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Google earth engine for spatio-temporal drought monitoring in Bangkalan, Indonesia

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Abstract. Drought occurrence in a certain area can be monitored by remote sensing through cloud-based platform of Google Earth Engine (GEE). The objective this study was to analyze spatially and temporally distribution of drought in Bangkalan Regency between 2017 to 2022 with GEE. This study employed CHIRPS and satellite images of Landsat 8 at Level 2 covering Bangkalan area from 2017 to 2022. Masking and Cloud masking had been carried out before analyzed the satellite images. Data was processed using Java scrip API algorithm in GEE to obtain rainfall, LST, NDVI, NDWI and NDDI data. Result of rainfall analysis from CHIRPS data showed that dry months from 2017 to 2022 occurred from June to October. The value of LST was between 24.75 - 38.87 ^{o}C. Drought events in the study area from 2017 to 2022 were dominated by severe and extreme drought. The severe drought covers the area of 83.17% (2017), 57.34% (2018), 67.13% (2019), 84% (2020), 80.93% (2021), and 89.89% (2022). Meanwhile, the extreme drought wraps the area of 14.05% (2017), 40.05% (2018), 30.17% (2019), 13.15% (2020), 16.27% (2021), and 7.03% (2022). The area with severe drought was always over the one with extreme drought, and when the severe drought area increased; the extreme drought area decreased Result of this study could be employed in planning of drought mitigation and adaptation, the use of water and land resources, and public information on risks and actions for drought-affected communities.

1 Introduction

Indonesia is a tropichal country with sensitive to the ENSO (El-Nino Southern Oscilation) anomaly which has an impact on increasing drought. Drought is related to four aspects, namely meteorological, hydrological, agricultural [1], and socio-economic [2].

Drought observation can be carried out by remote sensing methods. This method has some advantages in providing information as it is cheaper, faster, and more precise, and covering a large area. This method can even cover very large areas with large data sizes when combined with cloud computing platforms, such as Google Earth Engine (GEE). The platform makes it easy to access and analyze large geospatial data [3].

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One of the remote sensing algorithms that can be employed to analyze the drought index is the *Normalized Different Drought Index* (NDDI). NDDI has the advantage of having the highest correlation value with precipitation and describes farmland drought well compared to several other Vegetation Index observations [4]. NDDI is obtained from the calculation of *Normalized Difference Vegetation Index* (NDVI) and *Normalized Difference Wetness Index* (NDWI).

NDVI focused on canopy chlorophyll content of plant leaves [5] and NDWI is for vegetation moisture content [6]. The index used for vegetation analysis [7], especially in water-limited area [8]. NDVI and NDWI can be used for agriculture drought monitoring and assessment [9].

The objective of this study was to analyze spatially and temporally distribution of drought in Bangkalan Regency from 2017 to 2022 with GEE.

2 Materials and methods

2.1 Study area

The study area was Bangkalan district (112°40'06" – 113°08'04" BT dan 6°51'39" – 7°11'39"LS), one of regency in Madura Island located in East Java, Indonesia, having total area of 1,260.14 km^2 (See Fig. 1).

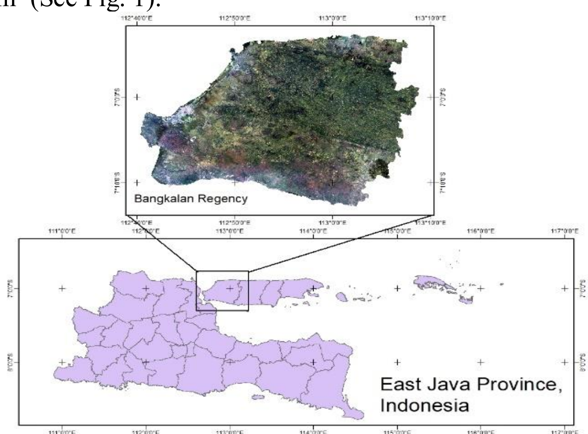

Fig. 1. The study area of Bangkalan.

2.2 Methodological

Rainfall data acquisition was from *Climate Hazard Group InfraRed Precipitation with Station data* (CHIRPS) through function *ee.ImageCollection('UCSB-CHG/CHIRPS/DAILY')*. This satellite imagery in combination with *in situ* station data can be apply to monitor drought events with trend analysis, as it has a more than 30 years of global rainfall dataset. This data had been used to identify dry months in year over the past six years.

Land Surface Temperature (LST) is defined as the outermost temperature of a land object controlled by the balance of the atmosphere, the energy and thermal properties of the surface, and the media below the ground surface [10]. LST describes energy and water exchange between atmosphere and land surface. It influences the timing and rate of plant growth. LST was analyzed from band 10 - Thermal Infra-Red (TIRS) 1 of Landsat 8 TIRS TOA

Reflectance through ee.Image Collection('LANDSAT/LC08/C01/T1_SR). LST was calculated from median NDVI, minimal and maximal NDVI value, fractional vegetation, and emissivity. In the end, LST value with Kelvin degree was converted to Celcius degree [11].

Drought analysis was based on value of *Normalized Different Drought Index* (NDDI), which was calculated from value of NDVI and NDWI. Those indexes used the satellite images analysis from Landsat 8 OLI at collection 2 (ee.Image Collection('LANDSAT/LC08/C02/T1_L2')). This satellite images were substantial improvement of geometric accuracy and radiometric calibration. Mosaic, masking and cloud masking had been carried out before analyzed the satellite images of covering Bangkalan area from 2017 to 2022. Data were processed using Java scrip API algorithm in GEE to obtain rainfall, LST, NDVI, NDWI and NDDI data. Data variables in this study can be seen in Table 1.

Table 1. Data variables in this study.

Data source	**Spatial resolution**	**Temporal resolution**	**Data variable**
CHIRP	0.05° (~5.3 km)	Daily, monthly, pentadal	Rainfall
Landsat 8 TIRS TOA Reflectance	30 m	16 days	LST
Landsat 8 OLI Surface Reflectance	30 m	16 days	NDVI
Landsat 8 OLI Surface Reflectance	30 m	16 days	NDWI
Calculated from NDVI and NDWI	30 m	-	NDDI

The NDVI is a greenness canopy indicator and able to be used to monitoring of vegetation dynamics [12]. In this reason, NDVI was established to evaluate vegetation stress cause drought through spectral calculation in near infrared (NIR) and red band.

$$\mathbf{NDVI} = (NIR - Red) / (NIR + Red) \quad (1)$$

The NDWI is a remote sensing method that can be used to estimate vegetation water content, especially leaf water content at canopy level. This index was calculated from the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) landsat 8 channels.

$$\mathbf{NDWI} = (NIR - SWIR) / (NIR + SWIR) \quad (2)$$

The NDDI is one of remote sensing methods used to determine the level of drought of area based on vegetation index (NDVI) and wetness index (NDWI) (Lillesand &Kiefer, 1993). The NDDI was classified into normal (< 0.01), mild (0,01–0,15), moderate (0.15-0.25), severe (0.25-0.1) dan extreme (>1) [13].

$$\mathbf{NDDI} = (NDVI - NDWI) / (NDVI + NDWI) \quad (3)$$

3 Results

Drought monitoring of a region can be used for various purposes by the government, Non Government Organitation (NGO), and communities in general, such as appropriate and effective decision-making and planning related to the use of water and land resources, planning and implementation of drought mitigation and adaptation, and public communication or information on risks and actions that can be taken by drought-affected communities.

3.1 Rainfall

Monthly rainfalls from 2017 - 2022 that were analyzed from Chirps data showed that from July-October it tended to be low (Fig. 2). This is the basis for analyzing drought in Bangkalan Regency in that year. Drought event is the occurrence of lower rainfall than the normal average in a certain period. This would result in low water reserves in surface and subsurface areas such as reservoirs, lakes, and aquifers. This condition will result in disruption of growth, reduce agricultural production, and socio-economic impacts on drought-affected communities.

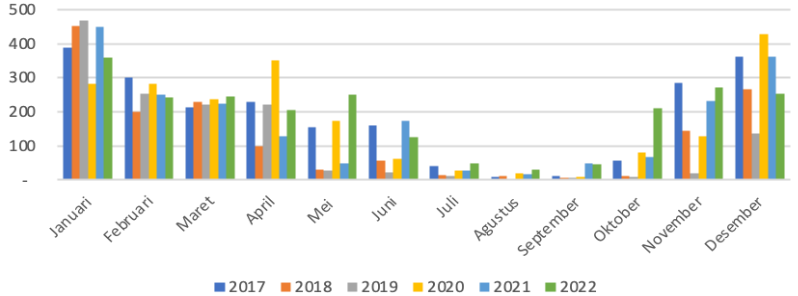

Fig. 2. Monthly rainfall of Bangkalan 2017-2022.

3.2 Land Surface Temperature (LST)

LST values were obtained from the extraction of annual average Landsat 8 image values that have been cloud masked. LST was determine by a single infrared channel or Band 10 in Landsat 8. The results of LST values for 2017-2022 were in the range of 24.75 - 38.87 ^{o}C. The spatial distribution from 2017 to 2022 showed that the high LST value was in the southern part of the region (Fig. 3) and this distribution pattern tended to be similar from year to year. Some of the reasons why this part of the region has high LST values are due to low vegetation density, soil surface roughness, soil moisture content, [14] human activities and land use. LST is one of the climate variables that describes the exchange of energy from on land surface and atmosphere. LST affects the timing and rate of plant growth, and is very useful for analyzing land drought in a region.

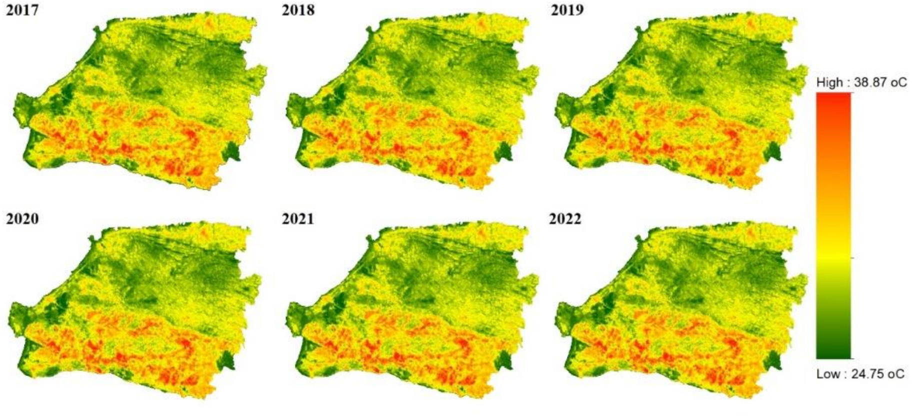

Fig. 3. Land Surface Temperature (LST) of Bangkalan 2017-2022.

3.3 Normalized Difference Vegetation Index (NDVI)

NDVI is widely used for vegetation analysis using remote sensing methods. NDVI can be used as a numerical representation of the greenness, density and condition of vegetation in an area calculated using indicator data. In this study NDVI values are obtained from mathematical calculations between red band and Near-Infrared Radiation (NIR) band. When using Landsat 8 imagery the red band is band 4 (light wavelength 640-670 nm) and the NIR band is band 5 (light wavelength 850-880 nm). NDVI can also be used as one of the components to calculate drought using NDDI.

NDVI analysis is grouped into 5 categories, namely land with no vegetation, very low, low, medium and high density [15]. The majority of NDVI values from 2017 to 2022 fall into the high category, especially in the central and northern regions. The area of Bangkalan with high NDVI values from 2017 to 2022 is 126,191.56 ha or 96.74% of the total area, 113,789.47 ha (87.24%), 117,432.16 (90.03%), 126,177.08 (96.73%), 124,715.12 (95.61%), and 127,372.26 (97.65%), respectively. A small portion falls into the low-medium category, especially in the western and southern of Bangkalan (Fig. 4).

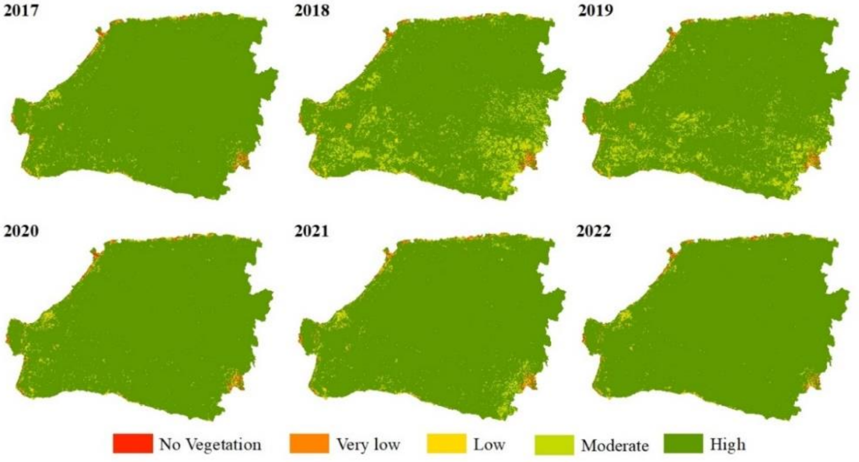

Fig. 4. Normalized Difference Vegetation Index (NDVI) of Bangkalan 2017-2022.

3.4 Normalized Difference Wetness Index (NDWI)

NDWI has a strong relationship with the water content of vegetation. NDWI in this study is derived from Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. NIR reflectivity is influenced by total dry matter of vegetation biomass, especially leaves (not the moisture content of the vegetation). Whereas SWIR reflects the water content of vegetation, so the SWIR value in the electromagnetic spectrum is influenced by the amount of vegetation water. This is why NDWI is used for monitroing the drought level of an area. The level of vegetation wetness obtained from the NDDI analysis results is categorized into non-water body, medium, and high wetness [16]. The NDWI value category of the total area of Bangkalan Regency 2017-2022 (see Fig. 5) generally falls into moderate category, namely 80% (2017), 56.69% (2018), 64.75% (2019), 80.42% (2020), 77.31% (2021), and 84.88% (2022).

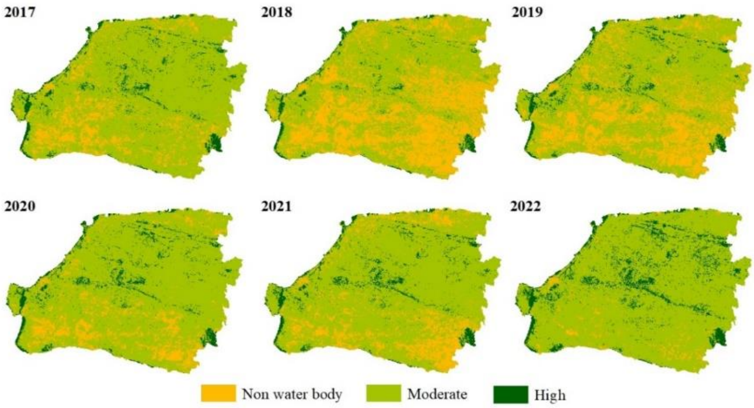

Fig. 5. Normalized Difference Wetness Index (NDWI) of Bangkalan 2017-2022.

3.5 Normalized Different Drought Index (NDDI)

NDDI is a satellite image data-based analysis to display the drought index. The NDDI is classified into 5 categories. Those are normal (< 0.01), mild (0,01–0,15), moderate (0.15-0.25), severe (0.25-0.1) dan extreme (>1) [13]. NDDI values in Bangkalan were visualized for each year from 2017-2022 (Fig. 6). The analysis shows that severe drought in 2017 occurred in Bangkalan covering 108,485.22 ha or 83.17% of the total area. Whereas in 2018-2022, it is 74,783.70 ha (57.34%), 87,560.57 ha (67.13%), 109,557.69 ha (84%), 105,559.8 ha (80.93%), 117,239.34 ha (89.89%) respectively. While the extreme drought category has the second largest area after the severe category with each area in 2017-2022 is 18,324.83 ha or 14.05% of the total area of Bangkalan, 52,234.05 ha (40.05%), 39,355.04 (30.17%), 17,145.18 (13.15%), 21,223.25 (16.27%), 9,168.6 (7.03%). Both 2018 and 2019 are the years with the largest area affected by extreme drought. Apart from the results of the NDDI calculation, the results of the CHIRPS data analysis that year had lower rainfall than other years. The area with severe drought was always over the one with extreme drought, when the severe drought area increased; the extreme drought area decreased. Drought identified by NDDI has a strong correlation with NDVI & NDWI. If both indices tend to increase, then NDDI decreases [17]. In this case, the research area with a moderate category (NDVI and NDWI) tends to have an increasing area from 2017 to 2022.

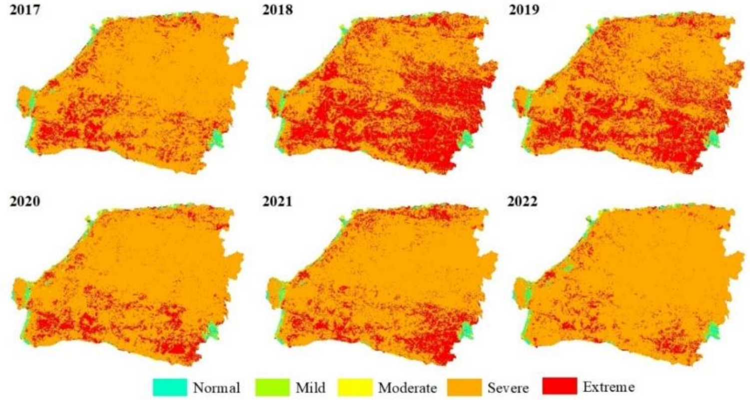

Fig. 6. Drought categories in Bangkalan 2017-2022.

4 Conclusion

This study was to analyze spatially and temporally distribution of drought in Bangkalan Regency between 2017 to 2022 based on remote sensing method in GEE cloud computing platform. The result of this study showed that monthly rainfall in each years tends to be low in July-October, LST is in the range of 24.75 - 38.87 ^{o}C and high LST value is in the southern part of the region, NDVI with high category, NDWI with moderate category, drought categories in the study area from 2017 to 2022 were dominated by severe and extreme drought.

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