic and agricultural use, affecting soil moisture content and watersheds (Orimoloye et al., 2020). Dry agricultural land is limited by high soil particle cohesion due to low groundwater potential, which inhibits plant root growth. This condition causes plant growth to be disrupted and results in low crop productivity. Drought causes a decrease in paddy yields by up to 68% (Polthanee and Promkhambut, 2014). The dry season in Wonogiri Regency causes paddy production to decrease and the area of fallow land to increase (Central Bureau of Statistics of Wonogiri Regency, 2020). Corn yields in rainfed land have reduced due to drought (Popova et al., 2014), and teak crops are affected because of the decreasing trunk diameter and height, and wood quality with irregular stem shape (Eliyani et al., 2005).

Agricultural land in Eromoko District dominates the area, as much as 79.76% of the total area, so most of the population's livelihood is in farming. In the dry season, drought is the main problem because of the low rainfall creating drought and decreasing food production yields to crop failure (Ignatius, 2013). Eromoko is located in the Wonosari geological formation. It has a limestone parent rock

Citation: Mujiyo, Nurdianti R, Komariah, Sutarno. Agricultural land dryness distribution using the normalized difference drought index (NDDI) algorithm on Landsat 8 imagery in Eromoko, Indonesia. Environ. Nat. Resour. J. 2023;21(2):127-139. (https://doi.org/10.32526/ennrj/21/202200157)

(Bronto et al., 2009) with limestone parent material that has soil problems in water availability (Finch et al., 2014) because of a shortage of water in the root layer soil due to the water movement into the soil (Maulana, 2019).

Drought disasters due to low rainfall directly correlate with unavoidable global CO_2 emissions (Benti and Abara, 2019), but the impact on agriculture can be minimized by monitoring to obtain information on the latest land drought conditions. The method by the National Agency for Disaster Countermeasure, and Indonesian Agency for Meteorological, Climatological, and Geophysics, is based on regional rainfall data (National Disaster Management Coordinating Board, 2007). The observation data of climate stations do not have a sustainable spatial range to obtain spatial characters and patterns of dry conditions (Gu et al., 2007). The use of variables from remote sensing can provide more comprehensive information on drought conditions. Remote sensing data is needed to monitor and evaluate agricultural land's drought conditions. Using remote sensing data in the form of Landsat 8 images can be one solution for the drought monitoring method because of its high spatial and temporal resolution and also efficient use of time and cost (Hazaymeh and Hassan, 2017). Landsat 8 imagery has a spatial resolution of 30 meters and a temporal resolution of 16 days (USGS, 2008), so it can be used to assess agricultural land dryness. The results of the Normalized Difference Drought Index (NDDI) transformation into a drought index are used to provide information on the dryness of agricultural land. This index is used because it is the result of calculations from the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) transformations so that it has a higher sensitivity level to drought (Dobri et al., 2021).

This study aimed to identify dry conditions with a soil moisture estimation model, and find the factors of land characteristics and soil conditions that determine dry conditions, so that they can provide recommendations regarding appropriate mitigation efforts in the agricultural area of Eromoko District, Wonogiri Regency, Indonesia. Variables of soil moisture content (pF 2.5 and 4.2) and NDDI were used in simple regression analysis to obtain a model for soil moisture estimation. This estimation model is then used to obtain a dry category on agricultural land and also used to determine the area that requires additional irrigation water and the required volume of water.

2. METHODOLOGY

2.1 Study area

The study was conducted on agricultural land consisting of a plantation, irrigated paddy fields, rainfed paddy fields, and a moor in Eromoko District, Wonogiri Regency, Indonesia. The study area was located at coordinates 110°45'38,814" - 110°53'39,955" E and 7°53'41,425" - 8°1'52,644" S (Figure 1). Eromoko has an agricultural land area of 9,600 ha (79.76% of the Eromoko area) (Central Java Geoportal, 2019). The plantation has dominant plants of teak, acacia, and mahogany. The irrigated paddy fields are used for paddy and maize cultivation in the dry season. Some rainfed paddy fields and the moor have springs and pump wells are used for seasonal crop cultivation. Rainfed paddy fields are used for tobacco and bulrush, while the moor is used for cassava and bulrush.

Geologically, the study area is located in the Wonosari Formation and has limestone parent rocks (Bronto et al., 2009). Soil types at the research site are Alfisol and Inceptisol. The topography is in the form of various slopes with a range of 2% up to 40%. Eromoko District is a dry land with an annual rainfall of 1,600 up to 1,800 mm/year, classified as low-intensity rainfall. The lowest daily temperature in a year is 18.5ºC, and the highest is 37ºC (Research Agency for Solo Watershed Area, 2020).

2.2 Land observation and sampling method

The study approaches remote sensing data used, field surveys, laboratory analysis, and statistical data analysis. The variables observed in this study were the NDDI, soil moisture content, soil water retention (pF 2.5 and 4.2), and agricultural land characteristics in Eromoko District. The variability of land characteristics provided an image of Landsat 8 by radiometric and geometric corrections (Burapapol and Nagasawa, 2016). The working map is based on an overlay of land use, soil types, slopes, and rainfall map (Figure 2), and the result is named a land unit. The selection of sample points based on the similarity of land units assumes that it has similar land characteristics.

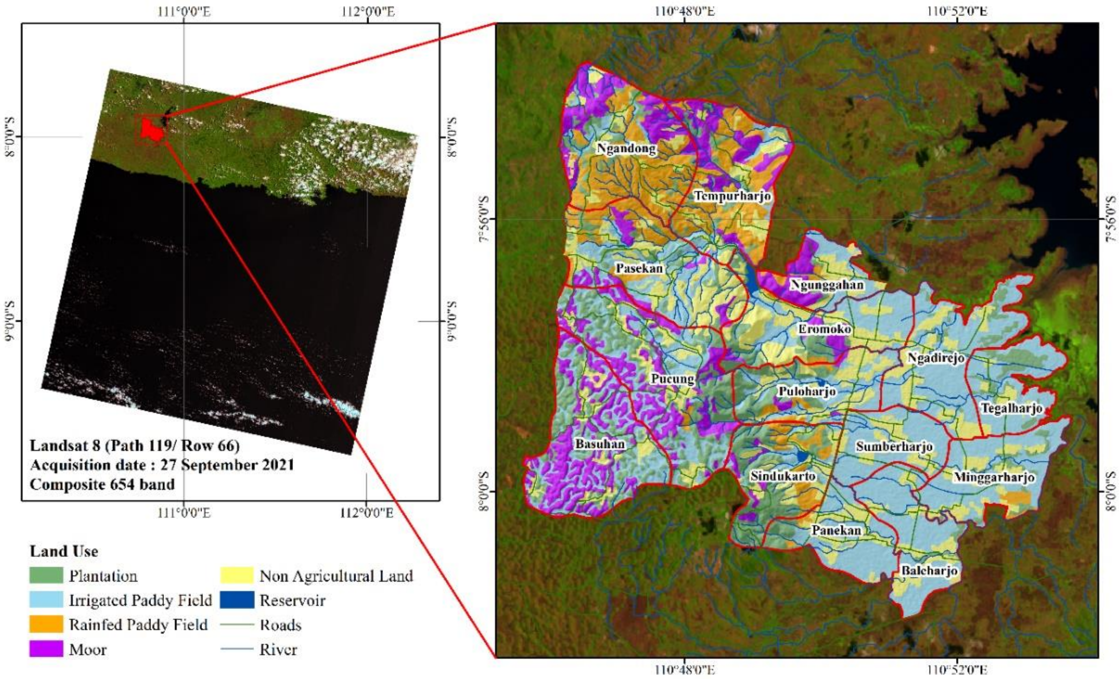

Figure 1. Study area location

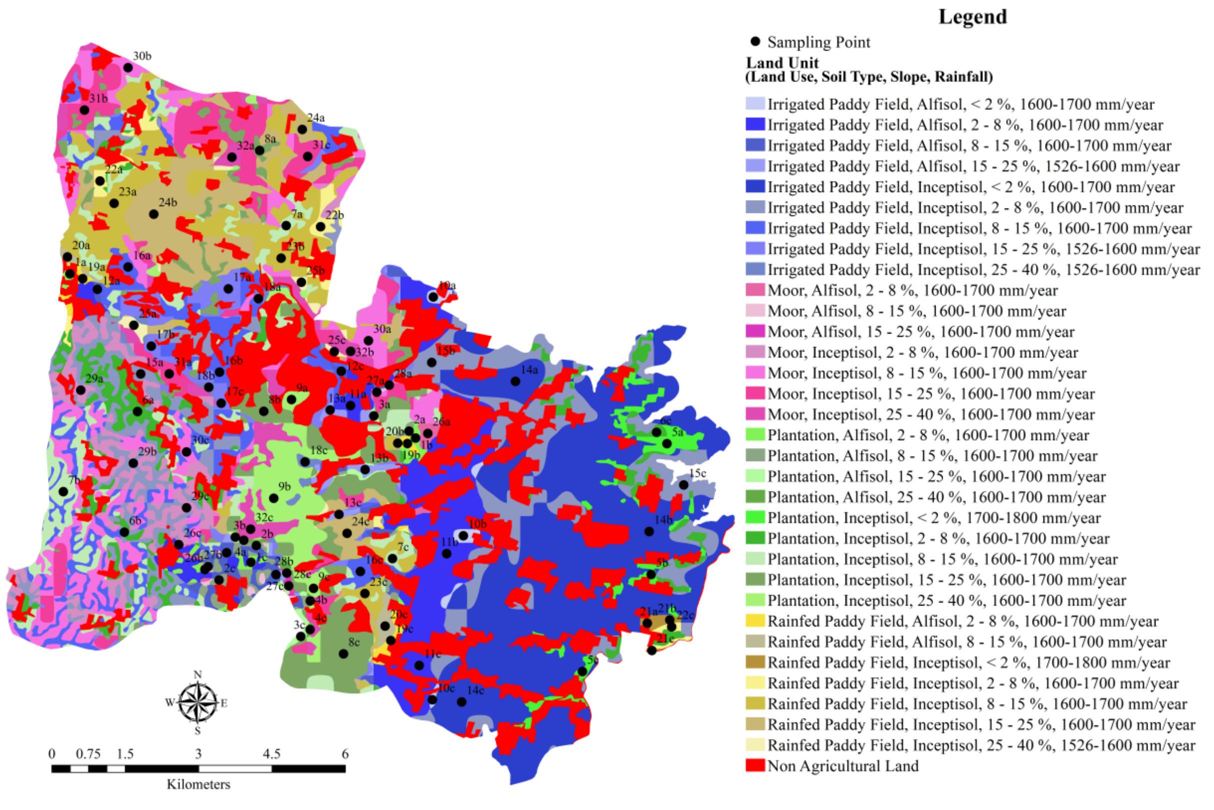

Figure 2. Land unit of study area

Sample points are determined by using the purposive random sampling technique. Based on the land characteristics map results, the agricultural land in Eromoko District is divided into 32 land units, each repeated three times. Hence, the total is 96 sample points. Soil samples were collected by a ring sampler with a diameter of 7.63 to 7.93 cm at each observation point. The type of sample is an undisturbed sample. Soil samples were then used to analyze actual soil moisture content, soil moisture content at pF 2.5 (field capacity), and soil moisture content at pF 4.2 (permanent wilting point).

2.3 Laboratory analysis

Soil parameters that needed laboratory analysis were actual soil moisture (using the gravimetric method) and soil water retention (using the pressure plate apparatus method). The principle of the gravimetric method is the measurement of water loss based on the weight of the soil sample before and after being dried at a temperature of 110ºC in an oven (Adimihardja et al., 2006). The principle of the pressure plate apparatus method is applying pressure which is equal to the ability of the soil to pass water naturally, providing water for plants, and the moisture content of the soil where plants are unable to absorb water. Applying pressure to the saturated soil sample at an interval of 48 h until it reaches the given equilibrium point determines the moisture content (Sudirman et al., 2006).

2.4 Satellite image processing

Remote sensing data used in this study are Landsat 8 imagery red channel (band 4), near-infrared (band 5), and short-wave infrared (band 6). The satellite image recording time was on September 27th in, 2021. Processing of satellite image data was done in several steps:

2.4.1 Pre-processing

(1) Radiometric correction

Satellite image used for index processing went through radiometric correction. This stage aims to improve image quality which is influenced by the position of the sun and the atmosphere when recording. The study area has varied topography so radiometric correction is necessary (Fawzi and Husna, 2021) to change the digital number value to the reflectance value (Muchsin et al., 2022).

(2) Study area cropping

Image cropping aims to narrow the work area so the processing process can focus on the research area. The radiometrically corrected image is then cropped based on the research area's map of agricultural land use.

2.4.2 Processing

The algorithm used is a combination of the NDVI (greenness of vegetation) and NDWI (vegetation wetness). The NDDI algorithm is considered more accurate in detecting drought on agricultural land than using the NDVI or NDWI algorithms separately (Dobri et al., 2021). The NDDI transformation formula (Gu et al., 2007) is:

$$\text{NDDI} = \frac{(\text{NDVI} - \text{NDWI})}{(\text{NDVI} + \text{NDWI})}$$

Where: NDVI=(Band 5 - Band 4)/(Band 5 + Band 4); NDVI=(Band 5 - Band 6)/(Band 5 + Band 6); Low NDVI and NDWI values will result in high NDDI values, meaning that the area is experiencing drought. The higher the NDDI value produced, the drier an area is.

2.5 Drought distribution

The dryness distribution on agricultural land in the study area was obtained from data on actual soil moisture content, soil moisture retention (pF 2.5 and 4.2), and soil moisture content estimation model resulting from NDDI transformation on Landsat 8 imagery. Each parameter is described as follows:

2.5.1 Soil moisture estimation model and its accuracy

Linear regression analysis is used to obtain an estimation model of soil moisture. The soil moisture data was used as the dependent variable, and the NDDI value as the independent variable. The soil moisture estimation model produces estimated soil moisture data. The estimation model accuracy test is carried out to see how accurate the model is. The accuracy test was performed using standard deviation calculation, standard error estimate (SE), minimum % error, maximum % error, minimum accuracy, and maximum accuracy (Akbari and Jatmiko, 2016).

2.5.2 Agricultural land drought spatial distribution

The dryness category of agricultural land was obtained by overlaying estimated moisture content and soil water retention data (pF 2.5 and 4.2). The dryness category is classified according to Table 1 (Adimihardja et al., 2006).

Table 1. Dryness category

Category	Description
Dry	Soil moisture < pF 4.2
Moist	Soil moisture pF 4.2 < actual soil moisture < soil moisture pF 2.5
Wet	Soil moisture actual > soil moisture pF 2.5

2.6 Dryness determinant factor

The dryness determinant factor describes the effect of land use variability (as land characteristics) on the dryness category. The dryness determinant factor was carried out by Analysis of Variance (ANOVA) and continued by DMRT to find the difference of dryness condition between several land uses, and considered as dryness factor.

3. RESULTS AND DISCUSSION

3.1 NDDI transformation on Landsat 8 imagery

Atmospheric factors strongly influence the recorded image data, so radiometric corrections are made to change the pixel value into the unit value of radiation energy received by the sensor. The radiometric correction process converts the digital number to reflectance value. The difference between the image before and after radiometric correction is seen based on the range of raster values before and after correction (Figure 3).

Original image data has a digital number value with a value range of thousands. The image data result of the radiometric correction has a reflectance value with a unit value. The digital number range value in band 6 is 5247 up to 41942. In band 5 it is 5635 up to 57789, and in band 4 it is 6237 up to 54771. The results of radiometric correction produced a range of reflectance in band 6 of 0.0057 up to 1, in band 5 of 0.0147 up to 1, and in band 4 of 0.028 up to 1 (Figure 3). Landsat 8 imagery that is used in index transformation needs to go through radiometric correction (Fawzi and Husna, 2021). Agricultural land dryness assessment through remote sensing is based on the greenness and wetness of vegetation through the use of a vegetation index which can then be developed into a drought index or determining dryness of area (Renza et al., 2010). Meteorological monitoring and prediction of drought are monitored through weather data from meteorological stations. The NDDI transformation combines the data obtained from NDVI and NDWI in a broader and more accurate range of transformation values with a difference of up to 5%. Through radiation absorption, NDVI measures the chlorophyll and mesophyll content of the vegetation canopy. In contrast, NDWI measures the humidity of the vegetation canopy based on the results of the moisture content and mesophyll content of the vegetation canopy spots. In the NDVI and NDWI transformations, the higher the resulting value, the higher the density and wetness of the vegetation in the area. Whereas in the NDDI transformation, the higher value indicates the drier an area.

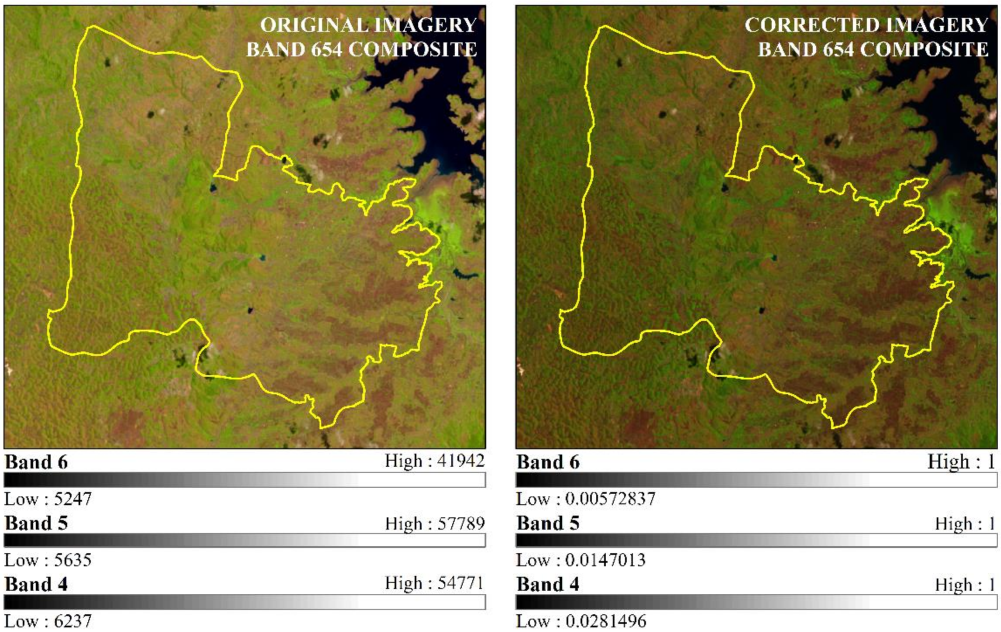

Figure 3. Radiometric correction

Based on the results of the index transformation in Figure 4, NDVI has a range of -0.179 up to 0.789 with a mean value of 0.49 and a standard deviation of 0.12. A higher NDVI value (dark green) indicates a greater density and photosynthetic capacity of the vegetation canopy (Gu et al., 2007). The results of the NDWI transformation have a range of -0.212 up to 0.610, with a mean value of 0.10 and a standard deviation of 0.11. A higher NDWI value (dark blue) indicates an area with high vegetation canopy wetness (Gao, 1996). The NDDI transformation combines the values of NDVI and NDWI to produce information on dry areas (dark red). The results of the NDDI transformation have a range of -1 up to 2 with a mean value of 0.76 and a standard deviation of 0.35. Areas that do not experience drought and are not dry areas are indicated by a Z-score <0, while areas experiencing drought are dry areas indicated by a Z-score >0 (Gulácsi and Kovács, 2018). Eromoko's agricultural land that has no dry conditions or did not experience drought was 6,078 ha, while dry conditions occurred in an area of 3,505 ha.

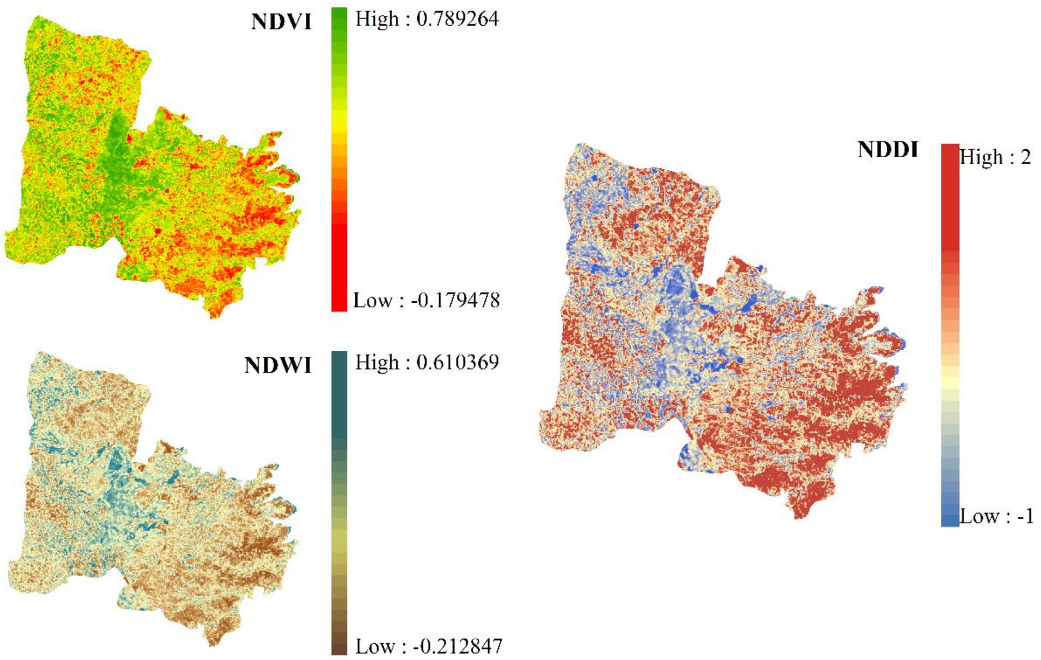

Figure 4. The transformation results

3.2 The distribution of agricultural land drought

This study uses estimated soil moisture data and actual soil moisture at pF 2.54 and 4.20 to determine the dryness category. Estimated soil moisture was obtained from linear regression analysis where actual soil moisture data was used as the dependent variable and NDDI value as an independent variable. Using one parameter without a combination of other parameters or indicator cannot determine condition in multi-scale and multi-impact drought (Hayes et al., 2012). Additional field hydrologic parameter, such as soil moisture, is needed to determine drought properties (Gulácsi and Kovács, 2018).

The condition of the soil moisture content in the study area shows different values for each land use. Moor and plantation land use have no additional moisture content, while irrigation paddy field and rainfed paddy field soil moisture levels are higher than other agricultural land uses. The condition of the actual average moisture content in several agricultural land uses in Eromoko are moor (25.38 %vol), plantation (26.40 %vol), rainfed paddy field (28.88 %vol), and irrigation paddy field (38.25 %vol), so it can be concluded that the condition of agricultural land in the study area has conditions of moderate moisture content and dryness category at dry to moist levels that is affected differently by land use.

In the estimation model of soil moisture content obtained in the study area, it can be predicted that in each increase in NDDI value, the soil moisture in the plantation decreases by 20.275%, in irrigated paddy fields by 28.525%, in rainfed paddy fields by 49.585%, and in moor 17.073% (shown in Table 2). Estimated soil moisture cannot be estimated accurately or is not always the same as the actual soil moisture content. Estimated soil moisture content can approach the actual soil moisture content but is less able to predict soil moisture content with a high value. Estimated soil moisture in the study area has a maximum accuracy to be used on a plantation, irrigated paddy fields, rainfed paddy fields, and moor of 85.31%, 75.99%, 76.62%, and 88.48%, respectively (Table 2). Based on the study results by Burapapol and Nagasawa (2016), the accuracy of the estimated soil moisture model was found to be 76.65% and consistent with actual and estimated soil moisture. The moisture content accuracy model produced in this study ranges from 74.76% up to 88.48% in the dryness category, so it has sufficient value to predict dry conditions for each agricultural land use in the study area. The spatial resolution of Landsat 8 imagery and cloud pixels estimates low groundwater content in an area (Fawzi and Husna, 2021). In addition, there are paddy cultivation activities that are in the ripening phase, where there are paddy panicles and yellowing leaves, so NDDI cannot show detailed results of the paddy condition that is experiencing dry conditions or not (Sukmono, 2018).

Table 2. Accuracy of soil moisture estimation model

Agricultural land	Soil moisture estimation	Standard error	Minimum accuracy (%)	Maximum accuracy (%)
Plantation	-20.275(NDDI) + 39.804	4.02	84.21	85.31
Irrigation paddy field	-28.525(NDDI) + 54.528	9.41	74.76	75.99
Rainfed paddy fields	-49.585(NDDI) + 60.945	6.98	75.03	76.62
Moor	-17.073(NDDI) + 36.640	3.03	87.59	88.48

The distribution map of estimated soil moisture on agricultural land in the Eromoko was made based on the soil moisture estimation model calculation on the results of the NDDI transformation. The darker blue indicates the higher soil moisture in the area, while the darker red on the map shows the lower soil moisture. Figure 5 shows that the dry conditions of the study area are seen from the estimation model results, which show areas with a dominance of low soil moisture content and high NDDI values. The estimated soil moisture using NDDI can indicate dry vegetation Burapapol and Nagasawa (2016).

Estimated soil moisture has a very significant positive correlation with leaf moisture content, so an increase will follow any increase in predicted water content in leaf water content which can be an indication of dry vegetation. Dry conditions and crop water requirements can be identified by determining tissue water status at the organ and canopy to improve the sustainability of food security and water use in agricultural land (Browne et al., 2020). Identification of dry vegetation and remote sensing monitoring with leaf water content could accurately reflect the level of dry plants and predict plant growth and development capabilities (Song et al., 2021). The estimated soil moisture content in this study provides the information that the leaf water content of vegetation in the Eromoko agricultural land mostly has low water content and impacts low crop production.

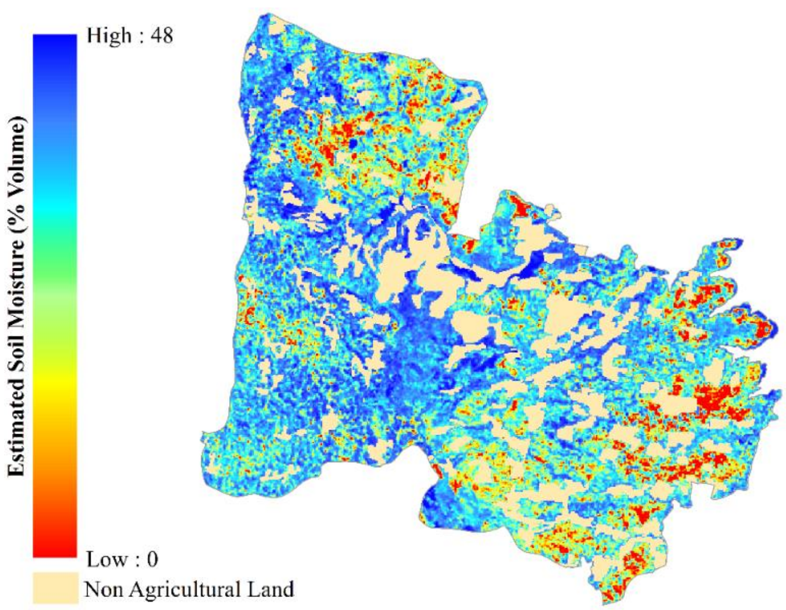

Figure 5. Distribution of estimated soil moisture

The dryness category is determined based on the estimated soil moisture amount toward soil moisture at field capacity (pF 2.54) and permanent wilting point (pF 4.20) amount (Figure 6). Field capacity represents the maximum amount of soil moisture in the soil, and field capacity is a condition of soil moisture that plants cannot uptake because the soil holds the water too tight. The difference between the amount of soil moisture at field capacity and permanent wilting point represents soil moisture availability (Voroney, 2018). Based on Table 1, it can assume that areas with the dry category are experiencing drought in the dry period of the year, and areas with the moist and wet category are not experiencing drought. The overlay of the estimated soil moisture map with soil moisture at pF 2.54 and 4.20 map result is shown in Figure 7. The agricultural land dryness condition is dominated by the moist category of 5,205.20 ha (55.17% of the study area), the dry category of 3,314.82 ha (35.13% of the study area), and the wet category of 915.30 ha (9.70% of the study area) (Figure 7). Each land use has the highest percentage of dryness conditions in the moist category, followed by the dry and wet categories (Table 3).

Land Unit	1	2	3	4	5	6	7	8
$\bar{x}$ pF 2.54 (% Vol)	34.23	38.84	41.83	30.76	33.33	42.25	35.64	41.82
$\bar{x}$ pF 4.2 (% Vol)	27.42	28.82	32.24	18.30	22.13	34.23	22.43	24.62
Land Unit	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
$\bar{x}$ pF 2.54 (% Vol)	35.09	35.64	44.40	47.61	43.09	43.18	36.79	43.09
$\bar{x}$ pF 4.2 (% Vol)	29.57	30.16	26.43	30.38	25.42	32.62	18.74	24.77
Land Unit	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
$\bar{x}$ pF 2.54 (% Vol)	39.09	44.82	35.75	44.15	34.86	37.99	35.51	37.20
$\bar{x}$ pF 4.2 (% Vol)	21.27	28.11	25.97	35.20	16.71	26.19	21.28	20.57
Land Unit	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
$\bar{x}$ pF 2.54 (% Vol)	38.36	37.85	35.60	36.44	35.28	37.92	31.42	36.25
$\bar{x}$ pF 4.2 (% Vol)	29.99	22.05	23.74	21.07	26.85	25.18	19.24	26.08

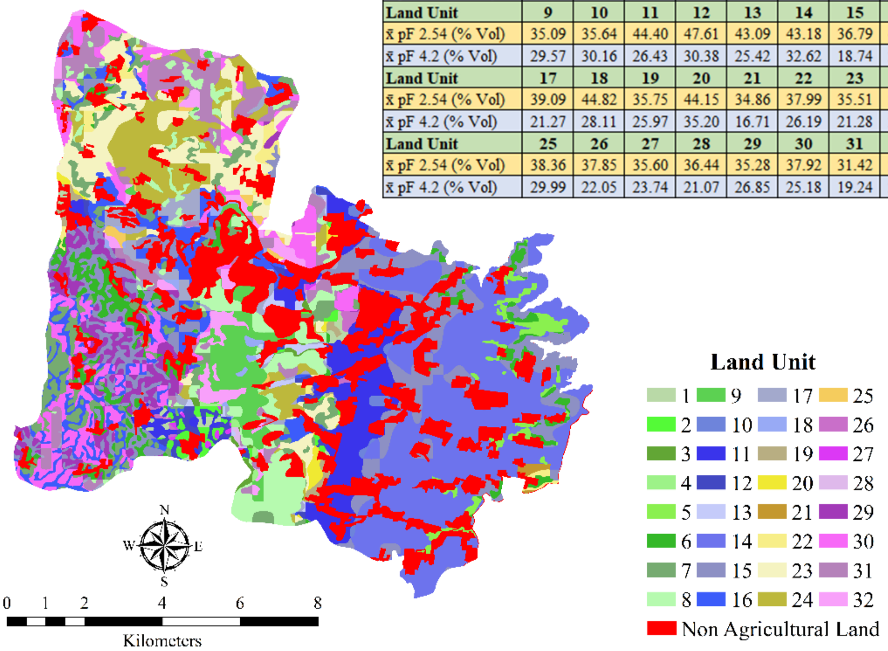

Figure 6. Soil moisture at field capacity (pF 2.54) and permanent wilting point (pF 4.20)

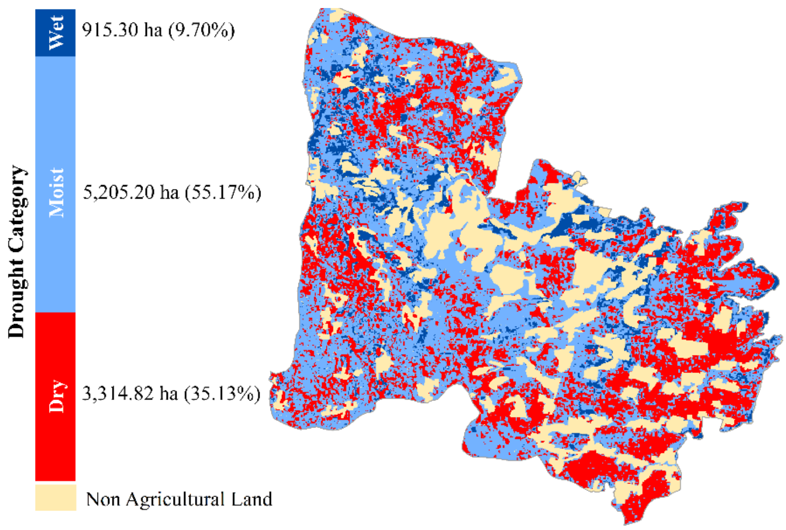

Figure 7. Distribution of agricultural land drought

Table 3. Dryness category in study area

Agricultural land	Dryness category	Area (ha)
Plantation	Dry	724.47
	Moist	1,273.79
	Wet	26.03
Irrigated paddy field	Dry	1,499.33
	Moist	2,153.85
	Wet	630.04
Rainfed paddy field	Dry	540.22
	Moist	641.48
	Wet	230.36
Moor	Dry	550.80
	Moist	1,136.07
	Wet	28.86

The plantation has the highest percentage area in a moist category based on the condition of the planted land having dense canopy, which causes little sunlight to reach the soil resulting in low evaporation (Shahidan et al., 2007). The existence of teak gives lower light intensity, as much as 45.13% (5 years teak) and 38.76% (7 years teak), which will reduce evaporation and micro temperature so the soil moisture will be maintained (Maharani et al., 2022). A cover crop of the plantation is often found to cause a decrease in solar radiation received by the soil and maintain soil moisture by evaporation (Kaye and Quemada, 2017; O'Connell and Snyder, 1999). The majority of teak plantations found in Eromoko are cultivated on dry land with rocky soil, high slope, and no irrigation, making this land use drier in the dry season. The teak tree has a wide leaf shape that can intercept rainwater, so the raindrops that fall on the leaves' surface will accumulate and form more giant raindrops. The accumulated raindrops fall to the ground surface with a greater kinetic energy that can result in large runoff (Kusumandari et al., 2020). The infiltration runs faster on land with high vegetation cover (Archer et al., 2016). Similar results were also reported by (Yang et al., 2014), who found that the introduced vegetation has lower soil moisture and is drier than mature trees because of the low soil infiltration.

The irrigated paddy fields are mostly cultivated with paddy that is in the generative phase towards the harvest phase in the third cropping period, and the soil conditions are moist to dry (Ghazali et al., 2020), while the soil conditions in the vegetative to generative phase is wet to moist (Domiri, 2017). The need for water during the productive phase of lowland paddy is lower than during the vegetative phase because the water requirement for the growth of plant parts is higher in the vegetative stage. Irrigated paddy fields that were mostly in the dry category were caused by the harvested condition and were not being cultivated, so the moisture content in the soil evaporated but did not receive water input (Ghazali et al., 2020). Growing paddy crops during this stage increases the water on the soil surface and decreases the evaporation beneath the canopy. Irrigated paddy fields are land with intensive tillage, which causes a decrease in the ability of the soil to hold water and reaches a permanent wilting point on day 5 after irrigating at a depth of 0-20 cm (Wahyunie et al., 2012).

Rainfed paddy fields and the moor is dry land that theoretically experience the greatest percentage of the dry category during the dry season. According to the study results, the moist category dominates in dry land. Some of the lands that have springs or pump wells are still used for irrigating cultivation during the dry season. Most of the dry land is planted with teak at the land edge and boundary so that the canopy can reduce the solar radiation received by the soil (Shahidan et al., 2007). The condition of land that has a dry category in rainfed paddy fields and the moor is caused by the absence of cover trees around the land so that the water in the soil continues to evaporate. Still, there is no water input, or it is not used for cultivation.

Hydrological indicators such as evapotranspiration, infiltration, and water stage strongly connect with land cover and land use (Srivastava et al., 2020). In the study area, the variability of land use has a very significant effect on the dryness distribution (F-count=4.706; p-value=0.001; n=96). Dry condition in moor is not significantly different compared to plantation and rainfed paddy fields, while the dry condition in rainfed paddy fields was not significantly different compared to moor and irrigated fields. The highest dry condition occurred on a plantation, while the lowest occurred in irrigated paddy fields (Table 4). Land use affects dry conditions because it is related to water input and different types of vegetation resulting in the quantity of evaporation and sunlight absorption into the soil.

The plantation has the lowest available water potential compared to dry land (forest and moor), with low organic matter content resulting in a decreased ability of the soil water holding capacity (Faiz and Prijono, 2021), and also low soil moisture content that continues to decrease along the increasing age of the tree due to the increased crop water requirements

(Abdallah et al., 2020). Rainfed and irrigated paddy fields are still used for cultivation, so the water irrigation is still conducted by farmers, resulting in moist to wet conditions.

Table 4. The difference dryness category means on several land use

Land use	n	Dryness category mean
Plantation	27	1.4444[a]
Moor	21	1.5714[ab]
Rainfed paddy field	21	1.8571[bc]
Irrigated paddy field	27	2.1852[c]

The values followed by the same letter are not significantly different at = alpha 0.05.

The moor has no significantly different dry conditions compared to the plantation because in the dry season and post-harvest period, most of the land is not used for cultivation, and there is no water input from irrigation or rainfall. The effect of soil tillage on rainfed paddy fields and moor makes the soil more easily eroded, which can decrease the availability of soil organic matter that does not support the process of water absorption into the soil and soil water holding capacity (Busari et al., 2015).

3.3 Drought mitigation recommendations

To minimize the effects of drought conditions in the study area, mitigation activities are taken to fix the factors that determine dry conditions, such as adopting appropriate agricultural technologies (Adunya and Benti, 2020). The condition of available soil moisture content of less than 50% would disrupt plant growth (Adimihardja et al., 2006). In this study, the recommended mitigation effort is to add irrigation water. Furrow-irrigated paddy with organic matter can avoid drought stress and dry condition of soil because it can increase infiltration and soil moisture and reduce surface runoff (Tarigan et al., 2019).

The calculation of the additional irrigation water to reach 60% at pF 4.2 (field capacity) is carried out to maintain sufficient water conditions for plants and the efficiency of the distribution of irrigation water reserves. Based on data on the spatial distribution of estimated soil moisture content and soil moisture retention, information on the additional irrigation water volume is presented in Figure 8.

Estimated soil moisture can be used to predict and manage irrigation water. Agricultural land with the highest percentage requiring additional irrigation water is 85.82% of the moor, with a total area of 1,472.40 ha of additional irrigation water needs. Irrigated paddy fields are land with a lower percentage of the area that needs additional irrigation water, which is 62.22%. The location of irrigated paddy fields is traversed by rivers that have water flow during the dry season so that they still get a supply of water all year.

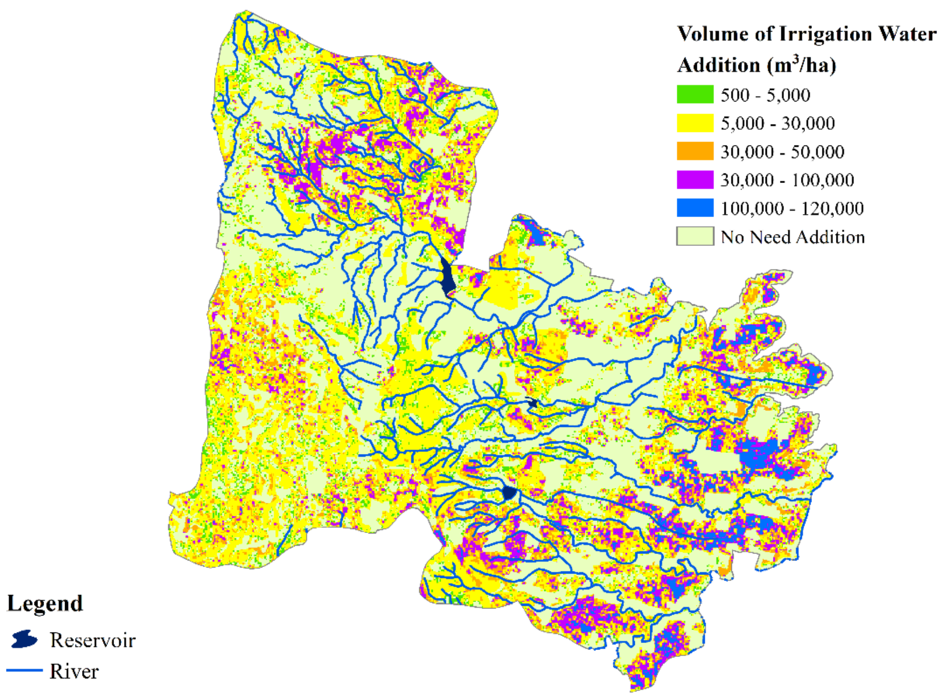

Figure 8. Irrigation water volume requirements on agricultural land

Minggarharjo Village has the largest need for additional water irrigation (21,961,825.89 m^3) and the second largest area of irrigated paddy fields (449.33 ha) in Eromoko District (Table 5), so it becomes a priority village for additional water irrigation. Irrigation water for Minggarharjo Village can be obtained from the irrigation canals of Song Putri Reservoir (Central Java Geoportal, 2019). In addition to using additional irrigation water, there are several recommendations for mitigation efforts to reduce the impact of drought on agricultural land by increasing soil water holding capacity. Using organic mulch as a cover crop *Crotalaria juncea* can increase soil water holding capacity by 56.9% and soil moisture content by up to 68.5% at a depth of 30 cm on plantation land (Reddy and Ramkumar, 2011).

The application of organic mulch gave better results than the control to create an optimal growing environment for the growth of areca nut seedlings because it provides water content to support the growth after germination (Syaranamual et al., 2022). Using cow dung and compost as organic fertilizer can hold water in the soil and be used by plants, thereby increasing plant growth and water use efficiency (Vengadaramana and Jashothan, 2012). Paddy cultivation without flooding with straw mulch application can optimize water use in drought areas in southeastern China (Qin et al., 2006). In dry lands that depend on rainfall as input for irrigation water, water harvesting is one of the efforts to fulfill crop water needs (Velasco-Muñoz et al., 2019). Harvesting of rainwater is carried out in the rainy season by making a rorak/dam so that water reserves can be utilized during the dry season and extend the planting period (Noelle et al., 2018).

Table 5. The volume of additional water irrigation and area of irrigation paddy field

Location	Additional irrigation water (m^3)	Area of irrigation paddy field (ha)
Minggarharjo	21,961,826	449.33
Tempurharjo	20,998,964	71.12
Baleharjo	18,265,298	443.56
Pucung	18,167,012	387.73
Basuhan	17,777,906	346.45
Ngadirejo	16,773,782	594.83
Tegalharjo	15,912,524	338.03
Ngandong	15,302,497	58.85
Sindukarto	14,615,865	76.46
Panekan	12,680,052	326.92
Sumberharjo	7,971,619	367.31
Eromoko	7,883,831	267.48
Ngunggahan	5,632,634	120.91
Pasek	5,535,389	308.75
Puloharjo	4,740,333	212.25

4. CONCLUSION

The estimation model of soil moisture can be used to estimate soil moisture in a range of about 74.76% up to 88.48%, with maximum accuracy in each plantation at 85.31%, irrigated paddy fields at 75.99%, rainfed paddy fields at 76.62%, and the moor at 88.48%. The moist category in 5,205.05 ha dominates the distribution of the dryness in agricultural land at Eromoko. The dry category is 3,314.82 ha and the wet category is 915.30 ha. The variability of land use greatly affects dryness conditions. Dryness conditions can be minimized by fixing the dryness factors. Dryness mitigation efforts can be made by calculating irrigation needs obtained through the results of the estimation model of soil moisture and soil water retention data, the use of organic mulch, the addition of organic matter, and water requirements in the harvesting period. By mapping dryness conditions on agricultural land, future land use can be adjusted between the actual physical condition of the soil and its utilization in more detail. A future perspective is an estimation of land dryness based on each land use using GIS technology can be carried out regularly by policyholders and the government as an alternative way to minimize drought disasters, decreased crop productivity, and soil degradation.

ACKNOWLEDGEMENTS

This research was supported by Universitas Sebelas Maret under the research grant 2022. The authors would thank to GIFU Laboratory Station, Government of Eromoko District, Wonogiri survey team (M. Arsya, M. Agan, Reza EP) and Tiara Hardian for their participation in the paper elaboration.

REFERENCES

Abdallah MAB, Durfee N, Mata-Gonzalez R, Ochoa CG, Noller JS. Water use and soil moisture relationships on western juniper trees at different growth stages. Water 2020;12(6): 26-31.

Adimihardja A, Haryati U, Juarsah I. Determination of soil moisture content using the gravimetric method. In: Technical Manual for Soil Physics Analysis. Bogor: Indonesian Center for Agricultural Land Resources Research and Development; 2006. p. 132-42.

Adunya T, Benti FC. The impacts of climate-induced agricultural drought on four cereal crops: A case study in Bako Tibe District, Oromia National Regional State, Ethiopia. Caraka Tani: Journal of Sustainable Agriculture 2020;35(1):135-46.

Akbari AN, Jatmiko RH. Utilization of landsat 8 oil images and geographic information systems for soil organic matter content mapping in Karanganyar Regency. Jurnal Bumi Indonesia 2016;5(1):10-1.

Archer NAL, Otten W, Schmidt S, Bengough AG, Shah N, Bonell M. Rainfall infiltration and soil hydrological characteristics below ancient forest, planted forest and grassland in a temperate northern climate. Ecohydrology 2016;9(4):585-600.

Benti F, Abara M. Trend analyses of temperature and rainfall and their response to global CO_2 emission in Masha, Southern Ethiopia. Caraka Tani: Journal of Sustainable Agriculture 2019;34(1):67-75.

Bronto S, Mulyaningsih S, Hartono G, Astuti. Parangjoho and songputri reservoirs: Alternative eruption sources for the semilir formation in the Eromoko area, Wonogiri Regency, Central Java. Indonesian Journal on Geoscience 2009; 4(2):79-92.

Browne M, Yardimci NT, Scoffoni C, Jarrahi M, Sack L. Prediction of leaf water potential and relative water content using terahertz radiation spectroscopy. Plant Direct 2020; 4(4):e00197.

Burapapol K, Nagasawa R. Mapping soil moisture as an indicator of wildfire risk using landsat 8 images in Sri Lanna National Park, Northern Thailand. Journal of Agricultural Science 2016;8(10):107-19.

Busari MA, Kukal SS, Kaur A, Bhatt R, Dulazi AA. Conservation tillage impacts on soil, crop and the environment. International Soil and Water Conservation Research 2015;3(2):119-29.

Central Bureau of Statistics of Wonogiri Regency. Harvest Area and Rice Production in Wonogiri Regency 2020. Wonogiri: Central Bureau of Statistics of Wonogiri Regency; 2020.

Central Java Geoportal. Geospatial data and information [Internet]. 2019 [cited 2021 Jul 15]. Available from: http://geoportal.jatengprov.go.id/.

Dobri RV, Sfîcă L, Amihăesei VA, Apostol L, Țîmpu S. Drought extent and severity on arable lands in romania derived from normalized difference drought index (2001-2020). Remote Sensing 2021;13(8):Article No. 1478.

Domiri DD. The new method for detecting early planting and bare land condition in paddy field by using vegetation bare water index. Proceedings of the 2nd International Conference of Indonesian Society for Remote Sensing (ICOIRS 2016); 2017 Dec 17-20; The Sahid Rich Jogja, Yogyakarta: Indonesia; 2016.

Eliyani, Handoko, Koesmaryono Y. Water deficit effect on growth of young fast growing teak (*Tectona grandis* L.F.). Agromet 2005;19(1):11-20.

Faiz AM, Prijono S. Differences in the ability of soil to hold water on various slopes of coffee land in the Sumbermanjing Wetan area, Malang Regency. Jurnal Tanah Dan Sumberdaya Lahan 2021;8(2):481-91.

Fawzi NI, Husna VN. Landsat 8: A Basic Processing Theory and Technique. Bengkulu: Elmarkazi Publisher; 2021.

Finch HJS, Samuel AM, Lane GPF. Soils and soil management. In: Lockhart and Wiseman's Crop Husbandry Including Grassland. 9th ed. England: Woodhead Publishing; 2014. p. 37-62.

Gao B-C. NDWI: A normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment 1996;58:257-66.

Ghazali MF, Wikantika K, Harto AB, Kondoh A. Generating soil salinity, soil moisture, soil pH from satellite imagery and its analysis. Information Processing in Agriculture 2020; 7(2):294-306.

Gu Y, Brown JF, Verdin JP, Wardlow B. A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States. Geophysical Research Letters 2007;34(6):1-6.

Gulácsi A, Kovács F. Drought monitoring of forest vegetation using modis-based normalized difference drought index in Hungary. Hungarian Geographical Bulletin 2018;67(1):29-42.

Hayes MJ, Svoboda MD, Wardlow BD, Anderson MC, Kogan F. Drought monitoring: Historical and current perspectives. In: Remote Sensing of Drought: Innovative Monitoring Approaches. CRC Press; 2012. p. 1-19.

Hazaymeh K, Hassan QK. A remote sensing-based agricultural drought indicator and its implementation over a semi-arid region, Jordan. Journal of Arid Land 2017;9(3):319-30.

Hidayat AM, Efendi U, Agustina L, Winarso PA. The correlation of the nino 3.4 index and the southern oscillation index (SOI) with variations in rainfall in Semarang. Journal of Science and Weather Modification Technology 2018;19(2):75-81.

Ignatius SR. Potential water resources and calculation of rainwater storage volume to overcome water shortage in South Wonogiri. Journal of Rural and Development 2013; 4(2):157-66.

Kaye JP, Quemada M. Using cover crops to mitigate and adapt to climate change: A review. Agronomy for Sustainable Development 2017;37(4):1-17.

Kusumandari A, Pratiwi I, Widiasmoro S. Run off prediction by using small plots at teak forest, dry land and settlement areas in Pitu village, Ngawi, East Java. IOP Conference Series: Earth and Environmental Science 2020;449:Article No. 012040.

Liu C, Yang C, Yang Q, Wang J. Spatiotemporal drought analysis by the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) in Sichuan Province, China. Scientific Reports 2021;11(1):1-14.

Maharani D, Sudomo A, Swestiani D, Murniati, Sabastian GE, Roshetko JM, et al. Intercropping tuber crops with teak in

Gunungkidul Regency, Yogyakarta, Indonesia. Agronomy 2022;12(2):1-20.

Maulana FW. Aquifer potential of Eromoko Village, Eromoko District, Wonogiri Regency, Central Java Province based on geoelectrical data. Teknomineral 2019;1(2):79-87.

Muchsin F, Harmoko A, Prasasti I, Rahayu MI, Pradhono KA, Technology RS. Comparison of the radiometric correction of landsat-8 images based on object spectral response. International Journal of Remote Sensing and Earth Sciences 2022;18(2):177-88.

National Disaster Management Coordinating Board. Introduction to Disaster Characteristics and Mitigation Efforts in Indonesia. National Disaster Management Coordinating Board; 2007.

Noelle NM, Weru WP, Rodrigue SJ, Karlin G. The effects of drought on rice cultivation in sub-Saharan Africa and its mitigation: A review. African Journal of Agricultural Research 2018;13(25):1257-71.

O'Connell NV, Snyder RL. Cover crops, mulch lower night temperatures in citrus. California Agriculture 1999;53(5):37-40.

Orimoloye IR, Kalumba AM, Mazinyo SP, Nel W. Geospatial analysis of wetland dynamics: Wetland depletion and biodiversity conservation of Isimangaliso Wetland, South Africa. Journal of King Saud University - Sciences 2020; 32(1):90-6.

Polthanee A, Promkhambut A. Impact of climate change on rice-based cropping systems and farmers' adaptation strategies in Northeast Thailand. Asian Journal of Crop Science 2014;6(3):262-72.

Popova Z, Ivanova M, Martins D, Pereira LS, Doneva K, Alexandrov V, et al. Vulnerability of Bulgarian agriculture to drought and climate variability with focus on rainfed maize systems. Natural Hazards 2014;74(2):865-86.

Qin J, Hu F, Zhang B, Wei Z, Li H. Role of straw mulching in non-continuously flooded rice cultivation. Agricultural Water Management 2006;83(3):252-60.

Reddy RM, Ramkumar. Prospect and importance of green mulching on the soil status of tropical tasar plantation fields in India. Nature Precedings 2011;1-13.

Renza D, Martinez E, Arquero A, Sanchez J. Drought estimation maps by means of multidate landsat fused images. Proceedings of the 30th EARSeL Symposium Remote Sensing for Science, Education, and Natural and Cultural Heritage; 2010 31 May-3 Jun; París, Francia; 2010.

Research Agency for Solo Watershed Area. Daily rainfall data [Internet]. 2020. [cited 2021 Jul 15]. Available from: https://bbwsbengawansolo.id/.

Shahidan MF, Salleh E, Mustafa KMS. Effects of tree canopies on solar radiation filtration in a tropical microclimatic environment. Proceedings of the 24th Conference on Passive and Low Energy Architecture (PLEA2007); 2007 Nov 22-24; National University of Singapore, Singapore; 2007.

Song X, Zhou G, He Q. Critical leaf water content for maize photosynthesis under drought stress and its response to rewatering. Sustainability 2021;13(13):1-14.

Srivastava A, Kumari N, Maza M. Hydrological response to agricultural land use heterogeneity using variable infiltration capacity model. Water Resources Management 2020; 34(12):3779-94.

Sudirman, Sutono S, Juarsah I. Determination of groundwater retention in the laboratory. In: Technical Manual for Soil Physics Analysis. Bogor: Indonesian Center for Agricultural Land Resources Research and Development; 2006. p. 167-76.

Sukmono A. Rice fields drought identification using a combination of leaf water content index and vegetation index with landsat 8 imagery. Elipsoida: Jurnal Geodesi Dan Geomatika 2018;1(2):44-50.

Syaranamual S, Sipyan D, Tuhumena VL. The seedlings growth performance of areca nut palm (*Areca catechu* L.) Under different types of organic mulching. Caraka Tani: Journal of Sustainable Agriculture 2022;37(2):233-42.

Tarigan PL, Tohari T, Suryanto P. Physiological response of upland rice varieties to furrow with organic matter on agroforestry system with kayu putih (*Melaleuca leucadendra* L.). Caraka Tani: Journal of Sustainable Agriculture 2019; 34(2):223-31.

USGS. Landsat missions [Internet]. 2008 [cited 2021 Mar 31]. Available from: https://www.usgs.gov/core-science-systems/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con.

Velasco-Muñoz JF, Aznar-Sánchez JA, Batlles-delaFuente A, Fidelibus MD. Rainwater harvesting for agricultural irrigation: An analysis of global research. Water 2019;11(7):1-18.

Vengadaramana A, Jashothan PT. Effect of organic fertilizers on the water holding capacity of soil in different terrains of Jaffna peninsula in Sri Lanka. Journal of Natural Product Plant Resources 2012;2(4):500-3.

Voroney P. Soils for Horse Pasture Management. Horse Pasture Management: Elsevier Inc.; 2018. p. 65-79.

Wahyunie RE, Baskoro DPT, Sofyan M. Water retention capacity and resistence of soil penetration in intensive tillage system and conservation soil tillage. Journal of Soil Science and Environment 2012;14(2):73-8.

Wild A. Soils and the Environment: An Introduction. Melbourne: Cambridge University Press; 1993.

Yang L, Wei W, Chen L, Chen W, Wang J. Response of temporal variation of soil moisture to vegetation restoration in semi-arid Loess Plateau, China. Catena 2014;115:123-33.