Assessment the impacts of climate change on drought in the Ba River basin, Central Vietnam using Landsat remote sensing data

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Abstract. Sustainable management of the river basin is a profound challenge for environmental management in the context of climate change. Drought situations in a basin occur in relation to meteorological, hydrological, agricultural factors and climate change as well. In this study, remote sensing technology was applied to assess the impacts of climate change on drought in the Ba River basin, Central Vietnam. Drought in the basin has been created by land use/land cover changes in recent years, which has resulted in a sharp decrease in forest area in the period 1989 to 2019 (\textbf{-41.5}) and a significant increase of agricultural land with 38.2%. Following that, the area of drought agriculture rose by 28.8%. The remarkably high drought areas in agricultural land were in El Niño years, 2016 (99.2%) and 2019 (87.3%), which indicated that under climate change impacts, a drought occurred more severely. Moreover, drought also appeared in the forest. The forest area deceased but the drought levels in the forest increased slightly since 2005 and hit a peak drought value in 2016 with 97.0% of forest area. During El Niño years, the precipitation, atmospheric moisture, and water flow in the basin were all lower than in previous years.

1. Introduction
South-East Asia has long endured severe droughts, which occur on average every five years. The prolonged 2015 and 2018 droughts were the worst on record for two decades [1]. According to the United Nations, drought risk is already intensifying across the region. The drivers of drought risk in South-East Asia are inherently created by various climatic drivers, mainly the El Niño-Southern Oscillation (ENSO). Moreover, average temperatures have risen due to climate change which means drought severity will increase if the climate gets warmer.
Drought is a complex natural phenomenon caused by the imbalance of precipitation and evapotranspiration. It usually occurs with a lack of precipitation and results in a decrease in soil moisture content [2]. Drought, in general, may negatively affect agriculture, fisheries, power production and water supply in river basins. The drought in 2019-2020 heavily devastated the South Central and Central Highland regions in Vietnam [3] including the disrupted livelihoods and food security and created forest fire and haze. It is crucial to understand how recurrent droughts exacerbate in a changing climate. Then adaptive policy interventions need to be promoted to reduce and prevent droughts from occurring, prepare and respond to droughts when they happen, and restore and recover after a drought has passed [1]. The latest developments in science and technology will reinforce the successful scale-up of drought management interventions. With advances in remote sensing systems, droughts can be monitored on a regional and continental scale. To date, the research on drought based on the images from space technology is flourishing in every corner of the world as well as in Vietnam [4-8], which shows the advantages of remote sensing technology in environmental studies.

Figure 1. Location of the Ba River basin in Vietnam. As the largest river in the Central Vietnam, the Ba River has an abundant water resource to supply for agricultural and socio-economic activities in the basin. The lower part of the river forms the Tuy Hoa delta in Phu Yen Province and meets the East Sea at the Da Rang estuary [9].

The Ba River basin is on the South-Central Coast of Vietnam with an area of 13,900 square kilometers, consisting of Gia Lai, Dak Lak and Phu Yen Province. It extends from 12°35′N to 14°38′N latitude and from 108°00′E to 109°55′E longitude (Fig.1). The basin has several advantages in the land, climate, and water resources for the development of agriculture and local agricultural products have had
a high export value since 2010 [10] such as coffee, rubber, pepper, cashew nuts. Socio-economic growth and climate change, however, have been putting more pressure on the environment in the basin. Nowadays, land use/land cover (LULC) in the basin has been changed to meet human demand. Furthermore, drought destroyed crops and affected water resources in the basin in recent years [11-13]. Especially, in the background of global warming and during the specific timing of El Niño, drought events occurred more seriously.

Typically, the 2015-16 El Niño caused scorching temperatures and prolonged drought in the Central and Central Highlands in Vietnam, which affected agriculture activities [14]. As reported by the Central Highlands Regional Hydrometeorological Center in 2018-2019, the Eastern and Southeastern districts of Gia Lai Province were experiencing an intense drought. Not only did the precipitation in region just reach the amount of approximately below 60% of the annual rainfall, but the Ka Nak Hydroelectric Reservoir, the largest one in the upper basin, was also in a state of being the driest ever [15].

Hence, this work focuses on the examination of climate change effects on drought in the Ba River basin by applying space-based technology. A paper first reviews the changes in land use/land cover (LULC) from 1989 to 2019. Then, soil moisture is assessed in each type of LULC to reveal drought variability across the basin. The paper also lends a hand to understand how land resources here are being affected by climate change, which helps the local people use natural resources economically and sustainably.

2. Materials and Methodology

2.1. Materials

Figure 2 provides a descriptive workflow of the study. The information from remote sensing data is practical in depicting how the LULC and soil moisture have changed in the basin. A part of the data process was managed in Google Earth Engine and an overlay technique was implemented to calculate the drought affected LULC area. After that, from the collected climate data, the effects of climate change on drought were assessed.

![Figure 2. Workflow of the study](image)

The materials were used in this study include satellite images, field data and the relevant documents from authorities in the basin. Landsat-5 and Landsat-8 images were applied to extract information about LULC and reveal the soil moisture through TVDI (Temperature Vegetation Dryness Index) in the dry season (from January to May) in 1989, 2000, 2005, 2010, 2017, and 2019. Meanwhile, field data was collected in 2017 and 2019 to assess the accuracy of LULC classification. In addition, documents and data regarding hydrometeorology, drought or climate change in the Ba River basin were also aggregated to consider generally the research's feasibility compared to the actual situation.

2.2. Land use/land cover classification

In this study, the classification method was used to obtain information about LULC change over time from a source of remote sensing images. A supervised classification algorithm was conducted to classify land surface entities into three categories including agriculture, forest, and other lands. The supervised classification is a method where taxonomies are established based on sampling regions and use decision rules based on the appropriate algorithms for labeling pixels for specific coverage areas. The supervised classification method with Maximum Likelihood Classifier (MLC) was applied in the study. This method takes into consideration each LULC class in each spectrum channel
to have a standard distribution. Then, pixels will be classified into the class that has the highest probability.

Accuracy of classification is evaluated based on error matrix and norms such as overall accuracy and Kappa coefficient [16]. Overall accuracy is computed by the number of correctly classified pixels divided by the number of pixels used for classification. The high accuracy of commonly accepted classification is over 85%. Kappa coefficient (K) is used as a measure of the accuracy of image classification. It shows the basic difference between what is real about the error of the deviation of the matrix and the total number of changes indicated by the row and column. The Kappa coefficient is usually between 0 and 1. The high accuracy of the accepted classification is commonly with K > 0.8.

2.3. Soil moisture - Temperature Vegetation Dryness Index

TVDI is a simplified land surface dryness index developed by Sandholt et al. [17], which is based on an empirical parameterization of the relationship between Ts (Land Surface Temperature) and NDVI (Normalized Vegetation Difference Index). NDVI can monitor vegetation status and stress, specifically in water shortage sectors which reflects vegetation drought conditions [18, 19], and Ts rises rapidly with water stress [17, 20]. Hence, soil moisture could be estimated through the relationship between Ts and NDVI and this method only uses information derived from satellite images [17].

Figure 3 depicts the scatter plots of the conceptual Ts/NDVI space that often results in a trapezoidal shape with dry edge and wet edge [21, 22]. The points closer to the dry edge reflect many water-stressed surfaces with lower soil moisture and higher Ts. On the other hand, the wet edge indicates the evapotranspiration capacity and soil moisture become higher due to under no-water-lack conditions.

TVDI is one of the best-documented predictors of drought as vegetation index (NDVI) and other surface parameters (Ts) derived from satellite data have been widely used to monitor drought. Several studies show that integrating NDVI and Ts can offer more complete information on drought with requirements from bare soil to complete vegetation coverage [2, 23, 24].

![Figure 3. Definition of TVDI](image)

The TVDI for a given NDVI is estimated using Ts, Ts_{min} and Ts_{max} shown in Equation (1) [17]:

\[
TVDI = \frac{(T_s - T_{s_{min}})}{(T_{s_{max}} - T_{s_{min}})}
\] (1)

On the dry edge, Ts_{max} can be represented by straight-line relations with the NDVI as Equation (2). For a given pixel, Ts_{max} is the value of Ts on the dry edge corresponding to the value of NDVI in that pixel.

\[
T_{s_{max}} = a + b*NDVI
\] (2)

where the parameters a and b are estimated based on pixels from an area large enough to represent the entire range of surface moisture contents.

The NDVI value is calculated from the near-infrared (NIR) and red bands as follows:

\[
NDVI = \frac{(NIR - Red)}{(NIR + Red)}
\] (3)
3. Results and Discussion

3.1. The changes in agricultural and forest areas

In 1989 and 2019, LULC in the basin has changed dramatically (Fig.4). The accuracy assessment of classification results of 2017 and 2019 using field data indicated overall accuracies of 89% with a kappa coefficient of 0.77 and 0.71, correspondingly.

Over 30 years, the West and Southeast areas of the Ba basin were the most dramatic LULC changes. Most of the forest area was transformed into agricultural and other lands. Only the forest area in the North of the basin remained since the region is a part of Kon Ka Kinh National Park and Kon Chu Rang Nature Reserve. Besides that, ranges of dangerous mountains in the boundary between Phu Yen and Dak Lak (M’ Drak and Song Hinh districts) and in the East areas of Gia Lai province (Kong Chro, Ia Pa and Krong Pa districts) (Fig.1) were the unchanged-forest area.

Figure 5 and Table 1 show agricultural area increased from 176,969 ha to 686,526 ha (+287.9% with the rate +9.3% per year) from 1989 to 2019, while forest area diminished by 553,321 ha (~41.5% with the rate ~1.38% per year) and declined fastest between 1989 and 2005. From 2005 to 2019, the agricultural area more than doubled with a 108% increase or rose by 7.2% per year, which proved to be the greatest increase since 2005. On the other hand, the basin in 1989 was covered by 79.2% of forest (1,055,049 ha), but nearly half of the forest area disappeared after 31 years (plunged to 501,728 ha) and the agricultural accounted for over ½ area of the basin (51.5%) in 2019.

Moreover, there was a slight growth in the area of other lands including water bodies, impervious surface, and bare land, from 7.5% (1989) to 10.8% (2019). A part of this is due to urbanization and the construction of hydropower and irrigation reservoirs since 1995 such as Ayun Ha and An Khe-Kanak (Gia Lai Province), Song Ba Ha and Song Hinh (Phu Yen Province), and Krong H’Nang (Dak Lak Province).

Figure 4. Land use/land cover change in the Ba River basin from 1989 to 2019
Figure 5. Percentage of land use/land cover area in the Ba River basin from 1989 to 2019

![Graph showing percentage of land use/land cover area in the Ba River basin from 1989 to 2019]

Table 1. Land use/land cover area (ha) in the Ba River basin from 1989 to 2019

| Class name | 1989       | 2000       | 2005       | 2010       | 2017       | 2019       |
|------------|------------|------------|------------|------------|------------|------------|
| Forest     | 1,055,049  | 906,138    | 667,612    | 687,526    | 602,353    | 501,728    |
| Agriculture| 176,969    | 290,630    | 329,713    | 472,084    | 648,305    | 686,526    |
| Other lands| 100,592    | 135,842    | 335,285    | 173,000    | 81,952     | 144,356    |
| Total      | 1,332,610  | 1,332,610  | 1,332,610  | 1,332,610  | 1,332,610  | 1,332,610  |

3.2. The change of soil moisture

In line with previous studies [26, 27], TVDI ranging in [0, 1] is defined in five levels, which are labeled as follows: very wet (0.0 < TVDI ≤ 0.2), wet (0.2 < TVDI ≤ 0.4), balanced (0.4 < TVDI ≤ 0.6), dry (0.6 < TVDI ≤ 0.8), and very dry (0.8 < TVDI ≤ 1.0).

Figure 6. Average TVDI values of the dry season in the Ba River basin extracted from Landsat data acquired in the period of 1989 - 2019

![Graph showing average TVDI values of the dry season in the Ba River basin]

Figure 6 showed the average TVDI values increased slightly from 2005 to 2019. It means soil moisture values of the basin changed from a balanced (0.55 in 1989) to a dry level (0.64 in 2019). Especially, the TVDI in 2016 got the highest value (0.76) which was very dry. That points to the fact that dryness in the basin might continue to escalate in the following years. In order to follow the soil moisture changes in each LULC, soil moisture distributing spatially were also depicted in Figure 7.
3.3. The impacts of climate change on drought

El Niño is described as one of the most unspoken climate risks in East Asia and the Pacific [25]. El Niño's impacts harm society, the economy, and the agricultural sector with droughts and water scarcity. From the regional scale to the whole of Vietnam, there is always a high exposure probability to climate shocks and the South Central Coast as well as Central Highlands are ones of the country's most vulnerable regions to ENSO. The research investigated historical data which show there were five in six El Niño years causing severe droughts: 1997-1998, 2004-2005, 2010, 2014-2016, and 2018-2019. In these El Niño periods, the 2014-2016 (the longest El Niño) and 2018-2019 droughts were witnessed to be the most terrible [1].

From 1989 to 2019, the drought area in the basin has increased markedly in two levels with the dry level rising from 40.3% to 59% and the very dry going from 1.6% up to 5.6% (Fig. 8). The most noticeable change in drought was in 2016. The basin in 2016 was almost in the dry and very dry level which were 66.8% and 30.2%, respectively. This was known as the highest values in the basin over the past two decades. The second-highest percentage of drought area was in 2019 with 59% in the dry level and 5.6% in the very dry.

The result of calculating drought through TVDI index showed that the drought situation in the basin was occurring more severely, especially in 2016 and 2019, caused by El Niño. That coincides with the UNESCAP report [1] that the prolonged droughts in the periods of 2014-2016 and 2018-2019 were the worst on record for two decades in South-East Asia.
The variation of drought area on each LULC in the basin was scrutinized below in order to consider in more detail the change of drought under the impact of climate change.

As described in Figure 9, drought area in agriculture had a rising tendency from 1989 to 2019, increasing by 495,662.56 ha (Table 2). Especially, due to El Nino, the highest drought areas were indicated in 2016 (643,176.84 ha) and in 2019 (599,124.17 ha), comprising 99.2% and 87.3% agricultural land, respectively. Moreover, the very dry level in 2016 reached a peak during a 30-year period, accounting for 44.8% of the total drought area (288,027.92 in 643,176.84 ha). That led to a substantial number of plants drying during 2016 and the year after 2017 such as annual crops, coffee, pepper, rice plants. Furthermore, according to the statistics of the Departments of Agriculture and Rural Development in the Ba River basin, the drought in 2015-2016 ravaged more than 2,100 billion Vietnam Dong in the agriculture sector due to crop death and yield loss of 30-70% compared to previous years. This was also a consequence of a slow incline in agricultural land after 2016 (2017-2019) (Fig.5).

Table 2. Drought area in agricultural land (ha) in the Ba River basin from 1989 to 2019

|       | 1989   | 2000   | 2005   | 2010   | 2016   | 2017   | 2019   |
|-------|--------|--------|--------|--------|--------|--------|--------|
| Dry   | 93,390.41 | 162,150.74 | 237,581.29 | 342,710.31 | 355,148.93 | 383,026.57 | 543,042.82 |
| Very dry | 10,071.20 | 5,233.58 | 11,513.44 | 20,079.12 | 288,027.92 | 35,750.86 | 56,081.35 |
| Total drought | 103,461.61 | 167,384.31 | 249,094.74 | 362,789.43 | 643,176.84 | 418,777.43 | 599,124.17 |
| Agriculture area | 176,969.00 | 290,630.00 | 329,713.00 | 472,084.00 | 648,305.00 | 648,305.00 | 686,526.00 |
In regard of drought in the forest, although the drought area went down from 386,579.04 ha in 1989 to 138,775.39 ha in 2019 (Table 3) owning to the cutting-down forest to convert into cultivated areas, the drought area of forested land also increased but more slightly than that of agriculture from 1989 to 2019 (Fig.10). During El Niño years, 2005, 2010, 2016 and 2019, the total drought area in these years was all higher than the others, accounting for 28.2%, 39.7%, 97.0% and 27.7% forest area, correspondingly. It is obvious that the very dry area in the forest started increasing from 2005, whereas there was a rather quick decrease in forest area since that year (Fig.5). That signified the basin is already being ravaged by drought and drought could aggravate human’s life as well as the ecosystem in the basin.

Under aggressive greenhouse gas emission, extreme El Niño may increase in frequency and amplitude by the end of the 21st century. That means in a warming climate when strong El Niño increases, rainfall extremes are projected to shift eastward along the equator in the Pacific Ocean during El Niño events [28]. From these statements, the results also demonstrated that the drought situation in the Ba River basin is occurring with increasing frequency and severity, especially during El Niño years, which IS drought in the basin is being affected by a climate transition.

In El Niño years (2004-2005, 2010 and 2014-2016), the recorded data from meteorological stations in the basin was witnessed to be lower than in the other years, such as lower precipitation, atmospheric moisture, and water flow. For example, in the 2004-05 El Niño, the Central Highlands and South Central Coast had low rainfall and the rainy season ended 1 to 1.5 months sooner than the average. Then, in 2010 El Niño, the Central region in Vietnam was the most severely affected area and the rainfall was exceptionally low, at only about 70% of the average. For the next El Niño event (2016), the rainfall and river flows in the Central Highlands and South Central Coast were only 50 to 70% of the average, and in some areas, rainfall reduced to only 20% of the average [1]. As the report by the General Department of Hydrometeorology revealed that the natural reserve of water in the Central Highland was not

**Figure 10.** Percentage of drought area in forest land in the Ba River basin from 1989 to 2019

**Table 3. Drought area in forest land (ha) in the Ba River basin from 1989 to 2019**

|        | 1989      | 2000      | 2005      | 2010      | 2016      | 2017      | 2019      |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Dry    | 377,701.41| 220,239.50| 186,759.27| 267,379.81| 508,850.01| 91,847.11 | 132,994.70|
| Very dry | 8,877.63  | 3,344.99  | 1,793.07  | 5,603.92  | 75,280.86 | 3,376.66  | 5,780.69  |
| Total drought | 386,579.04 | 223,584.50 | 188,552.34 | 272,983.73 | 584,130.87 | 95,223.77 | 138,775.39 |
| Forest area | 1,055,049.00 | 906,138.00 | 667,612.00 | 687,526.00 | 602,015.00 | 602,353.00 | 501,728.00 |
abundant in recent years as the forest had been cleared and the rainfall in the region during the 2019 dry season was about 50% lower than the annual average [29].

4. Conclusions

The paper had presented the impact of drought on LULC and how seriously climate change affects the drought in the Ba River basin. The study analyzed the change of LULC as well as the change in drought area in the Ba River basin from 1989 to 2019 by using remote sensing.

The remote sensing-based results showed that there was a significant modification in LULC over 30 years with the most transformation was from forest to agricultural land and the soil moisture was becoming drier. Furthermore, the changes of drought in each LULC were prominent that the levels of drought had a rise, especially in El Niño years. Hence, it can be concluded that droughts in the basin change due to both the change of climate and LULC.

These findings are encouraging that the drought situation in the Ba River basin under climate change could threaten the residents’ livelihood and food. Besides that, the nature of ENSO is a cyclical and natural event that has consistently detrimental impacts on the basin's environment, economies, and agriculture. Therefore, it is essential that the government and local scientists have to take actions and address undeniable problems related to the severity of drought.

Acknowledgement

The study was conducted within the framework of the research project “Study and evaluate the impacts of climate change and socio-economic activities on the Ba/Da Rang River Basin environment by using remote sensing and GIS technology,” project number VT-UD.10/18-20, which is part of the National Program on Space Science and Technology (2016–2020), Vietnam Academy of Science and Technology.

We would like to thank Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for the support of time and facilities for this paper.

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