Analysing Drought Intensity in the Mekong River Delta using Time Series Analysis and Google Earth Engine

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Abstract
This study aims to examine variations in drought severity in the Mekong River Delta, Vietnam using the Normalized Difference Water Index (NDWI) derived from the Landsat satellite images. The spatial analysis approach integrated Theil-Sen slope and Mann-Kendall significance tests were applied to time-series NDWI data from 1989 to 2018 and to estimate the spatiotemporal dynamics of drought in the study area. Results showed that drought increased in large area (approximately 13,675.38 square kilometres) and covered almost the Mekong River Delta. However, upward trend was significant observed in coastal areas, particular in Kien Giang and Ca Mau provinces.

1. Introduction

Drought is one of the most crucial natural hazards in the Mekong River Delta (CGIAR and AFS, 2016) as it negatively contributed to agricultural production. Drought monitoring traditionally has been based on weather station observations (Dao et al., 2017, Huynh et al., 2012, Thuong, 2016, Tuan et al., 2017 and Ty et al., 2015) but the lengths and variable date quality of meteorological data are different between individual meteorological stations (AghaKouchak et al., 2015, AghaKouchak and Nakhjiri, 2012 and Easterling, 2013). It breeds a lack of the continuous spatial coverage needed to characterize and monitor the detailed spatial pattern of drought conditions (Gu et al., 2007). Since that time, international collaboration has significantly improved the situation, culminating in analysis (Alexander et al., 2006) that provided a global perspective on drought monitoring. The availability of daily observations is steadily improving and has led to the development of gridded regional (Haylock et al., 2008) and global datasets (Caesar et al., 2006). Established in 2010 (Patel et al., 2015), Google Earth Engine (GEE) is an online portal that brings a wide range of satellite and geospatial data to research community in a more accessible way. It leverages cloud computing services to obtain analysis capabilities on satellite data. The GEE allows access to a large warehouse of satellite imagery and the computational power needed to analyse those images. It, therefore, is as a powerful tool for providing enhanced opportunities for undertaking earth observation studies (Hird et al., 2017 and Patel et al., 2015).

Normalized Difference Water Index (NDWI) is an indicator of soil and vegetation water content (Amalo et al., 2018, Fensholt and Sandholt, 2003 and Palacios-Orueta et al., 2006). It has a quicker response to drought conditions than vegetation indices (Amalo et al., 2018) because the NDWI is influenced by both desiccation and wilting in the vegetation canopy (Gu et al., 2007). Besides, Landsat imagery with 30 m spatial, multispectral resolution and temporal continuity has been commonly used for

Online ISSN 2673-0014/

drought change analysis (Kumar et al., 2018 and Urban et al., 2018). In this study, the NDWI and Landsat time series obtained from GEE were used to implement drought situation and its dynamics in space and time. The objectives of this study are to (i) determine spatiotemporal changes in the NDWI; (ii) explore the reflectance of the NDWI to drought situation; (iii) investigate satellite-derived methods for measuring and monitoring drought; (iv) characterize the dynamics of agricultural drought intensity. The Mekong River Delta was selected to employ the research because it has been rigorously affected by drought in dry season (CGIAR and AFS, 2016). This information is authentic for planning and designing applications of water resource development schemes, related to various supply and the environment.

2. Material and Methods

2.1 Study Site

The Mekong River Delta (MRD) extends from $8^0 34'$N-$10^0 24'$N latitude and from $104^o 27'$E-$106^0 48'$E longitude (Figure 1). It is counted as "Vietnam's Rice Bowl" and is the largest rice production region in the country (Clauss et al., 2018). The MRD is one of the pivotal agricultural regions in the Lower Mekong River Basin, which covers about 5% of the area of the Mekong River Basin (MRB). The proportion of rice manufacturing in the MRD was always over 50% in comparison with rest of economic regions in Vietnam (General Statistics Office of Vietnam, 2016). It hence plays a crucial role in contributing the output of agriculture to economic development of Vietnam and an apart of rice production over the world (Dao et al., 2017). However, this figure significantly decreased over year because the potential consequences of global warming and hydropower dams (Thuong, 2016). Particularly, it was fifth position in ten of the largest rice producing countries all over the world in 2016 (Tuan et al., 2017).

2.2 Spectral Index

The Normalized Difference Water Index (NDWI) is developed by Gao (1996) to enhance the water related features of the landscapes. This index uses the near infrared (NIR) and the short wave infrared (SWIR) bands, followed by Equation 1.

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR}$$

Equation 1

The NDWI has been applied to examine drought severity (Amalo et al., 2018 and Gulácsi and Kovács, 2015). In this study, the NDWI derived from Landsat Thematic Mapper (TM), Enhanced Thematic Mapper plus (ETM+) and Operational Land Imager (OLI) data, obtained from Google Earth Engine, were used for analyzing spatiotemporal changes in drought in dry season during the period of 1989 - 2018. The categories of NDWI for drought determination are listed in following Table 1. As shown in Table 1, the NDWI was applied to estimate spatiotemporal situation and trend of drought in the Mekong River Delta.

Table 1: NDWI classification

Category	**Description**	**NDWI**
D0	None Dry	0.4 or more
D1	Semi-arid	0.20 to 0.30
D2	Arid	0.00 to 0.20
D3	Hyper-arid	0.00 or less

2.3 Mann-Kendall Test and Theil-Sen Slope Approach

The nonparametric Mann-Kendall (MK) test (Kendall, 1946 and Mann, 1945) has been commonly used to assess the significance of monotonic trends in climatological, meteorological, hydrological, environmental data time series (Kisi and Ay, 2014 and Wang and Myint, 2016). The rank-based nonparametric Mann–Kendall method is adopted to employ trends in the annual series. The choice of this method is based on the fact that it has the advantage of being less sensitive to outliers over the parametric method (Otache et al., 2008). The MK test statistic (*S*) is calculated in the following equations:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

Equation 2

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

Equation 3

where x_i and x_j are the data values at times *i* and *j*, and *n* indicates the length of the dataset. While a positive value of *S* indicates an increasing trend, negative of *S* indicates a decreasing trend. The following expression, as an assumption, is used for the series where the data length $n > 10$ and data are approximately normally distributed (variance ($\sigma^2 = 1$) and mean ($l = 0$) value).

$$Var(S) = \frac{n(n-1)(2n+5)}{18}$$

Equation 4

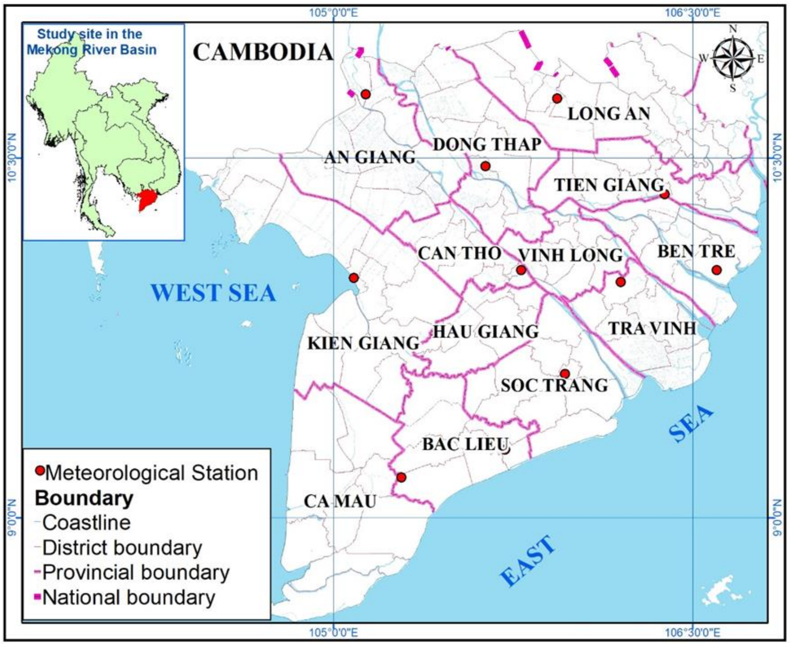

Figure 1: Location of the study area

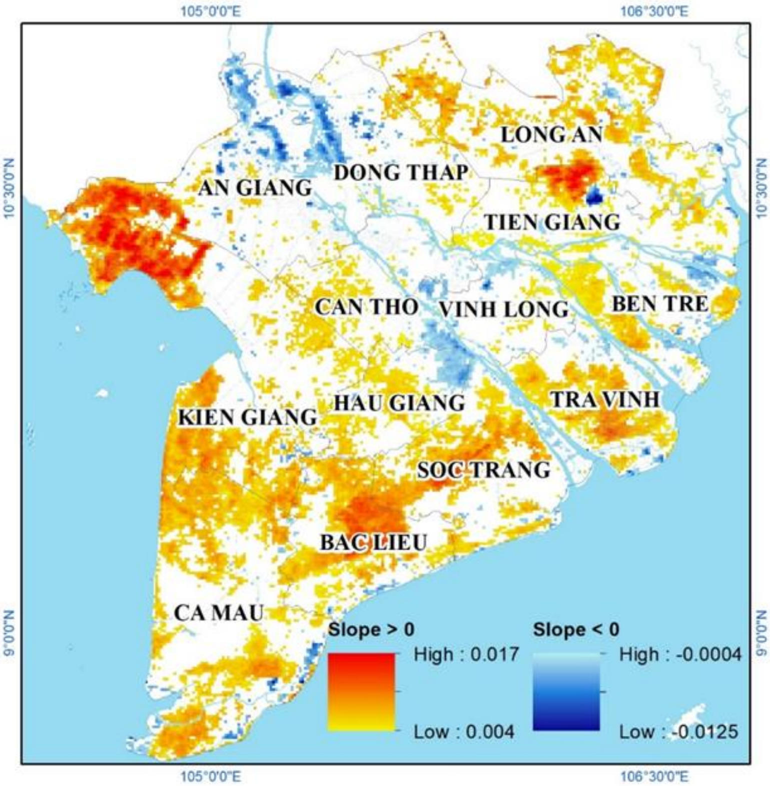

Figure 2: Spatiotemporal trend for NDWI variation in the study area during the 1989–2018 period

After the calculation of the variance if time series data with Equation (4), the standard Z value is calculated according to the following Equation (5).

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\operatorname{var}(s)}}, & if \;\; S > 0 \\ 0, & if \;\; S = 0 \\ \dfrac{s+1}{\sqrt{\operatorname{var}(s)}}, & if \;\; S > 0 \end{cases}$$

Equation 5

The calculated standard Z value is compared with the standard normal distribution table with two-tailed confidence levels ($\alpha = 0.05$). If the calculated Z is greater $|Z| > |Z_{1-\alpha}|$, then the null hypothesis (H_0) is invalid. Therefore, the trend is statistically significant. Otherwise, the H_0 hypothesis is accepted that the trend is not statistically significant, and there is no trend in the time series (trendless time series) (Kisi and Ay, 2014). On the other hand, slope in NDWI time series (change per unit time) is estimated by procedure described by Sen (1968) in case the trend is linear. The method requires a time series of equally spaced data (Shahid, 2011). The magnitude of trend is predicted by the Sen's slope estimator (Q_i). The magnitude of trend is predicted by the Sen's slope estimator (Q_i).

$$(Q_i) = \frac{x_j - x_k}{J - K}, \text{ for } i = 1, 2, \ldots N$$

Equation 6

where x_j and x_k are data values at times j and k ($j > k$) respectively. The median of these N values of Q_i is represented as Sen's estimator. $Q_{med} = \frac{Q(N+1)}{2}$ if N is odd, and $Q_{med} = \frac{\left[\frac{QN}{2} + \frac{Q(N+2)}{2}\right]}{2}$ if N is even. Positive value of Q_i indicates an increasing trend, and negative value of Q_i shows decreasing trend in time series.

3. Results and Discussion

3.1 The Trend of the NDWI Variations

The Figure 2 presents the trend of significant changes in NDWI and the Table 2 shows the area of drought change based on Sen's slope. The value of the factor increased most across the delta with a slope value greater than zero. The downward trend of drought was seen in the upper Hau and Tien River with a decrement of around 477.61 km^2 and 471.73 km^2 in Dong Thap and An Giang provinces, respectively. The results of the regression analysis for the annual drought indices are presented in Table 2. Strong positive relationships between measured indices at ground observation and spectral indices were found. All regression models showed high *r* values that were above 0.7. It proved that the NDWI is correspondence with drought indices measured from ground observation. The NDWI increment expanded significantly across much larger area (13,675.38 km^2) compared to NDWI decrement (2,533.86 km^2). The increase NDWI area was mainly concentrated in coastal region, including Kien Giang and Ca Mau with an area of 2,952.74 km^2 and 2,121.82 km^2, respectively. These provinces have experienced high development of tourism activates in recent years which led to the mangrove deforestation. Hence, it is notable that the increase in drought area in coastal areas reflected negative human influences (Kantoush et al., 2017 and Le et al., 2007).

3.2 The Spatiotemporal Variations of Drought in the Study Area

The temporal dynamic of drought area from 1989 to 2018 is shown in Figure 3.

Table 3: Significant changes in drought by province level Unit: km^2

Province	Decreased Area	Increased Area
An Giang	471.73	364.08
Bac Lieu	64.59	1,376.05
Ben Tre	192.8	783.94
Ca Mau	182.04	2,121.82
Can Tho	138.98	364.08
Dong Thap	477.61	250.55
Hau Giang	218.25	553.94
Kien Giang	47.96	2,952.74
Long An	93.96	1,619.75
Soc Trang	145.83	1,378.01
Tien Giang	163.44	750.66
Tra Vinh	106.68	1,015.89
Vinh Long	229.99	143.87
Total	**2,533.86**	**13,675.38**

In general, the drought area tended to increase during the study period. In addition, it reveals that there was intensity as a sinusoidal path with bottom peaks in 1990, 1993, 1997, 2002, 2007, 2012, 2015, and 2017. Based on this, the study therefore divided the investigation into different periods including 1989-1991, 1991-1993, 1993-1998, 1998 - 2003, 2003-2008, 2008 – 2013, 2013 – 2016, and 2016 - 2018. The spatial pattern of annual drought risk in the study area from 1989 to 2018 is presented in Figure 4. During the study period, annual drought took place in inland and then expanded to the coastal areas.

Table 2: The relationship between NDWI and RDI, SPI measured at the meteorological stations in the study area during the 2001–2018 period

	SPI		**RDI**	
	r-value	*p*-value	*r*-value	*p*-value
NDWI	0.74	0.010	0.71	0.014

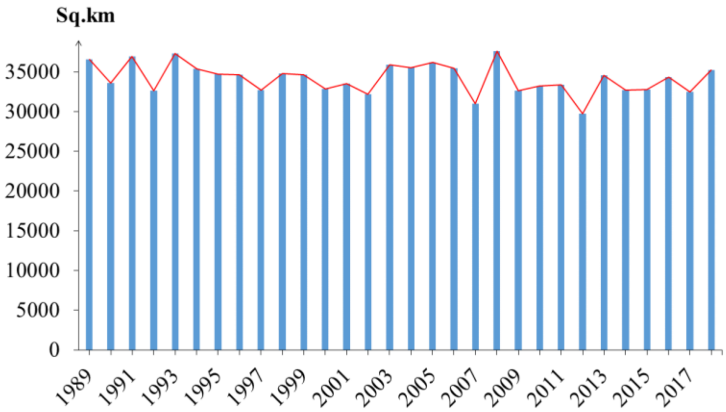

Figure 3: The temporal change in total drought area during the 1989-2018 period

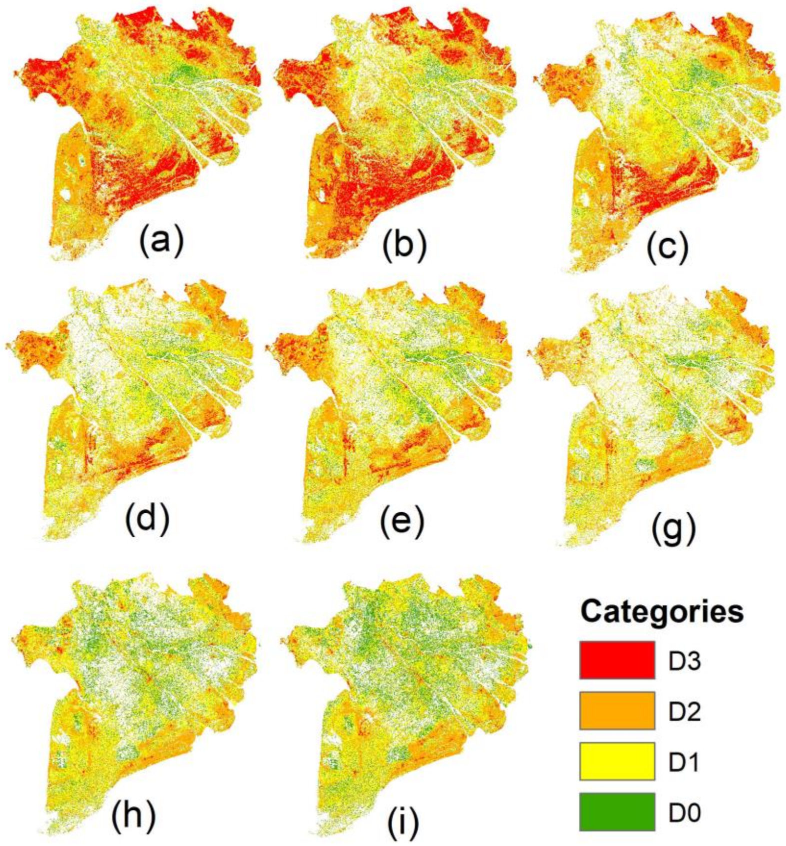

Figure 4: The changes in NDWI categories in the delta each period includes 1989 – 1991 (a); 1991 – 1993 (b); 1993 – 1998 (c); 1998 – 2003 (d); 2003 – 208 (e); 2008 – 2013 (g); 2013 – 2016 (h); and 2016 – 2018 (i)

The intensity of the drought index developed rapidly from 1989 to 1998, but decreased gradually until the period of 2008 - 2013. From 2013 to 2018, the level of drought became gradually intense, concentrated in coastal areas, especially in Ca Mau and Kien Giang. It is explored that before 1998 the drought area was mainly dependant on natural conditions. Major farming practices were single rice crop in the rainy season and shrimp farming in the dry season (Sâm, 2003 and Ty et al., 2015). Moreover, local farmers have converted into farming systems to adapt natural phenomenon in specific agricultural system from 2013 until the present. It is important to note that the 2016 – 2018 period, a major drought level occurred across almost the coastal area due to the combined impact of upstream dams, climate change, and El Niño (Chopra, 2006 and Kantoush et al., 2017).

4. Conclusions

The study explored the spatiotemporal change of the NDWI and its reflectance to drought severity in the Mekong River Delta using the derived Landsat product, obtained from Google Earth Engine, and spatial analysis approach. Results showed that frequency of drought occurred in a cycle, with a top peak in 2009 and a bottom peak in 2013, and it was more serious in coastal areas. It was clearly demonstrated that the region with the largest areas of serious drought is Kien Giang, Ca Mau, Soc Trang, and Bac Lieu provinces. It is recommended that the government should promulgate appropriate policy and solution, especially focused on these affected areas, to reduce the negative impacts of drought.

Results from this study are valuable for agricultural land suitability evaluation and agricultural practices. For instance, drought map provides important information for selecting appropriate crop types. Under the impacts of global warming and sea level rise, drought and salinity will be more severe in the future, particularly in the Mekong River Delta. It is no doubt that spatiotemporal of drought at pixel level is pivotal information for agricultural land use planning and management. Besides, Landsat-derived indices obtained from GEE and time-series analysis, are efficient for drought monitoring and assessment in broad scale.

Acknowledgments

The authors thank the Google Earth Engine via Climate Engine apps for the freely accessible Landsat and single band data products. This study was supported by the Ministry of Education and Training (5652/QĐ-BGDĐT), Hanoi National University of Education (B2019 –SPH - 03) in Vietnam.

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