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Application of remote sensing technique for drought assessment based on normalized difference drought index, a case study of Bac Binh district, Binh Thuan province (Vietnam)

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Abstract. Drought is a natural phenomenon, which occurs in most regions in the world, caused immense damage in agricultural production and seriously affected on the environment. Droughts often occur on a large scale, so traditional observation techniques for drought monitoring are difficult, time consuming and costly. Remote sensing data provides information on the Earth's surface at different spectrum channels and and wide coverage has been used effectively in monitoring and severe drought. This paper presents the results of the study on drought assessment in Bac Binh district, Binh Thuan province using LANDSAT multispectral imagery based on normalized difference drought index (NDDI). The results obtained in the study can be used to create drought level map and provides information to help managers set measures to minimize damage caused by drought.

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1. Introduction

Drought is one of the most costly natural disasters in Vietnam. In recent years, drought tends to happen both in rainy season and dry season due to the impact of climate change [*Ngo et al.,* 2017; *Pham and Nguyen,* 2012; *Trinh,* 2014]. Droughts are particularly severe in the Central and Central Highlands of Vietnam that causes great damage in the socio-economic and environment sectors. According to the Ministry of Agriculture and Rural Development Vietnam, more than 240,000 hectares of rice, 18,000 hectares of crops, 55,000 hectares of fruit trees and more than 100,000 hectares of industrial crops were damaged by water shortages only in drought years 2015–2016 [*Ministry...,* 2008].

The traditional drought monitoring methods used in Vietnam are based on data on precipitation, temperature, and soil moisture collected from the meteorological stations. Ground-based observations reflect only drought situation of local area around the station and in fact cannot establish the number of meteorological stations with expected density due to the high cost. Therefore, such data-sets fail to monitor drought conditions accurately and in a timely fashion. Remote sensing technology with advantages such as wide area coverage and short revisit interval has been used effectively in the study of drought monitoring.

Optical remote sensing data such as MODIS, LANDSAT and SPOT have been used for the large-scale drought monitoring. During the past few years, many studies in Vietnam have demonstrated the effectiveness of remote sensing techniques for drought monitoring and assessment of soil/vegetation moisture [*Ngo et al.,* 2017; *Nguyen et al.,* 2016; *Tran,* 2007; *Trinh,* 2014].

More than 100 drought indices have so far been proposed, some of which are operationally used to characterize drought using gridded maps at regional and national levels. These indices correspond to different types of drought, including meteorological, agricultural, and hydrological drought [*Gulacsi and Kovacs,* 2015; *Zagar et al.,* 2011]. Some of the indices derived from satellite data and used for drought monitoring include vegetation condition index – VCI [*Kogan,* 1990], crop water stress index – CWSI [*Idso et al.,* 1981], normalized difference infrared index – NDII [*Hardisky et al.,* 1983], vegetation health index – VHI [*Kogan,* 1995], normalized difference water index – NDWI [*Gao,* 1996], global vegetation moisture index – GVMI [*Ceccato et al.,* 2002], soil water index – SWI [*Wagner,* 2003], remote sensing drought risk index – RDRI [*Liu et al.,* 2008]. Some drought indices are based on the relationship between land surface temperature and land cover, such as the temperature condition index – TCI [*Kogan,* 1995], vegetation temperature condition index – VTCI [*Wang et al.,* 2001], temperature vegetation dryness index – TVDI [*Lambin and Ehrlich,* 1996; *Sandholt et al.,* 2002].

Gu et al. [2007] proposed the normalized difference drought index (NDDI), which combines both vegetation greenness (NDVI) [*Rouse et al.,* 1974] and wetness conditions (NDWI) [*Gao,* 1996]. This drought index can be suitable for long-term drought monitoring, particularly for agricultural drought [*Hazaymeh and Hassan,* 2016].

This paper focuses on the application of normalized difference drought index to assess and monitor drought in Bac Binh district, Binh Thuan province (South Central Coast of Vietnam) in period 1988–2017.

2. Materials and Methods

2.1. The Study Area

Bac Binh is a rural district of Binh Thuan province in the South Central Coast region of Vietnam (Figure 1). The area is bounded between latitude $10^{\circ}58'27''$ N to $11^{\circ}31'38''$ N and longitude $108^{\circ}06'30''$ E to $108^{\circ}37'34''$ E. The district covers an area of 1868.82 km^2 and had a population over of 120,000 people (http://bacbinh.binhthuan.gov.vn).

Bac Binh has three geographical terrains: plain, semi-mountain and mountain. It located in tropical monsoon region and is characterized by semi-arid climate in the south central region. The climate is divided into two seasons: the rainy season from May until October and the dry season from November to April. According the monitoring results, the average annual rainfall in Bac Binh district is very low and the average temperature is high. This is one of the most regions severely affected by drought in Southeast region of Vietnam. The major form of desertification in Bac Binh district is desertification of sand dunes. The total red sandy area is 32,600 ha (17.5% total area of district).

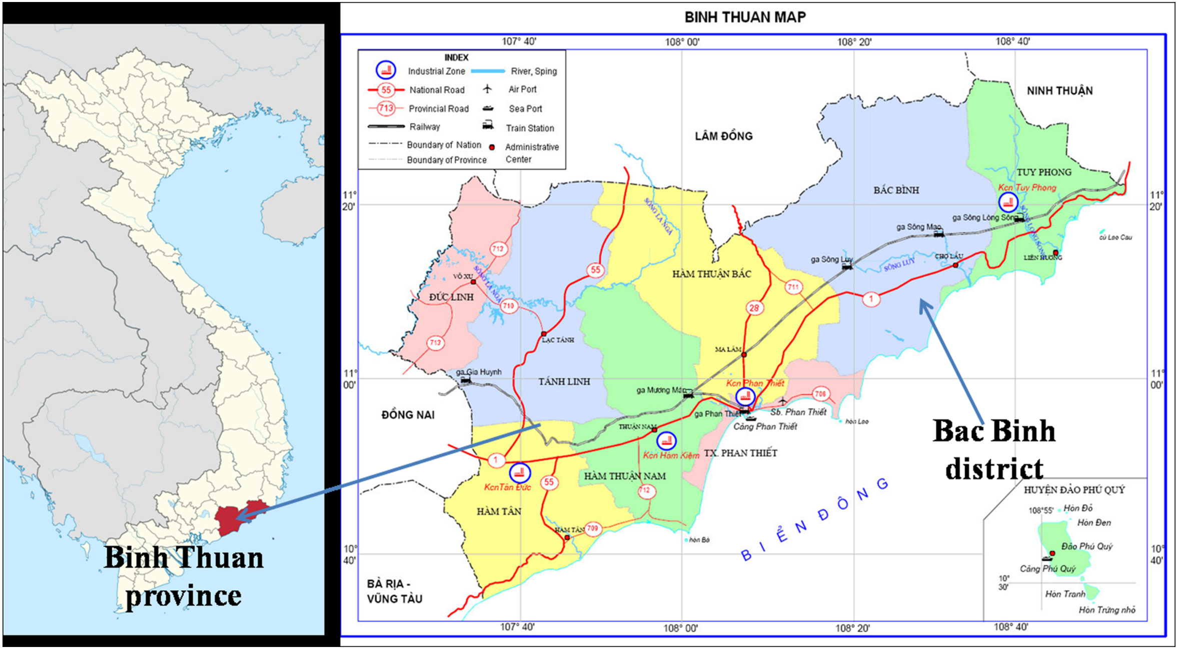

Figure 1. The study area, Bac Binh district, Binh Thuan province (Vietnam).

2.2. Materials

In this study, nine multispectral cloud – free LANDSAT 5 TM, LANDSAT 7 ETM+ and 8 OLI-TIRS images (path 124, row 52) with a spatial resolution of 30×30 meters were acquired from 1988, 1993, 1996, 1998, 2002, 2004, 2009, 2011 and 2017 (Figure 2 and Table 1). The LANDSAT data was the standard terrain correction products (L1T), downloaded from United States Geological Survey (USGS – http://glovis.usgs.gov) website. These satellite images were taken during the peak time of the dry season in South Central Coast of Vietnam (January to March).

2.3. Methods

Image processing started with radiometric and geometric correction. In first step, the brightness of the pixel value (digital number) is converted into the spectral radiance value ($Wm^{-2}\ \mu m^{-1}$). Then, the spectral radiance value is used to calculate the top of atmosphere value – TOA. The surface reflectance value can be calculated using "dark object subtraction" (DOS) atmospheric correction method [*Chavez,* 1988, 1996]. This method estimates the atmospheric contributions to a

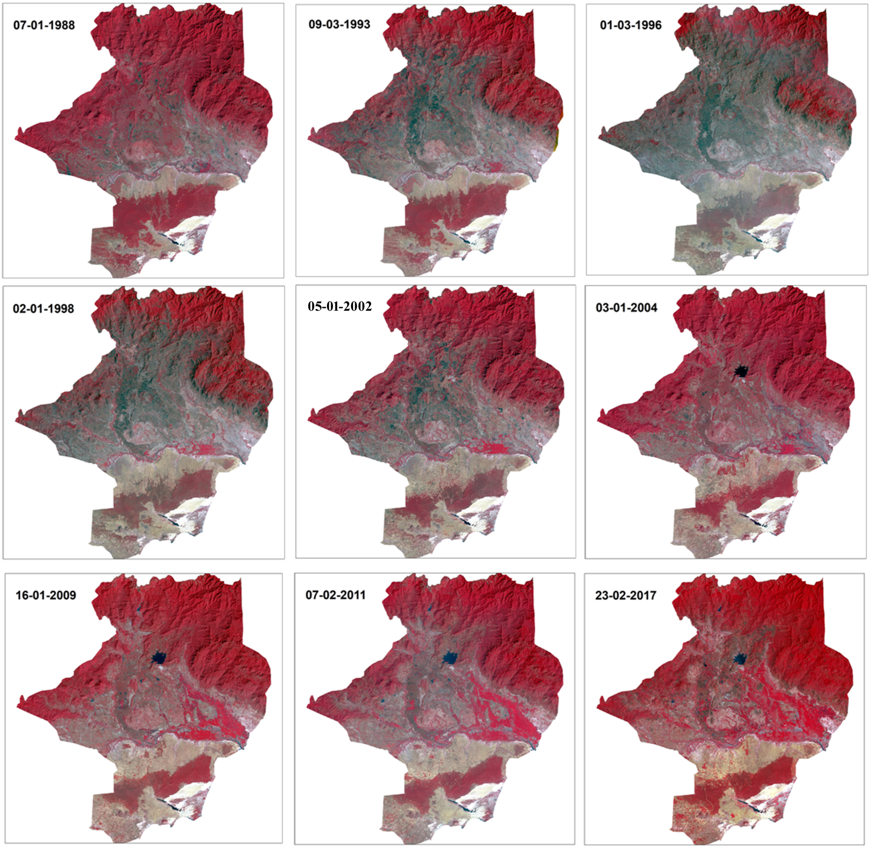

Figure 2. LANDSAT multispectral images in Bac Binh district, RGB=NIR: RED: GREEN.

Table 1. The LANDSAT Multispectral Images Used in This Study

No.	Data type	Time of data acquisition
1	Landsat 5 TM	January 07, 1988
2	Landsat 5 TM	March 09, 1993
3	Landsat 5 TM	March 01, 1996
4	Landsat 5 TM	January 01, 1998
5	Landsat 7 ETM+	January 05, 2002
6	Landsat 5 TM	January 03, 2004
7	Landsat 5 TM	January 16, 2009
8	Landsat 5 TM	February 07, 2011
9	Landsat 8 OLI	January 30, 2017

surface spectrum by measuring homogeneous surfaces over a range of illumination conditions.

The reflectance values of green, red, near infrared (NIR) and short wave infrared (SWIR) bands were used to calculate normalized difference vegetation index (NDVI) [*Rouse et al.,* 1974] and normalized difference water index [*McFeeters,* 1996] following the equations:

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}}}$$

$$\text{NDWI} = \frac{\rho_{\text{GREEN}} - \rho_{\text{SWIR}}}{\rho_{\text{GREEN}} + \rho_{\text{SWIR}}}$$

where ρ_{GREEN}, ρ_{RED}, ρ_{NIR}, ρ_{SWIR} are reflectance values of green, red, near infrared (NIR) and short wave infrared (SWIR) bands of LANDSAT multispectral image.

Finally, the NDDI index combines information from both the NDVI and NDWI indices following the equations [*Gu et al.*, 2007]:

$$\text{NDDI} = \frac{\text{NDVI} - \text{NDWI}}{\text{NDVI} + \text{NDWI}} \tag{1}$$

According to Drought Categories [*Gu et al.*, 2007], NDDI index was classified into 3 classes: "non-drought" (NDDI value is smaller than 0.1); "drought-moderate" (NDDI value range from 0.1 to 0.3) and "drought-severe" (NDDI value larger than 0.3) (Table 2).

In this study, image processing is done by using ERDAS Imagine 2014 program, and drought maps were created using ArcGIS 10 program.

Table 2. Classification of Drought Levels Based on NDDI Index [*Gu et al.*, 2007]

No.	NDDI value	Drought level	Legend
1	NDDI < 0.1	Non-drought	Green
2	$0.1 \leq$ NDDI < 0.3	Drought-moderate	Yellow
3	$0.3 \leq$ NDDI	Drought-severe	Red

3. Result and Discussion

The LANDSAT multi-temporal data after pre-processing was cut along the boundary of study area. The reflectance values for red and NIR bands were used to calculate normalized difference vegetation index and the reflectance values of green and SWIR bands were used to calculate normalized difference water index. Subsequently, the NDVI and NDWI indices are used to calculate the normalized difference drought index following formula (1). The result of NDDI index in Bac Binh district retrieval from LANDSAT satellite images in period 1988–2017 is present in Figure 3.

The dark pixels of NDDI index have low drought level, and the light pixels have high drought level. The inter-annual variation in the percentage of drought im-

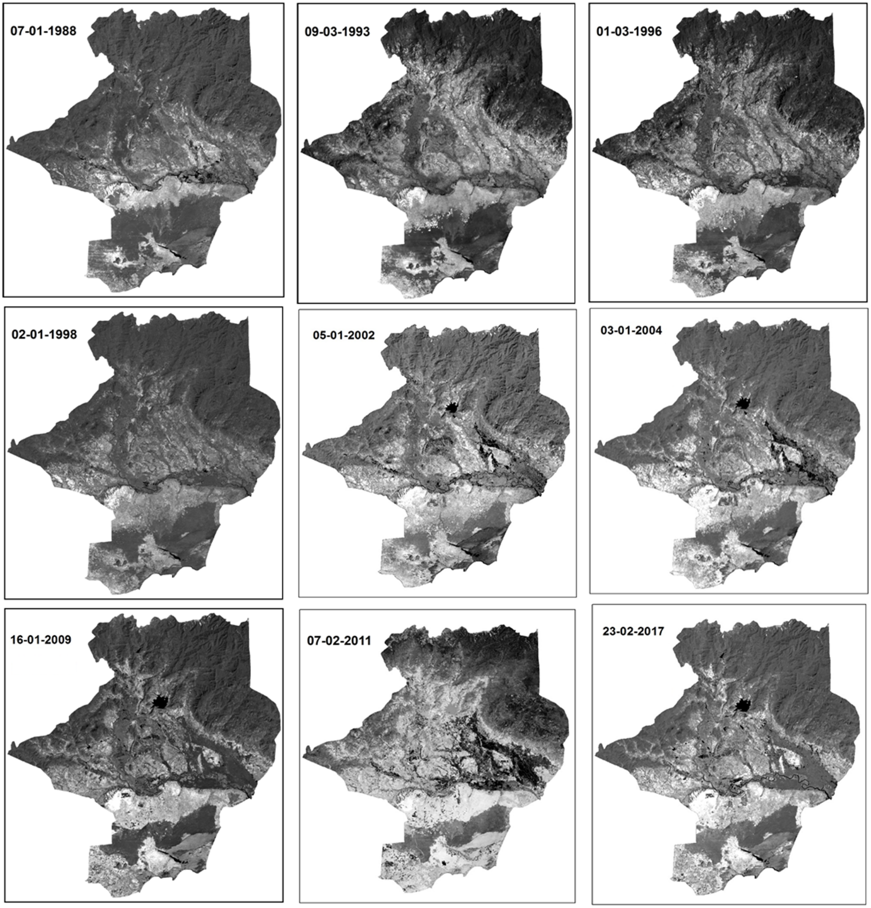

Figure 3. NDDI index over study area in period 1988–2017 retrieval from LANDSAT data.

pacted areas in the Bac Binh district from 1988–2017 due to drought categories [*Gu et al.*, 2007] are shown in Figure 4 and Table 3.

Thus, it can be seen that relative large drought areas recorded in the middle of the 1993–2002 period, in which the area affected by drought severe was highest in 1996 (13.02% of total area) and 1998 (18.78% of total area) (Table 3). This is also the time when the south central coast region of Vietnam is severely affected by the El Nino phenomenon (El Nino years in period 1993–1995 and 1997–1998).

Analysis of the obtained results showed that, the regions with "non-drought" level are mainly concentrated in forested areas, where distributed in the north and a part in the south of the study area (vegetation cover is shown by red color on the Figure 2). The areas with "non-drought" level strongly decreased in period 1988–1998, from 80.17% of total area to 49.50% of total area due to the decline of forest area, especially in the northwest region of Bac Binh district. These areas are likely to increase in period 1998–2009, from 49.50% to 70.04% of total area of district and then continue to decrease in 2011 (65.41% of total area) and 2017 years (58.67% of total area).

The results obtained in this study also show the im-

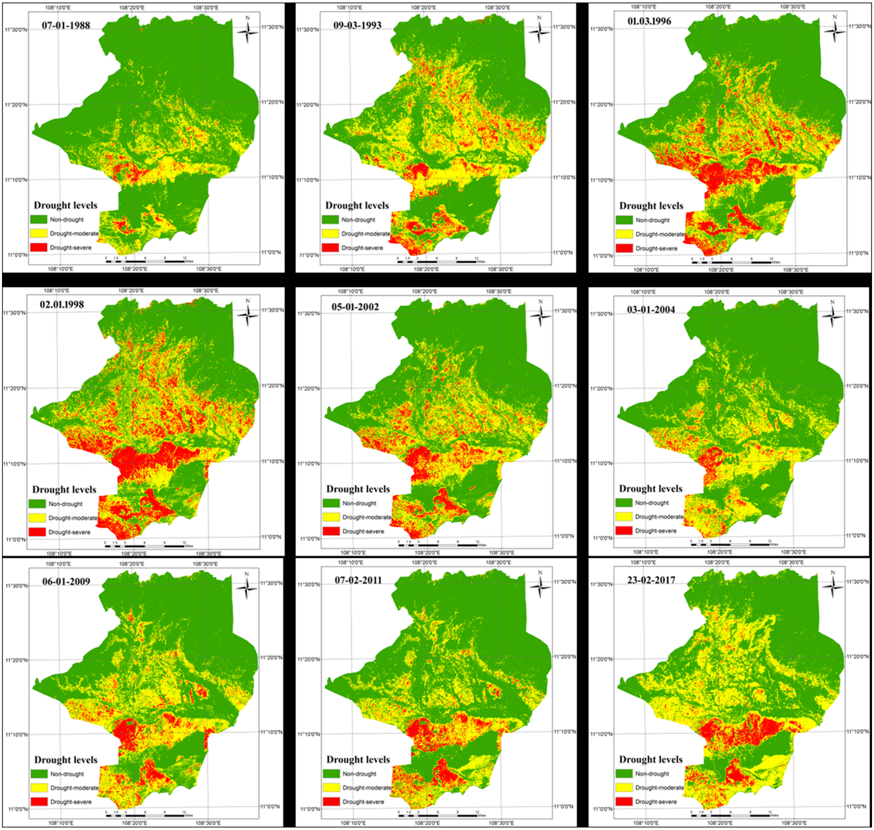

Figure 4. Map of drought in the Bac Binh district in period 1988–2017.

Table 3. Result of Drought Assessment in Bac Binh District in Period 1988–2017

Year	Non-drought		Drought–moderate		Drought–severe	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
1988	150327.54	80.17	32623.74	17.40	4559.31	2.43
1993	111467.88	59.45	61433.73	32.76	14609.07	7.79
1996	115221.69	61.45	47866.23	25.53	24422.58	13.02
1998	92821.86	49.50	59465.25	31.71	35223.48	18.78
2002	119893.95	63.94	49296.96	26.29	18319.59	9.77
2004	135093.15	72.05	44641.80	23.81	7775.73	4.15
2009	131340.33	70.04	43304.13	23.09	12866.13	6.86
2011	122642.46	65.41	51354.63	27.39	13513.59	7.21
2017	110013.39	58.67	64184.49	34.23	13312.71	7.10

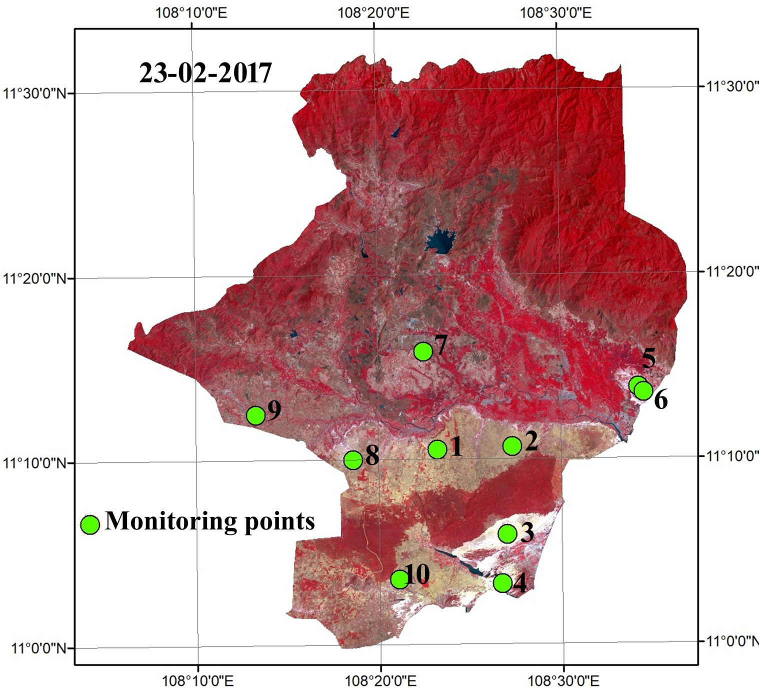

Figure 5. Location of the soil moisture and land surface temperature monitoring points.

portant role of vegetation cover in reducing drought risk. In planted forest areas (Phan Hiep, Hoa Thang, Hong Thai regions) in east of the district, drought level is at "severe" in period 1988–1996 to "moderate" and "non-drought" in 2011 and 2017 years (Figure 4).

Measurement data of soil moisture and land surface temperature at 10 sample points (Figure 5) at 23

February 2017 were used in the comparison with NDDI values retrieval from LANDSAT 8 image, which acquired from same day. This in situ data was observed in the framework of the ministry-level project (Ministry of Natural Resources and Environment (Vietnam), No. 2015.08.10). Comparison between NDDI values and measurement data of soil moisture and land surface temperature is presented in Table 4. It can be seen, 8 out of 10 measurement points are located at "drought-severe" level and 2 measurement points are located at "drought- moderate" level. The soil moisture at the all 10 sampling points is less than 10%, and land surface temperature is high than 305 (K). The soil moisture at sampling points at "drought-moderate" level is highest, and the land surface temperature at these points is lowest in comparison with the measurement points with drought level at "severe".

We also compared the results obtained in the study with the meteorology index (MI) values which calculated from rainfall data at 13 meteorological stations in the period 1960–2010 *Pham and Nguyen,* 2012]. These meteorological stations are located in Bac Binh district and some neighboring districts in Binh Thuan province. The results showed that the northern part of study area has drought level "non-drought" and "less

Table 4. Comparison Between NDDI Values and Measurement Data of Soil Moisture and Land Surface Temperature

No.	Coordinate (m) X	Y	Land surface temperature (K)	Soil moisture W (%)	NDDI value	Drought level
1	869931	1237474	314.3	3.1	0.398	Severe drought
2	877403	1237824	313.9	3.6	0.318	Severe drought
3	876936	1229069	310.2	4.6	0.302	Severe drought
4	876469	1224166	308.6	5.8	0.189	Moderate drought
5	890010	1243894	315.8	3.4	0.435	Severe drought
6	890504	1243387	311.4	4.3	0.323	Severe drought
7	868531	1247280	305.0	3.5	0.392	Severe drought
8	861526	1236423	313.2	6.6	0.247	Moderate drought
9	851837	1240859	315.9	4.2	0.345	Severe drought
10	866226	1224538	312.0	3.4	0.540	Severe drought

drought" (the MI values higher than 1.2). Meanwhile, the central and southern part of Bac Binh district suffered severe drought (the MI values less than 0.4). This result is also consistent with the distribution map of drought in the Bac Binh district (Figure 4).

4. Conclusion

In this study, we used Landsat time series data in period 1988–2017 to assess drought conditions in Bac Binh district, Binh Thuan province (South Central Coast of Vietnam). The results obtained show that NDDI index can be used effectively for drought monitoring due to simplicity in calculation.

The results show that relative large drought areas recorded in the middle of the 1993–2002 period, in which the area affected by drought severe was highest in 1996 and 1998 (En Nino years). The drought-prone areas are mainly distributed in agricultural and sandy lands, which is concentrated in the center and southern part of the study area. In spite of the large inter-annual variability, the long-term trends in the drought impacted areas in the Bac Binh district as a whole increased dramatically over the period 1988–2017, especially in the El Nino years of 1993, 1996 and 1998.

The results obtained in the study can be used to create drought distribution map and provide information to effectively respond and minimize damage caused by drought.

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