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Mapping Droughts Over the Central Highland of Vietnam in El Niño Years Using Landsat Imageries

Nguyen Thi Thu Ha*, Mai Trong Nhuan, Bui Dinh Canh, Nguyen Thien Phuong Thao

Faculty of Geology, VNU University of Science, 334 Nguyen Trai, Hanoi, Vietnam

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Abstract: Recently, drought has occurred severely in the Central Highland of Vietnam, particularly during dry seasons of El Niño years. Towards disaster mitigation and sustainable management for drought, this study aims to clarify relationship between drought area detected in dry peak month (March) in years El Niño occurred such as 1998, 1999, 2004, 2005, 2010, 2015, 2016 with local main climate factors and land-uses. Normal Difference Drought Index (NDDI) retrieved from the difference of NDWI and NDVI was used in this study. Results showed that the most severe drought occurred in March 2005 with total area under severe level reached to 1,170 thousand hectares corresponding to 21% of the highland's total area, and the smallest drought was recorded in March 1999 with total severely affected area of 550 thousand hectares. Drought-impacted area has increased dramatically for recent years, the largest drought-impacted area was recorded in dry season 2015 with 2,486 thousand hectares, corresponding to 46% of the highland's total area. If the severe drought area is highly dependent on seasonal average rainfall (R=-0.91), the drought-impacted area is much more dependent on the expansion of residential area and coffee planting area. Therefore, sustainable land-use planning for drought mitigation should be paid attention.

Keywords: Drought, El Niño, Landsat Imagery, NDDI, the Central Highland.

1. Introduction

Droughts are considered to be one of the major natural hazards causing destructive impact on the environment as well as the economy of the Central Highland (TâyNguyên) throughout the Vietnam country. In 2015, the Vietnamese Government has provided 5,221 tons of food and allocated 1008 billion VND (45 million USD) worth of relief and disaster support services for people in the Central Highland's drought-affected regions. As a consequence, it is estimated that about 2 million people have lack freshwater supply, 1.75 million people have compromised livelihoods and 1.1 million need food aid in 2016 (CGIAR Research Centers in Southeast Asia, 2016) [1]. Therefore, monitoring and understanding spatial distribution and root causes of droughts in the highland, particularly in years El Niño occurred, to design and manage water resources schemes for the region is indispensable.

Traditional methods of drought monitoring were purely based on rainfall data, which had many limitations as network of stations are limited and data innear real-time (both spatially and temporally) is difficult to obtain. Remote

*Corresponding author. Email: hantt_kdc@vnu.edu.vn

sensing technology has been revolutionary to greatly enhance the ability for monitoring and managing the natural resources, particularly in the domain of water resources, through collecting this data at a synoptic view (at both global and regional scales) rapidly and providing repetitive coverages. Therefore, drought dynamics and its impacts can be rapidly assessed by using this technique.

The normalized difference drought index (NDDI), which is the normalized reflectance difference between the normalized difference vegetable index (NDVI) (Tucker 1979, 127-150; Rouse et al. 1974, 371) [2, 3] and the normalized difference water index (NDWI) (Gao 1996, 257-266) [4], proposed by Gu et al. (2007) [5] can be suitable for drought monitoring, particularly for agricultural drought (Kapoi and Alabi, 2013) [6]. Landsat imageries have been widely used to generate drought related indices such as NDVI, NDWI and the land surface temperature (LST) therefore they provided an optimal tool for drought monitoring (Orhan et al. 2014, 11; FaourGhaleb et al. 2015, 563-577) [7,8]. With more than 40 years history, Landsat imageries help better understand drought in the Central Highland of Vietnam in the past El Niño years and are extremely useful for detecting drought impacted areas and additional drought causing factors such as local land-use, land-cover changes.

This study aims to map droughts in the Central Highland of Vietnam in Marches of 1998, 1999, 2005, 2010, 2015 and 2016 using Landsat images. Furthermore, local major climate factors, such as seasonal average temperature and rainfall, length of dry season and land-uses (including forests, residential districts, coffee planting land) were dependently analyzed with resultant severe drought area and drought impacted area to clarify factors that caused or mainly contributed to the drought in the highland.

2. Materials and methods

2.1. Study area

The Central Highlands is one of eight agro-ecological regions of Vietnam (Figure 1). The region consists of various plateaus surrounded by mountain ranges. The elevations of plateaus range from 500-1500 meters above sea level. The Central Highlands has a total land area of 5,454,500 ha (17% of the national area), covering five provinces: Kon Tum, Gia Lai, Dak Lak, DakNong and Lam Dong.

The Central Highland of Vietnam is well - known as an area of industrial crops with the average GDP growth rate in a period from 2001 until now is 11.9% per year. However, economic sectors there have been positively shifted with remarkable transformation of agricultural production and urbanization. There are 1,560 reservoirs were constructed to provide about 60% of irrigation needs (Viettrade, 2016).

El Niño or El Niño Southern Oscillation (ENSO) is an irregularly periodical variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting much of the tropics and subtropics (Climate Prediction Center, 2005). According to FAO (2016) Vietnam has been impacted by the El Niño phenomenon resulting by severe droughts in the Central Highlands, Southern Central and Mekong Delta regions during dry season 2015-2016. In history, the highland was also severely impacted by drought in dry seasons of 1998, 2005 (FAO, 2016) (Figure 1).

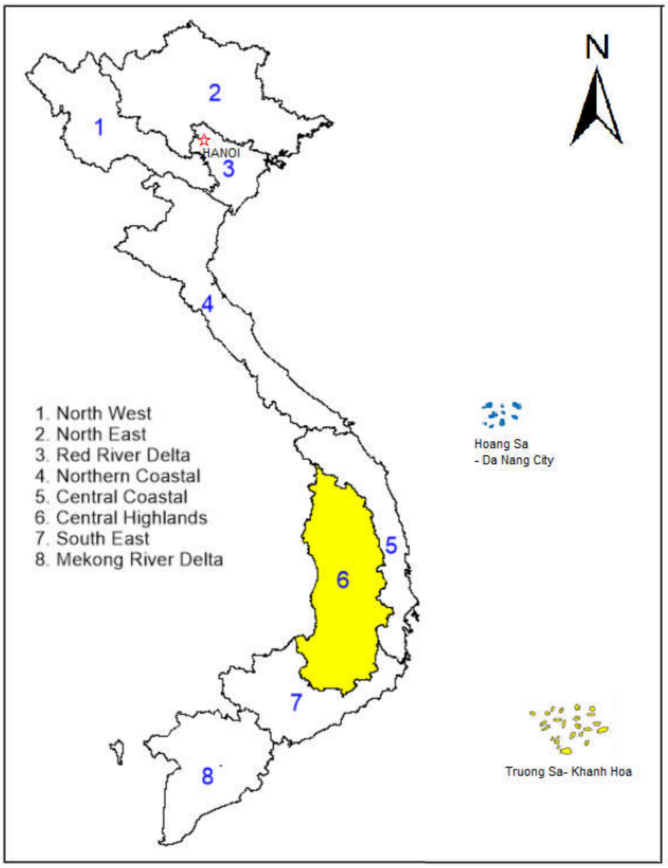

Figure 1. Location of the Central Highland of Vietnam.

2.2. Data used

In this study, three local climate factors such as seasonal average temperature and rainfall, length of dry season were assembled and retrieved using statistical data recorded in Pleiku Hydro-climatological Station which stated in Climate Announcement and Forecast Reports for the years 1998, 1999, 2005, 2010, 2015 and first six months of 2016 published by National Center for Meteorological and Climatology (Table 1). According to the climate data, dry season in 2005 had the lowest rainfall with seasonal average value is only 9 mm, and the 2010's dry season had the highest average rainfall value (20.88 mm). Seasonal average temperature and length of dry season values have not much varied, from 20 to 23^{o}C and within 5 to 6 months, respectively.

Additionally, three land-uses those have rapid changed during 1998-present in the Central Highland such as total area of residential districts (residential area), total area of forest land (forest area), and total area of coffee planting (coffee planting area) were also collected and analyzed in this study. Land-uses data in this study were collected in National Statistical Year Books in 1998, 1999, 2005, 2010, 2015, and 2016's estimated data for the Central Highland of Vietnam. Noticed features of land-use changes in the highland during 1998 - present are the dramatic conversion of natural ecosystem into artificial ecosystem through the decrease rapidly of forest area and the increases of residential and coffee planting areas (Table 1).

Table 1. Descriptive statistics of local climate factors and land-uses

Factors/Land-uses	Unit	Minimum	Maximum	Mean	Standard Deviation
Seasonal average rainfall	mm	9.00	77.00	24.03	26.36
Seasonal average temperature	^oC	20.76	23.24	21.88	1.06
Length of dry season	month	5.00	6.00	5.67	0.52
Residential area	thousand ha	33.00	54.20	44.77	10.18
Forest area	thousand ha	2,567.00	3,059.60	2,837.32	217.66
Coffee planting area	thousand ha	370.60	645.20	531.78	106.11

2.3. Image processing

Landsat satellites acquire images over the Central Highland of Vietnam from 2:40 to 3:12 GMT (corresponding 9:40 to 10:12 local time) every 16 days following path 124 row 50, 51, 52 and path 125 row 50. 24 Landsat scenes acquired in March of the years 1998, 1999, 2005, 2010, 2015, 2016 were used in this study. Detail information of these images was shown in Table 2.

Table 2. Landsat images used to map droughts in the Central Highland

No.	Image ID	Sensor
1.	LT51240501998034BKT00	ETM
2.	LT51240511998034BKT00	ETM
3.	LT51240521998034BKT00	ETM
4.	LT51250501998041BKT00	ETM
5.	LE71240502000064SGS00	ETM
6.	LE71240512000064SGS00	ETM
7.	LE71240521999317SGS00	ETM
8.	LE71250502000087SGS00	ETM
9.	LT51240502005069BKT00	TM
10.	LT51240512005069BKT00	TM
11.	LT51240522005069BKT00	TM
12.	LT51250502005076BKT00	TM
13	LT51240502010035BKT00	TM
14	LT51240512010035BKT00	TM
15	LT51240522010035BKT00	TM
16	LT51250502010026BKT00	TM
17	LC81240502015065LGN00	OLI-TIRS
18	LC81240512015065LGN00	OLI-TIRS
19	LC81240522015065LGN00	OLI-TIRS
20	LC81250502015104LGN00	OLI-TIRS
21	LC81240502016068LGN00	OLI-TIRS
22	LC81240512016068LGN00	OLI-TIRS
23	LC81240522016068LGN00	OLI-TIRS
24	LC81250502016091LGN00	OLI-TIRS

With the exception of cloud-masking, all pre-processing of the Landsat images, including radiometric calibration, atmospheric correction was completed using ENVI 5.3 image processing software. All used Landsat images were first radiometric calibrated using designed tool to convert image DNs into top-of-atmosphere (TOA) reflectances. Accordingly, the pixel TOA-reflectance was computed using eq. (1):

$$N\rho_\lambda = \frac{\pi L_\lambda d^2}{ESUN_\lambda sin\theta} \quad (1)$$

Where L_λ is radiance in units of $W/(m^2 \cdot sr \cdot \mu m)$; d is Eart-sun distance in astronomical units; $ESUN_\lambda$ is solar irradiance in $W/(m^2 \cdot \mu m)$; θ is sun elevation in degrees. These images then were atmospheric corrected using dark-object subtraction method (Chavez, 1996) to transfer TOA-reflectances into surface reflectances.

NDVI and NDWI were calculated according to Eqs. (2) and (3):

$$NDVI = \frac{R(NIR) - R(red)}{R(NIR) + R(red)} \quad (2)$$

$$NDWI = \frac{R(NIR) - R(SWIR)}{R(NIR) + R(SWIR)} \quad (3)$$

where $R(NIR)$, $R(Red)$, and $R(SWIR)$ are the reflectances at 666 nm and 655 nm, 830 nm and 865 nm, 2215 nm and 2200 nm, for Landsat TM and Landsat OLI imageries, respectively. NDDI then was calculated using Eq. (4) below:

$$NDDI = \frac{NDVI - NDWI}{NDVI + NDWI} \quad (4)$$

According to Drought Categories proposed by Gu et al. (2007), "*abnormally dry*" state was detected when NDDI value is larger than 0.1; "*moderate drought*" was detected by area within NDDI range from 0.2 to 0.3; "*severe drought*" occurred in area with NDDI larger than 0.3 whereas "*extreme drought*" was where NDDI is larger than 0.4.

3. Results and discussion

NDDI maps produced for the Central Highland of Vietnam and presented in Fig. 2 indicate change in drought impacted area in late dry seasons (in March) of 1998, 1999, 2005, 2010, 2015, 2016. Accordingly, severe drought often occurred in western districts of Gia Lai, Dak Lak and DakNong provinces such as Chu Prong (Gia Lai), Ea Sup, Buon Don (Dak Lak), Cu Jut, Dak Mil (DakNong) which is conformable to reports on drought by local provincial governments and technicians, scientists (Hang 2012, 37; Huy et al. 2016, CGIAR Research Centers in Southeast Asia, 2016) [9,10]. The 2005's drought is the most severe with severe drought area, area of NDDI larger than 0.3, was covered 1,170 thousands ha corresponding 21% total area of the highland.

Severe drought area recorded in 2015 is smaller than in 2005 but has larger drought impacted area. Total impacted area of drought (calculated by sum of both moderate and severe drought area and abnormal dry area) in 2015 is 2,486 thousands ha corresponding to 46% of the highland's total area.Drought in the smallest area of severe drought occurred in 1999 with approximately 550 thousands ha under severe drought, corresponding to 10% of the highland's total area (Fig. 2 and 3).

A noticeable trend is the significant increase of both severe drought area and drought impacted area in recent years (2010, 2015, and 2016), particularly for drought impacted area. If the most severe drought impacted area (2005) was 1,866 thousand ha, corresponding to 1.6 times to severe drought area, in 2010, 2015, 2016's droughts number of hectares under these droughts impact were 2,192 ha, 2486 ha, and 2184 ha, respectively, corresponding to 2.1 to 2.5 times to severe drought area (Fig. 3). From this result, it is the reason why the drought impacted areas in the highland has increased in recent years (2010, 2015, 2016) but being under less severe drought.

3.2. Discussion on drought causing factors

Result of severe drought area is significantly correlated to dry seasonal average rainfall (R=-0.91) and length of dry season (R=0.79). It has also moderate correlations with dry seasonal average temperature, total area of residential area with R=0.57 and 0.54, respectively. Result of multiple regression analysis between severe drought area with local climate factors and land-uses again confirmed the strong dependence of severe drought area on dry seasonal average rainfall by the beta coefficient is 0.91 whereas length of dry season and total area of coffee planting took the second and the third impact levels with beta coefficients are 0.27 and 0.21, respectively (Table 3). In SPSS multiple regression analysis, beta coefficient is the standardized regression coefficient. Beta coefficient magnitude indicates the dependent level of variable to considering factor. In other words, dry seasonal average rainfall is main factor causing severe level of drought in the Central Highland of Vietnam.

Drought impacted area has no significant correlation to any climate factor or land-uses rather than severe drought area. The highest Pearson correlation coefficient is -0.36 for relationship between drought impacted area and forest area, thus is not appropriate to determine the dependent level of the area to this factor. Multiple regression analysis between drought impacted area with local climate factors and land-used were produced and presented in Table 2. Accordingly, main climate factor that causes the expansion of drought impacted area increases residential area corresponding with the highest beta coefficient (0.84). More three factors those mainly contributed to the expansion of drought impacted area in descending order lead to the increase of coffee planting area, the decrease of rainfall in dry season, the length of dry season. This feature was highly confirmable to the fact that residential areas with impervious surfaces (concrete, asphalts) frequently reduce the soil - atmosphere water vapor exchange that lead to increase the land surface temperature, therefore drought occurred more severe along with expansion of residential area.

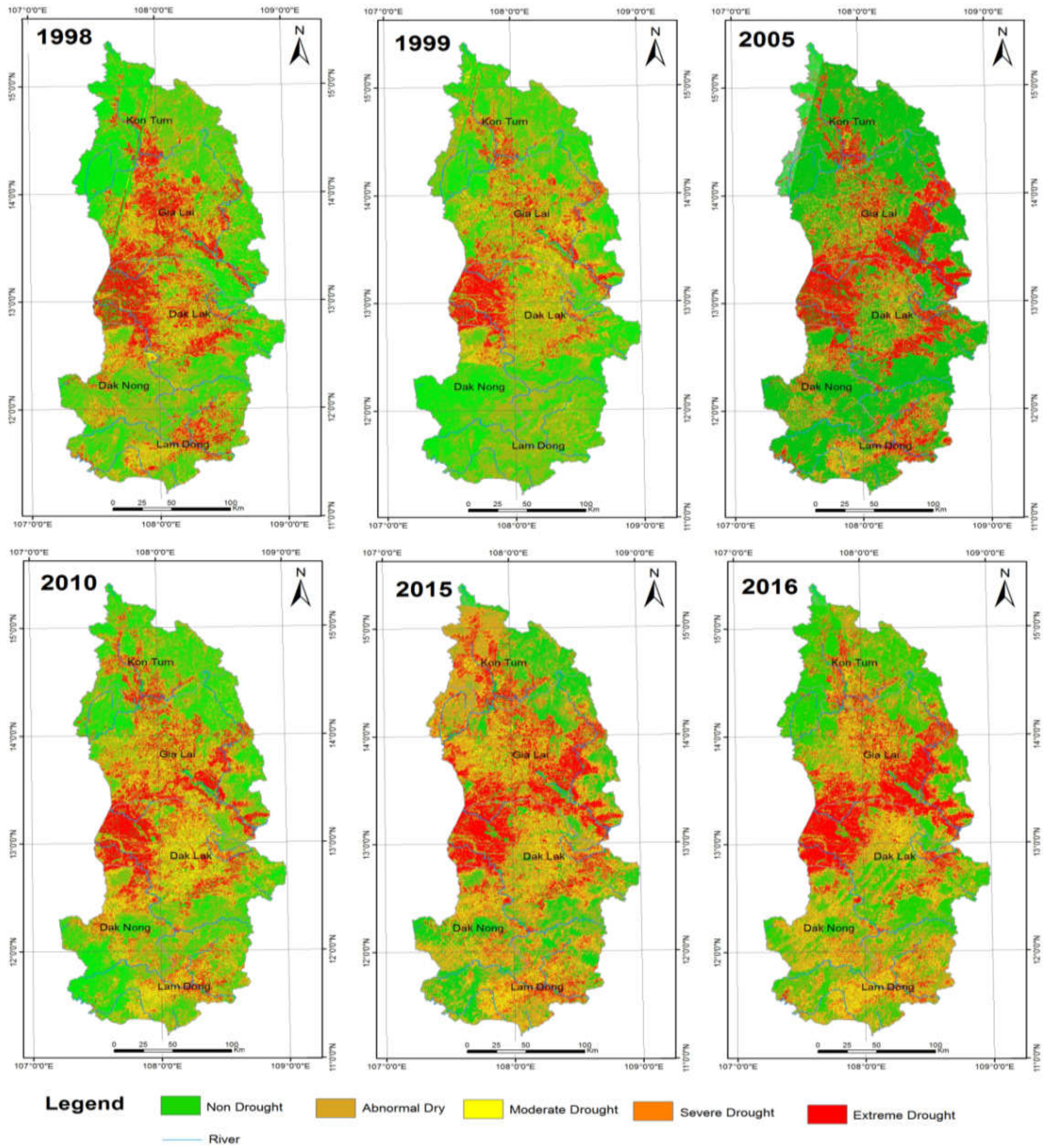

Figure 2. Maps of drought areas using Landsat based NDDI.

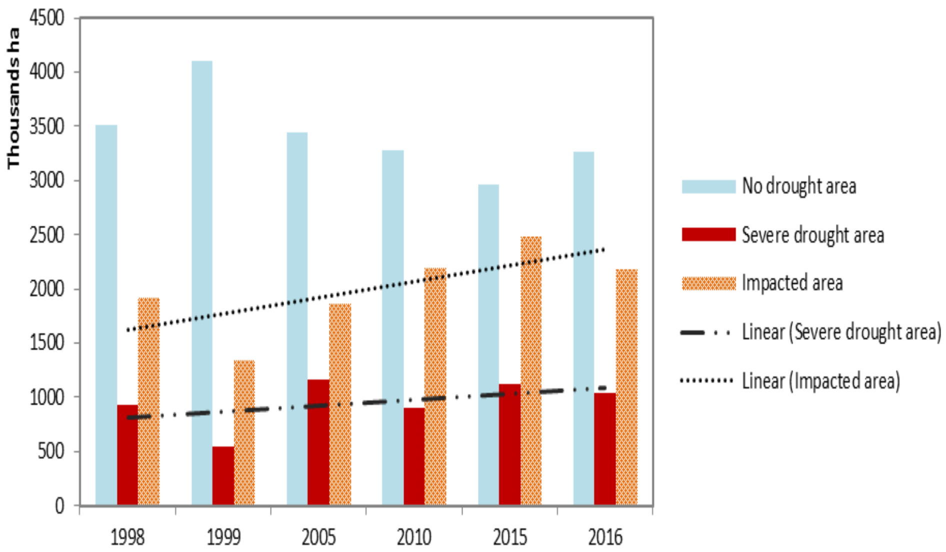

Figure 3. Change in severe drought area and drought impacted area in observed years.

Table 3. Multiple regression analysis for dependent level of drought impacted area and severe drought area on local climate and land-uses

Model	R-square	Beta					
		Re	L	T	R	C	F
Drought impacted area = *f*(Re,R,L,T, R,C,F)	0.71	0.84	0.34	-0.24	-0.51	-0.75	-0.00
Severe drought area = *f*(R,L,C,F,Re,T)	0.83	0.14	0.27	-0.01	-0.91	0.21	-0.18

L: Length of dry season (months), T: seasonal average temperature (^oC); R: seasonal average rainfall (mm); C: coffee planted area (thousand ha); F: Forest area (thousand ha); Re: Residential area (thousand ha)

4. Conclusion

This study applied Landsat TM and OLI images to estimate area under and impacted by droughts in the Central Highland of Vietnam over the past two decade. Through NDDI retrieved from the difference between NDVI and NDWI, area under severe droughts and impacted by those droughts in dry seasons of 1998, 1999, 2005, 2010, 2015 and 2016 was mapped highly conformable to reports on drought of local governments. Using NDDI recorded not only areas under severe drought but also areas under impact of moderate drought and abnormal dry. It helps to determine effectively causing factors for high vulnerable level of drought in the highland. Using multiple regression analysis between drought features such as severe drought area, drought impacted area with features of local climate and land-uses should be considered that if severe level of drought in the Central Highland is highly dependent on local dry seasonal average rainfall, the impact of drought is much more dependent on the expansion of residential area and coffee planting area. Therefore, drought mitigation and management in the Central Highland of Vietnam should be considered in suitable land-use planning.

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Sử dụng dữ liệu ảnh Landsat đa thời nghiên cứu diễn biến của hạn hán tại Tây Nguyên (Việt Nam) trong những năm El Niño

Nguyễn Thị Thu Hà, Mai Trọng Nhuận,
Bùi Đình Cảnh, Nguyễn Thiên Phương Thảo

*Khoa Địa chất, Trường Đại học Khoa học Tự nhiên, ĐHQGHN,
334 Nguyễn Trãi, Hà Nội, Việt Nam*

Tóm tắt: Trong thời gian gần đây, hạn hán xảy ra trong những tháng mùa khô ở Tây Nguyên ngày càng trở lên nghiêm trọng, đặc biệt là mùa khô những năm hiện tượng El Niño xảy ra. Nhằm xây dựng cơ sở khoa học cho việc quản lý và giảm thiểu tác động của hạn hán đến đời sống và sản xuất của người dân Tây Nguyên, bài báo này tập trung phân tích mối quan hệ giữa diện tích bị hạn tại thời điểm cao điểm nhất của mùa khô (nửa cuối tháng 3) của Tây Nguyên trong những năm 1998, 1999, 2005, 2010, 2015, 2016 (năm xảy ra El Niño) và tình hình sử dụng đất ở đây. Chỉ số hạn (NDDI - Normal Difference Drought Index) tính toán từ sự khác biệt giữa chỉ số nước (NDWI) và chỉ số thực vật (NDVI) được sử dụng trong nghiên cứu này. Kết quả cho thấy hạn hán xảy ra trong mùa khô 2004-2005 xảy ra khốc liệt nhất với tổng diện tích chịu hạn nặng là 1.170 nghìn ha (tương ứng 21

% tổng diện tích Tây Nguyên) và nhỏ nhất trong mùa khô 1999 với diện tích hạn nặng chỉ chiếm 550 nghìn ha. Diện tích vừng chịu tác động của hạn hán có xu hướng tăng đột biến trong những năm gần đây, đạt cao điểm vào mùa khô năm 2015 với tổng diện tích chịu tác động bởi hạn hán là 2.486 nghìn ha, chiếm 46% tổng diện tích vùng. Nếu diện tích vùng bị hạn nặng có tương quan cao với lượng mưa trung bình các tháng mùa khô (R = -0,91) thì diện tích chịu tác động bởi hạn hán lại phụ thuộc nhiều vào sự mở rộng của đất nhà ở và đất trồng cà phê. Do đó, xây dựng quy hoạch sử dụng đất một cách hợp lý nhằm giảm nhẹ rủi ro từ hạn hán là việc vô cùng cần thiết.

Từ khóa: Hạn hán, El Niño, dữ liệu ảnh Landsat, NDDI, Tây Nguyên.